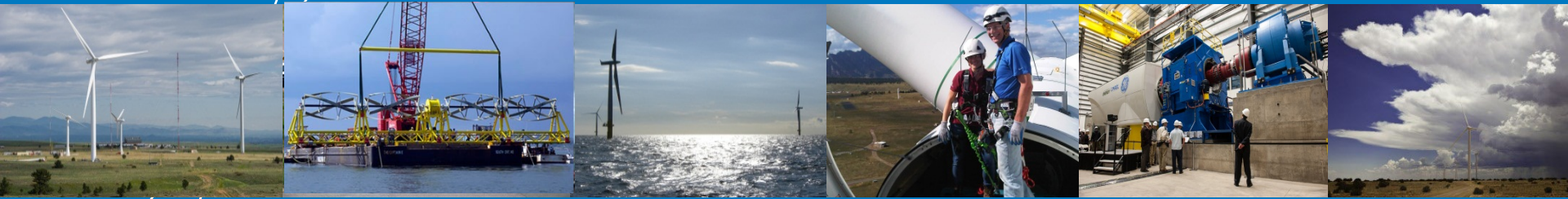


2014-2015 Offshore Wind Technologies Market Report

Progress Toward Cost Reduction in Europe and
Implications for the U.S. Market



WINDExchange Webinar

Aaron Smith

18 November 2015

2014-2015 Market Report Background

New report that covers the global and U.S. offshore wind industries:

- Market developments and drivers
- Deployment status and projections
- Technology trends
- Economic trends
 - Cost
 - Performance
 - Finance
- LCOE reduction progress.

Available at:

<http://www.nrel.gov/docs/fy15osti/64283.pdf>



1. Methodology/Approach

2. Overview of Offshore Wind Developments

3. Economic and Performance Trends (Macro)

4. Case Study: Empirical Evidence of LCOE Reduction

5. Challenges and Opportunities in the U.S. Market

Methodology/Approach

- **NREL Offshore Wind Database**

- 1,382 offshore wind projects, located in 40 countries, and totaling about 730,000 MW (including active and dormant projects)
- Projects in the database range in maturity and cover 1991 to 2034.

- **Database scope**

- Project characteristics (e.g., water depth, distance from shore)
- Technical specifications (e.g., turbine type, component weights)
- Economic attributes (e.g., project- and component-level costs, performance)
- Detailed data on turbine models, vessels, ports, etc.

- **Normalization of cost and price data to 2014 U.S. Dollars (USD)**

- Conversion to USD using the exchange rate for the year in which the latest data were reported
- Inflation to 2014 USD using the U.S. Consumer Price Index
- **TAKEAWAY:** This year's report does not take into account the recent appreciation of the USD, which will likely result in lower costs for initial projects given the need to import some key components from Europe.

Outline

1. Methodology/Approach

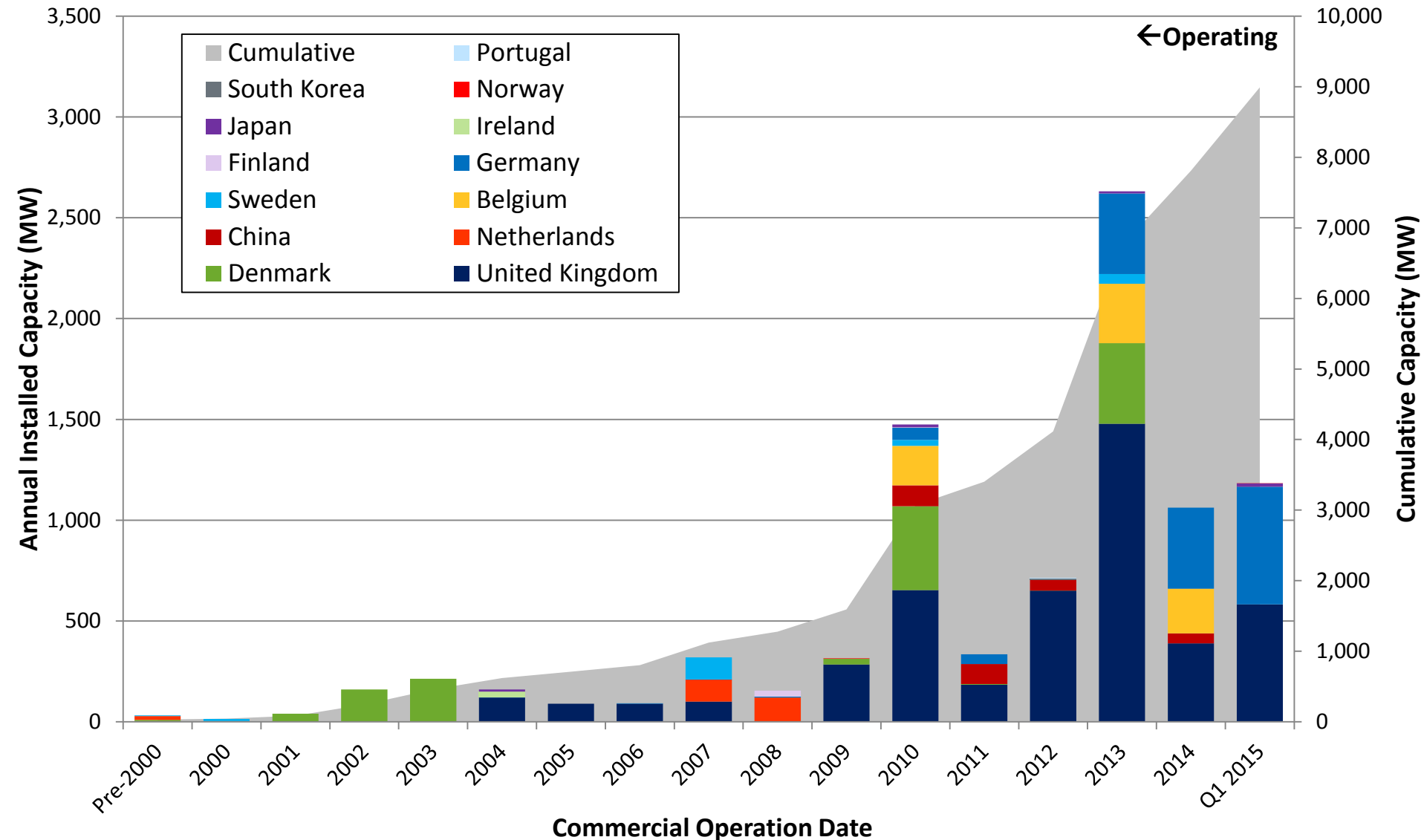
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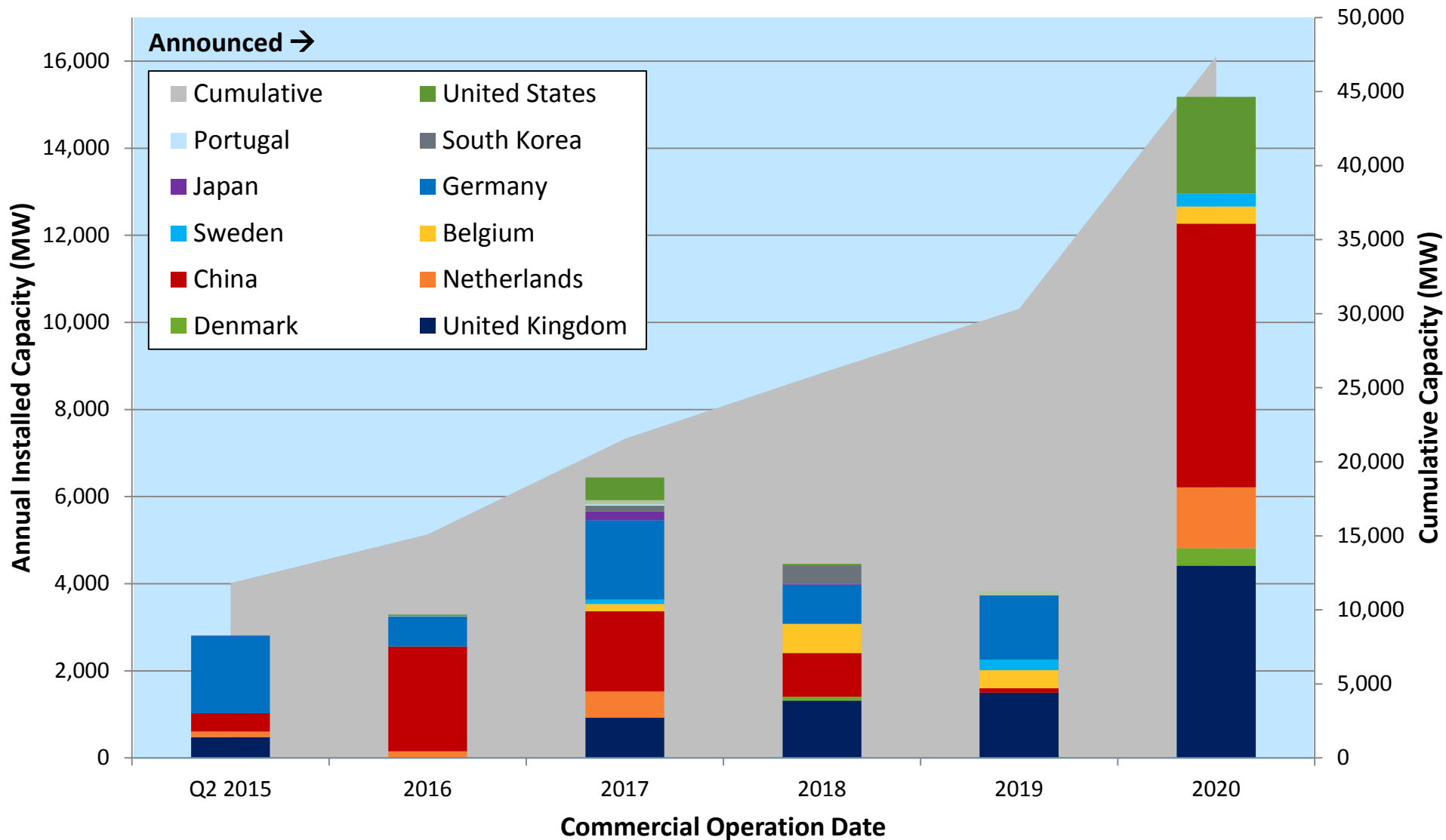
5. Challenges and Opportunities in the U.S. Market

The cumulative operating offshore wind market reached 8,990 MW by June 30, 2015 (Q2)



