Support by:

INNWIND.EU
OVER VIEW OF PROJECT and RECENT RESULTS

Peter Hjuler Jensen
Anand Natarajan
DTU Wind Energy

Background for the project

- The UpWind project completed in Feb 2011 produced many results on the technologies required for the next generation 10-20MW wind turbine.

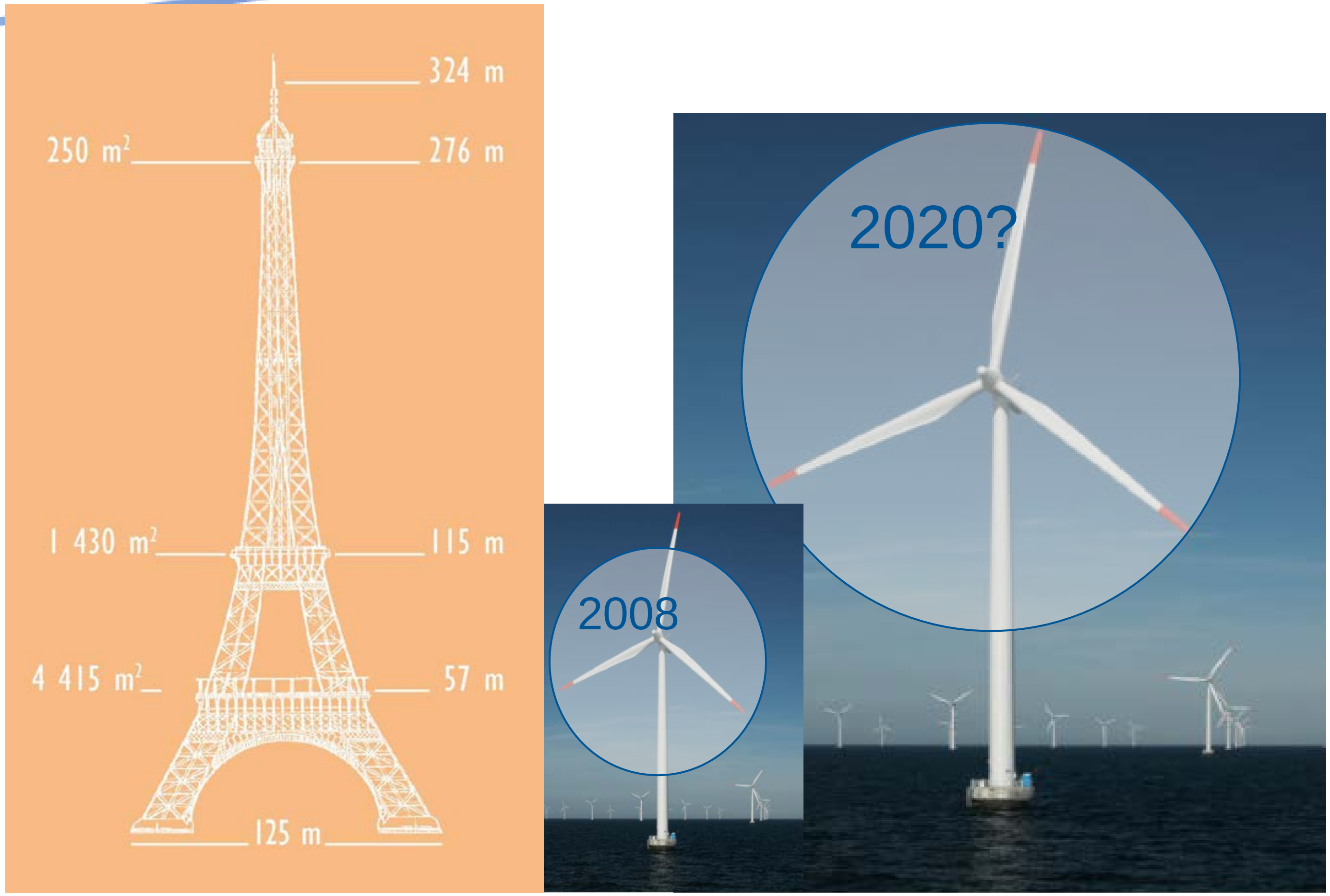
- The UpWind project examined conventional 3 bladed upwind turbines.

- Moving deeper offshore, the need is to design and manufacture large wind turbines that are specifically designed to operate in deeper, farther offshore sites.

- This project INNWIND.EU will use the results from UpWind, but will go beyond the three bladed conventional wind turbine to conceptualize, Prioritize and put forth to the market the best innovations for offshore wind turbines.

Support by:
SEVENTH FRAMEWORK PROGRAMME

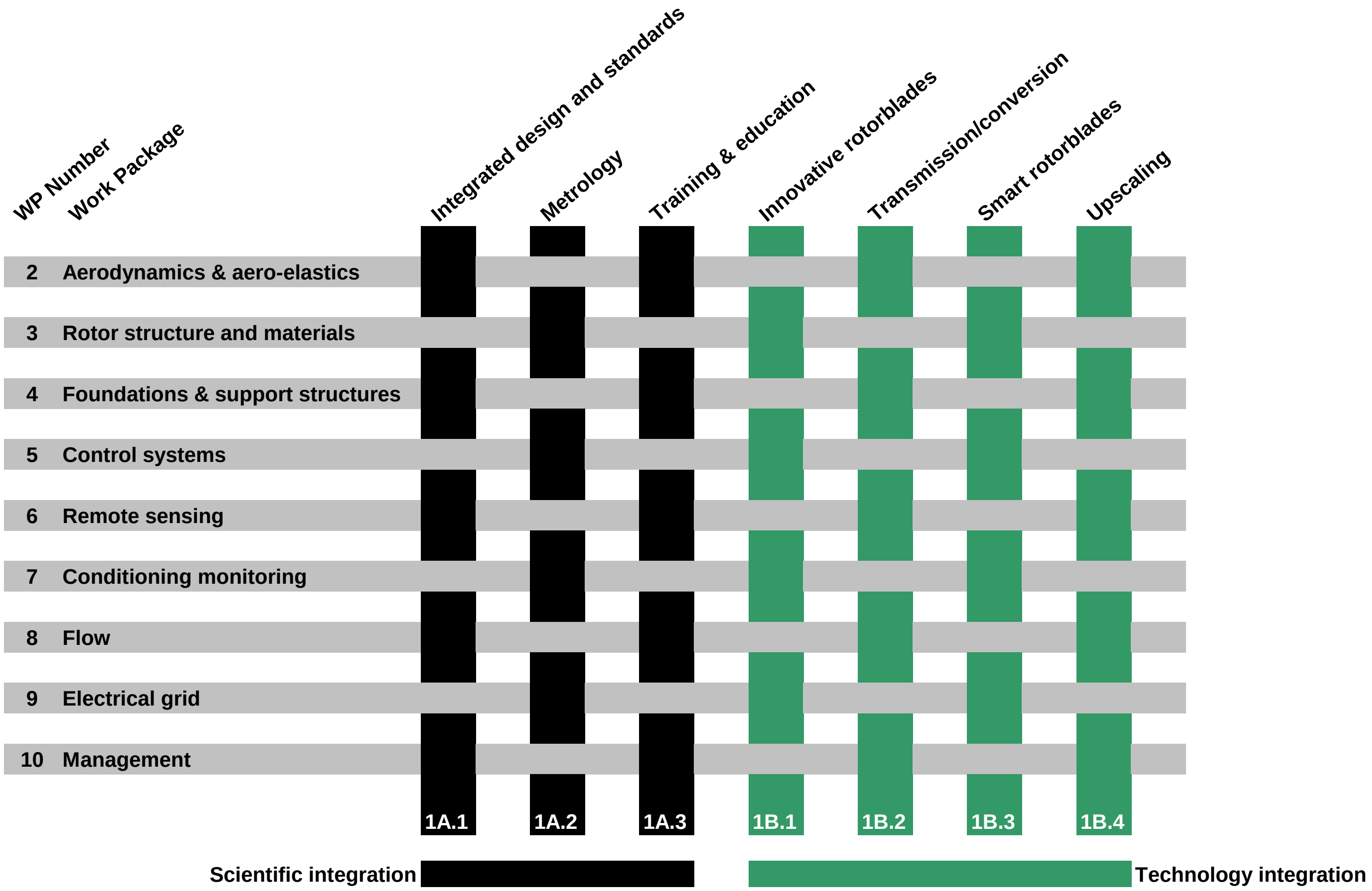
Question 2008: Will upscaling continue?



