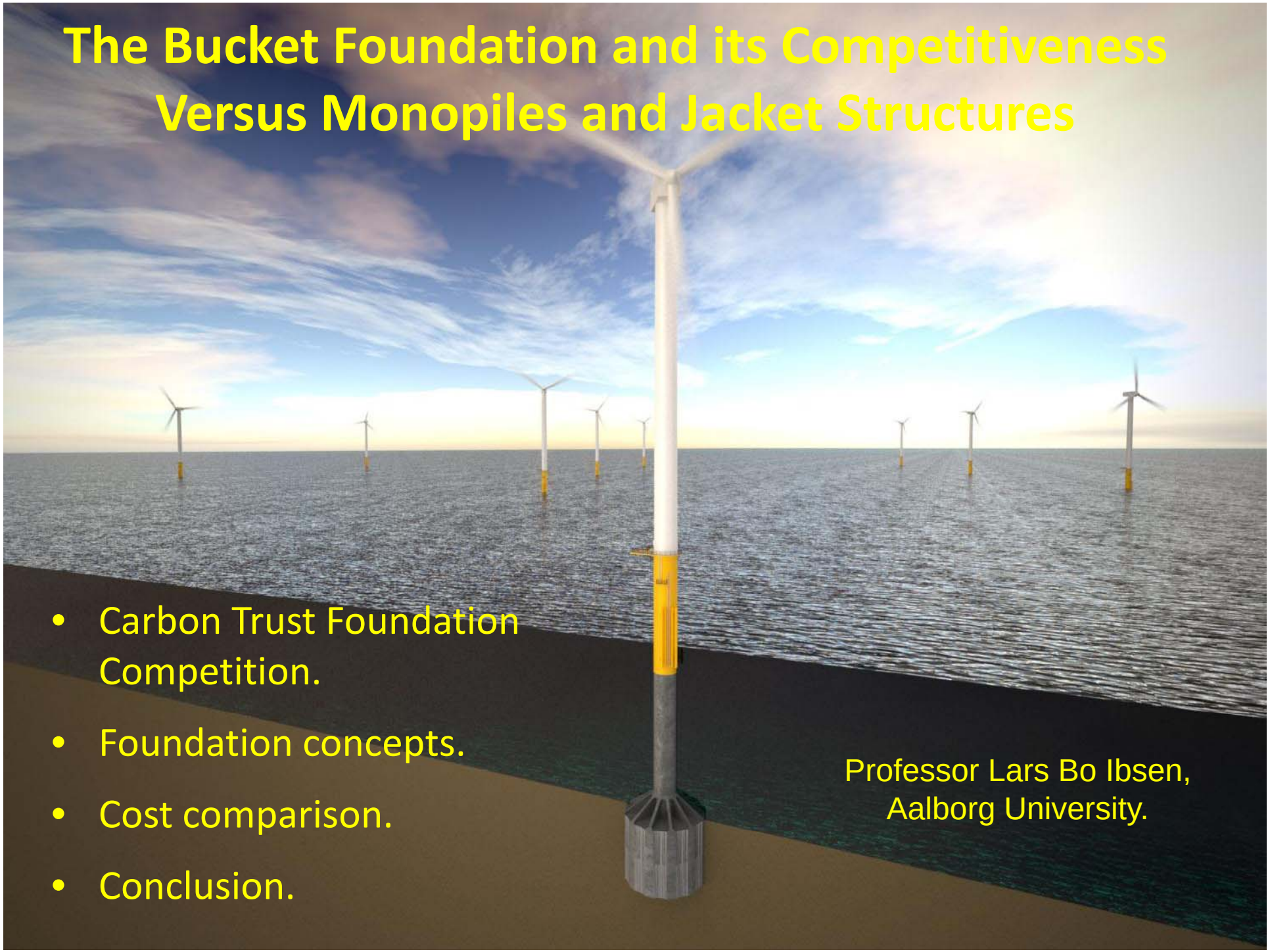
The Bucket Foundation and its Competitiveness Versus Monopiles and Jacket Structures

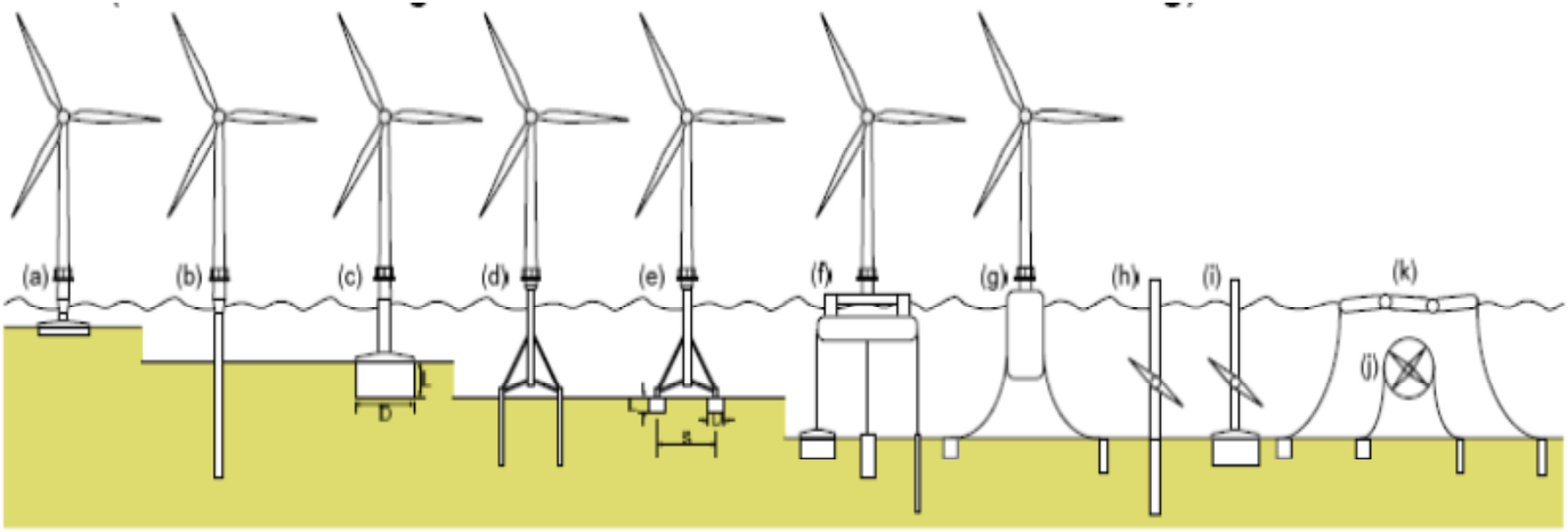


- Carbon Trust Foundation Competition.
- Foundation concepts.
- Cost comparison.
- Conclusion.

Professor Lars Bo Ibsen,
Aalborg University.

Structural and foundation for Wind Turbines but also applicable to other offshore renewable

Cost of energy



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OWA focuses on strengthening economics of offshore wind

Stage I (Oct '08 to Apr '10) examined four technical areas

CARBON TRUST

Offshore wind returns

CAPEX | **OPEX** | **Yield** | **Financing costs**

Foundations — **Access**

Four technology areas, selected on basis of detailed analysis of over 70 technical barriers

Electrical systems

Wake effects

Source: Carbon Trust

Universal Foundation A/S

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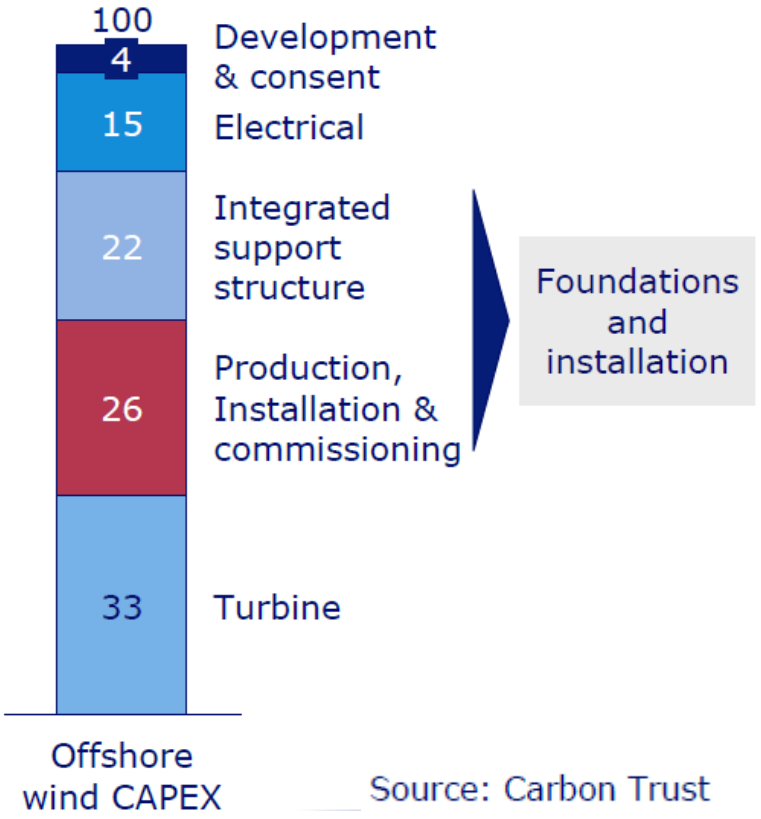
Foundations vision: Reduce cost of deeper water foundations

