Owner's Perspective of Offshore Wind & R&D in Support of the Hornsea Offshore Wind Farms

The world's first Multi GW-scale wind farm

Andrew Henderson, Lead Offshore Windfarm Engineer

SUPERGEN Wind Hub General Assembly, Durham Thursday 27th April 2017

DONG energy

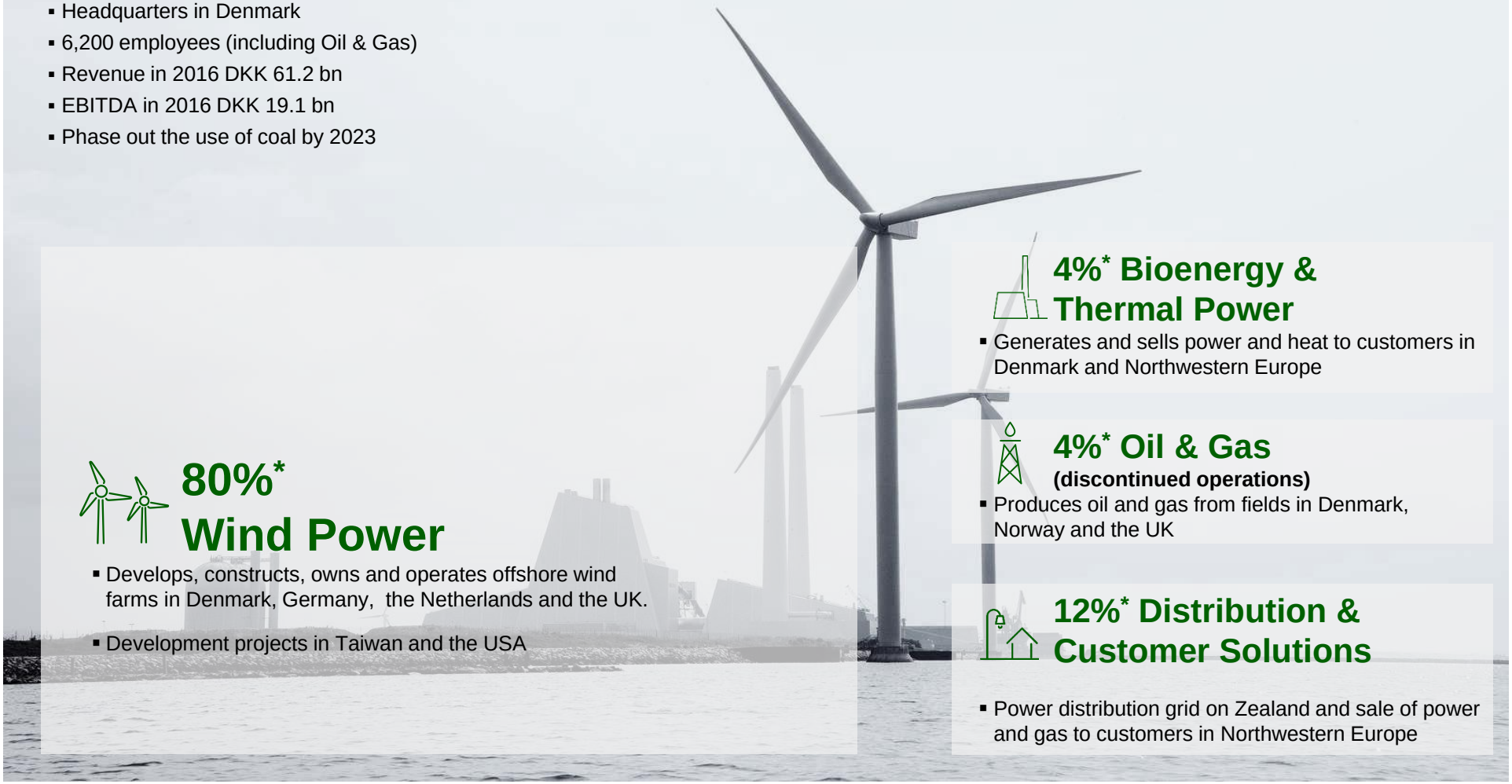
this is what we do

Belfast Harbour

DONG energy

DONG Energy at a glance

- Headquarters in Denmark
- 6,200 employees (including Oil & Gas)
- Revenue in 2016 DKK 61.2 bn
- EBITDA in 2016 DKK 19.1 bn
- Phase out the use of coal by 2023



80%* Wind Power

- Develops, constructs, owns and operates offshore wind farms in Denmark, Germany, the Netherlands and the UK.
- Development projects in Taiwan and the USA

4%* Bioenergy & Thermal Power

- Generates and sells power and heat to customers in Denmark and Northwestern Europe

4%* Oil & Gas

(discontinued operations)

- Produces oil and gas from fields in Denmark, Norway and the UK

12%* Distribution & Customer Solutions

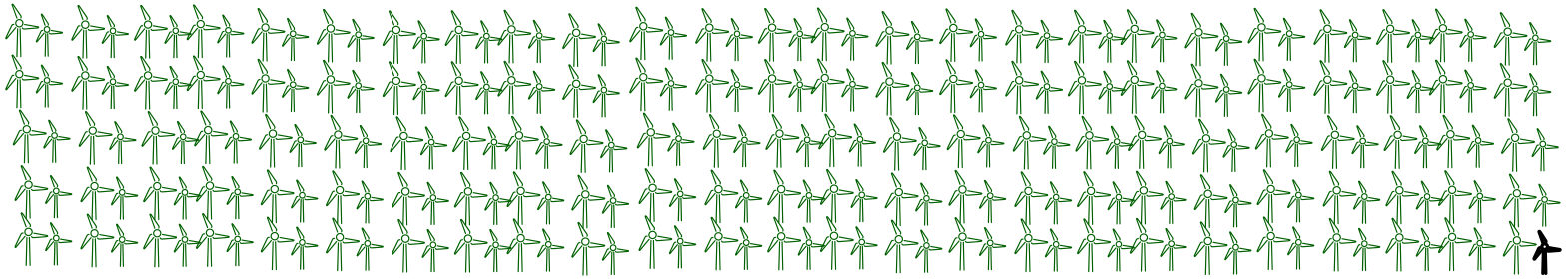
- Power distribution grid on Zealand and sale of power and gas to customers in Northwestern Europe

