Industrialized Offshore Wind Foundations

The Tetra Concept

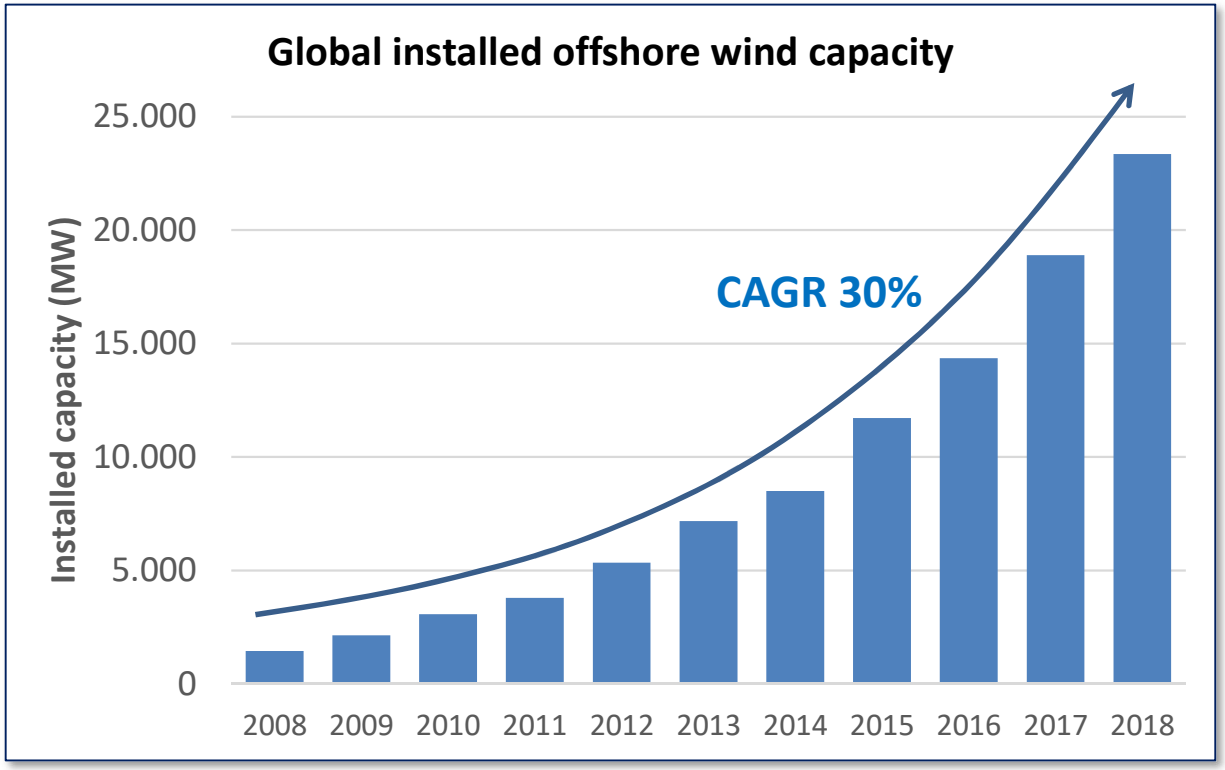
Henrik Stiesdal, 14.11.19

Offshore wind power is developing tremendously

One of the fastest growing energy sectors

- 10-year Compound Annual Growth Rate 30%
- Market has doubled every 3 years
- Over same period LCOE has dropped 60%

Within a few decades offshore wind can become the main source of electricity in large parts of the world

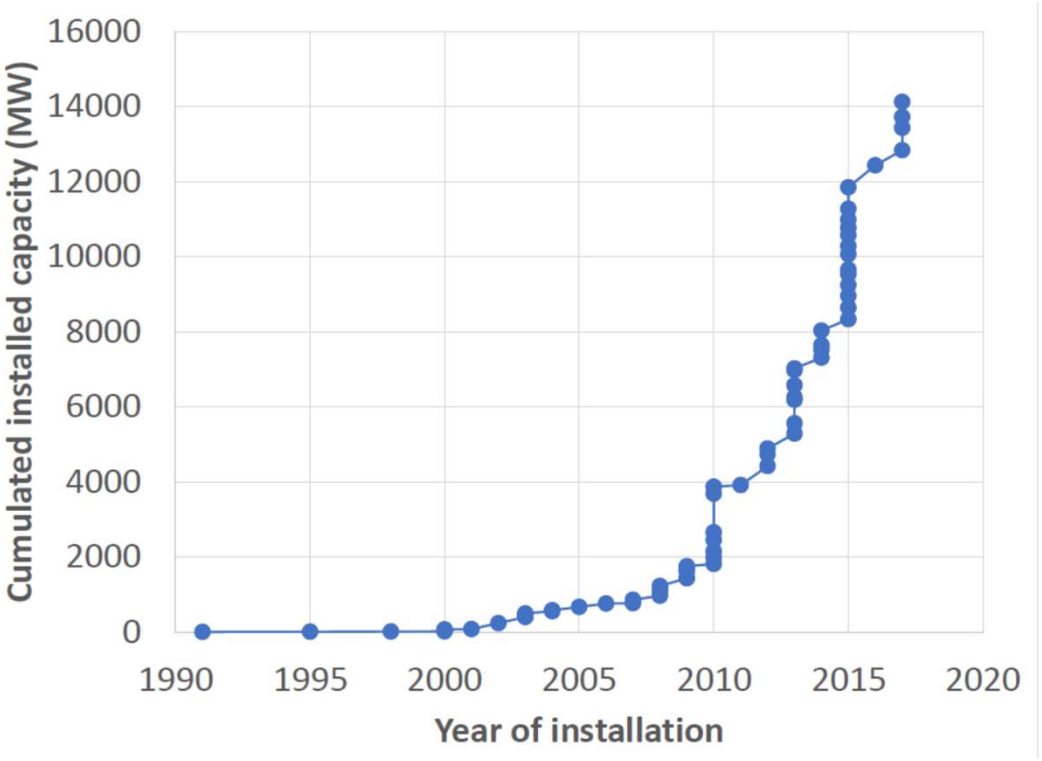


Source: GWEC

The first 25 years of European offshore wind power

The total installed fleet

- 70 projects
- 14.2 GW
- Projects in
  - Denmark
  - Sweden
  - Norway
  - UK
  - Ireland
  - Germany
  - Netherlands
  - Belgium

