Industrialized Floating Foundation

Henrik Stiesdal, 22.09.15

We need to industrialize offshore wind power

The gap is widening

- Wind turbine costs are steadily decreasing
- Infrastructure costs are not
- Turbines now often represent less than 40% of total investment

We need industrialization of infrastructure

- Application of industrialized solutions
- Creation of open competition with wide range of potential suppliers

Industrialization of the whole value chain is needed to reach cost levels that society can and will accept

Floating wind power is a good example

Floating wind power has well-known advantages

- Floating systems greatly expand the potential of offshore wind
- Floating systems simplify installation work with turbine assembly and commissioning at quayside, followed by towing to site and hook-up

But it also has severe challenges

- Existing solutions are much too expensive
- Current designs are not easily adapted for large-scale industrial implementation

Without significant innovation floaters will be confined to demonstration projects and niche markets

Existing solutions

Photo credit: Siemens

Existing solutions

Photo credit: EDP Renewables

Existing solutions

Picture credit: Fukushima

Existing solutions

Picture credit: Mitsubishi

Existing solutions

Picture credit: University of Maine

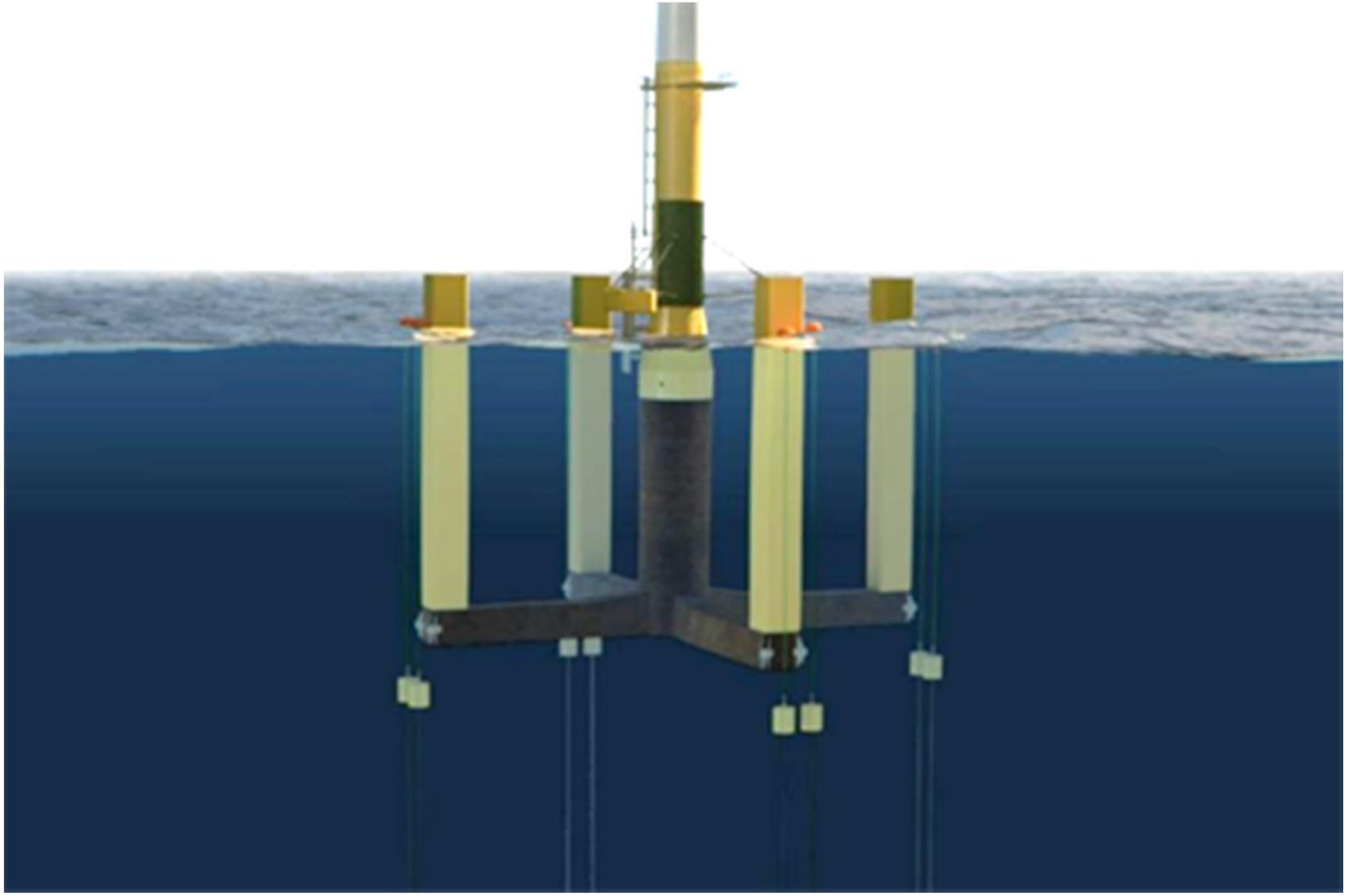
Proposed solutions

Picture credit: Ideol

Proposed solutions

Picture credit: Ideol

Proposed solutions



Picture credit: Iberdrola

Proposed solutions

Picture credit: Gicon

Characteristics of known concepts

Shared characteristics

- Very heavy – 2000–6000 tons for 6 MW class turbines
- Construction methods from offshore oil and gas sector
- Fabrication typically at port of floater launch
- Build times typically measured in months

Particulars for steel structures