* Share of the Group's capital employed

DONG energy

Leading the charge to decarbonisation

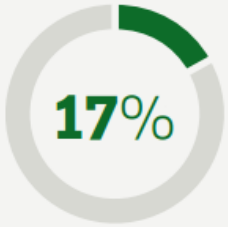
1,000th turbine installed



Our green transformation

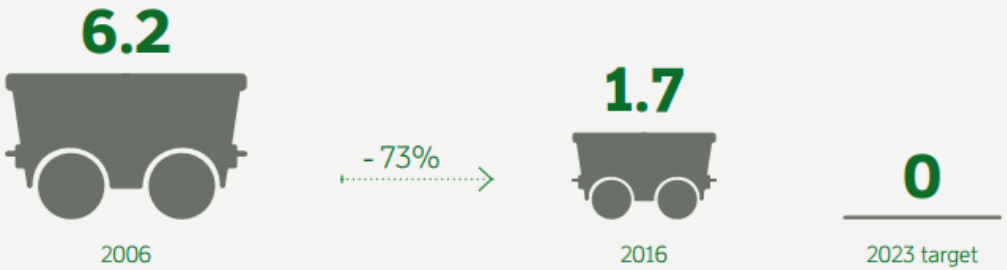
Renewable energy share of our power and heat generation*

2016



2006

Our coal consumption (million tonnes)



2006 | 2016 | 2023 target

Our CO_2 emissions* (gCO_2e/kWh)

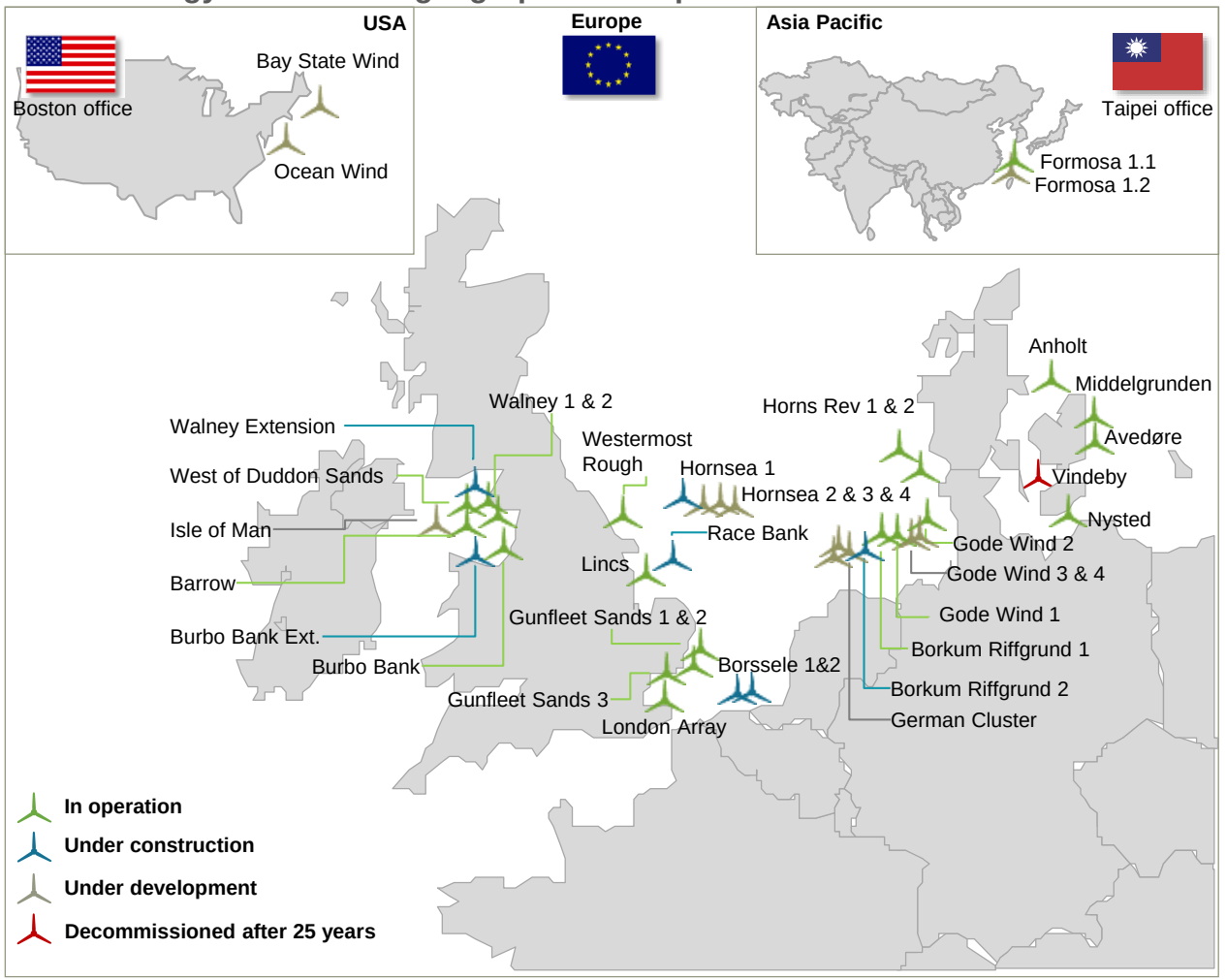
2006 | 2016 | 2023 target

*We ensure this by having our suppliers of wood pellets and wood chips document their compliance with our sustainability requirements.
**This is the most ambitious target among our European peers.