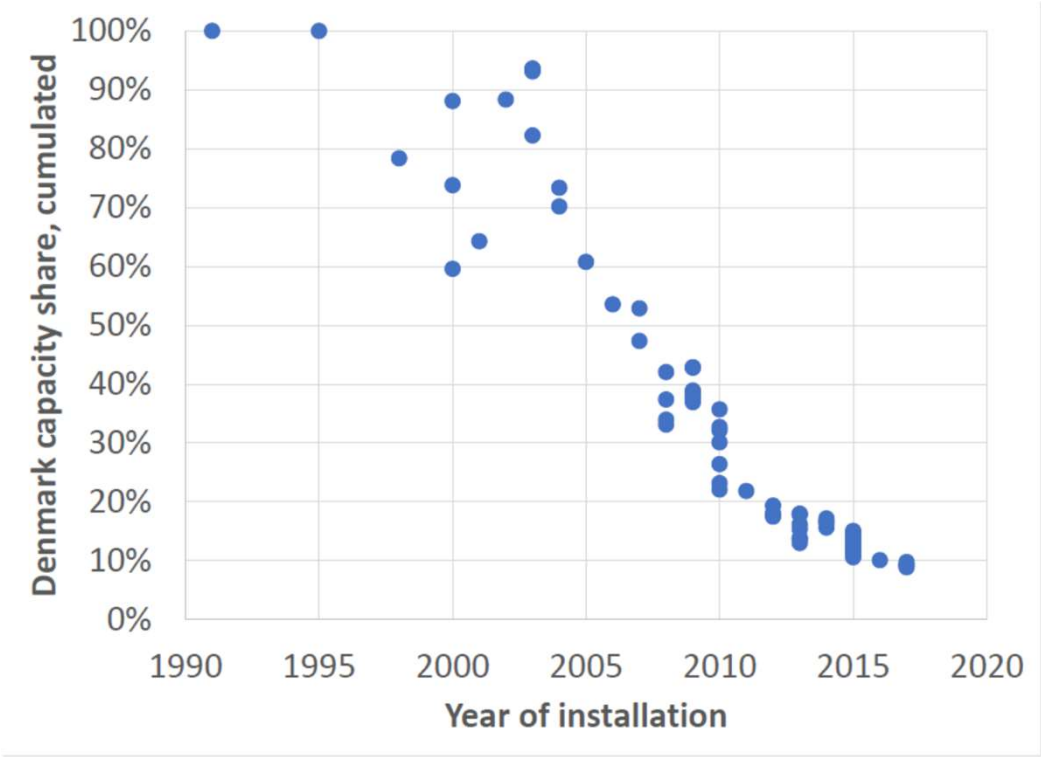


Source: Wikipedia

The first 25 years of European offshore wind power

Denmark's share of the total installed fleet

- 100% share the first years
- >60% for first 15 years
- After that dropping rapidly as consequence of very large projects in UK and Germany other 70 projects
- Present share ~8%, will probably grow over coming years due to strong focus on offshore wind as vehicle for Danish green transition