Support by:
SEVENTH FRAMEWORK PROGRAMME

UpWind organisation Integrated project

with 15 technical and scientific work packages



Support by:

Upwind participants

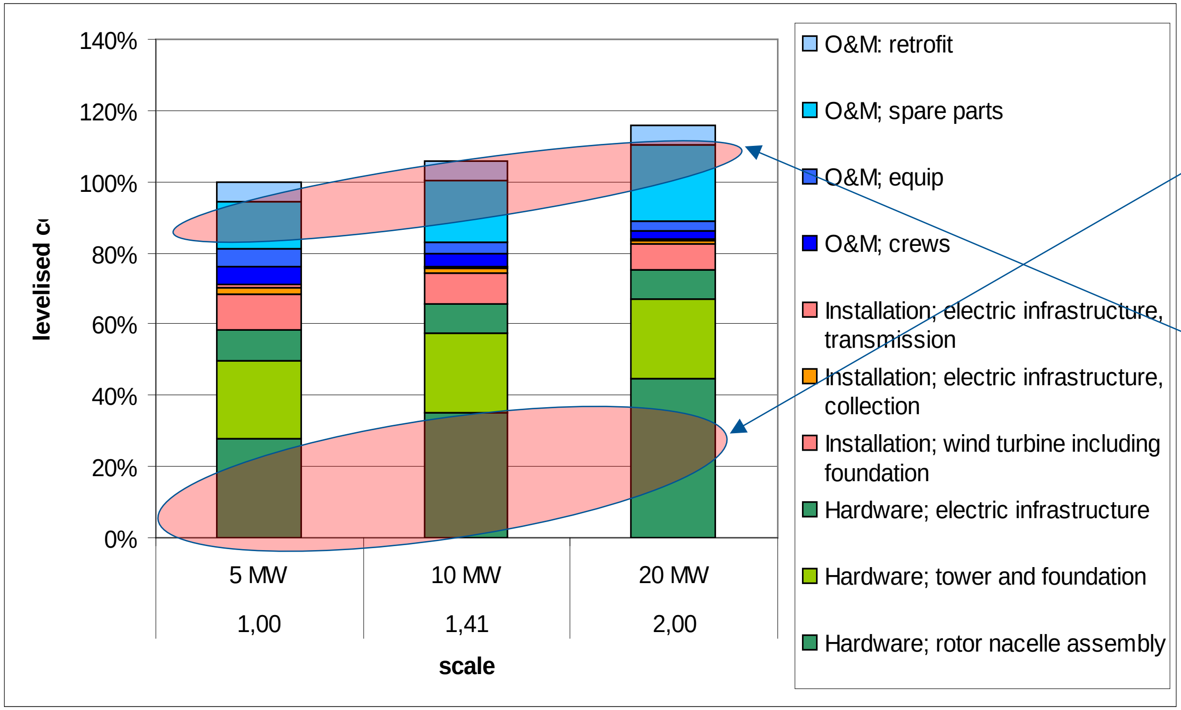
- 39 participants

  - 11 EU countries
  - 10 research institutes
  - 11 universities
  - 7 turbine & component manufacturers
  - 6 consultants & suppliers
  - 2 wind farm developers
  - 2 standardization bureaus
  - 1 branch organisation

Support by:

UpWind:
Overall result from cost functions

Up scaling – levelised cost



- **Levelised cost *increases* with scale**

- **Reasons:**
  - Rotor and nacelle costs scale ~s^3 (?)
  - 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**

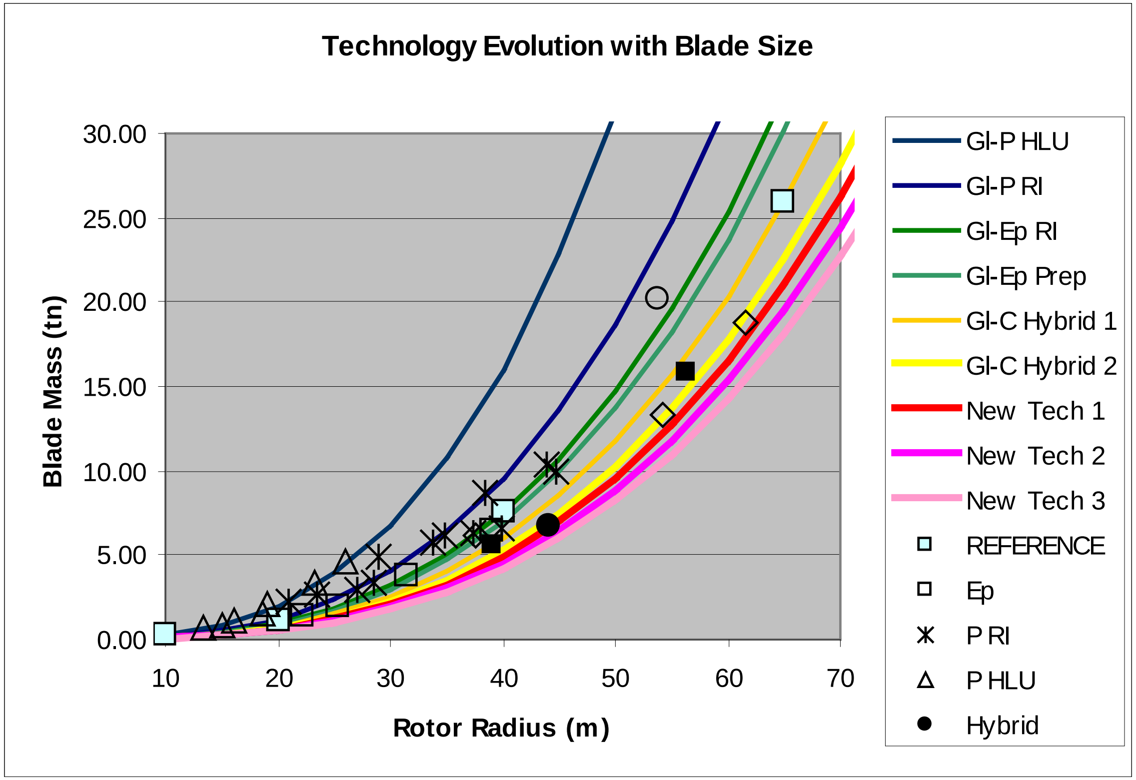
Support by:

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

		PAST						FUTURE		
		GI-P HLU	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	0,86	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	3,05	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	6,02
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	27,89
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	82,18	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

Overall UpWind results:
Case study: Blades – technology evolution with size

Innovations drive cost down in the past



Support by:

INNWIND.EU

an EERA project

Support by:

EERA Project - procedure

- Overall project description
- Coordinator and core group
- Call for expression of interest to all EERA members
- Expression of interest send to core group
- Core group makes project proposal
- Project proposal approved by EERA Wind management

Support by:

Key Objectives

1. Beat the cubic law of weight (and cost) of classical up scaling and render a 10-20 MW offshore design cost-effective.
2. Develop innovative turbine concepts, performance indicators and design targets and assess the performance of components and integrated conceptual designs.
3. Development of new modeling tools capable of analyzing 20MW innovative turbine systems.
4. Integrate the design, manufacturing, installation, operation and decommissioning of support structure and rotor-nacelle assembly in order to optimize the structure and life-cycle as a whole.
5. Establish effective communications channels in the co-ordination of all project activities between the partners and dissemination of the knowledge gained.