- Hydrostatic pressure managed with internal braces/stringers
- Tens of thousands of manual welding hours

Particulars for concrete structures

- High weight requires specialized launch arrangements
- High mobilization effort

It would be fun to do it in a different way!

Imagine if we could

- Build floating offshore foundations with a weight of ~1000 tons for 6 MW class turbines
- Have build times on the order of weeks instead of months
- Reach cost levels at 100-200 m depth equal to or lower than costs for fixed foundations at 40-50 m depth

How do we get there?

Look for inspiration …

- Take bearing from industry with proven experience in
  - cost reduction
  - Industrialized implementation of large structures around the world
- Now .. who could that be … ?

The onshore wind industry, of course!

- Lowest cost new capacity
- Installation time for 500-1000 ton structures measured in days

Photo credit: Siemens

Introducing a world champion …

The humble wind turbine tower

- Probably the world's lowest cost per kg of any large steel structure
- High quality welds and surface protection
- More than 20.000 towers manufactured annually in highly industrialized processes

How did we get there?

- Separation of fabrication and installation
- Modularization and standardization
- No IP of any significance – costs kept low through open competition

Photo credit: Vindmølleindustrien

Dogma for new floater design

Trivialize!

- Keep it simple
- Manufacture components “the onshore wind way”
- Assemble floater with onshore wind methods in simple harbor areas
- Launch floater, install turbine, commission, tow out, hook up, operate

Photo credit: DS SM

Application of dogma

Overall construction concept

- No fabrication on site
- No special processes outside factory environment
- All components assembled by bolting