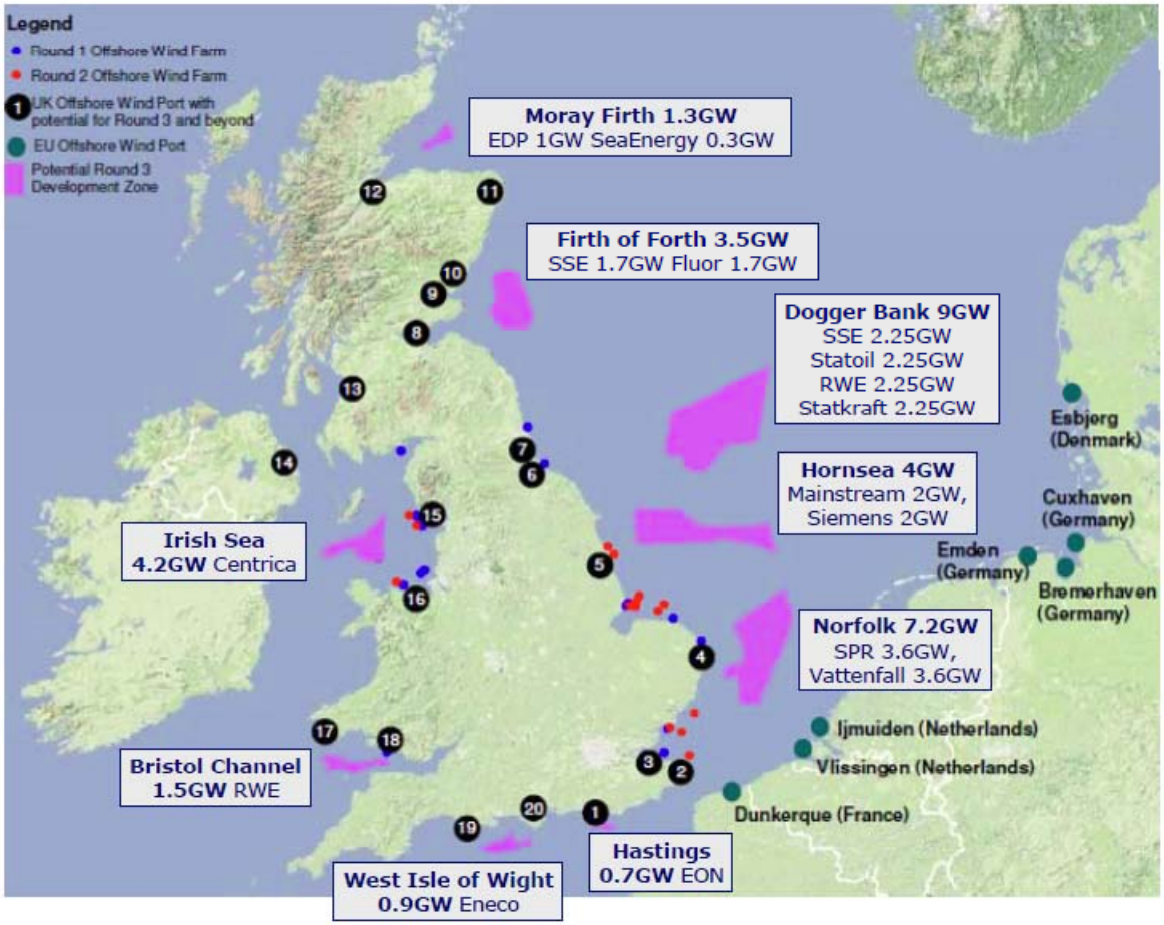
- To demonstrate new, lower-cost foundation designs
  - For 30-60m depths expected in late Round 2 & Round 3
- To reduce lifecycle cost of foundations by 30%
  - TDC target £0.4-0.6m/MW
- To stimulate the supply chain
  - Particularly in volume manufacturing and installation
  - To provide more competition and flexibility in the market

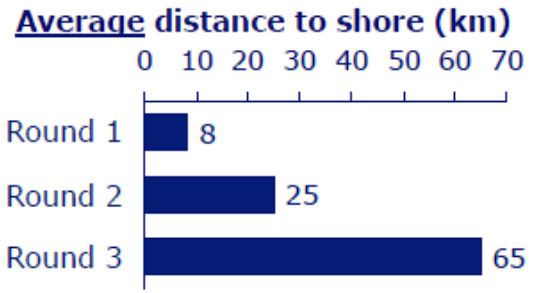
Offshore wind CAPEX breakdown



Source: Carbon Trust

The Challenges





Dogger Bank stretches 285km offshore

Source: Carbon Trust

Universal Foundation A/S

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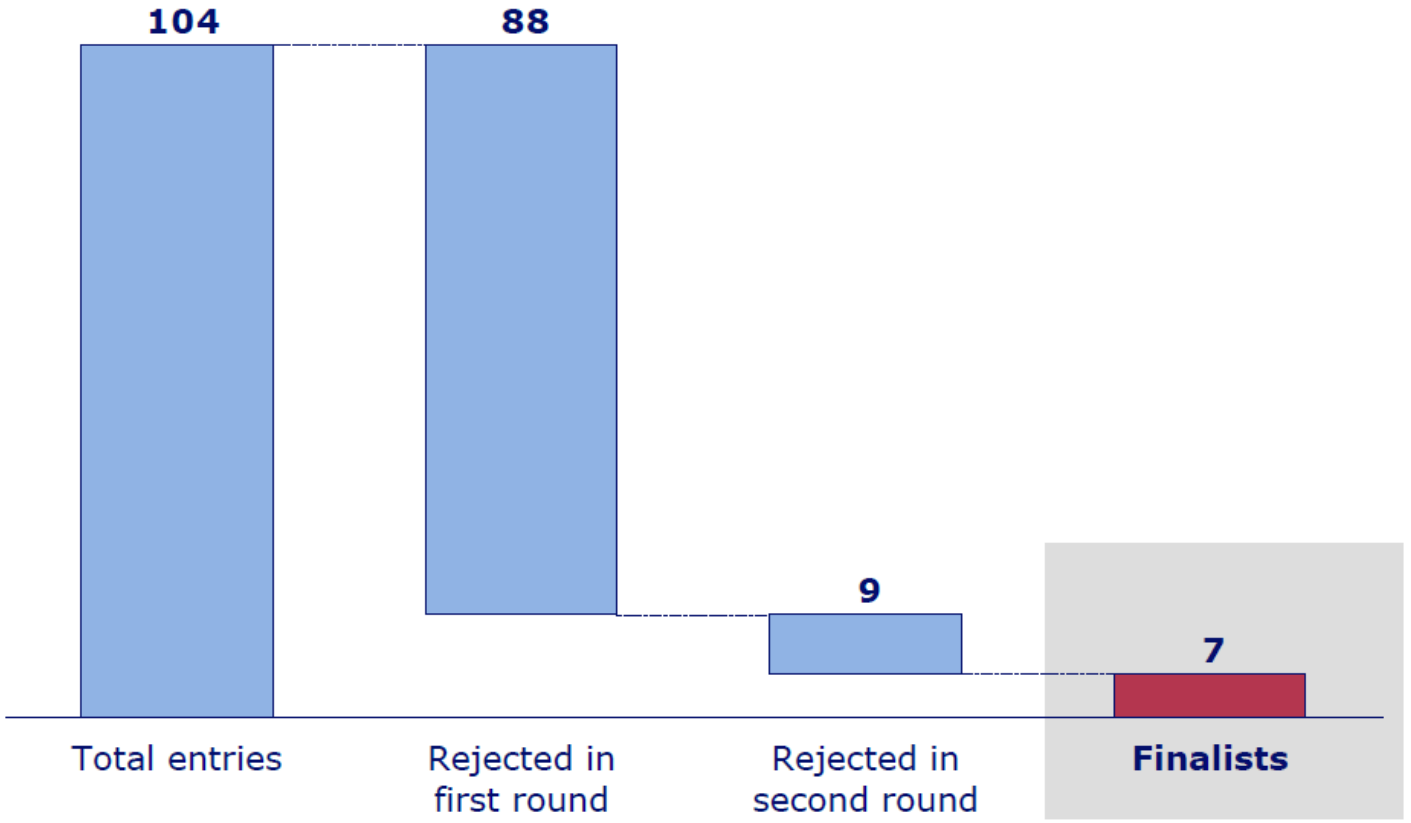
Competition attracted 104 entries from around the World

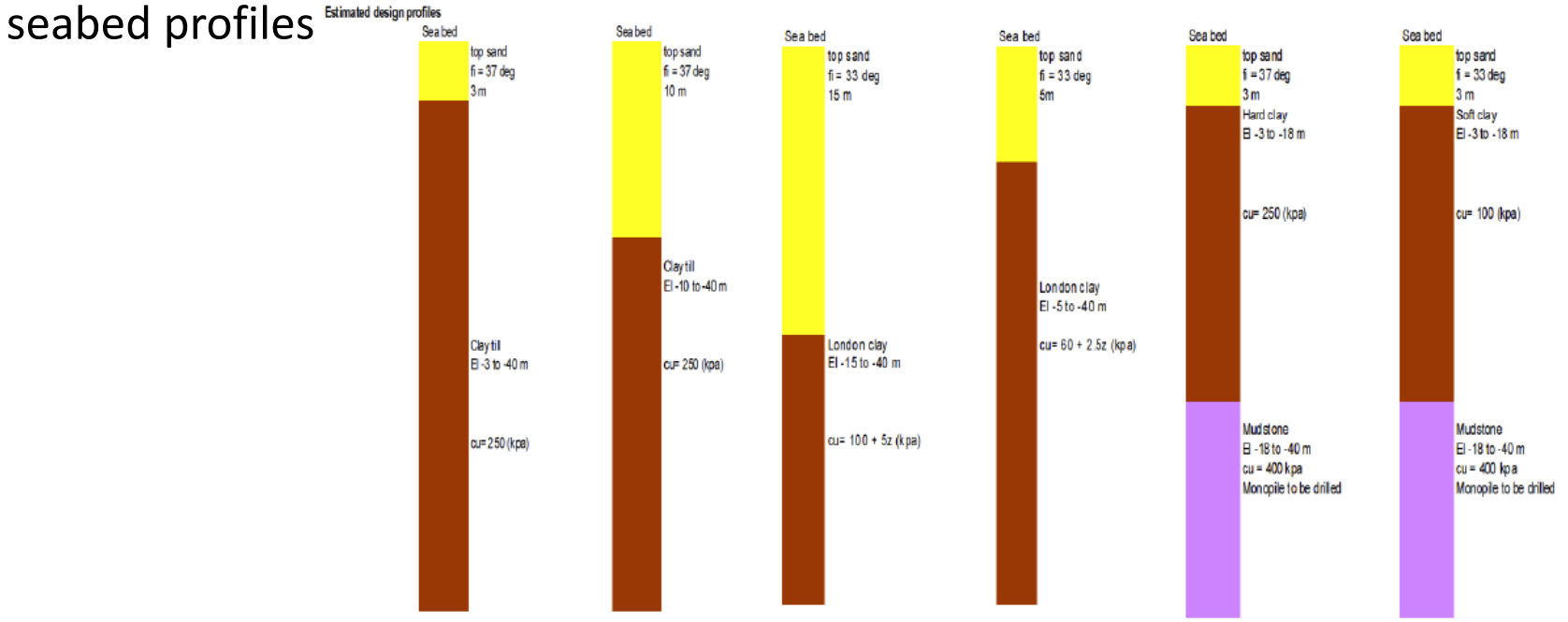
Seven concepts were selected as finalists