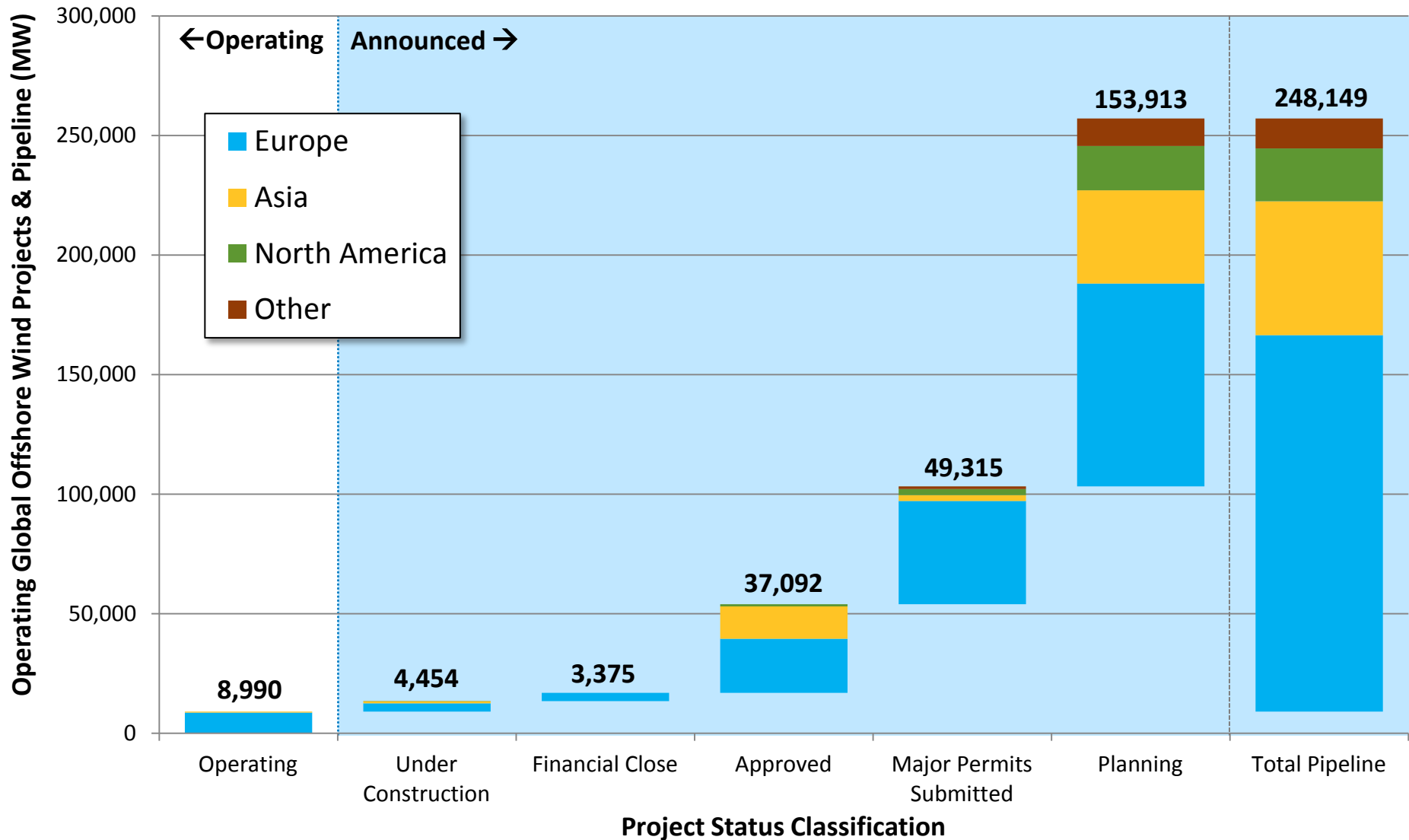
Note: Only includes projects where all capacity within a phase has been fully commissioned; does not include intertidal projects or scaled demonstration projects; cutoff date for inclusion is June 30, 2015 (end Q2)

The expected global project pipeline to 2020 is nearly 38,400 MW, which would bring cumulative installed capacity to 47,400 MW



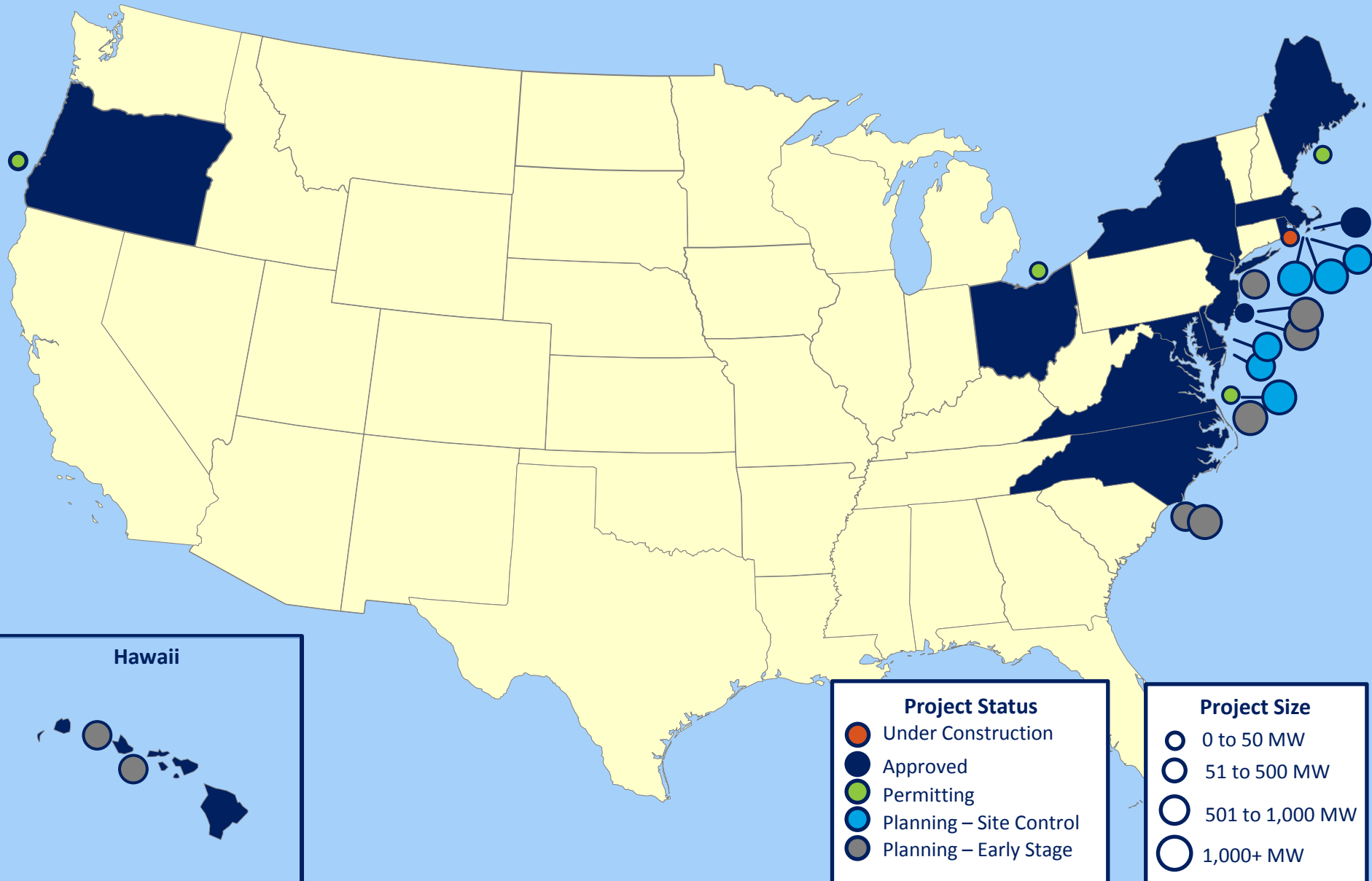
Note: Global pipeline is based on developer-announced commercial operation date; NREL did not evaluate individual projects to determine likelihood of achieving announced schedule, so this should not be treated as a forecast.

The global offshore wind pipeline totals nearly 250,000 MW of capacity; regional diversity expected to increase in the future

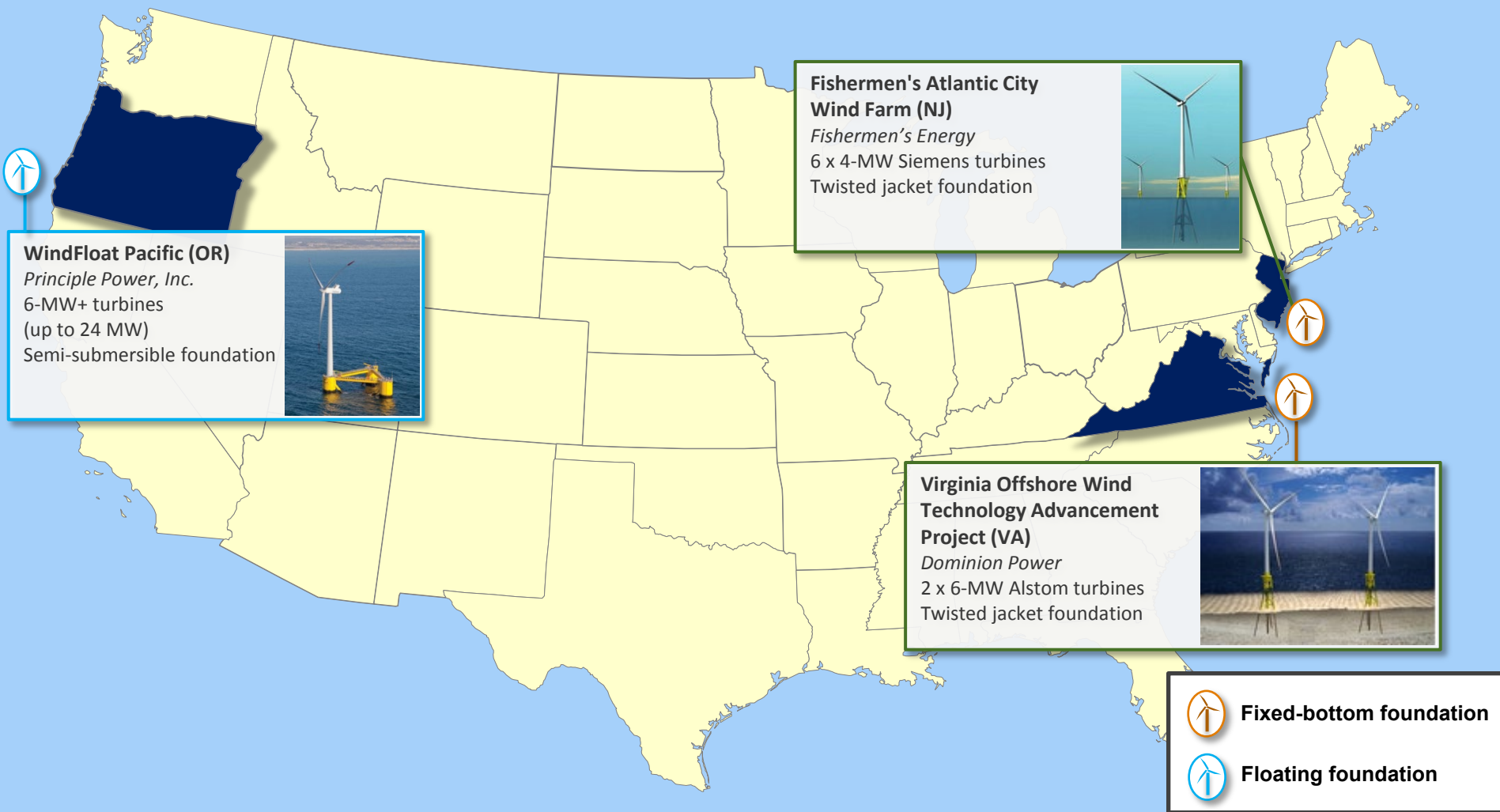


Approximately 63% of the projects in the identified pipeline are located in Europe, 23% in Asia, 9% in North America, and 5% in the rest of the world (Other)