DONG energy

DONG Energy Wind Power overview

DONG Energy Wind Power geographical footprint



Unparalleled experience and track record

1991 — **25+ years of experience and track record in the offshore wind sector** — 2017

21 offshore wind farms in operation

7 offshore wind farms under construction

3.6 GW Constructed capacity

2,000 Dedicated employees

3.8 GW under construction

7.5 million Europeans with clean electricity

3.3 GW World's leading operator

14 Partnerships

DONG Energy Wind Power has built a strong integrated end-to-end business model

DONG Energy Wind Power core competencies

~2,000 Full-time employees[2]

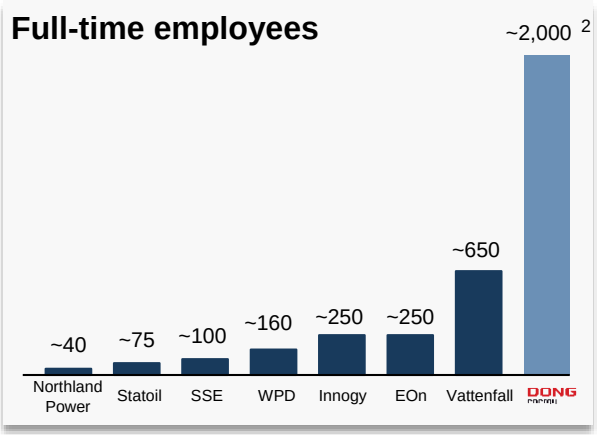
Develop
Identify and mature projects
~110

Build
Manage construction, sourcing and supply
~1,150

Operate
Conduct life-cycle maintenance
~640

Own
Attract capital through partnerships
~100

- ✓ Ability to **design and optimise** projects with a **'total life-cycle cost of wind farm'** mindset
- ✓ Experience and expertise along the entire value chain allow for **better understanding and management of risks**
- ✓ End-to-end model reduces LCoE through **fast** feedback and **learning** across the entire organisation