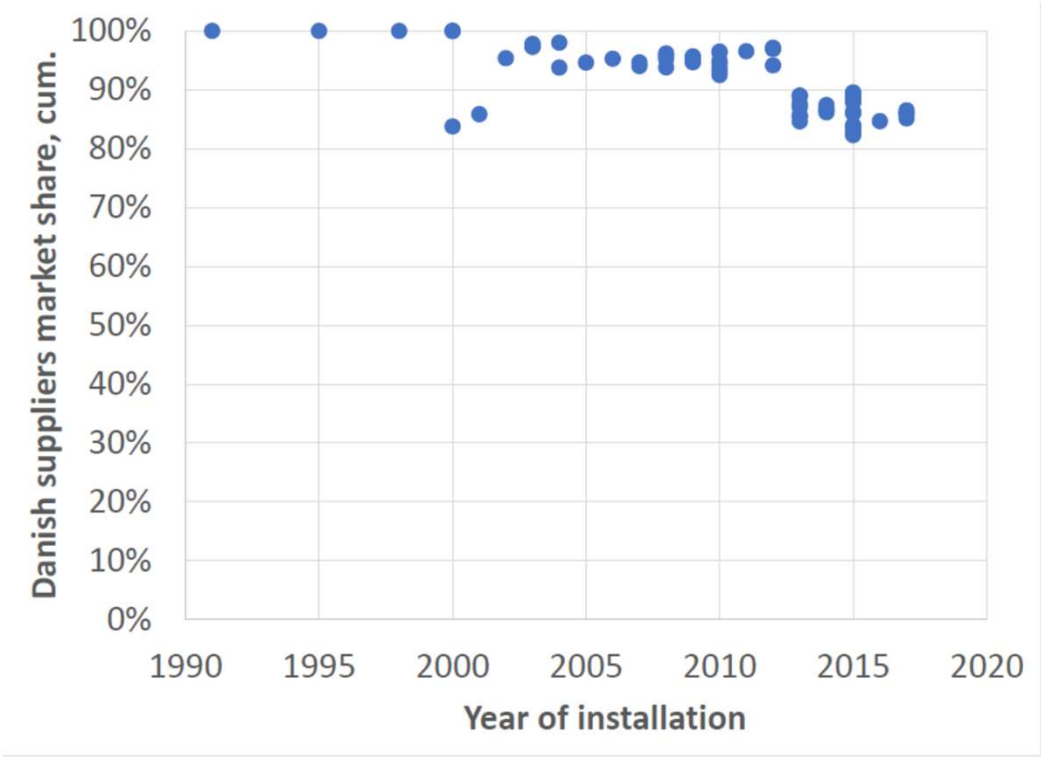


Source: Wikipedia

The first 25 years of European offshore wind power

Danish OEM market share

- Danish OEMs (Siemens Gamesa and MHI Vestas) and predecessors have retained very high market shares despite strong reduction in Denmark's share of total installed capacity
- Market share has never dropped below 80%



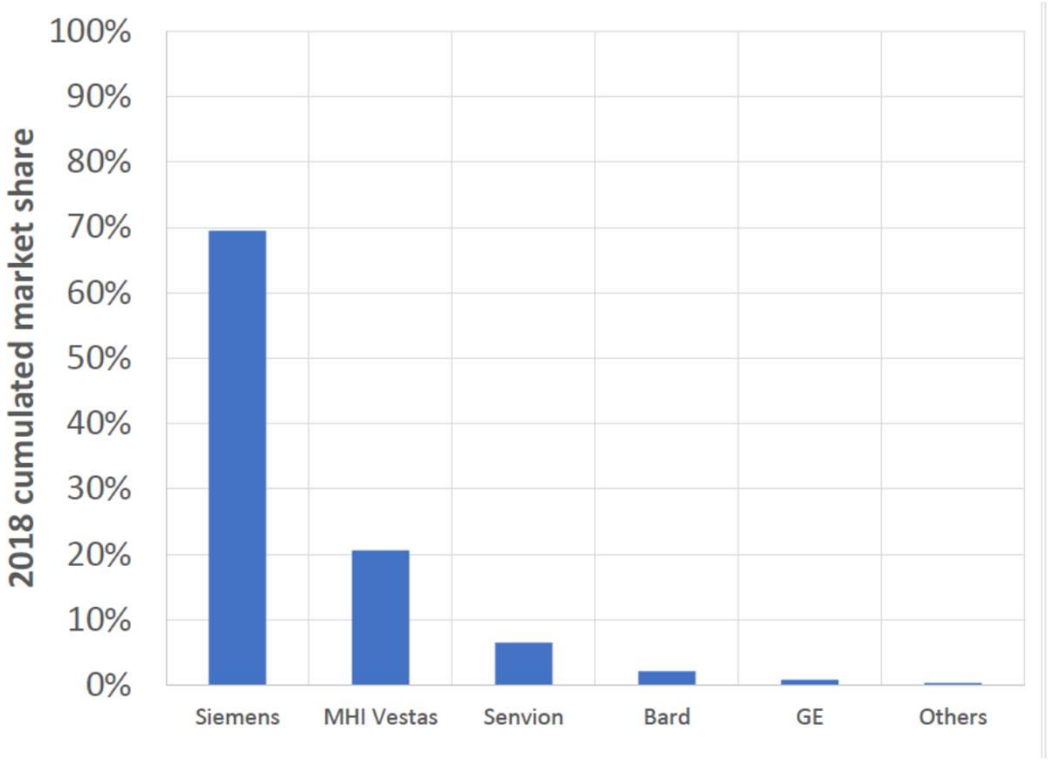
Source: Wikipedia

The Danish OEM dominance remains strong

By the end of 2018 –

- 18.5 GW total installed capacity in 11 countries
- 4500 offshore turbines
- Siemens Gamesa cumulated capacity 12.8 GW
- MHI Vestas cumulated capacity 3.8 GW