U.S. projects totaling 15,650 MW of potential capacity are in various stages of development; ~5,940 MW have obtained site control



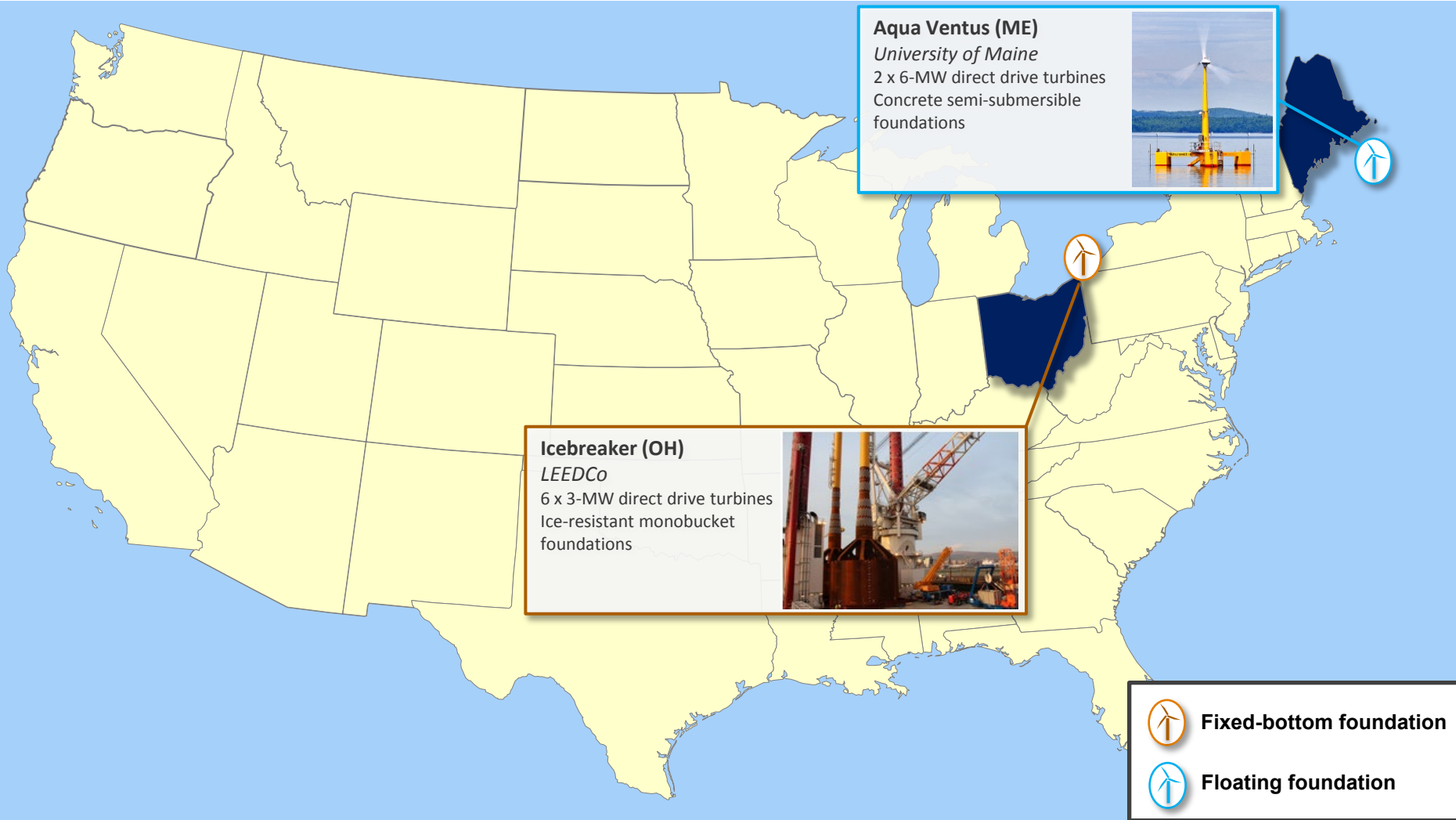
DOE selected three projects to progress to the second phase of the Advanced Technology Demonstration (ATD) program



Projects are eligible to receive up to \$47M to complete final design, fabrication, and deployment.

Awards announced May 2014

DOE selected an additional two projects to advance innovative technology design concepts



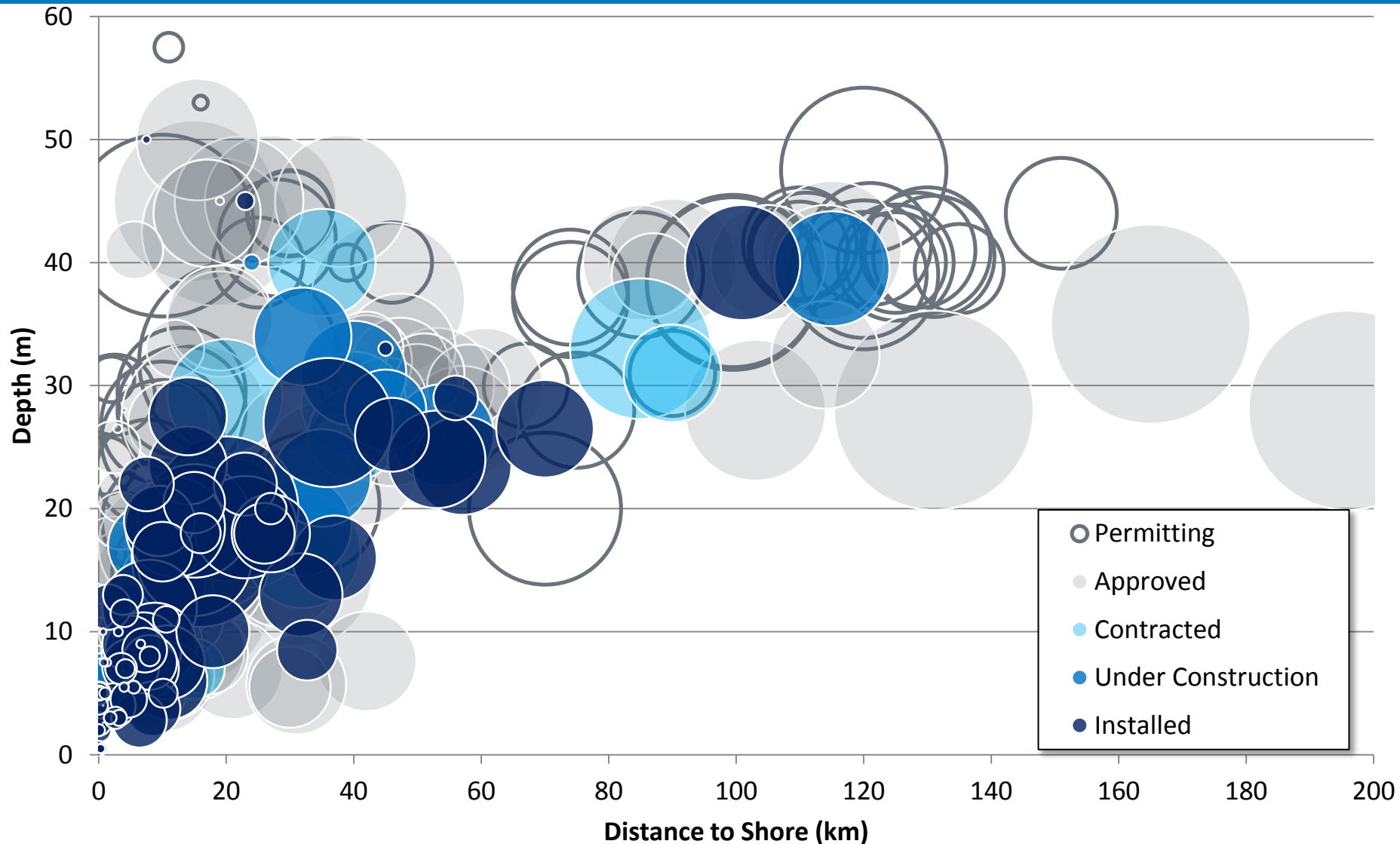
Projects will receive \$3M to advance their designs to deployment readiness. These designs will further position the United States to lower the barriers to commercial-scale offshore wind deployment.

Awards announced May 2014

Outline

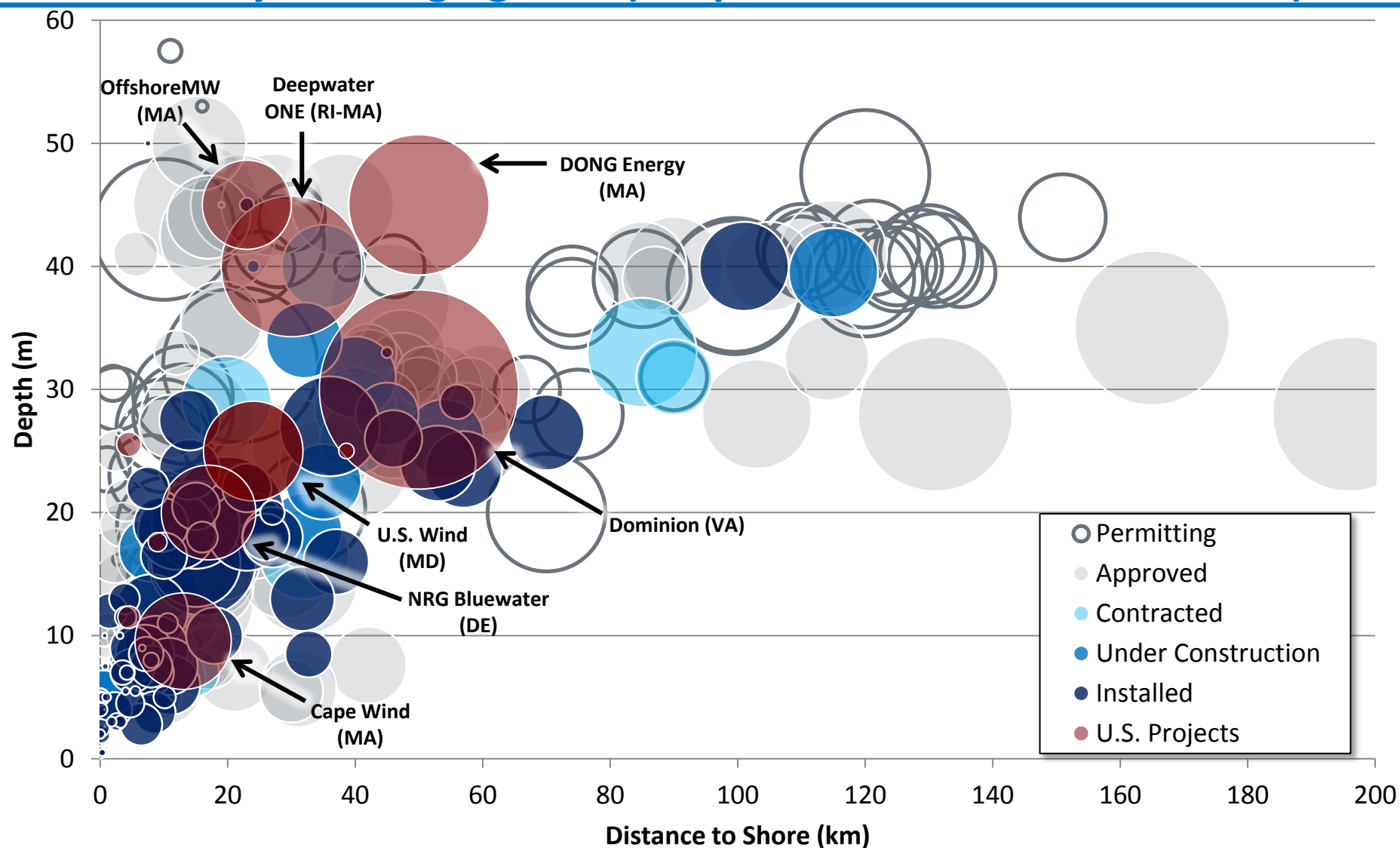
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OSW projects are growing larger and are being installed in technically challenging sites (deeper water and far from shore)



