University of Stuttgart
Stuttgart Wind Energy (SWE)
@ Institute of Aircraft Design

Offshore Wind Energy, the new conventional green electricity

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University of Stuttgart

09.07.2018

CIRCE, Universidad de Zaragoza

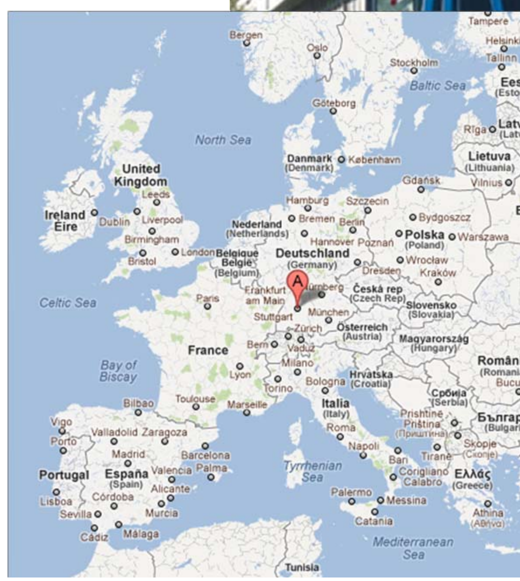
SWE

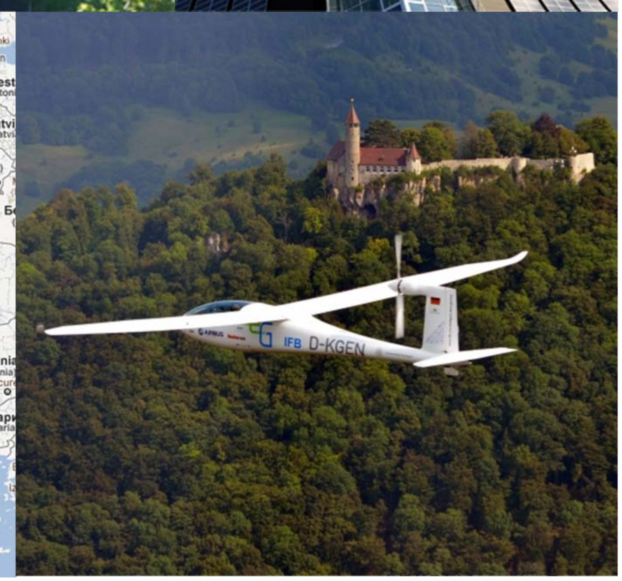
WindForS
Windenergie
Forschungscluster

University of Stuttgart

Universität Stuttgart

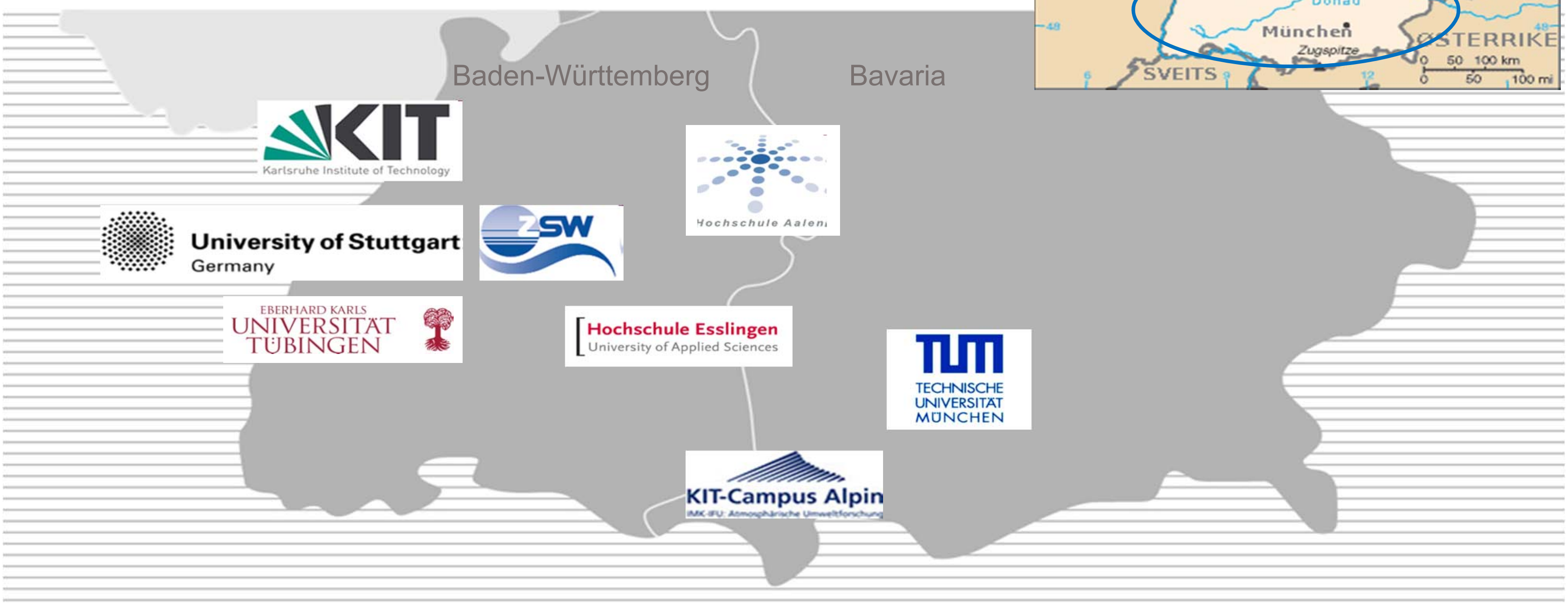
- Founded in 1829
- 23 000 Students , 5 000 Employees
- Focus on:
  - Natural Sciences
  - Engineering
- Engineering:
  - Mechanical
  - Automotive
  - Electrical
  - Aerospace
  - Aeronautical..





What is WindForS?

Windenergie
Forschungscluster
Süddeutschland



Wind Energy Research at University of Stuttgart

Tradition

Ulrich Hütter: pioneer work on wind turbine design and GRP (1950s)

F.X. Wortmann: airfoil design, LWT (IAG)

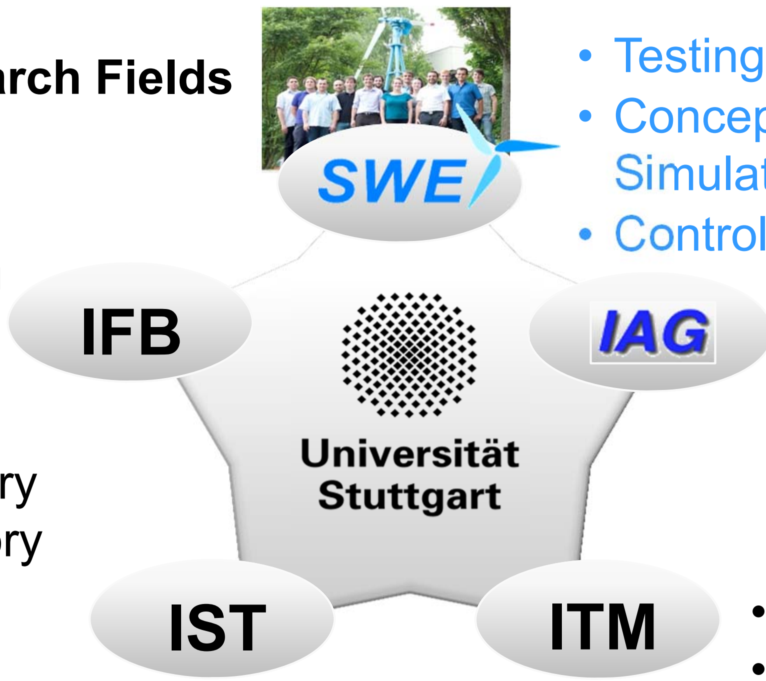
Test site Schnittlingen: UNIWEX (ICA)

Wind Energy (SWE, since 2004)

Current Research Fields

- Automated composite manufacturing techniques
- UAV

- Control Theory
- System Theory
- Applications



- Testing and Measurement
- Conceptual Design and System Simulation
- Control, Optimization and Monitoring

- Aeroelasticity (IAG & SWE)

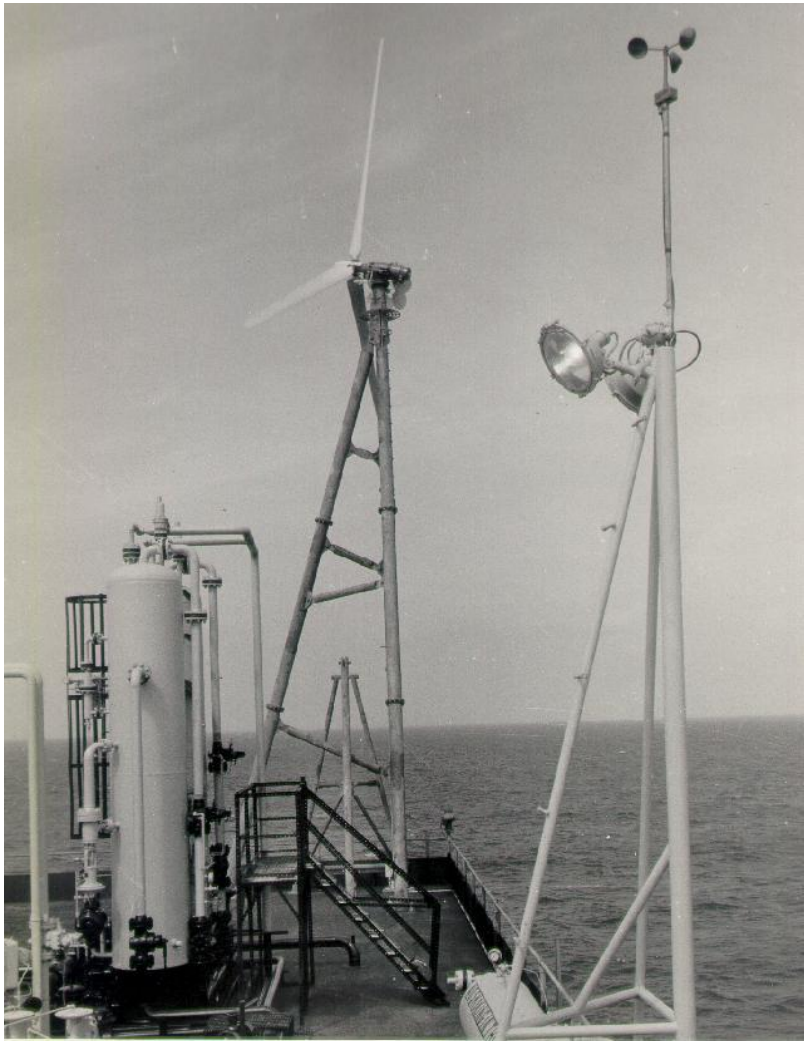
- Aerodynamics and aeroacoustics with CFD
- Airfoil design, wind tunnel tests