Support by:

Proposal Time line 2013

First core group meeting	Jan 24th
Preliminary budget and partner template	Jan 26th
Confirmation from all partners and feedback with deliverables	Feb 07th
Final decision on partners	Feb 10th
First draft of stage 2 proposal	Feb 16th
First meeting with all partners	Feb 21st
Meet with EU consortium Rep	Feb 24th
Second budget revision	Feb 28th
Second draft of proposal	March 5th
Second core group meeting	March 07th
Partners comments on second draft	March 20th
Final budget and proposal	April 01st

Support by:

Guidelines for the Proposal development

- A core group decides in co-ordi**nation with all partners the details of the work packages.**
- **The underlying theme** of the proposal is innovation in design.
- There is no requirement for demonstration of an innovation.
- Entities that wish to demonstrate a component or sub component should do so at their own expense.
- Each partner will commit to deliverables that can be tracked on a yearly basis. It is possible for a deliverable to be shared amongst partners.
- The proposal process must be transparent to all partners.

Support by:
SEVENTH FRAMEWORK PROGRAMME

INNWIND.EU Project Overview and Consortium

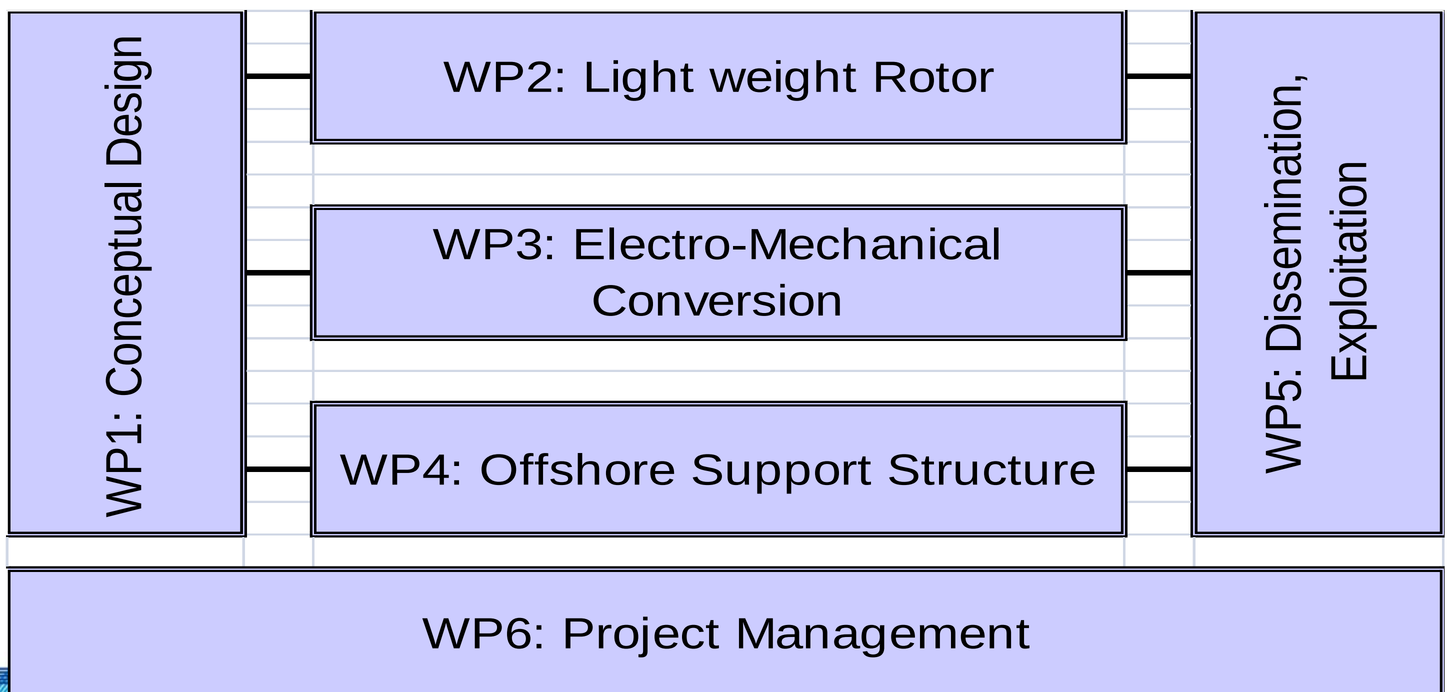
- Innwind.eu started 1. October 2013 – long negotiation period
- 5 year project, 19.6M€ overall budget
- 27 Participating organizations
- 7 Leading wind energy industries, 19 leading Universities/Research organizations, 1 trade institution
- Main Objectives:
  - a light weight rotor having a combination of adaptive characteristics from passive built-in geometrical and structural couplings and active distributed smart sensing and control
  - an innovative, low-weight, direct drive generator
  - a standard mass-produced integrated tower and substructure that simplifies and unifies turbine structural dynamic characteristics at different water depths

Support by:
SEVENTH FRAMEWORK PROGRAMME

Structure of the Project

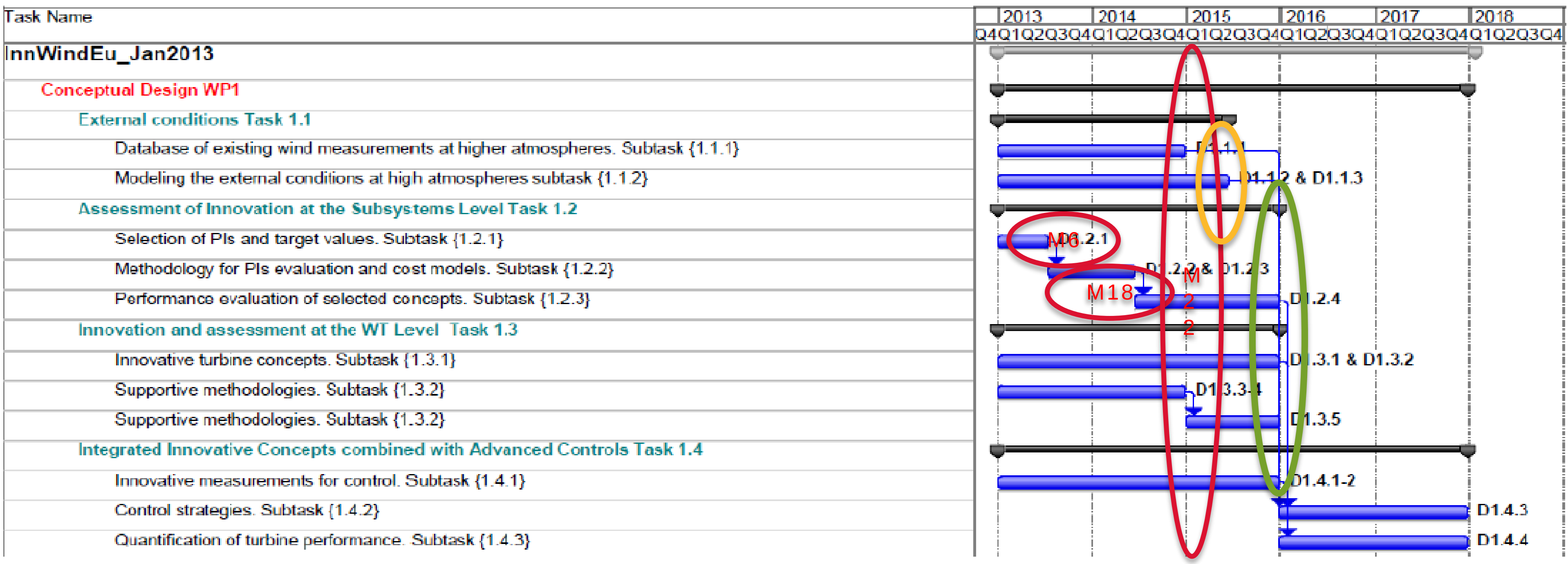
Innovative large offshore wind turbine design

1. **Component level innovations** integrated into the wind turbine, virtually tested and further developed.
2. Demonstrations of Innovations include **super conducting generators, pseudo magnetic drives and smart blades**.