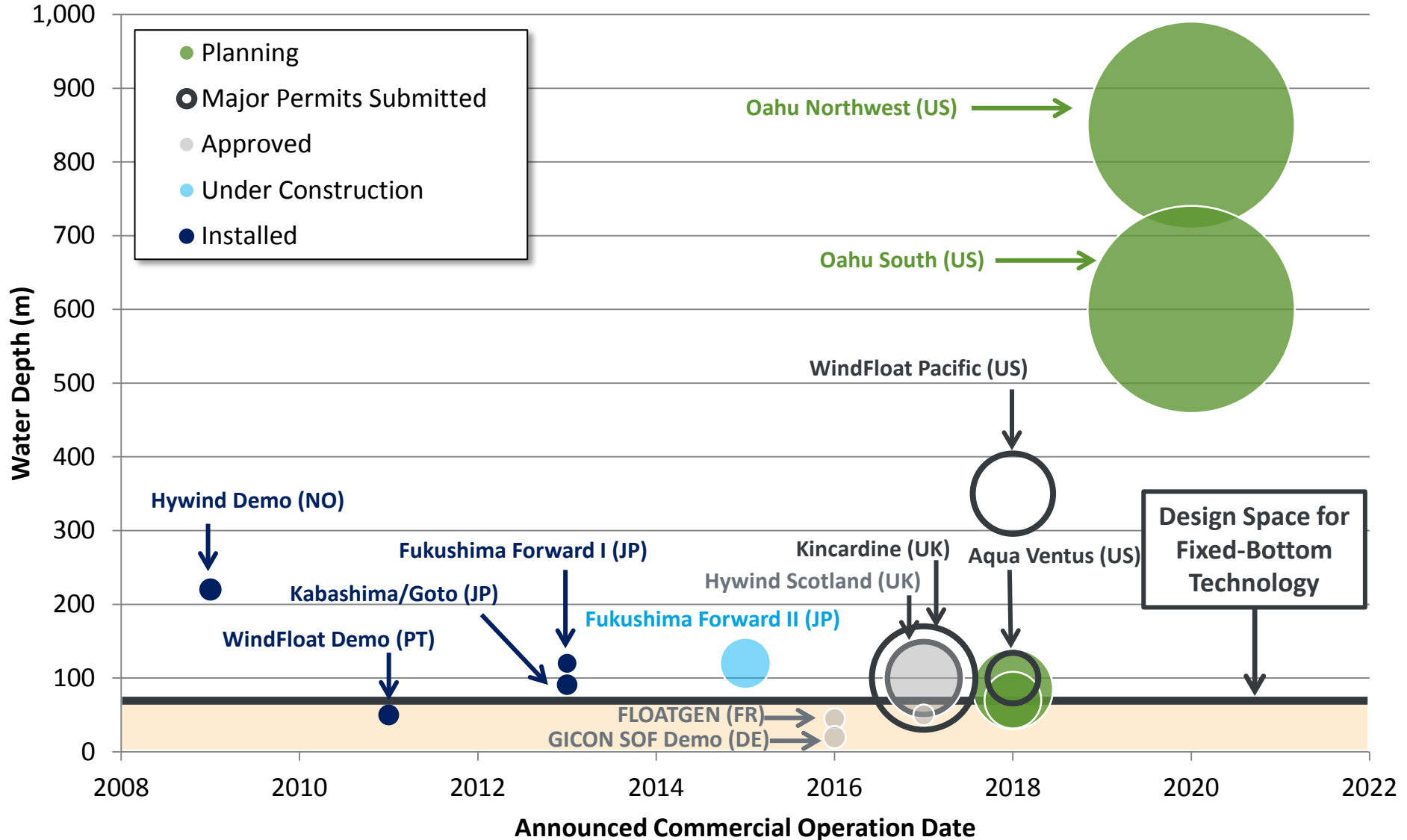
Bubble size represents project rated capacity (in MW): Proposed U.S. projects reflect the 13 projects (~5,940 MW) that have achieved site control. Note that WindFloat Pacific (OR, 350 m) and Aqua Ventus (ME, 95 m) are not shown due to truncation of the Y-axis

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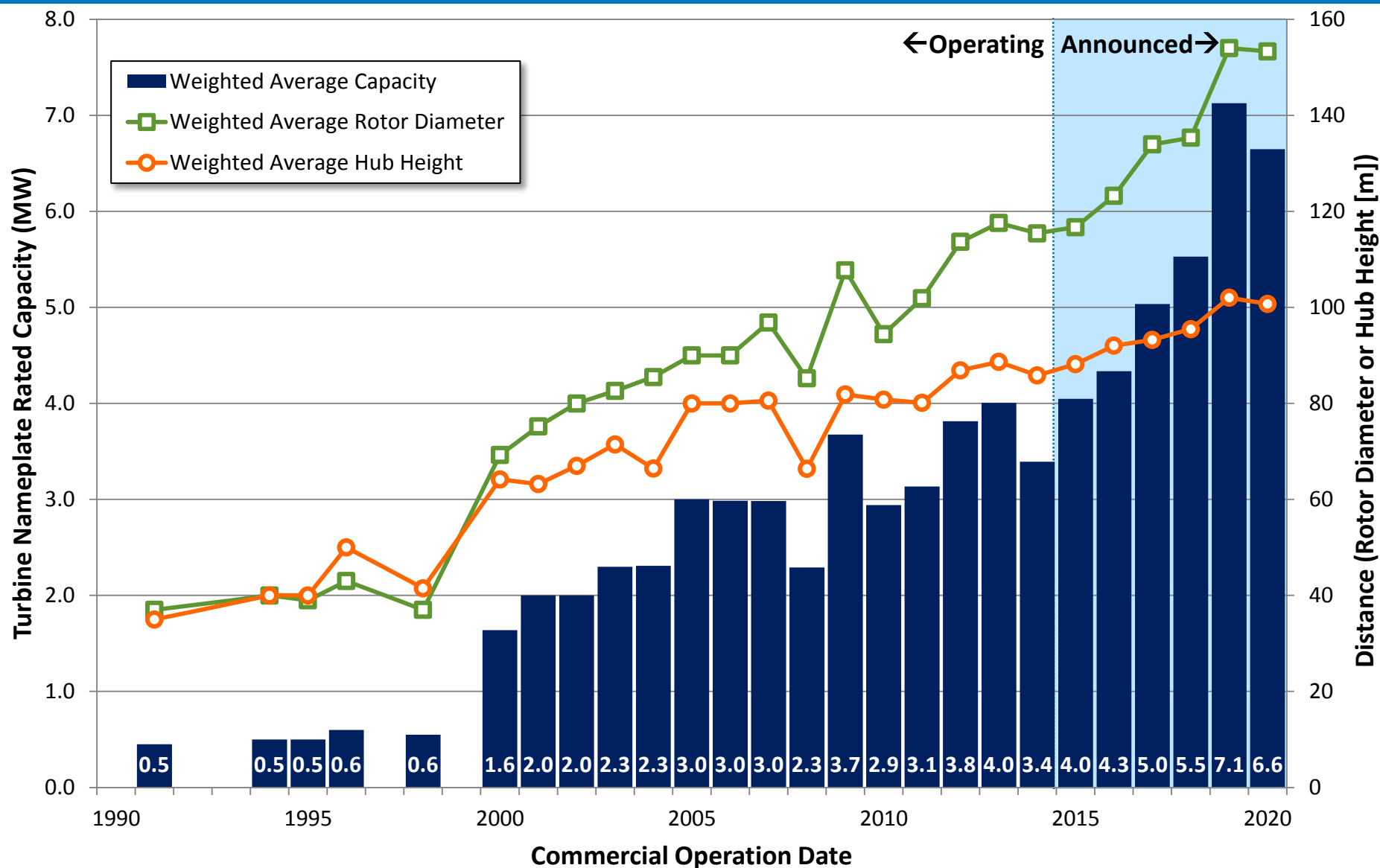


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Floating technology is maturing; proposed pre-commercial and commercial-scale arrays total more than 1,000 MW