- Multibody Dynamics
- Particle simulation

Institute of Aircraft Design

Beginning of the Offshore Wind Energy:

WE-10 Hütter Algaier Wind Turbine in 1958 on an Oil Platform



Wind Energy as Seen by Policy Makers

Where will the installed wind energy capacity be in 2030

- Currently EU has ca.169 GW of installed capacity, 153 GW onshore, 16 GW offshore.
- 15.6 GW were installed in 2017, 12.5 GW onshore and 3.1 GW offshore

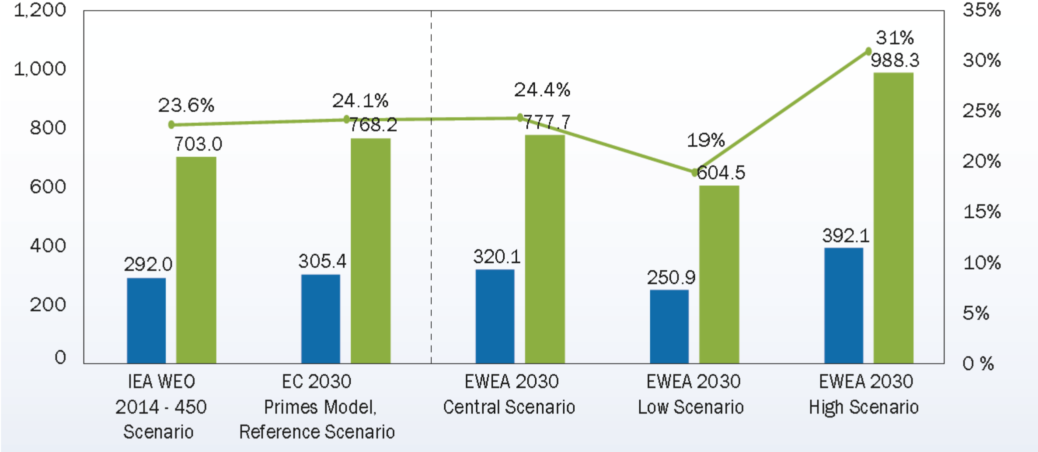


TABLE 1: EWEA 2030 SCENARIOS: CAPACITY INSTALLED, POWER GENERATION AND PERCENTAGE OF EU ELECTRICITY DEMAND MET

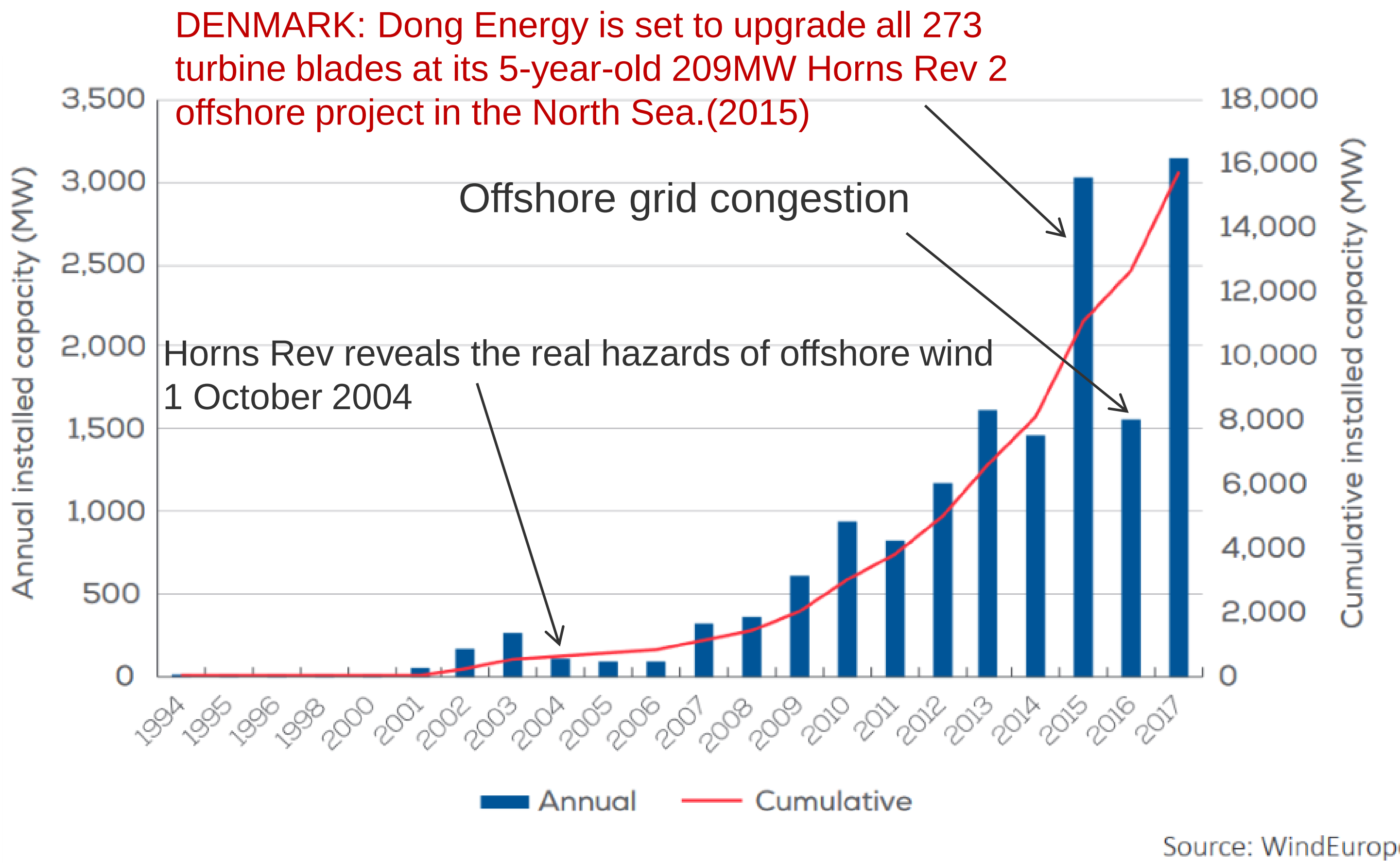
	Installations (GW)			Generation (TWh)			EU electricity demand met by wind energy (%)		
	Onshore	Offshore	Total	Onshore	Offshore	Total	Onshore	Offshore	Total
Low Scenario	206.3	44.6	250.9	440.2	164.2	604.5	13.8%	5.2%	19%
Central Scenario	253.6	66.5	320.1	533.1	244.5	777.7	16.7%	7.7%	24.4%
High Scenario	294.0	98.1	392.1	627.5	360.8	988.3	19.7%	11.3%	31%

Source: EWEA

Development of Offshore Wind Energy

Is the central scenario of EWEA for offshore wind energy realistic?

- 2017 was a record year for Wind, Germany and U.K. accounts for 90% of the 3.1 GW new installed capacity
- Political uncertainty in the biggest offshore wind energy market UK
- Changes to the EEG (2012, 2014, 2016) in Germany
- Unknown technical risks



Current State of Development

Where are we today in term of the market

- Installed capacity currently at ca. 18 GW that is less than 5% of the total installed capacity of wind energy
- Geographically concentrated, U.K Germany, Denmark, Belgium, The Netherlands represents almost 90% of the installed capacity
- Dominated by two suppliers, Siemens and Vestas-MHI

- Currently the levelized cost of energy of offshore wind is still significantly higher than onshore wind
- Significant cost reduction has been achieved. 100€/MWh is achievable before 2020 (Borssele 1 and 2 €72.2 (700MW) and Kriegers Flak 49.9€ (600MW), subsidy free in 2024?
- To sustain cost reduction a market size sufficiently large is necessary to achieve economy of scale, Supportive national policies crucial

Current State of Development

Where are we today in term of technology

- Direct drive versus gear concept (including medium speed concept)
- 6-7 MW is the current size of the wind turbine.
- 7-9 MW installation will accelerate in the next few years
- 10+ MW machine is on the horizon
- Scaling becomes an issue (very low RPM, high tower top mass)
- Tower top mass can be a crucial factor for the foundation design and logistics

- Reliability has improved continuously but is still a issue for all the offshore wind turbines, blade erosions
- Installation and logistics need to keep up with the turbine technology development, cost reduction potential still not exhausted
- Significant cost reduction possible through innovation of service and maintenance

Current State of Development

Where are we today in term of technology

- Size of offshore wind turbine to approach 10 MW. MHI-Vestas,DTU, Sandia.
- Rotor Size is still increasing but the tip speed will become an issue
- Take out the reserve of the wind turbine through better use of the generator reserve (Power boost 9-9.5 MW)
- Alternative concepts still prototype stages (2 blade 2-B Energy, Downwind Hitachi)

