INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems
Task 11

67th IEA Wind Topical Expert Meeting

LONG TERM R&D NEEDS FOR WIND POWER

5 October 2011

EWEA - The European Wind Energy Association
Wind Energy House, Rue d'Arlon 80 | B-1040 Brussels, Belgium

Organized by: CENER

Scientific Co-ordination:

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For more information about IEA Wind see www.ieawind.org

International Energy Agency Implementing Agreement for Co-operation in the Research, Development and Deployment of Wind Energy Systems: IEA Wind

The IEA international collaboration on energy technology and RD&D is organized under the legal structure of Implementing Agreements, in which Governments, or their delegated agents, participate as Contracting Parties and undertake Tasks identified in specific Annexes (Tasks).

The IEA's Wind Implementing Agreement began in 1977, and is now called the Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems (IEA Wind). At present, 25 contracting parties from 21 countries, the European Commission, and the European Wind Energy Association (EWEA) participate in IEA Wind. Australia, Austria, Canada, Chinese Wind Energy Association (CWEA), Denmark, the European Commission, the European Wind Energy Association (EWEA), Finland, Germany, Greece, Ireland, Italy (two contracting parties), Japan, the Republic of Korea, Mexico, the Netherlands, Norway (two contracting parties), Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States are now members.

The development and maturing of wind energy technology over the past 30 years has been facilitated through vigorous national programs of research, development, demonstration, and financial incentives. In this process, IEA Wind has played a role by providing a flexible framework for cost-effective joint research projects and information exchange.

The mission of the IEA Wind Agreement continues to be to encourage and support the technological development and global deployment of wind energy technology. To do this, the contracting parties exchange information on their continuing and planned activities and participate in IEA Wind Tasks regarding cooperative research, development, and demonstration of wind systems.

Task 11 of the IEA Wind Agreement, Base Technology Information Exchange, has the objective to promote and disseminate knowledge through cooperative activities and information exchange on R&D topics of common interest to the Task members. These cooperative activities have been part of the Wind Implementing Agreement since 1978.

Task 11 is an important instrument of IEA Wind. It can react flexibly on new technical and scientific developments and information needs. It brings the latest knowledge to wind energy players in the member countries and collects information and recommendations for the work of the IEA Wind Agreement. Task 11 is also an important catalyst for starting new tasks within IEA Wind.

IEA Wind TASK 11:

BASE TECHNOLOGY INFORMATION EXCHANGE

The objective of this Task is to promote disseminating knowledge through cooperative activities and information exchange on R&D topics of common interest. Four meetings on different topics are arranged every year, gathering active researchers and experts. These cooperative activities have been part of the IEA Wind Agreement since 1978.

Two Subtasks

The task includes two subtasks. The objective of the first subtask is to develop recommended practices for wind turbine testing and evaluation by assembling an Experts Group for each topic needing recommended practices. For example, the Experts Group on wind speed measurements published the document titled "Wind Speed Measurement and Use of Cup Anemometry." A document dealing with Sodar measurements is presently under development.

The objective of the second subtask is to conduct Topical Expert Meetings in research areas identified by the IEA Wind Executive Committee. The Executive Committee designates topics in research areas of current interest, which requires an exchange of information. So far, Topical Expert Meetings are arranged four times a year.

Documentation

Since these activities were initiated in 1978, more than 60 volumes of proceedings have been published. In the series of Recommended Practices 11 documents were published and five of these have revised editions.

All documents produced under Task 11 and published by the Operating Agent are available to citizens of member countries participating in this Task.

Operating Agent

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COUNTRIES PRESENTLY PARTICIPATING IN THE TASK 11	
COUNTRY	**INSTITUTION**
Canada	National Resources Canada
Denmark	Risø National Laboratory - DTU
Republic of China	Chinese Wind Energy Association (CWEA)
European Commission	European Commission
Finland	Technical Research Centre of Finland - VTT Energy
Germany	Bundesministerium für Unwelt , Naturschutz und Reaktorsicherheit -BMU
Ireland	Sustainable Energy Ireland - SEI
Italy	CESI S.p.A. and ENEA Casaccia
Japan	National Institute of Advanced Industrial Science and Technology - AIST
Republic of Korea	POHANG University of Science and Technology - POSTECH
Mexico	Instituto de Investigaciones Electricas - IEE
Netherlands	Netherlands Agency
Norway	The Norwegian Water Resources and Energy Directorate - NVE
Spain	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas CIEMAT
Sweden	Energimyndigheten
Switzerland	Swiss Federal Office of Energy - SFOE
United Kingdom	UK Dept for Business, Enterprises & Regulatory Reform - BERR
United States	The U.S Department of Energy -DOE

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INTRODUCTORY NOTE

Prepared by Filippo Gagliardi, TPWind Secretary General
Project Manager The European Wind Energy Association (EWEA)

a) Background

The International Energy Agency (IEA) Wind agreement is a vehicle for member countries to exchange information on the planning and execution of national large-scale wind system projects and to undertake co-operative research and development (R&D) projects called Tasks.

At the close of 2010, 84% of the near 200 GW of worldwide wind generating capacity was operating in the IEA Wind member countries, with the addition of the Chinese Wind Energy Association as the newest member. Hence the needs of strategic research on wind energy deployment are concentrated to these countries. Common research tasks which are in progress at present under IEA Wind are:

- Social Acceptance of Wind Energy Projects
- Cost of Wind Energy
- Power Systems with Large Amounts of Wind Power
- Wind Energy in Cold Climates
- Development and Deployment of Small Wind Turbine Quality Labelling
- Offshore Code ComparisonBenchmarking Wind Farm Flow Models
- Analysis of Wind Tunnel Data
- Base technology information exchange

A similar meeting on strategic research needs was arranged in 2007. It is now time to arrange a new meeting on the same subject in order to sum up progress and identify future research needs.

b) The Present and Future Status of Wind Energy

Total electrical generation from wind in the IEA Wind member countries has increased from less than 10 TWh in 1995 to nearly 300 TWh in 2010. The contribution from wind energy to the combined electricity demand of the member countries varied from under 1% in some countries to 21% in Denmark. In five countries wind energy exceeded 8% of the contribution to national electrical demand. Portugal supplies 18% of its electricity demand with wind and Spain supplies 16 %. It is clear that wind energy can be a significant source of electrical generation.

Moreover, the European Union (EU) is currently increasing its support to the development of wind power, thanks to the launch of the European Wind Initiative (EWI) in 2010. EWI was developed by EU Institutions, Member States, and the European Wind Energy Technology Platform (TPWind). EWI is rooted in the 2007 EU Strategic Energy Technology Plan (SET-Plan), a blueprint for the development of low-carbon technologies.

In the coming years an even larger introduction of wind energy will be seen. In order to actualize this deployment, it has to be supported by extensive R,D&D actions. Future R&D will support incremental improvements in understanding extreme wind situations, aerodynamics, and electrical machines. The challenge is to try to find those evolutionary steps that can be taken to further improve wind turbine technology, for example, in large scale integration incorporating wind forecasting and grid interaction with other energy sources.

c) Aim and Objectives

The aim of the Topical Expert Meeting (TEM) is to discuss long-term research needs for the timeframe 2020. The objective of the meeting is to try to identify needed future results from R&D both in the 5 to 10 and the 10 to 20 year time frames. The strategic goal of the TEM is to give recommendations to the IEA Wind Executive Committee and to the governments involved that are at the latest international wind technological stage. The outcome of the meeting will be used to develop a new strategic R&D plan for IEA Wind.

The objectives are to review the latest wind energy technology and to draw conclusions for a further successful development to expand the place of wind energy in the world's energy mix by means of R&D.

The participants are encouraged to prepare presentations relevant to these objectives.

d) Expected Outcomes

One of the goals of the meeting will be to gather the existing knowledge on the subject and come up with suggestions and recommendations on how to proceed. This will involve definition of necessary research activities for "Recommendations" to the IEA Wind Agreement and the governments involved on the following topics:

- Future turbine and drive train technologies,
- Rotor blade design and new materials,
- Offshore aspects as foundations, logistics, grid connection, condition monitoring and maintenance, prevention of environmental impact etc.
- Grid integration and intermediate storage of large energy amounts,
- Environmental impact and acceptance,
- Improvement of wind turbine production technologies.

Based on the above a document will be compiled containing:

- Presentations by participants
- Compilation of the most recent information on the topic
- Input to define IEA Wind’s future role in this topic

e) Agenda

Wednesday, 5th October

9:00 **Registration**. Collection of presentations and final Agenda

9:30 **Introduction by Host**

Filippo Gagliardi, EWEA

09:45 **Introduction by IEA Wind Task 11 Operating Agent. Recognition of Participants**

Mr. Felix Avia, Operating Agent Task 11 IEAWind R&D

1st Session Individual Presentations:

10:00 **P1 TPWind and the EWI**

Filippo Gagliardi, EWEA

10:20 **P2 Research needs identified in the IEA Wind Implementing Agreement Strategic Plan 2009-2014**

Joachim Kutscher, Germany

● *10:45 Coffee Break*

11:10 **P3 R&D Needs for Large Scale Deployement a U.S. Perspective**

Mark Higgins, *U.S. Department of Energy, USA*

11:45 **P4 Wind Energy R&D Needs, Spanish Case**

Emilien Simonot. AEE, Spain

12:10 **P5 Research Needs from the View of a Certification Body**

Christian Nath, Germanischer Lloyd Industrial Services GmbH, Germany

12:30 **P6 Long Term R&D Needs on Wind Power**

Stephan Barth, ForWind Center for Wind Energy Research, Germany

12:50 P7 RWE INNOGY - Research & Development Offshore Wind

Fiedrich Koch, RWE Innogy GmbH, Germany

● *13:15 Lunch*

2nd Session Individual Presentations:

14:00 P8 Arctic/Cold Climate Needs

Hannele Holttinen, VTT, Finland

14:15 Offshore Wind R&D Needs (examples)

John Olav Tande, Nowitech/Sintef, Norway

14:35 Long Term Research Needs: Status and Perspectives

Flemming Rasmussen, Riso-DTU, Denmark

15:00 UpWind, New Test Station and Drive Train Test Facilities in Denmark

Peter Hjuler Jensen, Riso-DTU, Denmark

15:20 Future R&D Challenges as Seen from the Vattenfall Horizon

Sven Erik Thor, Vattenfall, Sweden

15:30 Long Term R&D Needs on Wind Power

Lars Gertmar, Power Technologies, ABB Corporate Research, Sweden

15:40 Electric Power Wind Energy Research

Ola Carlson, Chalmers University of Technology, Sweden

16:00 The Netherlands. Long Term R&D Needs on Wind Power

Jaap 't Hoof, The Netherlands

● *16:20 Coffee Break*

16:30 Discussion

17:30 Summary of Meeting

18:00 End of the Meeting

PRESENTATIONS

European Wind Energy Technology Platform

TPWind and the EWI

IEA Task 11 TEM 67, Brussels
5 October 2011

European Wind Energy Technology Platform

General Introduction

- The purpose of this meeting is to identify relevant R&D needs both in the 5 to 10 and the 10 to 20 year time frames
- Following this TEM, recommendations will be provided to the IEA Wind Executive Committee as well as to relevant public authorities
- The outcome of the meeting will be used to develop a new strategic R&D plan for IEA Wind
- Presenting the European Wind Initiative, one of the most important instruments for funding wind energy at EU level, can therefore represent a significant contribution to this meeting
- The EWI, which was developed and is now being implemented by TPWind (together with EU Institutions and Member States), identifies the main wind energy R&D priorities of the 2010 – 2020 period
- This presentation will therefore focus on TPWind and the EWI. Recommendations on future IEA activities will be provided in the end

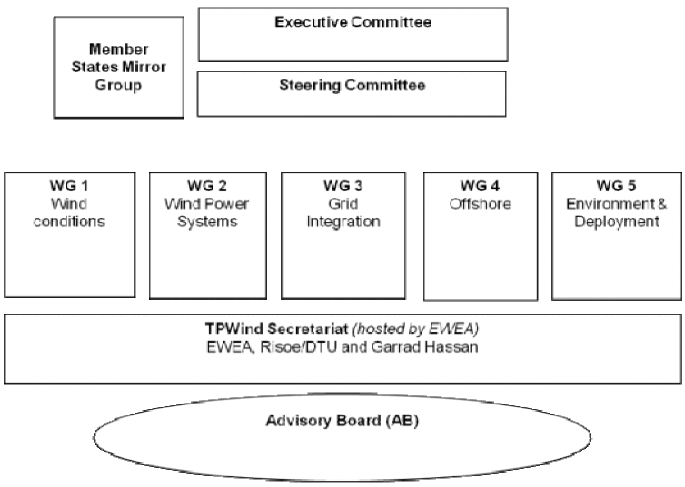
European Wind Energy Technology Platform

TPWind: Introduction

- TPWind was established in 2005 and officially launched in 2006, together with many other EU technology platforms (there are approximately 30 TPs currently operational in Europe)
- Since 2007, TPWind receives EU funding through the following projects:
  - Windsec (Wind energy technology platform Secretariat): it was funded through the 6th Framework Programme and covered the 2007 – 2010 period
  - TOP Wind (Technology platform Operational Programme Wind): it is funded through the 7th Framework Programme and will cover the February 2011 – January 2014 period
- Both projects are managed by EWEA (which hosts the TPWind Secretariat) in cooperation with Risoe/DTU and Garrad Hassan
- TPWind was initially created as a permanent network and forum for wind energy R&D experts
- With the development and launch of the European Wind Initiative (EWI) however, TPWind acquired also a new role, since it became an essential player in the EU energy policy framework

European Wind Energy Technology Platform

TPWind structure



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TPWind objectives

- The objectives of the Platform for the 2011 – 2014 period are the following:
  - Improve the internal communication and the external representation of the wind energy sector
  - Disseminate information on wind power R&D
  - Draft strategic plans for the development of wind energy in Europe (e.g. EWI documents and new SRA/MDS)
  - Contribute to the development and implementation of relevant EU energy policies
  - Provide members with a permanent forum focused on wind energy research

European Wind Energy Technology Platform

TPWind main deliverables so far

- The Platform's main deliverables so far are the following:
  - The "Strategic Research Agenda / Market Deployment Strategy" (SRA/MDS), published by TPWind in 2008, which outlines the R&D challenges faced by the European wind energy sector. This publication, available on the TPWind website, quickly became a reference text in the sector
  - The "European Wind Initiative" (EWI), published by the European Commission in 2009 in its Communication on "Investing in the Development of Low-Carbon Technologies" (COM(2009) 519)
- The EWI is an extremely important tool for the EU wind energy sector, which deserves to be presented in greater details

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The EWI: introduction

- The European Wind Initiative (EWI) is a long-term, large-scale Programme aiming at improving and increasing public funding for wind energy R&D
- The EWI is rooted in the EU Strategic Energy Technology Plan (SET-Plan) and has a € 6 bn budget (private and public resources) for the 2010 – 2020 period
- The SET-Plan was published by the European Commission in 2007: it is a blueprint for the development of low carbon technologies
- One of the goals of the SET-Plan was to launch European Industrial Initiatives (EIIs), i.e. Programmes for fostering R&D in 8 sectors:

Wind	Bio-energy
Solar	Energy efficiency
Nuclear	Smart grids
CCS	Hydrogen and fuel cells

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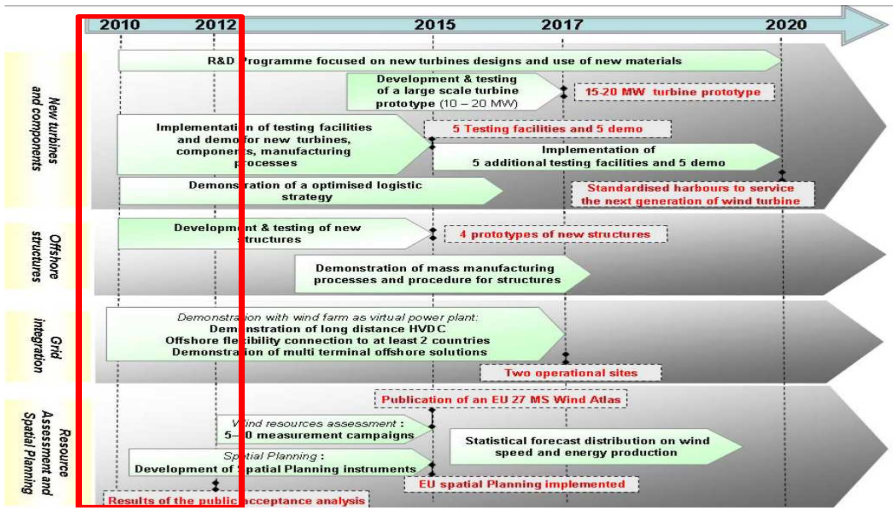
The EWI: overview



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The EWI: development and implementation (I)

- TPWind received the mandate to develop the EWI, which was published in 2009 in the EC Communication on “Investing in the development of low carbon technologies”
- The EWI was one of the first EIIs to be officially launched in June 2010 at the Madrid SET-Plan conference
- With the launch of the EWI, the EC published also its 2010 – 2012 Implementation Plan and established its implementing mechanism: the Wind EII Team
- The Wind EII Team is composed of EU, national and TPWind representatives: its goal is to implement the EWI by translating it into EU and national calls for proposals and budget allocations
- Funding indications developed by the Wind EII Team are included in annual EWI Work Programmes

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The EWI: development and implementation (II)

- TPWind representatives in the Wind EII Team are Executive Committee members and selected Secretariat staff
- The Wind EII Team is supervised by the SET-Plan Steering Group, composed of high level EU and national representatives
- Last year the Wind EII Team developed the EWI 2011 Work Programme, which was finalized in October 2010
- Its funding recommendations were followed by the EC when designing this year’s FP7 Energy call for proposals, which includes two topics on wind power:
  - New materials for large scale turbines (ENERGY.2012.2.3.1)
  - Reliability of large scale wind turbines (ENERGY.2012.2.3.2)
- These two topics should provide the EU wind energy sector with an allocation of € 24 m. Much more would be needed to properly implement the EWI, but the EC is following its funding indications (the situation should improve as from 2014 with Horizon 2020)

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The EWI: development and implementation (III)

- In addition, the EC published complementary topics in the NMP call, which could also be relevant to wind energy players:
  - Topic NMP.2012.2.2-4: Cost-effective materials for larger blades for off-shore wind energy applications
  - Topic NMP.2012.4.1-2 Innovative recycling technologies of key metals in high-tech applications
  - Topic NMP.2012.4.1-3 Development of advanced magnetic materials without, or with reduced use of, critical raw materials
  - Topic NMP.2012.4.1-4 Substitution of critical raw materials: networking, specifying R&D needs and priorities
- TPWind is now focusing on:
  - The implementation of the EWI 2011 Work Programme
  - The development of the 2012 one
  - The development of the EWI 2013 – 2015 Implementation Plan (which will replace the current one, covering the 2010 – 2012 period – Implementation Plans are the starting point of yearly Work Programmes)

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The different documents of the EWI

EWI
- It covers the 2010 - 2020 period
- It clarifies the development trajectory of wind power up to 2020 and identifies its main R&D priorities and challenges

2010 - 2012 Implementation Plan
- It covers the 2010 - 2012 period
- It provides a detailed description of the actions to be launched in the first 3 years, including their budgets. However, it is not designed to be put immediately into action by funding authorities

2012 Work Programme
- It focuses on 2012 only
- It provides a detailed list of EU and national calls for proposals and budget allocations that can be easily implemented by relevant authorities
- It is an operational document, rather than a strategic one like the EWI or its 2010 - 2012 Implementation Plan

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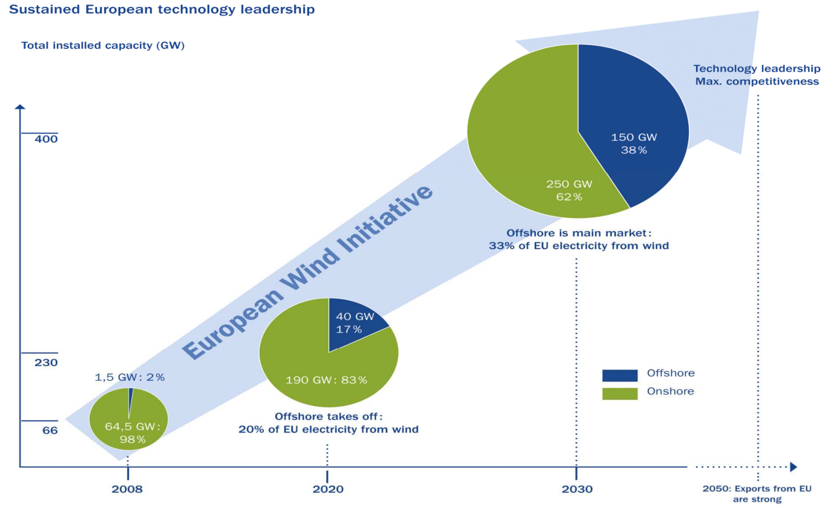
The EWI: expected impact on the sector



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EWI pending issues

- On top of working on the implementation of the EWI, TPWind is also dealing with two pending issues concerning the structure and implementation mechanism of the Initiative:
  - TPWind is rewriting the EWI's Grid Integration strand in order to avoid overlaps with the European Electricity Grid Initiative (EEGI). This is the outcome of several meetings with EEGI representatives, which resulted in a Memorandum of Understanding defined at EWEA's Grid Conference in Berlin (November 2010): only wind-specific activities will remain in the EWI, while other grids-related R&D tasks will be moved to the EEGI
  - TPWind is currently in touch with the European Energy Research Alliance (EERA) to maximize the synergies between the EWI and the EERA's Joint Programme (JP) on wind energy

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Recommendations to IEA Wind ExCo (I)

- The basic goal of Task 11 is for the IEA to monitor wind energy R&D needs and developments
- TPWind will update its SRA/MDS next year, which looks at the R&D challenges faced by the EU wind energy sector (the previous version was published in 2008)
- The IEA, which is also represented in the TPWind Advisory Board, could therefore follow this process and provide inputs to it
- The Advisory Board will indeed be in charge of developing an annex focusing on R&D issues shard by wind energy and other sectors (e.g. oil & gas, grid, ocean energy and shipping players), so the IEA could actively contribute to it
- The new version of the SRA/MDS will be published in 2013 at the latest

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Recommendations to IEA Wind ExCo (II)

- Further to this, IEA Wind could launch new tasks in key R&D areas that were identified as strategically important at the last ExCo meeting in Amsterdam (April 2011):
  - Cost reduction (which could be considered an extension of task 26 on the cost of energy)
  - Decommissioning (recycling of wind turbines)
  - Materials (including replacement of rare earth materials)
- The next ExCo meeting in Dublin (October 2011) could focus on these issues in order to move forward on the launch of relevant tasks

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European Wind Energy Technology Platform

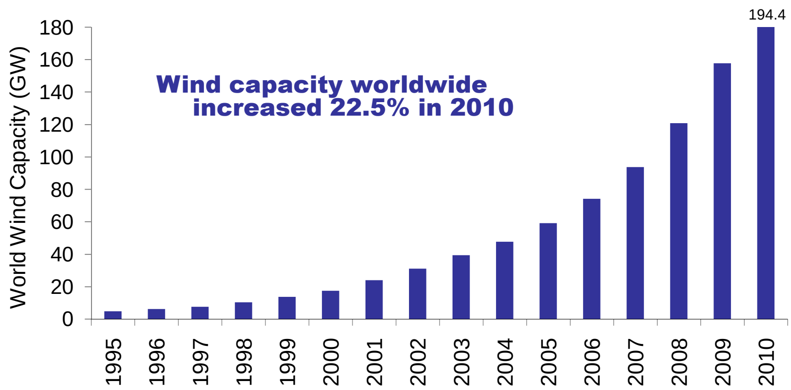
Thank you for your attention!

European Wind Energy
Technology Platform

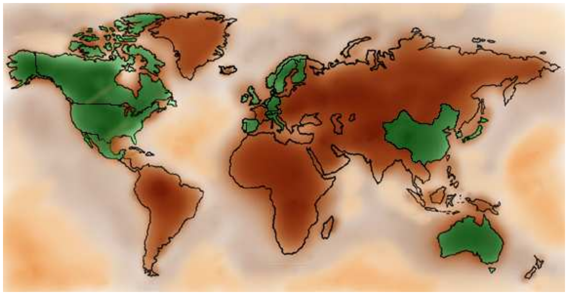
http://www.windplatform.eu/

Wind generation is significant and growing

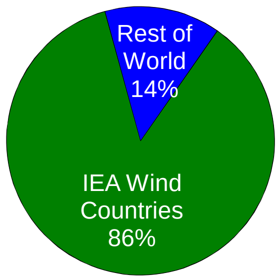
In Europe, wind power is 9.6% of total installed electrical generation capacity. (Source: EWEA, 2011)



86% of the world wind capacity is in IEA Wind member countries



IEA Wind Countries



World Wind Capacity

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IEA Wind has broad membership

OECD Participating Countries:

Europe:

Austria, Denmark, Finland, Germany, Greece, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the European Commission

North America:

Canada, Mexico, and the United States

Asia and Pacific:

Australia, Chinese Wind Energy Association, Japan, and South Korea

International Organizations (sponsors):

Chinese Wind Energy Association and the European Wind Energy Association

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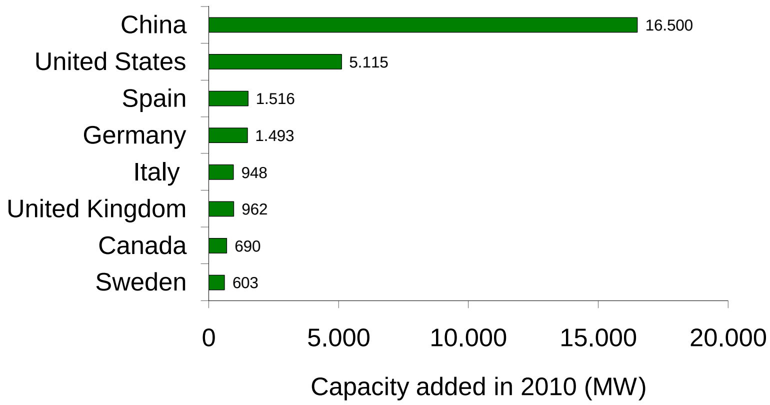
IEA Wind participants added 29, GW of wind generation in 2010



Source: GWEC 2011

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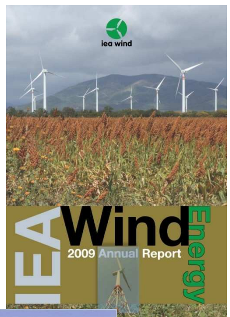
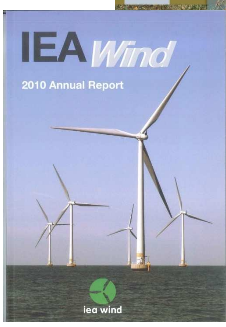
Information Exchange:

- Country and Task reports at meetings of the IEA Wind Executive Committee (two per year,
- IEA Wind Annual Report, contains chapters on research tasks, country activities, and an Executive Summary.
- Public Web site: **www.ieawind.org**
- Members-only Web pages





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Active Research Tasks of IEA Wind

WAKEBENCH: Benchmarking of wind farm flow models (Task 31)

Dynamic Codes and Models for Offshore Wind Energy (Task 30)

Aerodynamic Data Analysis of the EU MEXICO Project (Task 29)

Social Acceptance of Wind Energy Projects (Task 28)

Consumer Labeling of Small Wind Turbines (Task 27)

Cost of Wind Energy (Task 26)

Power Systems with Large Amounts of Wind Power (Task 25)

Wind Energy in Cold Climates (Task 19)

Base Technology Information Exchange (Task 11)

LiDAR Systems (Task 32)

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Task 11 Topical Experts Meetings:

exclusively for experts from participating member countries (recent topics explored)

- High reliability solutions and innovative concepts for offshore wind technology (30 experts from 11 countries)
- Micrometeorology inside wind farms and wakes between wind farms (15 experts; 9 countries)
- Wind farms in complex terrain (12 experts; 6 countries)
- Radar, radio and links with wind turbines (27 experts; 8 countries)
- Remote wind speed sensing techniques using Sodar and Lidar (31 experts; 11 countries)
- Sound propagation models and validation (17 experts; 9 countries)

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Task 19 addresses cold climate issues for wind energy

- Establishes a site classification scheme
- Explores technologies to increase productivity
- Develops tools to predict performance

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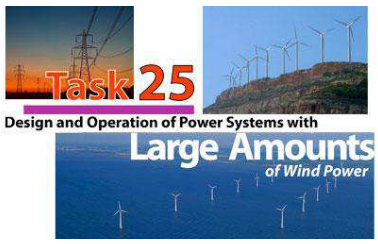
Design and operation of power systems with large amounts of wind power – Task 25

- International forum for wind integration, actively following also parallel activities (CIGRE, UWIG, IEEE, other IEA IAs).
- analysing and further developing the methodology to assess the impact of wind power → best practices to assess the impacts
- summaries on the range of impacts, evolving experience as well as integration solutions



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Task 26 Cost of Wind Energy

•GOAL: understand cost of wind energy among participating countries
- •Identified cost elements from the perspective of a private investor, in a given project, in each country
- •Calculated levelized cost of energy (LCOE) - the sum of all costs over project lifetime, discounted to present, and levelized based on annual production

• Used two approaches: 1. high level scenario planning and 2. sophisticated financial cash flow analysis

•Results:
- •LCOE varies considerably between countries
- •Variation is attributed to energy production, investment cost, operations cost, and financing cost

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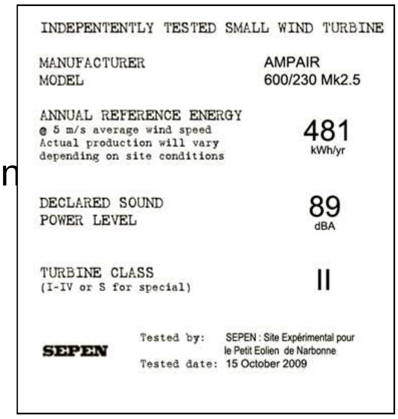
Labeling Small Wind Turbines, Task 27

- Develop approved test procedures and consumer label for small wind turbines
- Set up Small Wind Association of Testers (SWAT)
  - – Encourage peer review of test protocols and data analysis
  - – Promote dissemination of results


INDEPENDENTLY TESTED SMALL WIND TURBINE

MANUFACTURER AMPAIR
MODEL 600/230 Mk2.5

ANNUAL REFERENCE ENERGY
@ 5 m/s average wind speed
Actual production will vary depending on site conditions
481 kWh/yr

DECLARED SOUND POWER LEVEL
89 dBA

TURBINE CLASS (I-IV or S for special)
II

SEPEN
Tested by: SEPEN : Site Expérimental pour le Petit Eolien de Narbonne
Tested date: 15 October 2009

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Social Acceptance of Wind Energy Projects, Task 28

•State-of-the-Art Report compiled current knowledge about social acceptance of wind energy projects.

•Strategies to resolve social acceptance challenges, include:

- Engage and seek public consultation early
- Employ participatory development and investment models
- Implement coordinated and efficient processes
- Continue refining and communicating state-of-the-art knowledge

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Aerodynamic Research, Task 29

- MexNEXT analyses wind tunnel measurements and improves aerodynamic models
  - Using measurements of a wind turbine in the large German Dutch Wind Tunnel, DNW
  - Measurements are available from EU-funded project *Measurements and Experiments in Controlled Conditions, MEXICO*

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Comparing Structural Models for Offshore Wind Development, OC4 Task 30

- Technical research for deeper water
  - Benchmarks structural dynamics models for estimating offshore dynamic loads
  - Identifies and verifies model capabilities and limitations

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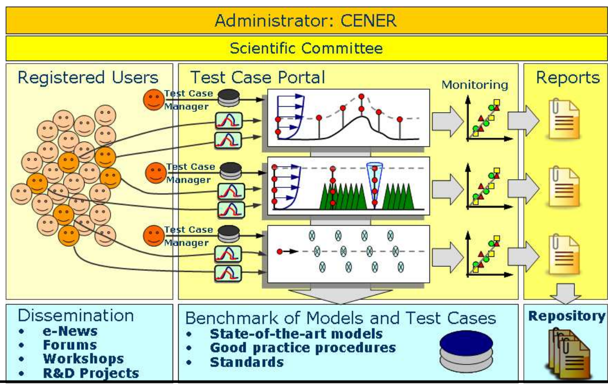
Bench Wind Farm Flow Models,Task 31

- Improves wind farm wake modeling techniques
- Provides a forum for industry, government, and academic partners
- Develops, evaluates, and improves atmospheric boundary layer and wind turbine wake models for use in wind energy.



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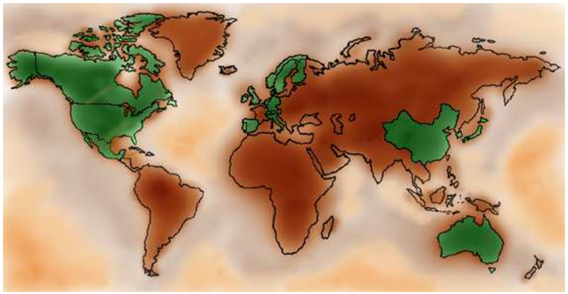
IEA Wind Strategic Plan



2009-2014

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Mission of IEA Wind

"…to stimulate co-operation on wind energy research and development and to provide **high quality information and analysis to member governments** and commercial **sector leaders** by addressing **technology development** and deployment and its **benefits, markets, and policy instruments**." – IEA Wind Strategic Plan

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IEA Technology Roadmap Wind Energy

Key Targets

Reduce the costs of wind energy use

Increase the flexibility of transmission and power systems

Increase of social Acceptance of wind energy projects

Increase the exchange of best practices

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IEA Wind Strategic Plan for 2009-2014

Key Research Topics

1. Wind Technology Research to Improve Performance and Reliability at Competitive Costs

2. Power System Operation and Grid Integration of High Amounts of Wind Generation Including Development of Fully controllable, Grid-friendly "Wind Power Plants"

3. Planning and Performance Assessment Methods for Large Wind Integration

4. Offshore Wind in Shallow and Deep Waters

5. Social, Educational, and Environmental Issues

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Topic 1: Improve Performance and Reliability at Competitive Costs

Increase component and sub-system performance and reliability –
Adding intelligence to rotors and drive trains; bearing structures; low-speed generators; improved test methods;

Reduce costs of turbine and component production by using new and recycled materials, new manufacturing techniques, and new methods for transport and installation
- mass production techniques, economies of scale, supply chain development
- new materials; recycle materials
- Logistics and transport; modular concepts in construction; commissioning procedures
-Innovative marine installation equipment

Reduce costs of wind turbine towers and foundations
- Towers: processes, materials, and strategies that minimize loads on towers
- Foundations: optimization of offshore structures

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Topic 1: Improve Performance and Reliability at Competitive Costs

Reduce operations and maintenance costs that are driven by subcomponent characteristics
- component reliability data, failure statistics
- condition monitoring, reliable sensing devices, remote
- improve reliability of small turbines
- security and safety of operation (offshore safety standards)

Explore advanced design concepts with the potential to reduce costs
- aerodynamics and wakes; rotor and drive train concepts
- control strategies for load reduction

Develop test facilities to demonstrate cost-reducing concepts and improve reliability
- larger blades, drive trains, offshore foundations, turbines (cold climates)
- grid code compatibility and grid supporting services
- time saving test methods

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Topic 2: Power System Operation and Grid Integration of High Amounts of Wind Generation

Improving grid integration and system operation -

- Development and validation of dynamic models of wind power plants and aggregation of multiple wind power plants
- Operating systems with high penetration, security of supply

Developing new integrated power system applications -

- Storage solutions and plug in vehicles, demand side management (in cooperation with other IAs)
- new applications for production regulation (desalinization etc)

Developing fully controllable, grid-friendly wind power plants -

- improved short term forecasting
- wind turbine capabilities in providing system services
- monitoring and central control systems for aggregates of wind power plants

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Topic 3: Wind Resources and Planning Assessment for Large Wind Integration

Increasing knowledge of the wind field -

- improve resource assessment and forecasting
- explore methods to minimize loss of kinetic energy in the wake,
- increase knowledge of wind field in front of the turbine for improved control,
- develop remote sensing techniques

Understanding wind power plant performance in complex conditions

- CFD tools, wake models, noise propagation
- cold climate: icing event prediction

Providing a publicly accessible wind database

- A publicly accessible database with the greatest possible coverage, taking into account commercial sensitivities, is needed of onshore and offshore wind resources and conditions.