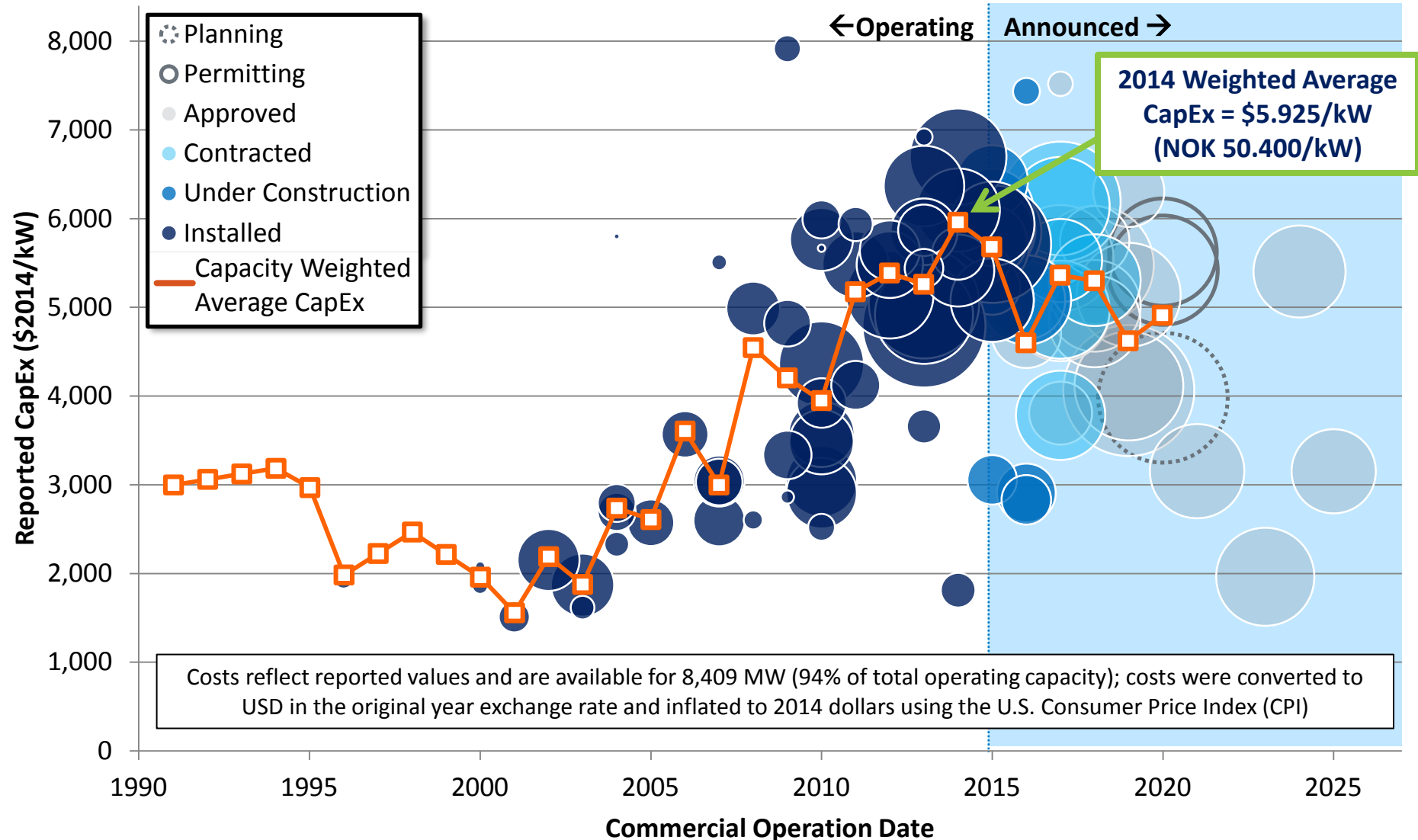


Average turbine capacities, rotor diameters, and hub heights decreased in 2014 but are expected to increase through 2020



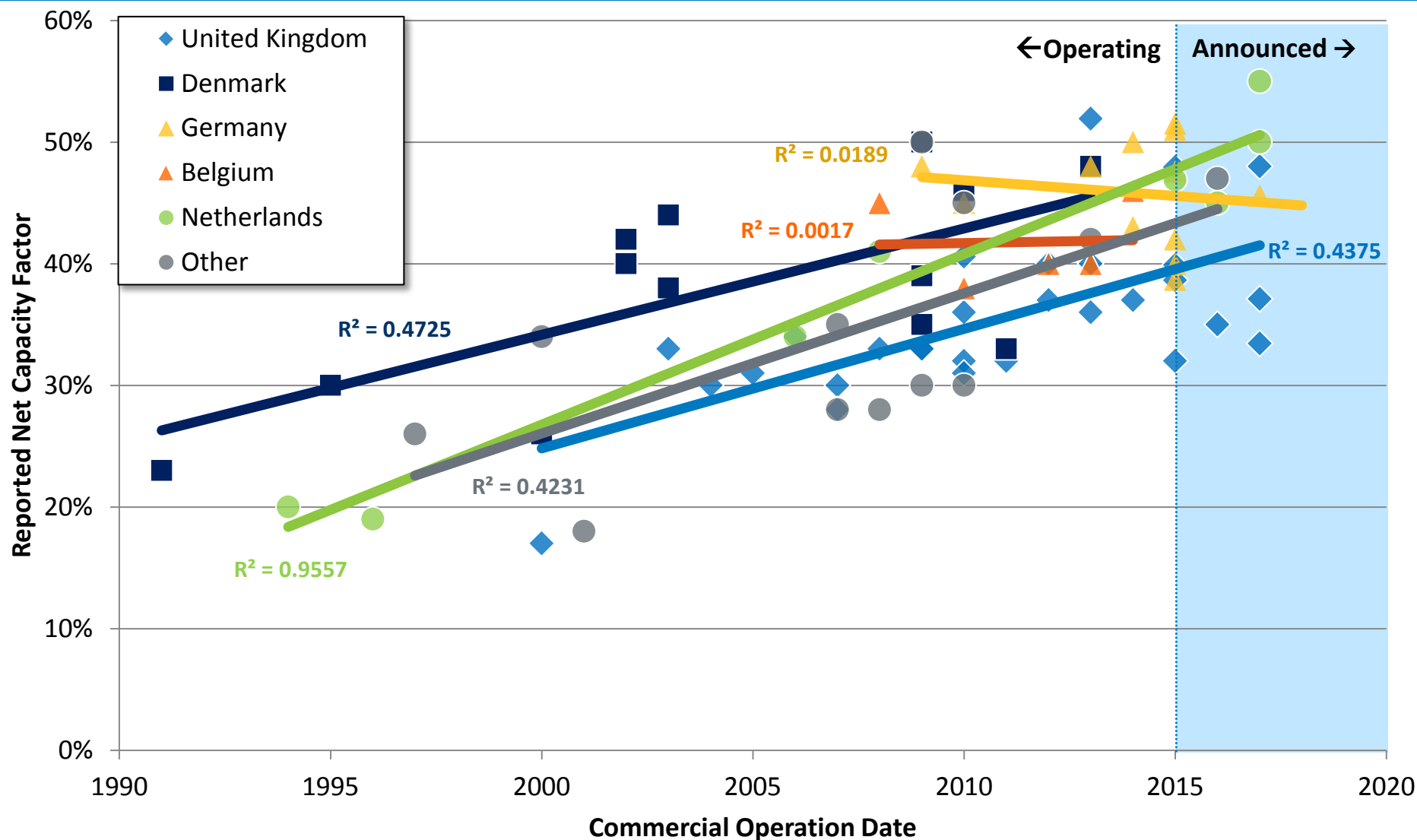
Pipeline refers to the subset of projects that have announced a turbine supplier through an unconditional order, conditional order, preferred supply agreement, or where the turbine OEM is a partner in a development consortium. Must also have announced COD.

CapEx for E.U. projects rose significantly between 2005 and 2014; projections suggest that CapEx may be entering a period of decline



14% CapEx increase (2013 vs. 2014) largely driven by differences in site conditions and market conditions for sample of projects commissioned in each year

Increases in CAPEX have been offset to some extent by increases in net capacity factors



Belgium and Germany show flat and decreasing trends, respectively, with almost no correlation between time and net capacity factors. Unlike offshore wind projects in other countries, the first projects in BE and DE markets were installed in unsheltered, open ocean locations with high wind speeds. Average capacity factors for BE (42%) and DE (47%) are higher than the global fleet-wide average of 37% for operating projects.

Outline

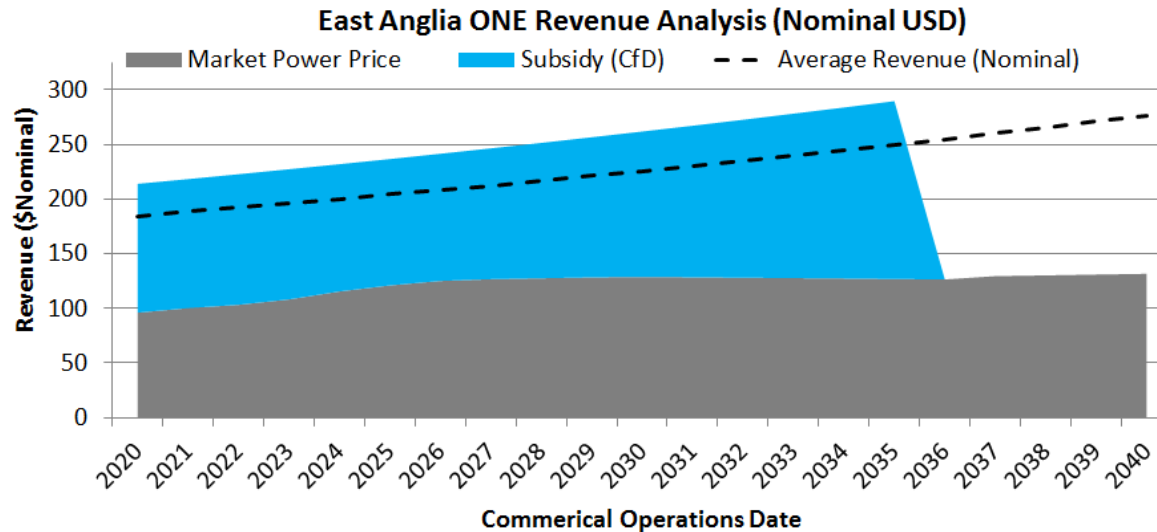
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Cost Reduction Case Study: Background and Data Sources

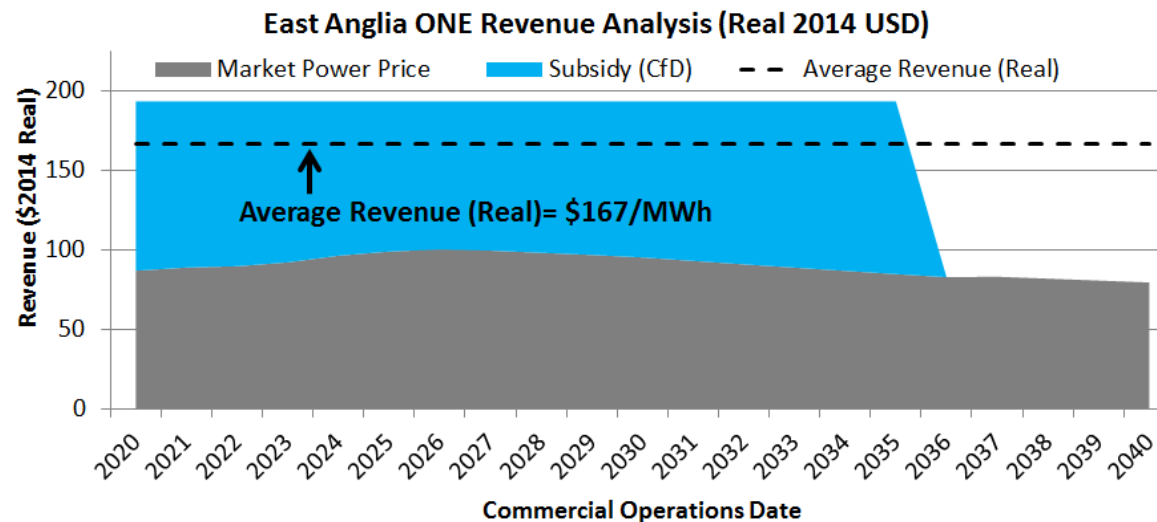
- **European cost reduction goals (from 2010)**
 - **UK:** £100/MWh (\$164/MWh) for projects that reach Final Investment Decision (FID) in 2020 – approximate commercial operation date (COD) 2022
 - **Continental Europe:** - €100/MWh (\$130/MWh) by FID 2020
 - Differences in scope
 - UK projects responsible for transmission system costs (OFTO)
 - Europeans generally allocate transmission system costs to transmission system operator
- **Two sources of empirical evidence about LCOE for future projects**
 1. **UK Cost Reduction Monitoring Framework**
 - 10 projects (3,078 MW) that reached COD between 2010 and 2014
 - 6 projects (1,793 MW) that reached FID between 2012 and 2014
 - Average LCOE has declined from \$235/MWh in 2010/2011 to \$209/MWh for projects reaching FID in 2012/2014, **an 11% reduction**
 2. **Competitive Tenders for Subsidy in the UK and Denmark**