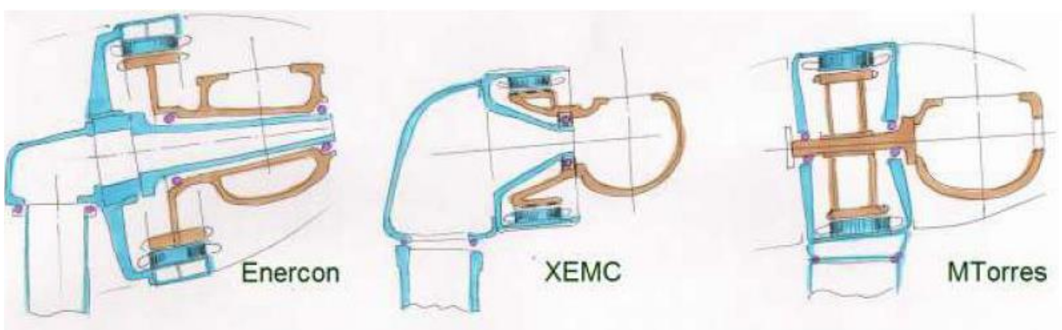
The DTU 10 MW Reference Wind Turbine Design Summary

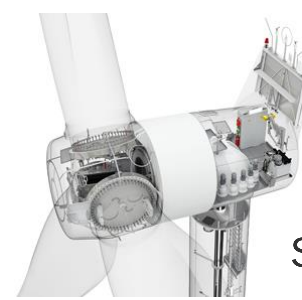
Description	Value
Rating	10MW
Rotor orientation, configuration	Upwind, 3 blades
Control	Variable speed, collective pitch
Drivetrain	Medium speed, Multiple stage gearbox
Rotor, Hub diameter	178.3m, 5.6m
Hub height	119m
Cut-in, Rated, Cut-out wind speed	4m/s, 11.4m/s, 25m/s
Cut-in, Rated rotor speed	6RPM, 9.6RPM
Rated tip speed	90m/s
Overhang, Shaft tilt, Pre-cone	7.07m, 5° , 2.5°
Pre-bend	3m
Rotor mass	229tons (each blade ~41tons)
Nacelle mass	446tons

Comparison of Current Commercial Offshore Wind Turbines

The game on the tower top mass

Turbine	Rotor Diameter (m)	Rated Power (MW)	Tower Top Mass* (t)
Siemens	154	7.0	360**
Vestas-MHI	164	8.0	490
Adwen	180	8.0	550
Senvion	152	6.2	490
GE	150	6.0	480



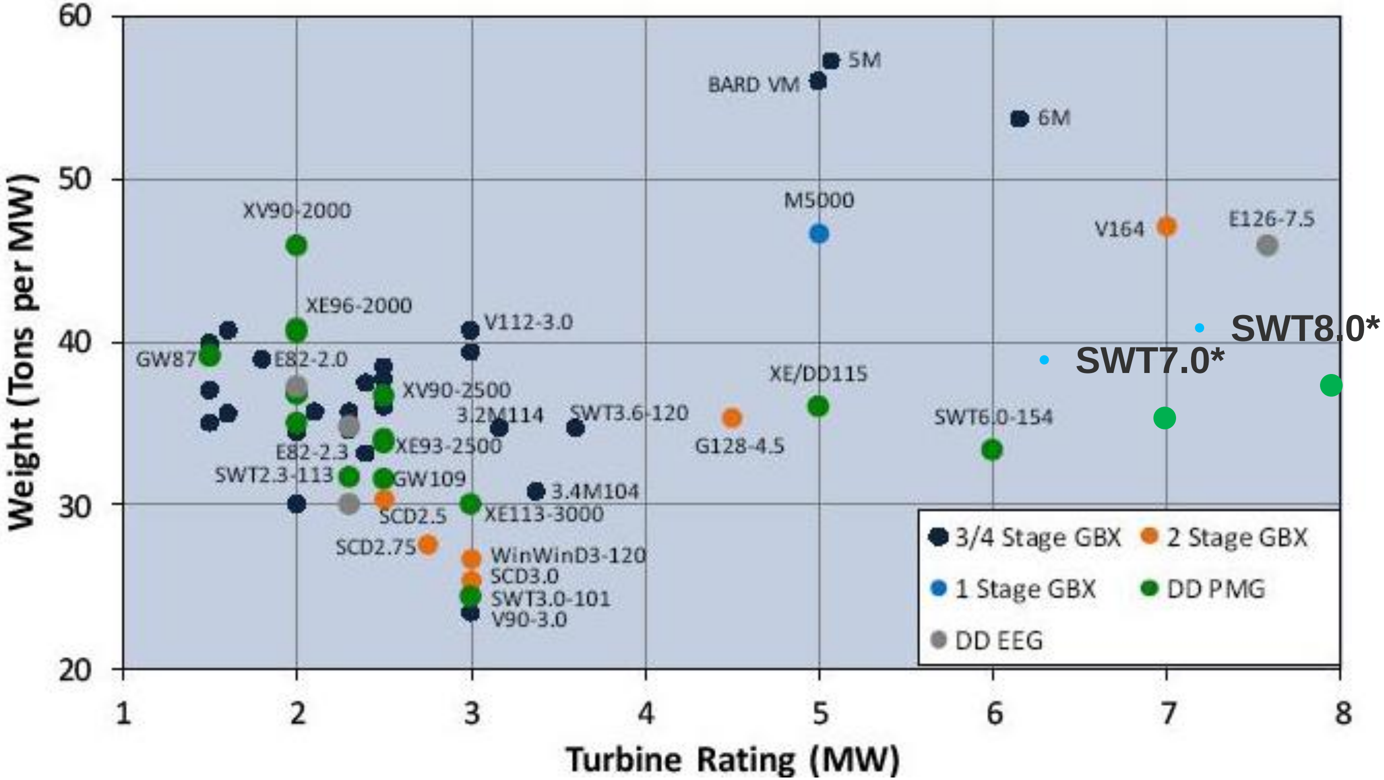


Siemens

Estimated mass
Source: Siemens, Innowind

** Unclear whether it includes rotor

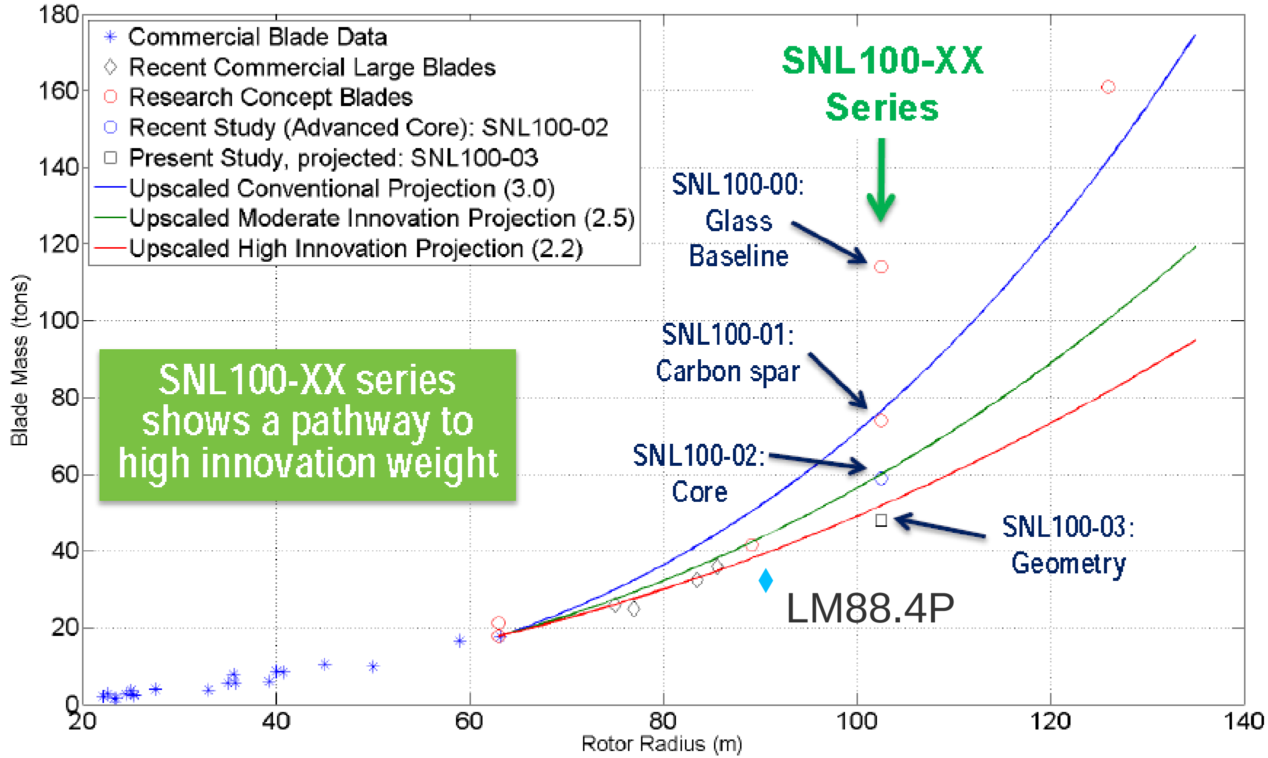
Nacelle Weight per MW



* Estimated weight per MW
Source: MAKE Consulting

Blade Mass versus Rotor Diameter

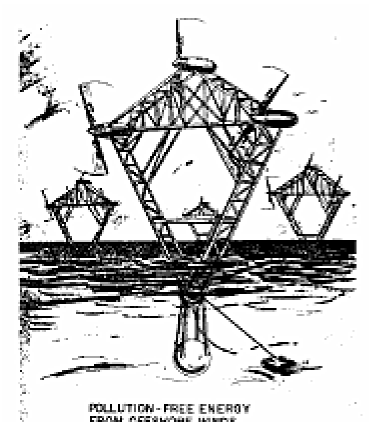
Industry survey of blade mass: Commercial blades (20-60 meters), recent large prototype blades (73-83 meters), and research concept blades (61.5, 86, 100, 123 meters)