Source: Carbon Trust

Stage I: Foundation Designs total 72

- Fixed prices
- Two turbine: 3.6 and 5 MW
- Water depts: 35m, 45m and 55m
- Two see condition Aver. and Exp.
- 6 seabed profiles



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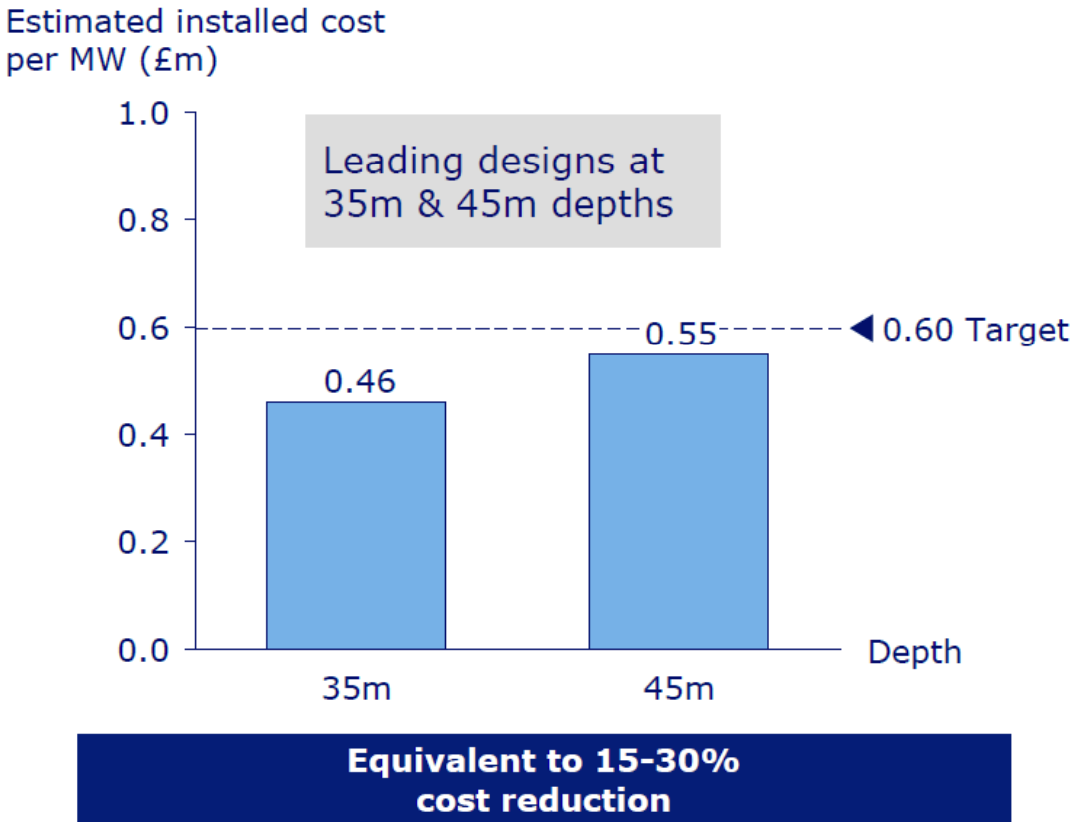
Estimated installed costs show promise

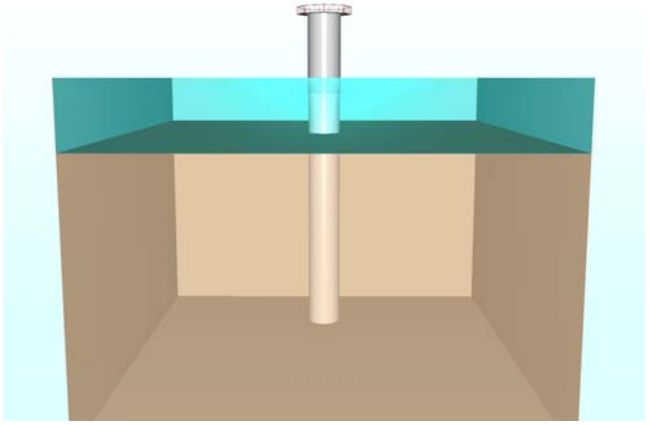
5MW turbine, normal climate



Equivalent to 15-30% cost reduction

Foundation concepts for offshore Wind Turbines
Shallow depth 10-30m

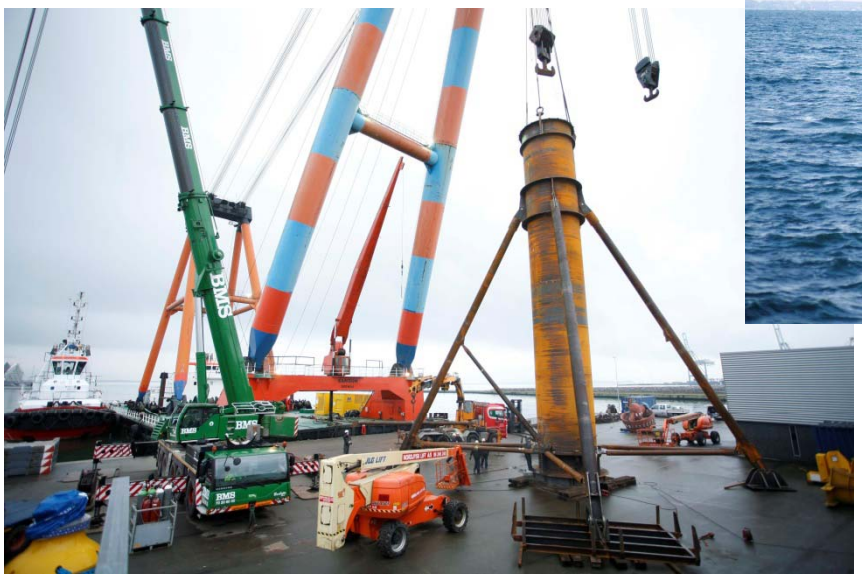
- Mono piles
  - 75% of all wind parks today
  - Simple fabrication with welded steel pile
  - No preparations of the seabed are necessary.
  - Requires heavy duty piling/drilling equipment
  - Not suitable for locations with many large boulders in the seabed.



Noise

- The recommended requirements of maximum: 160 dB SEL and 190 dB Peak for underwater pile driving noise levels.

- So far, Germany is the only country having ratified the legislation, but the remaining EU countries are expected to follow Germany's example.



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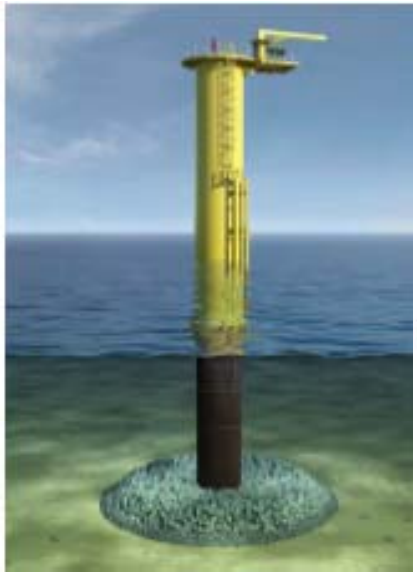

