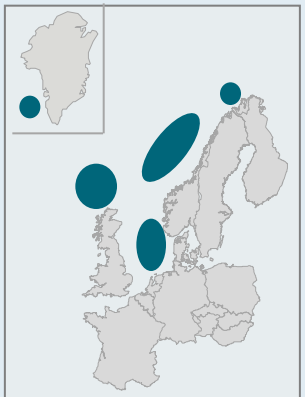
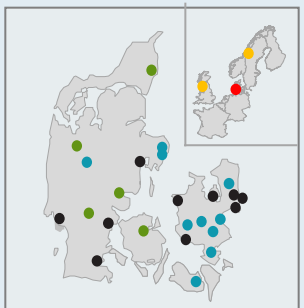
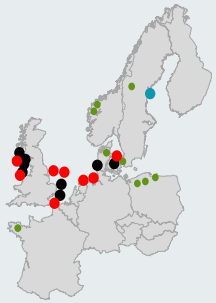
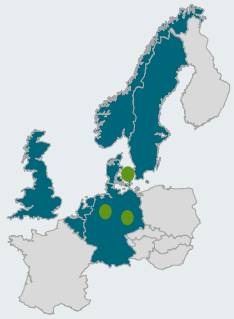
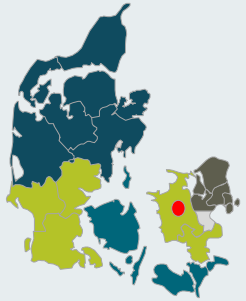
Dansk spuns- og rammedag
Offshore wind farms - Foundations