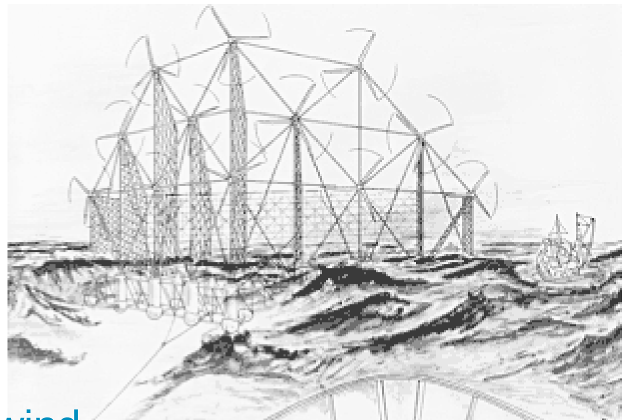


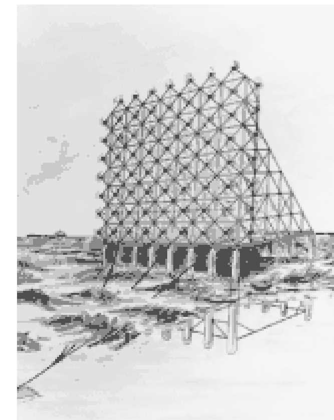
History

When offshore wind energy started

- Historical Design from Bill Heronemus of University of Massachusetts







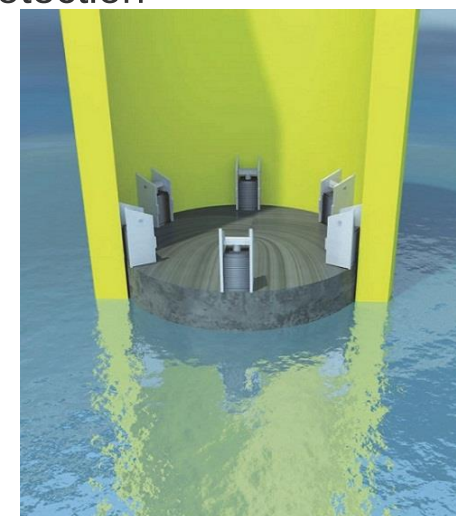
Milestones of offshore wind

Source:Umass, Rechargenews, GE Renewables, Senvion

History

What did we learn from the past

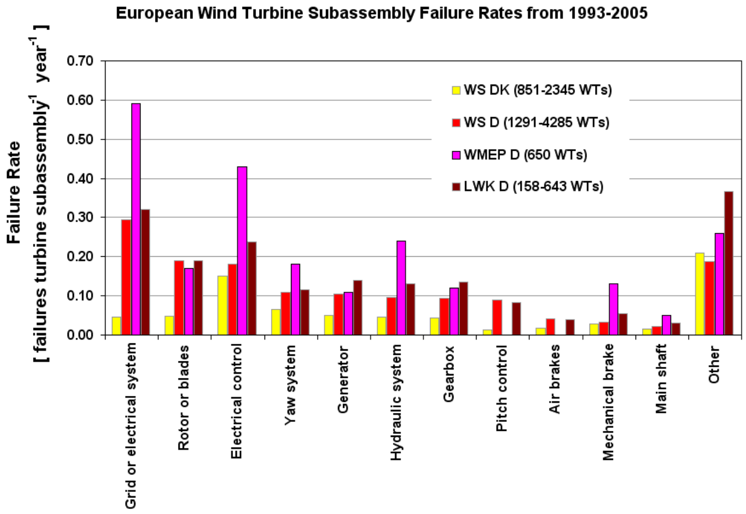
- Corrosion of steel structures
- Manufacturing quality for offshore operating environment, generator, transformer, reliability of gearbox, blade damages
- Monopile-TP grouting, damage of export cables, scour protection



History

What did we learn from the past

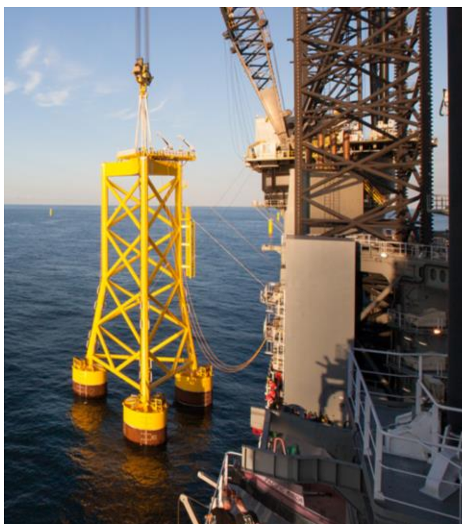
- Reliability Availability Mantanability should be taken into account during design
- Accessibility affects significantly the availability
- Failure probabilities and downtimes are not necessarily correlated
- Monitoring and making sense out of the data to drive preventive maintenance



History

What did the industry learn from the past

- Focus on cost reduction potential both on turbine, installation and BoP
- Innovative foundation design (suction bucket jacket) and installation concepts (vibrohammering of piles)
- Push the limit of the old design XXL monopile (large diameter)
- Reduce offshore activities to a minimum



Source : Dong Energy, EEW special pipes, RWE and CarbonTrust

Future

Where is the offshore wind energy heading to

- Europe
  - ❑Offshore wind will provide a significant part of the electricity production. Europe will lead in term of installation and technology development driven by UK and Germany. Offshore will achieve cost competitiveness sooner than predicted if stable market size, favourable market conditions and supportive policies
- Asia
  - ❑Mainly driven by China, Japan and Taiwan. In China mainly driven by industrial policy to develop offshore wind energy supply chains. In Japan mainly driven by government policy to drive floating wind energy development. In Taiwan driven by government policy to increase the share of offshore wind energy
- Americas
  - ❑Mainly driven by US, very competitive (wind) energy market, potential projects driven by east coast states renewable policy

New Concept- Down Wind + Fixed Foundation or Floating

10 MW Conceptual Study

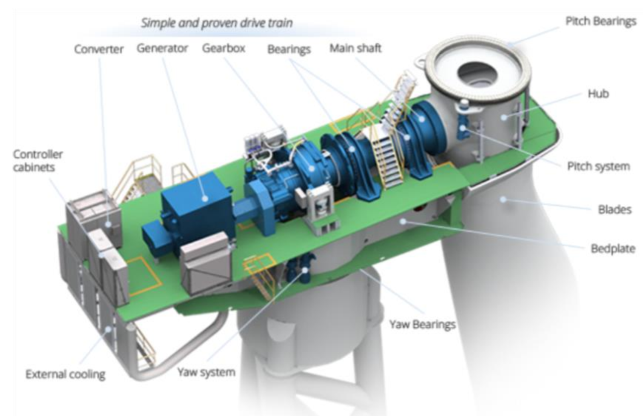
- 10 MW rating, 180 m rotor
- Downwind rotor with rigid hub
- Aggressive downwind coning
- Thick airfoils, advanced structure
- Passive blade load attenuation
- Reduced blade planform area
- PMDD generator
- Twisted jacket substructure
- 500 MW wind plant

- 5.2 MW
- 136 Meter Rotor Diameter

Source: Sandia National Laboratories, NREL, Hitachi

New Concept- Down Wind + 2 Blades

- 2-B Energy 6
- 6 MW rated power
- 140 meter rotor diameter
- Down wind rotor
- 3 stage gearbox
- DFIG and partial power conversion
- Intergarted jacket+ tower

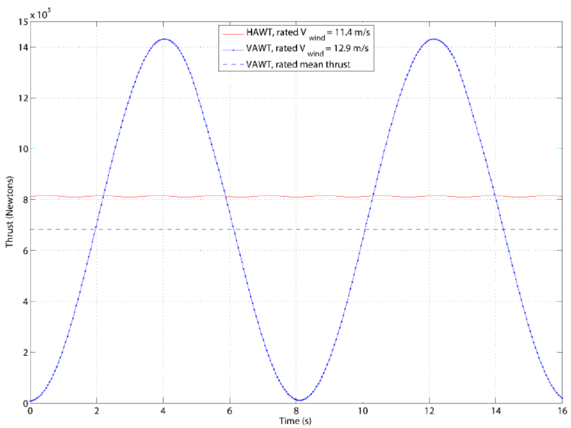


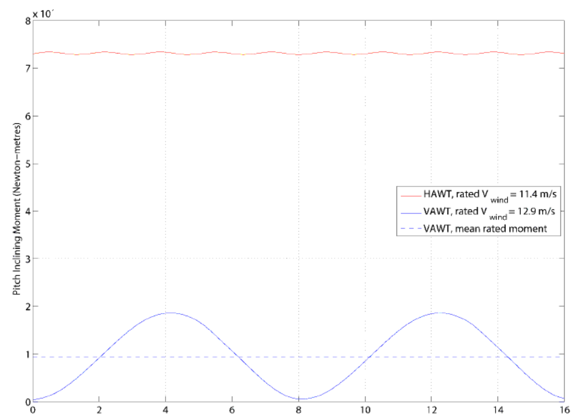
Source: Groningerkrant, 2-B Energy

Vertical Axis versus Horizontal Axis

A Possible Comeback in Floating Offshore Wind?







- Complex dynamics and Instability
- Fluctuating aerodynamic thrust
- Non standardized components
- Emergency stops
- Lower center of gravity
- Easy access of machinery and electrical components
- Simplified installation

Source: Borg-DTU, NREL, INFLOW

Future

Innovative concepts for offshore wind turbines?