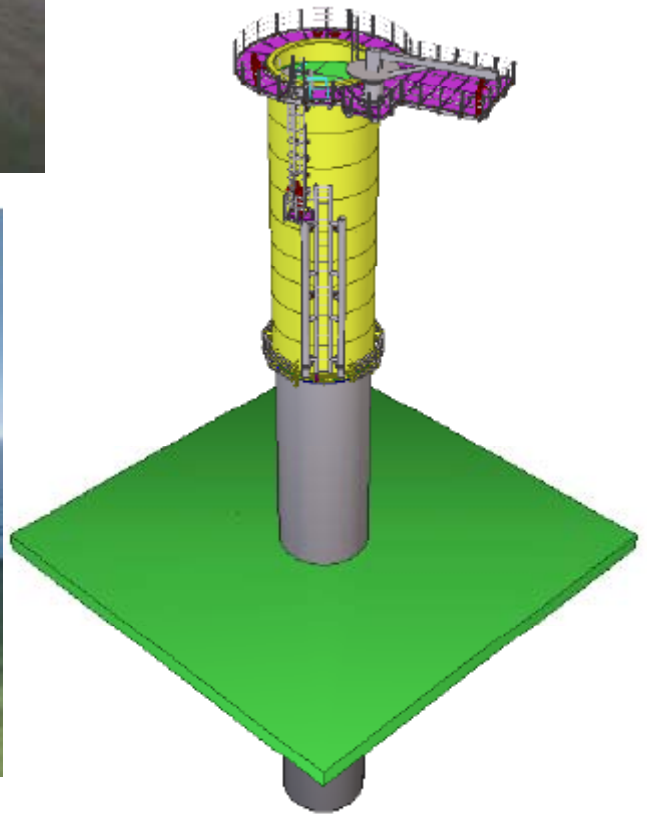

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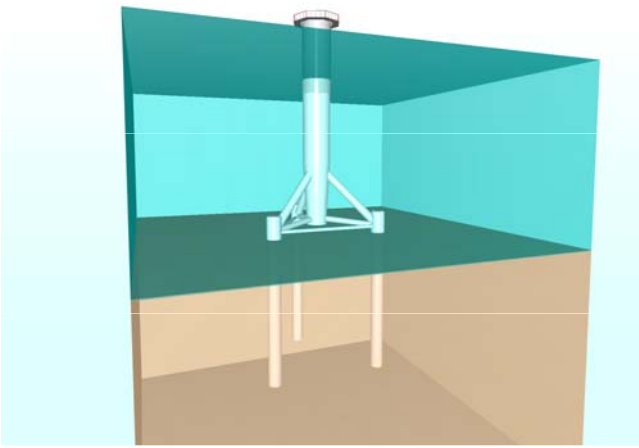
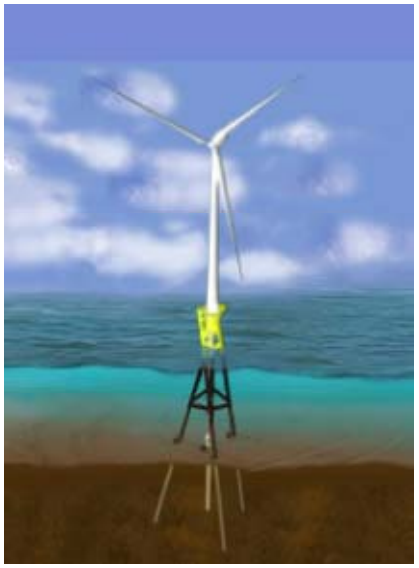
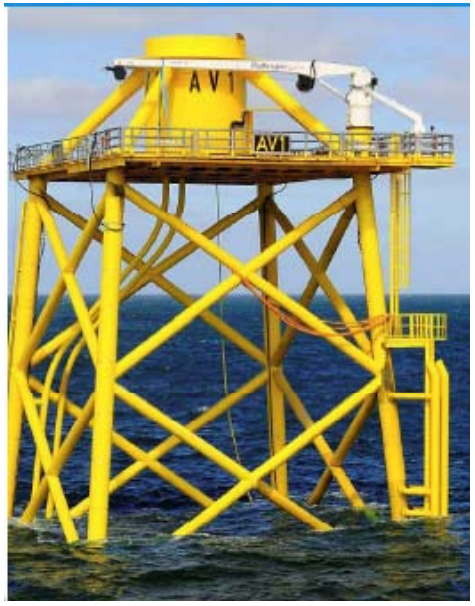
Foundation concepts for offshore Wind Turbines
Depth 30-60m

- Jackets and Tripod
  - Suitable for larger water depths.
  - Minimum of preparations are required at the site before installation
  - Complex welded main structure
  - Known technology from oil & gas industry







Foundation concepts for offshore Wind Turbines
Depth 30-60m

Tripod

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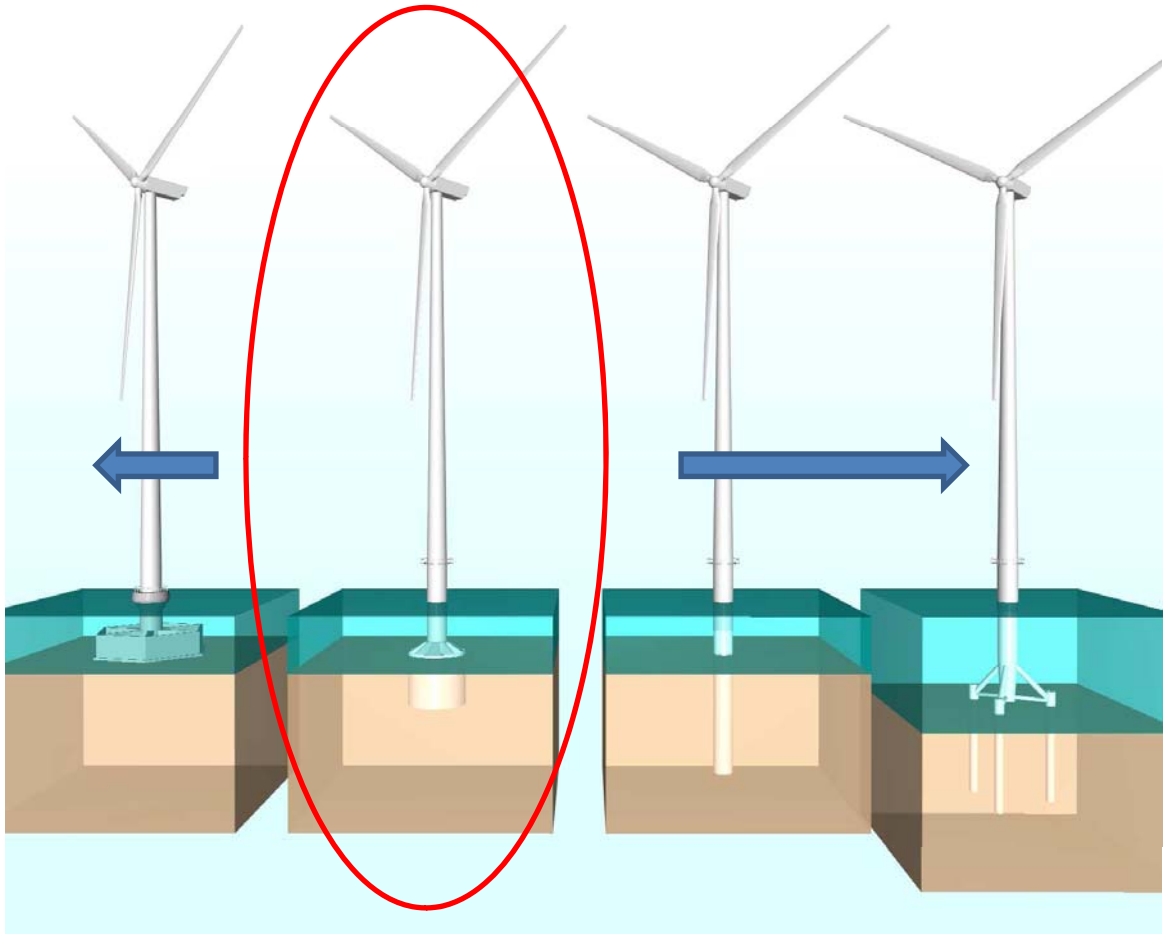
Offshore wind turbine foundations

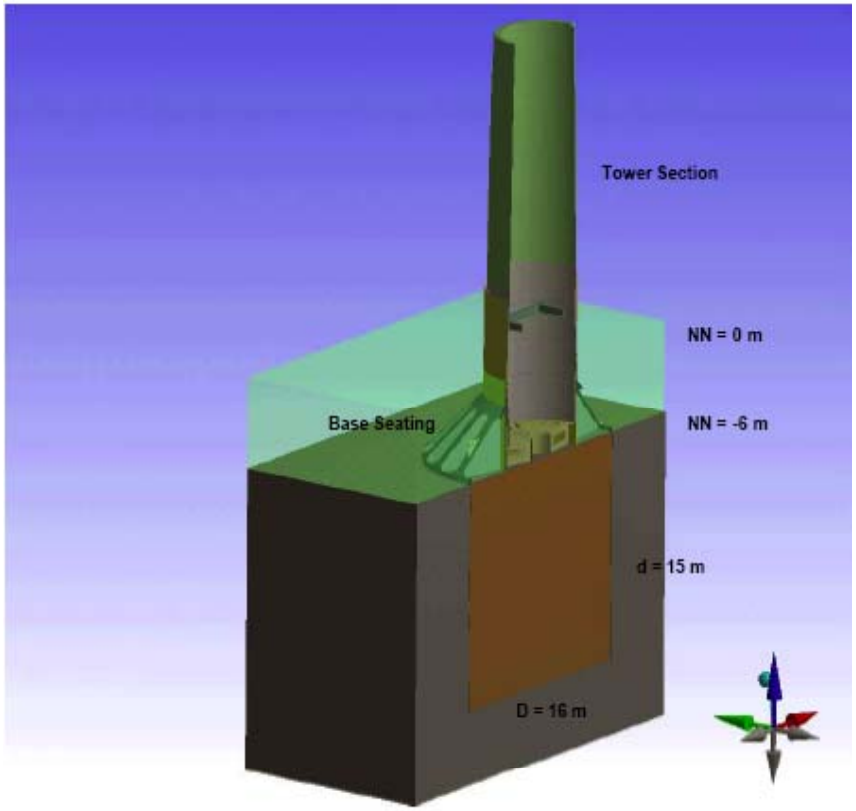


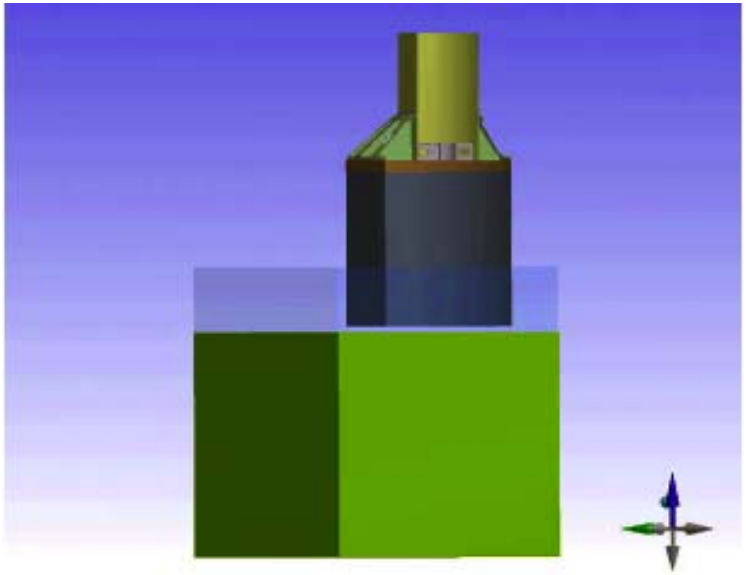
Platform **Bucket** **Mono pile** **Tripod/ jacket**

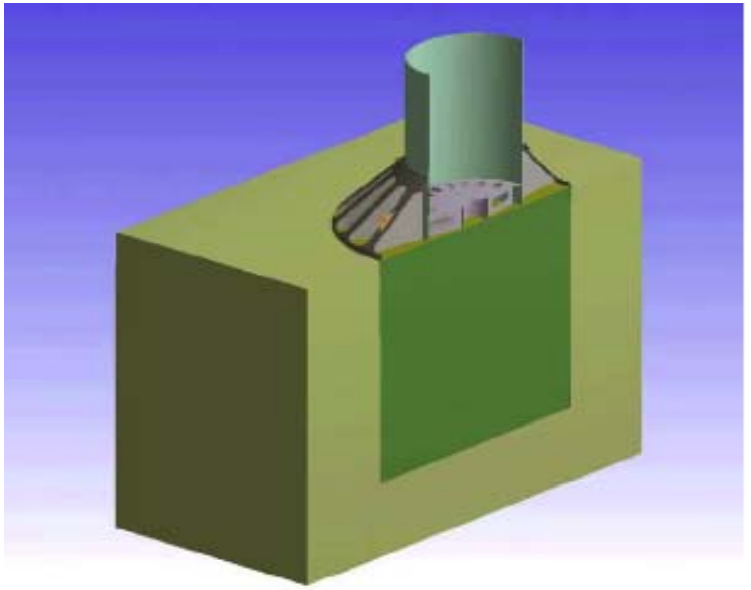
The **flexibility** of the bucket foundation gives **wider range** of application.