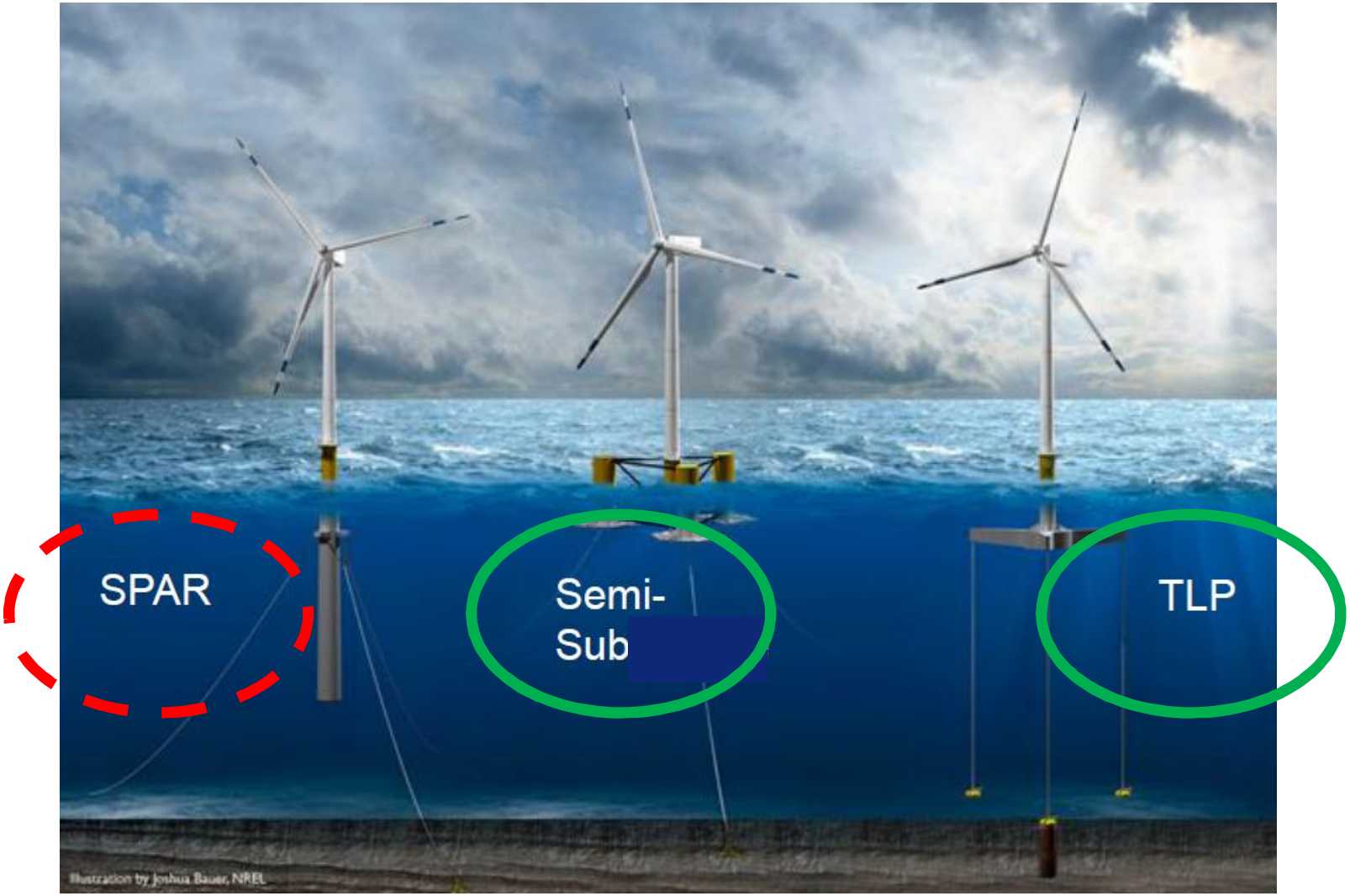
Engineering philosophy

- Minimize bending moments
- Minimize welded stress risers => casted nodes, no welded stringers

Main limits on dimensions and weights

• Maximum diameter of pipes:	6 m
• Maximum length of pipes:	50 m
• Maximum wall thickness of pipes:	75 mm
• Maximum weight of castings:	40 tons
• Maximum weight of foundation w/o ballast:	1000 tons