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Topic 4: Offshore Wind in Shallow to Deep Waters

Research Targets

Research supporting offshore wind power plants in coastal waters (<50 m) -

- Offshore wind and ocean measurements and resource assessment,
- Improved access to offshore structures,
- Integrated wind and wave energy conversion technologies for shallow water

Research supporting offshore wind power plants in deep waters -

- New foundation design concepts for deep waters – floating technologies for wind turbines and power plants
- New concepts for large multi-megawatt wind technologies for deep waters
- Offshore infrastructures and construction development (rigs, mooring, and anchoring)

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Topic 5: Social, Educational, and Environmental Issues

Research Targets

Social acceptance of wind energy projects -
Establish best practices and tools for policy makers and planners to reduce project risks, accelerate time of project development,

Education and training for the wind industry -
Establish co-operative research and development agreements between national state-of-the-art test facilities and field demonstration facilities

Assessing environmental impacts -
Improve knowledge of acoustical influence of offshore construction activities on marine mammals

Interference with the radar systems and air space operations
Develop radar technologies that mitigate the effect of wind turbines, develop rotor blades with reduced backscattering.

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IEA Disclaimer

The IEA Wind agreement, also known as the Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems, functions within a framework created by the International Energy Agency (IEA). Views, findings, and publications of IEA Wind do not necessarily represent the views or policies of the IEA Secretariat or of all its individual member countries.

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U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Wind Power Program R&D Overview

October 5th, 2011

Mark Higgins
Wind R&D Lead
Wind and Water Power Program

Wind Power Program
Recent Accomplishments

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

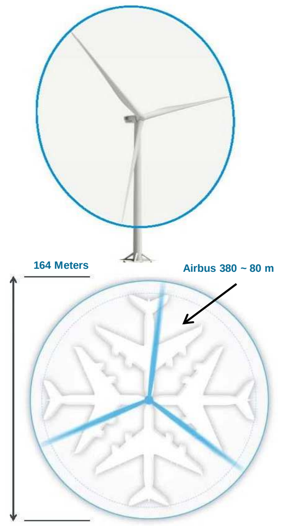
- 41 Awards for $43M in Technology Development and Market Barrier Removal in 20 states to push the Offshore Wind Market forward.
- 6 Awards for $7.5M in four states focused on developing the next generation of drivetrain technologies to reduce the cost of energy (COE) produced by wind turbines.
- Design and Development of two mid-size turbines at Northern Power and Texas Tech University to spur low-cost wind deployment in the community and distributed wind market segment via a 2010 competitive solicitation.
- Published final reports for the Western Wind and Solar Integration Study and the Eastern Wind Integration and Transmission Study that analyze interconnection wide operation implications for high penetration wind and solar technologies.
- Published a National Offshore Wind Strategy
- Defined and developed an integrated reliability program to address current reliability issues with existing wind turbine technology
- Funded the development of key technology innovations that are used currently by industry: next generation rotors, feed forward control systems, advanced materials, and industry standard design tools.
- Launched $6.5M short-term wind energy forecasting field project with NOAA and two industry partner teams as first major joint effort under new DOE-NOAA MOU for weather-dependent renewable resource characterization

2 | Wind and Water Power Program eere.energy.gov

Technology Future

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- **Commercial Technology:**
  - **2.5 MW - Typical Commercial Turbine Installation**
  - **Offshore 5.0 MW Prototypes Being Installed for Testing in Europe**
  - **Most Manufacturers Have a 10-15 MW Offshore Machine in Design**
- **Large Turbine Development Programs Targeting Offshore Markets**
- **US Deployment Characterized by Large Multi-Array Wind Farms Containing Broad Spectrum Inflow Load Drivers**
- **Turbine Dynamic Stability and Non-Linear Behavior are Becoming a Major Design Factor Requiring High Fidelity Coupled Models**



Vestas V164
7 MW Offshore Wind Turbine Design

3 | Wind and Water Power Program eere.energy.gov

Wind Program Unique Role

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Industry Focus

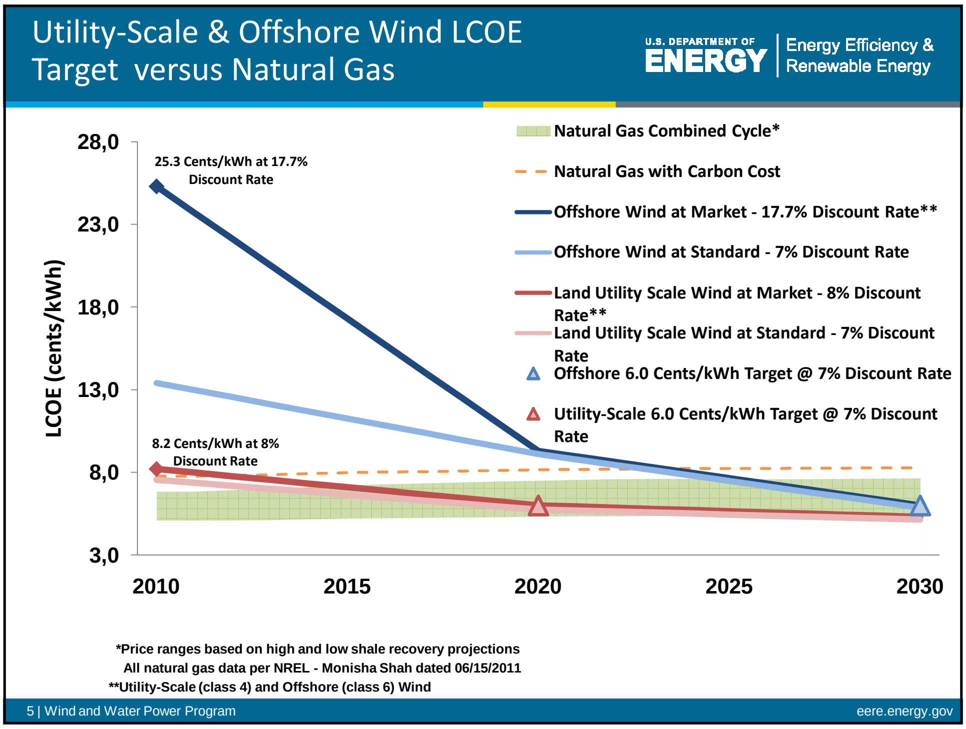
- Reducing costs through scaling turbine size
- Reducing levelized replacement costs (LRC) through increased reliability

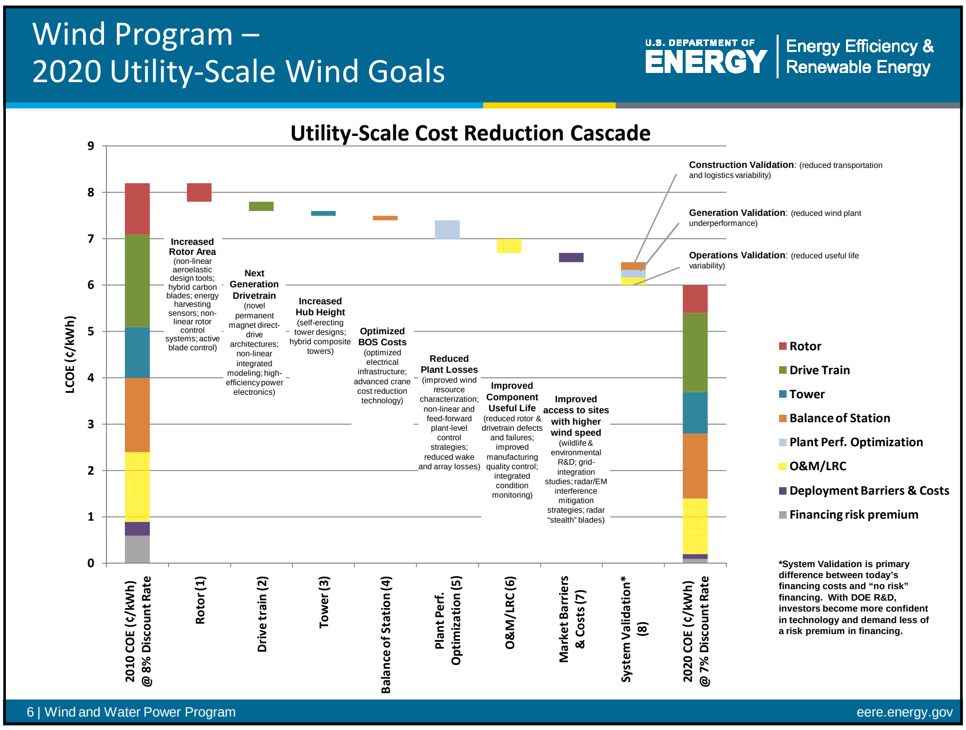
Wind Program Focus

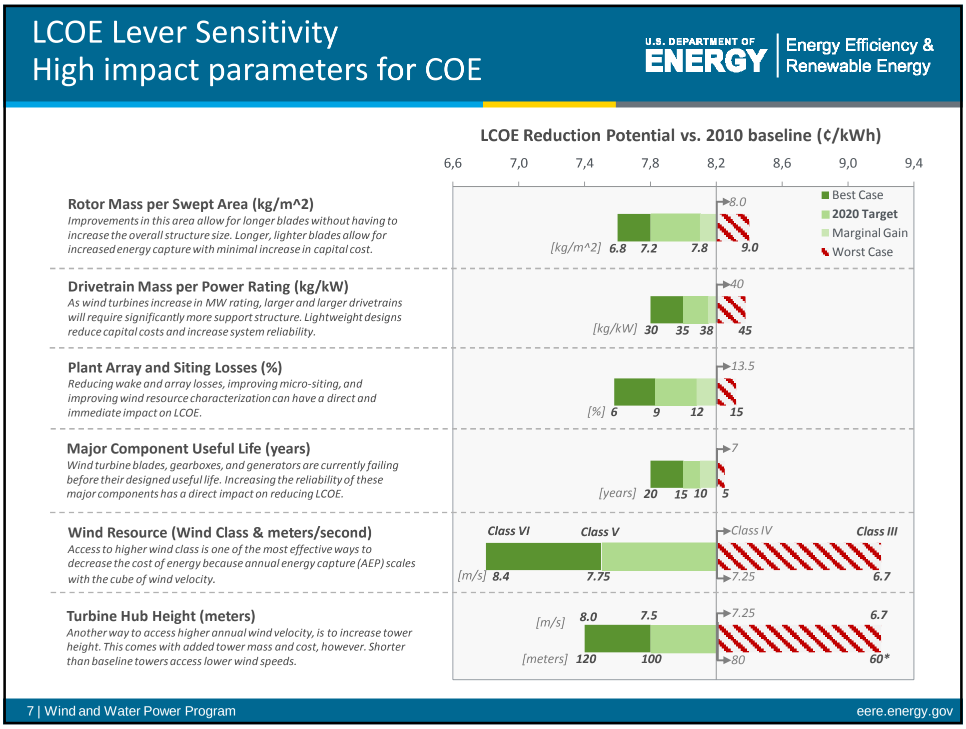
- Innovative Technology Research which benefits entire industry
- Leveraging inter- and intra-agency relationships to accomplish critical functions industry is unable to accomplish on their own
- Acting as an honest broker of critical information that industry is otherwise unwilling to share with itself

Wind Program Focus	Activity	Partners
Wind Resource Characterization	Development of 80-150 meter national wind speed data	NOAA
Radar	Mitigation of siting barriers	DHS, DOD & FAA
Reliability	Broker of confidential information	Industry
Environmental	Role as “anchor tenant” lends credibility to environmental impact reports	EPA, BOEMRE
Testing	Provision of multi-user world-class national test facilities at much lower cost than individual companies would incur, open to entire industry	Industry
Scaling	Development and sharing of codes and models over the entire industry	Industry
Grid	Keeps wind perspective from being lost within competing grid and transmission priorities	OE, FERC
New Markets	Leading deep water platform technology development	Industry

4 | Wind and Water Power Program eere.energy.gov


Utility-Scale & Offshore Wind LCOE
Target versus Natural Gas
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
LCOE (cents/kWh)
28,0
23,0
18,0
13,0
8,0
3,0
2010
2015
2020
2025
2030
25.3 Cents/kWh at 17.7% Discount Rate
8.2 Cents/kWh at 8% Discount Rate
Natural Gas Combined Cycle*
Natural Gas with Carbon Cost
Offshore Wind at Market - 17.7% Discount Rate**
Offshore Wind at Standard - 7% Discount Rate
Land Utility Scale Wind at Market - 8% Discount Rate**
Land Utility Scale Wind at Standard - 7% Discount Rate
Offshore 6.0 Cents/kWh Target @ 7% Discount Rate
Utility-Scale 6.0 Cents/kWh Target @ 7% Discount Rate
*Price ranges based on high and low shale recovery projections
All natural gas data per NREL - Monisha Shah dated 06/15/2011
**Utility-Scale (class 4) and Offshore (class 6) Wind
5 | Wind and Water Power Program
eere.energy.gov


Wind Program –
2020 Utility-Scale Wind Goals
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
Utility-Scale Cost Reduction Cascade
LCOE (¢/kWh)
9
8
7
6
5
4
3
2
1
0
Increased Rotor Area (non-linear aeroelastic design tools; hybrid carbon blades; energy harvesting sensors; non-linear rotor control systems; active blade control)
Next Generation Drivetrain (novel permanent magnet direct-drive architectures; non-linear integrated modeling; high-efficiency power electronics)
Increased Hub Height (self-erecting tower designs; hybrid composite towers)
Optimized BOS Costs (optimized electrical infrastructure; advanced crane cost reduction technology)
Reduced Plant Losses (improved wind resource characterization; non-linear and feed-forward plant-level control strategies; reduced wake and array losses)
Improved Component Useful Life (reduced rotor & drivetrain defects and failures; improved manufacturing quality control; integrated condition monitoring)
Improved access to sites with higher wind speed (wildlife & environmental R&D; grid-integration studies; radar/EM interference mitigation strategies; radar “stealth” blades)
Construction Validation: (reduced transportation and logistics variability)
Generation Validation: (reduced wind plant underperformance)
Operations Validation: (reduced useful life variability)
2010 COE (¢/kWh) @ 8% Discount Rate
Rotor (1)
Drive train (2)
Tower (3)
Balance of Station (4)
Plant Perf. Optimization (5)
O&M/LRC (6)
Market Barriers & Costs (7)
System Validation* (8)
2020 COE (¢/kWh) @ 7% Discount Rate
Rotor
Drive Train
Tower
Balance of Station
Plant Perf. Optimization
O&M/LRC
Deployment Barriers & Costs
Financing risk premium
*System Validation is primary difference between today’s financing costs and “no risk” financing. With DOE R&D, investors become more confident in technology and demand less of a risk premium in financing.
6 | Wind and Water Power Program
eere.energy.gov


LCOE Lever Sensitivity
High impact parameters for COE
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
LCOE Reduction Potential vs. 2010 baseline (¢/kWh)
6,6 7,0 7,4 7,8 8,2 8,6 9,0 9,4
Best Case
2020 Target
Marginal Gain
Worst Case
Rotor Mass per Swept Area (kg/m^2)
Improvements in this area allow for longer blades without having to increase the overall structure size. Longer, lighter blades allow for increased energy capture with minimal increase in capital cost.
[kg/m^2] 6.8 7.2 7.8 9.0 8.0
Drivetrain Mass per Power Rating (kg/kW)
As wind turbines increase in MW rating, larger and larger drivetrains will require significantly more support structure. Lightweight designs reduce capital costs and increase system reliability.
[kg/kW] 30 35 38 45 40
Plant Array and Siting Losses (%)
Reducing wake and array losses, improving micro-siting, and improving wind resource characterization can have a direct and immediate impact on LCOE.
[%] 6 9 12 15 13.5
Major Component Useful Life (years)
Wind turbine blades, gearboxes, and generators are currently failing before their designed useful life. Increasing the reliability of these major components has a direct impact on reducing LCOE.
[years] 20 15 10 5 7
Wind Resource (Wind Class & meters/second)
Access to higher wind class is one of the most effective ways to decrease the cost of energy because annual energy capture (AEP) scales with the cube of wind velocity.
Class VI Class V Class IV Class III
[m/s] 8.4 7.75 7.25 6.7
Turbine Hub Height (meters)
Another way to access higher annual wind velocity, is to increase tower height. This comes with added tower mass and cost, however. Shorter than baseline towers access lower wind speeds.
[m/s] 8.0 7.5 7.25 6.7
[meters] 120 100 80 60*
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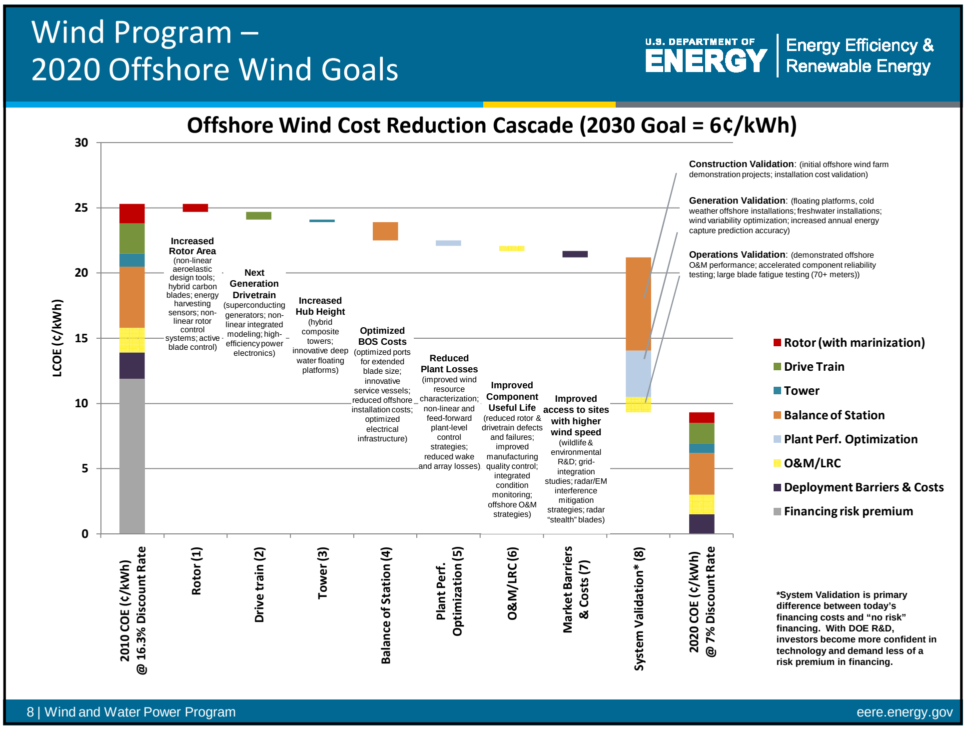
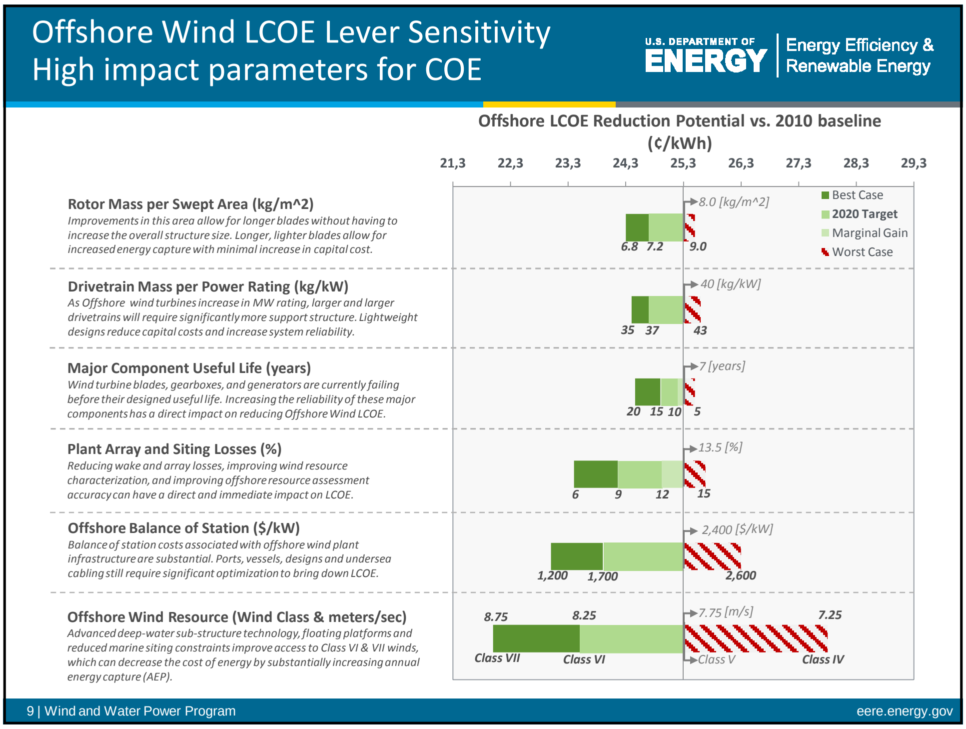
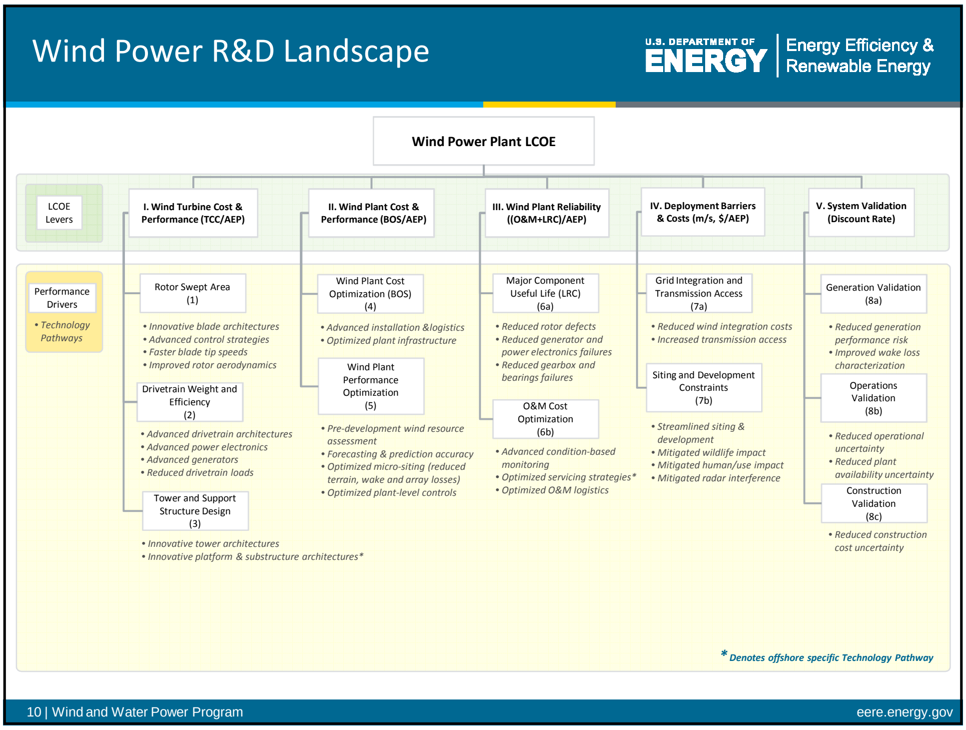
eere.energy.gov


Wind Program –
2020 Offshore Wind Goals
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
Offshore Wind Cost Reduction Cascade (2030 Goal = 6¢/kWh)
LCOE (¢/kWh)
30 25 20 15 10 5 0
Increased Rotor Area (non-linear aeroelastic design tools; hybrid carbon blades; energy harvesting sensors; non-linear rotor control systems; active blade control)
Next Generation Drivetrain (superconducting generators; non-linear integrated modeling; high-efficiency power electronics)
Increased Hub Height (hybrid composite towers; innovative deep water floating platforms)
Optimized BOS Costs (optimized ports for extended blade size; innovative service vessels; reduced offshore installation costs; optimized electrical infrastructure)
Reduced Plant Losses (improved wind resource characterization; non-linear and feed-forward plant-level control strategies; reduced wake and array losses)
Improved Component Useful Life (reduced rotor & drivetrain defects and failures; improved manufacturing quality control; integrated condition monitoring; offshore O&M strategies)
Improved access to sites with higher wind speed (wildlife & environmental R&D; grid-integration studies; radar/EM interference mitigation strategies; radar "stealth" blades)
Construction Validation: (initial offshore wind farm demonstration projects; installation cost validation)
Generation Validation: (floating platforms, cold weather offshore installations; freshwater installations; wind variability optimization; increased annual energy capture prediction accuracy)
Operations Validation: (demonstrated offshore O&M performance; accelerated component reliability testing; large blade fatigue testing (70+ meters))
Rotor (with marinization)
Drive Train
Tower
Balance of Station
Plant Perf. Optimization
O&M/LRC
Deployment Barriers & Costs
Financing risk premium
2010 COE (¢/kWh) @ 16.3% Discount Rate
Rotor (1)
Drive train (2)
Tower (3)
Balance of Station (4)
Plant Perf. Optimization (5)
O&M/LRC (6)
Market Barriers & Costs (7)
System Validation* (8)
2020 COE (¢/kWh) @ 7% Discount Rate
*System Validation is primary difference between today's financing costs and "no risk" financing. With DOE R&D, investors become more confident in technology and demand less of a risk premium in financing.
8 | Wind and Water Power Program
eere.energy.gov



Offshore Wind LCOE Lever Sensitivity
High impact parameters for COE
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
Offshore LCOE Reduction Potential vs. 2010 baseline (¢/kWh)
21,3 22,3 23,3 24,3 25,3 26,3 27,3 28,3 29,3
Best Case
2020 Target
Marginal Gain
Worst Case
Rotor Mass per Swept Area (kg/m^2)
Improvements in this area allow for longer blades without having to increase the overall structure size. Longer, lighter blades allow for increased energy capture with minimal increase in capital cost.
8.0 [kg/m^2]
6.8 7.2 9.0
Drivetrain Mass per Power Rating (kg/kW)
As Offshore wind turbines increase in MW rating, larger and larger drivetrains will require significantly more support structure. Lightweight designs reduce capital costs and increase system reliability.
40 [kg/kW]
35 37 43
Major Component Useful Life (years)
Wind turbine blades, gearboxes, and generators are currently failing before their designed useful life. Increasing the reliability of these major components has a direct impact on reducing Offshore Wind LCOE.
7 [years]
20 15 10 5
Plant Array and Siting Losses (%)
Reducing wake and array losses, improving wind resource characterization, and improving offshore resource assessment accuracy can have a direct and immediate impact on LCOE.
13.5 [%]
6 9 12 15
Offshore Balance of Station ($/kW)
Balance of station costs associated with offshore wind plant infrastructure are substantial. Ports, vessels, designs and undersea cabling still require significant optimization to bring down LCOE.
2,400 [$/kW]
1,200 1,700 2,600
Offshore Wind Resource (Wind Class & meters/sec)
Advanced deep-water sub-structure technology, floating platforms and reduced marine siting constraints improve access to Class VI & VII winds, which can decrease the cost of energy by substantially increasing annual energy capture (AEP).
8.75 8.25 7.75 [m/s] 7.25
Class VII Class VI Class V Class IV
9 | Wind and Water Power Program
eere.energy.gov



Wind Power R&D Landscape
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
Wind Power Plant LCOE
LCOE Levers
I. Wind Turbine Cost & Performance (TCC/AEP)
II. Wind Plant Cost & Performance (BOS/AEP)
III. Wind Plant Reliability ((O&M+LRC)/AEP)
IV. Deployment Barriers & Costs (m/s, $/AEP)
V. System Validation (Discount Rate)
Performance Drivers
• Technology Pathways
Rotor Swept Area (1)
• Innovative blade architectures
• Advanced control strategies
• Faster blade tip speeds
• Improved rotor aerodynamics
Drivetrain Weight and Efficiency (2)
• Advanced drivetrain architectures
• Advanced power electronics
• Advanced generators
• Reduced drivetrain loads
Tower and Support Structure Design (3)
• Innovative tower architectures
• Innovative platform & substructure architectures*
Wind Plant Cost Optimization (BOS) (4)
• Advanced installation &logistics
• Optimized plant infrastructure
Wind Plant Performance Optimization (5)
• Pre-development wind resource assessment
• Forecasting & prediction accuracy
• Optimized micro-siting (reduced terrain, wake and array losses)
• Optimized plant-level controls
Major Component Useful Life (LRC) (6a)
• Reduced rotor defects
• Reduced generator and power electronics failures
• Reduced gearbox and bearings failures
O&M Cost Optimization (6b)
• Advanced condition-based monitoring
• Optimized servicing strategies*
• Optimized O&M logistics
Grid Integration and Transmission Access (7a)
• Reduced wind integration costs
• Increased transmission access
Siting and Development Constraints (7b)
• Streamlined siting & development
• Mitigated wildlife impact
• Mitigated human/use impact
• Mitigated radar interference
Generation Validation (8a)
• Reduced generation performance risk
• Improved wake loss characterization
Operations Validation (8b)
• Reduced operational uncertainty
• Reduced plant availability uncertainty
Construction Validation (8c)
• Reduced construction cost uncertainty
* Denotes offshore specific Technology Pathway
10 | Wind and Water Power Program
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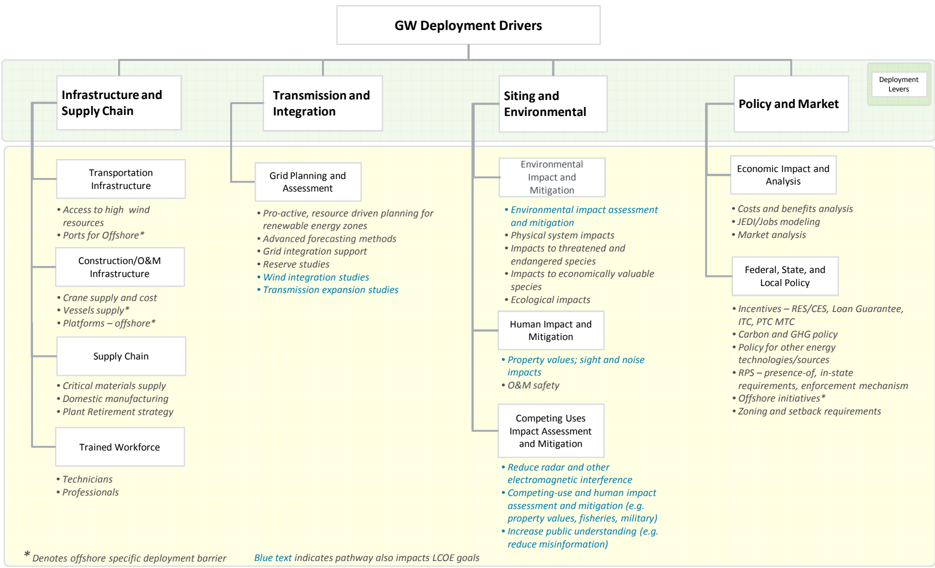
Wind Power R&D Landscape: Deployment Drivers

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



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Status of DOE Funded Test Facilities

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Large Wind Blade Test Facility
Boston, MA - **$24.7 Million**

Large Dynamometer Test Facility
Charleston, SC - **$44.5 Million**

NWTC Dynamometer Upgrade
National Wind Technology Center (at NREL)
Golden, CO - **$9.5 Million**

University of Minnesota – Siemens 2.3 MW Turbine
Minneapolis, MN - **$7.9M**

Illinois Institute of Technology – GE 1.5 MW Turbine
Chicago, IL- **$7.9M**

University of Maine – 1-3 Offshore Floating Platforms
Orono, ME - **$7.1M**

12 | Wind and Water Power Program eere.energy.gov

Offshore Wind Research FOAs - 2011

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

	Next-Generation Drivetrain Development	Offshore Technology Development	Market Barrier Removal
Impact	Develop core technologies for next-generation turbines, ensuring competitiveness of domestic OEMs	Develop modeling tools, optimized system designs, and components necessary for long-term R&D to reduce cost of energy	Close data gaps needed for efficient permitting; develop cost-competitive O&M strategies; transmission and interconnection planning
Topics	Stage 1: Conceptual design Stage 2: Preliminary design Stage 3: Final design and prototyping	Fully integrated wind plant designs; floating platform dynamics models; wind/wave simulation models; long-life components to reduce O&M	Market analysis; environmental risk reduction; supply chain development; ports, vessels & operations; resource characterization
Total DOE Funding	up to $7.5M	up to $24M	up to $18M
Cost-Share	up to $3.75M	up to $4.6M	up to $3M
Timeline	2 years	5 years	3 years
Applicants	Industry consortia with national labs, universities and engineering firms	Industry consortia with national labs, universities and engineering firms	Industry, NGO's, universities, national labs and consultancies
Award Date	June 2011	August 2011	September 2011

13 | Wind and Water Power Program eere.energy.gov

Wind Energy Fundamental Science Issues Requiring HPC

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

HPC Code Development for Predictive, Rational Design and Operation Supporting High Penetration Wind Energy

- **Wind & Solar Resource Assessment as a Strategic National Energy Resource**
  - Guide the Strategic Development & Deployment of Future Infrastructure – Generation & Transmission
- **Weather Driven Energy Forecast Models - Coupled Wind & Solar**
  - Integrated Monitoring, Forecast, Generation, Load Flow & Operational Dispatch
- **Quantify Potential Effects of High Penetration Scenarios**
  - Climate change Sensitivities
  - Macro & Micro Climatology Impacts
  - Insure against trading carbon alleviation for unknown consequences
- **Characterize Inflow and Outflow Resource**
  - Boundary Layer Processes, Stability, Marine & Nocturnal Formation
  - Atmospheric turbulence
  - Flow separation in complex terrain
  - Air/Sea Boundary Conditions & Wave Interaction
  - Inter & Intra Array Wake Effects
- **Coupled Physics Models Inflow / Wind Plant Interaction / Grid Response**
  - Energy production optimization and grid integration
  - Wind Plant Operation & Control Strategy Development
- **Establish the Design Criteria for Future Turbine & Plant Innovation -**
  - Individual blades and gearboxes, materials.
  - Multi-turbine arrays.
  - Mesoscale atmospheric models.
  - Wind/Wave models.
  - Inter/intra plant dynamics

Repower 5MW Demonstration at Beatrice Four-pile jacket

Classic Coupled Multi-Scale, Multi-Physics Problems

14 | Wind and Water Power Program eere.energy.gov

Wind Power Program
Priorities

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- **Develop and implement a successful Offshore Wind Demonstration Program that is both regionally and technologically diverse.**
- **Coordinate National Laboratory, Academia and Industry expertise to solve complex flow issues encompassing:**
  - **Large-scale data collection effort for wind plant aerodynamics and loads**
  - **High Performance Computing models for wind plant aerodynamics and loads**
  - **Accurate wind resource prediction models**
  - **Wind System/Wind Plant aerodynamic optimization studies**
  - **Improving overall wind plant performance**
- **Assist industry in the testing and certification of small and medium wind systems**
- **Complete a top-down programmatic technology roadmap and multi-year program plan that is valued by industry.**
- **Complete follow-on wind and solar integration studies that evaluate different operational structures, penetration levels, and reflects specific policy changes that impact high penetration of wind in the U.S. (Studies being coordinated and jointly funded with OE and Solar Program)**
- **Completing multi-agency atmospheric and oceanic research activities to define needs for expanded observation networks, improved models, and data systems supporting optimized onshore and offshore wind energy.**
- **Develop an integrated wind plant system model that integrates cost models with system dynamics models (blade models, drivetrain models, floating platform models, etc.).**
  - **This will be a first of its kind model, which will be used to link engineering metrics to the cost of energy model, thereby allowing the wind program to better identify Technology Improvement Opportunities.**
- **Address key industry wide barriers such as radar and wildlife impact issues.**

15 | Wind and Water Power Program — eere.energy.gov

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PLATAFORMA EOLICA TECNOLOGICA

Coordinted by
aee
Spanish Wind Energy Association

LONG TERM R&D NEEDS: SPANISH CASE.