Sites with **complex** geotechnical properties can be cover by a **single foundation concept**

The Bucket foundation







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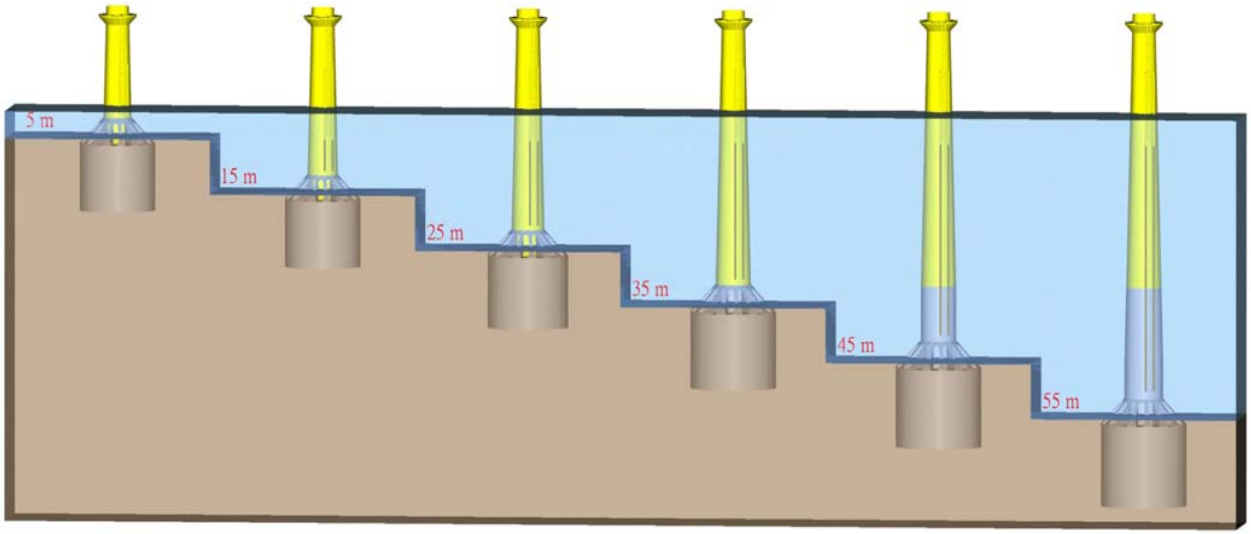
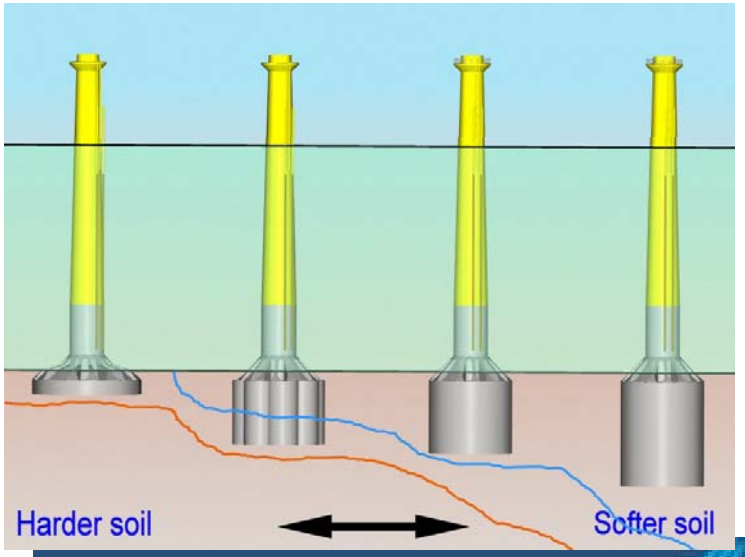
Universal foundation solutions

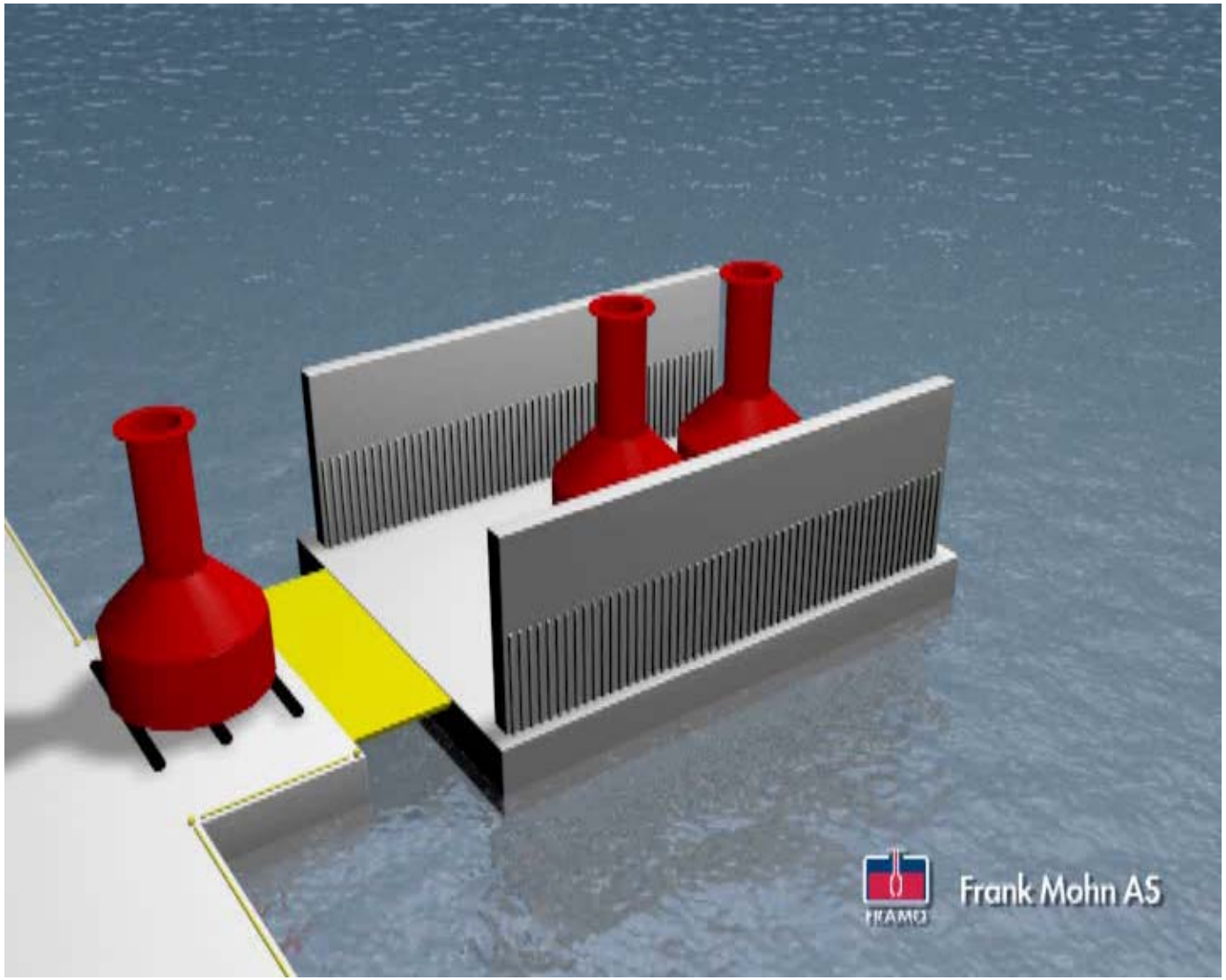


Variation in water depth
0 - 60 m

Variation in seabed properties
Hard clay, soft clay, sand, silt



Vision for Installation in 2001



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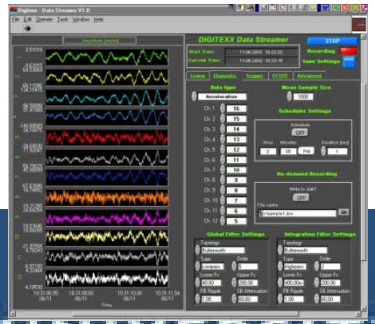
Reference 1: Pos. 1-Frederikshavn in operation 9 years

The Ø12x6 m prototype bucket foundation was designed for a Vestas V90 3MW turbine placed on 4 m of water. The design is certified by DNV. The bucket was installed in late 2002 and is in normal operation. The structure/soil interaction has been investigated with sophisticated modal analyse equipment.



The bucket foundation technology

Installation advantages:

- **Minimum noise impact**. No pile driving hammers or drill drives are used.
- **No grouted** connections.
- **Minimum disturbance** to the existing seabed.
- The use of excess material for **scour protection is reduced** or not necessary.
- All steel materials can be recovered from the seabed and **reused / recycled** when the foundation is decommissioned.