Support by:

Work Package Overview WG1



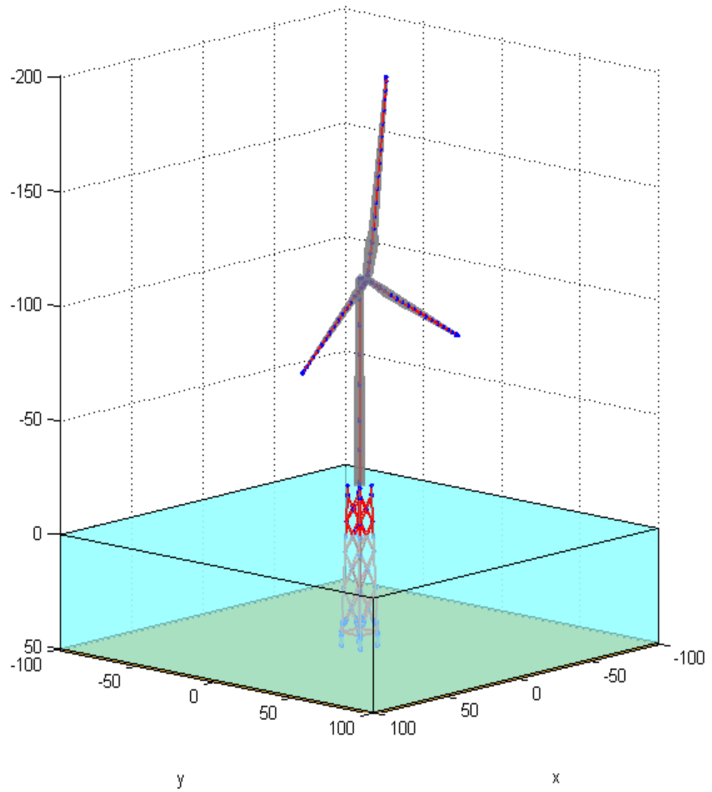
WP1	In Total	Partners														PMs
		AAU	CENER	CRES	DHI	DTU	ECN	FhG	GL-GH	GL-RS	NTUA	OLD	SWE	TUD	UoS	
		18	11,5	29	11	39	15,5	8	15	6	13,5	26	8	42,5	22	265

Support by:

INNWIND Reference Wind Turbine

- The INNWIND Reference wind turbine is a 10MW turbine designed at DTU mounted on a jacket structure designed by Rambøll at 50m water depth.

- 3 Bladed Up wind, Medium speed drive, variable speed pitch controlled turbine



Support by:

Reference Turbine Parameters

Rated Power [MW]	10
Number of blades [-]	3
Rotor Diameter [m]	178,33
Hub Height from m.s.l. [m]	119
Blade Length [m]	86,36
Rated Wind Speed [m/s]	11,5
Design Extreme Thrust Value [kN]	4600
Minimum Rotor Speed [RPM]	6
Rated Rotor Speed [RPM]	9,6
Optimal TSR [-]	7,5
Gear Ratio [-]	50
Blade Mass [tons]	41.7
Hub Mass [tons]	105.5
Nacelle mass [tons]	446
Tower mass [tons]	628.4
Tower Top Mass, RNA [tons]	676.7
Water depth (mean sea level - m.s.l.) [m]	50
Access Platform a.m.s.l. [m]	25
Jacket Mass [Tons]	720
Transition piece mass [Tons]	400

Support by:

WP 1.3 - Innovation & Assessment at WT level

Subtask 1.3.1. Innovative turbine concepts e.g.

- ✓ Designs aimed at a low (reduced) tower top mass, e.g.
  - ➢ Lowered bedplate mass
  - ➢ Two bladed down wind machines
  - ➢ Lowered rated wind speeds
- ✓ Turbines with innovative rotors, e.g.
  - ➢ 2- bladed
  - ➢ High rotor speed (to reduce torque in the drive train)
- ✓ More than 3 bladed (braced) rotors
- ✓ Multi rotor concepts on single support structure.

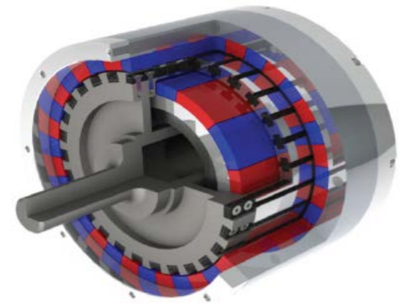
Subtask 1.3.2. Supportive methodologies will be developed like:

- ✓ methodology for support structure design assessment and WT integration (in close cooperation with WP 4, a preliminary design process based on parameterized support structure models will be implemented) and
- ✓ a methodology and tool for integrated system reliability analysis of mechanical, electrical and structural components for innovative wind turbine systems.

Support by:
SEVENTH FRAMEWORK PROGRAMME

New Innovations in the First Year

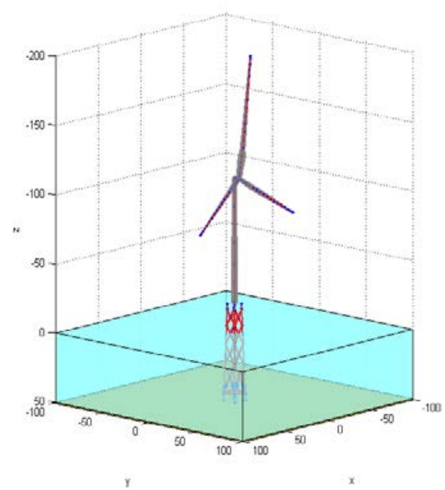
Kingpin Drive – Superconducting Generator in front of the rotor



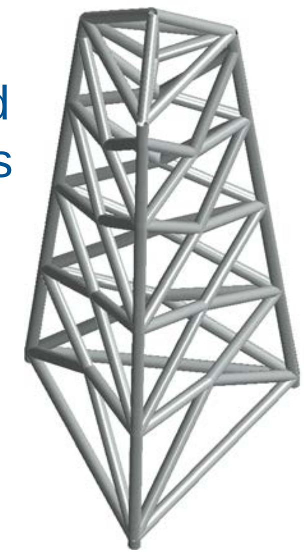
Magnetic Transmission

Passive, fixed ratio gearing

Gurney Flap



Three Legged Jackets



Support by:

Work Package Overview

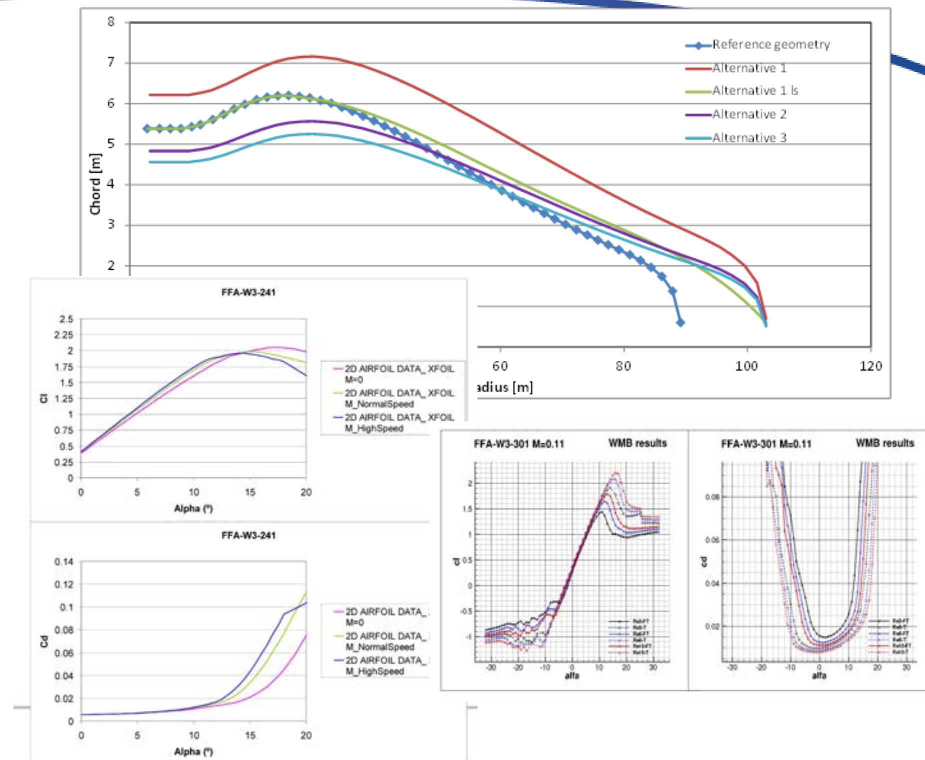
Summary of first year objectives of WG 2:

- To investigate new aerodynamic rotor concepts and
- To benchmark the aerodynamic, aeroelastic and structural design tools that will be used in the project by the different partners for the evaluation of the innovative designs.
- The preliminary investigation of the influence of increased Reynolds number and compressibility effects

Support by:

Summary of first year achievements

- High tip speed low induction rotors
- Targets for dedicated airfoil families
- Downwind rotor concept, tower wake influence, compressibility- and high Reynolds number effects
- Comparison of the 3 bladed 10MW reference rotor to two-bladed



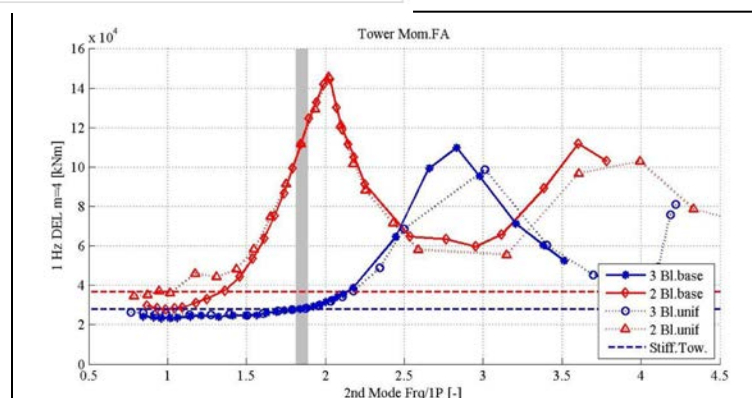
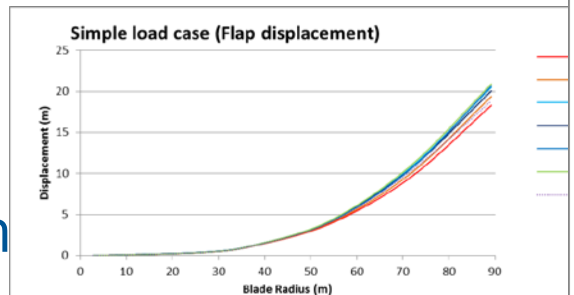


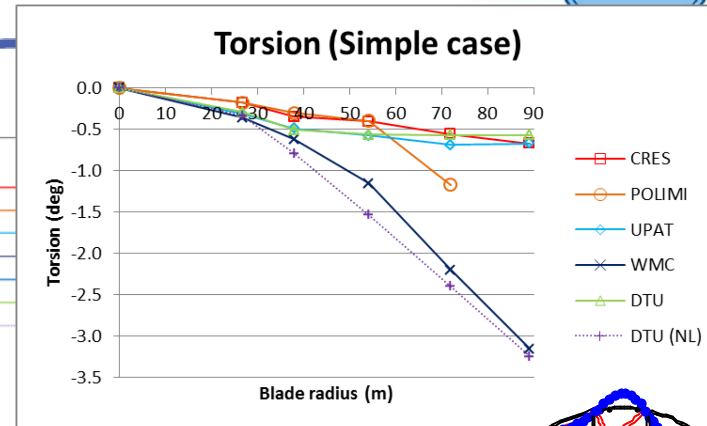
Figure 90: Response on the DEL at the tower bottom from different tower stiffness configurations. The grey shaded area indicates the tower mode frequencies for the reference wind turbine. Simulations at 10 m/s, 1P = 0.14 Hz.

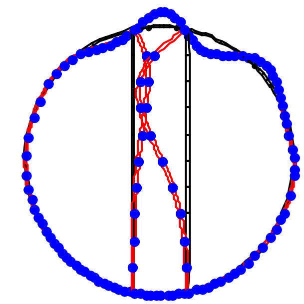
Support by:

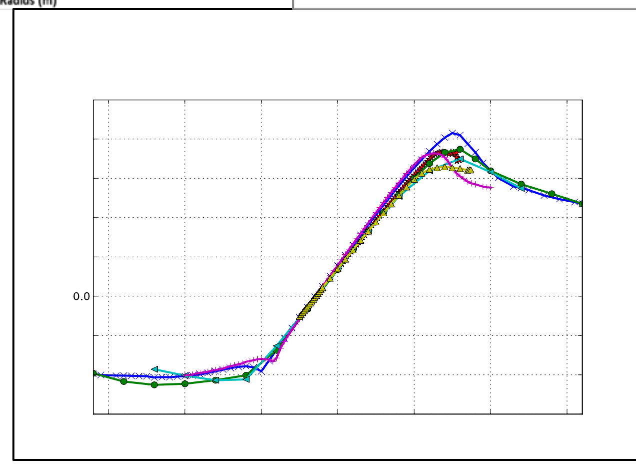
Summary of first year achievements WG 2

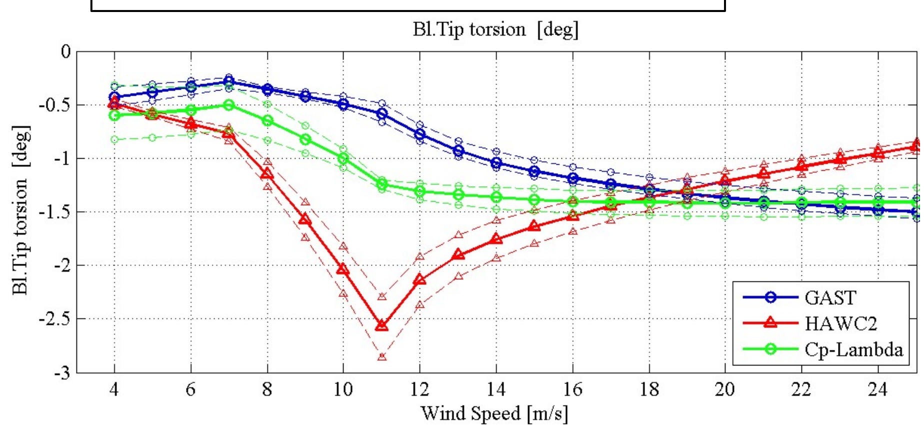
- Structural benchmark, stiffness, strength and buckling.
- 2D and 3D Aerodynamic benchmarking.
- Aero-elastic benchmarking