IEA topical expert meeting # 67
05/10/2011

Alberto Ceña
Emilien Simonot
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Plan nacional de I+D+i 2008-2011
Subprograma de plataformas tecnológicas – convocatoria 2009
Expediente nº: RET-120000-2009-01

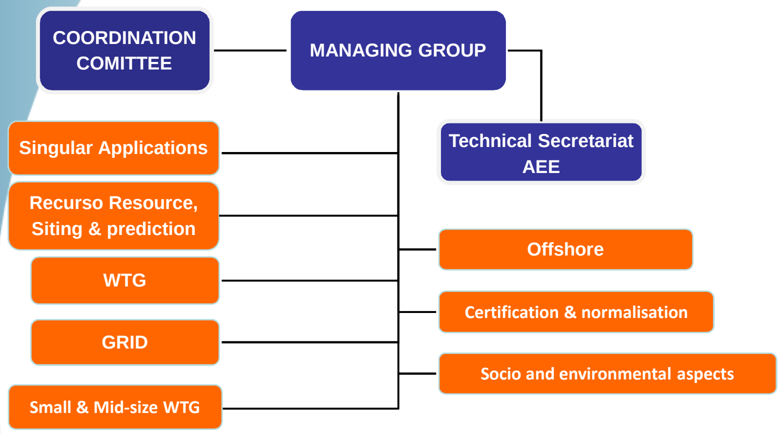
REOLTEC.NET
PLATAFORMA EOLICA TECNOLOGICA

WHAT IS REOLTEC?

- **REOLTEC** is the Spanish Wind Energy Technology Platform, created with financial support of the Spanish Ministry of Science and innovation (MICINN), since 2005.
- Main target: defining the R&D priorities of the sector.
- It is organized through a Managing Group and several Working Groups.

REOLTEC.NET
PLATAFORMA EÓLICA TECNOLÓGICA

WORKING GROUPS



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GENERAL TARGETS

- **Strategic targets:**
  - Reduction of life cycle generation costs (LCOE).
  - Increase of the availability and reliability of the systems.
  - Grid integration – Power quality.

Other targets:

- Improvement of the logistic (transport, installation and **O&M**)
- Security in network operation: LVRT, permanent voltage control, improvement of participation in ancillary services, regulating services.
- Solutions for energy storage & load management.
- Development of reliable local and autonomous applications (small wind power and smart grid concept).

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R&D Priorities in Site Assessment

- Wind profile at high levels (>150 m).
- Wind structure in wind farms (complex terrain, turbulence, vertical shear and offshore).
- Offshore wind measurements.
- Forecasting from 15 min to 15 days (all WF in Spain forecasts for the day ahead market).
- New adapted measurements systems (sodar, lidar, floating met towers, etc).
- Wind structure in urban areas.

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R&D Priorities in WTGs

General priorities:

- Aero-elastic codes development.
- WTG models & simulation algorithms.
- New materials:
  - Weight reduction.
  - Cost improvement.
- Design validation.

R&D Priorities in WTGs

Rotor:

- New profiles (for small and large blades).
- Larger blades (split blades).
- Lighter structural designs.
- New materials (nano-materials).
- Noise control.
- Automated production processes.

R&D Priorities in WTGs

Gearbox

- Condition monitoring & problem characterization.
- Increase of components' life span.
- High torque couplings.
- Dynamic behavior.

Generator

- Transient behavior & shaft alignment.
- High voltage generation.
- New materials and their supply (super-conductors, rare earth…).

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R&D Priorities in WTGs

Monitoring

- Load monitoring.
- Specialized sensors (blades – rotating parts – electronics).
- Signal analysis methods – Condition Monitoring Strategies (aeronautical references).
- WTG fleet supervision & management decision tools.

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R&D Priorities in O&M

- Predictive maintenance & condition monitoring:
  - Component sensing
  - State monitoring and breakdown forecast
- Component reliability (studies of rate and type of failures) – BADEX project (shared O&M database).
- Operation with failure tolerance.
- New O&M strategies (share spare part stock).

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R&D Priorities in Grid Integration

- Advanced control systems for wind farms
- Monitoring and prediction of voltage dips. Applications of voltage control systems.
- Studies of the impact and operation of a system with high wind penetration.
- Improvement of the use of the energy production forecasting for system operation.
- Specific analysis of electric systems in islands.
- Load management strategies: electric vehicles, demand side, …

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R&D Priorities in Offshore Wind Farms

- Offshore wind resource assessment
- Wave models.
- Floating foundations and new support structures.
- Environmental & social impact studies.
- Wind Turbine Protection (bio-fouling, corrosion…)
- Electrical substations
- Offshore Wind Farms Logistic
- Test and Demonstration Plants (Zéfir project)

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R&D Priorities in Certification and Standardization

- Development of test and verification standards applied to :
  - Wind farm design.
  - Wind farm security
  - Production capacity of wind farms.
  - Wind farm availability.
- Electromagnetic compatibility of wind farms:
  - Voltage control – Frequency control.
  - Development of norms for sub-systems that increase modularity accelerating market development.
- Mid-size wind power standards (100 – 300 kW).

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R&D Priorities in Singular Applications

- Development of short term energy storage systems:
  - Supercapacitors.
  - Flywheels.
  - Batteries.
  - Compressed Air
- Development of isolated solutions.
- Small WTs for autonomous systems.

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Sociological R&D Priorities

- Evaluation of the macroeconomic impact of wind farms.
- Optimization of socioeconomic returns.
- Analysis of the social response and degree of acceptability.

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R&D Priorities in Environment

- Recyclability of components: Blades
- Visual impact
- Impact on birds and sea fauna
- Noise reduction
- Study on the impact on radiofrequency and its limitation
- Impact of WF on aviation radar

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CONCLUSIONS

- Priorities similar to other technology platforms but adapted to the specificity of the Spanish market:
  - Grid integration.
  - Complex terrain & highly turbulent wind regimes.
- Important to reinforce the cooperation between technical centers.
- Response of Cies & technical centers to calls, mainly oriented to:
  - Grid integration.
  - Offshore (floating).
- Looking for best alignment possible with SET-Plan.

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THANK YOU FOR YOUR ATTENTION

IEA topical expert meeting # 67

05/10/2011

Alberto Ceña
Emilien Simonot
stecnica@reoltec.net

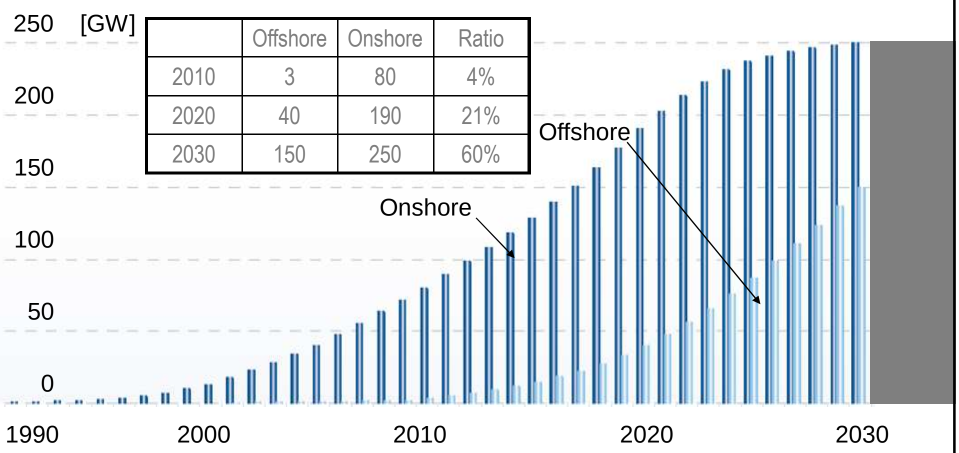
GL Renewables Certification

Research Requirements - View of a Certification Body

Kimon Argyriadis, Christian Nath

www.gl-group.com

Installed Power in Europe 1990 - 2030



	Offshore	Onshore	Ratio
2010	3	80	4%
2020	40	190	21%
2030	150	250	60%

Source: EWEA

Ambitious Targets for Wind Energy

400 GW to be installed in Europe put high requirements to wind industry:

- Wind farms will directly replace existing "classic" power plants combined with storage and smart grid applications wind energy has to guaranty the reliability of supply
- Wind energy penetration will be higher than 30% in some areas
- New geographical areas will be used for wind farm installation
- Offshore wind farm development will accelerate
- Mass manufacture and installation is required

→ New challenges on certification bodies regarding safety and reliability are set

→ New standards and guidelines have to be developed

Research Requirements Certification 5.10.2011 3

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Wind Energy a Replacement for Classic Power Plants

- Wind farms shall be in position to replace existing power plants and guarantee safety of supply
- Increased reliability of turbines due to better design
  - → Improve and validate design codes (e.g. load analysis)
  - → Improve modelling of wind farm effects
  - → Optimize structural analysis techniques under consideration of material properties (e.g. fatigue analysis of GRP/CFP structures, strain based analysis for steel cast etc.)
  - → Introduce reliability based methods in WT component design
  - → Use standardized risk based methods to identify hazards in design of new/advanced concepts
- Better availability of wind farms
  - → Improve maintenance effectiveness (CMS, Risk analysis based maintenance)
  - → Improve access for offshore wind farms
- Wind energy production to be combined with storage systems
  - → Special adjustment on wind turbine/farm management will be needed. New requirements shall be developed and formulated

Research Requirements Certification 5.10.2011 4

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Environment and Geographic expansion

- Better understanding of existing environment regarding safety
  - → Models for onshore conditions shall be improved (wind turbulence, hostile terrain...)
  - → Prediction and measurement methods and tools require better reliability and ease of use
  - → Data bases regarding conditions in Europe shall be improved
  - → Wake effects models (loads) shall be improved, validated, corrected and simplified!
- Further geographical expansion
  - → Understand new, difficult environments like cold/hot climate, influence of tropical/arctic storms on wind turbine design. Development of specialized design requirements

Research Requirements Certification 5.10.2011 5

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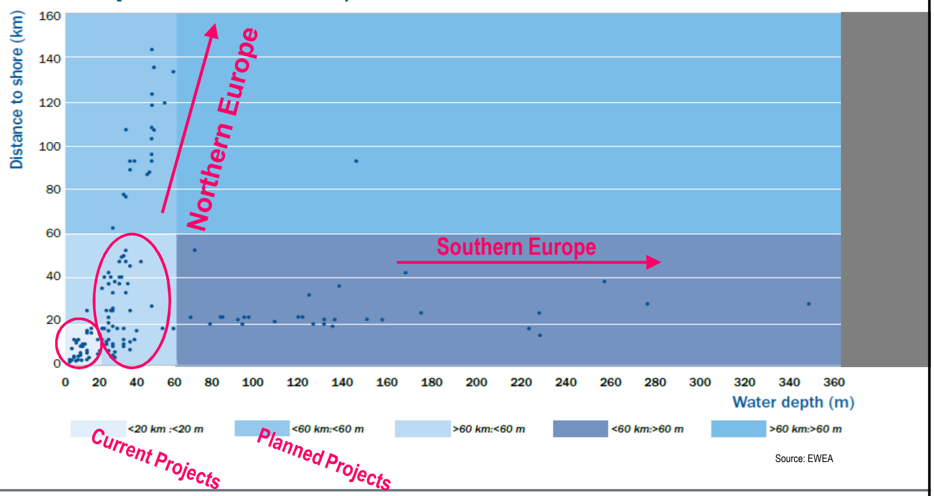
Offshore Windfarming development – deeper and further, Trend until 2025



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Offshore expansion

- Requirements for offshore WT design shall be reviewed based on existing experience with focus to accelerate development without loss of safety
- Measurement methods of offshore conditions have to be improved:
  - → Development of affordable offshore measurement methods
  - → Guideline for offshore measurement (best practice) based on experience from North Sea, UK applications
  - → Wind & Wave mapping for Europe
- Engineering characterisation for offshore WF & WT design Development of design tools to allow optimal design of every single turbine in the WF under consideration of variation of environmental conditions, interaction of turbines and substructure-turbine interaction
- Specialized CMS systems for offshore covering the complete WT system
- Multi rotor WF design analysis
  - → Wake influence
  - → Tool development

Research Requirements Certification 5.10.2011 7

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Conclusions

- New Standards and Guidelines to be developed for:
  - Far and deep offshore wind energy applications
  - Installation of wind farms in zones with extreme environmental conditions
  - Combination of wind energy with storage systems, smart grids, weak grids
  - New concepts
  - Measurement of environmental conditions
  - Measurements on WT in remote areas
- Improvement of design methods needed
  - Further develop and validate design tools and data bases e.g. for very large wind turbines
  - Expand component testing to validate design assumptions and increase reliability
  - Introduce risk analysis in wind turbine design, e.g. for new concepts
  - Reliability based methods shall be developed to allow optimized use of material

...and...

Research Requirements Certification 5.10.2011 8

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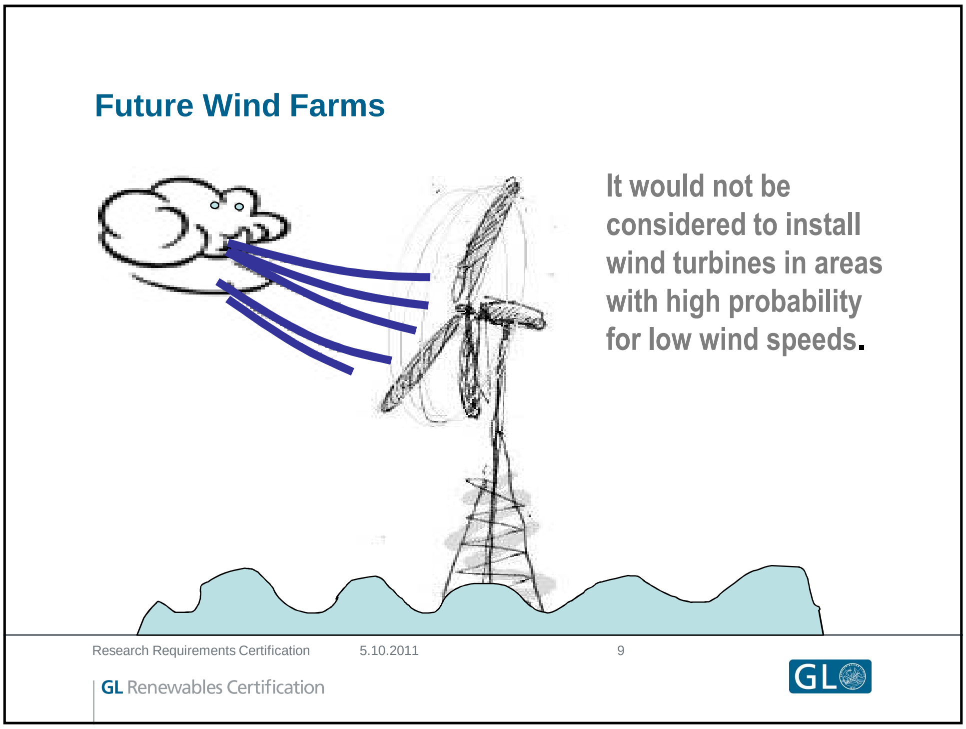
Future Wind Farms
It would not be considered to install wind turbines in areas with high probability for low wind speeds.
Research Requirements Certification
5.10.2011
9
GL Renewables Certification
GL

IEA Wind • TEM #67
Long Term R&D Needs on Wind Power

Brussels, 5 October 2011

ForWind
Center for Wind Energy Research
Bremen Hannover Oldenburg
ForWind
Head Office
Dr. Stephan Barth

Wind / Flow Conditions

- measurement campaigns in order to capture the full wind information, i.e. turbulence, shear, wakes, etc. ▸ open access database
- new anemometry techniques, including high-frequency point measurements as well as spatial remote sensing techniques - especially LiDAR (e.g. WindScanner.eu)
- enhancement of numerical models

Wind Power Systems

- **on turbine level**
  - smart rotors and smart turbines
  - make use of the numerous standard sensors and signals (e.g. SCADA) and derive crucial information in the most efficient way
  - fault tolerance - especially offshore
- **on wind park level**
  - wind power plants: include flow information (e.g. from LiDAR) into control strategies

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Next Generation Wind Turbines

- design of innovative concepts, e.g. two-bladed downwind offshore wind turbines (?)
- modular design for faster changes and maintenance (e.g. converter stations)
- new (hybrid) materials, e.g. support structures

RWE INNOGY - Research & Development Offshore Wind

Dr.-Ing. Friedrich Koch

RWE
The energy to lead

Agenda

>Overview and motivation for Wind Energy Offshore

>Research activities in the Offshore Wind sector
- current projects and
- project ideas

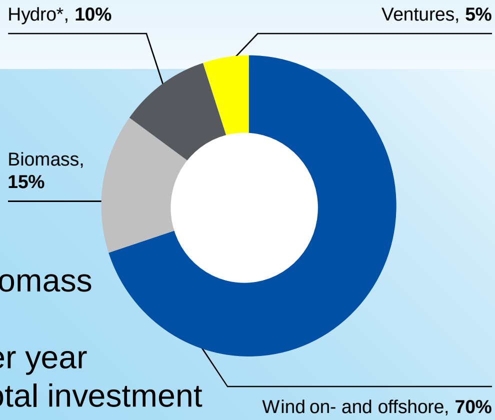
>Summary and Outlook

RWE
The energy to lead

RWE Innogy 10/25/2011 PAGE 2

RWE Innogy

Investment Plan 2008 – 2012



Strategy
- Focus on wind, hydro & biomass (today > 2300 MW)
- Investment ~ 1 Billion € per year
- Wind Offshore > 50% of total investment

* Including geothermal energy and other renewable energies

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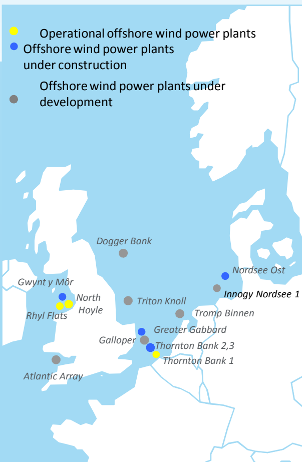
RWE Innogy 10/25/2011 PAGE 3

RWE Innogy current project pipeline for Wind Offshore is > 7.600 MW



Project name	Country	Status	Capacity	RWE Share
Rhyl Flats	GB	Operation	90 MW	90 MW
North Hoyle	GB	Operation	60 MW	60 MW
Thornton Bank 1	B	operation	30 MW	8 MW
Greater Gabbard	GB	construction	504 MW	252 MW
Gwynt y Môr	GB	construction	576 MW	346 MW
Nordsee Ost	D	construction	295 MW	295 MW
Thornton Bank 2,3	B	construction	295 MW	79 MW
Innogy Nordsee 1	D	development	996 MW	996 MW
Tromp Binnen	NL	development	295 MW	295 MW
Galloper	GB	development	500 MW	250 MW
Triton Knoll	GB	development	1.200 MW	1.200 MW
Atlantic Array	GB	development	1.500 MW	1.500 MW
Dogger Bank	GB	development	9.000 MW	2.250 MW
Total			15.341 MW	7.621 MW

RWE The energy to lead

RWE Innogy 10/25/2011 PAGE 4

R&D at RWE Innogy for further development of offshore wind energy

Motivation

Reduction of CAPEX by:

> Offshore Wind Turbines (Reduction of top mass per MW)
> Foundations (Mass reduction & environmental impact)
> Electrical infrastructure / grid integration (Reliability)
> Powerful Installation equipment (Vessels)

Reduction of OPEX by:

> Increase of efficiency and availability of offshore wind power plants
> Reduction of maintenance
> Intelligent methods for prediction of energy production

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RWE Innogy 10/25/2011 PAGE 5

Agenda

>Overview and motivation for Offshore Wind Energy

>**Research activities in the Offshore Wind sector**
- current projects and
- project ideas

>Summary and Outlook

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Wind on- & offshore

RWE Innogy's current R&D activities in the wind offshore sector

- **OWA Offshore Wind Accelerator Stage II**
- **FLOW (Far Large Offshore Wind Farms)**
- **Offshore Grid – regulatory framework for electricity grids offshore and for European electricity grids**
- **Ekko – Development of concepts for the identification of offshore wind energy power plants**
- **GridSim – simulation of a offshore wind farm with a direct HVDC-link**
- **Integrated model to assess the availability of offshore wind farms**
- **Crew Transfer Vessel and modelling of boat landing design**
- **Capacity of grouted connections in Wind Turbine Structures**
- **Evaluation of systems to reduce piling noise at an offshore test pile**

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R&D project ideas

Demonstration of innovative foundations

Issue	Foundations make up ~20% of the investment of an offshore wind park→ possible potential for cost reduction. Increasing water depths → challenges for installation **Theoretical concepts have been tested on a small scale, the demonstration is still due.**
Procedure	Develop a Demonstartion field Installation of innovative foundations, Monitoring & analysing of interaction of structure / subsoil
Project partners	Research institutions, installation companies, foundation manufacturers, approving authority, certifier
Result	Certified / ready to be certified

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R&D project ideas
Concept of an inter-array cable-laying ship

Issue	The internal cable system at offshore wind parks is usually laid with modified pontoons or available ships. **The actual situation reflects 80% of the claims in the offshore wind market can be attributed to poor quality in cable installation.**
Procedure	Analyse of: - Soil characteristics of various offshore wind farms - Installation technologies - Kinds of cables including lengths and weights → Concept & design of deck equipment, ship basic design
Project partners	Research institutions, Engineering companies, ship designers
Result	Basic design of a special cable-laying ship for internal cable installation of offshore wind farms

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R&D project ideas
Development of an integrated CMS

Issue	Various Monitoring Systems (CMS, meteorological data, operation data, etc.) are recording data. Until now, no structured, automated analyses and interpretation of the data has been made. → **unused resource**
Procedure	Integration of the various Monitoring Systems and Structuring of the data → Development of suitable algorithms and regulations for the analyses and interpretation → Field test and improvement of the algorithms; transform into applicable software
Project partners	Research institutions, WTG manufacturers and experts in operation / diagnostic systems / software
Result	Automated analyses of the CMS-data and transformation into instructions for the operator / Asset manager

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R&D project ideas Development of a Wind Farm Management System

Issue	Operation & maintenance of large offshore wind farms. Until now, each wind turbine is considered individually, no distinctive operational mode as **wind power plant**
Procedure	Development & test of innovative management concepts,, - revenue-optimized operation and maintenance on - self-learning control and regulatory concepts - turbulence-based control. Field test at offshore wind farms with extended instrumentation
Project partners	Research institutions, turbine manufacturers
Result	Higher revenue on a long-term basis and diminished charges on the structures

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Summary and Outlook

Wind power plants / manufacturers should deliver and verify:

Large nominal power output

Low maintenance

High Quality / Availability

Which means for the future (especially for Wind turbines) :

Extended specific test-procedures & -processes

Extension of (IEC 61400) standards

Extended data exchange between manufacturers and operators

Extended R&D activities and communication of actions & results

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THANK YOU VERY MUCH
FOR YOUR ATTENTION
RWE
The energy to lead
Dr. Friedrich Koch
Wind Energy Offshore
Head of Engineering
RWE Innogy GmbH
Überseering 34
D - 22297 Hamburg

Business from technology

Cold climate R&D needs

Topical Expert Meeting #67 Long term R&D needs on wind power

Esa Peltola, Hannele Holttinen
VTT Technical Research Centre of Finland

R&D themes – cold climate

Operational and design conditions

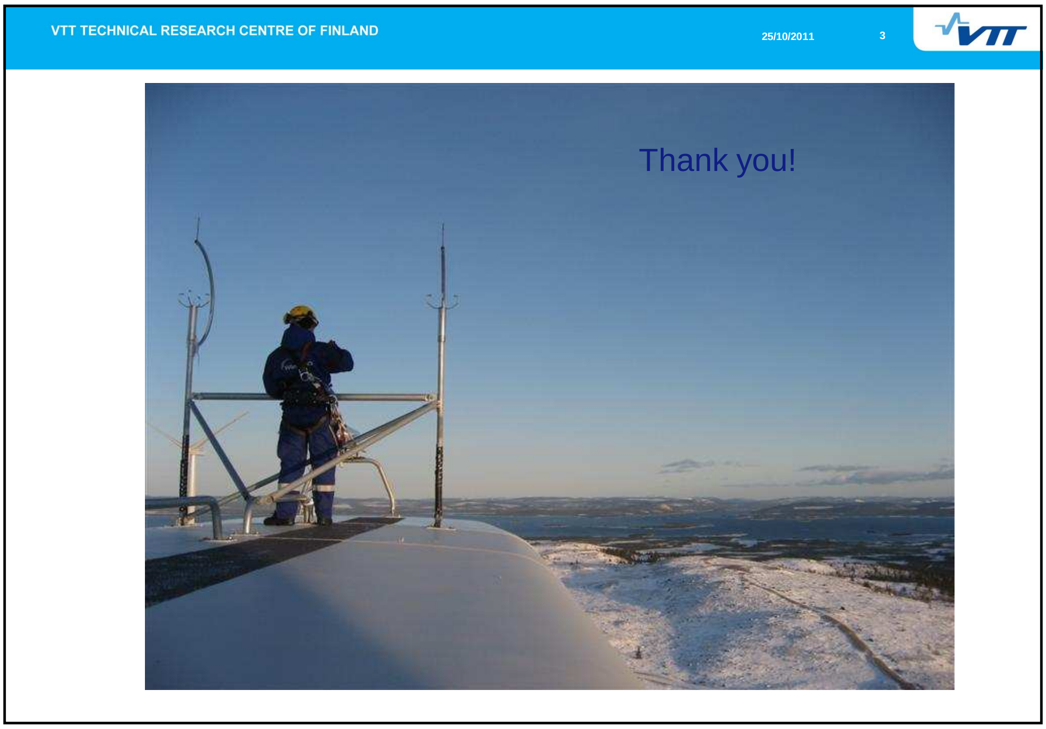
- Design conditions
  - Atmospheric icing and sea-ice: frequency, intensity and duration
  - Temperatures << 0 C
- Resource assessment tools
  - Instrumentation eg. for ice detection, ice-free sensors, remote sensing
  - Computational tools for wind and icing conditions

Technology

- Turbine
  - Blade technology in icing conditions
  - Integrated design tools and processes
- Loads and lifetime
  - Design loads
  - Cyclic thermal loading
  - Design tools for ice loads

Operation

- Production forecasting
  - On-line including ice
  - Surveillance and monitoring
- O&M
  - RAMS in cold and icing climate
  - Condition monitoring and prediction
- Safety


VTT TECHNICAL RESEARCH CENTRE OF FINLAND
25/10/2011
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VTT
Thank you!

Norwegian Research Centre for Offshore Wind Technology

Offshore wind R&D needs (examples)
www.nowitech.no

John Olav Giæver Tande
Director NOWITECH
Senior Research Scientist
SINTEF Energy Research
John.tande@sintef.no

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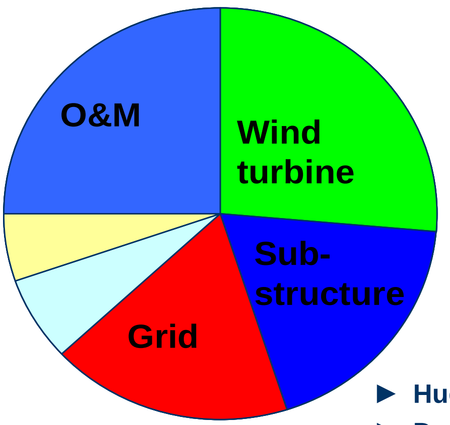
Strong motivation for offshore wind R&D



LPC distribution of offshore wind farm (example)

- Huge potential
- Development at an early stage
- Technology needs to be developed to reduce costs per kWh

2

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TP wind WG4 Offshore
Sub Group Topics defined June 2011

- SG-1: Offshore sub-structures
- SG-2: Innovative offshore turbines
- SG-3: Logistics
- SG-4: O&M
- SG-5: Electric infrastructure
- SG-6: Wind farm designs – Wakes

European Wind Energy Technology Platform

SP Offshore Wind Energy

EERA European Energy Research Alliance

Research objectives

- Integrated numerical design tools for large deep offshore WTs
- Characterization of wind, wave and current cond.
- Tools for offshore grid and WF electric design
- Predictive tools for O&M
- New deep sea concepts

Participants

- Risø DTU (DK)
- ECN (NL)
- CRES (GR)
- CENER (ES)
- FhG IWES (DE)
- LNEG/INETI (PT)
- **SINTEF (NO) – SP coordinator**
- VTT (FI)
- Uni of Strathclyde (UK)
- Forwind / Uni of Oldenburg (DE)
- Forwind / Uni of Bremen (DE)
- Forwind / Uni of Hannover (DE)
- NTNU (NO)
- IFE (NO)
- DHI (DK)
- Uni of Aalborg (AAU) (DK)

NOWITECH in brief

- **Objective:**
  Pre-competitive research for industrial value creation and cost-effective offshore wind farms. Emphasis on deep sea (+30 m).
- **Work packages:**
  1. Integrated numerical design tools
  2. Energy conversion system (reduce top-weight)
  3. Novel substructures (bottom-fixed and floaters)
  4. Grid connection & integration
  5. Operation and maintenance
  6. Concept validation & experiments
- **Total budget (2009-2017):**
  +NOK 320 millions incl. 25 PhDs / post docs

NOWITECH Norwegian Research Centre for Offshore Wind Technology

R&D partners

SINTEF
NTNU – Trondheim Norwegian University of Science and Technology
IFE Institute for Energy Technology

Associate R&D partners

Risø DTU National Laboratory for Sustainable Energy
Fraunhofer IWES
University of Strathclyde Glasgow
TU Delft
Massachusetts Institute of Technology
NREL
Nanyang Technological University