Potentials in relation to the well-known family of concepts



Picture credit: DNV GL

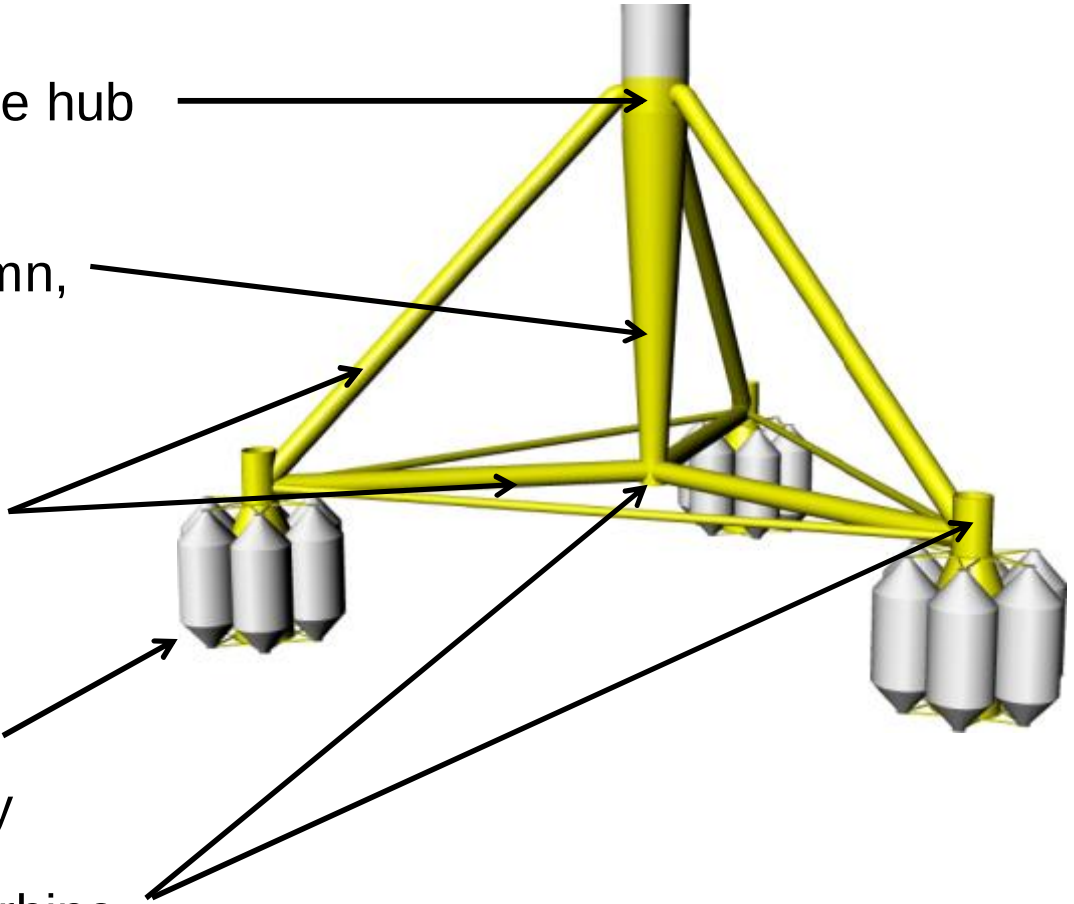
A practical example

Principles

- Tetrahedral structure with minimal bending moments
- Modular – all components brought in from outside, no fabrication in harbor
- Components with dimensions and weights known from wind turbines, assembled with bolts
- Buoyancy with pressurized tanks – lightweight structures with no need for dimensioning to hydrostatic pressure
- Can be implemented as both TLP and semisub (subject to design adjustments)

A practical example – TLP variant

- Cast TP, classical wind turbine hub technology
- Tapered, welded center column, classical wind turbine tower technology
- Cylindrical, welded braces, classical wind turbine tower technology
- Filament-wound GRP tanks, classical industrial technology
- Cast nodes, classical wind turbine hub technology