- Scaling rules will make it increasingly difficult to build a larger and larger rotors. The 8MW has rotor speed ranging from 4.8 rpm to 12.1 rpm
- Multi-rotor concept is not new, but is probably not the answer. Vibration and control issues are pre-programmed. Wake induced vibrations already can be observed in current offshore wind turbines
- Direct drive may win the race of larger offshore wind turbines through new generator concepts and new materials to keep the tower top weight down
- Vertical axis wind turbine is unlikely to return for offshore wind energy
- Modularity and exchangeability of components are keys to drive down the costs
- Incremental innovation rather than disruptive innovation

Source: Vestas Wind System

Long History of Multi-Rotor Concepts

Dynamics and Control is a Big Challenge

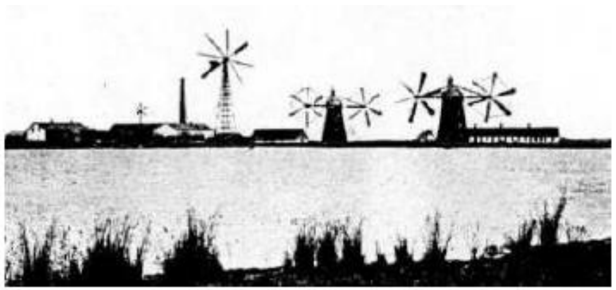


Fig. 2.2: A multi rotor wind mill installed in Denmark in 1873

- Due to asymmetry of the flow the loading on the rotors are not equal which cause load fluctuations on the structure
- Control of the blade pitching can add additional dynamic excitation to the tower
- Flow interference between the rotors

Hermann Honnef

Source: Heiner Dörner

Future

How will the offshore wind energy technology develop

- Incremental innovation in wind turbine technology, size will continue to increas (uprating)
- Focus shifts from wind turbine to wind farm control, increase power output (active wake control), optimize power output and life time
- Grid Integration and energy storage- Power to X

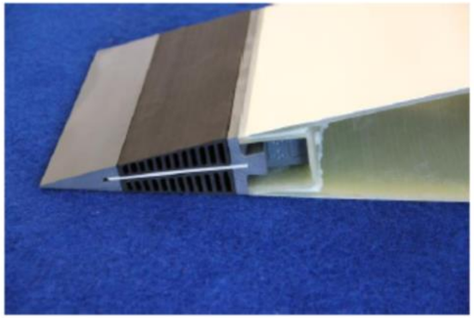
Source: Dong Energy

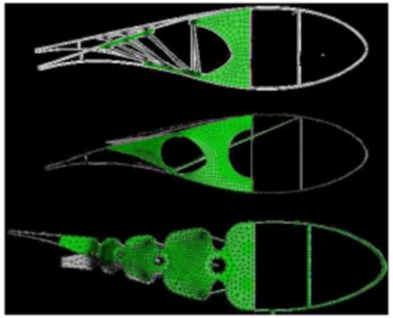
Future: Passive versus Active Blade

Load Reduction and Optimization

Figure 2-1: Test rig at DTU test field with blade section 2.2m spanwise length and 1m chord

- Load reduction through active blade control – flaps, shapes
- Potential reliability Issues with active elements
- Increase performance through better control of the local aerodynamics
- Reduce noise



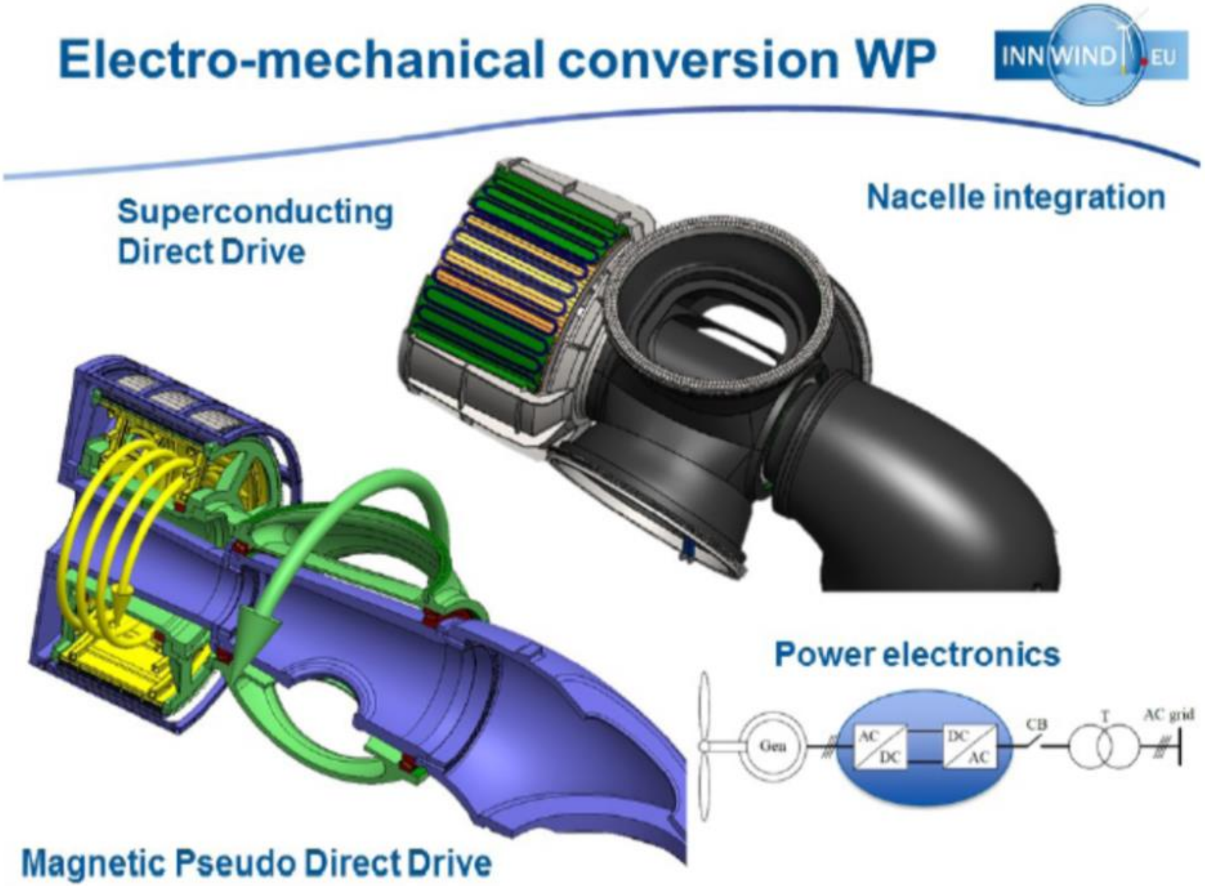


- Passive control
- Bend-twist coupling
- Aeroelastic tailoring
- Passive control elements integrated in the blade

Source: Innwind

Future: New Generator Concept

Further Reduction of the Tower Top Mass and Turbine Size Increase



In order to increase the turbine size beyond 10 MW, light weight generator concept with high torque density will be needed.

Very large offshore wind turbine will be most likey direct drive due to the very large torque and low RPM which will result in very large gearbox

Future Lidar for Wind Turbine Control

Load Reduction and Power Performance Increase

University of Stuttgart (SWE) LIDAR - CART2

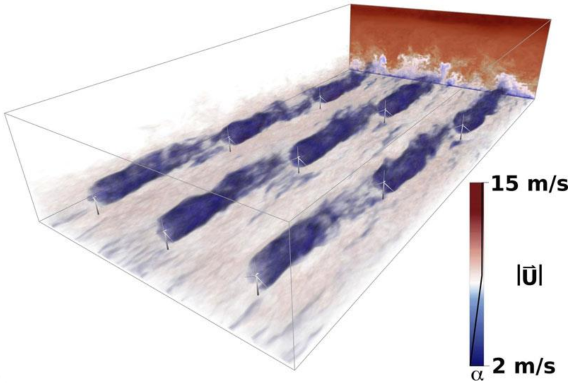
- Proof of concept feed-forward collective pitch control
- Two campaigns:
  - CART3: commercial pulsed LIDAR
  - CART2: SWE-Scanner LIDAR.
- Control objective: reduction of rotor speed variations in above-rated operation.