After 28 years, Danish OEMs have 90% cumulated market share

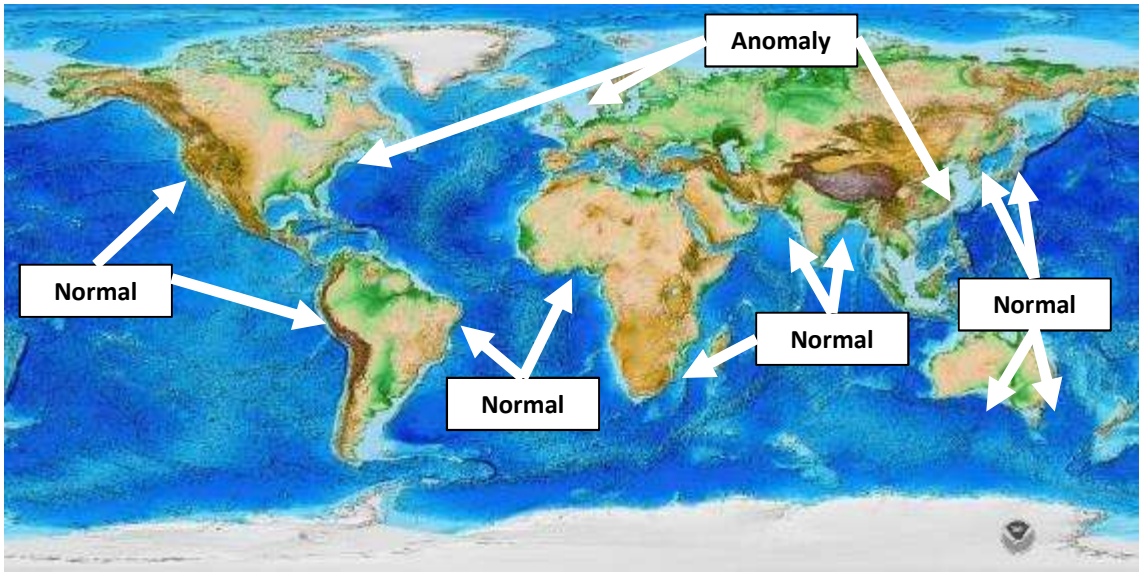


Source: WindEurope

But there is a problem -

Offshore wind as we know it now is only applicable in selected locations

- Maximum water depth of fixed foundations 40-50 m
- Can be applied in Northern Europe, off China and off US East Coast
- Most other population centers have much too deep nearshore waters



Source: NOAA

The solution is obvious – floating offshore wind

Source: Equinor, Principle Power, Hitachi, MHI

Floating wind power has many advantages

The obvious advantage – the solution to the challenge

- Floating foundations extend the servable market tremendously, from areas of up to 60 m depth to areas of up to 1000+ m depth

The perhaps less obvious but equally important advantages

- Mass production benefits even for small projects
- One size fits all turbines in a given project. No need for adaptation to individual location depths or seabed conditions
- Tow-out concept with pre-installed turbine solves vessel challenges of very large turbines
- Anchors are much less sensitive to seabed conditions than piles or suction buckets

But again, there is a problem – floaters are not industrialized

Shared characteristics

- Very heavy – from 3000 tons to 10.000 tons for 8 MW class turbines
- Construction methods from shipbuilding and offshore oil and gas sector
- Fabrication typically required to be at port of floater launch
- Build times typically measured in months
- Tens of thousands of man-hours per foundation for steel cutting, fitting, welding, handling, etc.

Source: Equinor, Principle Power, Mitsui, MHI U Maine

Equinor Hywind, Scotland, 2017

Hywind Scotland

- World's first floating offshore wind farm
- 30 MW, 5 Siemens 6 MW
- Installed 2017

Wind turbine tower (Siemens)

- 83 m, 620 t
- 2000 man-hours

Floater (Equinor)

- 91 m, 3600 t
- 90.000 man-hours

Source: Equinor

Principle Power Windfloat, Scotland, 2020

Kincardine

- World's so far largest floating offshore wind farm
- 47.5 MW, 5 MHI Vestas V164 9.5 MW
- To be installed 2020

Windfloat foundation

- 3000 t
- 250.000 man-hours

Stiesdal TetraSub

- 2000 t
- 10-15.000 man-hours

Source: Principle Power, Navantia

The first truly industrialized large-size product – the Ford Model T

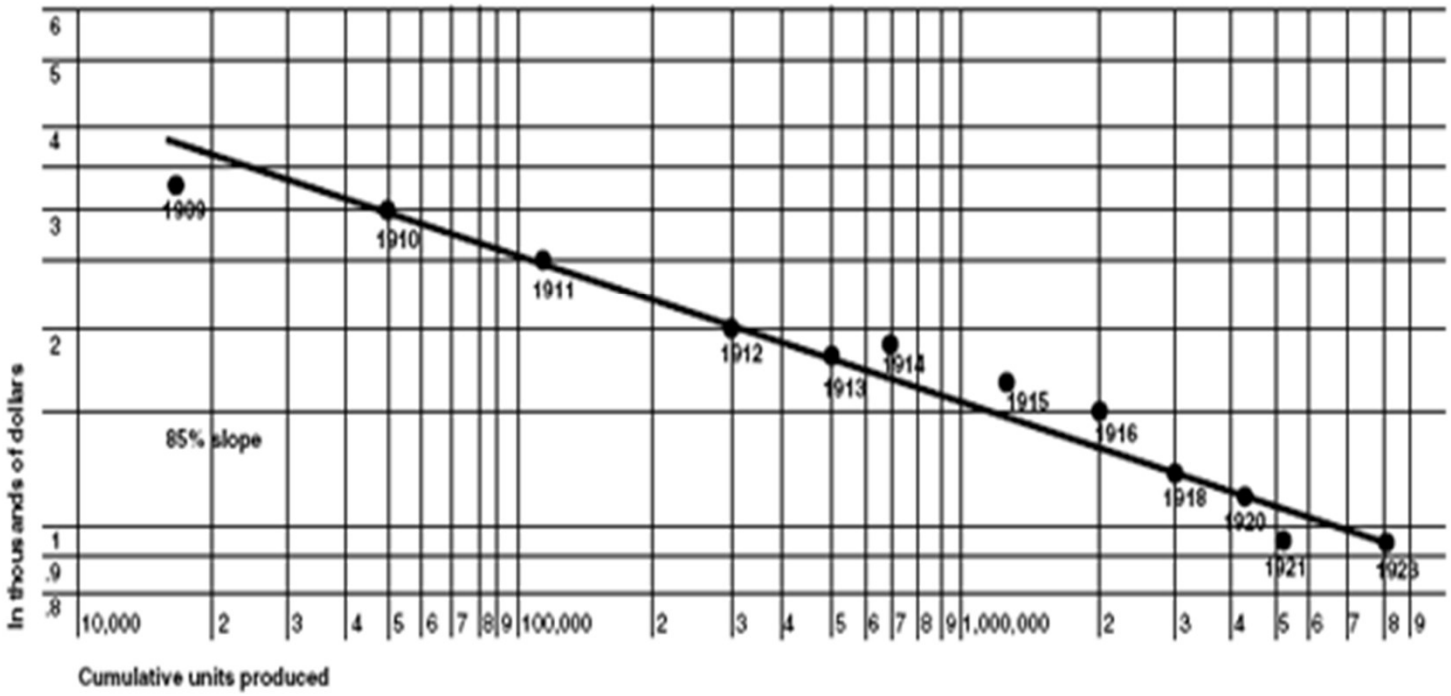
1909

1923

Source: Ford Motor Co.