23 maj 2013

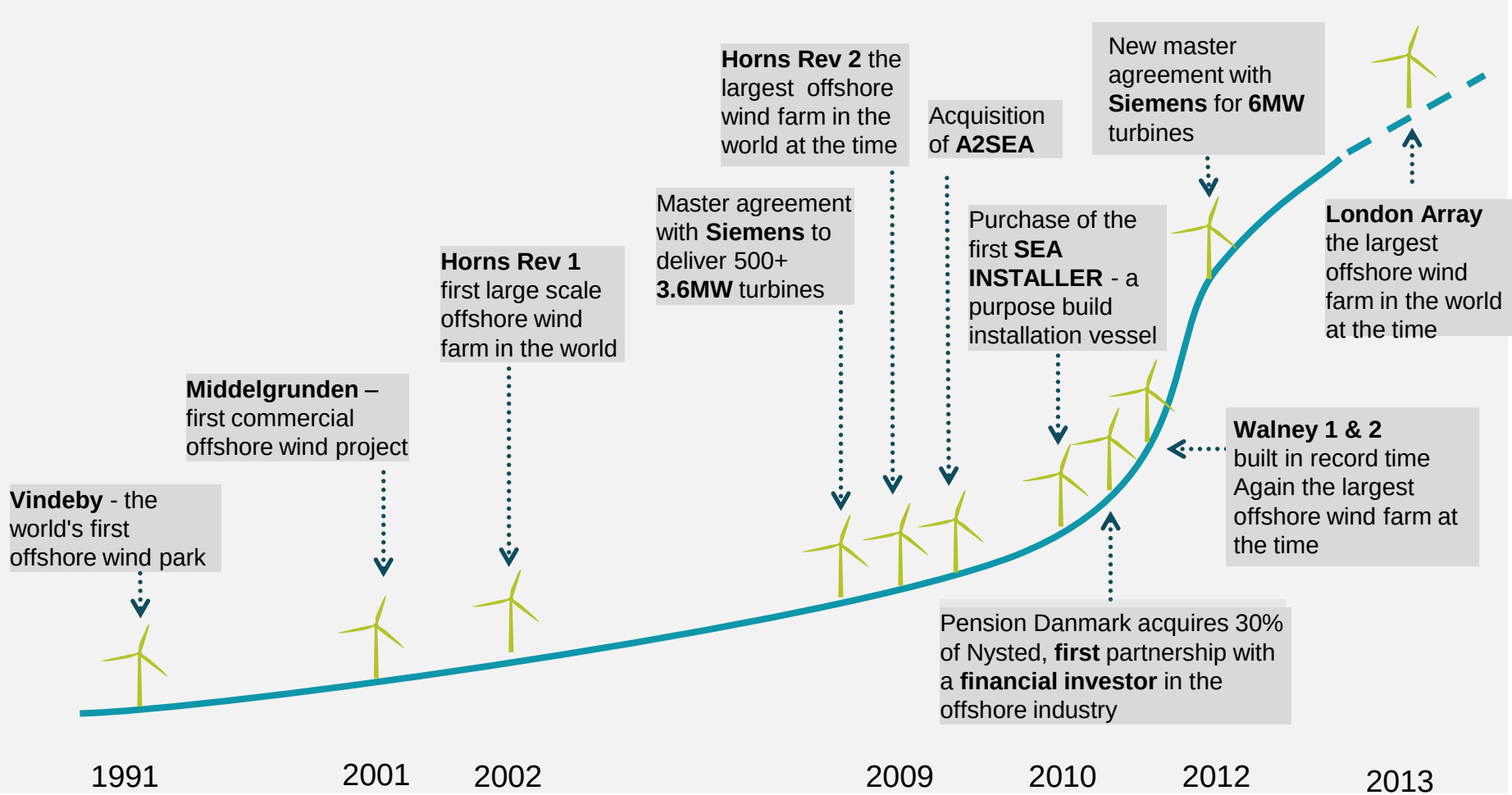
By Hans Pedersen /
Jon Kringelum

DONG Energy is an integrated energy company and active throughout the value chain

	E&P	Thermal Power	Wind Power	Energy Markets	S&D
Main positions	 Geographic focus areas	 Central power plant Waste-to-Energy generation Small-scale CHP plants Gas-fired power plant Gas-fired power plant under construction	 Offshore wind Onshore wind Hydro power Wind farms under planning/construction	 Power and/or natural gas customers Gas storage capacity	 Power and gas sales Gas distribution Power distribution Gas storage
Current market position	Strong and growing equity gas position	The leading thermal generator on Nord Pool and market leader in district heating in Denmark	Growing wind power portfolio with market leading position in offshore wind power	Leading position in power and gas infrastructure. Retail positions in Sweden and Holland	Leading seller of power and natural gas in Denmark and active in several other countries

Source: DONG Energy

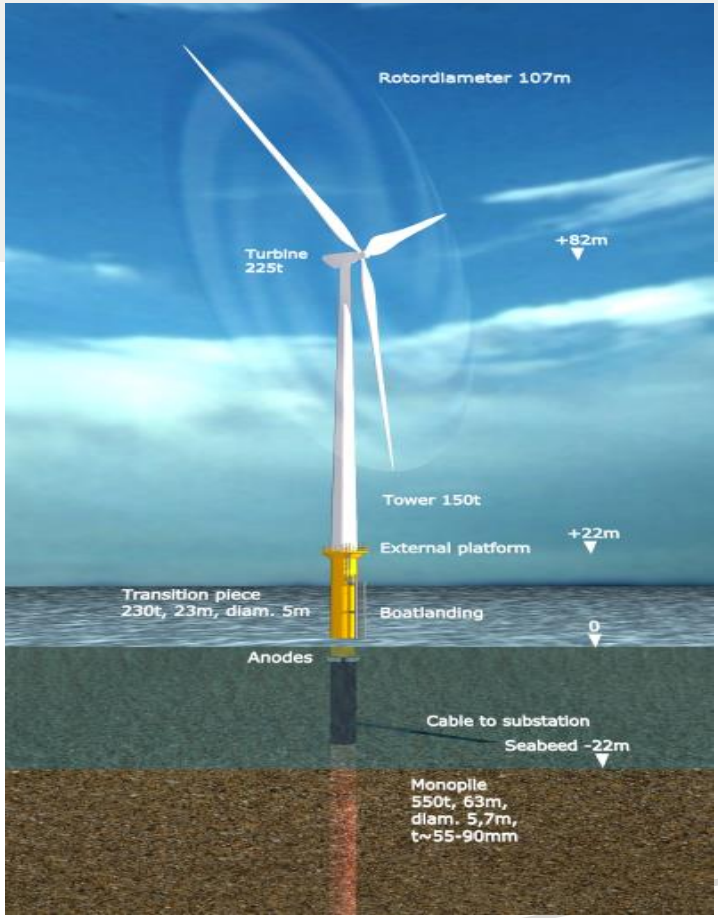
Wind Power has been leading the offshore wind industry from the very beginning