Blue Scout Technologies LIDAR – CART3

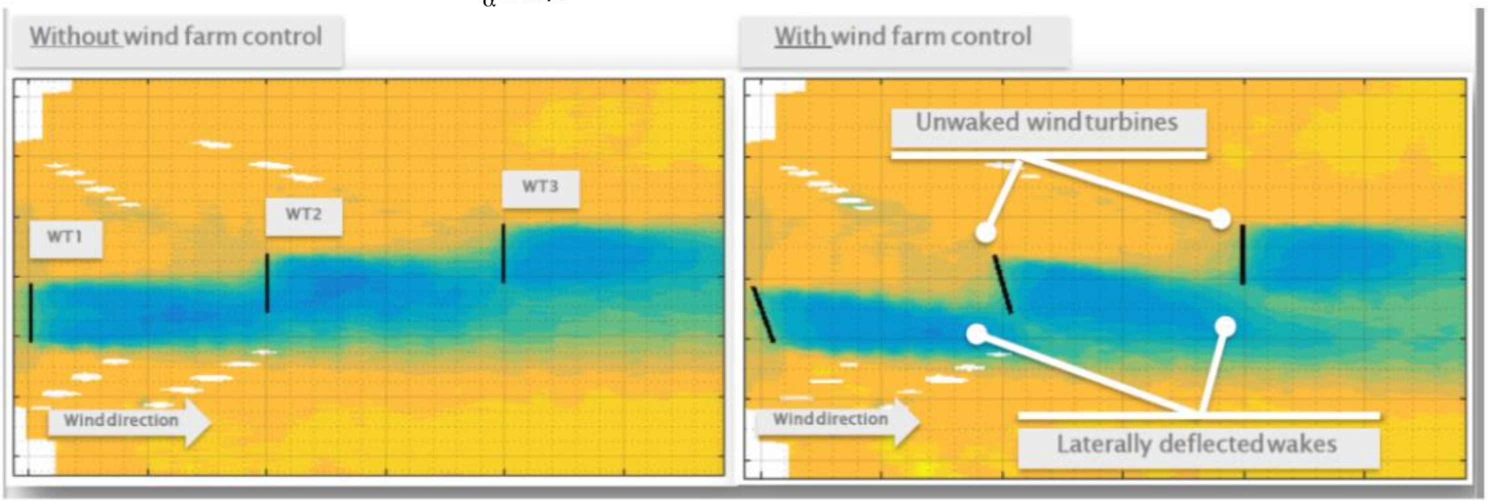
Source: NREL

Wind Farm Control

Increase Power Output of the Wind Farm through Wake Steering



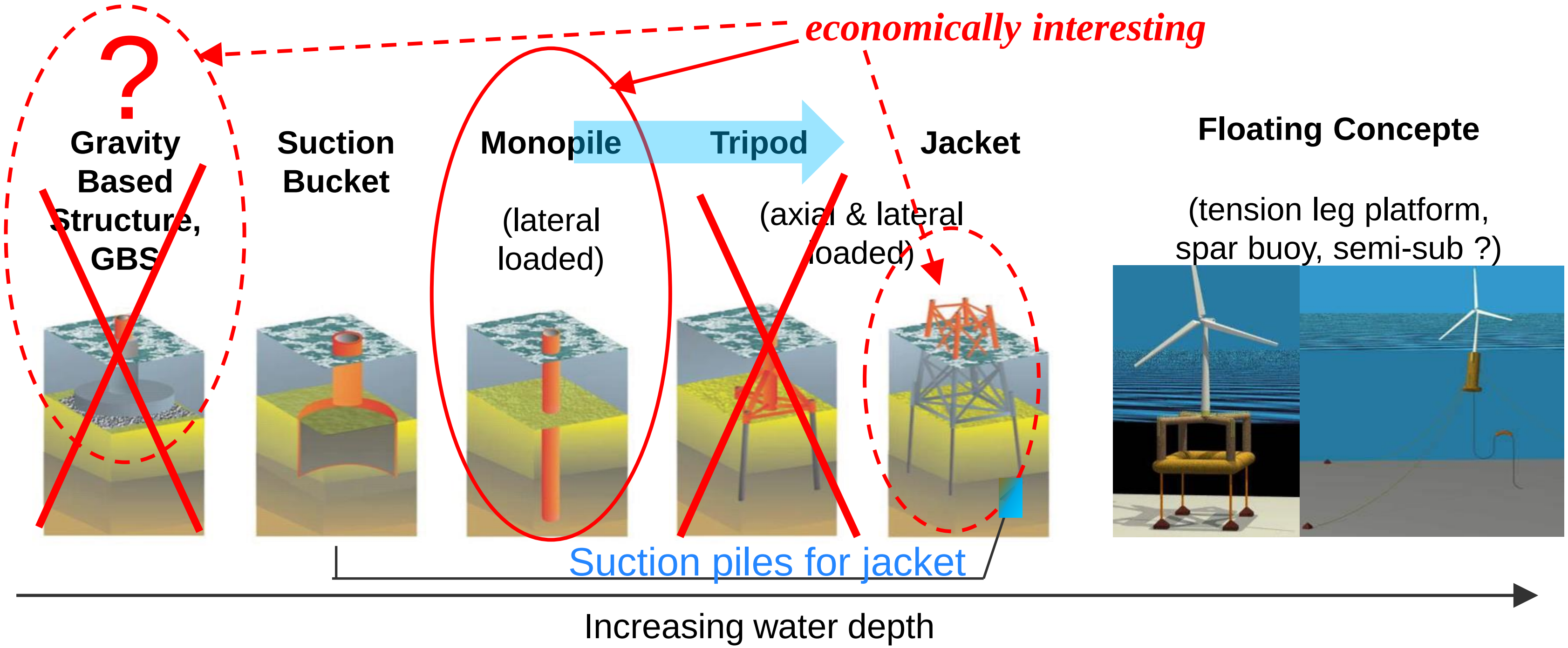
- It is possible to increase the power output of the wind farm by steering the wake so that it will not affect the subsequent wind turbine. Lidar feedback can be used to improve the control in order to make sure that the wake is not affecting the wind turbines negatively by increasing the loads



Source: NREL, TUM

Offshore Foundation Types

Concept Convergence and Incremental Improvement

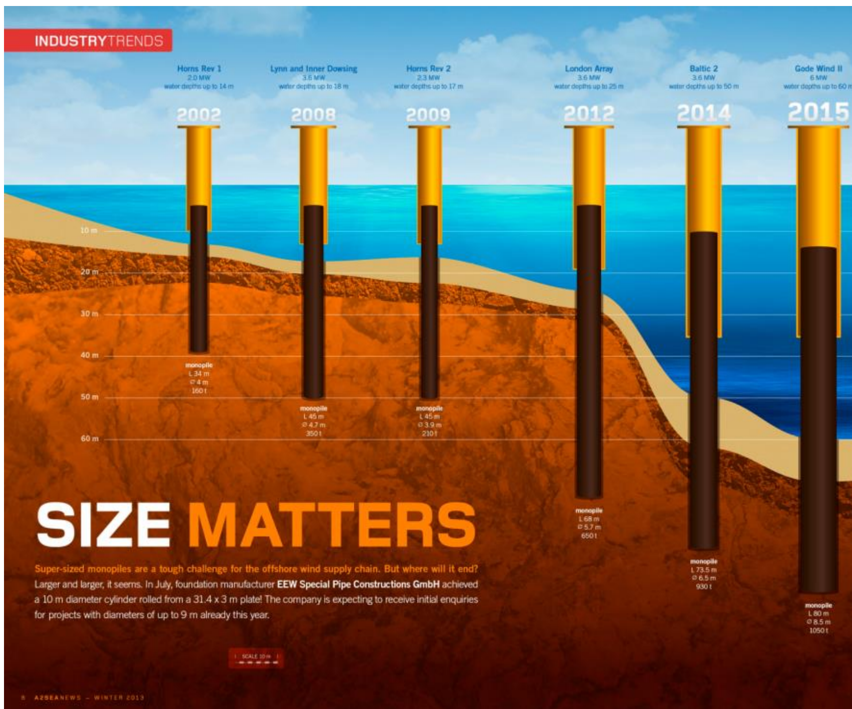


Monopile Moving into Jacket Territory

Veja Mate originally planned with jacket

Water depth 40 meters - 6MW wind turbine

Pile length 84.5 meters - Diameter 7.8 meters

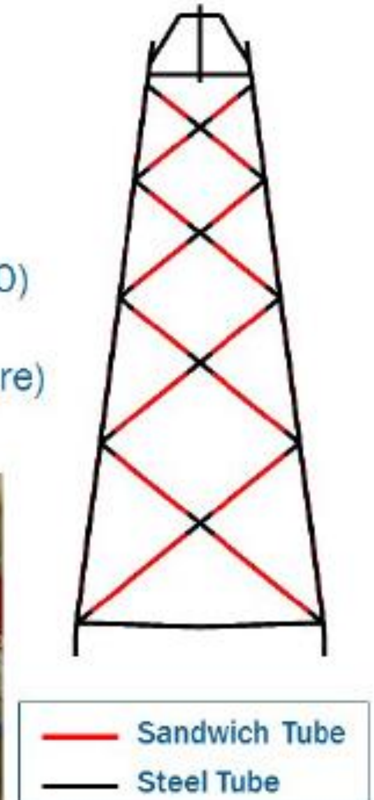


Source: EEW

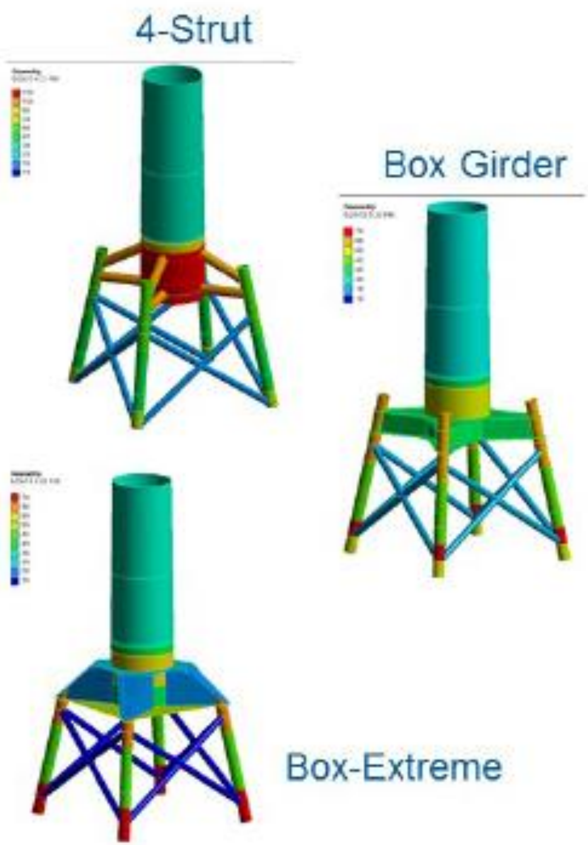
Sandwich materials for jacket tubes

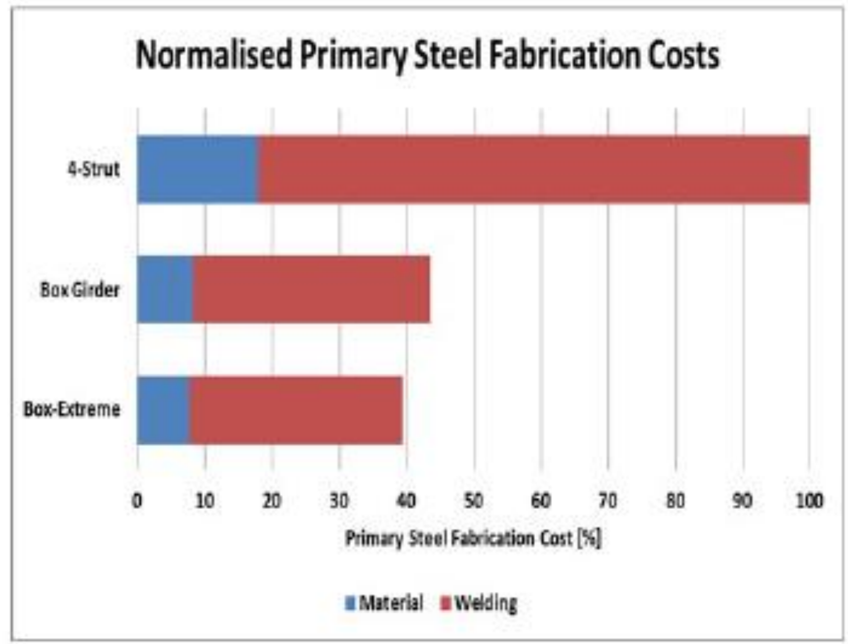
- Sandwich tubes
  - two relatively thin steel tubes
  - core (made of UHPC or Elastomer)
- Cost reduction potential:
  - buckling and wrinkling are mitigated
  - possible use of high strength steel (S460 and S690)
  - faster welding of the steel tubes
  - cost reduction potential: ~7,5% (whole substructure)
- Tubes: TRL 3, Structure: TRL: 1-2