1. Front-end engineering design
2. Excluding CT Offshore and A2SEA as of January 2017

At the forefront of making the industry cost competitive

Multiple levers to drive down cost in offshore wind

1 Scale

- Turbines and rotor size
- Sites
- Vessel size
- Cable capacity

✓

2 Innovation

- Foundation design (e.g. monopiles)
- Electrical

✓

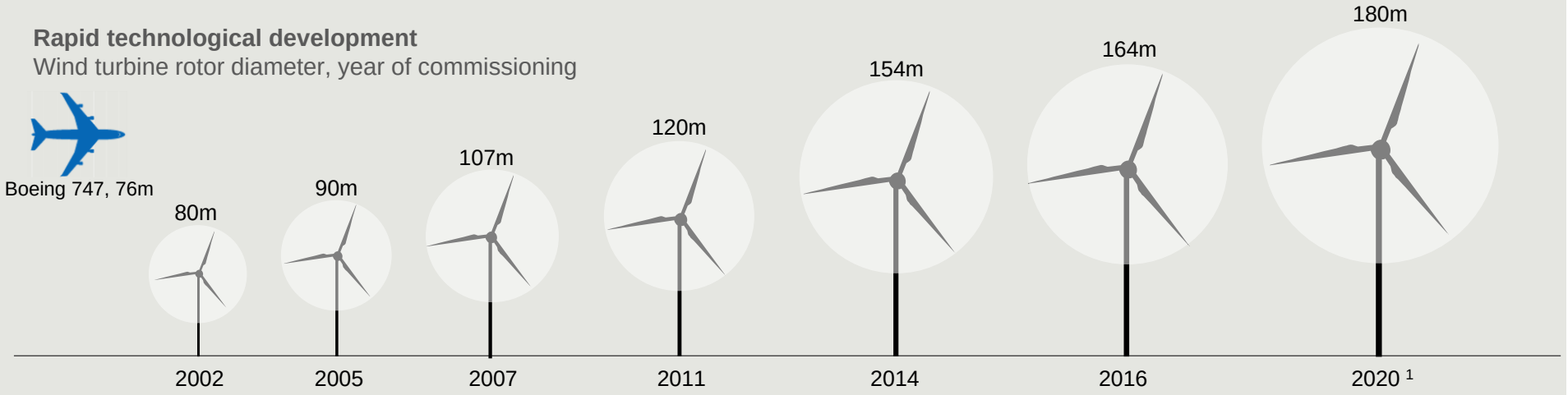
3 Industrialisation

- Transition from single supply to multiple global suppliers

✓

Rapid technological development

Wind turbine rotor diameter, year of commissioning



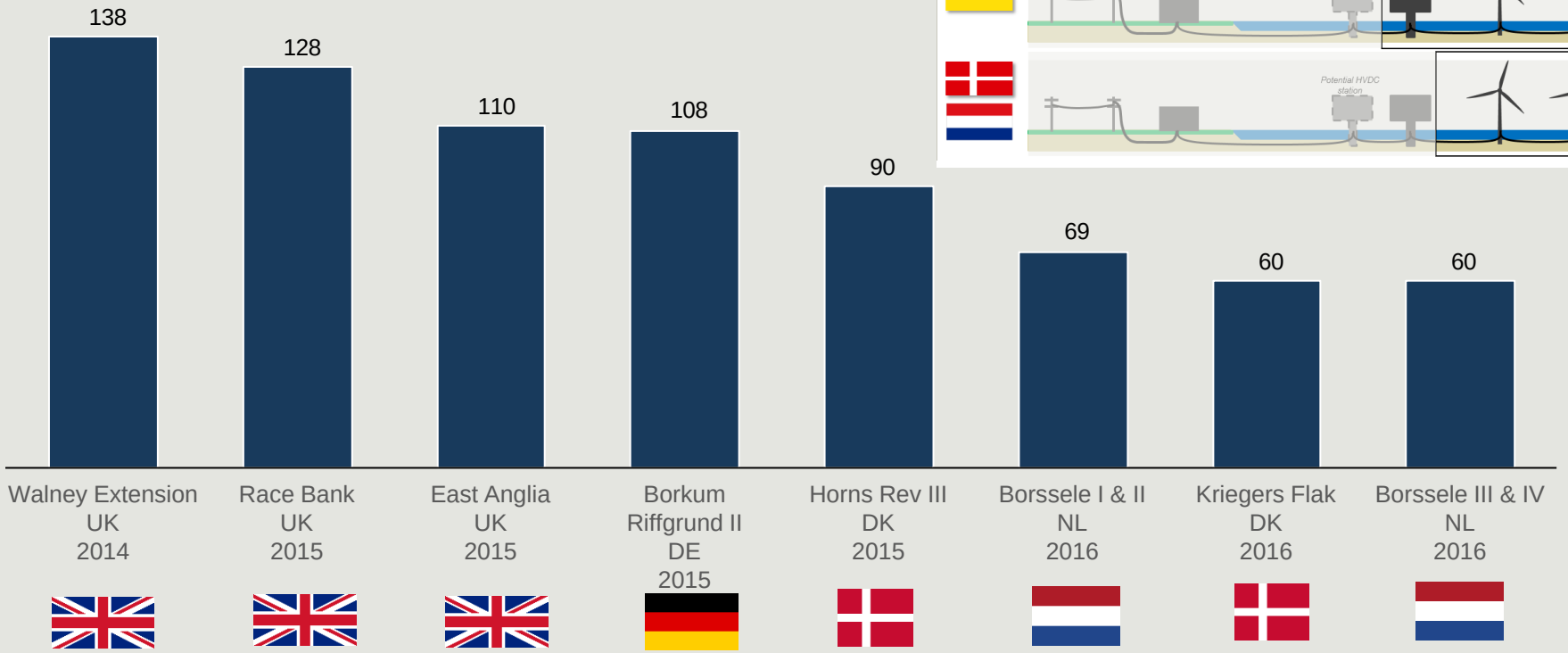
1. Currently there are no turbines available on the market with a rotor diameter of 180m, however Adwen has announced that they expect to bring such a turbine to market in 2020.

DONG energy

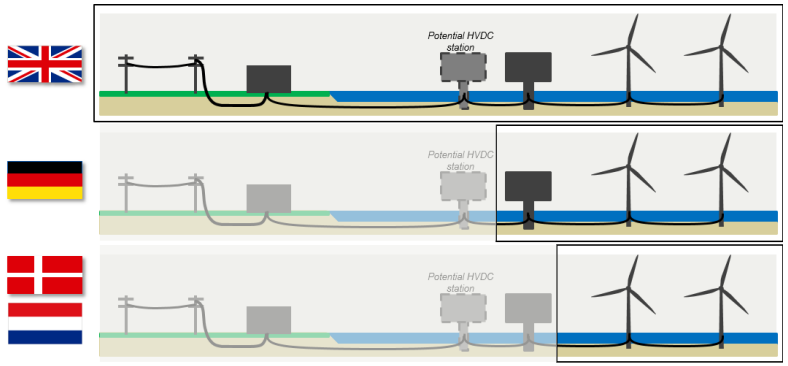
In 2012, DONG Energy set an ambitious target for cost reduction for 2020 and industry is well ahead of plan

Levelised revenue of electricity, incl. transmission costs

£/MWh[1], 2016-prices



Different national scope leads to differences in the cost of electricity from offshore wind