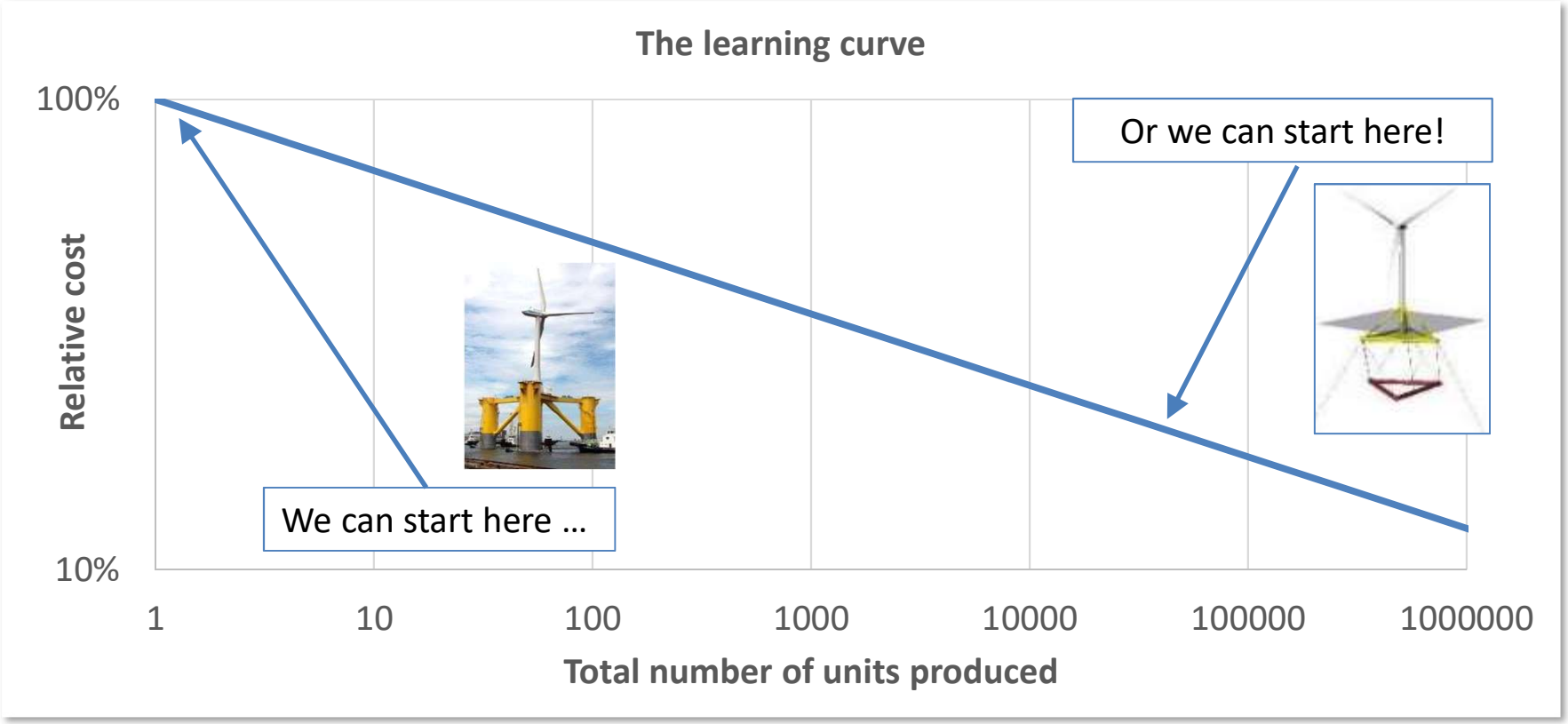
The power of industrialization

Exhibit I Price of Model T. 1909–1923 (Average List Price in 1958 Dollars)



Source: Ford Motor Co.

The fundamental choice regarding the supply chain



We need an industrialized component supplier

A world champion … the wind turbine tower

- Probably the world's lowest cost per kg of any large steel structure
- High quality welds and surface protection
- Around 100.000 tower sections 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 on cost and quality

Source: Danish Wind Industry Association

Enter the Tetra concept – industrialized floating wind power

Mindset

- Conventional thinking
  - We have designed this structure – now, how do we build it?
- TetraSpar thinking
  - We need to manufacture this way – now, how do we design it?

Concept

- Modular – all components factory-made, transported by road
- Components assembled at quayside, just like the turbine is assembled
- Turbine mounted in harbor and towed to site, no installation vessels
- Weight 1500-2000 t for 8 MW turbine

Mindset for delivery, assembly and deployment

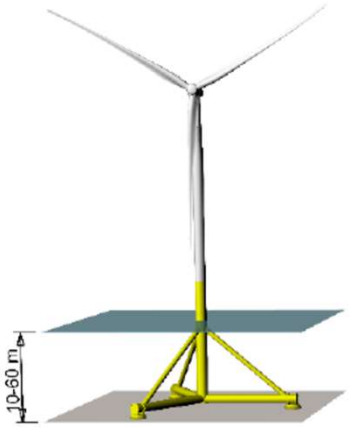
Design targets

1. No module should be heavier than the largest part of the turbine tower
2. No module should have a larger diameter than the largest part of the turbine tower
3. No module should be longer than the wind turbine blade