Project	Target COD	Capacity (MW)	First Year CFD/FIT (\$2014/MWh)	Subsidy Term (years)	Other Subsidies (\$2014/MWh)	Inflation Adjusted (Y/N)	Average Power Price (\$2014/MWh)
Horns Rev III (DK)	2020	400	\$134	12 ^a	NA	N	\$63 ^b
Neart Na Gaoithe (UK)	2019	448	\$184	15	NA ^c	Y	\$94 ^d
East Anglia ONE (UK)	2020	714	\$193	15	NA ^c	Y	\$94 ^d

Cost Reduction Case Study: Estimating LCOE from Total Revenue

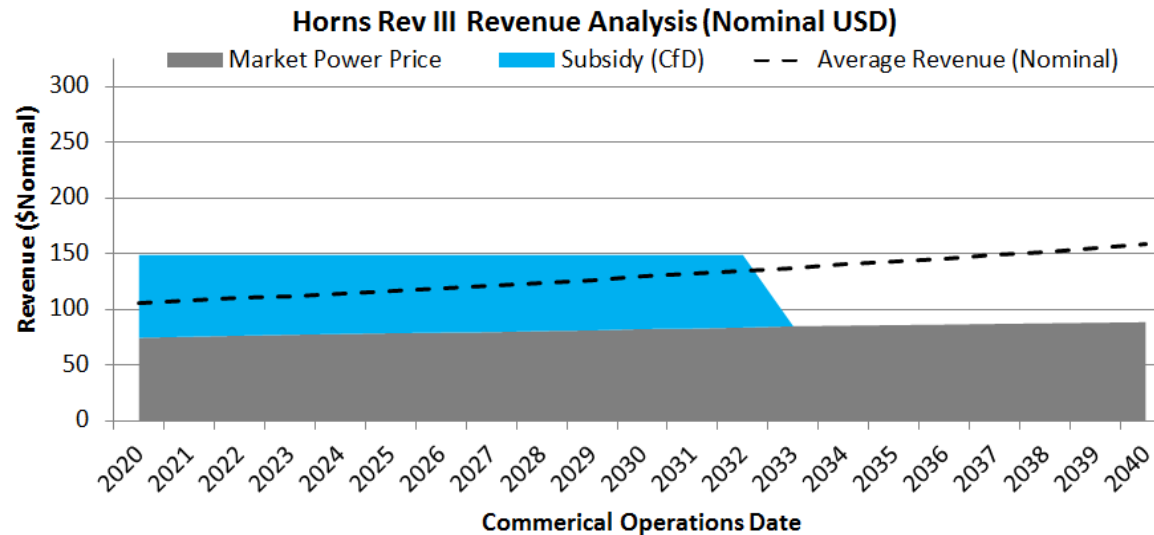


East Anglia ONE Contract for Differences (CfD) Value Analysis	
Incentive Rate	\$186/MWh
Incentive Term	15 years
Inflation Index	Consumer Pricing Index
Average Electricity Price	\$94/MWh
Electricity Price Source	(National Grid 2014)
Other	Levy Exemption Credit set to expire before project begins operation

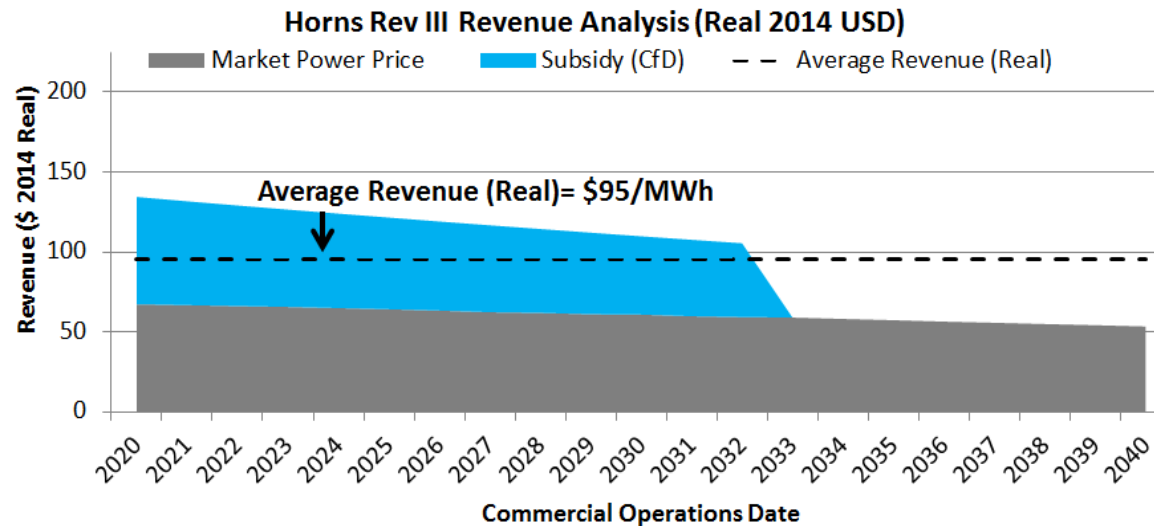


Real LCOEs approximated by averaging total revenue stream (subsidy tariff + market price) over project lifetime. Converted to USD assuming 2014 exchange rates and normalized to \$2014 using inflators from the U.S. Bureau of Labor Statistics

Cost Reduction Case Study: Estimating LCOE from Total Revenue



Horns Rev III Feed-in Tariff (FiT) Value Analysis	
Incentive Rate	\$134.4/MWh
Incentive Term	20 million MWh (~12 years)
Inflation Index	Consumer Pricing Index
Average Electricity Price	\$63/MWh
Electricity Price Source	(Energinet.dk 2013)
Other	State pays grid connection and some development costs

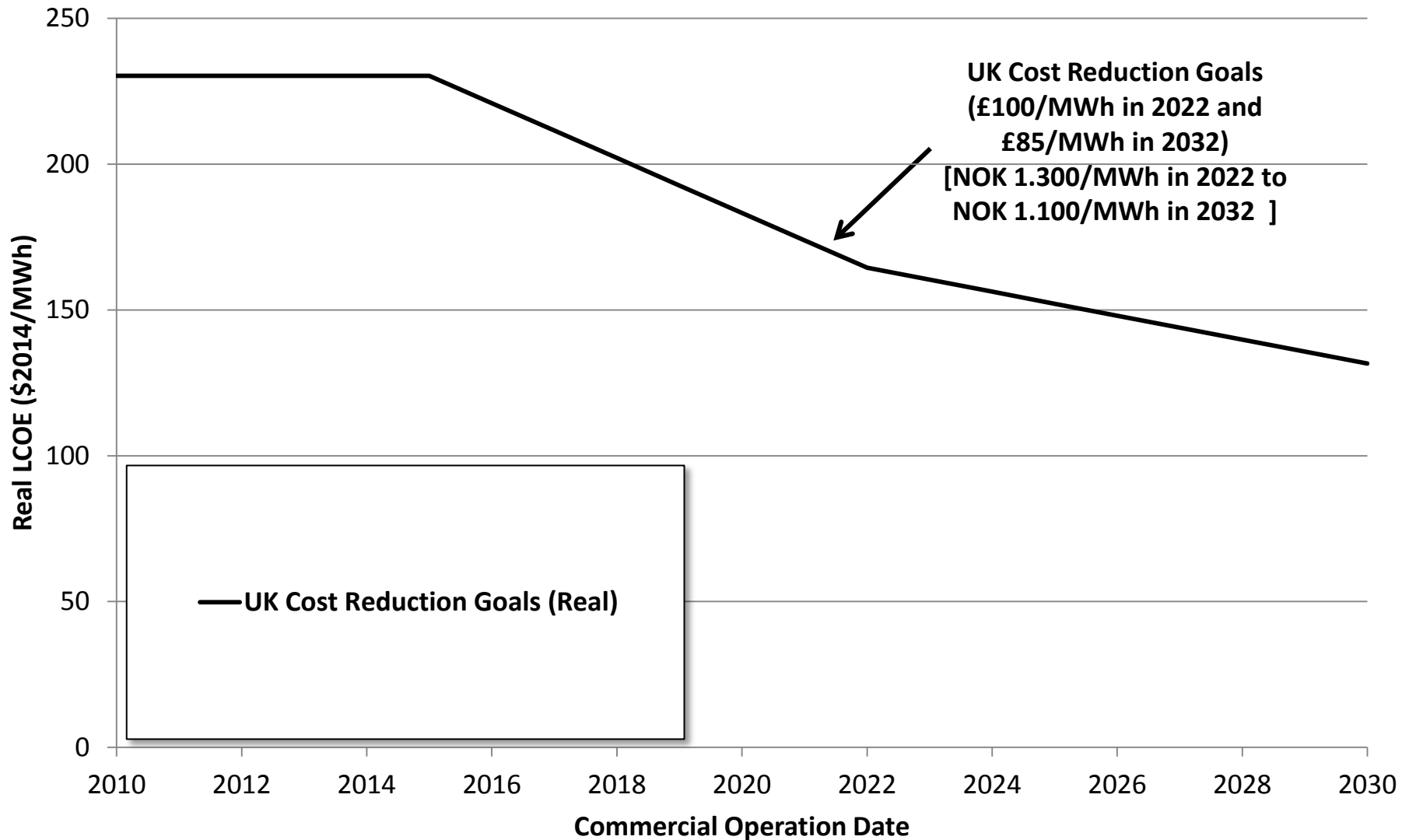


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Cost Reduction Case Study: Estimating LCOE from Total Revenue