Hornsea Project One Offshore Wind Farm

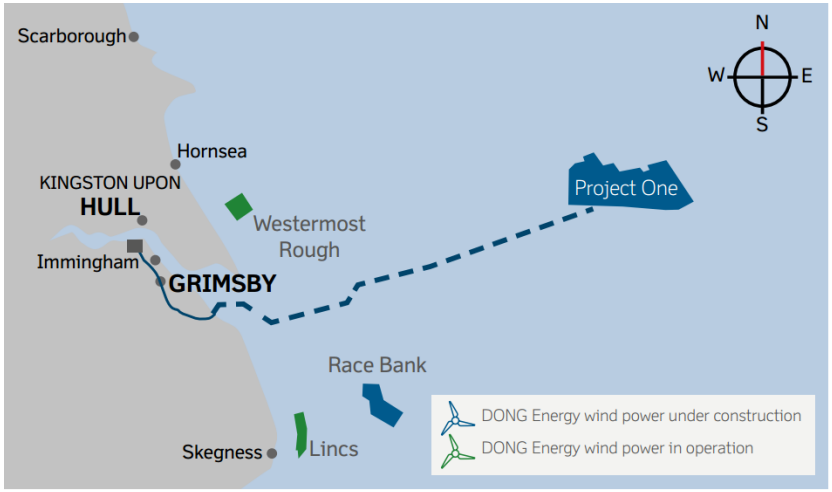
Project Facts

The Project will have a capacity of **1.2 GW,**

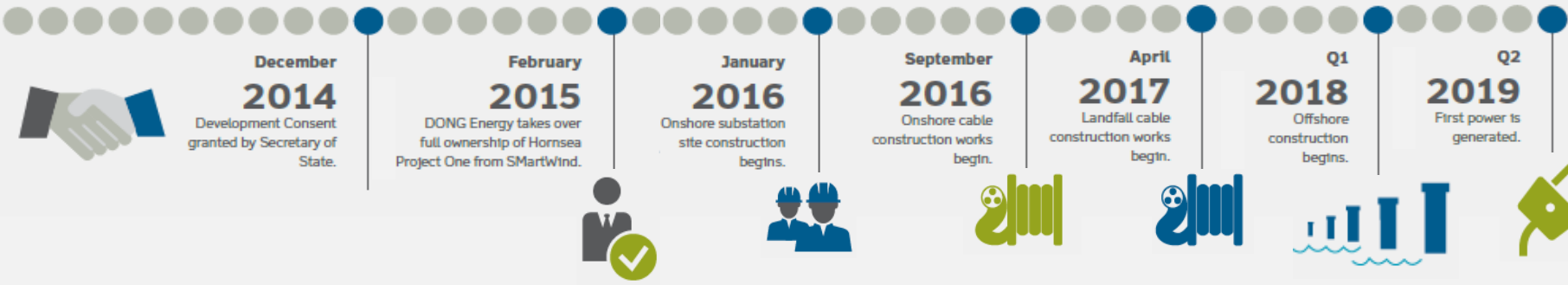
generated by **174** turbines.

This means that each year it will provide enough power for well over **1 million** UK homes.[1]

[1] Assuming a generic 42% load factor and UK annual domestic electricity consumption of 4.115MWh



Project timeline



DONG energy

Challenges presented by the Round 3 Projects

Greater distance from shore…

Bringing forward new technology to manage transmissions losses associated with longer export cable routes.

- Traditionally, offshore wind farms have used High Voltage Alternating Current (HVAC) transmission.
- Challenge of bringing forward 66kV cables to reduce losses over greater distances.
- Will Direct Current (DC) be used in future?

Walney offshore wind farm from air

Hornsea Project One will require a Reactive Compensation Station approximately half way along the cable route.

- The Reactive Compensation Station enables the high voltage AC system to work with cable lengths longer than those previously used for offshore wind.
- Multi-million pound contract awarded to Babcock for the construction of a world first offshore reactive compensation station.

Typical offshore substation platform

DONG energy

Challenges presented by the Round 3 Projects

Installing wind farms further offshore…

- Vessels need to be capable of holding larger components (e.g. next generation turbines)
- Longer distance from ports/staging facilities to offshore array and export cable route creates the need for greater efficiencies

Offshore accommodation platform during construction for Race Bank

Operating and maintaining windfarms further out to Sea….

- New state of the art “SOV” vessel to operate from the new East Coast hub, UK’s largest offshore wind O&M base located in Grimsby.
- Up to 28 consecutive days offshore.
- To service 6-8 turbines a day
- Innovative approach to O&M: extended technician shifts with 2 weeks on, 2 weeks off
- Safety and operational efficiency benefits: ability of technicians to “walk to work”
- Accommodation capacity for up to 60 people