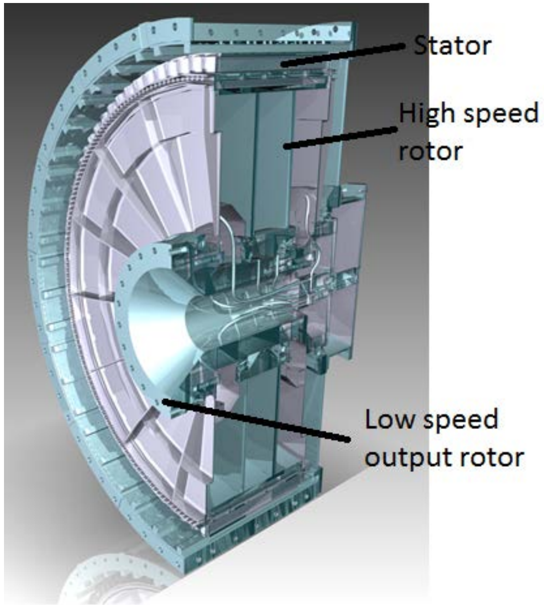


Support by:

SEVENTH FRAMEWORK PROGRAMME

Work Package 3 Objectives

- Investigate innovative wind turbine generator systems (SC and PDD) that have the potential to beat the cubic scaling law
- PI for 10 and 20 MW reference turbine for SC and PDD compared to PMDD
- PI:
  - Size, mass, cost
  - Efficiency
  - Energy yield using Weibul distribution
  - Cost of energy



Support by:
SEVENTH FRAMEWORK PROGRAMME

Tasks & Partners

- **3.1. Superconducting Direct Drive (DTU)**
  1. SCDD models (DTU, TUD)
  2. Industrial demonstration of pole pair: 2G YBCO (Siemens, DTU)
  3. MgB_2 coil demonstration (SINTEF, DTU)
- **3.2. Magnetic Pseudo Direct Drive (Magnomatics)**
  1. Analytical model and optimization of PDD (Sheffield)
  2. Industrial demonstration of PDD (Magnomatics)
- **3.3. Power electronics (AAU)**
  1. PE tailored to SCDD & PDD (AAU, Hanover & StrathClyde)
  2. New components and designs (Hanover, Strathclyde & AAU)
- **3.4. Mechanical integration in nacelle (TUD)**
  1. Nacelle design (Garrad Hassan)
  2. Assessment of SCDD & PDD (TUD)
  3. Mechanical support of SC coils (TUD)

Support by:
SEVENTH FRAMEWORK PROGRAMME

First year objectives and achievements (D3.42)

- Superconducting Generators
  - Overview of performance indicators
  - Model of MgB2 and YBCO
  - Definition of demonstrators (MgB2 coil + YBCO pole pair)
- Pseudo Direct Drive
  - Overview of performance indicators
  - Analytical optimization methods
  - Definition of industrial demonstrator
- Power Electronics
  - Overview of converters suitable for SC and PDD
  - Initial performance indicators (efficiency, THD)
- Mechanical integration
  - Nacelle concept defined

Support by:

Integrated Design of Super Conducting Generator

SC design 311
SC properties
Gen model &
sizing

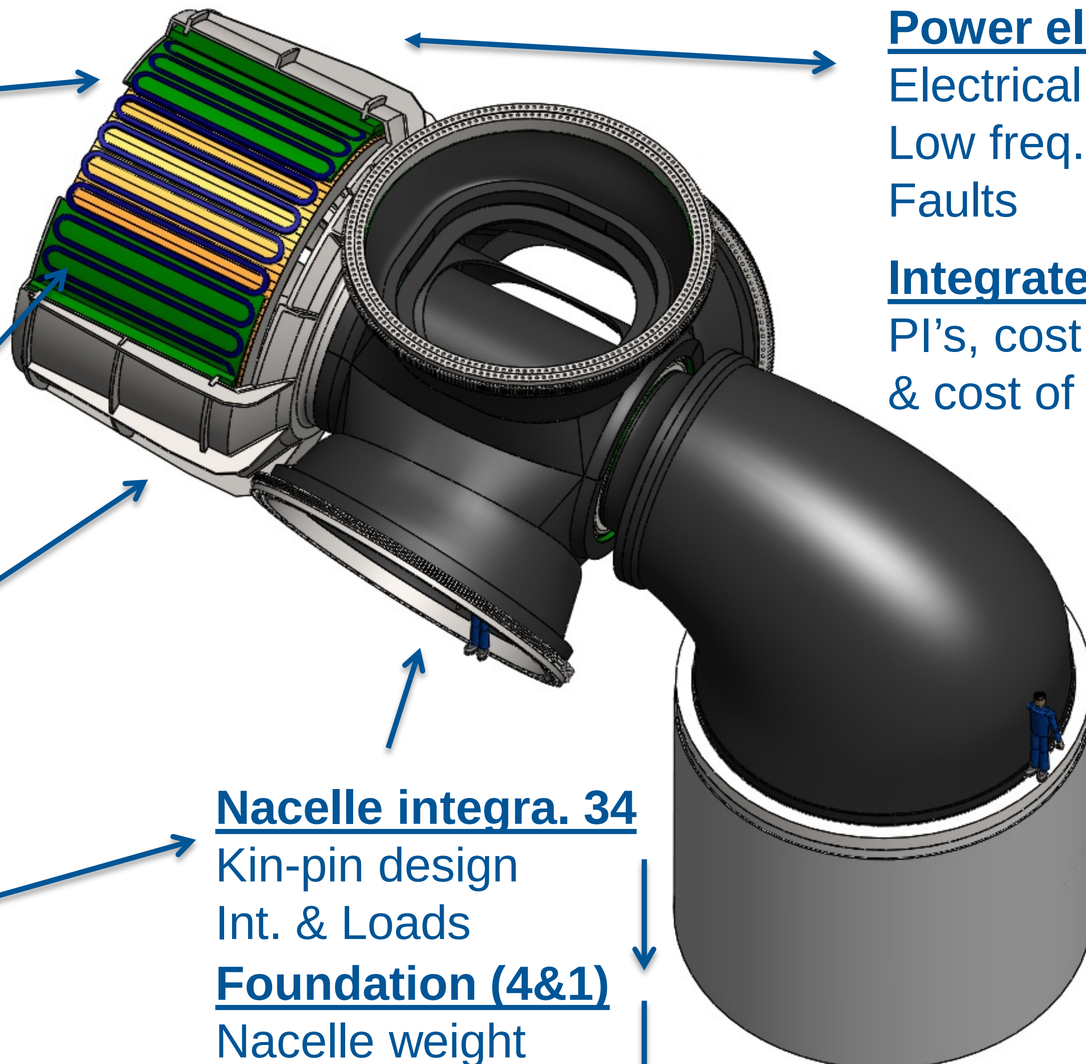
2G demo 312
Demo & PI's

MgB_2 demo 313
Wire & Coil

Ref. Turbine(1)
Speed. + Torque

Wind dist. (1)
Energy prod.