Reference 2: The Mobile Met Mast Horns Rev II 2009

"The Mobile Met Mast" is a prototype of a bucket foundation designed as support structure for a met-mast.

Purpose:

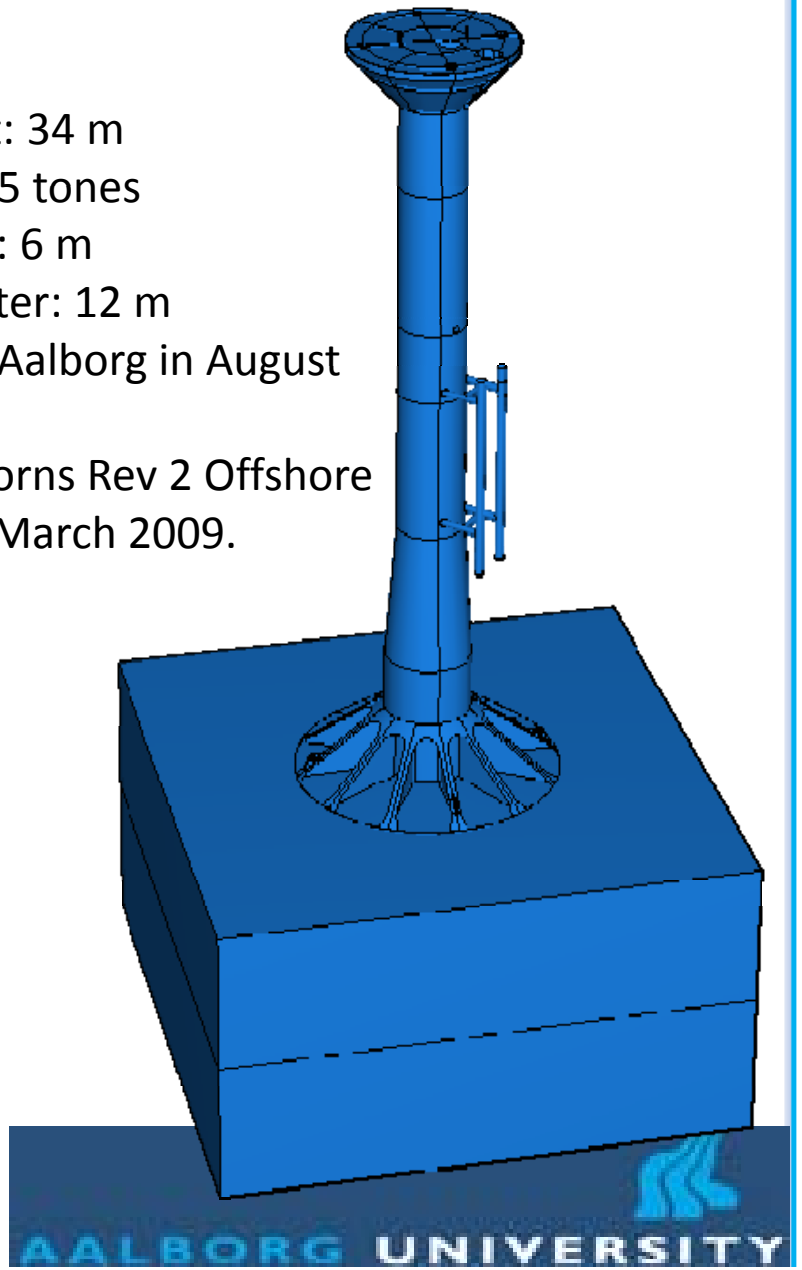
- To gain **confidence** that a monopod bucket foundation can be successfully installed offshore.
- To obtain a **movable met-mast**, which can be used in several offshore wind farms.

Specification

- Total height: 34 m
- Weight: 165 tones
- Skirt length: 6 m
- Skirt diameter: 12 m

Fabricated in Aalborg in August 2008.

Installed at Horns Rev 2 Offshore wind farm in March 2009.



Launching

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Float out to site

- Floated to site using 2 tug boats
- 40 m^3 water was pumped into the head of the Mobile Met Mast to ensure a horizontal orientation when floating.

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Site for installation

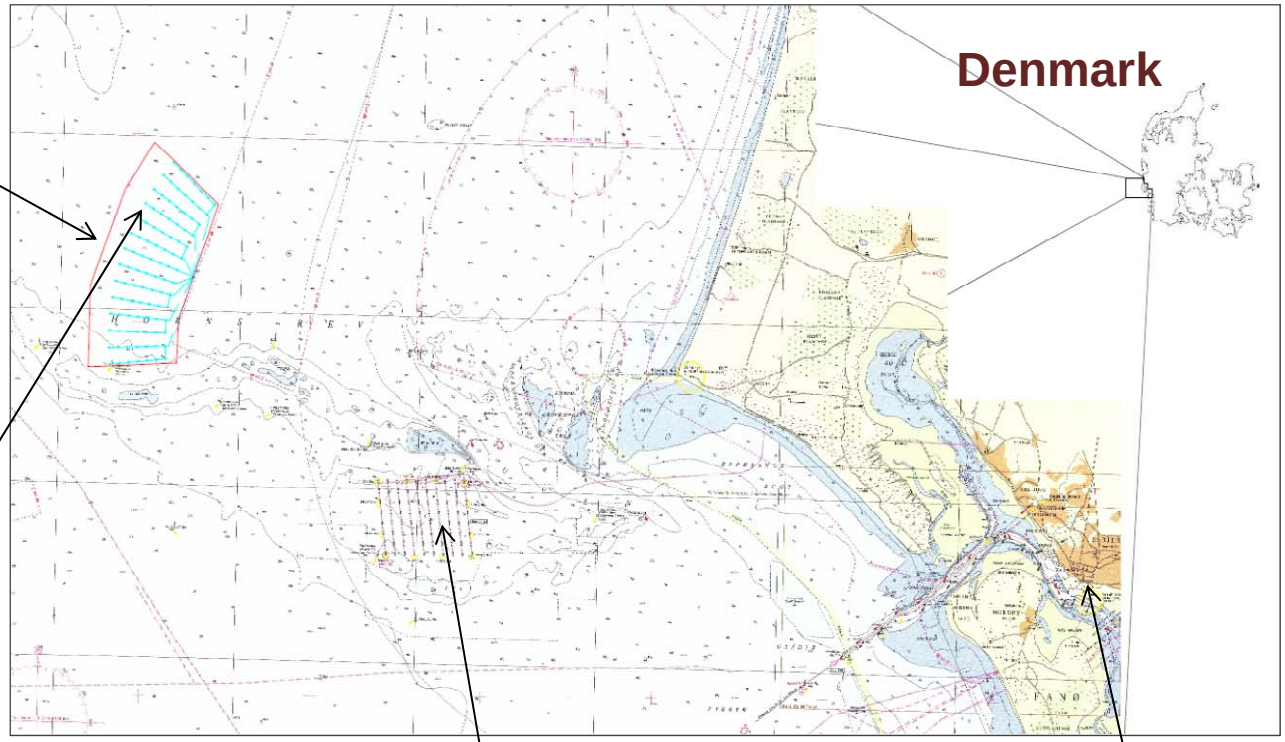
Horns Rev 2

Wind turbines:
- 91 Siemens 2.3MW
- 200 MW

Scheduled installation:
- - 2008: Foundations
- - 2009: Turbines

The Mobile Met Mast

- 3 installation tests were planned at different locations. (depending on weather)
- Was only installed on the final location.
- No data from CPT or borings are available (yet)



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The Mobile Met Mast
Offshore installation Horns Rev II 2009

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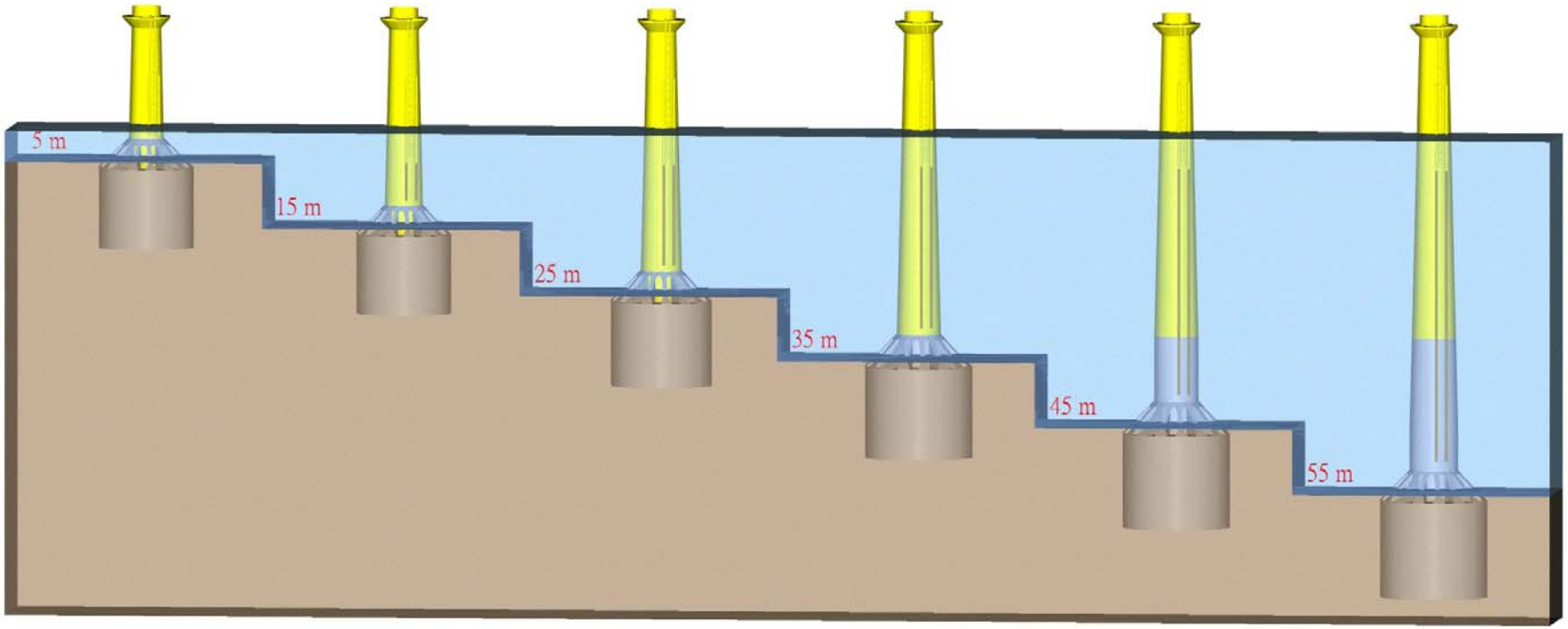
Cases: Carbon Trust Wind Accelerator Project