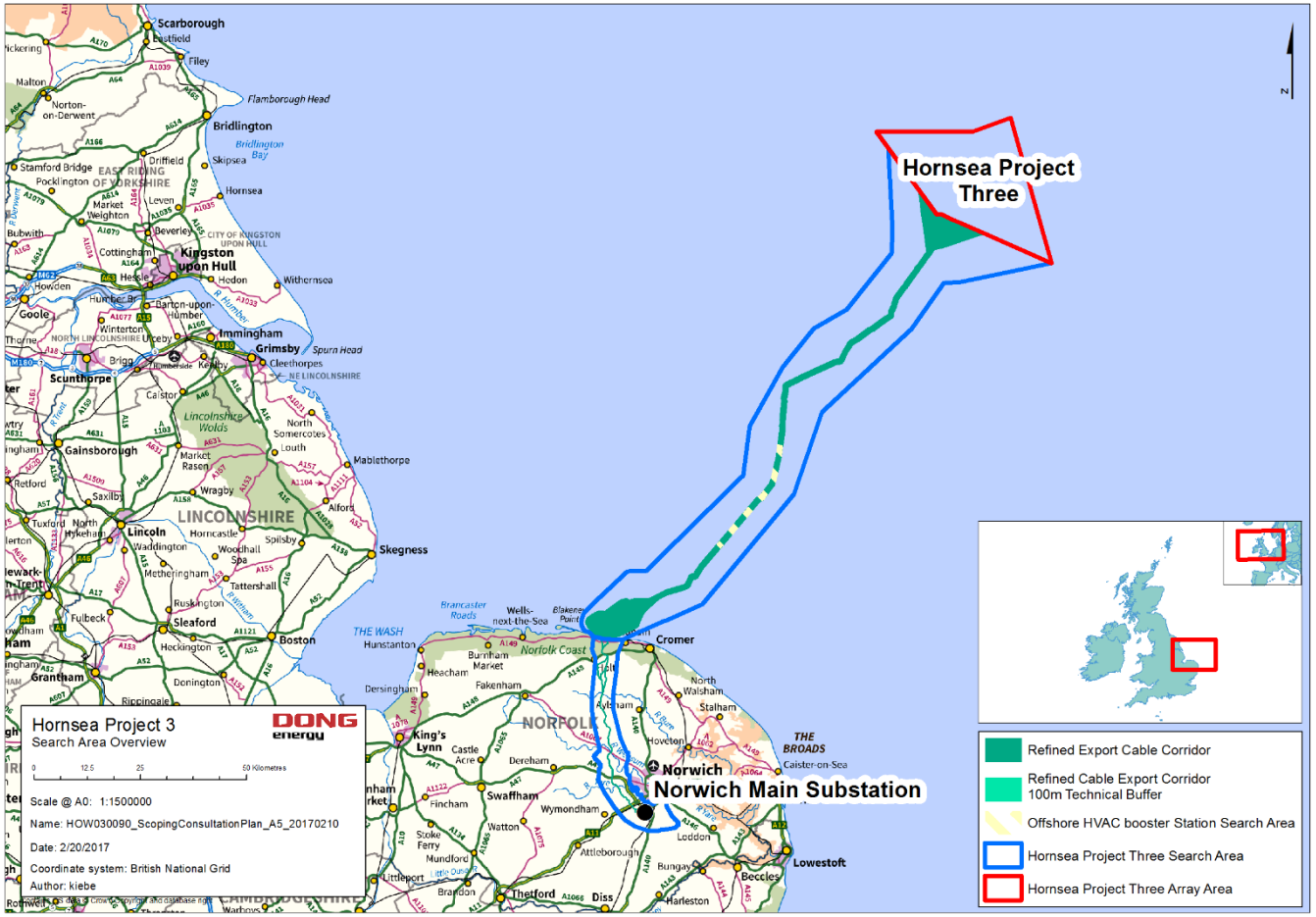
DONG energy

Offshore Substations

Race Bank

DONG Energy is currently exploring the potential to build one of the world's largest offshore wind farms

- The Project will have a total capacity of up to 2,400 MW and could be capable of generating enough electricity to meet the average daily needs of over **2 million** UK homes.
- Hornsea Project Three has signed a grid connection agreement with National Grid for connection at an existing 400 kV Substation, just south of Norwich.
- The Project has identified a suitable landfall zone in the vicinity of Weybourne and is currently consulting on an indicative export cable corridor.



Hornsea 3
Offshore Wind Farm

We have based the above calculation on a load factor of 42% and a household consumption of 4.1MWh per year. Source: DECC, 2015

DONG energy

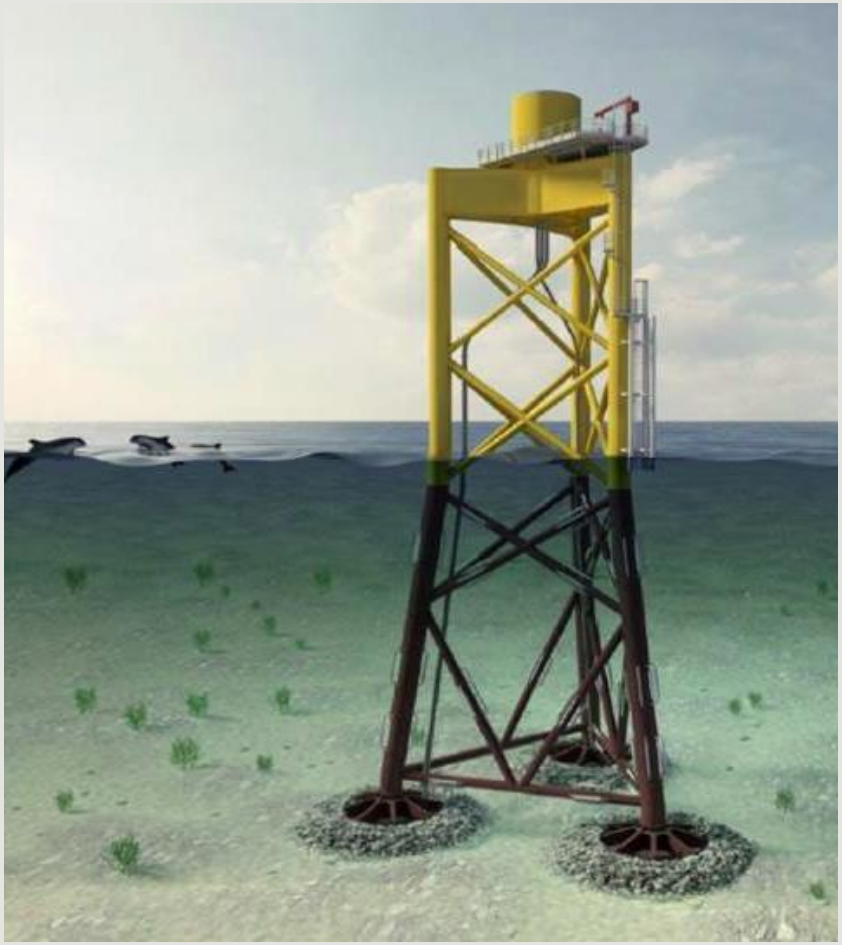
How R&D has Benefitted the Hornsea Zone Offshore Windfarms

New Technology at Hornsea One

- Offshore Reactive Compensation Substation
- Suction-Caisson Jacket Foundations
- Twisted Jacket Foundation (for Met Mast)
- Offshore LiDAR on platforms (secondary source)
- 400MW transmitted down each export cable
- O&M at 140km from Shore

More general Technology Developments

- Continuous Design Optimisation of Monopile Foundations
- Optimised (to the extent possible) Windturbine Layout



DONG energy

Highlights of R&D at DONG Energy

- Development and testing of new Foundations Structures
- BEACon: scanning radar currently scanning Westermost Rough Offshore Windfarm
- Joint Industry technology demonstration
  - Floating LiDAR
  - Monopile design PISA & SLIC
- Other Key Areas
  - Power Curve Measurements