Test specimen



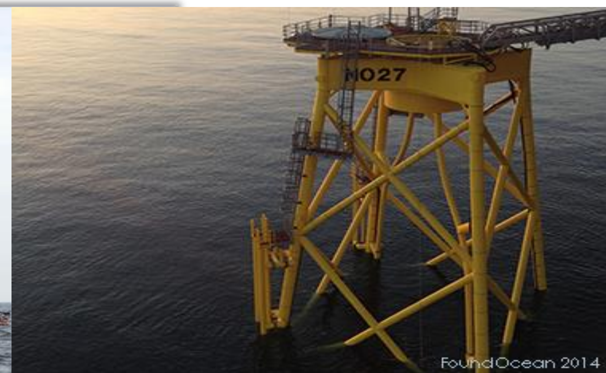
Manufacturing cost: Transition piece

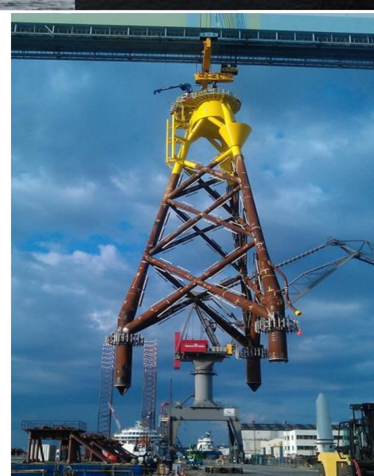




Jacket Structure Development

Simplification of the transition piece, load transfer from the tubular tower to the jacket structure, simplification of the installation procedure (suction bucket)



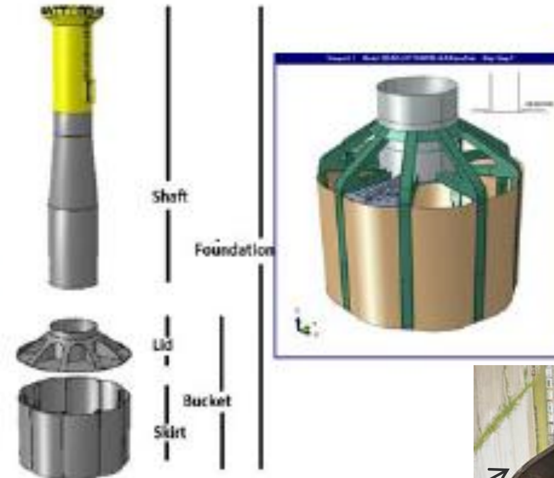


Source:EWE, FoundOcean, Samsung, Dong, Bladt Carbon Trust

Suction Bucket Foundation

Design of a Mono Bucket for the 10 MW turbine

- Based on DLC 1.2 for FLS and 6.2a for ULS as used for the ref. jacket
- Cost estimate for 80 WTGs considering fabrication and installation
  - Weights: shaft 848 t, bucket incl. CC 384 t, secondary steel 50 t
  - Lump sum cost: 4.4 M€



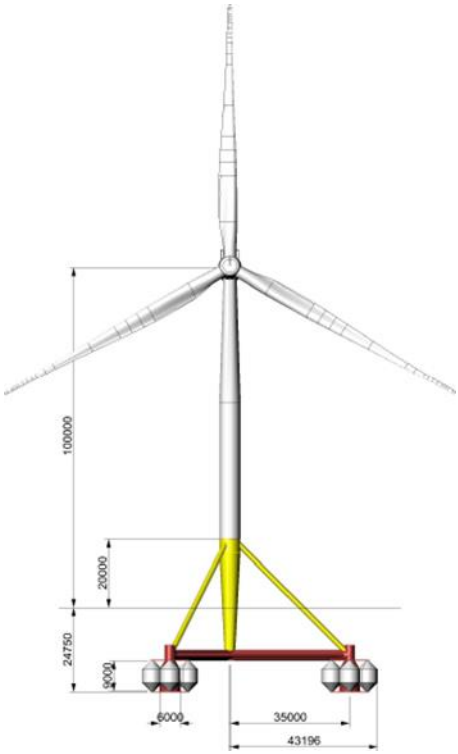
Outlook: Design of bucket foundations for 10 MW & 20 MW jacket

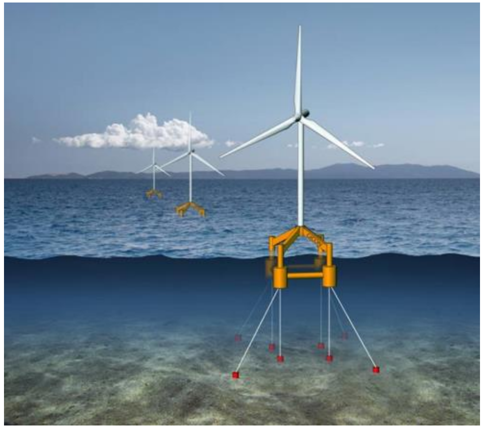
- Use of coil steel instead of steel plate to save cost

Source: Innwind, Universal Foundations

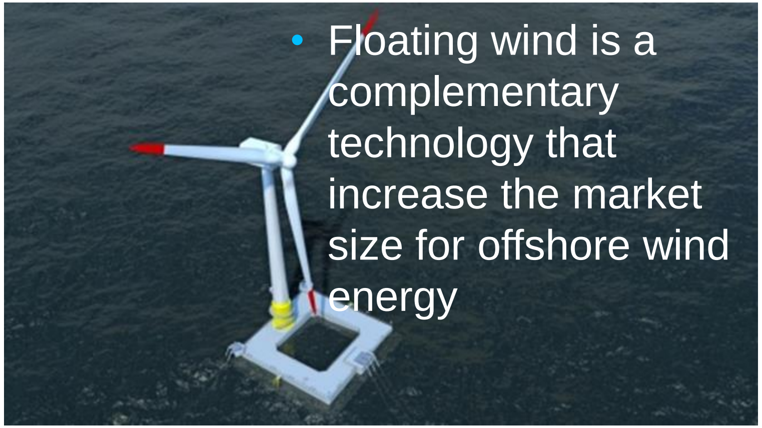
Floating Wind Energy

Fixed foundations suitable only for limited parts of the sea, North Sea, less than 50 meters water depth. Floating structures scale more favorably for larger wind turbines (10 MW+)





- Competition of concepts-> survival of the fittest->cost reduction through economy of scale

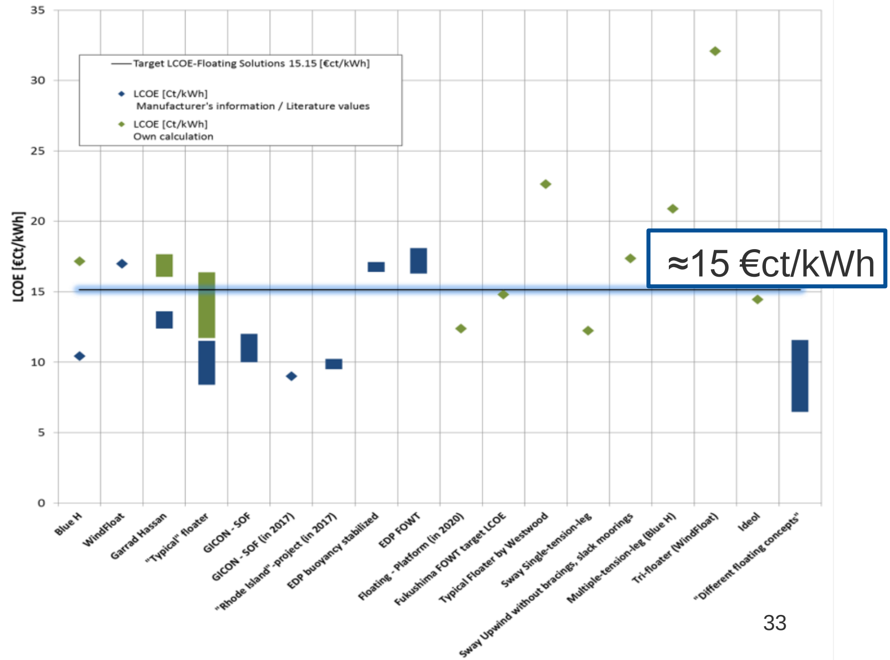


- Floating wind is a complementary technology that increase the market size for offshore wind energy