Conclusions

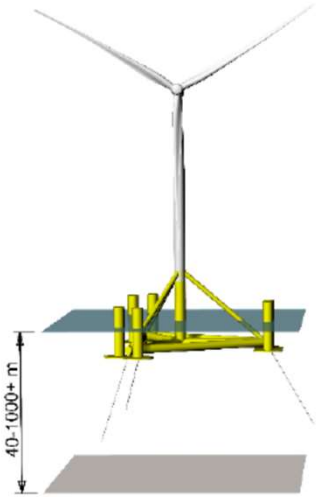
- If it is possible to get the turbine to the port of embarkation, then it is also possible to get the foundation there
- No on-site manufacturing is required

The Tetra product range



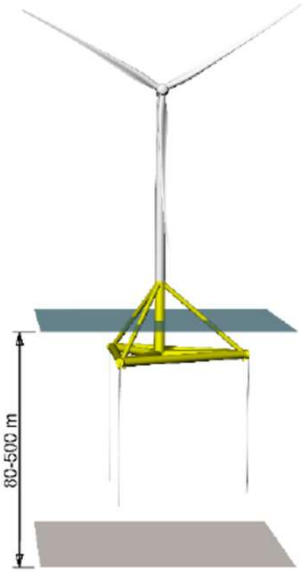
TetraBase® bottom-fixed foundation

Bottom-fixed foundation with crane-free offshore installation. Suited for 10-60 m depth.



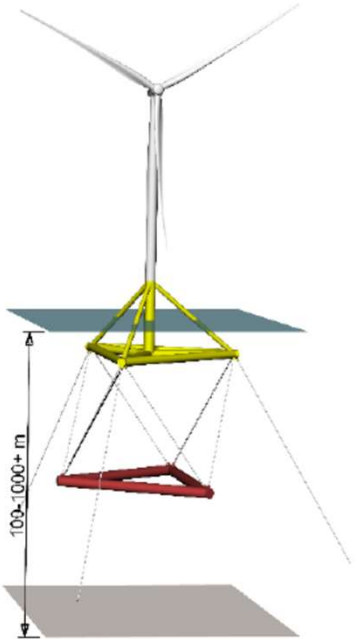
TetraSub® floating foundation

Floating foundation in semisubmersible configuration. Suited for 40-1000+ m depth.



TetraTLP® floating foundation

Floating foundation in tension-leg configuration. Suited for 80-500 m depth.

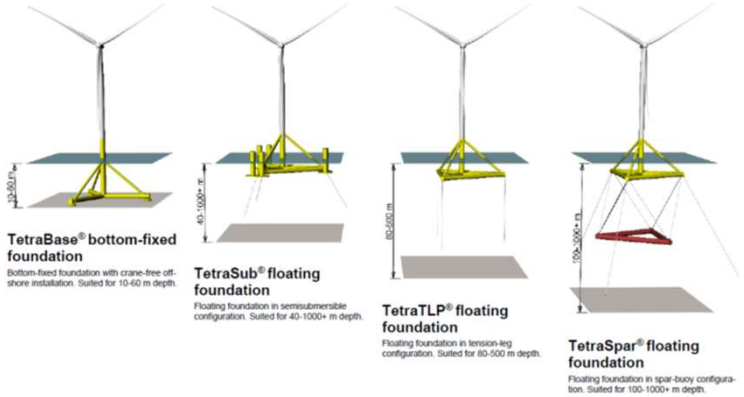


TetraSpar® floating foundation

Floating foundation in spar-buoy configuration. Suited for 100-1000+ m depth.

Shared characteristics for the Tetra product range

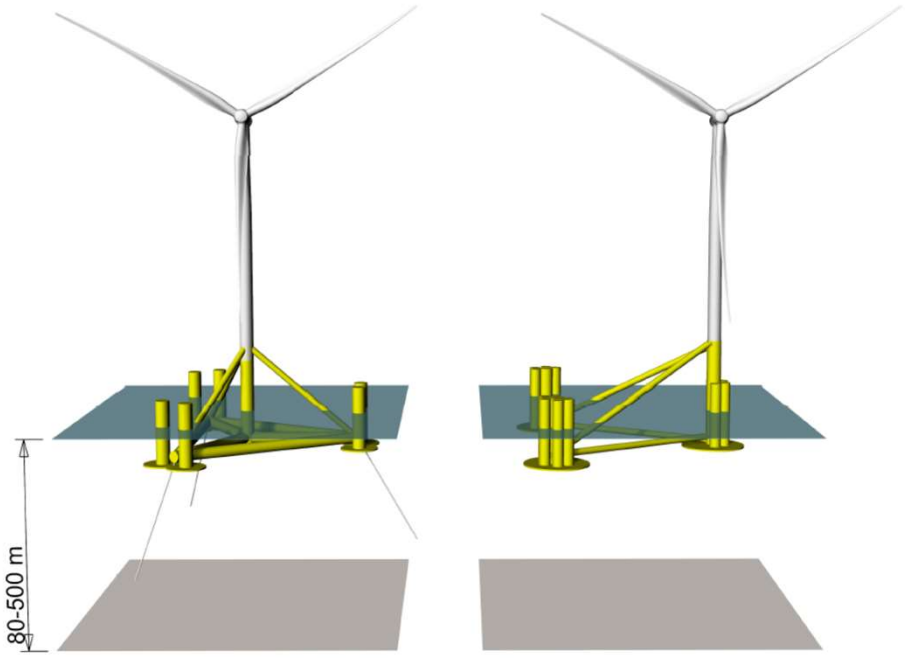
- Can be adapted to any turbine size and any water depth – bottom-fixed to 10-60 m water depths, floating to 40-1000+ m water depths
- Fully industrialized, utilizing existing tower-manufacturing supply chain
- Fast and robust assembly in port of embarkation; no facilities needed other than a flat area at quayside
- Easy launch using slip or semisubmersible barge
- Turbine installation at quayside using land-based crane
- Pre-commissioning at quayside possible
- Easy towing to site using conventional vessels



The keyword: Industrialization!