6

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Industry partners
Vestas
Vestavind OFFSHORE
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Statkraft
Lyse
FUGRO
FUGRO OCEANOR
Statoil
DONG energy
eDF
Statnett
FEDEM
Fedem Technology AS
DEVOLD
AMT
Advanced Multiaxial Technology
SmartMotor
Energy Efficient Technology
AkerSolutions
DNV
Associate industry partners / stakeholders
NORWEA
Norsk vindkraftforening
EnergiNorge
Navitas Network
NVE
Norwegian Centres of Expertise
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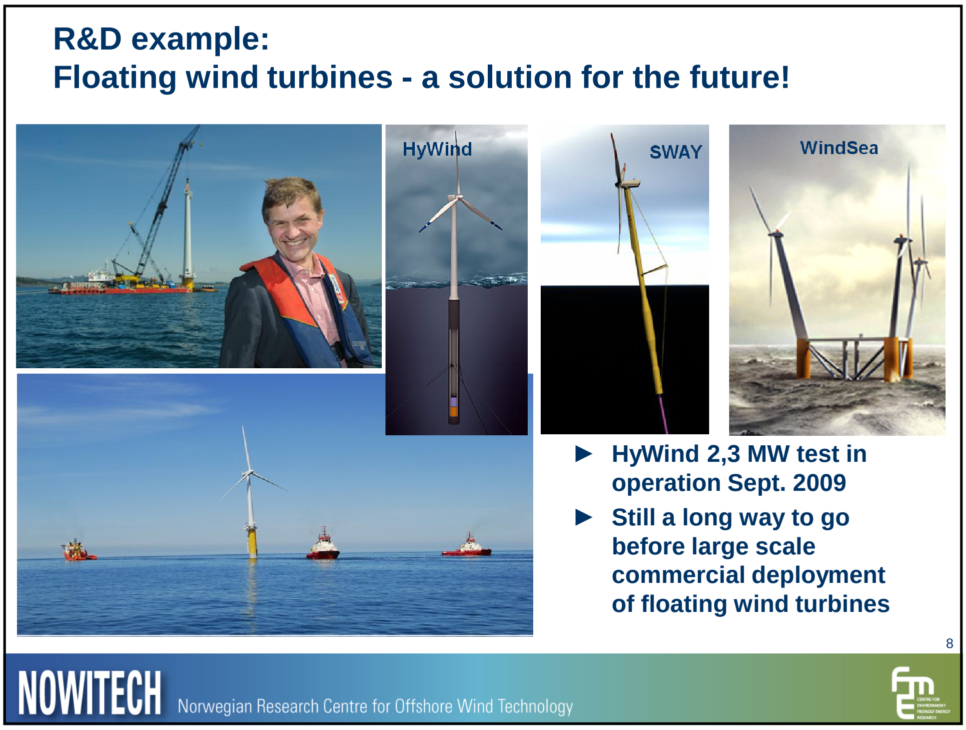
R&D example:
Floating wind turbines - a solution for the future!
HyWind
SWAY
WindSea
HyWind 2,3 MW test in operation Sept. 2009
Still a long way to go before large scale commercial deployment of floating wind turbines
8
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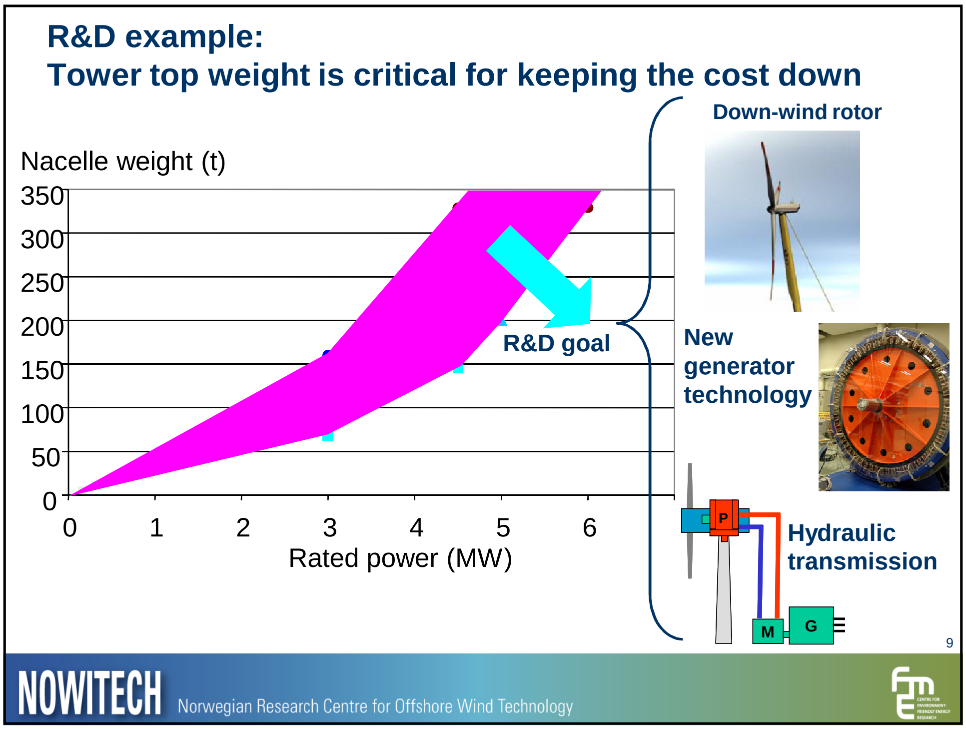
R&D example:
Tower top weight is critical for keeping the cost down
Nacelle weight (t)
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
Rated power (MW)
R&D goal
Down-wind rotor
New generator technology
Hydraulic transmission
P
M
G
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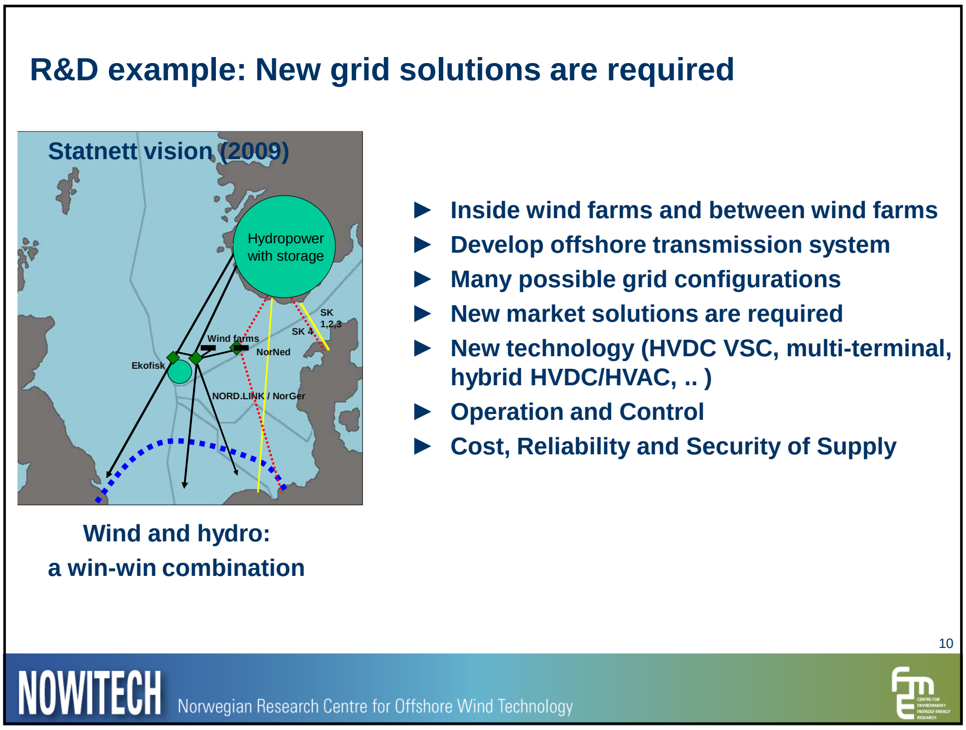
R&D example: New grid solutions are required
Statnett vision (2009)
Hydropower with storage
Wind farms
NorNed
Ekofisk
NORD.LINK / NorGer
Wind and hydro:
a win-win combination
Inside wind farms and between wind farms
Develop offshore transmission system
Many possible grid configurations
New market solutions are required
New technology (HVDC VSC, multi-terminal, hybrid HVDC/HVAC, ..)
Operation and Control
Cost, Reliability and Security of Supply
10
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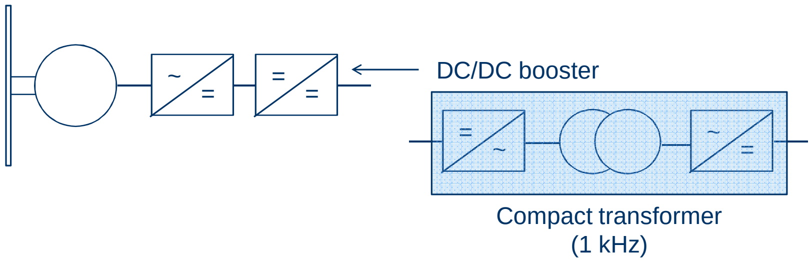
R&D example: DC wind farm grids



- Replace standard wind turbine step-up transformer with compact DC/DC booster
- Alternative configurations; e.g. low frequency generator; AC/DC at substation
- Protection and fault handling

11

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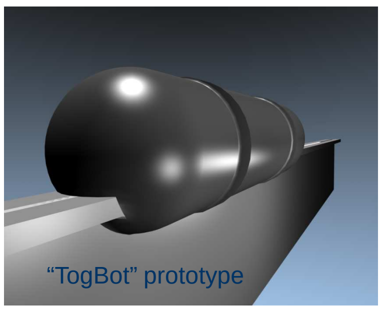
R&D example: Remote presence

- It is time consuming and costly to have maintenance staff visiting offshore turbines

⇩

- Remote operation, condition monitoring, maintenance
  - Remote inspection through installation of a small robot train on a track in the nacelle. Equipped with camera, heat sensitive camera, various probes, microphone.
  - Remote maintenance through robotized maintenance actions
  - Autonomous, robust turbine


“TogBot” prototype

12

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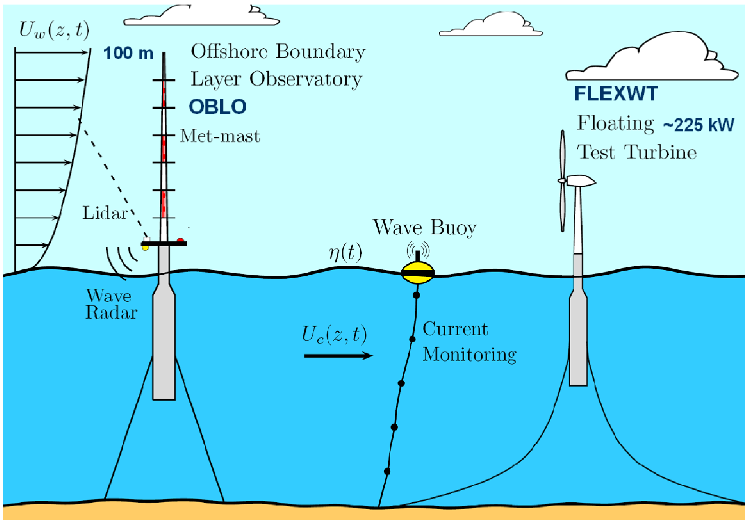
Infrastructure for open research
NOWERI – Norwegian Offshore Wind Energy Research Infrastructure
(NORCOWE & NOWITECH – in pre-engineering 2011)



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Rounding up

- Remarkable results are already achieved by industry and R&D institutes on deep offshore wind technology
- Technology still in an early phase – Big potential provided technical development and bringing cost down
- Significant R&D efforts are required to reduce risks, uncertainties and qualify innovative solutions
- Cooperation between research and industry is essential for ensuring relevance, quality and value creation

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Long Term Research Needs - status and perspectives

Flemming Rasmussen
Aeroelastic Design
Wind Energy Division
Risø DTU

Risø DTU
National Laboratory for Sustainable Energy

Outline

- Wind energy perspectives
- Technology status and trends
- Long term research needs

Challenge:

- The huge potential of wind, the rapid development of the technology and the impressive growth of the industry justify the perception that wind energy is changing its role to become the future backbone of a secure global energy supply.

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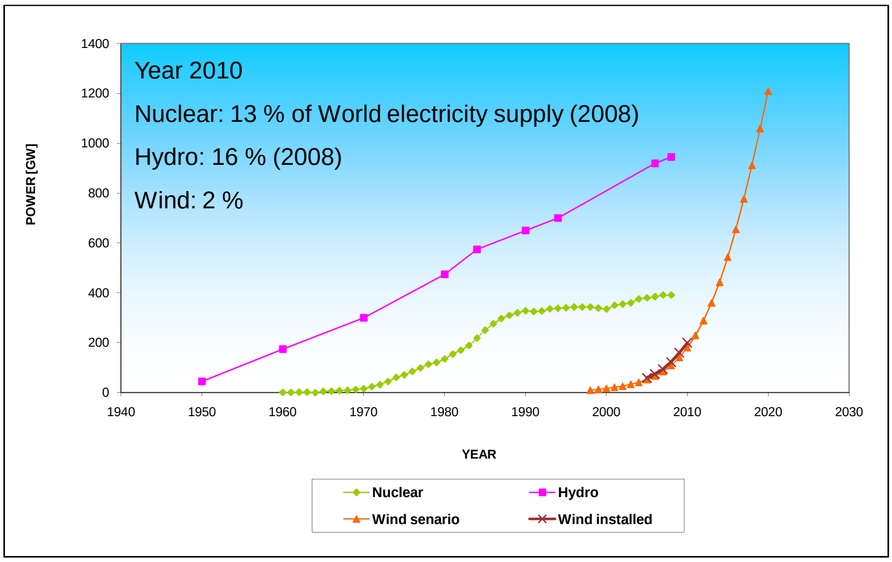
Accumulated power in the world
10 % Wind energy-scenario (1998)

DTU



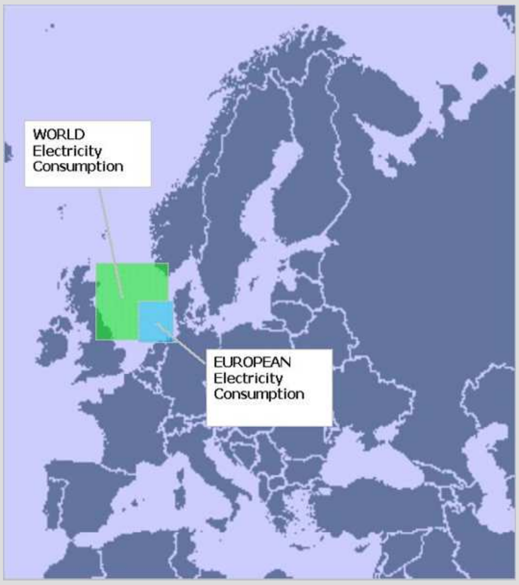
The perception of wind energy as the backbone of a secure energy supply

Integration is the challenge.
- -Electric cars (V2G)
- -Pumped storage

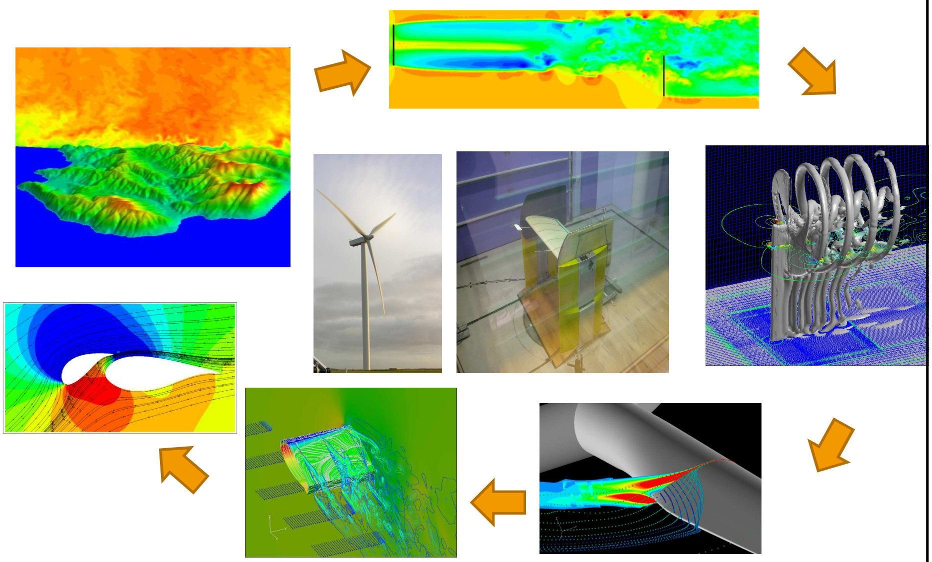
Norway:
25 GW Hydro power.
~2 GW pumped storage.
Potentials for more.

World:
945 GW hydro power to supply 50 %

1 Tri US dollars ~ 500GW
~ 5 % of World El. Com.



Advanced Wind Turbine Aerodynamics -modeling and exp. validation



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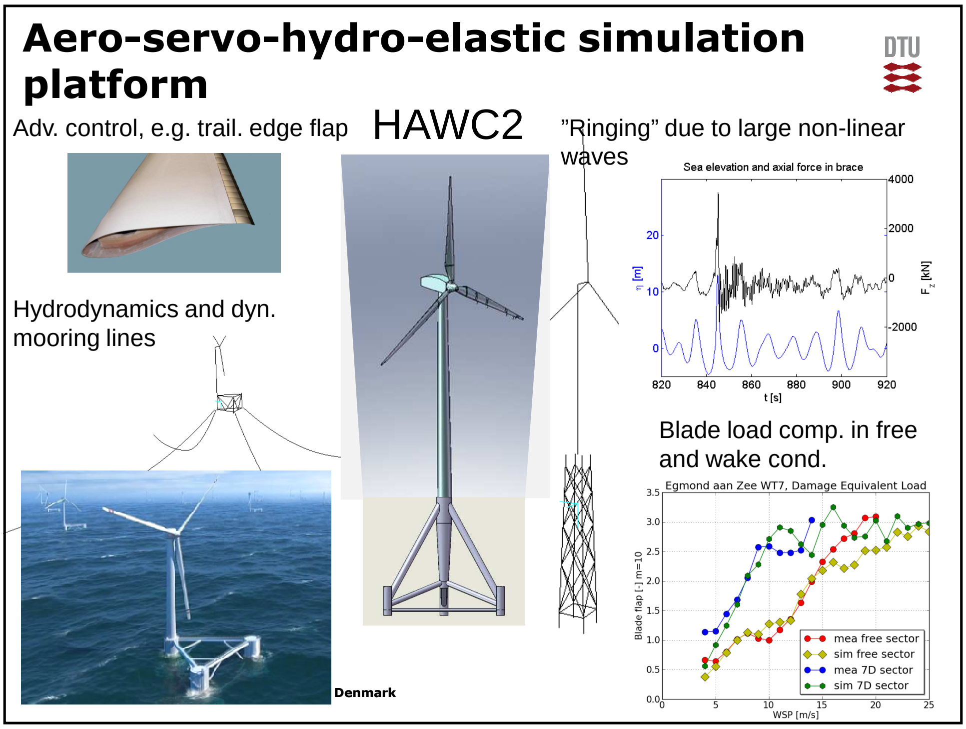
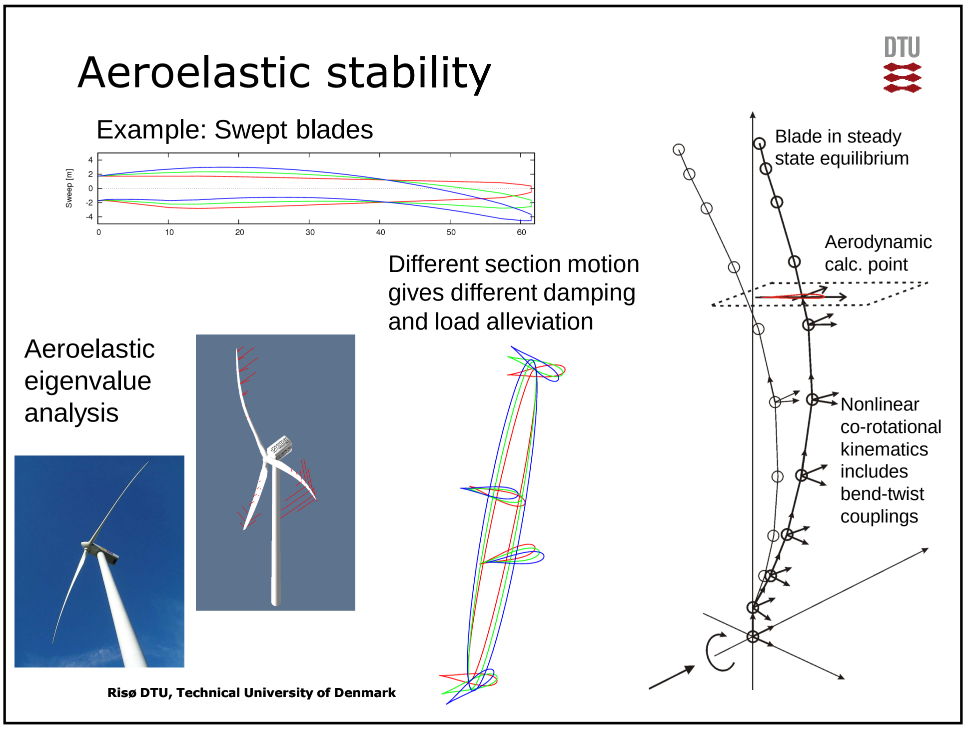

Aero-servo-hydro-elastic simulation platform
DTU
Adv. control, e.g. trail. edge flap
HAWC2
"Ringing" due to large non-linear waves
Sea elevation and axial force in brace
η [m]
F_z [kN]
t [s]
Hydrodynamics and dyn. mooring lines
Blade load comp. in free and wake cond.
Egmond aan Zee WT7, Damage Equivalent Load
Blade flap [-] m=10
WSP [m/s]
mea free sector
sim free sector
mea 7D sector
sim 7D sector
Denmark

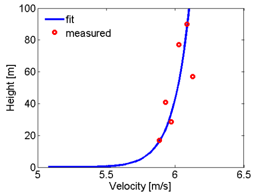

Aeroelastic stability
DTU
Example: Swept blades
Sweep [m]
Different section motion gives different damping and load alleviation
Aeroelastic eigenvalue analysis
Blade in steady state equilibrium
Aerodynamic calc. point
Nonlinear co-rotational kinematics includes bend-twist couplings
Risø DTU, Technical University of Denmark

Comb. modeling and large scale experiments

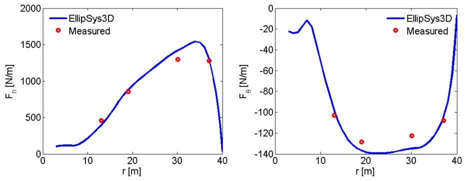
Measured and computed results at nearly uniform inflow condition:

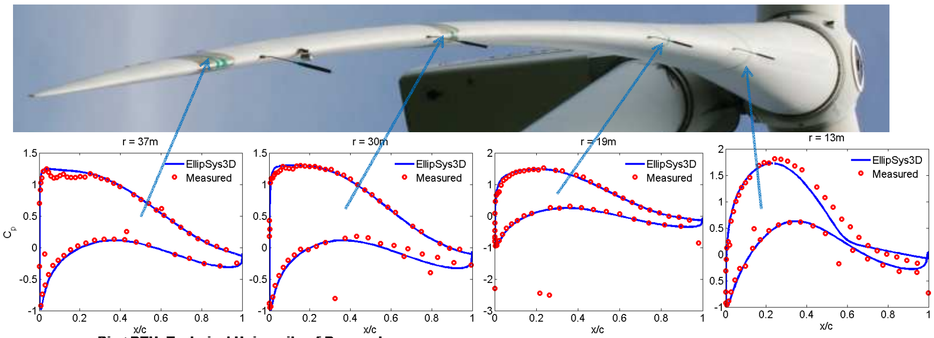
$$V_0(z) = V_\infty \left(\frac{z}{H}\right)^\alpha$$

$\alpha = 0.02$
$V_\infty = 6.2\,m/s$
$TI \approx 10\%$



Normal and tangential loads along blade:

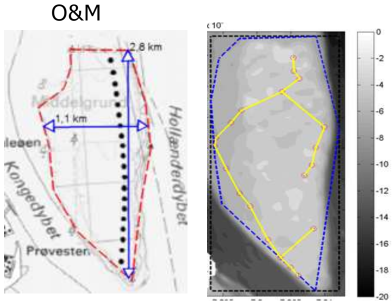


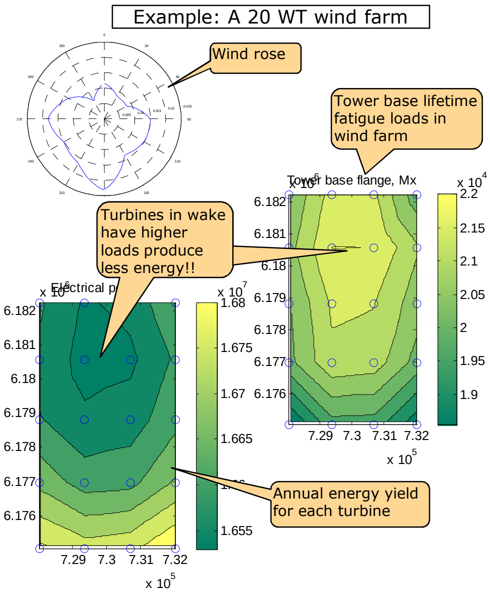


Risø DTU, Technical University of Denmark

Topfarm wind farm optimization approach - loads and power

- Optimum wind turbines position for the lowest cost of energy
- Wake modeling using DWM (Dynamic Wake Meandering)
- Quick lookup for power and fatigue loads in a database based on HAWC2 aeroelastic simulations
- Cost function including: Annual energy production and costs of: Turbines, Grid, Foundation and O&M





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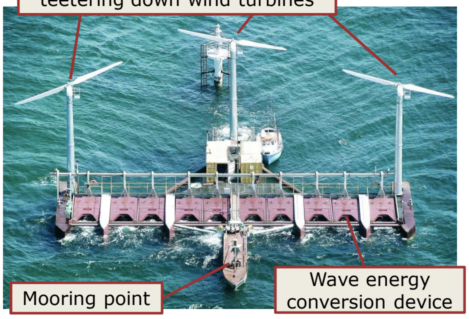
Combined wind and wave energy – Poseidon

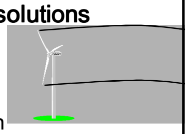
World's first floating combined wind and wave energy plant



- Primarily a wave energy platform
- Large dimensions makes it stable and suitable for wind turbines
- 5 months measurement campaign
- Fully coupled hydro-aero-elastic model developed

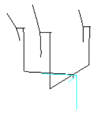
Modeling challenges and solutions

Wake from upwind rotors



- Dynamic wake meandering model in HAWC2

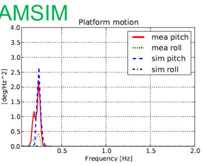
Three rotors in one simulation



- Possible in HAWC2's multi-body formulation
- Aerodynamic model extended to handle multiple rotors

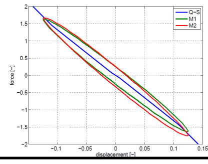
Large water surface area

- Fully coupled HAWC2-WAMSIM simulations
- Validated against measurements



Mooring system

- Dynamic mooring lines included in HAWC2



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System Engineering

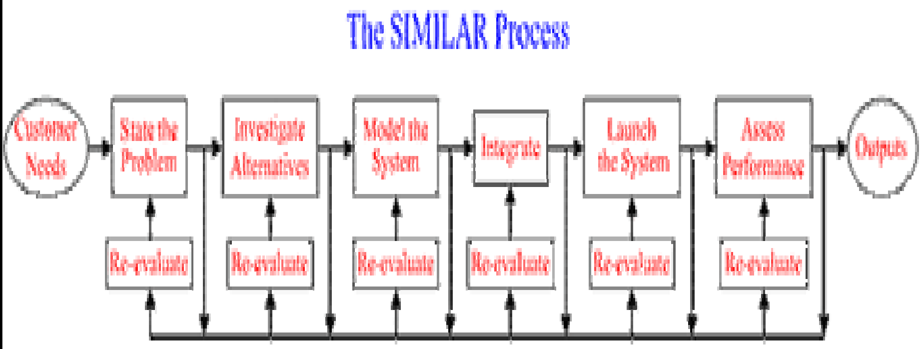

Figure 1. The Systems Engineering Process from A. T. Bahill and B. Gissing, Re-evaluating systems engineering concepts using systems thinking, *IEEE Transaction on Systems, Man and Cybernetics, Part C: Applications and Reviews*, **28** (4), 516-527, 1998.

Risø DTU mission:

Quality – Relevance – Impact

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Future wind turbine industry? -and research/industry interaction

We can imagine four existing industries which a future wind turbine industry might come to resemble:

"Shipbuilding" Large structures, but relatively low-tech: probably the worst case, as it would discourage investment in new technology.
"Aerospace" A handful of global wind turbine manufacturers supported by a larger number of niche suppliers. This scenario describes the wind industry until five years ago, since which time many new players have entered the scene.
"Automotive" R&D involves the component suppliers as well as the wind turbine manufacturers themselves. This scenario has the attraction of creating widely-used standard components which make good use of common R&D effort.
"Power stations" Component manufacturers supply contractors who in turn are project-managed by large energy companies. This scenario could make it hard to exploit the full benefits of mass production.

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Typical new wind turbine

Wind turbine 2011

- Three bladed upwind
- Pitch-controlled
- Variable speed
- Grid connected
- 18 % with direct drive
- Average size 1.7 MW
- 7-10 MW being developed

14 Ris

DTU

A material-efficient machine

Risø DTU, Technical University of Denmark

10 m/s:

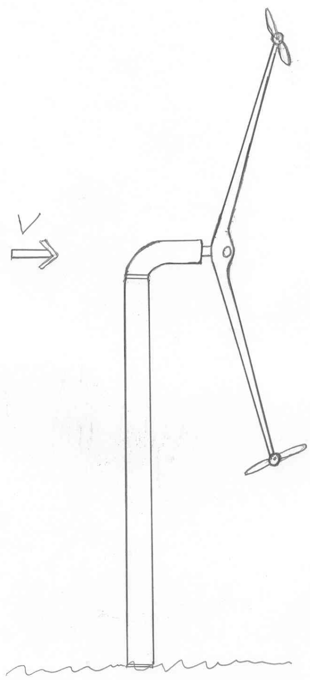
- 80 tons/sec: Mass of air througt rotor disc.
- Handles mass of air corresponding to it's own total weight in 5 seconds.

- Thrust and torque.

- Up to 6 MW at present.
- Reliability!

Drive train concepts

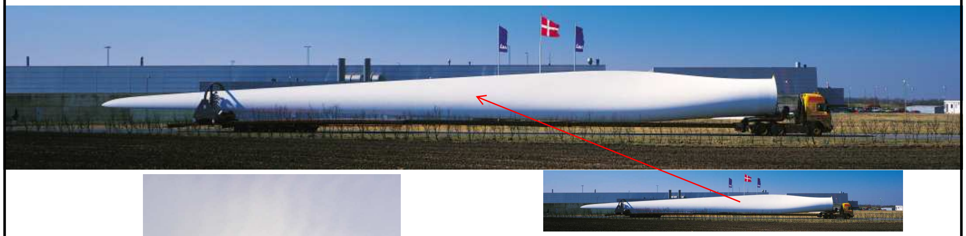
DTU



Multipole generator (super conduction)

Main carrier, Generator rotor/stator, Axle pin/hub

Upscaling

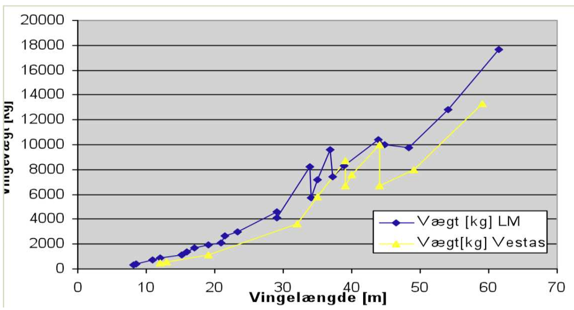


Upscaling: ”Square-cube law”

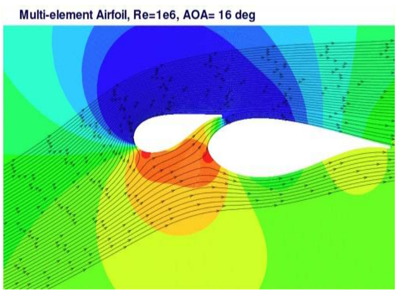
•Power increases as diameter squared
•Mass increases as diameted cubed

Limit in size

Lightweight blades



Blade mass increases close to the diameter squared due to optimised and thick airfoils



Lift enhancing devises to compensate for bad aerodynamic characteristics of thick airfoils

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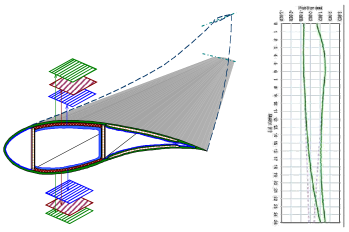
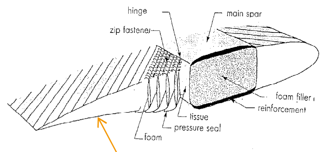
New developments: Twist-flap coupled blade



A Twist–flap Coupled Blade Design to Alleviate Fatigue Loads (on the left with material coupling and on the right with a curved blade



Feather

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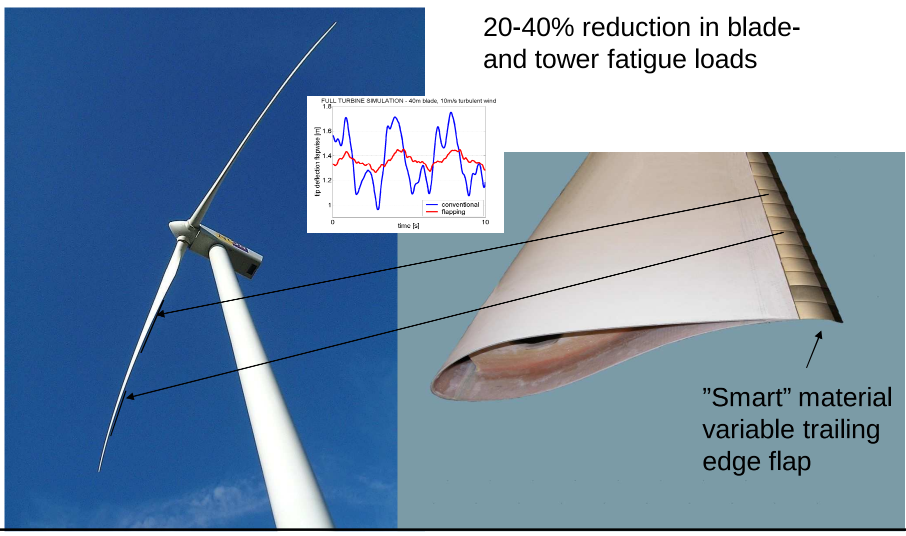
Individual pitch and smart trailing edge control

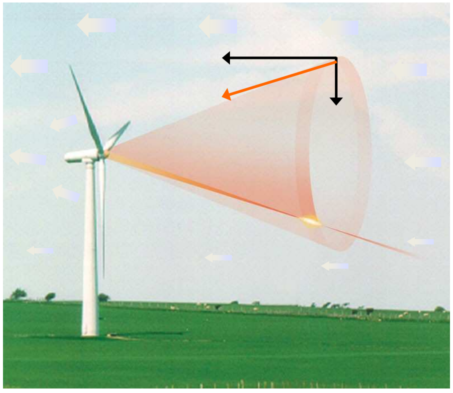
20-40% reduction in blade- and tower fatigue loads

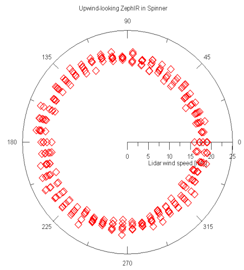


”Smart” material variable trailing edge flap

WINDSCANNER:

Pro-active wind turbine control from upwind measurements by lidars integrated in the nacelle… :

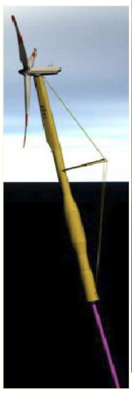




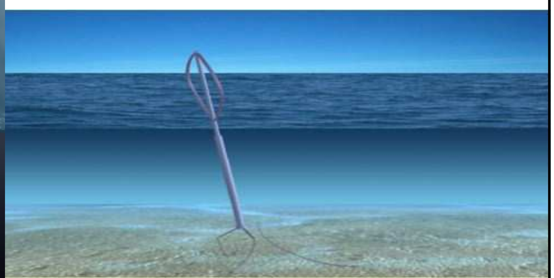
Collaboration between Risø DTU and Natural Power, UK

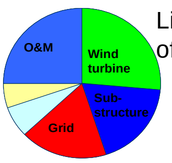
Risø DTU, Technical University of Denmark

New concepts offshore



Floating turbines





Life cycle costs offshore

Combined wind and wave energy converters

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Energy for the future
Thank you!