Infancy **Childhood** **Teenage**

DONG energy

Piled Foundations



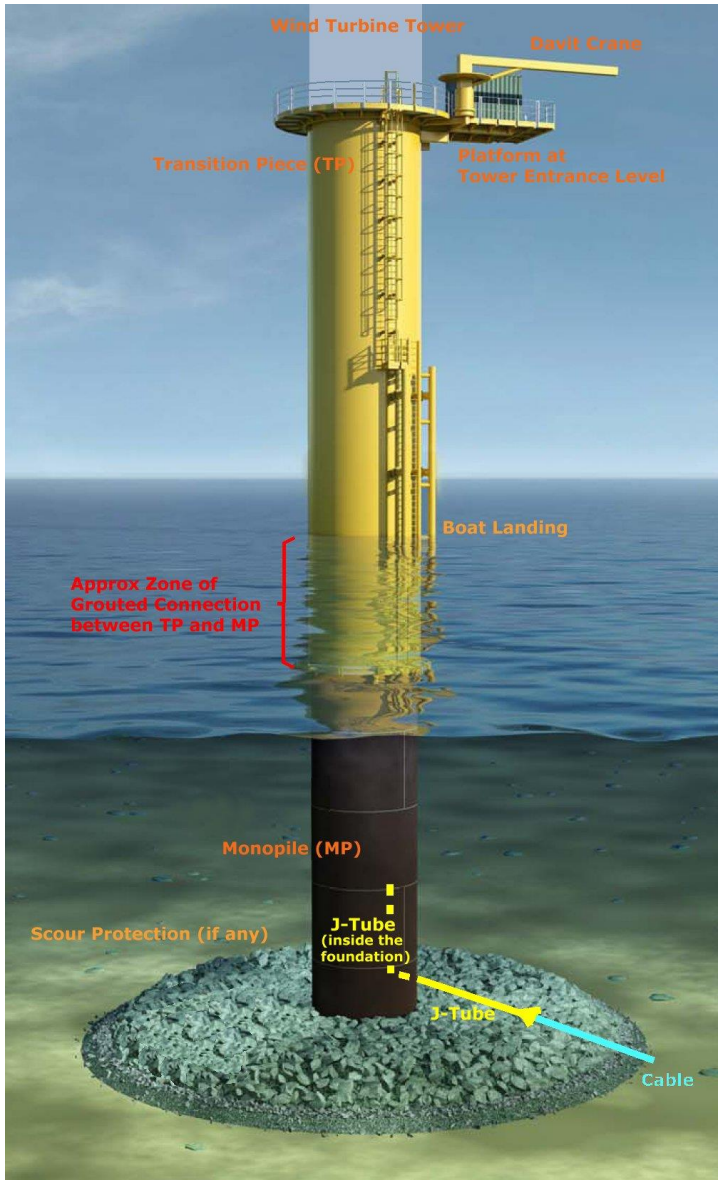
Monopiles

- From monopile foundations
- To jackets foundations on deeper waters

Jackets

DONG energy

Monopile Foundation Typical



DONG energy

Development of Monopiles

Project	Year Completed	Wind Turbine			Monopiles (MP)		
		Nos	Type	Size	Dia. (m)	Max Length (m)	Max Weight (tons)
Horns Rev (1)	2002	80	Vestas	2,00 MW	4,0	33	155
Kentish Flat	2005	30	Vestas	2,75 MW	4,3	41	181
Burbo Banks	2006	25	Siemens	3,60 MW	4,7	37	234
Rhyl Flats	2008	25	Siemens	3,60 MW	4,7	37	234
Linn & Inner Dowsing	2008	54	Siemens	3,60 MW	4,7	41	266
Robin Rigg	2008	60	Vestas	3,00 MW	4,3	45	264
Gunfleet Sands I & II	2009	49	Siemens	3,60 MW	4,7	54	423
Greater Gabbard	2009	140	Siemens	3,60 MW			650
Sheringham Shoal	2011	90	Siemens	3,60 MW	5,7	60	550
Walny 1 &2	2011	102	Siemens	3,60 MW	6,5	68	810
West of Duddon Sands	1013	108	Siemens	3,60 MW	6,0	55	520
Borkum Riffgrund 1	2014	77	Siemenns	3,60 MW	5,9		683
Westermost Rough	2014	35	Siemens	6,00 MW	6,5	65	805
GodeWind 1 & 2	2015	97	Siemens	6,00 MW	7,5	~67	~1012