Potentials of new concept

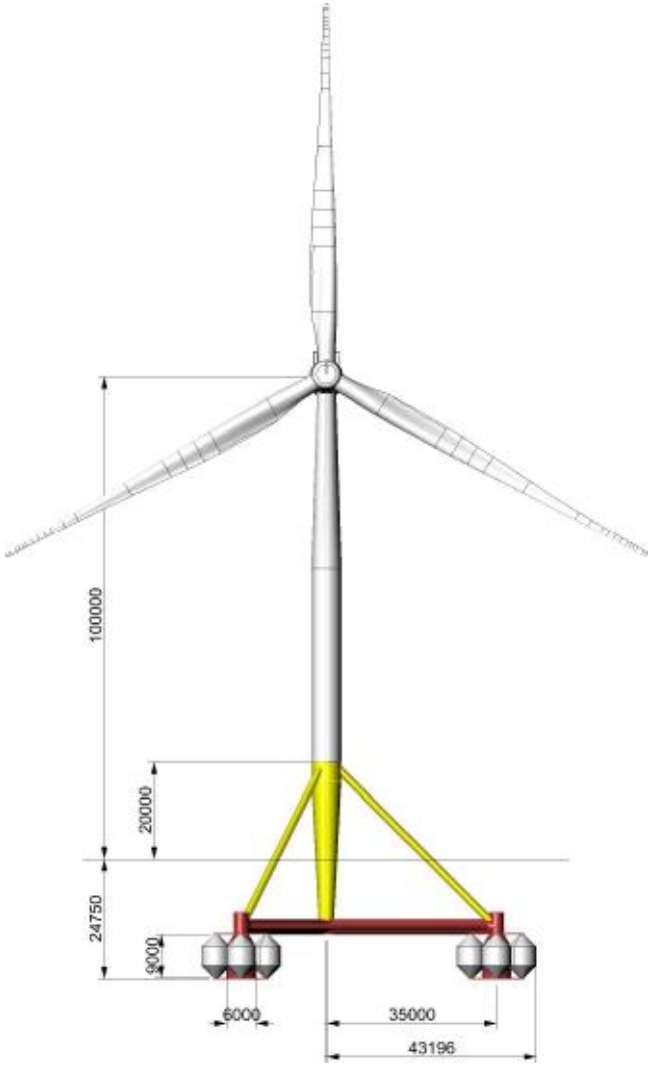
Logistics

- Modular arrangement permits assembly at any port with decent depth and normal entrance dimensions

Cost

- Low mobilization costs
- Double benefit on structural cost – low weight and low specific cost (€/kg) due to modularization and industrialization
- Low installation costs – can be floated to site with turbine mounted

Total costs not yet firm; indications are ~50% of existing floaters



Introducing a world champion …

The humble wind turbine tower

- Probably the world's lowest cost per kg of any large steel structure, and even in superior quality
- More than 20.000 towers manufactured every year in highly industrialized processes

How did we get there?

- Decades of optimization and refinement
- Modularization and standardization
- No IP of any significance – costs kept low through open competition

Photo credit: Vindmølleindustrien

Two levels of innovation in new floater design

Level 1 - Technical

- New structural concept with industrialization as key focus

Level 2 - Dissemination

- Open source arrangement with royalty-free license to IP offered to any interested party
- Joint Industry Project to firm up on details and prepare best-practice standard
- Invitation to universities and research institutes to participate in further improvement of concept – opportunity for engineering students to create the future

DNV GL Collaboration

- DNV GL has agreed to conduct an independent review of the floating foundation concept with the objective to provide a verification of its feasibility
- The collaboration is driven by the open source arrangement and is carried out through DNV GL's internal "Extraordinary Innovation" research program
- The results of the project will be provided as a part of the open source material

"We are proud to collaborate on this exciting project. Floating wind turbines has great potential but the costs need to come down significantly. Open source innovation is the perfect way to quickly bring new ideas to the market, spur ingenuity and industry collaboration. This fits very well with DNV GL's own purpose and values."

Johan Sandberg,

Segment Leader – Floating wind turbine technology

Next steps

Level 1 - Technical

- Complete initial design of “6 MW Class” foundation for North Sea
- Acquire DNV GL Statement of Feasibility for initial design

Level 2 - Dissemination

- Establish infrastructure for open source arrangement
- Prepare invitation for Joint Industry Project
- Prepare invitation for research collaboration

Deadline

- EWEA 2015 Annual Event, Paris 17-20 November

Thanks for your attention

Henrik Stiesdal
hst@stiesdal.com