Blade design (2)
Nacelle loads



Power electronics32
Electrical gen. model
Low freq. & segment
Faults

Integrated design(1)
PI's, cost of capacity
& cost of energy

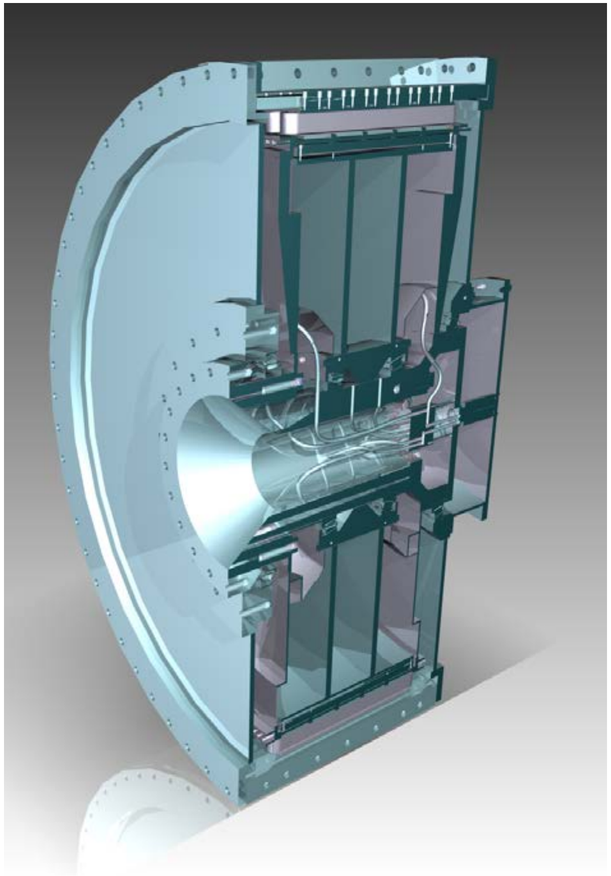
Nacelle integra. 34
Kin-pin design
Int. & Loads

Foundation (4&1)
Nacelle weight
Cost of weight?

Support by:

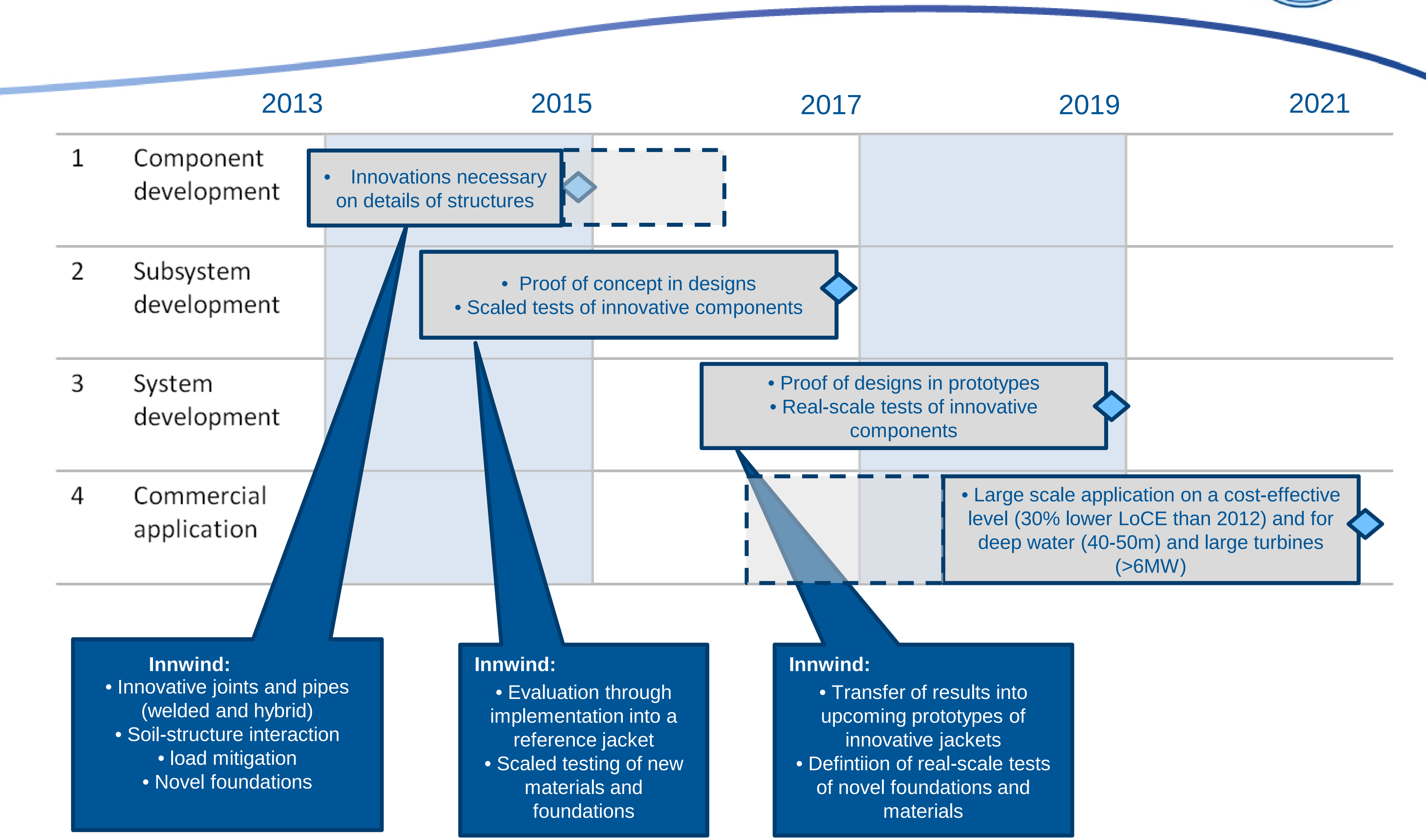
Direct drive trains

10 MW superconducting (DTU)



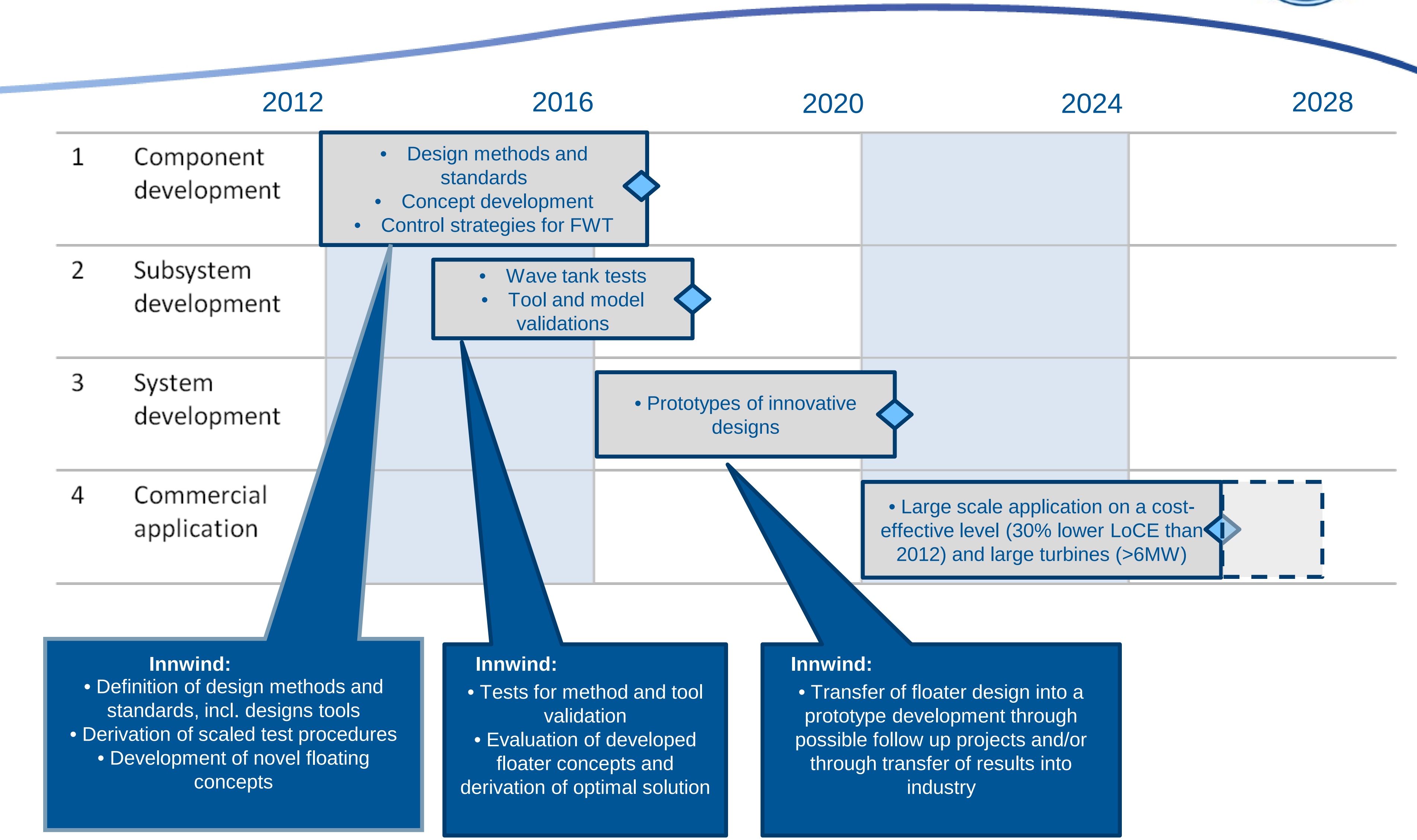
Pseudo direct drive (Magnomatics)