DONG energy

Development of Installation Vessels

- From barge modified Jack-ups
- To advanced selfpropelled Jack-ups

Innovation w/ 1500T crane

Pacific Orca w/ 1200T crane

Seajack w/ 1200T crane

DONG energy

..and Large Heavy Lift Floating Vessels

from the Bridge Building and Offshore industries

DONG energy

Pile Handling

Monopiles on jack-up using up-ending tool

DONG energy

Pile Handling

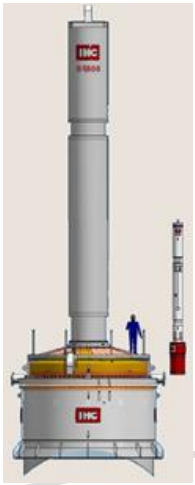
Floating Piles and Lifting Trunnions

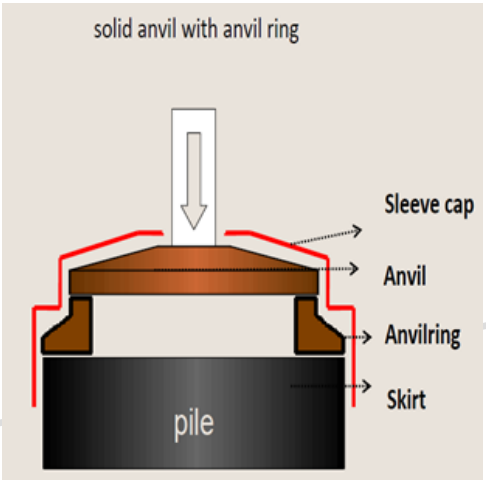
DONG energy

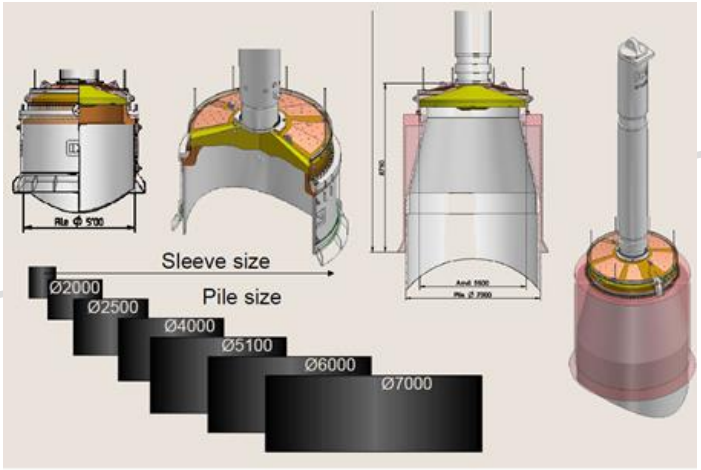
Pile Driving

Development of Hydraulic Hammers:

Project	Hammer Energy
Horns Rev 1	600 kJ
Burbo Banks	800 kJ
Lynn & Inner Dowsing	1500 kJ
Lincs	1900 kJ
Coming projects	2000 - 3000 kJ



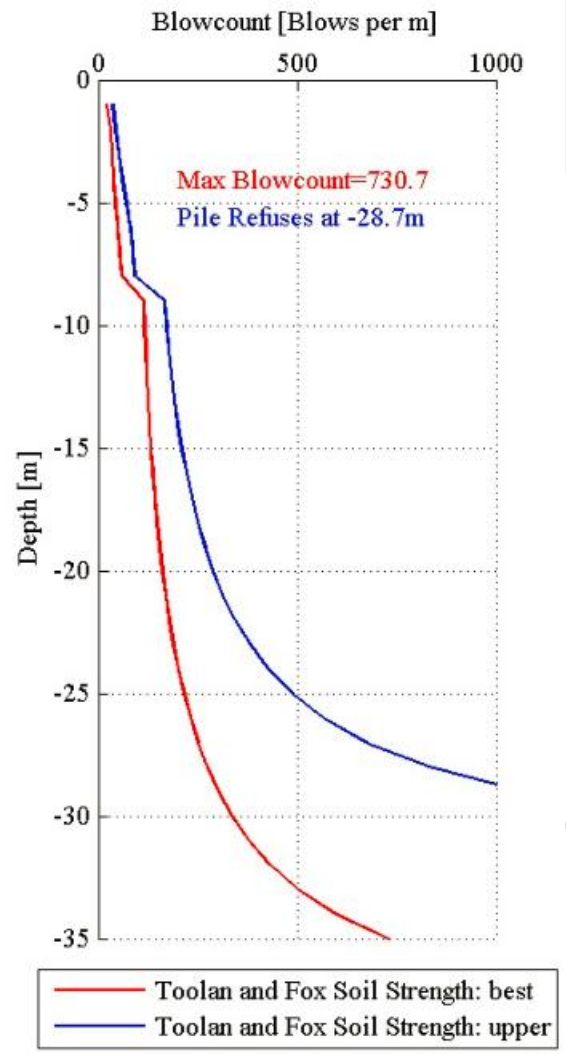




DONG energy

Pile Driving

Driveability analysis, refusal & drilling:

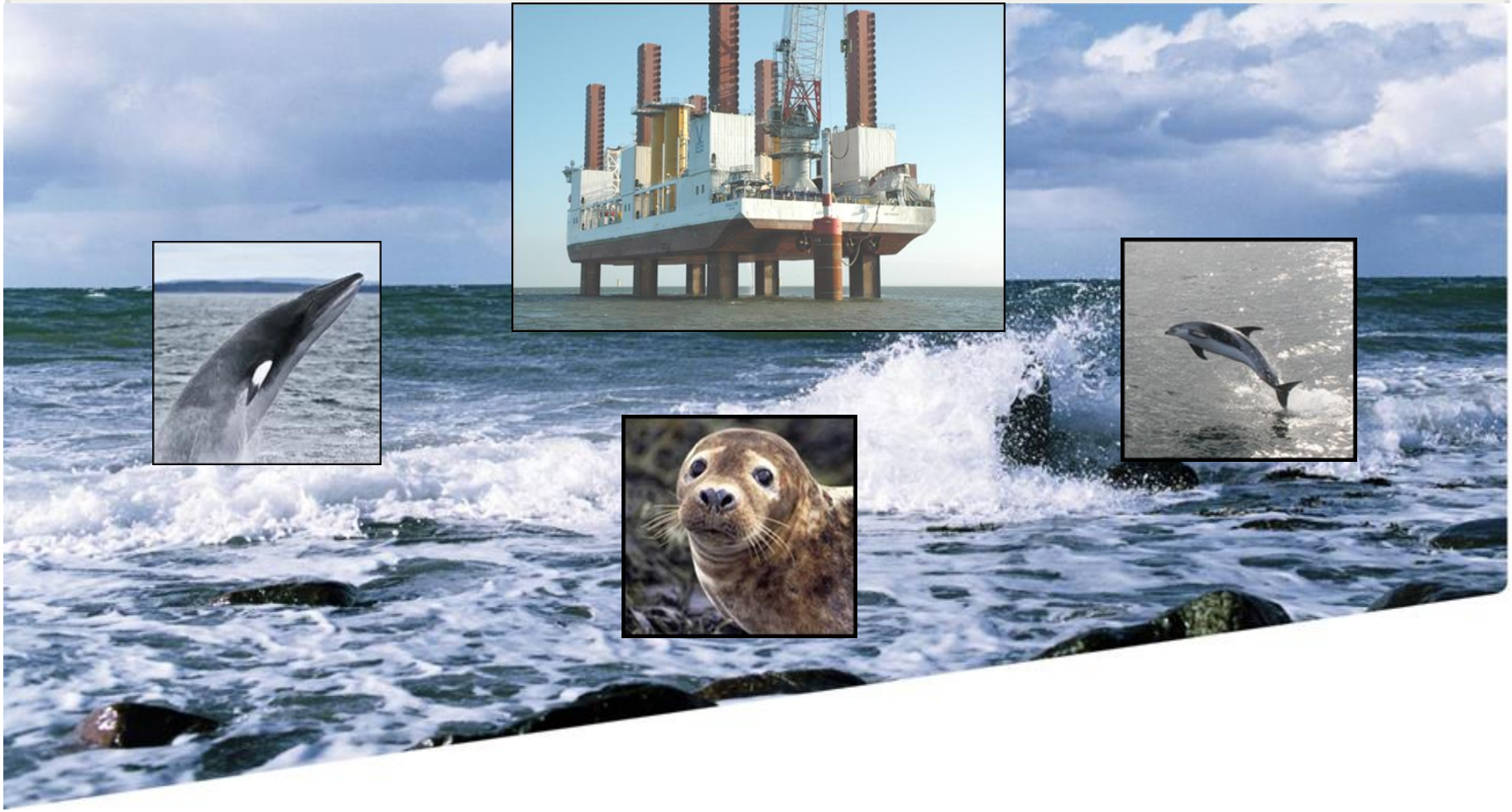


DONG energy

Noise & Environment

Challenges

- **Air-borne Noise: Not an issue when far from shore**
- **Underwater Noise: Increasing issue**



Underwater Noise

Strict Requirement for Noise Emissions in Germany:

Maximum Emission at 750m: 160 dB (SEL)
Noise Emission for monopile: ~ 180 dB (SEL)
Required noise reduction: ~ 20 dB (SEL)

Tough challenge!

- Noise mitigations must be employed
- Will increase cost and risk in a market committed to reduce the cost of energy!