Water depth	5 m	15 m	25 m	35 m	45 m	55 m	
Moment kNm	127.000	156.000	196.700	255.000	300.000	350.000	3.6MW
Bucket size m	Ø14x11	Ø15x12	Ø16x13	Ø17x14	Ø17x15	Ø17x16	
Weight tons	295	392	503	640	780	952	
Moment kNm				355.000	405.000	480.000	5MW
Bucket size m				Ø18x15	Ø18x16	Ø18x17	
Weight tons				760	920	1080	

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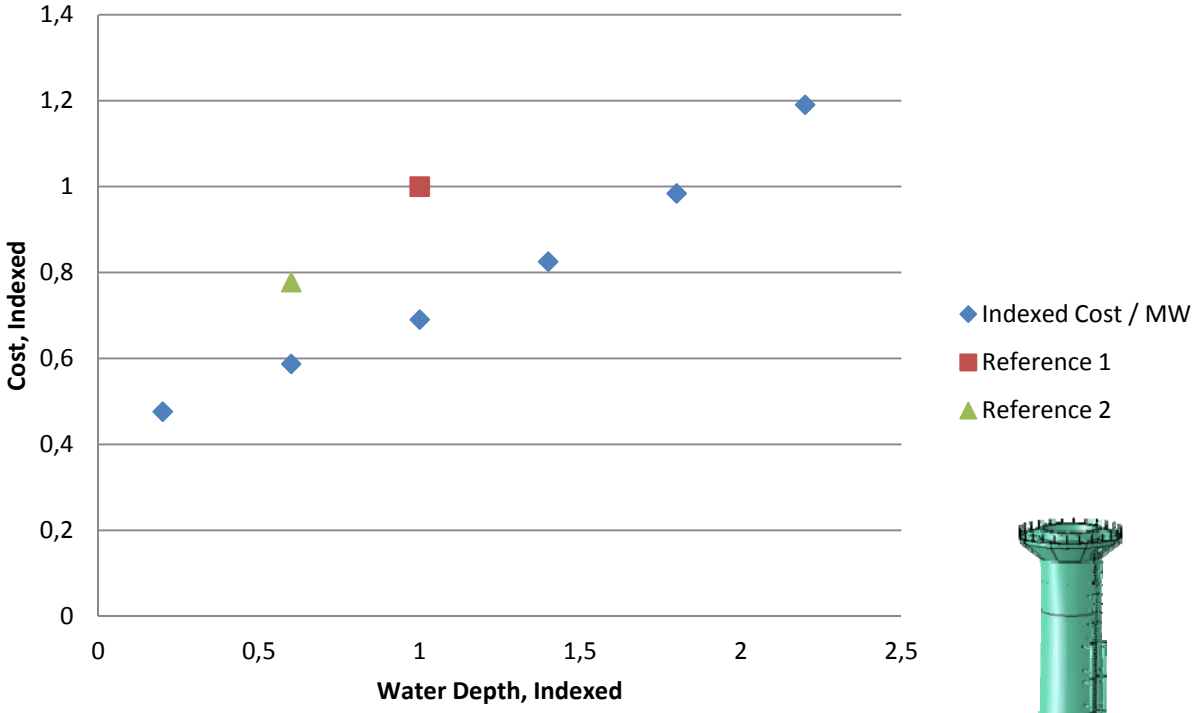
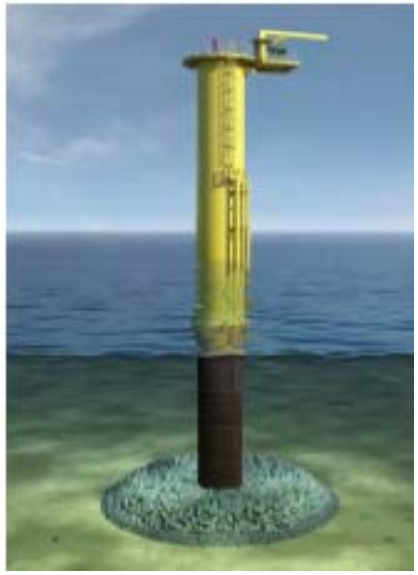
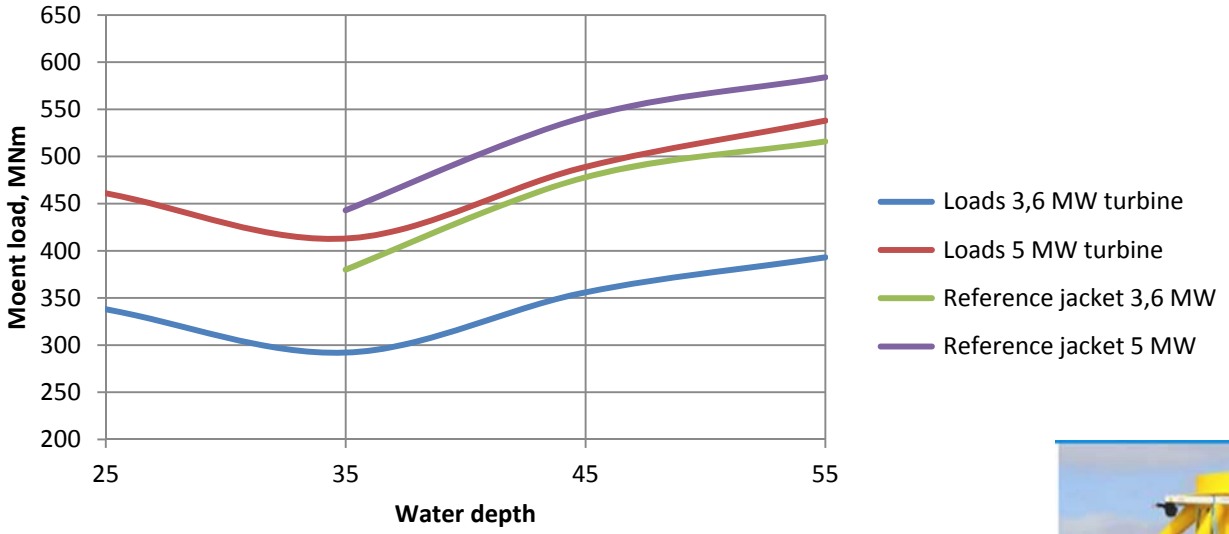
Costs Bucket Foundation - Monopile





Dogger Bank,
Foundation loads at seabed



Dogger Bank, data.

Loads Bucket foundation [MNm]	*)			
Water Depths	**25**	**35**	**45**	**55**
Loads 3,6 MW turbine	338	292	356	393
Loads 5 MW turbine	461	413	489	538
Reference jacket 3,6 MW		380	478	516
Reference jacket 5 MW		443	542	584

*) breaking waves

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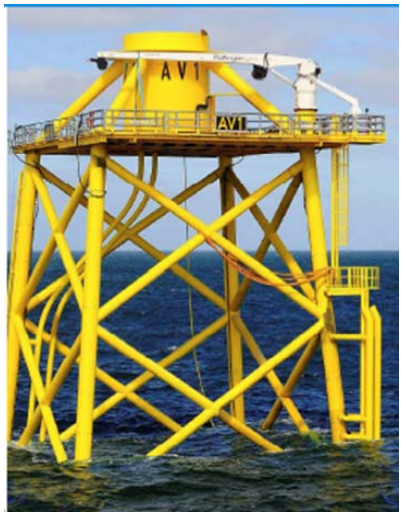
Comparison of Foundation Types		
Basis of Comparison - Tenders for Manufacture of 80 No. Foundations		
Foundation Type	Steel Weight (Gross) each	Cost % comparison
Tripod	1453	1.00
3-Leg Jacket	1394	0.96
4-Leg Lightweight Jacket	1170	0.84
Universal Foundation	992	0.50
Comments		
Note to balance the cost, Insurance, Bonds and Guarantees have been removed, where appropriate, as these were not applied equally to all tenders.		
Where service cranes were required to certain types, these have been removed		
Load out and transportation has been removed, where appropriate		

Installation cost of 100 foundations incl. of turbine installation

Carbon Trust Installation derisk study

	A2SEA	DEME	Technip
Buckets	100	100	100
Ref jacket	128	162	149



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Universal Foundation A/S

2011 - MBD Offshore Power A/S -> Universal Foundation A/S

Universal Foundations - Concept IP Holder

Universal Foundations – Solution Provider

Fred.Olsen

Dong Energi

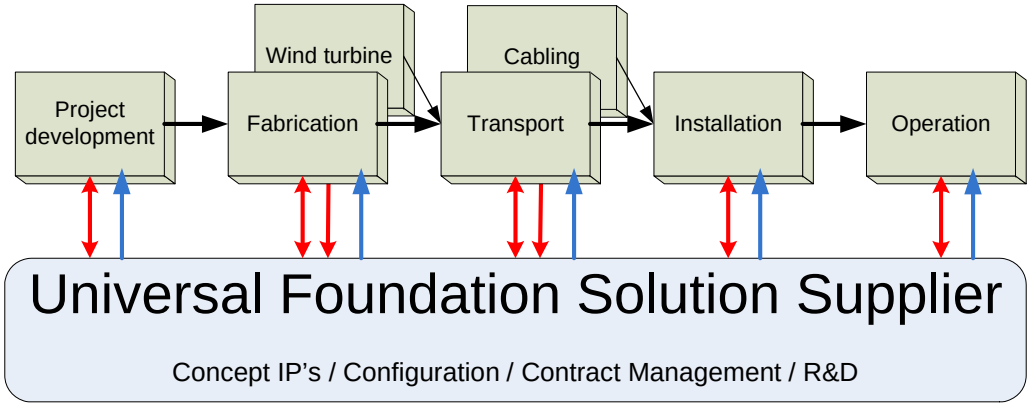
Novasion

Aalborg University

AALBORG UNIVERSITY

Universal Foundation

The Supply Chain



Buckets – a wide-ranging foundation solution

Client

Contract

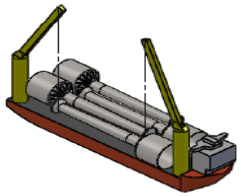
Fred. Olsen United AS

Fred.Olsen & Co /

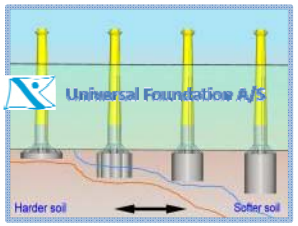
Support by way of
- Legal
- Accounting
- HR
- Finance