People to Contact

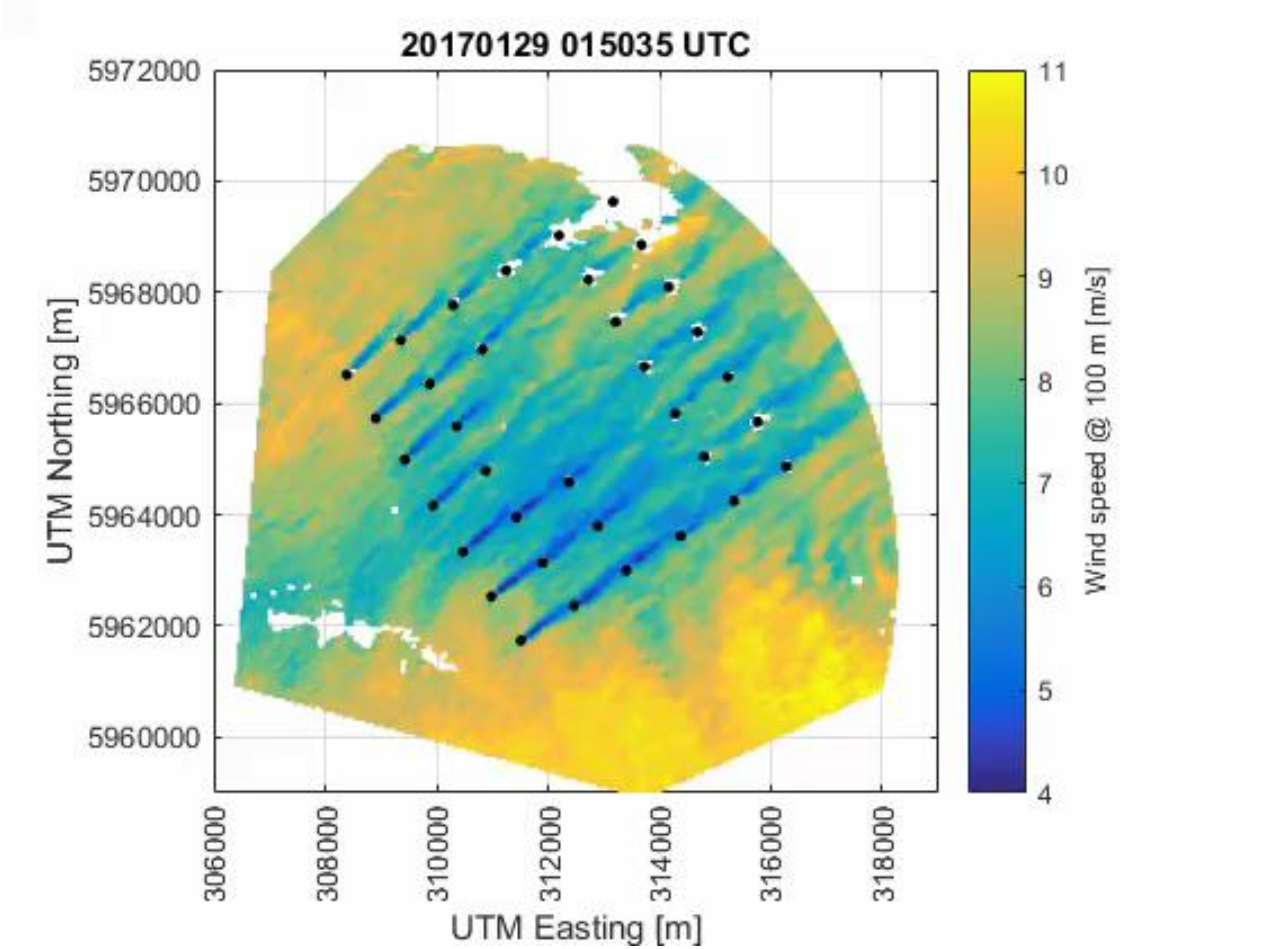
- Jørn Scharling Holm; Technology Partnerships Manager
  - JORSH@DONGEnergy.dk
- Christina Aabo; Head of R&D
  - CHRAA@DONGEnergy.dk
- Emily Woolfenden; UK Stakeholder Advisor
  - EMWOO@DONGenergy.co.uk
- *your presenter*
  - represents DONG Energy on the Carbon Trust “Wakes” R&D Workstream
  - ANHEN@DONGEnergy.co.uk