It is not about one particular configuration

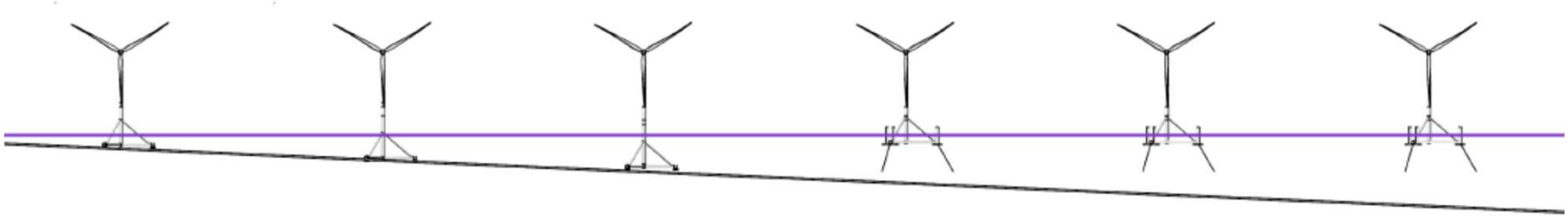
- The core of the Tetra concept is industrialized manufacturing
- The specific configuration depends on a range of parameters –
  - Water depth
  - Port of embarkation
  - Metocean conditions
  - Cultural factors
  - …



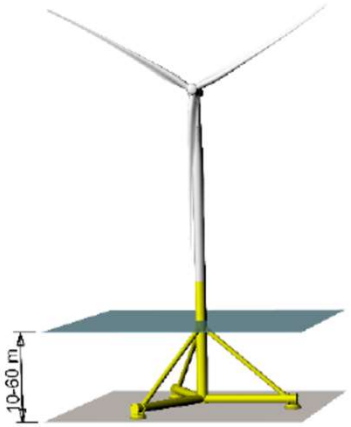
The Tetra concept allows maximum flexibility in site selection

Seamless transition from bottom-fixed to floating

- The bottom-fixed TetraBase can be used at water depths of 10 – 60 m
- The floating TetraSub can be used at water depths of 40 – 1000+ m, potentially at a depth as low as 30 m, depending on tidal conditions, etc.
- The optimum transition depth will generally be selected on the basis of seabed conditions, seismic challenges, etc.
- Conditions for O&M will generally be similar



The first Tetra demonstration project



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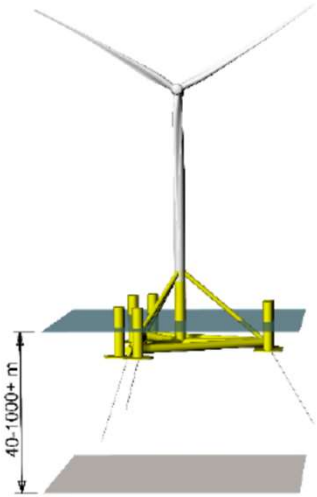

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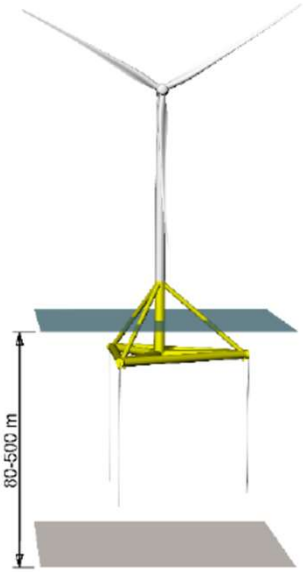

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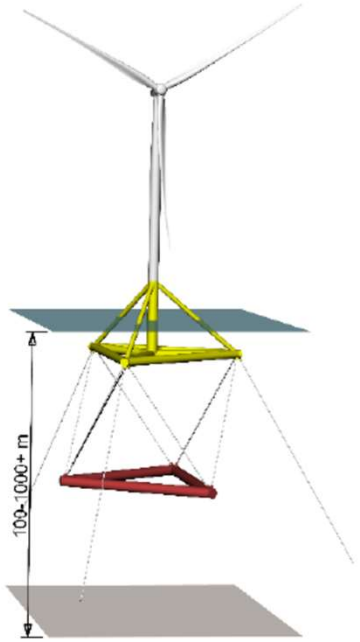


TetraSpar® floating foundation

Floating foundation in spar-buoy configuration. Suited for 100-1000+ m depth.