DTU

UpWind, new test station and drivetrain test facilities in Denmark

Peter Hjuler Jensen
Deputy head of Wind Energy Division
Risø DTU
Danish Technical University

Risø DTU
Nationallaboratoriet for Bæredygtig Energi

DTU

UpWind

Objective

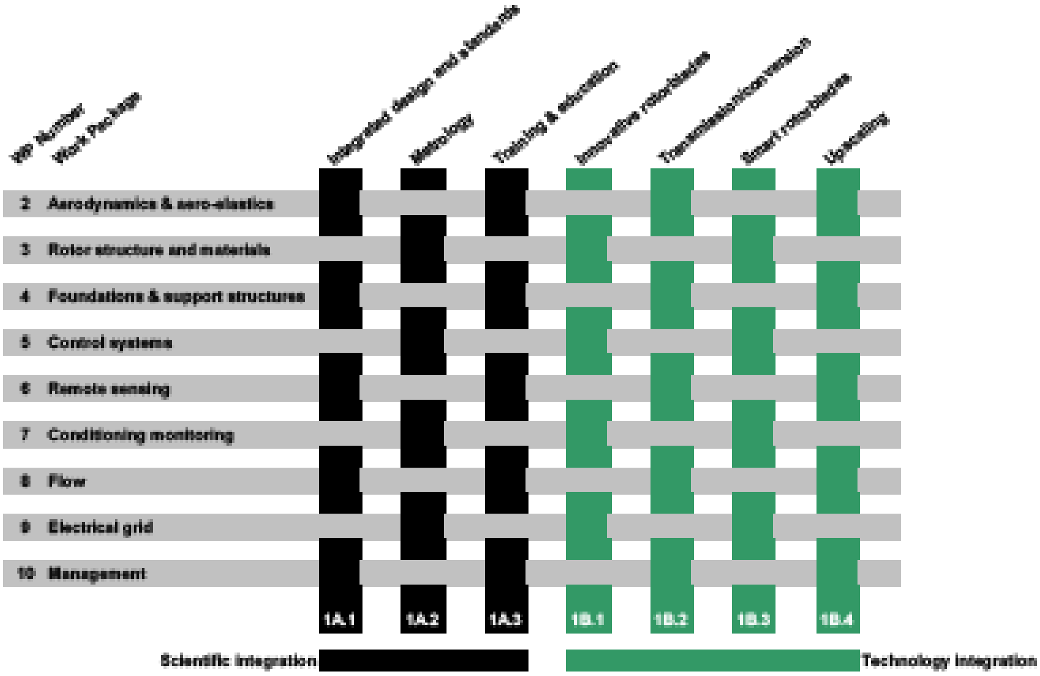
Develop new design models and verification methods for wind turbine components, industry needs for future design and manufacture of:

1 Very Large Wind Turbines
2 More Cost Efficient Wind Turbines
3 Offshore wind farms of several hundred MW

Start of project: WT up to P = 5 MW and D = 120 m
Now and future: WT upscaling: P = 10 MW and P = 20MW

Indentify showstoppers and develop technology to overcome challenges

Organisation
Classic and integrated research approach



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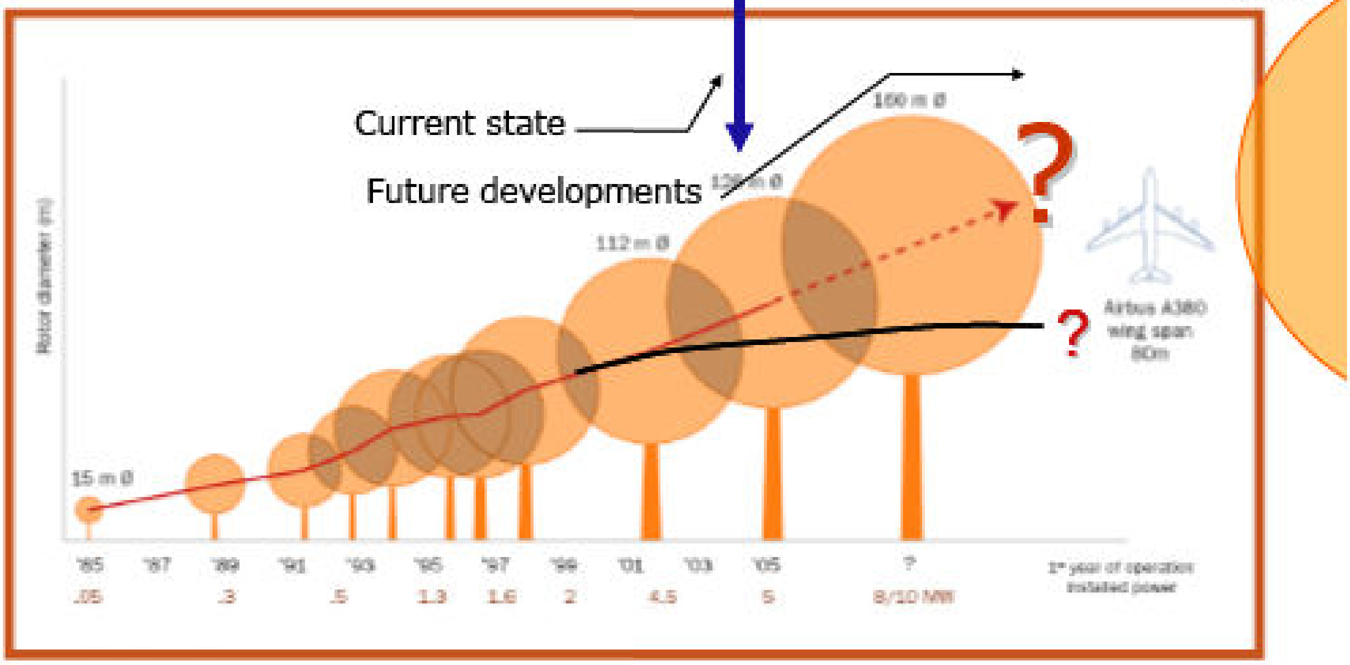
2008

How Large?

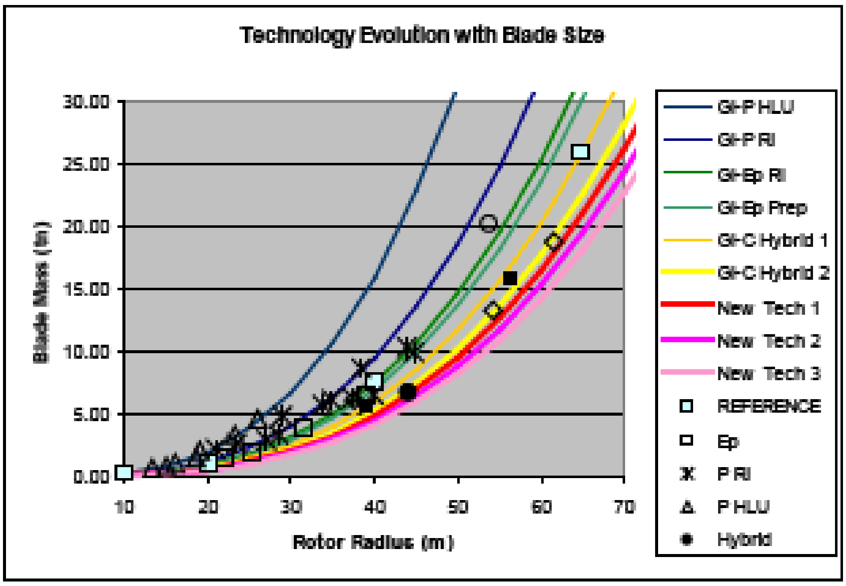
250 m Ø



Warsaw, April 21, 2010

DTU

Case study:
Blades – technology evolution with size



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Economical viability of 20MW W/Ts
Case study: Blades

		PAST						FUTURE		
		GI-P RLU	GI-P RI	GI-Ep RI	GI-Ep Prep	GI-C Hybrid 1	GI-C Hybrid 2	New Tech 1	New Tech 2	New Tech 3
	Single Step r(t)/r(t-1)	1,00	0,59	0,79	0,93	0,85	0,87	0,93	0,93	0,93
	Cummulative r(t)	1,00	0,59	0,47	0,44	0,38	0,33	0,31	0,28	0,26
	Single Step a(t)/a(t-1)	1,00	1,08	1,08	1,10	1,10	1,00	1,03	1,03	1,03
	Cummulative a(t)/a(t0)	1,00	1,08	1,17	1,28	1,41	1,41	1,45	1,50	1,54
WT Power (MW)	Rotor Radius (m)	Mass (tn)	Mass (tn)	Mass (tn)	Mass (tn)	Mass (tn)	Mass (tn)	Mass (tn)	Mass (tn)	Mass (tn)
0,125	10	0,25	0,15	0,12	0,11	0,09	0,08	0,08	0,07	0,07
0,281	15	0,85	0,50	0,40	0,37	0,32	0,28	0,26	0,24	0,22
0,500	20	2,00	1,19	0,94	0,88	0,76	0,66	0,61	0,57	0,53
0,781	25	3,91	2,33	1,84	1,71	1,48	1,28	1,19	1,11	1,03
1,125	30	6,76	4,02	3,17	2,96	2,55	2,22	2,06	1,92	1,78
1,531	35	10,74	6,39	5,04	4,70	4,05	3,52	3,28	3,06	2,83
2,000	40	16,02	9,53	7,52	7,01	6,04	5,26	4,89	4,55	4,23
2,531	45	22,82	13,57	10,71	9,99	8,60	7,49	6,96	6,48	6,03
3,125	50	31,30	18,62	14,70	13,70	11,80	10,27	9,55	8,88	8,26
3,781	55	41,66	24,78	19,56	18,23	15,71	13,67	12,71	11,82	11,00
4,500	60	54,08	32,17	25,40	23,67	20,39	17,75	16,51	15,35	14,28
5,281	65	68,76	40,90	32,29	30,09	25,93	22,57	20,99	19,52	18,15
6,125	70		51,09	40,33	37,58	32,38	28,19	26,21	24,38	22,67
7,031	75		62,84	49,60	46,23	39,83	34,67	32,24	29,98	27,88
8,000	80		76,26	60,20	56,10	48,34	42,07	39,13	36,39	33,84
9,031	85			72,20	67,29	57,98	50,47	46,93	43,65	40,59
10,125	90				79,88	68,82	59,91	55,71	51,81	48,19
11,281	95				93,95	80,94	70,45	65,52	60,94	56,67
12,500	100					94,40	82,16	76,42	71,07	66,10
13,781	105					109,29	95,13	88,47	82,28	76,52
15,125	110					125,65	109,38	101,72	94,60	87,98
16,531	115						124,98	116,23	108,09	100,53
18,000	120						142,00	132,06	122,81	114,22
19,531	125						160,50	149,26	138,81	129,10
21,125	130						180,54	167,90	156,15	145,22

Warsaw, April 21, 2010

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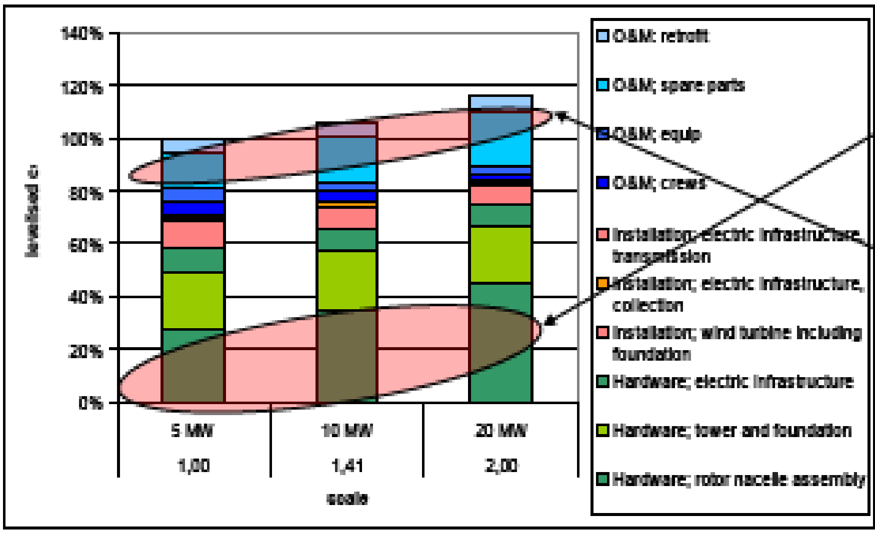
DTU

Result from cost functions

Up scaling – levelised cost



- **Levelised cost *increases* with scale**
- **Reasons:**
  - Rotor and nacelle costs scale ~s³ (?)
  - Spare parts costs follow
- **Cost of energy over lifetime increase more than 20 % for increasing the Wind Turbine size from 5 to 20 MW so the power law for the rotor**

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Upscaling of offshore wind turbines

Focus on development of new innovations, new design methods and cost functions for main components:

- Blades
- Drivetrain
- Tower and foundation
- Grid connection system
- Control and sensor systems
- Condition monitoring system

Large Wind Turbines in the future

- The details of the future design may be uncertain
- However it is obvious that...
  - Up scaling existing designs will *not* be enough
  - Integrated design for large scale should be pursued
  - New ideas and technological breakthroughs will be necessary to make very large wind turbines economically attractive
- It is certain therefore that **substantial R&D and industrial effort is still needed** to conquer all technical barriers!

Feasibility of 20MW wind turbines

The answers from available technical expertise and UPWIND project experience:

- Manufacturing *is* possible
- Transportation and installation *are* possible

BUT…

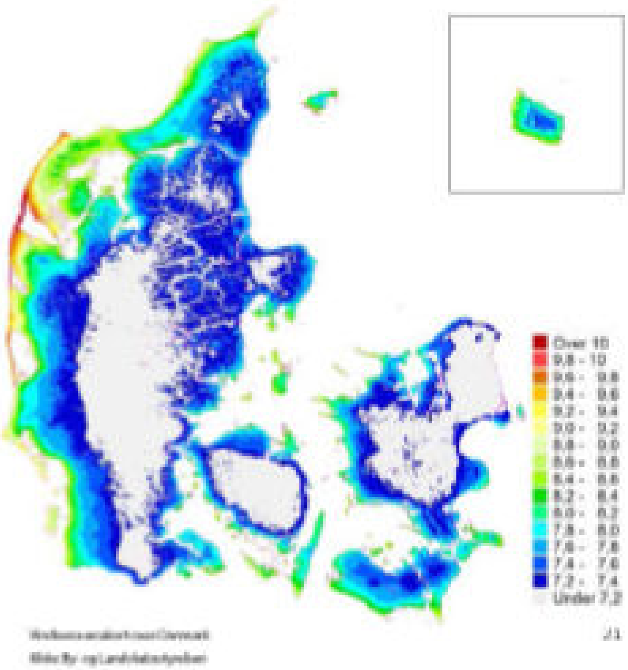
- …this does not mean that a 20MW version of a current state-of-the-art 5MW W/T will offer any cost/performance advantages

Warsaw, April 21, 2010

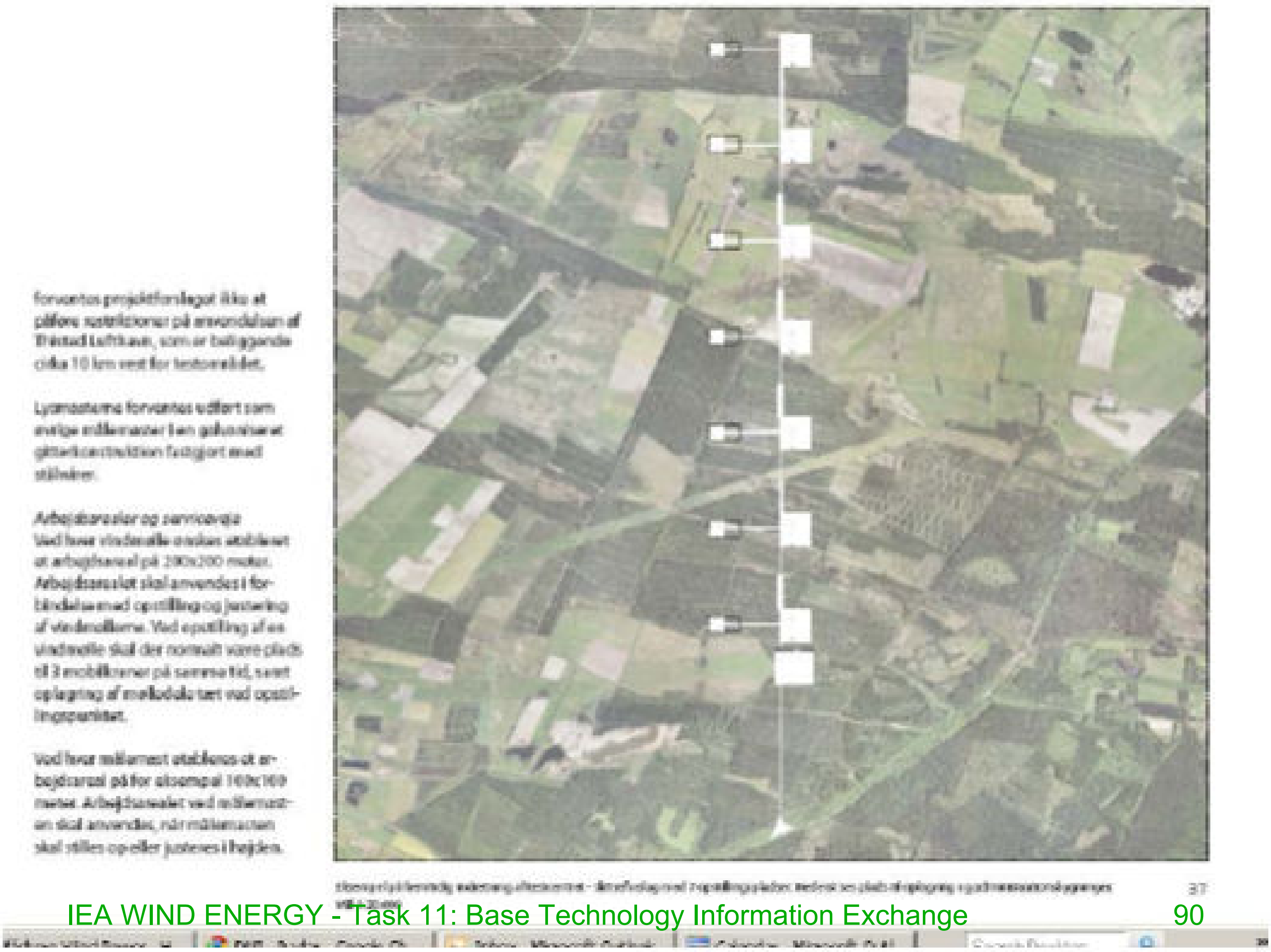
Competition between concepts continue

Risø DTU Test Station for Large Wind Turbines at Høvsøre, Lemvig and Risø DTU TS

Østerild
Identification of feasable sites




Distance = 2.6 km



Activities at the Testcenter

1. Measurements and test of wind turbines

2. Research:
   - Meteorology
   - Wind turbine Physics and technology
   - Integration of wind turbines in elec. grid

Meteorology

The Issue:

- Wind at large hight's
- Wind in different terrains
- Two different sites (Østerild and Høvsøre)

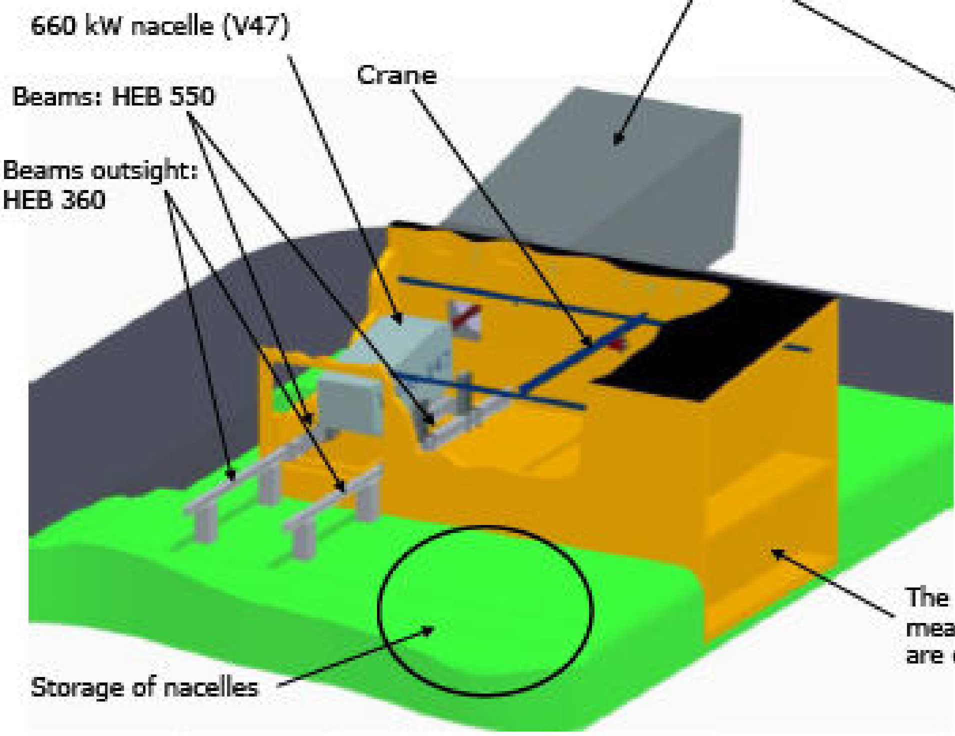
Høvsøre 116 m meteorology mast

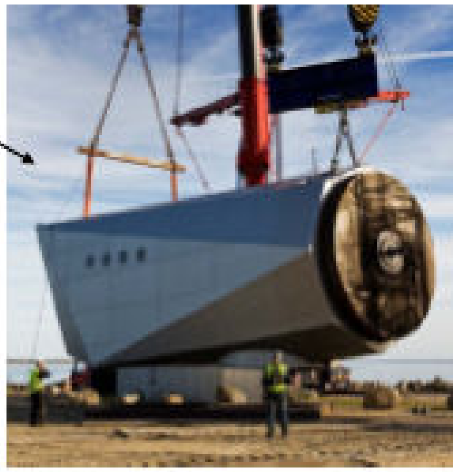
Østerild 250 meter meteorology mast

LIDAR

1 MW drive train test facility at RISØ-DTU

The test-setups motor and gear (the drive unit) is a 1MW nacelle, which has been modified with a frequency control drive system such that it is capable of applying variable-torque and variable-speed.





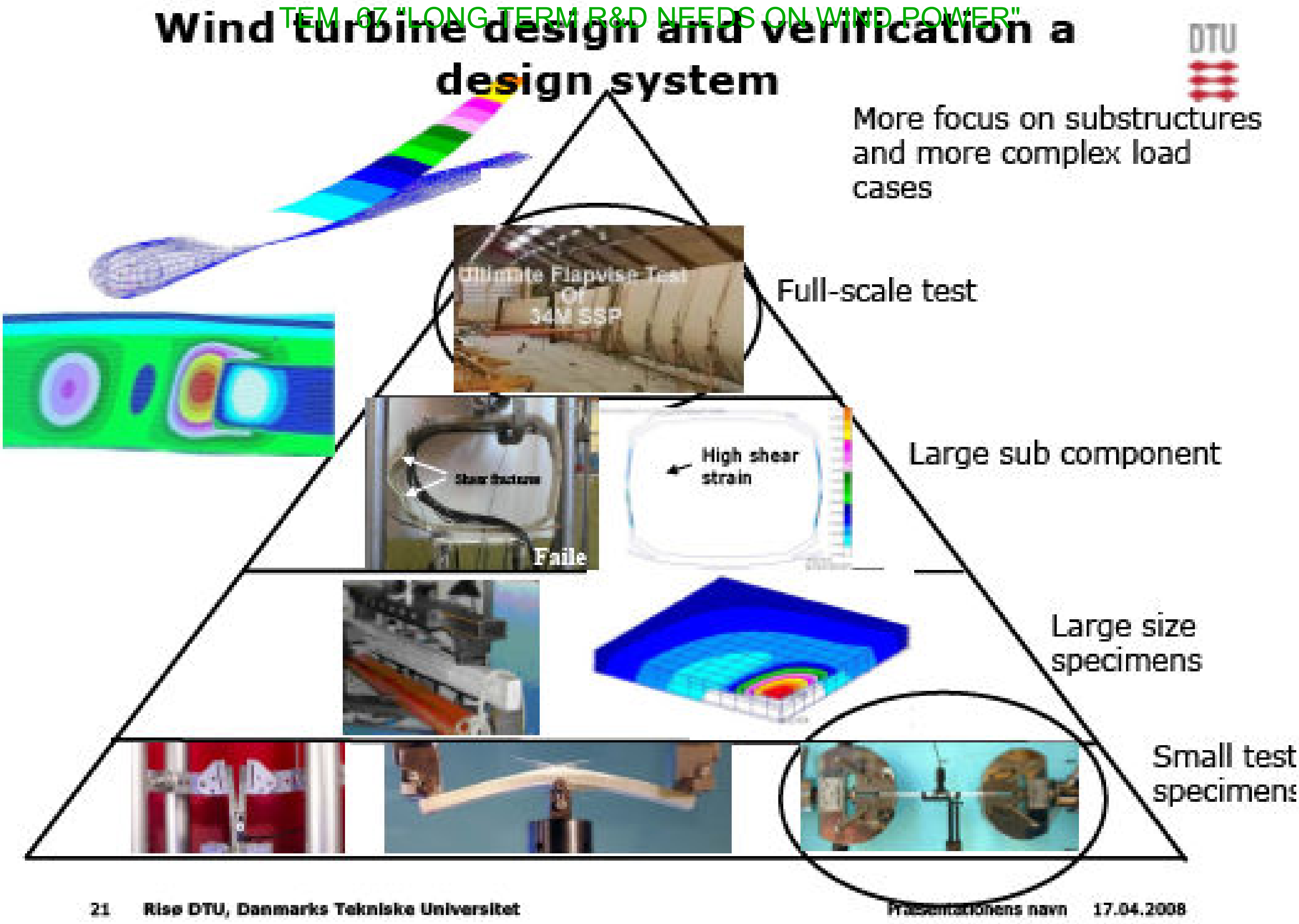
The basement is equipped with an measuring office from which the tests are controlled and monitored.

19 Risø DTU, Danmarks Tekniske Universitet Præsentationens navn 17.04.2008

LORC (Lindø Offshore Renewables Centre) - Wind turbine Drive Train Test facility 10/20 MW (cont.)

The new full scale test bench is located at Lindø (a shipyard under decommission), where LORC also has its seat. The site was selected so it may exploit the unique large-scale infrastructure that can be found here: Europe's largest cranes, with lifting capacities up to 1000 tons, transport facilities for particularly heavy items, facilities, storage capacity, etc., in addition to floor is suitable for carrying heavy and bulky items. There is also a large electrical capacity for the current welding of steel sections. LORC and Risø-DTU has already identified a suitable hall in Lindø for the purpose.

20 Risø DTU, Danmarks Tekniske Universitet Præsentationens navn 17.04.2008


Wind turbine design and verification a design system
DTU
More focus on substructures and more complex load cases
Ultimate Flapwise Test Of 34M SSP
Full-scale test
High shear strain
Large sub component
Large size specimens
Small test specimens
21 Risø DTU, Danmarks Tekniske Universitet
17.04.2008

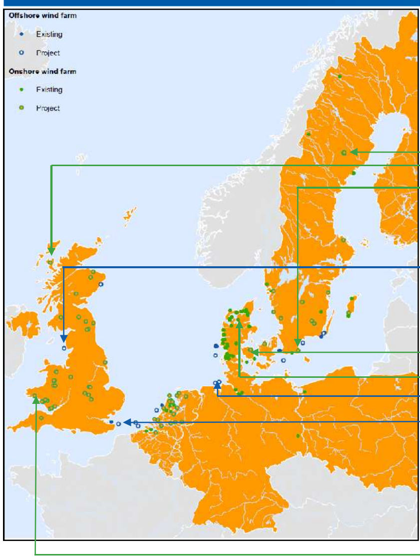
VATTENFALL

Future R&D Challenges as seen from the Vattenfall Horizon

Sven-Erik Thor

2011.10.05

Vattenfall is building nine wind farms in six countries



Stor-Rotliden in Sweden
40 Vestas V 90 turbines. Annual boost of around 240 GWh, sufficient to supply 50,000 homes per year with energy. Officially inaugurated August 2011.

Edinbane in Scotland
18 Enercon 2.3 MW turbines. Annual boost of around 128,3 GWh, sufficient to supply nearly 25,000 homes per year with energy. Officially opened in June 2010.

Östra Herrestad in Sweden
9 Vestas 1,8 MW turbines. Annual boost of around 58 GWh, sufficient to supply 11,000 homes per year with energy. Officially opened in May 2011.

Ormonde in England
30 Repower 5M turbines. Annual boost of around 500 GWh, sufficient to supply more than 100,000 homes per year with energy. Official opening spring 2012.

Draeby Fed in Denmark
4 turbines. Annual boost of around 25 GWh, sufficient to supply 6.100 homes per year with clean energy. Officially opened in September 2010.

Nørrekær Enge in Denmark
13 Siemens 2,3 MW turbines. Annual boost of around 120 GWh, sufficient to supply 30,000 homes per year with energy. Officially opened in Nov 2009.

Thanet in England
100 Vestas V90 turbines. Annual boost of around 1 TWh, sufficient to supply more than 200,000 homes per year with energy. Officially opened September 2010.

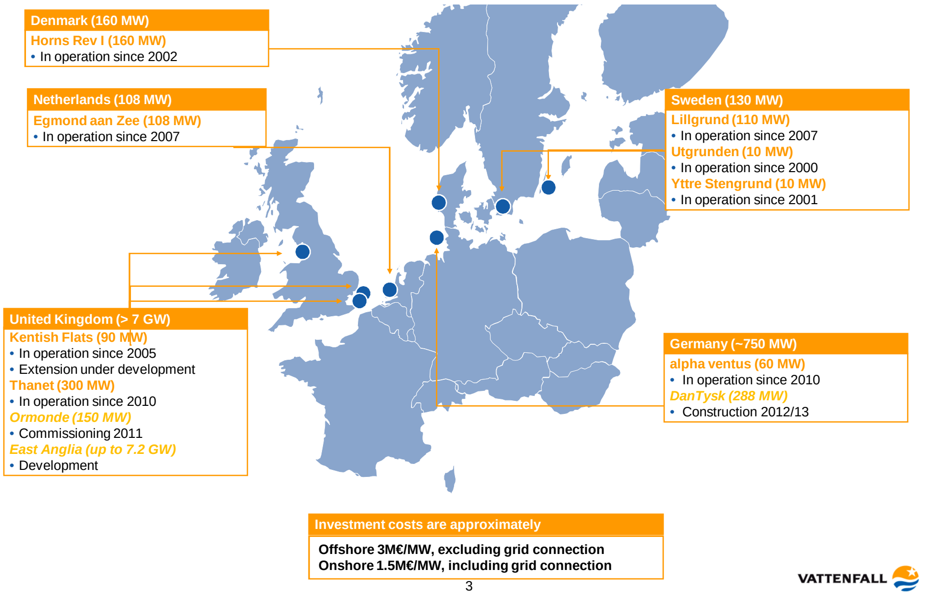
Parc Cynog in Wales
6 Enercon E48 turbines. Annual boost of around 14 GWh, sufficient to supply nearly 5,000 homes per year with energy.

Alpha Ventus in Germany
12 turbines (6 Areva Multibrid M5000, 6 Repower 5M). Annual boost of around 220 GWh,. Officially opened April 2010. *(Consortium of EWE, E.ON and Vattenfall)*

2

VATTENFALL

Vattenfall offshore wind portfolio



3

VATTENFALL

Needs of the Wind Business

1. Lower Cost/Risk of Site Development (Capex)
2. Lower Cost of O&M
3. Increased Public Acceptance
4. Improved Safety in O&M
5. Increased yield of existing assets

4

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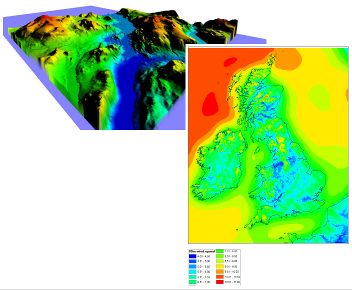
Lower cost/risk of site development (1)

Improved Wind Resource Mapping

Challenge
Better models for the estimation of average wind speeds on global and local scale

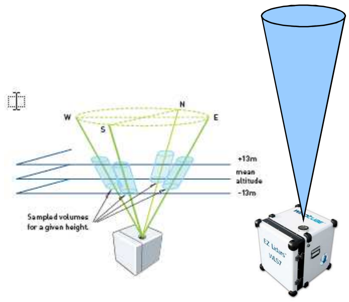
Benefit
Detailed knowledge of yearly average of wind speed.



Remote sensing of wind speed

Challenge
Utilize more efficient equipment for the measurement of wind speeds and models for yearly correction of wind speeds

Benefit
Reduced uncertainty in assessing wind speeds.



5

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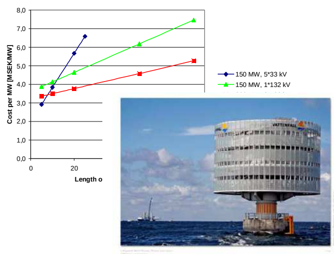
Lower cost/risk of site development (2)

Offshore transformer stations and HVDC

Challenge
One important issue in the design of the layout is whether to use an offshore transformer platform or not. The decision has great economic influence of the project cost.

Benefit
Reduced cost and risk



Offshore foundations at deeper water

Challenge
Foundation costs at deeper waters, >20m, increases dramatically with depth. There is no common view of the type of foundations for such applications

Benefit
Screen and evaluate cost efficient solutions

6

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Lower cost/risk of site development (3)

Generation losses in cold climate

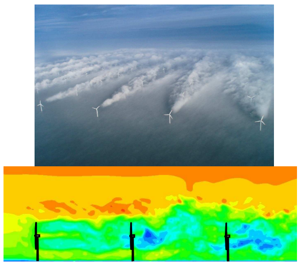
Challenge
Wind turbines in cold climate may lose production due to icing of blades.

Benefit
Better methods for the estimation of losses and methods for de/anti icing of WT

Shadow effects in wind farms

Challenge
Wind turbines tend to "steal" wind from their downwind neighbor. The result is lost production. Current engineering tools needs to be complimented with CFD tools.

Benefit
Better estimates of the production of the whole wind farm (power station)



7

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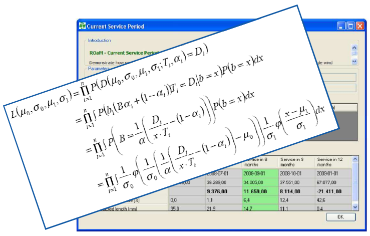
Lower Cost of O&M – Move from Corrective to Preventive

O&M Cost calculator

Challenge
Estimate O&M costs when developing projects. Support ambition to go from corrective to preventive maintenance.

Benefit
10% lower O&M costs onshore and 20% lower costs offshore



Gearbox failures

Challenge
Gearbox performace is poor, they do not live up to the expected life time of 20 years.

Benefit
Reduced failure rates. (The cost for exchanging a gearbox is in the order of 0,5M€)

8

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Increased Public Acceptance and Environment

Mitigation of noise from piling foundations

Challenge
Find solutions that will lower noise emitted during foundation piling to acceptable levels. Help easing permitting process.

Benefit: GO/NOGO

Minimize influence on flora and fauna

Challenge
Reduce impact on wildlife and help create new habitats for endangered species

Benefit: GO/NOGO

9

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Improved Safety in O&M

Access to wind turbines offshore

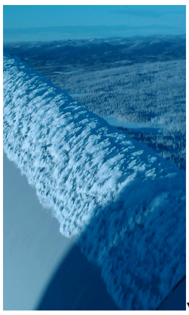
Challenge
Entering a windturbine at sea is associated with risks, especially when the waves are high.
Testing of new concepts for Boat/Helicopter Access Systems.

Benefit
Reduced risks for service personnel

Thrown ice

Challenge
Wind turbine blades in cold climate are sometimes iced. Falling ice may pose a hazard to the surrounding.

Benefit
Reduced risks for service personnel



10

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Increased yield of existing assets

- Challenges related to aging wind turbines
  - blades life time and repair
  - corrosion challenges
  - estimations of remaining life times
  - 20 year lifetime
- Increasing output from assets
  - RePowering
  - Intelligent park controlling

StorRotliden in Sweden

11

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Miscellaneous

- Lack of skilled people – on all levels
- Training and Education
- Decommissioning

12

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How to present R&D Challenges

By Technology

1. Wind Resource & Micro-siting
2. Turbine & Foundation Technology
3. System Integration & Grid Connection
4. Operation & Maintenance
5. Acceptance & Environment

By Needs

- Lower Cost/Risk of Site Development, CAPEX
- Lower Cost of O&M, OPEX
- Increased Public Acceptance
- Improved Safety in O&M
- Increased yield of existing assets

13

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Research is still needed

Thanks for listening!