WG 4 TECHNOLOGY ROADMAP
BOTTOM-MOUNTED SUPPORT STRUCTURES



Support by:

WG 2 TECHNOLOGY ROADMAP
FLOATING SUPPORT STRUCTURES



Support by:
SEVENTH FRAMEWORK PROGRAMME

First Project Leaflet

Project overview

The INNWIND.EU project is about innovative wind turbine design

It will:

- Investigate and demonstrate new designs for 10-20 MW offshore wind turbines and their components.
- Develop methodologies for assessing innovative subsystem and turbine system designs.

Introduction

Commercial offshore wind turbines are, currently, predominantly bottom fixed, mainly through monopile, tripod or gravity based sub-structures in waters up to 40 metres deep.

Moving into waters 50 metres deep or more opens huge opportunities for offshore wind power generation and is an important step in meeting Europe's offshore wind energy targets. Ensuring this innovative technology's reliability and cost-effectiveness requires new alternatives to the conventional design of wind turbine components.

A previous EU-funded project, UPWIND (www.upwind.eu), demonstrated that the development of large wind turbines (10 MW) is technically feasible but not yet cost-effective. To develop offshore wind farms in deep waters and further from shore, it is more cost-efficient to install turbines with a high rated capacity, 10 MW or more.

INNWIND.EU will build on the UPWIND project to increase cost-effectiveness of deep offshore wind farms by investigating and demonstrating new technologies.

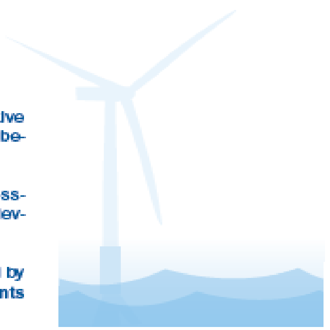
	UPWIND	INNWIND
WIND TURBINES	5 MW reference Wind Turbine (WT) design	10MW reference WT, 10 -20 MW offshore WT designs
	Up-scaling challenges and barriers identified	Investigate innovative concepts for WTs and key component technologies
	New modeling and design tools for large WT	Application of UpWind modeling tools on components and WT
		Explore synergies at component and WT level
COMPONENTS	Modular blades, 1st generation active flow control-test on small scale adaptive blade	Advanced active/passive flow control and new structural concepts. Validation on 2-3 MW adaptive rotor
	Conventional Drive Train optimisation (Radial and transvers flux permanent magnet - RFPM, TFPM)	Superconductive and Magnetic Pseudo Direct Drive Generators validated through prototypes
	Monopile optimisation and jacket concept evaluation for deep sea	Steel and hybrid-type jacket support structures design, floaters design for 10 MW horizontal and vertical axis wind turbines

The project in more detail

INNWIND.EU will investigate and demonstrate innovative designs for large wind turbines of rated capacities between 10 MW and 20 MW and their key components.

The project will also develop methodologies for assessing innovative designs at the turbine and subsystem levels.

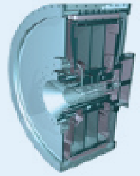
The integrated wind turbine concept will be supported by innovations and demonstrations of the key components of the 20 MW wind turbine:



Lightweight direct drive generators

Superconducting Direct Drive and magnetic Pseudo Direct Drive (PDD) generators can offer high shear stresses and, thereby, more light weight and compact machines compared to conventional direct drive generators. Key performance indicators such as size, weight, efficiency and cost will guide the development of a 10-20 MW offshore turbine by striving for decreasing the cost of energy. Demonstrations of down-scaled superconducting poles and a PDD generator are also part of the project.

Superconducting direct drive generator integrated in front of the turbine rotor using the King-pin nacelle layout (10 MW).



Magnetic Pseudo Direct Drive generator based on an integrated magnetic gearbox and an electrical machine.

Lightweight rotor

with a combination of adaptive characteristics from passive built-in geometrical and structural couplings and active distributed smart sensing and control.

Integrated design

- Innovative sub-structures with modular construction for mass production;
- Advanced controls for load mitigation;
- Water depths of 50 m and beyond.

Standard mass-produced integrated tower and substructure

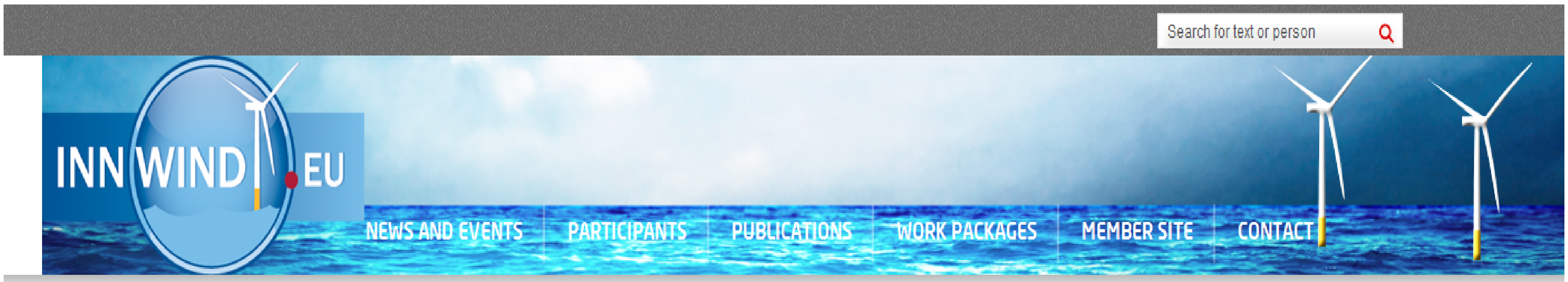
simplifying and unifying turbine structural dynamic characteristics at different water depths.

Support by:

SEVENTH FRAMEWORK PROGRAMME

Project Website

- http://www.innwind.eu



INNOVATIVE WIND CONVERSION SYSTEMS (10-20MW) FOR OFFSHORE APPLICATIONS

The proposed project is an ambitious successor for the UpWind project, where the vision of a 20MW wind turbine was put forth with specific technology advances that are required to make it happen. This project builds on the results from the UpWind project and will further utilize various national projects in different European countries to accelerate the development of innovations that help realize the 20MW wind turbine. DTU is the coordinator of this large project of 5 years duration and with a total of 27 European partners.

The overall objectives of the INNWIND.EU project are the high performance innovative design of a beyond-state-of-the-art 10-20MW offshore wind turbine and hardware demonstrators of some of the critical components.

The progress beyond the state of the art is envisaged as an integrated wind turbine concept with:

- a light weight rotor having a combination of adaptive characteristics from passive built-in geometrical and structural couplings and active distributed smart sensing and control
- an innovative, low-weight, direct drive generator
- a standard mass-produced integrated tower and substructure that simplifies and unifies turbine structural dynamic characteristics at different water depths

Support by:
SEVENTH FRAMEWORK PROGRAMME