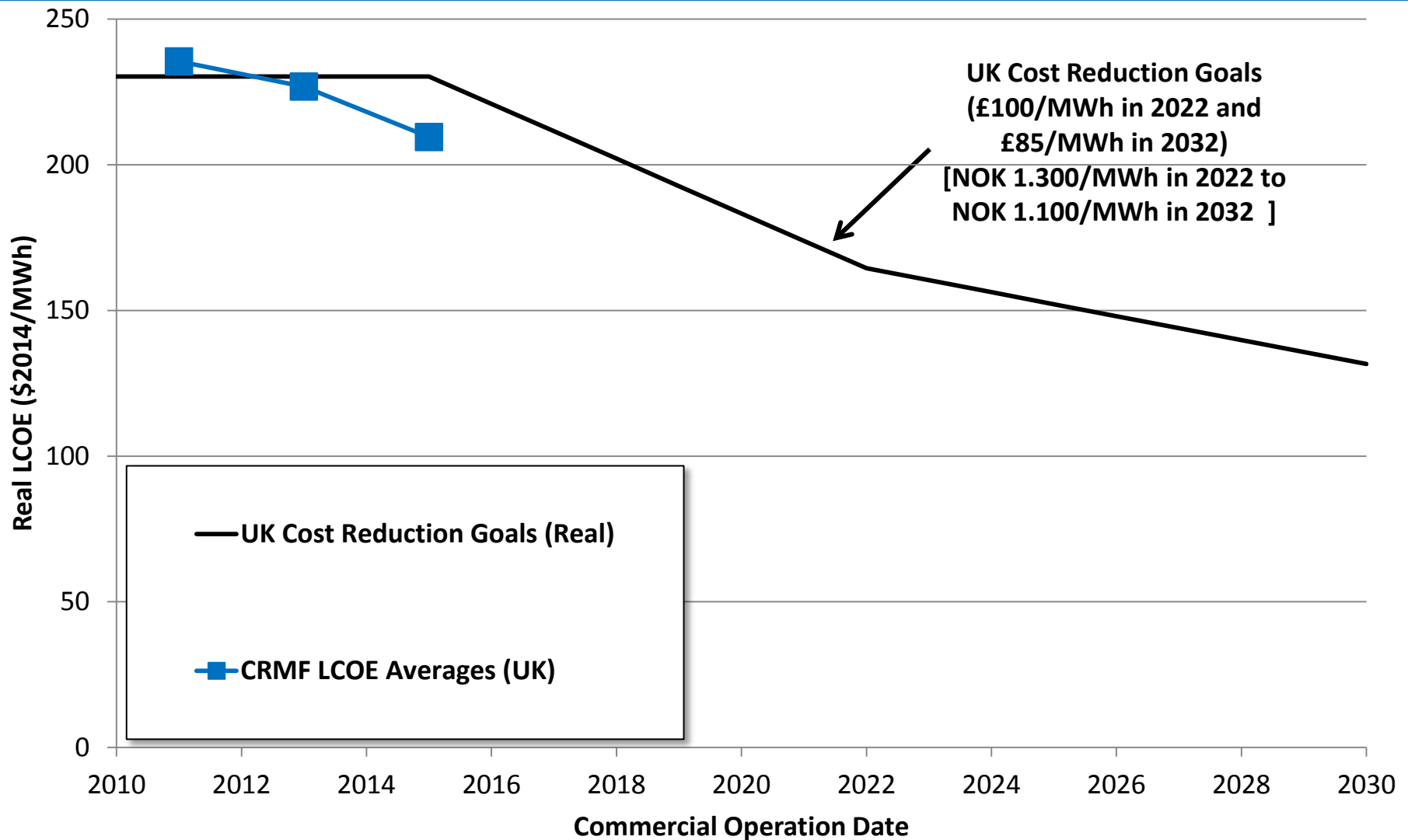
- **Approximate LCOEs show significant spread**
 - Horns Rev III (DK) \$95/MWh
 - Neart Na Gaoithe \$160/MWh
 - East Anglia ONE \$167/MWh
- **Drivers of differences**
 - **Scope:** Horns Rev III is not responsible for transmission infrastructure (offshore substation, export cables, and onshore substation). Increases lifecycle cost by ~20% to ~30% to roughly \$120/MWh
 - **Project characteristics:**
 - Horns Rev III: shallow water (**15 m**), close to shore (**30 km**), and **9.8 m/s** average wind speed at 100 m
 - East Anglia ONE: deeper water (**37 m**), farther from shore (**45 km**), and **9.5 m/s** average wind speed at 100 m
 - **Technology:** Horns Rev III will use Vestas V164 8-MW turbines, whereas Neart Na Gaoithe and East Anglia ONE will use Siemens SWT-7.0-154 turbines
 - **Policy conditions:**
 - Development costs covered by the Danish government and no seabed lease costs
 - Final subsidy tariff is negotiated between the developer and the Danish government
 - **Market structure:** Tax rates and depreciation schedules can have sizable effects on LCOE
 - **Financial structure:** Even though no details have emerged about the financial structures for any of these projects, differences in financing rates can have a large impact on LCOE.

Cost Reduction Case Study: Results



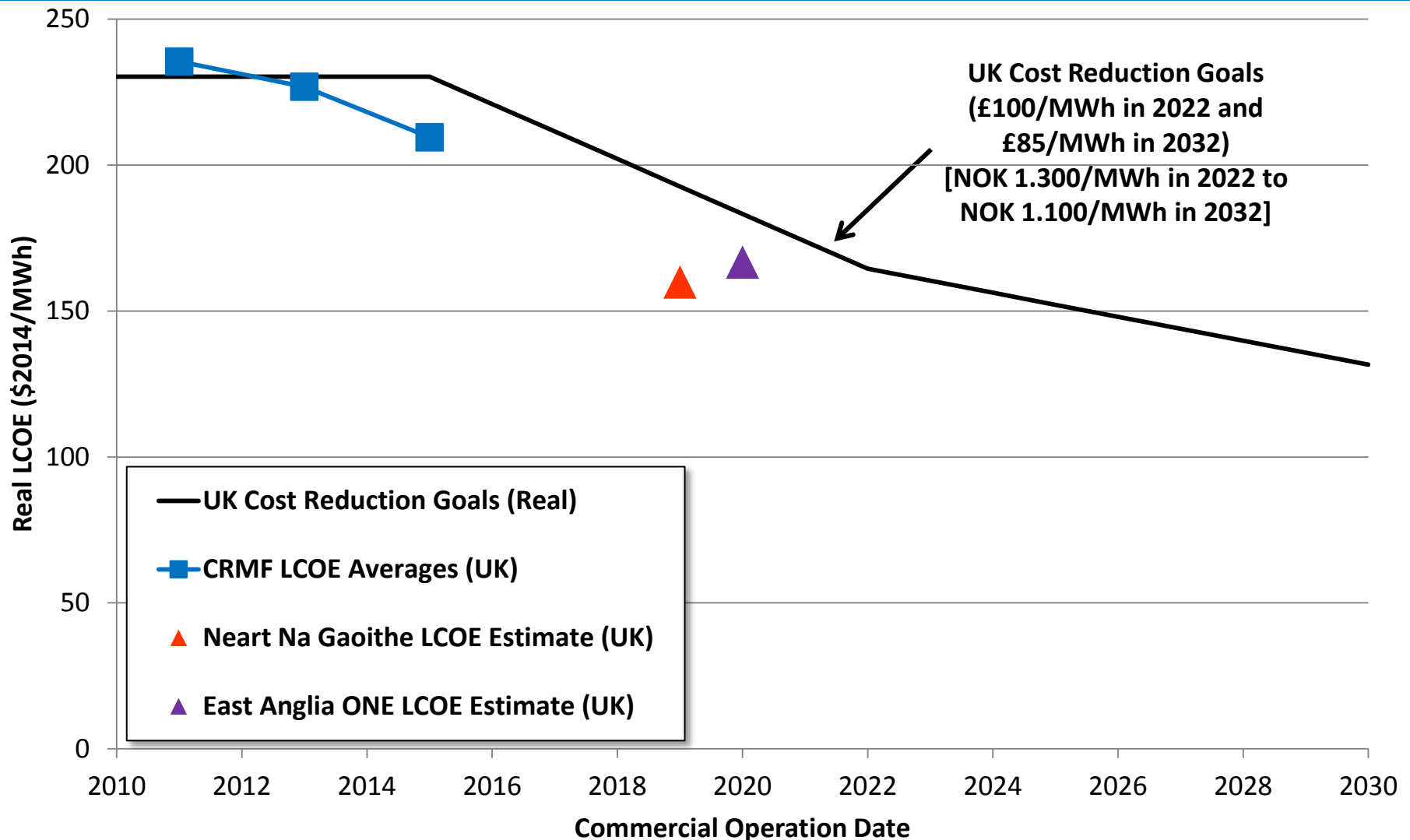
Note: There are significant challenges associated with comparing across different contract values due to differences in scope, market structure, and site characteristics. This analysis represents a reasonable approximation of LCOE for the projects considered but may not fully capture all drivers.

Cost Reduction Case Study: Results



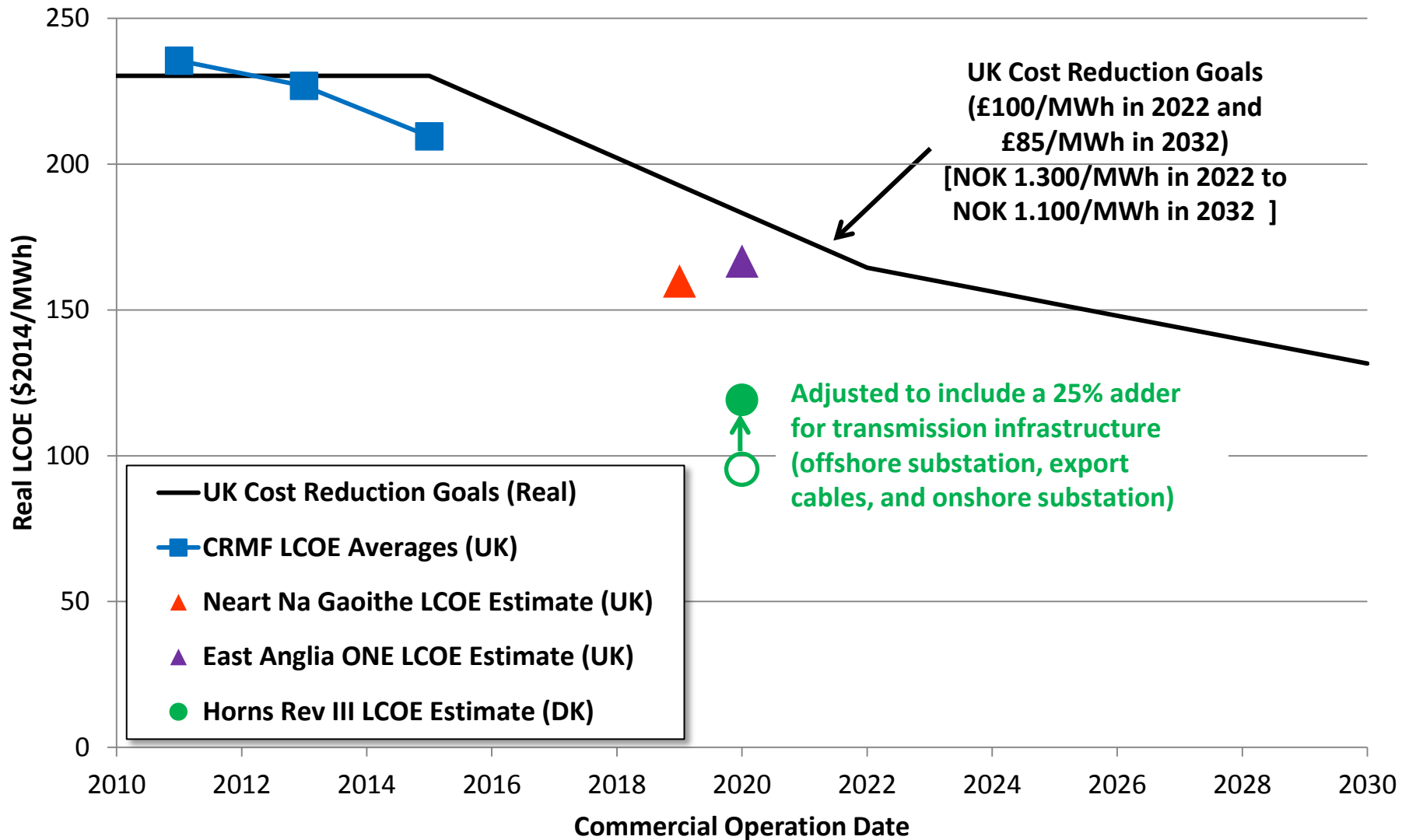
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Technologies and lessons learned from European deployment experience should translate to the U.S. market...