14

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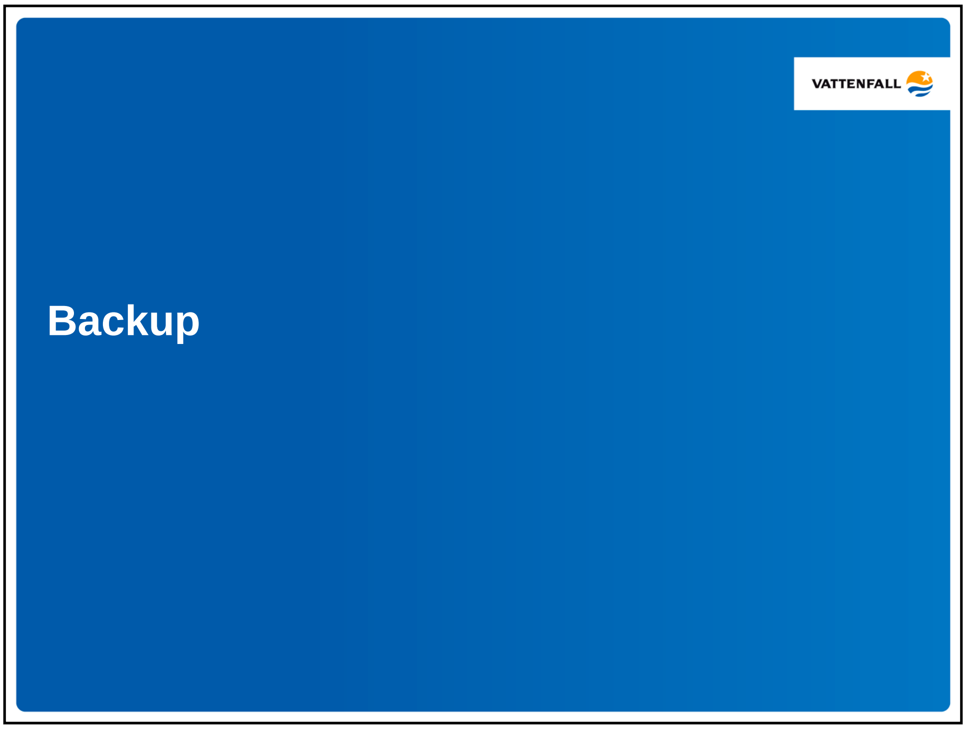
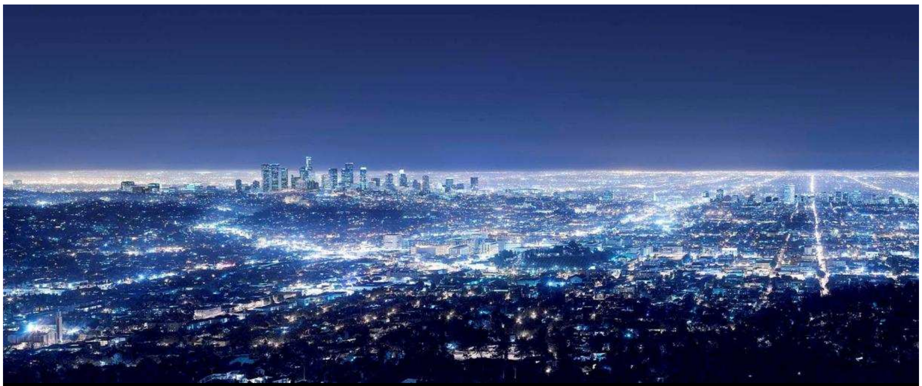

VATTENFALL
Backup



Lars Gertmar, Power Technologies, ABB Corporate Research, Sweden, Oct. 2011

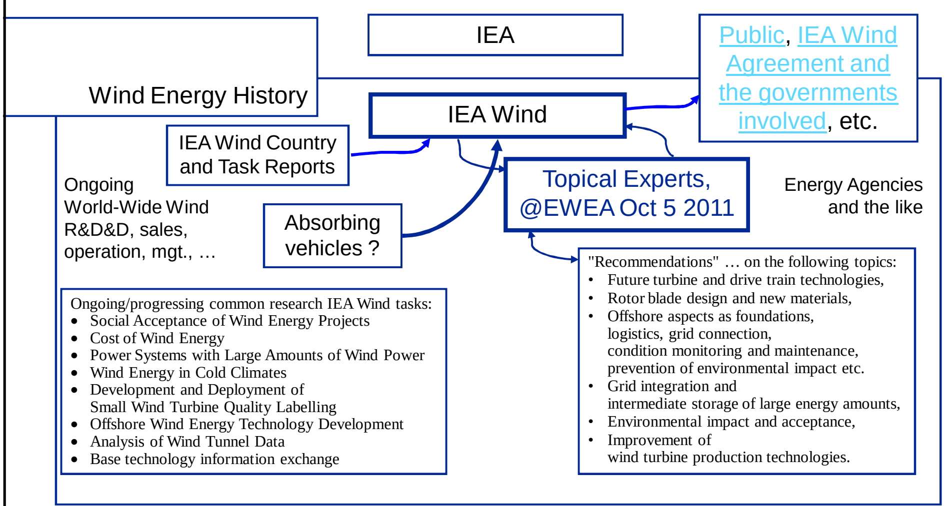
For IEA RD&D Wind, Task 11, Topical Expert Meeting #67 on

Long Term R&D Needs on Wind Power

held at EWEA - The European Wind Energy Association, Oct 5, 9-18

Power and productivity for a better world™

On actions/actors, …, disseminations/receivers



Background

IEA 11, Oct 5, 9-18 → "Recommendations" … on the following topics:
- Future turbine and drive train technologies,
- Rotor blade design and new materials,
- Offshore aspects as foundations, logistics, grid connection, condition monitoring and maintenance, prevention of environmental impact etc.
- Grid integration and intermediate storage of large energy amounts,
- Environmental impact and acceptance,
- Improvement of wind turbine production technologies.

On history for IEA RD&D Wind, Task 11: TopicalExperts.html
2011: IEA Wind Annual Report, IEAwind Strategic Plan for 2009–2014
2009: Technology Roadmap: Wind Energy
2007: … IEA Wind Co-operative Agreement, TOE#55 Berlin
2001: Long Term R&D Needs on Wind Energy 2000-2020, TOE#35 Petten NL
2001: Ad Hoc Group Report to the Executive Committee

IEA 11 TOE#67

An introductory note to the meeting was prepared.

Out of the note, the most adjacent issues with my ABB view are hereby quoted:
- *Cost of Wind Energy*
- *Power Systems with Large Amounts of Wind Power*
- *Wind Energy in Cold Climates*
- *Offshore Wind Energy Technology Development*

A challenge is to try to find those evolutionary steps that can be taken to further improve wind turbine technology, for example in large scale integration incorporating wind forecasting and grid interaction with other energy sources.

Research Area	Focus On	Time Frame/ Priority Mid-term	Time Frame/ Priority Long-term	Present Activity in IEA R&D Wind
More efficient generators, converters	Combined solutions for generation and transmission	++	+	Topical Expert Meeting 2001

Power Systems with Large Amounts of Wind Power / Wind Energy in Cold Climates

From my view with large turbines/farms, significant & tentative aspects are:
- Expand wind farm control into "multi points VPP", virtual power plants e.g. as used by TWENTIES
- Expand cold climates with probabilistics in difficult-/costly-to-visit sites and keep it simple and structured. Avoid risks for failures & defects.
- Include methods to overcome bottlenecks e.g. via feeder automation, to reduce risks for blackouts due to strain and stress, etc.

1. Contribute to complete systems out of turbines and farms into functional structures with real-time information exchange as a peer to traditional plants in the ac grids
2. Focus on turbines & grids; avoid uncertainties in equipment & operation; support offshore and onshore transmission system operators, TSOs
3. Develop reliability, availability & security in offshore technologies to match expectations, automation & wide-area monitoring for best grid stability
4. Aim for match-making wind and traditional electric power energies

(Life-Cycle) Cost of Wind Energy / Offshore Wind Energy Technology Development

Commercially-politically, it is complicated to handle electrical power & energy from wind separated from the traditional ones with much higher fungibility (interchangeability).

- There is a dichotomy (gap) between electricity's business and physical manifestations.
- From the business perspective, traditional electric power is a fungible commodity.
- The fundamental difference is that electricity so-far cannot be stored economically.

Associated with the dichotomy, there is a challenge to develop a bridge over the gap:

1. Storage (of wind power) will therefore be crucial and an area for cross-bordering with other EU research activities: TPwind, SmartGrids/EEGI, etc.
2. Better control—& higher efficiencies at partial loads—of wind & traditional power plants / New electrical-balance-of systems in both plant types as well as in solar ones.
3. Bettered interactions between short term forecasting systems, transmission systems and power plants capabilities. Who acts: IEAwind, TPwind, SmartGrids/EEGI, etc?

Gertmar PGdays ABB Milan 080605

Furthermore:

1. avoid sensors as well as cooling systems with rotating parts, their LCC are huge
2. reduce capital and operational expenditure, especially on the sites.

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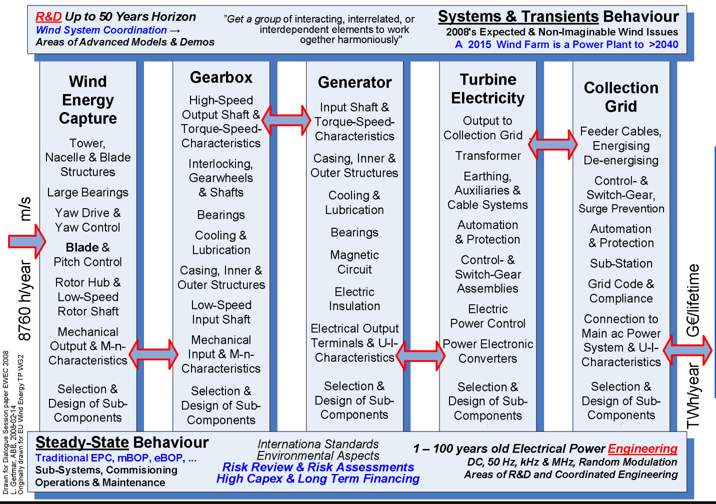
Wind System Coordination / Future turbine and drive train technologies

Reusing an own drawing from TPwind WG2 & EWEC 2008

Aspects of system solutions, e.g. geared or gearless, HVAC or HVDC, MVAC or MVDC

- Shaft system impacts on turbines' weight and cost-effectiveness, annual energy output, operations, maintenance and services, etc.
- Grid connections and faults do impact as far as "backwards" to gearboxes and "forwards" to grid codes and stability when power system operates under strain and stress



EWEC 2008
Gertmar et al
EWEC2008paper392

Some uncovered IEA TEM #67 topics:

- Offshore aspects as …, logistics, grid connection, … monitoring & maintenance, …. etc.
- Grid integration and intermediate storage

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Common research tasks which are in progress at present under IEA Wind are:
- Social Acceptance of Wind Energy Projects
- Cost of Wind Energy
- Power Systems with Large Amounts of Wind Power
- Wind Energy in Cold Climates
- Development and Deployment of Small Wind Turbine Quality Labelling
- Offshore Wind Energy Technology Development
- Analysis of Wind Tunnel Data
- Base technology information exchange

"Recommendations" … on the following topics:
- Future turbine and drive train technologies,
- Rotor blade design and new materials,
- Offshore aspects …,
- Grid integration and intermediate storage of large energy amounts,
- Environmental impact and acceptance,
- Improvement of wind turbine production technologies.

Conclusions / Action items

This contribution—by a mainly industrial participant—covers & expands 4 issues
- Power Systems with Large Amounts of Wind Power | Wind Energy in Cold Climates
- (Life-Cycle) Cost of Wind Energy | Offshore Wind Energy Technology Development

As wind energy is gotten at difficult/costly-to-visit sites, consider communication/automation

Suggestions / recommendations on how to proceed:
1. Define IEA Wind RD&D's future role in some selected topics: Old & new ones
   • Consider funding, needs for openness, executing bodies, usefulness, etc.
   • Absorb & distribute others' R&D: TPwind, SmartGrids/EEGI, etc. & China + US
2. **Top priority is suggested for offshore aspects as giant rating units' drive-trains incl. blades and towers; fault handling; foundations, logistics, grid connection, condition monitoring and maintenance, prevention of environmental impact; decommissioning; etc**.
3. Briefly define necessary IEA Wind R&D activities for "Recommendations" to the IEA Wind Agreement and the governments involved

For IEA RD&D Wind, Task 11, Topical Expert Meeting #67
Long Term R&D Needs on Wind Power

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Power and productivity
for a better world™

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SWPTC
SWEDISH WIND POWER TECHNOLOGY CENTRE

Ola Carlson

Chalmers University of Technology
Department of Energy and Environment
Division of Electric Power Engineering
20111005

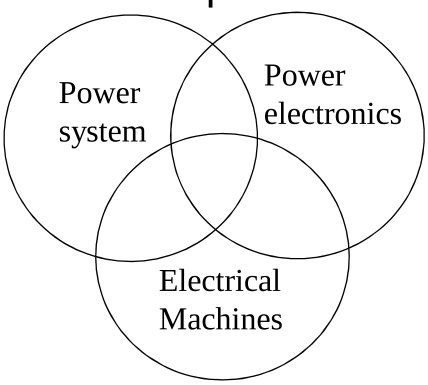
CHALMERS

Chalmers: Electric Power Engineering - research

Application areas:

1. wind power
2. transmission, distribution
3. electrical and hybrid vehicles

Core competences:



✓ Experimental and theoretical basis.

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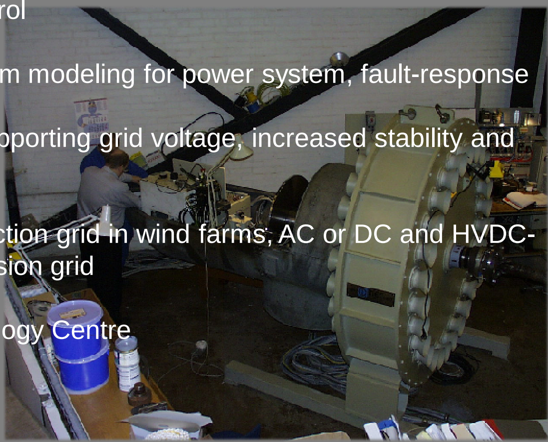
Wind Power at Chalmers

- 1975-1990 Generators, soft-starters, 1 generation of variable speed systems, test at Chalmers wind turbine, 40 kW's pitch-controlled
- 1985-2005 Design of permanent magnet generator, power electronic converters, design and control
- 1995-201x Wind turbine/farm modeling for power system, fault-response
- 2003-201x Wind turbine supporting grid voltage, increased stability and frequency control
- 2000-201x Design of collection grid in wind farms, AC or DC and HVDC-connections to the transmission grid
- 2010 – Wind Power Technology Centre



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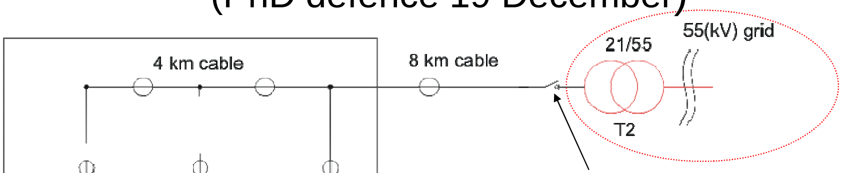
Analysis of Transients in Wind Park (PhD defence 19 December)



Switch at LV transformer side initiates energizing transient

General Electric – 1.5 MW

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Wind Energy Reaearch in Sweden

Vindval
- Acceptance and environment

Vindforsk
- Wind in forest and mountains
- Integration in the electric grid
- Future dc-grid, generator
- Operation and maintenance

Wind Centre
- Development, design, manufacture & maintenance of wind turbines

El. system for wind power off shore
- High voltage generators
- DC collection system
- HVDC transmission

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Goals of SWPTC

SWEDISH WIND POWER TECHNOLOGY CENTRE

Build up component and system know-how related to complete wind power turbines in order to bring about the following:

- Well-renowned Swedish development and production of complete wind turbines in Sweden
- Well-renowned Swedish development and production of sub-systems:
  - mechanical driveline
  - gearbox
  - axis
  - yaw and pitch mechanisms
  - turbine blades
  - tower
  - generator
  - transformers
- High-quality training of engineers with expertise in wind power

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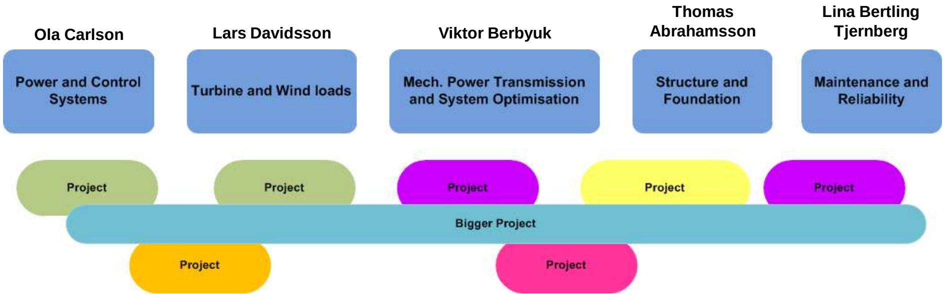
Theme groups



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Personnel at Chalmers

- At university: 14 senior researcher - professors
  13 PhD students
  2 technicians
- At industry in parallel research and development projects:
  25 experienced technical experts
- Totally: 54 persons working at university and in industry

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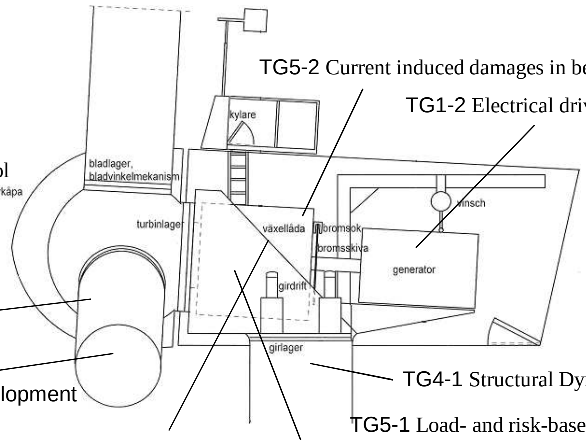
Ongoing projects within SWPTC



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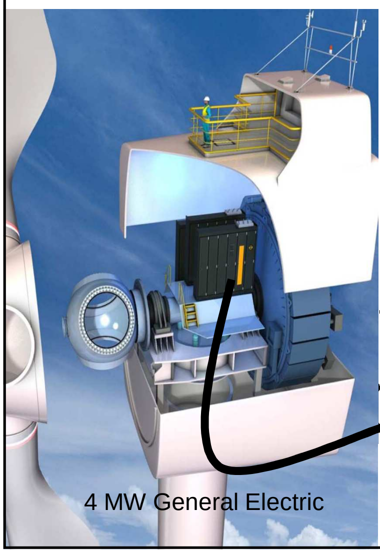
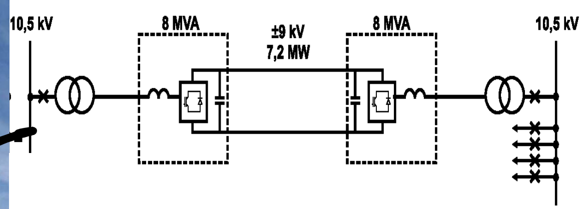
Grid Code Testing

General Electric design and install, Göteborg Energi operate:



Chalmers cooperation:

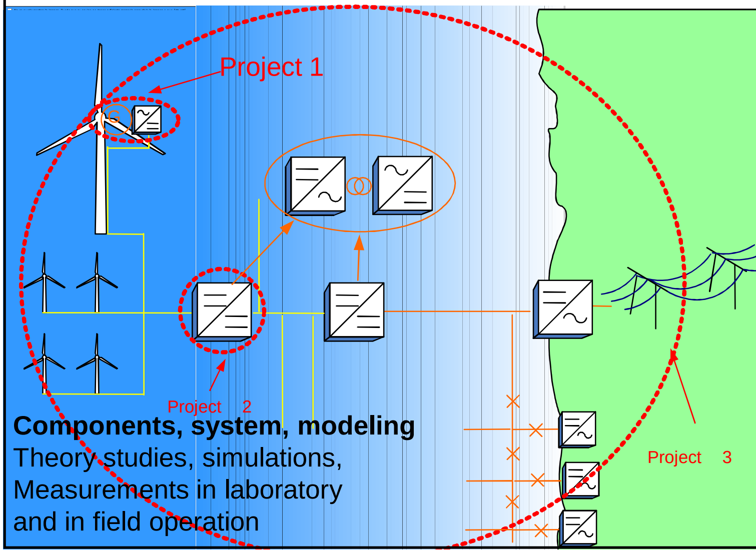
- Validation of models for mechanical and electrical systems
- Develop and carry out Grid code tests of the wind turbine



8 MW HVDC-light converter

CHALMERS

Offshore Wind Electric system



High voltage generator

dc/dc converters

Multi terminal HVDC

3 PhD & 2 researchers + Nordic (5 persons)

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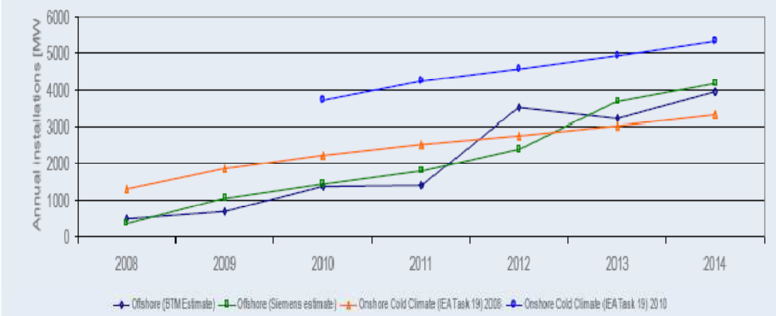
ESTIMATED COLD CLIMATE WIND POWER MARKET



- Turbines are and will be installed to icing and low temperature areas
- The share of cold climate installations annually 5 - 10% of total installations in US, Canada, Europe and China
- Market is segmented to low temperature and icing climate
- Estimated annual installations in cold climate around 5000MW in 2014

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Test station in Cold Climate

- Pre-study carried out
- Market increases
- Energy losses due to ice is not acceptable
- Some wind turbine manufactures interested
- Organization is under development
- Cooperation is important

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Futurer research

- HVDC-transmission, multi terminal, protection and fault
- DC connection grid within a wind farm
- Grid Code testing by Voltage Source Converter
- Wind turbine development, 10-20 MW
  - Load reduction by control and twisting blades
  - Lighter blades by carbon fibre and autoclave production methods
  - Reliability methods for electrical components, less temperature cycling
  - Diagnostic methods for generator, converter, bearing, mechanical components
- Cold climate development and test, icing and low temperature components

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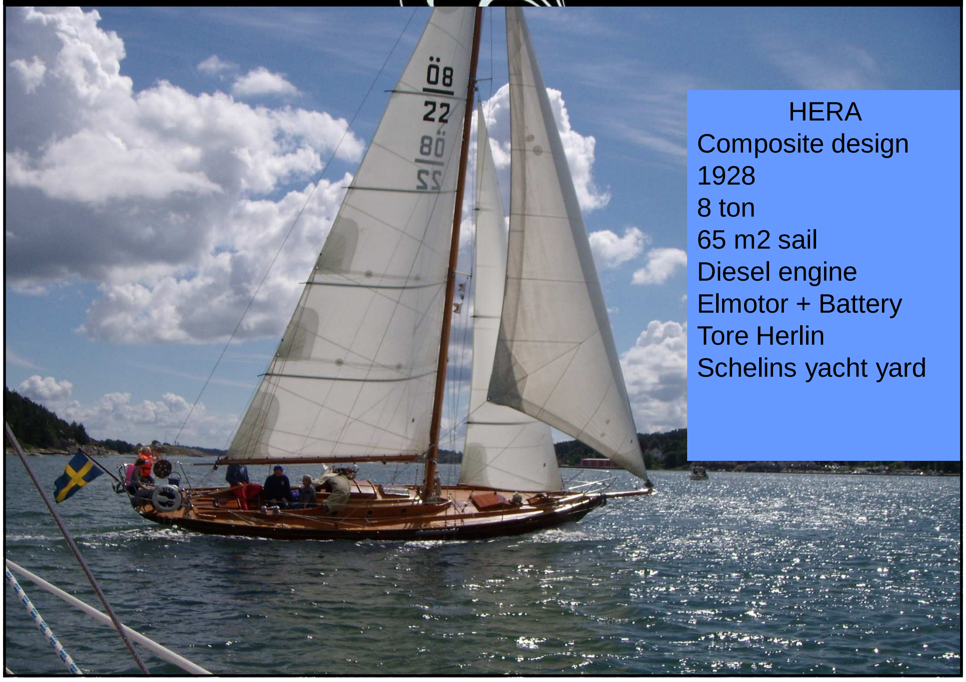

HERA
Composite design
1928
8 ton
65 m2 sail
Diesel engine
Elmotor + Battery
Tore Herlin
Schelins yacht yard

CHALMERS

Partners

Energimyndigheten
ABB
Marström
VÄSTRA GÖTALANDSREGIONEN
DIAB
CHALMERS
Triventus
Göteborg Energi
semcon
SKF
SWPTC
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Ongoing projects

- Stochastic model predictive control of wind turbines
- Models of electrical drives for wind turbines
- Current induced damages in bearings – mechanisms for charging, discharging and damage control
- Grid code testing by VSC-HVDC
- Measuring of a Wind Turbine for Verification of Component design
- Aerodynamic loads on rotor blades
- Wind Turbine Drive Train Dynamics, System Simulation and Accelerated Testing
- Validation of Wind Turbine Structural Dynamics Models
- Load- and risk-based maintenance management for wind turbines
- Reconfigurable lidar-system for wind measurement to support systems optimization of wind power plant

SWPTC
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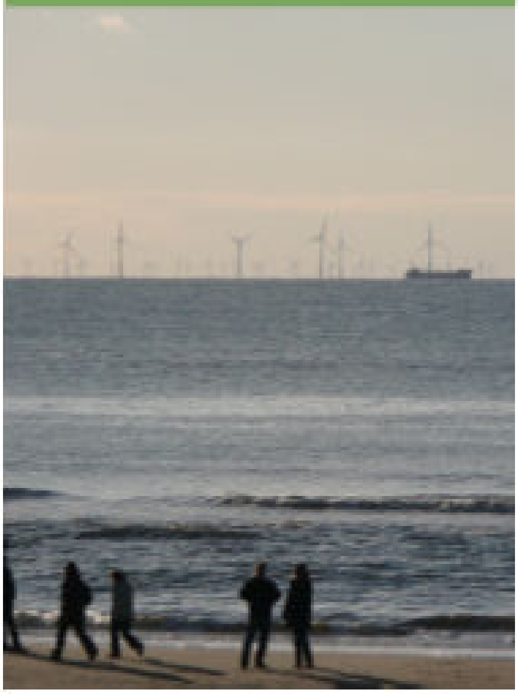


NL Agency
Ministry of Economic Affairs

The Netherlands

Thouhts on R&D needs

IEA Wind EM R&D needs

October 5, 2011

Jaap t Hooft

» Focus on energy
and climate change

Long term targets of Netherlands R&D

- Further cost reduction especially for offshore wind

- A healthy Dutch offshore wind industry

2

» Focus on energy
and climate change

R&D projects

In 2010 awarded (main)

- **XEMC Darwind 4.5 M€ O&O DD 5 MW offshore**
- **2B-Energy 4.5 M€ O&O 6MW 2-Blade downwind wind turbine on lattice tower**
- **Emergya Wind Technologies B.V.**

1.0 M€ DEMO 2 MW Direct Drive Wind (outside rotor)

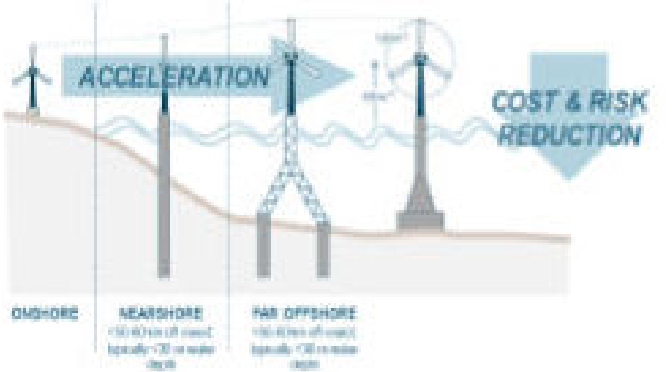
- **FLOW project 23.5 M€ O&O**
- **Total of 33.5 M€**

FLOW

- **Consortium FLOW**
- **Cooperation of 10 companies**
- **Offshore aimed at far and large**
- **R&D into offshore wind**
- **Aim substantial cost reduction**
- **23 M€ awarded**
- **Start 2011**

Themes

- **Wind farm design**
- **Support structures**
- **Electrical systems and grid integration**
- **Turbine development**



Projects ongoing

- Sustainable control = optimized feedback control + fault tolerant control + extreme event control + optimal shut down control
- North Sea Transnational Grid

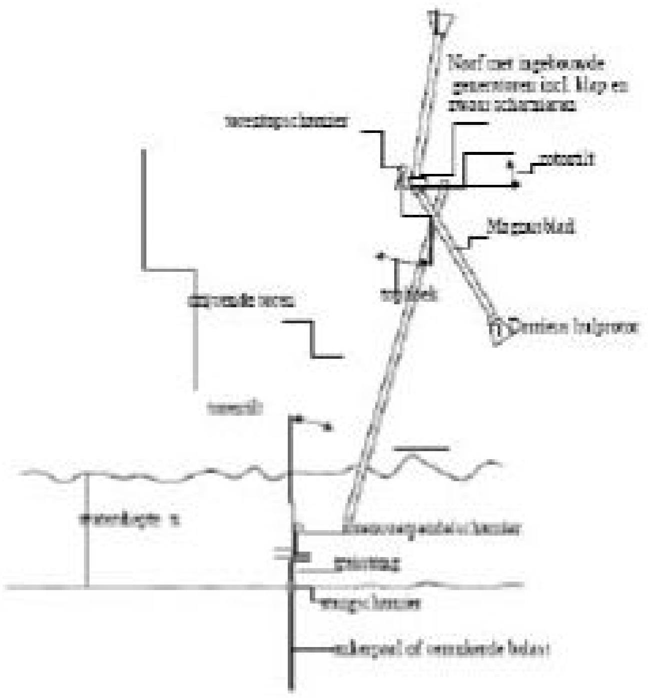
  investigates configurations of GW offshore grids (modular, flexible, mixed AC and DC), design and test multi- terminal nodes, develop operational strategy, stability of the system, and influence on connected onshore grids
- Boundary layer suction for wind turbine blades

5

» Focus on energy and climate change

Zero torque wind turbine

- Feasibility study concluded
- Combination of Magnus and Darrieus technologies
- Inflatable structures
- Patented
- Disruptive technology?



6

» Focus on energy and climate change

Dutch Permanent Magnet designs

Fabrikant	Vermogen	Rotordiameter	Ashoogte	A/P	Hoofdlagers	Bekrachtiging
	[MW]	[m]	[m]	[m2/kW]	[-]	[PM/EM] +
XEMC-Darwind	5,0	117,0	100	2,15	1	PM
Lagerwey Wind/ Global Wind Power	2,0	82,5	80/105/120	2,67	1	PM
STX Windpower	2,0	72,0	?	2,04	1	PM
STX Windpower	1,5	72,0	65/83	2,71	1	PM
STX Windpower	2,0	82,7	80/88	2,69	1	PM
STX Windpower	2,0	93,3	60/80/88	3,42	1	PM
Emergya Wind Technologies	0,8	54,0	?	3,05	1	EM
Emergya Wind Technologies	0,9	54,0	?	2,54	1	EM
Emergya Wind Technologies	2,0	90,5	85	3,22	1	PM

PM is permanente magneten, EM is bekrachtigde elektromagneten

7 » Focus on energy and climate change

Lagerwey

DarwinD

8 » Focus on energy and climate change

International Permanent Magnet designs

Fabrikant	Vermogen	Rotordiameter	Ashoogte	A/P	Hoofdlagers	Bekrachtiging
	[MW]	[m]	[m]	[m2/kW]	[-]	[PM/EM]
GE	4,1	113,0	onbekend	2,45	2	PM
Alstom	6,0	150,0	onbekend	2,95	1	PM
Siemens	3,0	101,0	onbekend	2,67	2	PM
Siemens	6,0	120,0	onbekend	1,88	2	PM
Nordex	6,0	150,0	onbekend	2,95	2	PM
Vestas	7,0	164,0	onbekend	3,02	3	PM
XEMC-Darwind	5,0	117,0	100	2,15	1	PM

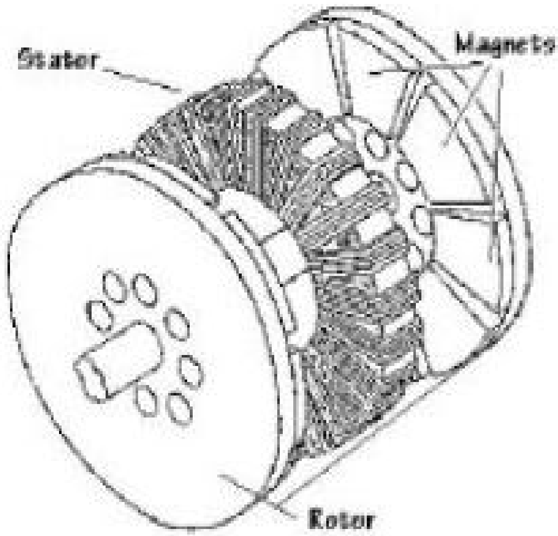
9 » Focus on energy and climate change

International PM design

10 » Focus on energy and climate change

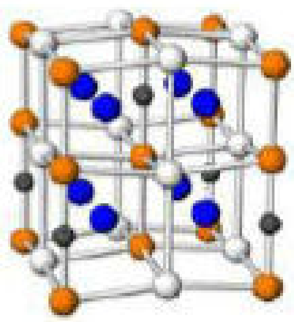
The fundamentals of (wind) electricity generation

- move a conductor through a magnetic field
- movement comes from wind
- magnetic field comes from permanent magnets or electromagnets



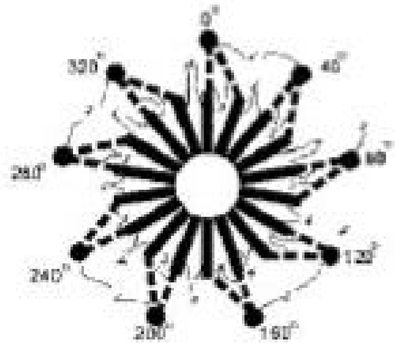
On permanent magnets and alternatives

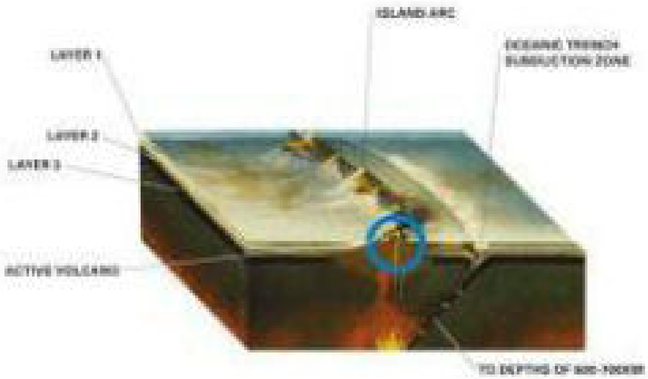
- Neodynium/dysprosium (NdFeB) getting more expensive
- Business case PM generators is eroding, costs going up.
- What are alternatives ?
  - Sources, materials, generator construction
- Alternative PM's e.g.
  - Sintered ferrites
  - Fe16N2 high (magnetism18% more than NdFeB)



Continued

- Alternative configurations e.g.
  - Hybrid magnetic systems, combine electromagnets with permanent magnets
  - Alternative methods of winding the generator
- Other sources of rare earth e.g.
  - Fertilizer material
  - Seafloor Massive Sulphide (SMS) deposits





Questions?