The TetraSpar Demonstrator

Stage 1 - 2016
- Concept
- Initial validation

€ 0.2m

Stage 2 - 2017
- Design
- Tank test OK

innogy

€ 18m

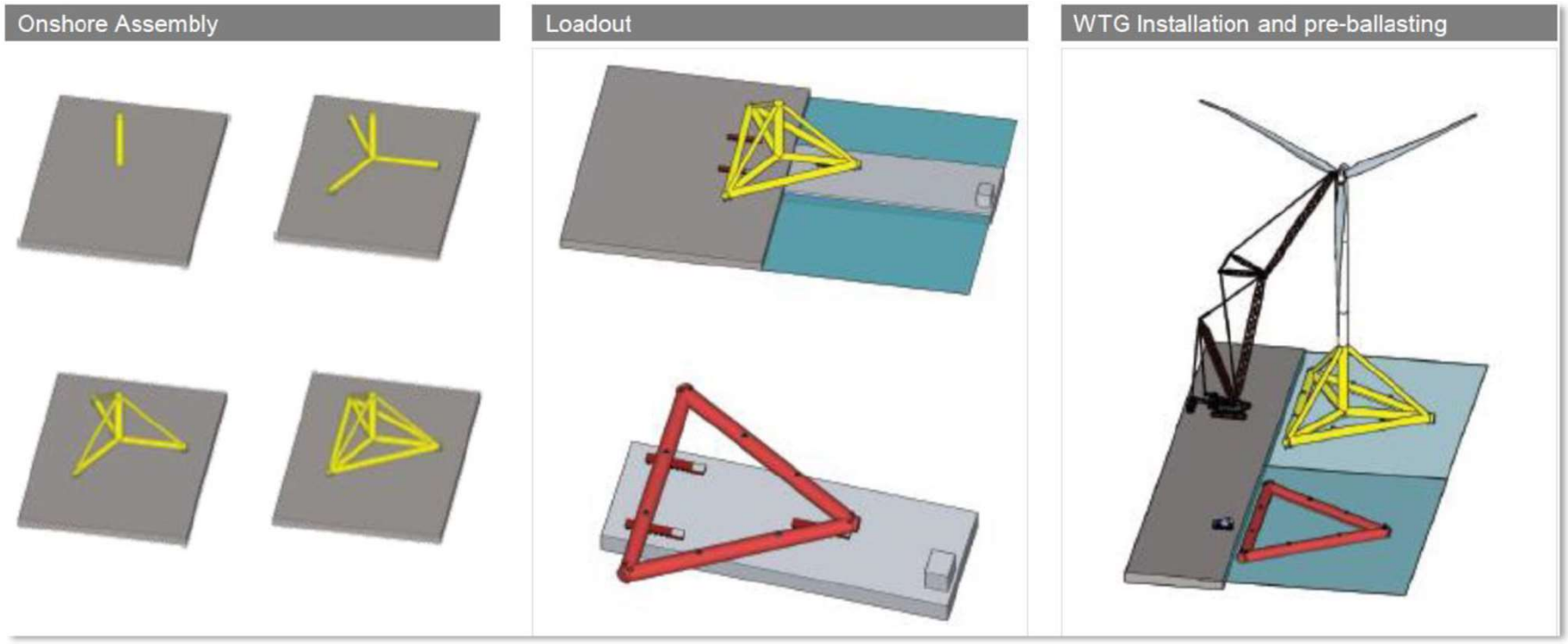
Stage 3 - 2020
- Prototype
- Full validation

Stage 4 - 2021
- Pilot project
- Release

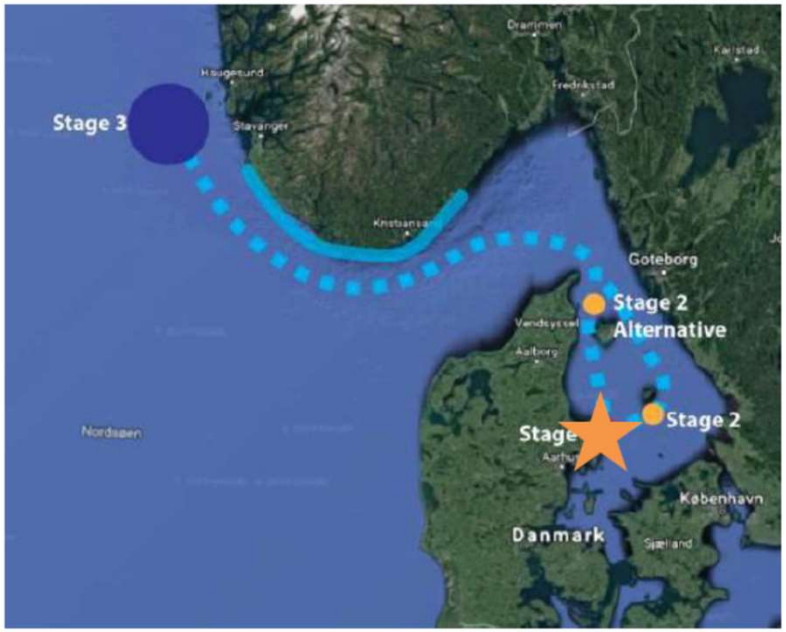
Prototype

- Siemens SWT-3.6-130, 3.6 MW rated power, 130 m rotor diameter
- Status 30.05.19: Fabrication start June 2019, installation scheduled for April, 2020
- Foundation contractor: Welcon

The TetraSpar Demonstrator installation process



Construction port and towing route



Manufacturing approach

Markets servable with components produced in Denmark

- Cooperation with Danish wind turbine tower manufacturer Welcon A/S for supply of tubular braces
- Welcon is the world's leading supplier of offshore wind turbine towers, with high degree of automation

Markets not servable with components produced in Denmark

- Where transportations costs from Denmark are prohibitive, or where local content is mandatory, Stiesdal and Welcon will establish local manufacturing through partnerships

WELCON

In summary – the Tetra concept

The keyword – Industrialization!

- Modular – all components factory-made, transported by road
- Components assembled at quayside, just like the turbine is assembled
- Turbine mounted in harbor and towed to site, no installation vessels
- Weight 1500-2000 t for 8 MW turbine, bottom fixed variant has weight around 1000 t
- Volumes can be ramped up quickly based on existing tower supply chain and existing port facilities

The Tetra concept has the potential to radically transform offshore wind power

Thanks for your attention

Henrik Stiesdal
hst@stiesdal.com