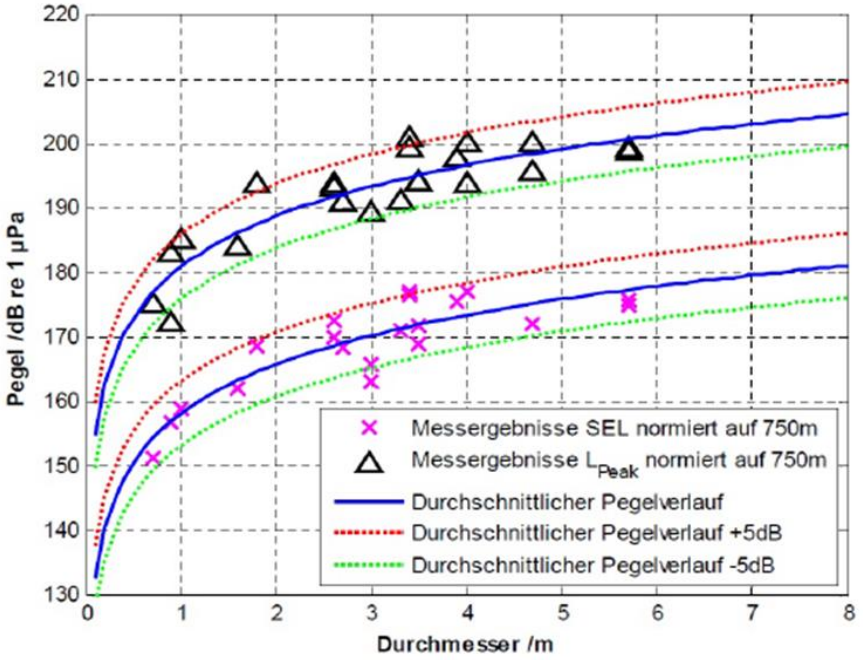


Fig. 3-1 Sound emission from piling increases with pile diameter (ITAP 2012).

❖ The Sound Exposure Level (SEL) sums the acoustic energy over a measurement period and is defined as:

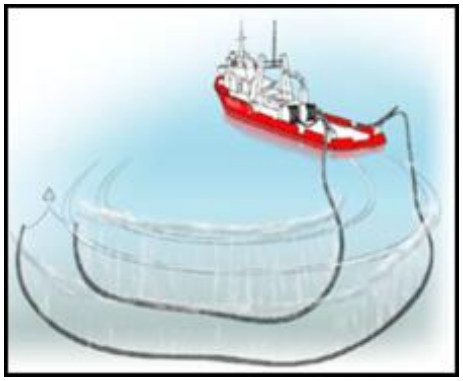
$$SEL = 10\log_{10}\left(\frac{\int_0^T p(t)^2\,dt}{T_0 \cdot p_0^2}\right)$$

DONG energy

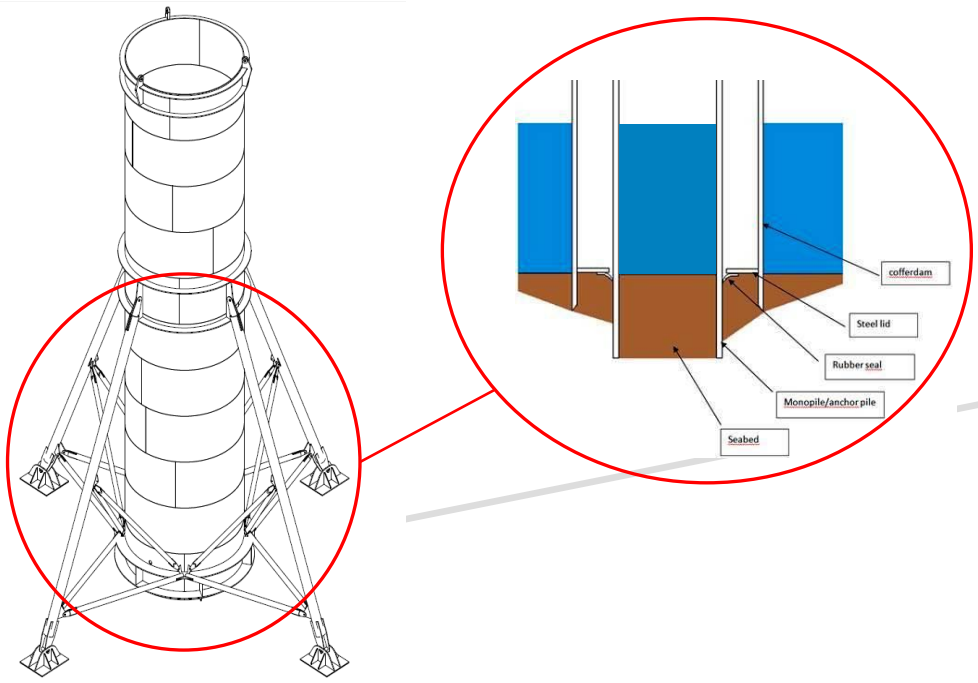
Noise Mitigations

Various suggested methods for Noise mitigation:

- Bubble Curtain
- Cofferdams
- Double walled noise mitigation shields
- …and a lot more



Big bubble curtain



Cofferdam from Lo-Noise

DONG energy

Noise Mitigation

DONG Energy is committed to mature solutions by:

1. Co-orperating with expert companies on development of solutions
2. Developing own DONG Energy solutions for detailed design (such as idea for selfstanding Noise mitigation shield or cofferdam supported by suction buckets)