Summary of IEA Wind – 67th Topical Expert Meeting: LONG TERM R&D NEEDS FOR WIND POWER

Félix Avia, CENER

a) Participants

The meeting took place on 5 October 2011 in Brussels, Belgium and was attended by 21 participants from 8 countries (Denmark, Finland, Greece, The Netherlands, Norway, Spain, Sweden, and the United States). Representatives from the EWEA, EC, and the IEA Secretariat also attended the meeting. Table 1 lists the participants and their affiliations. Fifteen presentations were given:

1. **TPWind and the EWI,** *Filippo Gagliardi, EWEA*
2. **Research Needs Identified in IEA Wind Implementing Agreement Strategic Plan 2009-2014,** *Joachim Kutscher, Germany*
3. **United States Wind Power Program R&D Overview.** *Mark Higgins***,** *U.S. Department of Energy, United States*
4. **Wind Energy R&D Needs: Spanish Case,** *Emilien Simonot. AEEE, Spain*
5. **Research Needs from the View of a Certification Body,** *Christian Nath, Germanischer Lloyd Industrial Services GmbH, Germany*
6. **Long Term R&D Needs on Wind Power,** *Stephan Barth, ForWind Center for Wind Energy Research, Germany*
7. **RWE INNOGY - Research & Development Offshore Wind,** *Fiedrich Koch, RWE Innogy GmbH, Germany*
8. **Arctic/Cold Climate Needs,** *Hannele Holttinen, VTT, Finland*
9. **Offshore Wind R&D Needs (examples),** *John Olav Tande, Nowitech/Sintef, Norway*
10. **Long Term Research Needs: Status and Perspectives,** *Flemming Rasmussen, Riso-DTU, Denmark*
11. **UpWind, New Test Station and drive train test facilities in Denmark.** *Peter Hjuler Jensen, Riso-DTU, Denmark*
12. **Future R&D Challenges as Seen from the Vattenfall Horizon**. *Sven Erik Thor, Vattenfall, Sweden*

13. **Long Term R&D Needs on Wind Power**. *Lars Gertmar, Power Technologies, ABB Corporate Research, Sweden***.**

14. **Electric Power Wind Energy Research.** *Ola Carlson, Chalmers University of Technology, Sweden*

15. **The Netherlands. Thoughts on R&D needs.** *Jaap 't Hoof, The Netherlands*

IEA # 67 TEM "LONG TERM R&D NEEDS ON WIND POWER"

LIST OF PARTICIPANTS

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20	**Thierry**	**Langlois D'Estaintot**	DG Research, European Commision		Thierry.D'Estaintot@ec.europa.eu
21	**Filippo**	**Gagliardi**	EWEA		Filippo.Gagliardi@ewea.org

Table 1 Participants in IEA Wind TEM on long-term R&D needs for wind energy

b) Background

This meeting in 2011 was planned because of the usefulness to IEA Wind participants of past meetings to develop long-term R&D strategies for wind energy. The most recent IEA Wind meetings on long-term R&D were held in 1995, 2001, and 2007. Results from these meetings can be found in Appendixes at the end of this report:

- TEM #27: Current R&D Needs in Wind Energy Technology, 1995, Utretch, The Netherlands (Appendix I);
- TEM #35: Long Term Research needs, 2001, Petten, The Netherlands (Appendix II);
- TEM #55: Long Term Research needs, 2007, Berlin, Germany (Appendix III).

c) Discussion

Following the 15 presentations, the floor was opened and a general discussion took place among the participants. There was general agreement that the group present should update the previous IEA Wind document *Long-term research and development needs for wind energy for the time frame 2000 to 2020* and write a new document "Long-term research and development needs for wind energy for the time frame 2011 to 2030."

However, because the TEM had been planned as a continuation of meetings that took place in Brussels on the 3rd and 4th of October, within the activities of the European Wind Energy Technology Platform (TPWind), many of the attendees had to leave early to return home. Due to the short time available and the reduced number of participants in the discussion, it was decided that the best way to proceed was to ask all the participants to send a list of five priority topics for R&D for the period 2011-2020, and to use this information for the elaboration of the TEM minutes.

Later in October, the Task 11 OA reported about this TEM and about the recommendation to update the IEA Wind document on long-term R&D to the 68th IEA Wind Executive Committee (ExCo), in Dublin, Ireland. At the ExCo meeting, it was decided to assemble a working group to develop the new "Long-Term R&D" document for IEA Wind. To elaborate the document, it was decided that the working group should collect five top priorities for long-term R&D from each country in IEA Wind. It was deemed especially important for non-European countries (Australia, Canada, Japan, Korea, Mexico, and the United States) and for countries that were not represented at the TEM to deliver their priorities.

By November 30, 2011, priorities had been received from 12 representatives. Table 2 lists the priorities defined by that group of respondents.

Table 2 Assembled R&D priorities

Social acceptance	
	Environmental aspects, mainly offshore
Basic Research	
	Compressibility effects at high tip speeds for offshore
	Research related to new concepts
	Topologies for electrical generators
	Momentless wind turbines
	Load reduction by control using LIDAR wind measurements and twisting blades
Engineering Tools	
	System engineering approach to aero-servo-elastic optimization of wind turbines
	Terrain and rotor flow interaction and topology optimization for sitting in wind farms with respect to loads, power, and cost.
	Integrated numerical design tools for large deep offshore wind turbines
	Development of full CFD-structure interaction tools.
Testing	
	Advances in wind turbine and components testing
	Development of testing facilities and methods for drive trains and large turbine components
Grid integration	
	DC connection grid within a wind farm
	HVDC-transmission, multi terminal, protection and fault
	Grid code testing by voltage source converter
	Offshore grids, transformers, and grid connection
	Monitoring and prediction of voltage dips. Applications of voltage control systems
	Improvement of the use of the production forecasting for system operation
	Electric vehicles, demand side, …
	Advanced control systems for wind farms
	Wind farm control methods (for optimizing performance and minimizing loads)
Reliability (O&M)	
	Increase component´s lifetime
	Recycling and end of life policies
	Condition monitoring techniques

	Predictive tools for O&M
	Ability for components to work under failure conditions
	Ability to go from corrective to preventive maintenance
	Diagnostic methods for generator, converter, bearing, mechanical components
	Reliability methods for electrical components, less temperature cycling
Materials	
	Materials (including rare earth): availability and replacement
	Lighter blades by carbon fiber and autoclave production methods
Offshore	
	Characterization of wind, wave, and current conditions
	Offshore foundations in deep waters. New deep sea concepts
	Wind speed estimation offshore, modeling and measurements
	Cost reduction through: design of offshore wind farm and support structures, electrical systems and grid integration and offshore turbine development
	Installation and other support vessels for offshore wind farms
	Offshore wind power: cost effective designs of offshore floating foundations for very deep waters and wind farm to shore transmissions solutions
	Tools for offshore grid and Wind Farms electric design
Cold Climate	
	Wind turbines in cold climate
	Cold climate development and test, icing and low temperature components
Small Wind Turbines	
	R&D to address reliability, performance, and reducing life cycle cost
	Community scale wind-diesel systems

d) Conclusions and Future Actions under the Umbrella of IEA Wind

In a first look at the information from this 2011 TEM and the previous meetings, it is possible to conclude that some of the issues selected as high priority in the previous TEMs are not as high on the priority R&D list. For example the following issues where there is still on-going development work were not considered as important as other topics:

- Visual impact of wind farms
- Efficient wind farm lay out
- Forecasting techniques
- Certification procedures

The situation has evolved since 1995 when the first TEM to identify R&D needs took place. Significant R&D has addressed priority issues and extensive experience has been obtained through development of the market and the associated technology. Expanded knowledge, a large number of tools, and detailed procedures have been developed to deal with these specific topics.

From 2011 through 2030 the main issues identified by the experts and the IEA Wind country representatives include:

1. Increase public acceptance
2. Lower the cost: lower wind turbine cost and transport and installation cost.
3. Increase wind turbine reliability and lower O&M cost
4. Increase capacity of grids, wind turbines, other generation and demand for high wind penetration
5. Open new markets: Cold sites; complex terrain; offshore installations in shallow, middle-depth, and deep waters; and autonomous systems

A Task Force under the umbrella of the IEA Wind has been identified to develop the new “Long-Term R&D” document. The group includes the vice chairs of the ExCo (Joachim Kutscher, Germany and Jim Ahlgrimm, United States); the OA of task 11, Felix Avia, Spain; a representative of TPWind to be designated; and a representative expert of each active research task (19, 25, 26, 27, 28, 29, 30, 31, 32, 33). The new long-term R&D document will present in a condensed way the results of the TEM on Long-Term R&D and the priorities sent from IEA Wind countries.

ANNEX I

Outputs and Summary of TEM #27:

"Current R&D Needs in Wind Energy Technology"

1995, Utretch, The Netherlands

Outputs from TEM #27

The priority areas for continued research directed towards improving the wind turbines design were:

■ Aerodynamics

-3D and unsteady aerodynamics

-Aerodynamics of rotors operating in deep stall. Dynamic stall characteristics

-Development of aerofoils tailored to wind turbine use

■ Aeroelasticity and load calculations

-Further development and verification of aeroelastic codes. More detailed modelling of atmospheric turbulence and extreme wind as input to these codes, including turbulence in complex terrain and in wind farms.

■ Aeroacustics

Develop calculation models based on better understanding or the physics of aerodynamic noise. Incorporation of acoustic requirements in aerofoil design

■ Materials

Verification of fatigue calculation procedures 3D stress distribution

Establishing data base of material properties

■ Lightning protection measures

■ Offshore installations

Combined wind – wave loading

Dynamics support structures

Wind and turbulence over the open sea

■ Power conversion. Wind turbine, grid integration

Direct drive, multipole generators, variable speed,

Power electronics

Power quality

Other areas for continued research were:

- Public acceptability, legal aspects
- Efficient park lay-out
- Certification procedures
- Recyclability of materials used

27th IEA Experts Meeting, sept. 11.-12. 1995, Utrecht

Current R&D Needs in Wind Energy Technology

SUMMARY

prepared by

B.Maribo Pedersen, DTU

The meeting which was kindly hosted by NOVEM, the Netherlands Agency for Energy and the Environment, was attended by 22 people. The purpose of the meeting was to get an impression of how far the efforts spent up to now on R&D world-wide has brought the general understanding of and possibly solution to the various problems within wind energy technology, thereby providing some guidance as to where to go from now.

In 1994 it is estimated that more than 100 MUSD was spent on R, D & D by those OECD countries which have a wind energy program, and since 1974 at least 1000 MUSD must have been spent.

Hence it appeared proper to step back and take a look at where future spending of R&D money may best contribute to the overall goal of decreasing the cost of energy produced from wind to the point where it is truly competitive with that from conventional sources. In particular it would seem valuable to obtain the views of the manufacturing industry on this issue.

Of the 22 persons attending the meeting, 7 came from industries in the Netherlands, Germany, Denmark, UK,and Sweden , and 5 written contributions are included in the proceedings. Another 5 persons came from various engineering consultancy companies, delivering 3 written contributions. 2 persons came from universities, 4 from research institutes, 3 from National Energy Agencies, and there was 1 IEA representative.

The first paper presented by G.v. Kuik, was based on a recent survey made in the Netherlands, where a great number of dutch wind energy experts - manufacturers, researchers and scientists - were interviewed. This survey gave a well-structured overview of all problem areas and also gave suggestions for further work in the short-, mid- and long term. This paper was frequently referred back to during the discussions. Similarly the tables provided in the introductory note gave a good scope for the discussions.

The meeting seemed to agree, that we have now reached a stage where the industry should be able to foot a larger share of the R&D bill. Also the fact that the industry has moved from the precompetitive phase into the compatitive stage indicates, that most of the product and component development should take place within the companies.

However there was consensus on the view, that there is still a need for basic, generic research to be carried out outside the companies and wholly or partly funded by public money, and that this need will continue to exist as long as there is wind energy development.

It was the impression that development of new "revolutionary" concepts was favoured more among consultants and research institutes than among manufacturers. The idea that the lightweight, flexible, gearless etc. turbine was the ultimate goal was tempered by manufacturers who warned, that such a machine not necessarily would give the lowest COE figures.

The issue of transfer of R&D results from institutions to industry was touched upon. Some manufacturers were of the opinion, that up to now the impact of the R&D work carried out in research institutes and in universities has been limited, and that they felt that the real value of the institutions is in training people who then can be taken on and be put to work by the industry. The contemporary priorities within industry seems to lie more in disciplines like value engineering, improvements in manufacturing technology, access to testing facilities, development of components etc.

Still - as mentioned above - the necessity for continued basic research within certain areas was recognized, and it was emphasized that one should be anxious to keep the size of the research teams above "the critical mass".

There seemed to be consensus among all participants that the areas for continued research were the following:

- Aerodynamics
    - development of aerofoils whose properties are taylored to wind turbine use; experimental verification essential.
    - aerodynamics of rotors operating in deep stall
    - 3D and unsteady aerodynamics
    - dynamic stall characteristics - wind tunnel and field experiments.
- Aeroelasticity and load calculations
    - further development and verification of aeroelastic codes
    - more detailed modeling of atmospheric turbulence and extreme winds as input to these codes, including turbulence in complex terrain and in wind farms.
- Aeroacoustics
    - develop calculational models based on better understanding of the physics of aerodynamic noise
    - incorporation of acoustic requirements in aerofoil design
- Materials
    - verification of fatigue calculation procedures for 3D stress distribution
    - establishing data base of material properties
- Lightning protection measures

- Off - shore installations

    - combined wind - wave loading
    - dynamics of support structures
    - wind and turbulence over the open sea

- Power conversion. Wind turbine - grid interaction

    - direct drive, multipole generators, variable speed
    - power electronics
    - power quality

Apart from these areas which all are directed towards improving the machine design, other areas were mentioned, such as

- recyclability of materials used

- efficient park lay-out

- certification procedures

- public acceptability, legal aspects

If research projects within these areas are carefully planned and prioritized the results will form the necessary background for industrial implementation, at least in the mid-to long term, and pave the way towards more cost-efficient designs.

During the round table discussion, the idea was put forward of trying to pool some of the efforts, particularly concerning costly experimental projects, f.i. wind tunnel testing. This could be one way of partly overcoming the difficulties created by diminishing funding for basic R&D, which has been experienced in several countries lately. The bodies through which such cooperative action could be taken could be the IEA Agreement and perhaps the European Commission.

The idea was favoured by the participants, and as a first step, Jaap 't Hooft proposed to the ExCo of the IEA Agreement at its meeting in october 1995 the idea of a project as a possible new Annex, titled "Aerofoils in Dynamic Stall in Wind Tunnels".

The ExCo beeing in favour of the idea asked the Netherlands, J. Beurskens and J. 't Hooft, to collect existing material on the subject in preparation of a detailed proposal.

ANNEX II

Summary of TEM #35**:**

“Long Term Research needs”

2001, Petten, The Netherlands

Outputs from TEM #35

After the 2001 meeting the document "Long-term research and development needs for wind energy for the time frame 2000 to 2020" (October 2001) was edited (Annex IV). In this document was stated:

- *"Large scale implementation of wind energy requires a continued cost reduction and an improved acceptability and reliability"*

- *"The technology of turbines, of wind power stations, of grid connection and grid control, the social acceptability and the economy of wind power in a liberalized market, all have to be improved in order to provide a reliable and sustainable contribution to the energy supply"*

- *"To reach these objectives there still is a need for generic long-term research. Besides that, there was also a need for a short to mid-term research that mainly is in the interest of utilities/manufacturing industries and to some extent to society. [Annex IV].*

For the mid-term time frame, R&D areas of major importance identified for the future deployment of wind energy were **forecasting techniques, grid integration, public attitudes, and visual impact**. In addition, **human resource development** also was selected as priority. Table 3 summarizes the priorities identified in the mid- and long-term time frames in 2001.

Research Area	Focus On
Increase value and reduce uncertainties	
Forecasting power performance	Increase value of electricity
Reduce uncertainties related to engineering integrity, improvement and validation of standards	Supply background material
Storage techniques	Storage for different time scales
Continue cost reductions	
Improved site assessment and new locations, especially offshore	Extreme wind and wave situations, forecasting techniques
Better models for aerodynamics/aeroelasticity	3D effects, aeroelastic stability
New intelligent structures/materials and recycling	Extremes, adaptive intelligent structures, recycling
More efficient generators, converters	Combined solutions for generation and transmission
New concepts and specific challenges	Intelligent solutions for load reduction
Stand alone and hybrid systems	Improved system performance
Enable large-scale use	
Electric load flow control and adaptive loads	Improve models, load flow control, power electronics
Better power quality	Power electronics
Minimize environmental impacts	
Compatible use of land and aesthetic integration	Information and interaction
Noise studies	Offshore issues
Flora and fauna	Background data

Research priorities identified in 2001 for the mid- and long-term time frames

Summary of IEA Topical Expert Meeting on

Long term R&D needs for wind energy. For the time frame 2000 – 2020

March 2001, ECN, Petten, the Netherlands

Åsa Elmqvist and Sven-Erik Thor

1 Summary and conclusions

A similar meeting was held in Holland 1995. At that meeting the discussions mainly focused on technological issues. The meeting 2001 also focused on these things and in addition to that made reference to such areas as sociotechnical aspects (visual intrusion, acceptance etc.) and wildlife, flora and fauna. This seems natural in a stage when wind turbines are becoming a more common element in society.

There is a consensus on the view that there still is a need for generic **long term** research. The main goal for research is to support the implementation of national/international visions for wind energy in the near and far future. It was the opinion that it is possible to reach this goal for the near future with available knowledge and technology. However, large-scale implementation of wind energy requires a continued cost reduction and an improved acceptability and reliability. In order to achieve a 10 to 20% part of the worldwide energy consumption provided by wind, major steps have to be taken. The technology of turbines, of wind power stations, of grid connection and grid control, the social acceptability and the economy of wind power in a liberalized market, all have to be improved in order to provide a reliable and sustainable contribution to the energy supply. It is for this objective that there is a need for long term R&D. Besides this, there is also a need for a short to mid term research that mainly is in the interest of utilities/manufacturing industries and to some extent to society.

The result of the meeting has given valuable information for updating the next version of the Strategic Document. Examples are the categorizing of the different research topics as well as an updated list of research areas, for example storage techniques, forecasting of production, autonomous systems and smart structures. Participants in the meeting “volunteered” to give comments and suggestions for improvement of the Strategy Document.

2 Background

The meeting was kindly hosted by ECN, Netherlands Energy Research Foundation, at Petten in Holland on the 22 - 23 of March 2001. The subject of the meeting was to identify Long-term R&D needs for wind energy, for the time frame 2000 – 2020. This meeting is an essential element in the process of developing a long term R&D strategy for the implementing agreement. Other activities to support the development of the document are:

- Meeting at the Kassel conference, Sept 2000
- Discussion at IEA ExCO #46 in Italy
- Presentation at the REWP meeting in Paris, Oct. 2000
- Ad hoc working group
- Discussion at IEA ExCO #47 in Norway

The meeting was attended by 16 persons, giving 10 presentations. The attendees represented seven countries and came mainly from national energy agencies or research organizations.

3 Summary of presentations

3.1 Categorization of needs

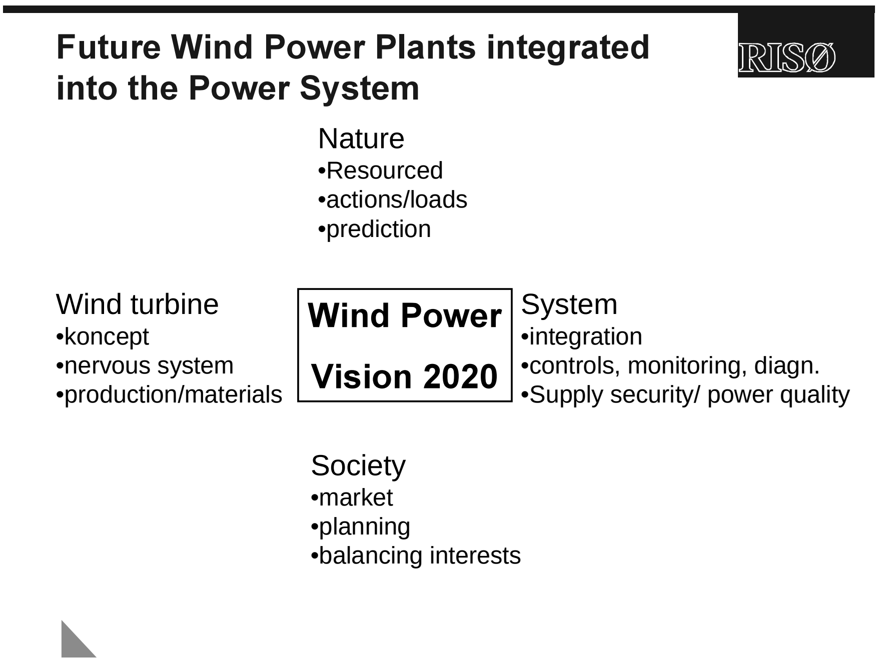
The presentations covered many aspects of wind engineering. Different approaches for sorting the R&D topics were given by the lecturers:

1. research topic oriented
2. overall view (holistic)
3. needs to achieve strategic goals.

An example of the first one is:

- Technology development
- Sociotechnical aspects
- Wildlife, flora and fauna

Another, holistic, way of presenting the subject was proposed by Rasmussen. This approach starts with the vision for future implementation of this energy source. The vision constitutes what we would like to achieve. Around this vision a number of interacting subjects are focused.



The presentation by Snel outlined R&D needs and priorities linked to strategic goals and success factors. The presentation was based on a recent survey made by EUREC/EWEA.

R&D needs and priorities: Link Strategic Goals and success factors

Strategic goals / Aspects	10% renewable energy in Europe	30% new RE capacity in developing countries	Maintaining Industrial capacity & employment
Cost reduction of wind energy	••	•••	•••••
Increasing the value of wind energy	•••	•••	•••
Finding new sites	••••	••	•
System development	••••	••••	•••
Reduction of uncertainties	••	•••••	•••••
Reduction of environmental effects and negative social impacts	•••	-	•
Education & human resource development	••	••	•••••
Development of policy and instruments	•••••	•••••	•••••

EWEA

EUREC

The last two ways take an overall view of the needs in different areas. This approach was considered to be the most suitable categorization to be used in the Strategy Document. However, the exact headings should be elaborated in more detail.

3.2 Research aiming at

In order to achieve visions many speakers mentioned that lowering the cost of generation as the main issue for R&D. In order to fulfill this, R&D should aim at:

- larger turbines
- offshore
- new concepts
- grid interaction and transmission
- reliability
- recycling
- free market aspects
- measures creating value and solutions to the energy supply

3.3 Turbine sizes

The size of turbines and related research was addressed. The general view is that there are three different categories of sizes:

1. multi MW size (≅5MW), wind turbines for large power stations off-shore or remote area
2. medium-size wind turbines (≅1MW) for grid connection, single turbines or farms
3. smaller wind turbines (≅ 30 kW) for electrification in developing countries, stand-alone, combined with solar energy and possibly hydrogen production for storage and transportation

The research needed is somewhat different for the different classes.

4 Round table discussion

The outcome of the discussion is summarized below.

4.1 Long term R&D –Research for whom? / Research for achieving what?

Main purpose of Long Term R&D is to create options. From them, the society can make the choices on direction of energy supply. The research is done for the whole society and the results will be used on a multi-national governmental level.

Short-term research is primarily for the manufacturers or the utilities. They are, together with R&D results, more like a helping tool to reach the existing political visions and goals for installed wind power. Progress ratio is only possible with a combination of manufacturers development and R&D.

4.2 Time scale

The time frame for research was touched upon. Three different horizons were proposed:

1. Short term 0 – 5 years — system development, human resource development
2. Mid term, 5 –10 years — mix of 1 and 3
3. Long term 10 – 20 years — increasing the value of wind, supporting strategic goals

Research in all time scales should be in discussion with government, utilities and industry. Though industry is normally not involved in long term R&D and has usually not formulated their long term needs, it is possible to get ideas for the long-term research from the short and medium term R&D.

There is a consensus on the view that there still is a need for generic **long term** research. The main goal for research is to support the implementation of national/international visions for wind energy in the near and far future. It was the opinion that it is possible to reach this goal for the near future with available knowledge and technology. However, large-scale implementation of wind energy requires a continued cost reduction and an improved acceptability and reliability. In order to achieve a 10 to 20% part of the worldwide energy consumption provided by wind, major steps have to be taken. The technology of turbines, of wind power stations, of grid connection and grid control, the social acceptability and the economy of wind power in a liberalized market, all have to be improved in order to provide a reliable and sustainable contribution to the energy supply. It is for this objective that there is a need for long term R&D. Besides this, there is also a need for a short to mid term research that mainly is in the interest of utilities/manufacturing industries and to some extent to society.

4.3 Topics

A similar meeting was held in Holland 1995. At that meeting the discussions mainly focused on technological issues. The meeting 2001 also focused on these things and in addition to that made reference to such areas as sociotechnical aspects (visual intrusion, acceptance etc.) and wildlife, flora and fauna. This seems natural in a stage when wind turbines are becoming a more common element in society.

A comparison of listed topics at the two meetings is shown in the figure below. Some of the 1995 topics were not mentioned at the 2001 meeting, they are marked in red/italic.

The total list of topics shall be interpreted as the sum of the two lists, except the red/italic bullets.

Comparison with 1995 meeting

1995
- Offshore
- Aeroelasticity and loads
- Aeroacoustics
- Materials
- *Lightning protection*
- Offshore
- Power conversion
- Recycling
- *Efficient park lay-out*
- *Certification*
- Public acceptability
- *Legal aspects*

New 2001
- Environment
- Storage
- Large scale introduction
- Forecasting
- Smart structures
- Autonomous systems
- HR development/training

International Energy Agency R&D Wind

4.4 Cross cutting issues

The aim was to identify areas that were relevant not only to wind energy, but also to other energy sectors. A number of topics were mentioned:

- Micro turbines
- Hybrid systems
- Integration with other production sources
- Free market movement

ANNEX III

Summary of TEM #55:

"Long Term Research needs"

2007, Berlin, Germany

Outputs from TEM #55

Former Operating agent of Task 11, Sven-Erik Thor, made a comparison of the outcomes of 2007 meeting and of the meeting in 2001. His conclusions were:

- It was noted that new initiatives were coming from other organisations looking into R&D needs. It was obvious that there were a number of new players in the R&D arena at that time.
- Wind power with its application in a broader sense was discussed in 2007. Examples were: wind / hydro / pump storage and plug in hybrids.
- Education and knowledge transfer networks were considered to be a crucial topic.
- Reliability and Operation & Maintenance was becoming more and more important.
- Other challenges, (except direct research needs) that the wind industry was facing in 2007 were:
- Commodities price increase; infrastructure was not in place to meet national goals
- Offshore: cost was increasing instead of going down as expected in the 2001 long-term report, and legal aspects as protection of property offshore
- Military issues involving radar and radio link issues

Summary of IEA RD&D Wind – 55th Topical Expert Meeting on

Long-Term Research Needs
In the Frame of the IEA Wind Co-operative Agreement

December 2007, Berlin, Germany

Sara Hallert and Sven-Erik Thor

Aim and Objectives

The aim of the Topical Expert Meeting (TEM) was to discuss long-term research needs for the timeframe 2020. The objective of the meeting was to try to identify needed future results from R&D both in the 5 to 10 and the 10 to 20 years time frames. The strategic goal of the TEM is to give recommendations to the IEA Wind Executive Committee and to the governments involved which are based at the latest international wind technological stage. The outcome of the meeting will be used to develop a new strategic R&D plan for IEA Wind.

The objectives were also to review the latest wind energy technology and to draw conclusions for a further successful development to expand the place of wind energy in the worlds energy mix by means of R&D.

Participants / Presentations

A total of 35 persons registered for this meeting. They represented the following countries: Canada, Denmark, Germany, Italy, Korea, Norway, Portugal, Spain, Sweden, the Netherlands, the UK and the US. The participants mainly represented National Energy Administrations, Research Organizations and Universities.

The following presentations were given:

1. Introductory Note – Long-Term R&D Needs for Wind Energy
2. Evaluation of the German Renewable Energies Research Programme: Wind
3. Research Needs from a Swedish Perspective
4. R&D Needs for Large Scale Deployment a US Perspective
5. Some Key Points of the Wind Power R&D Programme in Denmark 2007
6. Wind Energy R&D in Canada
7. R&D Tasks in Norway
8. Identification of R&D Necessities in Spain
9. Netherlands LT R&D Needs
10. The UK - Offshore Wind Programme
11. Wind Power as a "base load" - R&D Needs
12. Wind Energy Activities at the University of Massachusetts
13. Long-Term R&D Needs for Wind Energy and ReKnow.net
14. Wind R&D in Vattenfall
15. Research Needs for Wind Industry
16. EP UpWind Project
17. Identifying R&D Key Issues

Summary of discussion

Below is a summary of the topics which were considered essential for the future development of the wind turbine technology and the utilization of the technology.

Turbine development

a) Use of new materials e.g. thermoplastics
b) Special offshore turbine design can be a solution for deceasing the prices
c) Design validation, current design standards are considered not to be enough in certain areas. E.g. loads and load transmission in drive trains at static and dynamic situations
d) Lighter structural design. This is not necessarily a design driver, but is a subordinate cost driver
e) Control strategies for load reduction, adapt turbines to anticipated loads in various situations
f) Optimization, smooth output as a generation unit, treat it as a power plant
g) New concept - rotors for larger diameters
h) Transition from manufacturing to automated serial production – cost reduction potential, economies of scale
i) Aerodynamics, wakes
j) Fast up scaling, 'skip' the first half of the blade, make it a 'truss'
k) Combine passive built-in with multi-variable control
l) New drive train concepts

"Incremental development is important but new concept development must always be there".

"Need to develop better technology innovative oriented research; it produces innovations on both short and long-term." "Up scaling is a method not an objective. Developers and banks want reliable, cost effective turbines rather than JUST larger ones.."

Three levels of industrial technology development:

1) Incremental development focus on reliability
2) Change of component and subsystem concepts
3) Change of wind turbine concepts

Components

"System improvements are required to meet the necessary cost reduction, single component improvement is not enough."

a) Adding intelligence to get smart rotors, drive train, flexibility and magnetic bearings
b) Development of new bearing structures
c) Generator - problem characterisation and transient behaviour
d) Better communication between components and grid

Tower development

"26% of the wind power cost derives from the tower, something must be done in this area"

a) Methods to decrease the share of steel in the construction is important. Wind power energy is a large steel consumer in Europe. Some manufacturers are preparing for concrete towers.
b) Everything that minimises loads on towers

Foundations

a) Mainly offshore, optimisation of traditional structure and develop new structures
b) Deeper water solutions - floating wind turbines

O&M

"Reliability is a key issue today." "Design life does not live up to production service life."

a) Component reliability, studies of rate and type of failures, life length on gear boxes approx 4-12 years.
b) Condition monitoring maintenance (a lot to learn from the oil and gas industry)
c) Availability = function of (reliability, accessibility) must be increased
d) Reliability of small turbines
e) Security of operation, ship safety
f) Reliable sensing devices (learn from other industries such as aircraft, gas and oil offshore), remote sensors with intelligent software

Logistics

a) A general improvement of logistics, i.e. optimisation of transport and installation
b) Clever and cheap transport, installation equipment and concepts dedicated for offshore
c) Access to offshore structures
d) Procedures if commissioning on quay, transport, assembly etc.

Grid system/integration - local grid (AC/DC) and national level

a) Impact and operation in power system with high wind penetration – system operation, balancing of the system when realising the ambiguous deployment plans
b) Improvement of energy production forecasting for system operation
c) Regulation of power
d) Better communication between components and grid
e) Security of supply

Wind field knowledge

a) Resource assessment and forecasting - develop forecasting tools with increased accuracy
b) Remote and satellite measuring systems
c) Offshore wind measurements needed – today very little data, important with measurements for the learning curve
d) Methods to mix new air in wake of turbines/farms
e) Knowledge of wind field in front of the turbine, for control

Deployment

a) Deployment in forest terrain – challenges: Wakes and turbulences, wind models do not comply with reality that is a problem from a financial perspective. Most of the available sites are in forestry landscape, sometimes in combination with low density of population and weak grid
b) Measurement programme is needed (see also Wind Field Knowledge)
c) Deployment in cold climate areas – challenges: Rime ice forecasting, predict when ice will occur, turbulence and snow covered blades

d) Deployment in deeper water

Financing/insurance

The warranties get shorter (from 5 to 2 years) with less content. This is not considered to be a R&D issue, but was mentioned as an observation.

Portfolio management

Control system for all the wind power plants in the portfolio.

Environmental impacts

Bird (especially eagles) and mammal behaviour have to be studied. Bats may be in the risk zone for damages if not treated properly.

Competence

Hard to find the right competences, better to educate “general engineers” in-house.

Competition on skilled people within the industry, important with education already at university level.

Knowledge transfer network.

International cooperation - establish a common state-of-the-art facility and pooling its R&D spending of wind energy?

New applications

a) Plug-in vehicles (benefits: Energy storage and transportation) - need for demonstration
b) Clean water
a) Hydrogen
b) Wind power plant in combination with hydro power station incl. pumped storage - need for demonstration
c) Combine wind and wave plant suitable for shallow water

Test facilities

“Need for test facilities for onshore and offshore wind energy”

a) Testing large blades, drive trains and new materials to verify models
b) Testing facilities and methods for cold climate are needed

Recycling

Recycling of materials is becoming more important when older turbines are exchanged to newer ones. The “cradle to cradle“ concept has to be developed and implemented.

What’s new compared to 2001

Operating agent Sven-Erik Thor made a comparison of the outcomes of today’s meeting and of the meeting in 2001.

The CO_2-issue is a greater topic today. Wind is underestimated in CO_2-terms when making the primary energy comparison, CO_2-issue as an effect of increasing oil prices.

It was noted that there are new initiatives coming from other organisations which are looking into R&D needs. It is obvious that there are a number of new players in the R&D arena today. Examples of ongoing activities which aims at identifying R&D topics:

Structured initiatives for identifying R&D
- EU/EWEA TPWind
- REOLTEC
- MEGAWIND
- AWEA

Wind power with its application in a broader sense is now discussed. Examples are:
- wind – hydro – pump storage
- plug in hybrids

Education and Knowledge Transfer Networks are now considered to be a crucial topic for the industry and utilities. IEA Task 11 has an important role to play here. In some areas it is difficult to recruit persons with adequate knowledge within some technologies.