GLOBALWINDSERVICE

Fred. Olsen Windcarrier



Fred. Olsen Windcarrier



harland and wolff
heavy industries limited

SeaRoc

natural power

Universal Foundation A/S

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We are now launching Offshore Wind Accelerator Stage II

Objective: Reduce cost of energy by 10% through RD&D

Original partnership

CARBON TRUST

DONG energy

RWE The energy to lead

SCOTTISHPOWER RENEWABLES

SSE Renewables

Statoil

New partners

MAINSTREAM RENEWABLE POWER

Statkraft

- **4-year commitment**
- **Two new developers**
  - **Statkraft**
  - **Mainstream Renewable Power**
- **56% of licensed capacity in UK waters (~27GW)**
- **Total budget of £10m for collaborative R&D**
- **Up to £30m of demonstration projects**

Source: Carbon Trust

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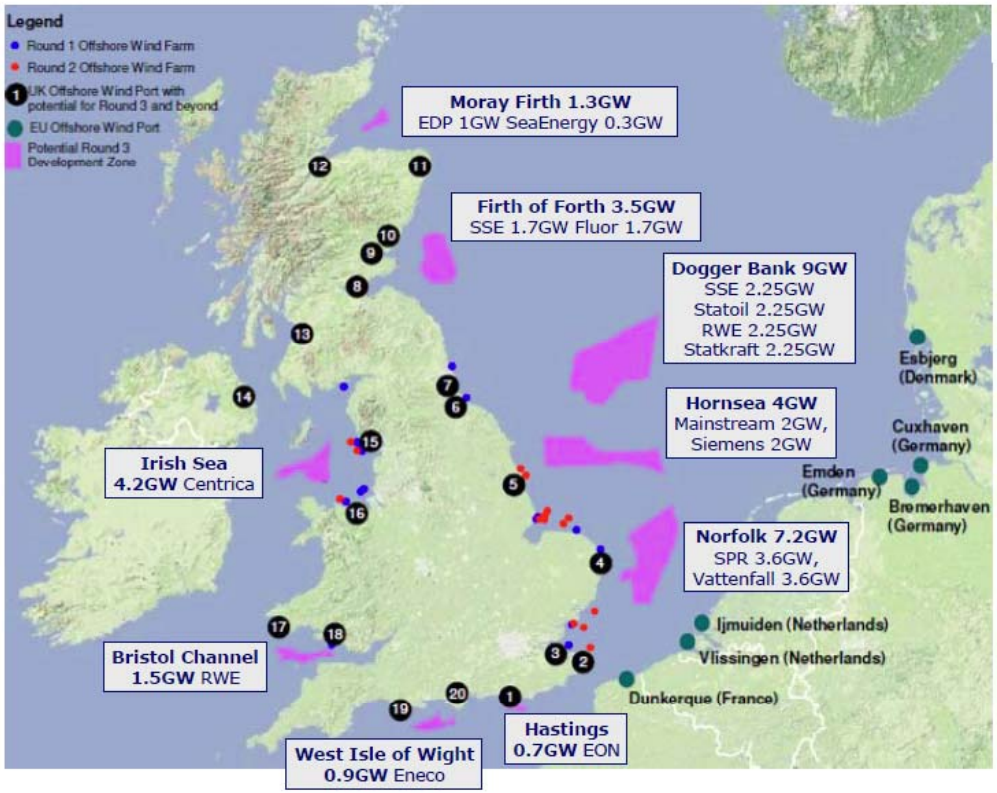
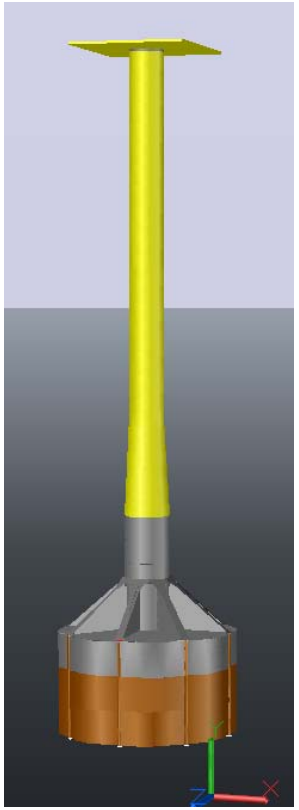
Dogger Bank: Two Metmast installations - August 2012. 24m of water.

Firth of Forth: Metmast installation – August 2012. 38m of water.





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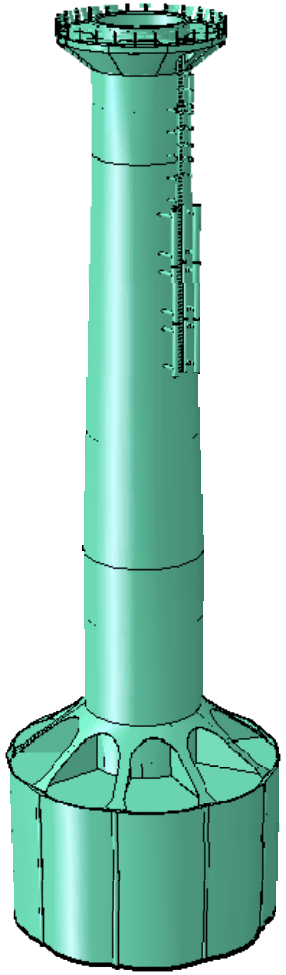
Conclusions



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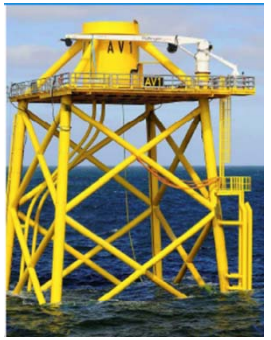
Mono Buckets - Versus Monopiles

- **Minimum noise impact**. No pile driving hammers or drill drives are used.
- **Few offshore operations**, with utilizing smaller equipment/vessels during installation.
- **No seabed preparation** and **no** or reduced need for **scour protection.**
- **No transition peace -** Adjusting the upper part of the shaft to fit the **standard wind turbine tower**.
- **Simple** decommissioning.
- **Cost reduction with 20%.**

Mono Buckets - Versus Jackets

- **Reduced steel** consumption compared to the Jacket.
- Use of **simple geometric** welded steel structures **suitable for mass production.**
- Bucket **20% expensive 80% cheap** welded steel. Jacket **80% expensive 20% cheap.**
- **Few offshore operations**, with utilizing smaller equipment/vessels during installation.
- **No seabed preparation** and **no** or reduced need for **scour protection.**
- **No transition peace -** Adjusting the upper part of the shaft to fit the **standard wind turbine tower**.
- **Simple** decommissioning.
- **Cost reduction 30-50%.**



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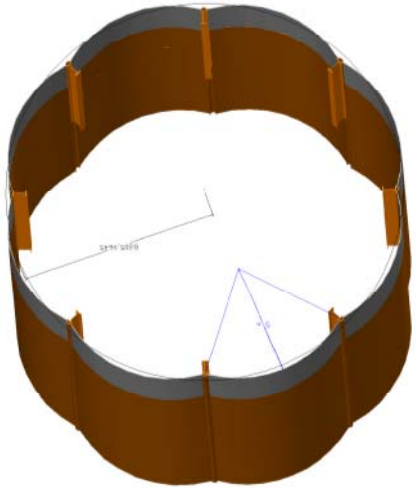
Thank you for listening

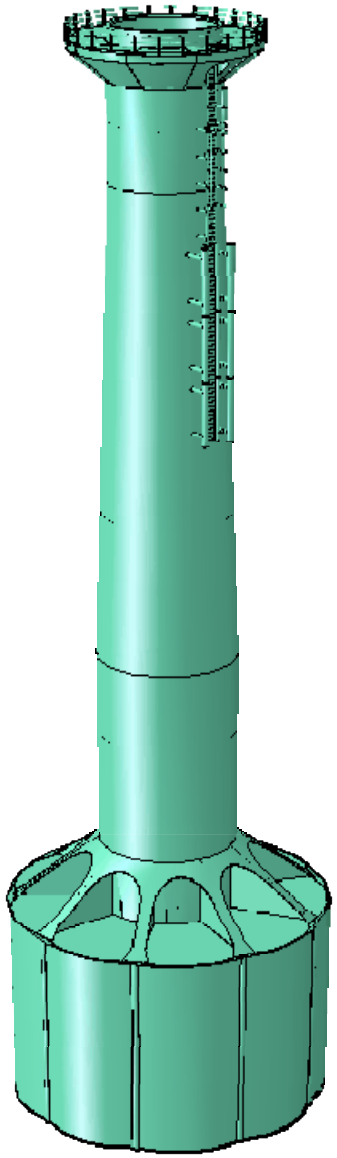
Questions ?

Lars Bo Ibsen

lbi@civil.aau.dk

www.civil.aau.dk





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