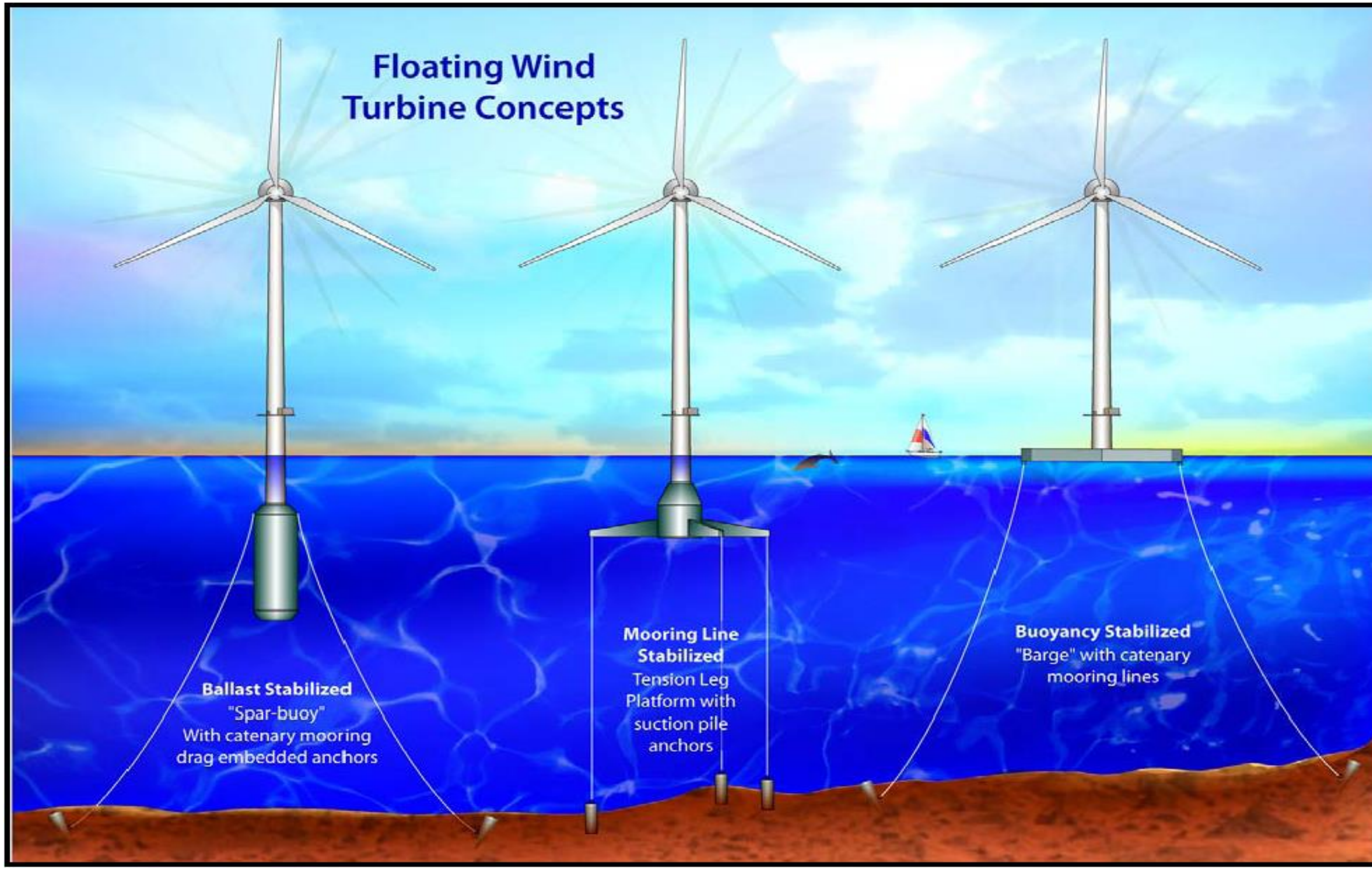
Source: Henrik Stiesdal, Gicon, Statoil, Principle Power, Ideol

Introduction

- Technical feasibility of FOWT has been demonstrated
  - Reaching **economical viability** is the current main goal for FOWT design
- FOWT **Design Process** relies on efficient application of
  - Numerical simulations
  - Model testing



Classification of Floating Wind Turbines



[Figure: http://www.nrel.gov/docs/fy08osti/41958.pdf]

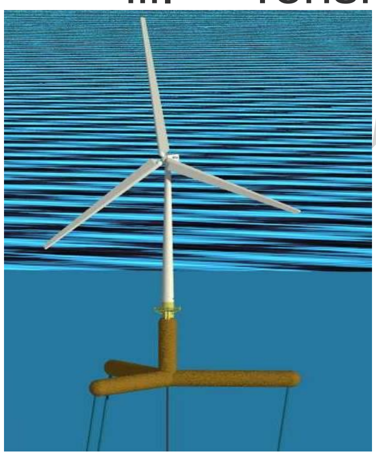
Classification Floating Wind Turbines

Method of achieving stability:

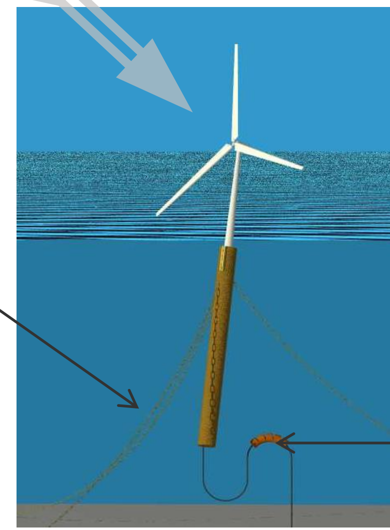
i. Hydrostatic forces

ii. Ballast (mass)

iii. Tensioned moorings



Tensioned Leg Platform (TLP)



Spar

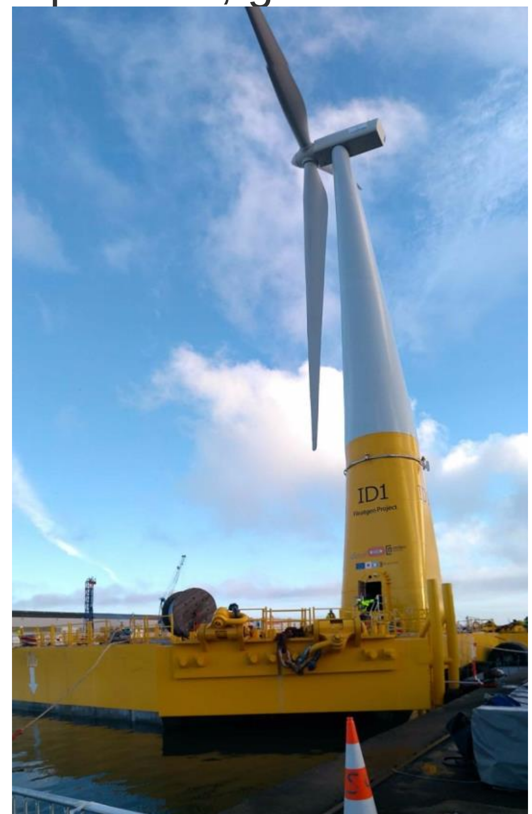
Semi-Sub (Floating Jacket)

typically will be a combination of these factors, with one dominant

[Figures: GL Garrad Hassan]

IDEOL – Concrete Floater Making Progress

2 MW Wind Turbine Modified. Control of floating wind turbines to reduce tower top motions (can have effecs on subcomponents, gearbox and electronic etc.)



- Different loading on the tower
- Effect of the motion on the fluctuation of the power production
- Wake effect within a wind farm
- Yaw motion of the floating structure less damped, e.g. spar type structure.
- Wind turbine design will remain the same than fixed offshore wind

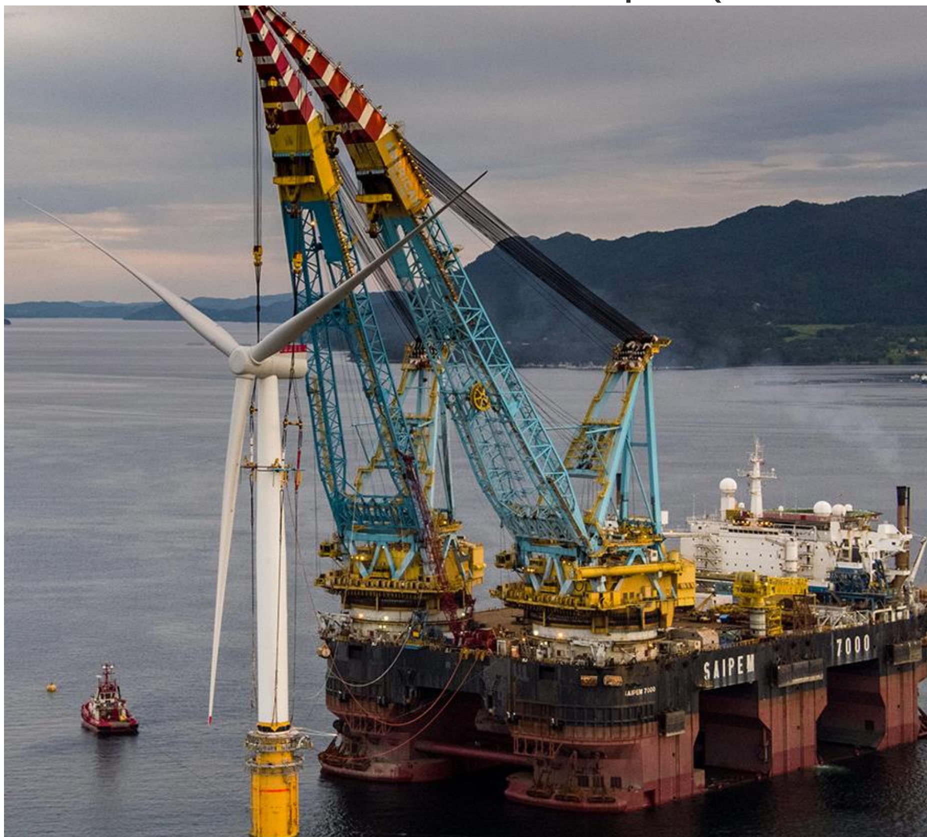
Moving from Floating Wind Turbine to Floating Wind Farm

5 x 6 MW wind Turbine on Spar, the main challenge is the installation procedure, the control of the wind turbine and the cost reduction of the spar structure (steel->concrete?)

Installation (Photo: Odd Henning Gilje/NSG)
Mooring chains. (Photo: Eva Sleire)

Moving from Floating Wind Turbine to Floating Wind Farm

5 x 6 MW wind Turbine on Spar (Installation and Transportation)



Installation Credit: Ørjan Richardsen / Woldcam/Statoil.
Transportation Credit Siemens

Offshore Wind Energy, the New Conventional Energy ?

Here my personal opinion

- Yes, in term of LCOE, installed capacity and contribution to the electricity production in Europe. In term of geographical locations, the center of offshore wind energy will still be Northern and Western Europe and Europe will lead the technology development.
- Not so much for Americas, the onshore wind farm in the Americas are very competitive with capacity factors over 40%. For projects located to large and densely populated urban areas with high electricity prices and the right governmental policy
- Offshore wind has the potential to contribute significantly to the electricity production in some countries in Asia, disparity of policies and support schemes as well as high cost will slow down the development
- Cost reduction potential for fixed offshore wind in the installation technique and new BoP design, including foundations concepts and electrical infrastructure for the transmission etc. O&M cost for offshore wind turbines remain relatively high.
- Floating offshore wind offers new opportunities for areas with deeper water and high population densities. Challenges remain in the floating structure design, dynamic cables, mooring system and control of floating wind turbines. Mass production is crucial for the cost reduction, however, there is no dominating concept at this stage

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Thank you!

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