Reliability and Operation & Maintenance are becoming more and more important, especially when considering the number of failures that occurs in wind turbines.

Other challenges

Other challenges, (except direct research needs) that the wind industry is facing today, are:

1. Military issues involving radar and radio link issues
2. Commodities price increase; infrastructure is not in place to meet national goals
3. Offshore; cost is increasing instead of going down as expected in the 2001 long-term report
4. Compensation to fishermen; or is offshore wind a recreation area for fish (reef effects)
5. Legal aspects; protection of property offshore

Miscellaneous

It is important to keep track on other technologies and how they develop.

It was suggested that IEA IA Task 11 arranges expert meetings on how to collect statistics from turbines and radar conflicts, respectively.

ANNEX IV

“Long-term research and development needs for wind energy for the time frame 2000 to 2020”

October 2001

LONG-TERM RESEARCH AND DEVELOPMENT NEEDS FOR WIND ENERGY

FOR THE TIME FRAME 2000 to 2020

Ad Hoc Group Report to the Executive Committee

Of the

International Energy Agency Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems

Approved by the IEA R&D Wind Executive Committee, October 2, 2001

The Implementing Agreement

This report on long-term R&D needs for wind energy was produced by the Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems (IEA R&D Wind), which forms part of a programme of international energy technology collaboration which is undertaken under the auspices of the International Energy Agency (IEA).

The IEA is the energy forum for 25 industrialised countries established in 1974. Its mission, as adopted by Energy Ministers of IEA countries in their Shared Goals in 1993, is to create conditions in which the energy sectors of their economies can make the fullest possible contribution to sustainable economic development and the well-being of their people and of the environment. Research, development, and market deployment of new and improved energy technologies and international co-operation, including industry participation and co-operation with non-Member countries, are an essential part of the shared goals.

The IEA R&D Wind Implementing Agreement, begun in 1977, has provided a flexible framework for cost-effective joint research projects and information exchange on wind energy for the past 25 years. Member countries in 2001 were Australia, Austria, Canada, Denmark, European Commission, Finland, Germany, Greece, Italy, Japan, Mexico, the Netherlands, New Zealand, Norway, Spain, Sweden, the United Kingdom, and the United States.

The basis for the IEA R&D Wind collaboration is the national wind energy programs of the Member countries. By participating in IEA R&D Wind, Members exchange information on the planning and execution of national large-scale wind system projects and undertake collaborative R&D projects approved as annexes to the original Implementing Agreement. The activities of national programs and of the collaborative R&D projects, called Tasks, are reported each year in a 200-page Annual Report that is provided to Members for their distribution. Overall control of information exchange and the R&D Tasks performed under Annexes is vested in the Executive Committee (ExCo). The ExCo consists of a Member and an Alternate Member from each Member country that has signed the Implementing Agreement.

Collaborative Research

Each Task is managed by an Operating Agent, usually one of the contracting parties to the IEA R&D Wind agreement. Participants in a Task sign an Annex proposal agreeing to contribute funds to support the work of the Operating Agent and, often, to perform specific tasks in their own laboratories. The technical results of Tasks are shared among participating countries. Each participant receives results from the effort of five to ten participating research organizations—a very good return on investment. In 2001, Members of the IEA R&D Wind Agreement were working on five Tasks. Several additional Tasks are being planned as new areas for cooperative research are identified.

Task XI - Base Technology Information Exchange
Operating Agent: Swedish Defence Research Agency (FOI). Participants conduct Topical Expert Meetings and Joint Actions in specific research areas designated by the IEA R&D Wind ExCo. Participants also prepare documents in the series "Recommended practices for wind turbine testing and evaluation" by assembling an Experts Group for each topic needing recommended practices. For the latest meetings scheduled, visit http://www.vindenergi.foi.se/IEA_Annex_XI/TEM.html.

Task XVI - Wind Turbine Round Robin Test Program
Operating Agent: National Renewable Energy Laboratory - NREL, United States.

Task XVII - Database on Wind Characteristics
Operating Agent: RISØ National Laboratory, Denmark.

Task XVIII - Enhanced Field Rotor Aerodynamics Database
Operating Agent: Netherlands Energy Research Foundation, ECN, the Netherlands.

Task XIX - Wind Energy in Cold Climates
Operating Agent: Technical Research Centre of Finland.

Summary

The dawn of research and development (R&D) for using wind energy to generate electricity was technologically driven. Later, when the technology became more mature, other topics emerged such as those related to noise from wind energy systems, integration of wind generators into utility systems, public attitudes toward wind development, and the impact of wind developments on the environment. The benefits of past R&D in the wind energy sector have been clearly demonstrated by the increasing sizes of turbines and the lower prices per installed production capacity of electricity. Production costs of wind turbines have been reduced by a factor of four from 1981 to1998. Today, wind energy is cost competitive with other forms of electrical generation at locations with a good wind resource. The cost of energy from wind power at such favourable sites can be as low as 0.047 U.S. dollars per kilowatt hour (USD/kWh). The cost of wind energy in 2020 has been projected to be 0.025 USD/kWh. This projection is based on an installed capacity of 80 gigawatts(GW) in 2010 and 1,200 GW by 2020 [1].

Thanks in large part to successful R&D, the wind energy market is in a state of rapid development. The market for wind turbine generators is growing faster than the personal computer industry and almost as quickly as the cellular phone market. In the last three years, a number of growth studies have been presented about wind energy. In a study called Wind Force 10, a scenario has been presented for production of nearly 3,000 terawatt hours (TWh) of electricity from wind by 2020 [1]. This corresponds to around 11% of the expected world consumption of electricity in that year. Under this scenario, the annual investment requirements for achieving this goal would be 3 billion USD in 1999 and 78 billion by 2020. This level of development would increase employment in the wind industry and supplying sector from 82,000 people in 2005 to 180,000 in 2020. The environmental benefit from this scenario would be an annual reduction of CO_2 emissions by 2020 of 1,780 million tonnes.

Research and development has been an essential activity in achieving the cost and performance improvements in wind generation to date. During the last five years, company R&D has put emphasis on developing larger and more effective wind turbine systems utilising knowledge developed from national and international generic R&D programs. Continued R&D is essential to provide the necessary reductions in cost and uncertainty to realise the anticipated level of deployment. Continued R&D will support revolutionary new designs as well as incremental improvements. Researchers will improve understanding of how extreme wind situations, aerodynamics, and electrical generation affect wind turbine design. The challenge is to try to find those evolutionary steps that can be taken to further improve wind turbine technology. For example, in large-scale integration of wind turbines into the electric generation grid, incorporating wind forecasting results and information on grid interaction with other energy sources may eliminate uncertainties that would otherwise inhibit the development of the technology in the deregulated electricity markets.

Arguments for continuing support for long-term research were touched upon at an IEA R&D Wind Topical Expert Meeting in April 2001. One of the conclusions in the resulting report was:

> *"There is a consensus on the view that there still is a need for generic long-term research. The main goal for research is to support the implementation of national/international visions for wind energy in the near and far future. It was the opinion that it is possible to reach this goal for the near future with available knowledge and technology. However, large-scale implementation of wind energy requires a continued cost reduction and an improved acceptability and reliability. In order to achieve a 10 to 20% part of the worldwide energy consumption provided by wind, major steps have to be taken. The technology of turbines, of wind power stations, of grid connection and grid control, the social acceptability and the economy of wind power in a liberalized market, all have to be improved in order to provide a reliable and sustainable contribution to the energy supply. It is for this objective that there is a need for long term R&D. Besides that, there is also a need for a short- to mid-term research that mainly is in the interest of utilities/manufacturing industries and to some extent to society." [2].*

For the mid-term time frame, R&D areas of major importance for the future deployment of wind energy are forecasting techniques, grid integration, public attitudes, and visual impact. R&D to develop forecasting techniques will increase the value of wind energy by allowing electricity production to be forecast from 6 to 48 hours in advance. R&D to facilitate integration of wind generation into the electrical grid and R&D on demand-side management will be essential when large quantities of electricity from wind will need to be transported through a grid. R&D to provide information on public attitudes and visual impact of wind developments will be necessary to incorporate such concerns into the deployment process for new locations for wind energy (especially offshore).

For the long-term time frame, it is of vital importance to perform the R&D necessary to take large and unconventional steps in order to make the wind turbine and its infrastructure interact in close co-operation. Adding intelligence to the complete wind system and allowing it to interact with other energy sources will be essential in areas of large-scale deployment. R&D to improve electrical storage techniques for different time scales (minutes to months) will increase value at penetration levels above 15% to 20%.

There is a need for continued long-term research supported by society in addition to internal product development and research, which is carried out within the industry. These are the R&D priorities this paper recommends in the mid-term and long-term time frame.

1. Introduction

During the first 25 years of modern wind energy deployment, national R&D programs have played an important role in promoting development of wind turbines towards more cost effectiveness and reliability. The technology has been deployed by accompanying demonstration programs in cooperation with industry. Commercial turbine sizes have increased from some hundreds of kilowatts to 2 MW during this period. The interaction between industry and national R&D programs has been important for the development of effective turbines.

1.1 History of R&D

In the middle of 1970, the oil crisis prompted investigations of energy sources that were not based on fossil fuels. At that time, wind energy was considered to be one such energy source that had the possibility to reduce dependency on fossil fuels. The propeller-type, horizontal axis wind turbine was identified as the most promising system for converting the kinetic energy of the wind to electricity.

The efforts to develop effective wind turbines were carried out by two kinds of groups. The first one within governmental programs focused on big, multi-megawatt wind turbines that would be operated by utilities. The second group consisted of activists and entrepreneurs building small turbines, starting at 20 kW. Both groups discovered that designing wind turbines was far more complicated and costly than was expected in the beginning.

The design knowledge base was rudimentary or outdated, and the need for R&D was identified at an early stage. As a result, national R&D programs were initiated in many countries. The early studies conducted in these programs pointed out that existing knowledge in meteorology, electrical machinery, and aeronautical fields could be applied in wind engineering. The wind energy research organisations were, to a large extent, coupled to meteorological and aeronautical research institutes and universities. As time and knowledge developed, the research topics were directed more towards specific questions relevant for wind technology, such as wind modelling, resource assessment, aerodynamics, and structural dynamics. In order to demonstrate the application of the technology, a number of megawatt-size demonstration programs were realised in the beginning of the 1980s. The main objectives were to improve technology and system integration in order to demonstrate feasibility.
Commercial turbines appeared on the market around 1980 and coincided with the boom in market demand for small turbines (50 – 200 kW) in Denmark and California. In spite of the good market conditions, many companies went bankrupt due to technical problems and poor understanding of loads interacting with the wind turbine. The demonstration programs of megawatt-class machines in the United States, Germany, Denmark, and Sweden had problems mainly related to fatigue. These prototype turbines provided useful information of system behaviour that has been applied in later years.

Later in the 1980s, wind turbines became larger (250 – 300 kW). Market demand increased mainly due to subsidies and tax credits. However, an expected lifetime of 20 years was difficult to achieve due to reliability and system integration problems. The technology could not compete economically without support.

In the beginning of the 1990s, wind turbines became larger and were installed in small groups called wind farms. Increasing national R&D programs were promoting the trend towards larger turbines with a standard size around 500 kW. This period's engineering challenges were related to the bigger turbine size and the conditions turbines experienced in wind farms. Problems related to fatigue were reduced due to better understanding of the interaction between loads and structures. The market was turbulent – new companies appeared, smaller companies were purchased, new collaborations were formed.

During the rest of the 1990s, turbine sizes increased. At good wind sites, wind turbines started to become competitive with new traditional fossil fuel and nuclear generation. The number of turbines in each wind farm grew. As a result, the penetration of wind-produced electricity on the grid was high in some areas. This resulted in a need to develop knowledge of power quality and interaction with weak grids. In addition, there was the need to find new locations offshore and in complex

Source	Location	Cumulative installed [GW] Year 2010	Year 2020
European Union White Paper, 1997 [6]	Europe	40	
EWEA, revised goals, 2000 [7]	Europe	60	150
IEA World Energy Outlook, 2000 [8]	Europe	34	67
BTM World Market Update, 2000 [5]	Europe	145	
Wind Force 10, Scenario, 1999 [1]	Europe	181	1,200

Table 1: Projections of installed cumulative capacity, year 2010 and 2020, in gigawatts

terrain where the wind resource was good. Around the world, new developments in standardisation and design codes were supporting market development and international trading.

In 1995, the need for continuing R&D was discussed at a Topical Expert Meeting sponsored by the R&D Wind Implementing Agreement of IEA. Some of the conclusions at that meeting were:

"... we have now reached a stage where the industry should be able to foot a larger share of the R&D bill. Also the fact that the industry has moved from the precompetitive phase into the competitive stage indicates that most of the product and component development should take place within the companies.

However, there was consensus on the view that there is still a need for basic, generic research to be carried out outside the companies and wholly or partly funded by public money, and that this need will continue as long as there is wind energy develoment." [3]

The conclusions at the 1995 meeting are still valid today. During the last five years, company R&D efforts have put emphasis on developing larger and more effective wind turbine systems utilising knowledge developed from national and international generic R&D programs.

1.2 Present and future markets

The Kyoto protocol has called for a decrease in the emission of CO_2 gases. Using wind energy to generate electricity can play a major part in achieving this target. At good wind sites, wind energy is already competitive with new traditional fossil fuel and nuclear generation. During the past five years, wind energy installed capacity has grown at around 30%/yr. At the beginning of 2001, generating capacity of 18.4 GW was installed worldwide (Figure 1). Production during 2000 was 37 TWh.

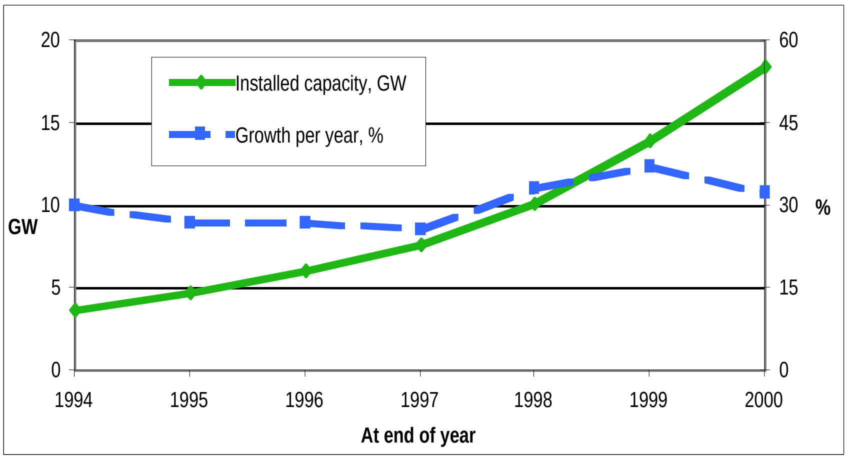


Figure 1: Installed cumulative capacity and growth rates per year [4, 5]

Predictions of global wind energy growth are published by many different organisations. In 1991, the European Union made a prognosis for the end of year 2001 of 4 GW. This was a great underestimate compared to the situation at the end of 1999, when 13.5 GW was already installed. Many other previous studies have shown such underestimations of the growth of wind energy capacity.
In the last three years, a number of growth studies have been presented (Table 1). Four of these are discussed in this paper.

The Wind Force 10 scenario for 2020 corresponds to a production of almost 3,000 TWh which is around 11% of the expected world consumption of electricity in that year. The annual investment requirements for achieving this goal, under this scenario, will be 3 billion USD in 1999, reaching a peak of 78 billion in 2020. This will increase employment in the wind industry and supplying sector from 82,000 people in 2005 to 180,000 in 2020. The environmental benefit from this scenario will be an annual reduction of CO_2 emissions by 2020 of 1.8 million tonnes.

The large spread in predictions for the future (Figure 2) probably result from the fact that wind energy is a relatively young technology. Compare, for example, trying to predict the future of the automobile in 1910 or of the Internet in 1990.

Another way to evaluate the current growth compared to other businesses is found in the Worldwatch Institute book *Vital Signs 2000* [9]. The authors make the following observations.

- The wind turbine industry is now growing faster than the personal computer industry, and almost as quickly as the cellular phone market.

- As of early 2000, eight countries—all in Western Europe—had raised taxes on environmentally harmful activities and used the revenue to pay for cuts in taxes on income.

For the future, Worldwatch stated the following:

"If wind energy achieves its goal of supplying 10% of the world's electricity in 2020, this may only be part of the story. By 2020, wind-derived hydrogen could be fuelling many of the world's cars, factories and even jet airlines."

1.3 Cost reductions

Today's wind turbines are similar in layout and design to the ones produced 10 to 15 years ago. But a number of steps have been taken in order to improve

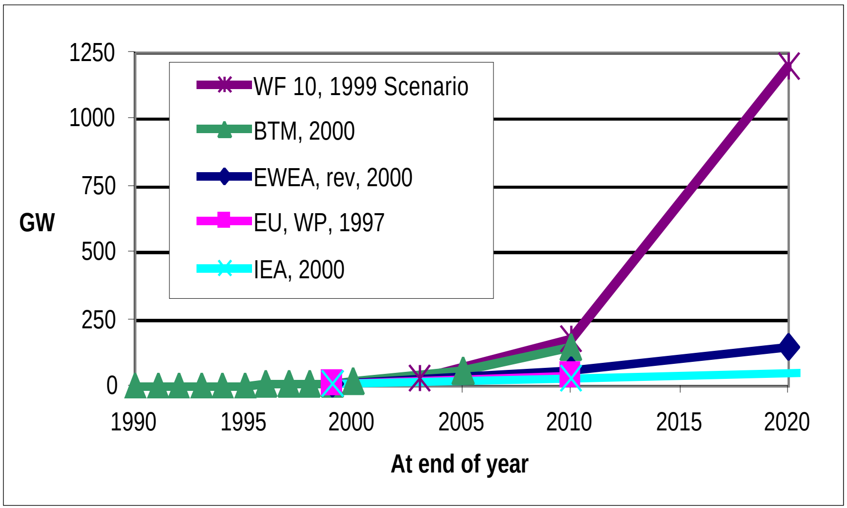


Figure 2: Actual (to end of 2000) and predictions of installed capacity, in gigawatts

the efficiency and to reduce cost. Examples are:

- Larger size
- More efficient use of materials
- Directly driven generators
- Improved system integration
- Flexible structures
- Control advancements

The cost of electricity produced from wind energy has decreased dramatically. Data from wind farms in California show a reduction from 0.45 USD/kWh in the early 1980s to less than 0.10 USD/kWh in the early 1990s [4]. Similar experiences have been reported from Denmark, where the cost has been reduced by a factor of almost four from 1981 to 1998 (1.2 to 0.3 DKK/kW). National research and demonstration programs combined with commercial programs have played an important role in supporting these improvements. Accepted values for the cost level of wind energy in 1999 follow.

Total investment cost:
1,000 USD/kW
Unit price, electricity:
0.047 USD/kWh

Recent studies by BTM in 1998 and 1999 apply learning-curve theory and assumptions and combine historical figures to project future cost reductions. (Figures 3 and 4) [4]. However, the results of the projections must be treated with caution, since they are based on a number of different assumptions and do not account for large technological steps.
The same study estimates sources of future cost reduction on wind power until 2004 (Table 2).

The most important contributor to cost reduction is assumed to be the economy of scale, which stands for half of the relative cost reduction. Contributions from improvements in design and performance are assumed to be 40%. This figure will be dependent on how successfully future R&D can be utilised in new machines.

2. Why continue long-term R&D?

In the first years of R&D (beginning of the 1980s), research institutes and universities produced more knowledge than the industry could handle. Research was mainly aimed at applying existing knowledge to the field of wind energy.

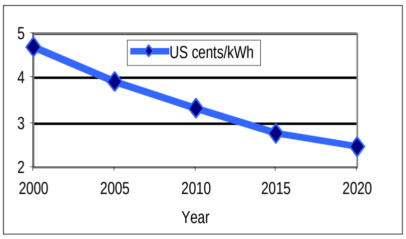


Figure 3: BTM Projected cost of energy [4]

Now, market-driven upscaling and offshore applications produce more uncertainties than the researchers can solve with current knowledge. Future research has to address the specific problems related to this engineering technology. Examples are electricity generation, grid interaction, aerodynamics, and structural dynamics, where specific questions of three-dimensional (3D) flow and large rotating structures have to be addressed.

The argument for supporting long-term research in the future was touched upon at an IEA R&D Wind Topical Expert Meeting in April 2001. One of the conclusions was:

"There is a consensus on the view that there still is a need for generic long-term research. The main goal for research is to support the implementation of national/international visions for wind energy in the near and far future. It was the opinion that it is possible to reach this goal for the near future with available knowledge and technology. However, large-scale implementation of wind energy requires a conti-ued cost reduction and an improved acceptability and reliability.

In order to achieve a 10 to 20% part of the worldwide energy consumption provided by wind, major steps have to be taken. The technology of turbines, of wind power stations, of grid connection and grid control, the social acceptability and the economy of wind power in a liberalized market, all have to be improved in order to provide a reliable and sustainable contribution to the energy supply. It is for this objective that there is a need for long-term R&D. Besides that, there is also a need for a short-to mid-term research that mainly is in the interest of utilities/manufacturing industries and to some extent to society." [2].

In the text below, the following four categorisations are used as reasons for continuing R&D work:

- Increase value and reduce uncertainties
- Continue cost reductions
- Enable large-scale use
- Minimize environmental impacts

In addition, human resource development plays an important part in all the topics above and must also be one of the objectives for supporting R&D work. Skilled people in different disciplines and at varying education levels will play an essential role in the steady growth of the industry and deployment of this energy source.

2.1 Increase value and reduce uncertainties

2.1.1 Forecasting power performance

The value of wind energy will be increased if reliable predictions of power output can be made on different time scales, such as 6 to 48 hours in advance. This requires model development and strategies for online introduction of data from meteorological offices as well as actual production figures from wind turbines in large areas. The present models have an uncertainty of 15% to 20%; an improvement will yield 5% to 10%.

2.1.2 Engineering integrity, improvement and validation of standards

The market-driven upscaling and offshore applications require better understanding of extreme environmental conditions, safety, power performance, and noise.

The development of international standards will be essential for the successful deployment of wind energy in different countries. This work will help remove trade barriers and facilitate free trade. R&D activities in many fields of wind engineering will support background basics for standardisation work.

Source of Cost Reductions	Relative Share (%)
Design improvements — weight reduction of wind turbine generators	35
Improved performance — improvement of conversion efficiency (aerodynamic and electric)	5
Economy of scale/manufacturing optimisation	50
Other contributions: foundations/grid connection/operating & maintenance cost	10

Table 2: Sources of future cost reduction on wind power from 1999-2004 [4]

2.1.3 Storage techniques

Effective storing of electricity could enhance the value and reduce the uncertainty of wind-generated electricity through the levelling out of delivered power. This consideration is especially important when penetration levels rise above 15% to 20%. There is a need for different storage techniques at different time scales (Table 3).

2.2 Continue cost reductions

2.2.1 Improved site assessment and identifying new locations, especially offshore

Sites with high winds are crucial for economic utilisation of wind energy. The fact that energy production is related to mean wind speed to the power of 3 is not sufficiently recognised. This means that a 10% increase in wind speed will result in 33% more energy gained. Improved site assessment and siting will require better models and input from measurements.

Better measures to predict extreme wind, wave and ice situations at different types of locations and in wind farms will eventually result in lighter and more reliable machines. This will make it possible to design site-specific systems that eventually will produce cheaper and more reliable turbines.

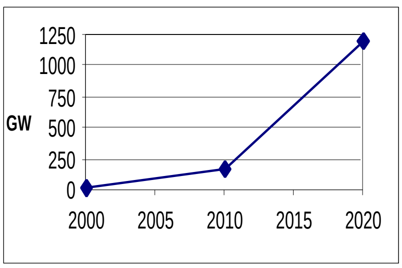


Figure 4: Cost reductions are based on total installed capacities, in gigawatts

2.2.2 Better models for aerodynamics and aeroelasticity

Improved methods for predicting 3D aerodynamic behaviour and aeroelastic stability are essential for calculation of loads on turbines. With the increasing size of turbines, new stability problems can occur. Solving the aeroelastic problems is a prerequisite for reliable upscaling. Incorporation of such models in aeroelastic models of the whole wind turbine is essential for optimised turbines that eventually will have lower weight and thus price.

2.2.3 New intelligent structures/materials and recycling

Wind turbines operating in the wake of another turbine will be exposed to excessive loads due to deficits in wind speed behind the upstream turbine. Reduction of loads through improved design and adding intelligence to single wind turbines in a wind farm will make it possible to optimise the use of land. Intelligent materials utilising adaptive control and interacting with the structure can be used to reduce strains and/or to control aerodynamic forces.

Development of new materials that can be part of a natural recycling process will increase the value and decrease environ-

Time scale	Function	Technology
Minutes	Fault protection	SMES, capacitors
Hours	Backup, smoothing, prediction	Batteries, flywheels, hydrogen
Days	Smoothing, prediction	Regenerative fuel cells, pumped hydro
Weeks	Smoothing, prediction	Regenerative fuel cells, pumped hydro
Months	Smoothing, prediction	Hydro storage, hydrogen storage (e.g., CH_4 creation from coal)

Table 3: Storage techniques for different time scales

mental impact of wind turbines. For example, new ways to decommission glass fibre blades must be developed.

2.2.4 More efficient generators, converters

Finding viable concepts and improving the design of direct-driven generators has great potential to make more efficient and lighter machines. Present generator technology results in large and very heavy machines.

It is also important to find combined solutions for generation and transmission of electricity, from low-voltage alternating current (AC) to high-voltage direct current (DC), while also achieving adaptable power factor (cos phi), and high power quality (low harmonic content and flicker frequency). By adding power plant characteristics to individual wind turbines, it may be possible to reduce the cost for transmission lines. Spinning reserve may also be utilised.

2.2.5 New concepts and specific challenges

Specific challenges include fly-by-wire concepts, adding intelligence to the turbine, and incorporating aspects of reliability and maintainability. Condition monitoring of components such as blade bearings and generators could reduce operations and maintenance costs. This is especially interesting at remote locations on land and offshore.

New concepts could include such things as highly flexible downwind machines and diffuser-augmented turbines.

2.2.6 Stand-alone and hybrid systems

Stand-alone turbines will be built in vast numbers, but the installed total capacity may not be large. However, the value of electricity from these machines can be of great importance, such as in remote locations where grid connection is not feasible.

System integration of wind generators with other power sources such as photovoltaic solar cells (PV) or diesel generating systems is essential in small grids where high reliability is required.

In the mid-term and long-term time frames, research will be needed on the interaction of wind turbine generators with the transmission and distribution grid. Photo: Sven-Erik Thor

2.3 Enable large-scale use

Projections of installed capacity indicate that deployment figures will increase dramatically during the next 20 years. The contribution of wind generation will be substantial on a local and/or national level. This will put special demands on the transmission grid and its interaction with the wind turbine generation units.

2.3.1 Electric load flow control and adaptive loads

Development of tools for modelling and controlling energy supply to the electric grid will be essential to large-scale deployment of wind energy, especially in areas where the share of wind energy is high. Combined technologies for generation and transport of large amounts of electricity will incorporate innovations in automatic load flow controls, adaptive loads and demand side management. Extensive use of high-capacity power electronic devices in national networks for high-voltage DC (HVDC) links will also be required.

There will be a need to study concepts for storage and AC/DC concepts in co-operation with other energy sources.

2.3.2 Better power quality

The ability to correct grid deficiencies, especially in weak grids, must be improved. Examples are voltage drops and flicker. Grid stability will also be a main concern.

2.4 Minimize environmental impacts

Finding suitable places where there is also general acceptance for implementation of wind turbines has become more and more complicated. Conflicting goals for use of the landscape by different interest groups is becoming more pronounced.

2.4.1 Compatible use of land and aesthetic integration

The environmental advantages of wind energy, such as reduced emissions of CO_2 and other greenhouse gases must be conveyed to the public. Public attitudes towards wind energy, as well as the influence from visual impact and interacting use of the landscape by different interest groups, have to be incorporated in the process of deployment.

2.4.2 Noise studies

Understanding of noise generation and transportation over large distances is essential. Challenges offshore are related to the acoustically hard water surface. Initial estimations that wind turbines may emit more noise offshore without disturbing onshore dwellings must be studied. Better knowledge and methods for design and prediction of noise must be validated to actual experiences.

2.4.3 Flora and fauna

Interaction between wind turbines and wildlife must be incorporated in the deployment process. This requires better understanding of background data and the behaviour of different species. This holds for both onshore and offshore application.

3. Conclusions and recommendations

Wind energy is not just a short-term solution to the energy needs of the world. On the contrary, wind energy is an integral and growing part of the energy supply system that will meet energy needs in an environmentally friendly way for the long term. To assure wind energy's contribution, short-, medium-, and long-term technology R&D are needed. Such R&D will increase benefits to society by making best use of its resources. R&D will accelerate the development of this cost-effective technology and promote system integration for various applications. In addition, R&D on the implementation of large-scale wind energy will help balance society's interests by promoting the design and control of energy systems appropriate to the energy market.

In the near-term and mid-term time frames, research will be needed to help find compatible land uses. Photo: Gunnar Britse

The main challenges for R&D efforts are to reduce technical uncertainties related to energy production, durability, and acceptability for future wind energy projects all over the world. R&D should continue development towards reliable and cost-optimised technology with improved power plant characteristics (power regulations, shared responsibility for power system stability, etc.). R&D should develop wind turbine technology for future applications such as large, highly reliable machines for offshore applications in shallow or deep waters; silent, "invisible" machines for distributed installations on land; or simple, easily maintained hybrid systems for smaller, isolated communities. R&D should develop technology that facilitates the integration of this variable energy source into energy systems such as HVDC transmission lines, energy storage technologies, and compensation units (voltage, frequency, power factor, phase imbalance, etc). And finally, R&D should develop methods to forecast electricity production from wind energy systems and to control wind power plants for optimal production and distribution of electricity.

In the mid-term time frame, research to help minimize environmental impacts of wind turbines will be needed.
Photo: Gunnar Britse

Similarly, there are challenges related to implementation uncertainties that can be addressed through R&D. Improved information can facilitate physical planning to optimise land use and minimise negative effects to people and nature. Improved understanding will help develop suitable markets (green certificates, fixed prices or others). R&D results can also help the integration of wind energy systems with distributed generation, which accommodates the varying production from most renewable energy sources through load control, energy storage, or international energy trading and transmission.

The overall aim of future research is to support development of cost-effective wind turbine systems that can be connected to an optimised and efficient grid or be used as non-grid-connected turbines. Future R&D will support incremental improvements in, for example, understanding extreme wind situations and reducing system weight. But, the challenge is to try to find those revolutionary steps that can be taken to further improve wind turbine technology. For example, in large-scale integration of wind generation into the electric grid, incorporating wind forecasting and coordinating grid interaction with other energy sources could speed deployment of wind energy.

In addition to challenges associated with the integration of the technology to produce electricity, wind energy could be used to produce other energy carriers, such as hydrogen. Wind energy technology has traditionally been used in producing electricity and will continue to do so in the future. But innovative concepts in hybrid systems and storage techniques may benefit other sectors of the economy—e.g., in transportation both on land and in the air.

For planning purposes, the time frame for research results to be obtained is divided into three different periods:

1. Short-term, 0–5 years—system development, human resource development, etc.
2. Mid-term, 5–10 years—mix of 1 and 3
3. Long-term, 10–20 years—increasing the value of wind, supporting strategic goals, etc.

In Table 4, the focus is on the last two time frames.

In the mid-term and long-term time frames, research will be needed to develop storage for electricity and to forecast when electricity will be generated. Photo: Gunnar Britse

3.1 Mid-term time frame

The research areas of major importance in the mid-term time frame for the future deployment of wind energy are forecasting techniques, grid integration, public attitudes, and visual impact.
Forecasting techniques will increase the value of wind energy by the fact that production can be forecast, for example 6 to 48 hours in advance. Integration of wind generation into the electrical grid and demand-side management will be essential when large quantities of electricity from wind will be transported in a grid. This is so because most existing grids are not suited for such large. quantities of power. Finding new locations for wind energy will require that public attitudes and visual impact are incorporated in the deployment process.

3.2 Long-term time frame

For the long-term time frame, it is of vital importance to conduct research that leads to large and unconventional steps in order to make the wind turbine and its infrastructure interact in close co-operation. Research that results in adding intelligence to the complete wind system, interacting with other energy sources, will be essential in areas of large deployment. In addition, developing storage techniques for different time scales (minutes to months) can increase value at penetration levels above 15% to 20%.

Research Area	Focus On	Time Frame/ Priority		Present Activity in IEA R&D Wind
		Mid-term	Long-term	
Increase value and reduce uncertainties				
Forecasting power performance	Increase value of electricity	++		Topical Expert Meeting 2000
Reduce uncertainties related to engineering integrity, improvement and validation of standards	Supply background material	++		Topical Expert Meeting 2001
Storage techniques	Storage for different time scales		++	
Continue cost reductions				
Improved site assessment and new locations, especially offshore	Extreme wind and wave situations, forecasting techniques	++		Annex XVII Wind Characteristics
Better models for aerodynamics/aeroelasticity	3D effects, aeroelastic stability	++	++	Annex XI Joint Action on Aero
New intelligent structures/materials and recycling	Extremes, adaptive intelligent structures, recycling		++	Topical Expert Meeting 2002
More efficient generators, converters	Combined solutions for generation and transmission	++	+	Topical Expert Meeting 2001
New concepts and specific challenges	Intelligent solutions for load reduction		+	
Stand alone and hybrid systems	Improved system performance	++		
Enable large-scale use				
Electric load flow control and adaptive loads	Improve models, load flow control, power electronics		++	
Better power quality	Power electronics	++		Recommended Practice
Minimize environmental impacts				
Compatible use of land and aesthetic integration	Information and interaction	++		Topical Expert Meeting 2002
Noise studies	Offshore issues	++		Topical Expert Meeting 2000
Flora and fauna	Background data	++		

++ Denotes high priority + Denotes priority

Table 4: Research priorities in the mid- and long-term time frames

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Photo: Gunnar Britse

Cover Photo: Gunnar Britse

This document presents recommendations of the Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems (R&D Wind) that operates under the auspices of the International Energy Agency (IEA). Work to develop this document began when IEA's Renewable Energy Working Party (REWP) asked the Executive Committees of Implementing Agreements dealing with renewable energy to contribute to a workshop on long-term research needs and to identify R&D issues that cut across implementing agreements.

The members of IEA R&D Wind then proceeded to develop a guideline for the long-term research needed to advance wind energy technology. A first step was to hold a meeting of experts on the subject of long-term R&D needs. Topical Expert Meetings are convened on important research topics several times per year under Annex XI to IEA R&D Wind, Base Technology Information Exchange. After the Experts Meeting, an ad hoc group wrote the first draft of this document, which was then reviewed by all members of IEA R&D Wind. This final version incorporates their valuable comments and has been approved by the Executive Committee of the IEA R&D Wind Implementing Agreement.

The next challenge is to design and carry out research and development projects to address the specific topics outlined in this document. The members of the IEA R&D Wind Implementing Agreement will use this document to identify areas for co-operation to mutual advantage. In addition, it is hoped that other research organizations will find this document useful in setting their own research agendas to advance wind energy technology.

For more information on the work of IEA R&D Wind or an electronic version of this document, visit the following Web sites: www.afm.dtu.dk/wind/iea/
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