IHC MERWEDE

Noise Mitigation System NMS-6900 Riffgat

Basic principle

Creating barriers with different medium & materials

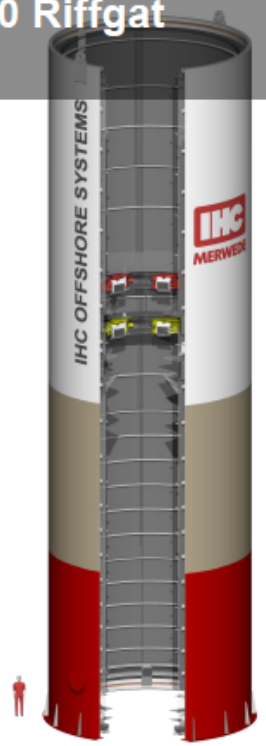
- Outer screen
- Air gap between inner/outer screen
- Inner screen
- Bubble screen

Extra features

- Multi level bubble injection system
- Multi size bubble injection
- Isolated inner & outer screen

Pile guiding

- Upper guiding
- Lower guiding



DONG energy

Dong idea: Selfstanding pilegripper with suction buckets and integrated noise reduction shield or cofferdam

Appr. dimensions:

- water depth 30m (+0,0)
- height shield 35m (top +5,0)
- outside footprint 25m
- bucket: OD 4m x 5m
- monopile: OD 8m
- screen: ID 9m
- screen: OD 10,6m (double wall 800mm)

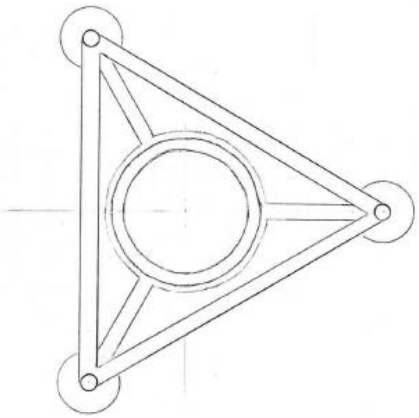
Weights & boyancy

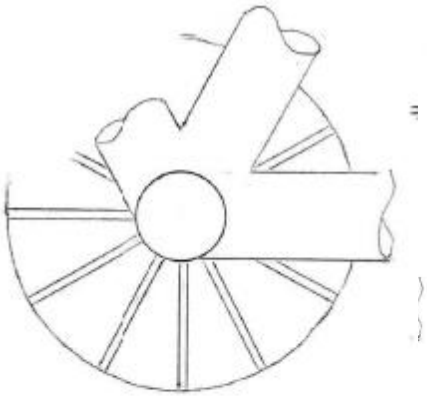
- dry weight: ~ 900 tons
- boyancy ~ 700 tons
- positive weight (after boyancy) ~ 200 tons

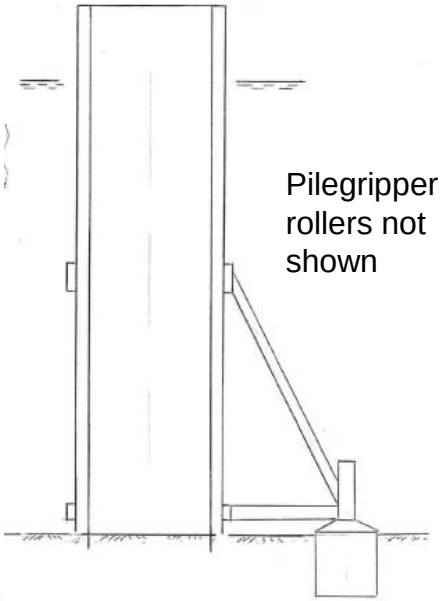
Additional cycletime:

- lift to seabed: 1 hr
- suction 2 hr
- extract 2 hr
- lift to deck 1 hr
- total: 6 hr