- **Block Island Wind Farm, ATD projects, and others will provide crucial experience that will enable the U.S. commercial projects to leverage European cost reduction while building U.S. capabilities:**
 - State-of-the-art turbines
 - Foundations developed by U.S. design firms and optimized to U.S. conditions, including:
 - Deepwater
 - Hurricane exposure
 - Surface icing
 - Streamline and de-risk offshore wind investment in the United States.
- **Could allow the industry to merge with or even advance beyond the European cost reduction trajectory.**



Image courtesy of Stanley White

...however, several barriers could limit the extent to which cost reductions can be realized in the United States

- **Infrastructure requires investment to 1) handle components for larger turbine sizes and 2) to match European industry standards for efficiency.**
 - Manufacturing facilities and/or shipyards require significant retooling.
 - Port facilities require upgrades to increase bearing capacity.
 - Jones-Act requires “creative” vessel strategies. The U.S. industry may eventually need to construct purpose-built installation vessels that comply with the Jones Act.
- **Fragmented (and uncertain) state and federal revenue mechanisms can be made to work on a one-off basis but do not provide the certainty needed to build an efficient industry.**
 - Site control is awarded independently from revenue mechanisms.
 - Federal policy (ITC, PTC) is uncertain and is insufficient to support project economics.
 - Revenue mechanisms are driven by states seeking first-mover advantages.
 - Potential for balkanized development due to focus on local instead of regional economic development
 - Could result in supply chain inefficiencies and higher cost levels.
- **Limited visibility into future market size makes it challenging for the supply chain to justify the necessary investments.**

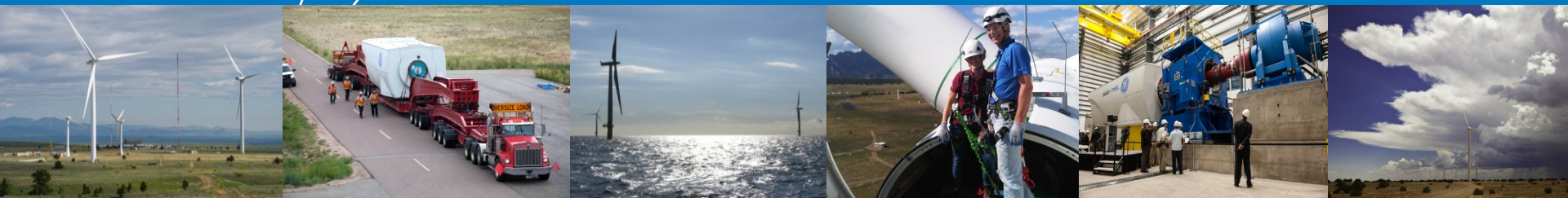
Summary

- **The U.S. offshore wind industry is ready for launch.**
- **However, stable, coordinated policy is needed to offset high initial costs and drive deployment.**
- **Costs in Europe are declining rapidly, with the industry poised to meet the targets of reducing LCOE by 40% from 2010 levels.**
- **A robust project pipeline is needed to encourage the investments in technologies and infrastructure that could enable the industry to merge with, or even surpass, the European cost reduction trajectory.**



Thank you for your attention!

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Offshore Wind Program
National Renewable Energy Laboratory
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Back-Up Slides and Supporting Information

Bottom-up LCOE calculations for Horns Rev III – \$100/MWh seems achievable with an excellent site, large turbines, and favorable policy

No Transmission System

Baseline Levelized Cost of Energy

Expenditures	
All-in Capital Costs (CapEx; \$/kW)	4000
Year 1 OpEx (\$/kW)	100.0
Annual OpEx escalation (Real)	0.0%
Levelized Operations Costs (OpEx; \$/kW)	100.0
Energy Production	
Net Annual Energy Production (AEP; MWh/MW)	4,600
Net Capacity Factor	53%
LCOE	
Real LCOE (\$/kWh)	\$0.096

Notes:

All-in CapEx includes Turbine, BOP, Spur Line and required substations, and construction financing

OpEx includes all operating expenses: turbine O&M, BOP O&M, property tax, lease payments, etc.

With two exceptions (debt interest rate and return on equity) all values are real dollar estimates and should be estimated in the preferred baseline year dollars

Financing	
Project Design Life (years)	20
Tax Rate (combined state and federal)	40.0%
Debt Fraction	70%
Debt Interest Rate (Nominal)	5.0%
Return on Equity (Nominal)	15%
WACC (Nominal; After-tax)	6.6%
WACC (Real; After-tax)	4.5%
Capital Recovery Factor (Real; After-tax)	7.7%
Depreciable Basis	100%
Depreciation Schedule	5 year MACRS
Depreciation Adjustment (NPV)	84%
Tax Adjustment	111%
Real Fixed Charge Rate	8.52%

Baseline Levelized Cost of Energy

Expenditures	
All-in Capital Costs (CapEx; \$/kW)	4700
Year 1 OpEx (\$/kW)	120.0
Annual OpEx escalation (Real)	0.0%
Levelized Operations Costs (OpEx; \$/kW)	120.0
Energy Production	
Net Annual Energy Production (AEP; MWh/MW)	4,416
Net Capacity Factor	50%
LCOE	
Real LCOE (\$/kWh)	\$0.118

Notes:

All-in CapEx includes Turbine, BOP, Spur Line and required substations, and construction financing

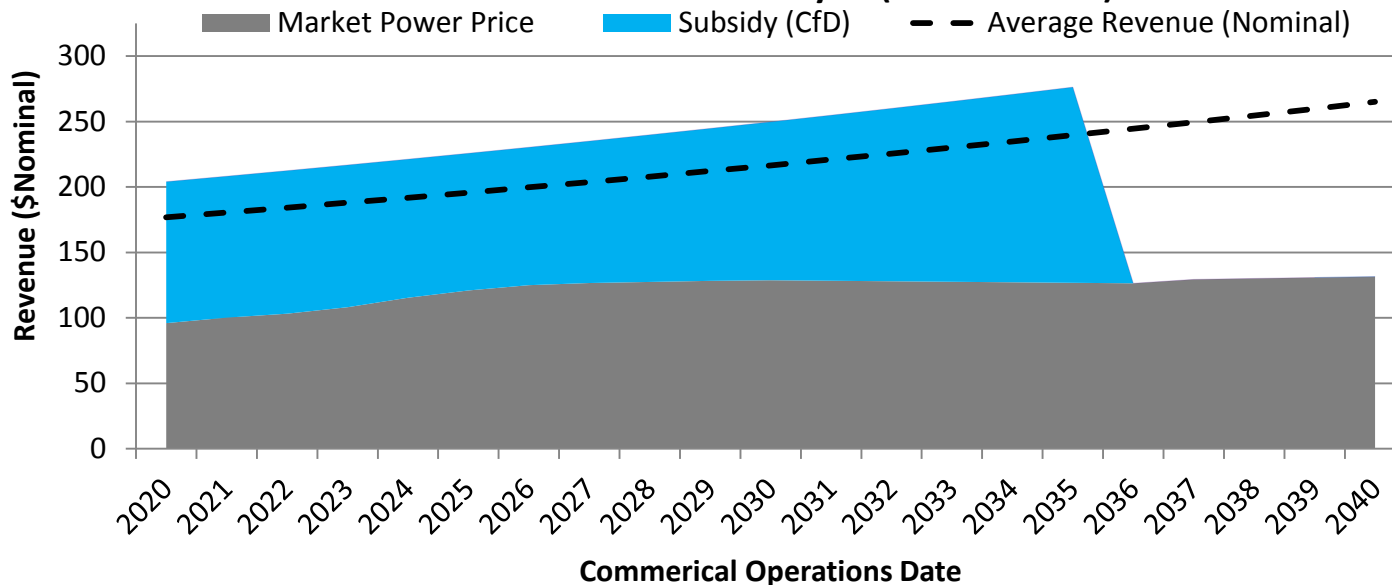
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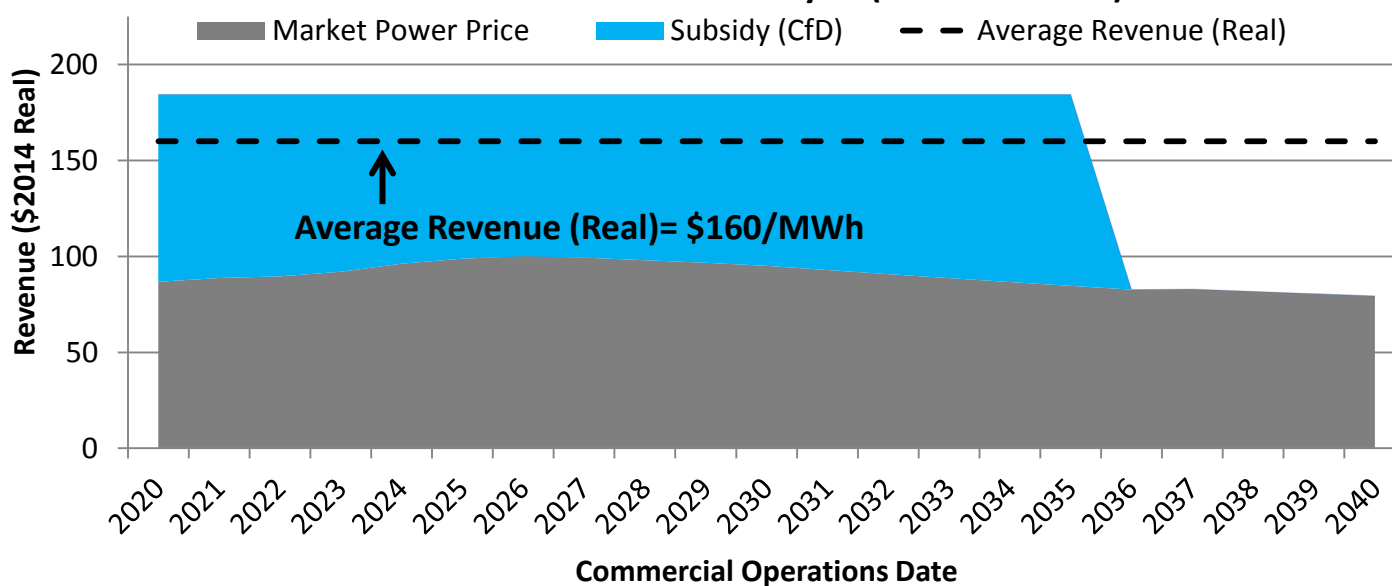
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* Energinet.dk reports that transmission system costs total 1,500 DKK (~\$280M), inclusion of transmission system increases OpEx (~20/kW) and lowers capacity factor (~-4%)

Neart Na Gaoithe Revenue Analysis (Nominal USD)



Neart Na Gaoithe Revenue Analysis (Real 2014 USD)



Neart Na Gaoithe Contract for Differences (CfD) Value Analysis	
Incentive Rate	\$184/MWh
Incentive Term	15 years
Inflation Index	Consumer Pricing Index
Average Electricity Price	\$94/MWh
Electricity Price Source	(National Grid 2014)
Other	Levy Exemption Credit set to expire before project begins operation