DONG energy

BEACon Scanning LiDAR
Westermost Rough

DONG energy

Wind speed measurements

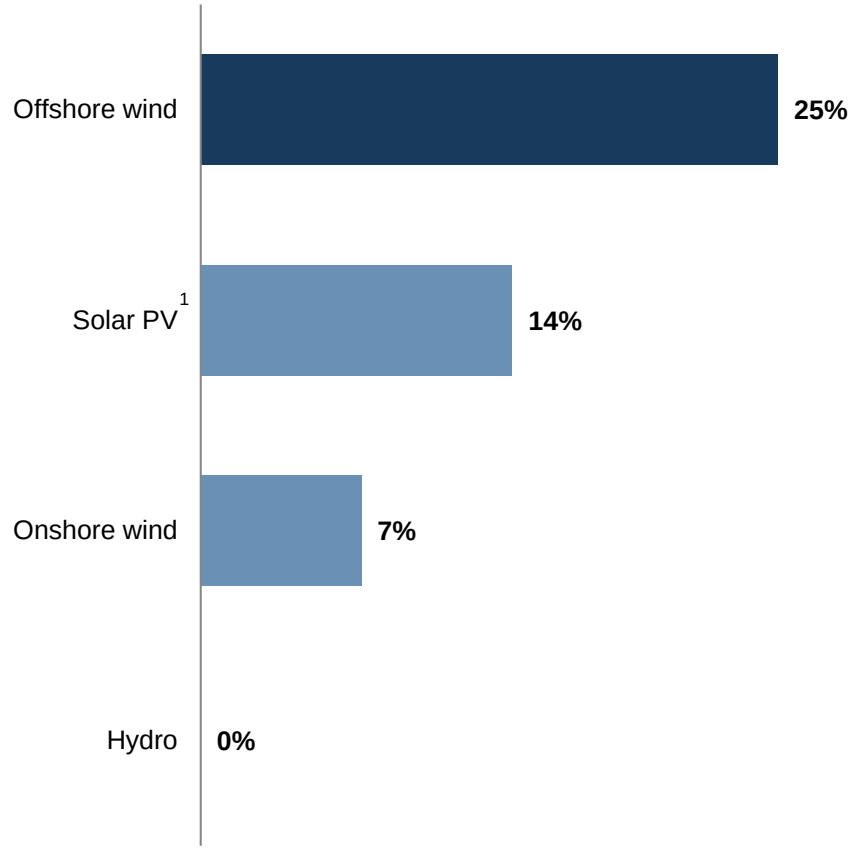


Offshore wind power is a large scale renewable technology with growth rates exceeding other renewables

Fastest growing renewable technology in OECD

Installed capacity CAGR, 2014-2020

%



Offshore wind power offers multiple advantages

Utility size power generation
659 MW Walney Extension will power more than 460,000 UK homes

Offers +45% capacity factors[2]
Significantly higher than onshore wind and solar PV

Rapidly declining cost
Industry maturity, volume and technological development reduce LCoE[3]

Limited visual impact on landscape
Wind farms are built far from shore

Source: Bloomberg New Energy Finance (BNEF)

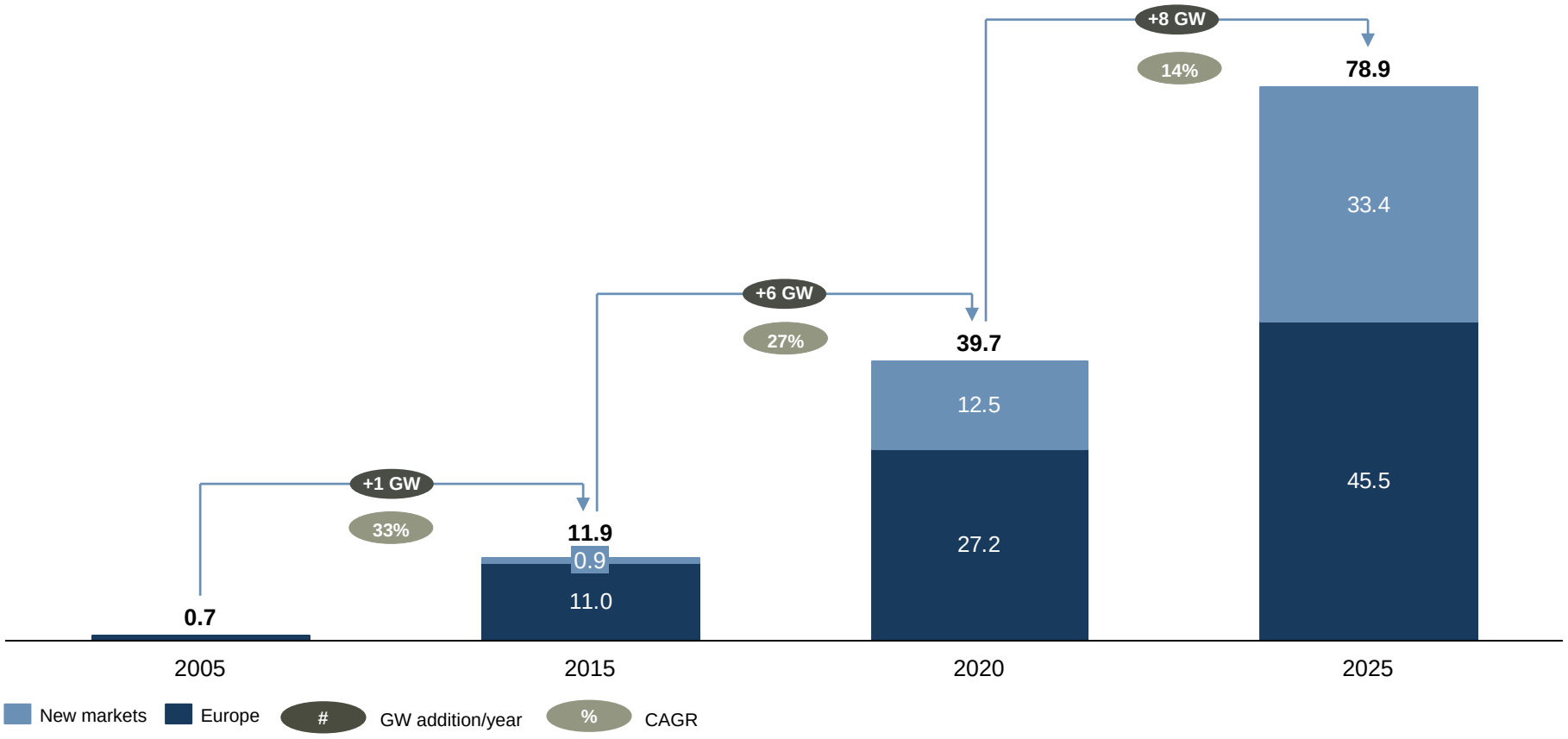
1. Sum of utility-scale PV and small-scale PV
2. Capacity factor is a performance indicator measuring to what degree a wind farm has produced according to the farms capacity (actual production / (capacity x hours in period))
3. According to BNEF, long-term offtake price required to achieve a required equity hurdle rate for the project

DONG energy

By 2025 offshore wind power will be truly global…

Strong growth in established and new offshore wind markets

Installed Capacity, GW



Source: Bloomberg New Energy Finance (BNEF), H2 2016 offshore wind market outlook

co-author acknowledgements:
Emily Woolfenden