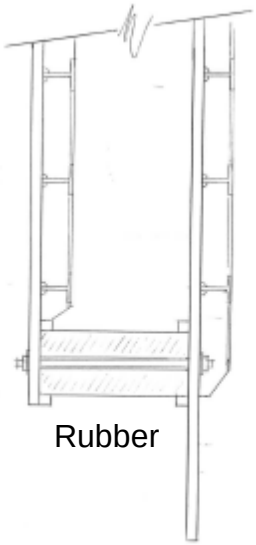
- **total + wow** **12 hours**



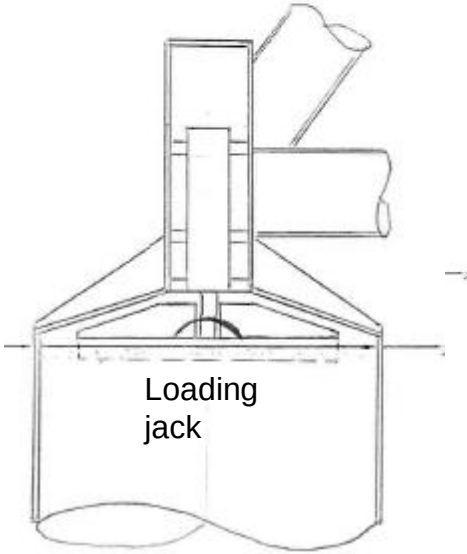




Pilegripper or rollers not shown



Rubber



Loading jack

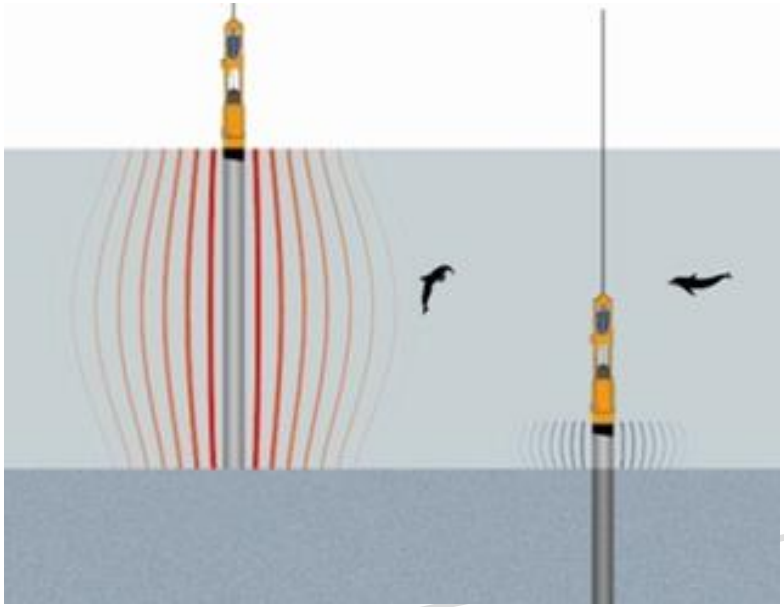
DONG energy

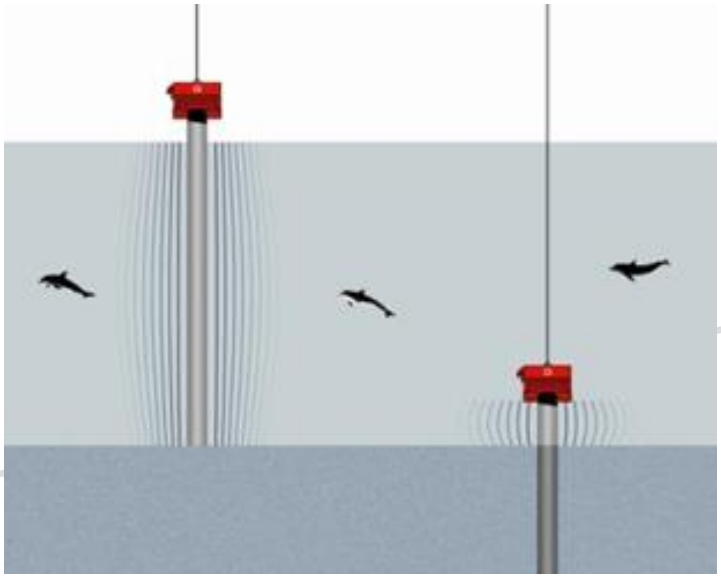
Published 23 May 2013 at Dansk spuns og rammedag

Alternative Pile Installation Methods

Use af vibrators:

- Standard pile driving with hammer
- Vibration alone

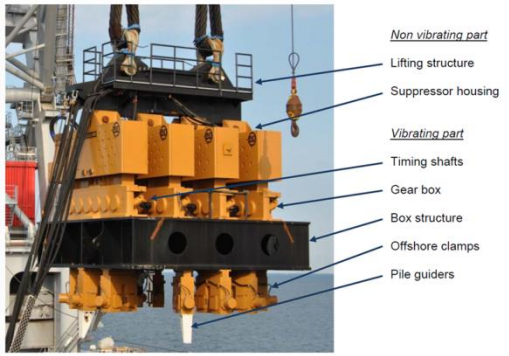




DONG energy

Alternative Pile Installation Methods

Vibrating equipment available in market



Still need to clarify on geotechnical issues:

- Prediction on "driveability"
- Vertical bearing capacity
- Lateral bearing capacity (p-y curves)

Vibration test at Anholt:

DONG energy

?