2013 Cost of Wind Energy Review

C. Moné, A. Smith, B. Maples, and M. Hand

National Renewable Energy Laboratory

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Technical Report
NREL/TP-5000-63267
February 2015

Contract No. DE-AC36-08GO28308

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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Prepared under Task No. WE15.CA03

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List of Acronyms

AEP	Annual energy production
AEP_{net}	Net annual energy production
AWEA	American Wind Energy Association
BNEF	Bloomberg New Energy Finance
BOEM	Bureau of Ocean Energy Management
BOS	Balance of system
CapEx	Capital expenditures
CF_{net}	Net capacity factor
C_p	Coefficient of Power
CRF	Capital recovery factor
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
EIA	U.S. Energy Information Administration
ENS	Danish Ministry of Energy and Environment
EPRI	Electric Power Research Institute
FCR	Fixed charge rate
GWEC	Global Wind Energy Council
JEDI	Jobs and Economic Development Impact
kW	Kilowatt
LCOE	Levelized cost of energy
LLC	Land lease cost
MACRS	Modified Accelerated Cost Recovery System
MAIN	Maintenance
MW	Megawatt
MWh	Megawatt-hour
NREL	National Renewable Energy Laboratory
OPER	Operation
OCS	Outer Continental Shelf
OpEx	Operational expenditures
PPA	Power purchase agreement
PTC	Production tax credit
PVdep	Present value of depreciation
SCBS	System cost breakdown structure
TSR	Tip-speed ratio
WACC	Weighted average cost of capital

Executive Summary

This report uses representative commerical project types to estimate the levelized cost of energy (LCOE) for both land-based and offshore wind plants in the United States (U.S.) for 2013. Scheduled to be published on an annual basis, it relies on both market and modeled data to maintain an up-to-date understanding of wind generation cost trends and drivers. It is intended to provide insight into current component-level costs and a basis for understanding variability in the LCOE across the industry. Data and tools developed from this analysis are used to inform wind technology cost projections, goals, and improvement opportunities.

The primary elements of the 2013 report include:

- Estimated LCOE for a reference land-based wind project installed in the interior region of the U.S. in 2013
- Estimated cost of energy for a reference fixed-bottom U.S. offshore wind project reflecting projects currently in late-stage development on the North Atlantic Coast
- Sensitivity analyses showing the range of effects that basic LCOE variables could have on the cost of wind energy for land-based and offshore wind power plants
- Historical trends in the LCOE for land-based and offshore wind plants.

The LCOE equation applied here is a standard methodology (Short et al. 1995, EPRI 2007) that includes four basic inputs: capital expenditures, operational expenditures, annual energy production, and the fixed charge rate (a coefficient that captures the cost of financing the construction of a wind project and the entirety of the planned plant's operational life). Additional detail on the LCOE can be found in the *2010 Cost of Wind Energy Review* (Tegen et al. 2012). The LCOE values reported within the reviews are expected to be greater than negotiated contract prices for wind power, as reflected by recent power purchase agreements. This increase is because recent power purchase agreements incorporate the value of the production tax credit (PTC), accelerated depreciation, other Renewable Energy Credits, or other applicable revenue streams.

Key Inputs and Results

Throughout this report, the representative land-based and offshore project types are referred to as "reference projects." Tables ES1 and ES2 summarize the four basic LCOE inputs for the reference land-based and fixed-bottom offshore wind projects, with some additional detail around project capital expenditures and the respective turbine capacity factor associated with the net annual energy production estimate. These are the assumptions used to calculate LCOE for the 2013 reference projects. In each table, the left-hand column shows the data source. "Model" refers to the techno-economic models used, such as the National Renewable Energy Laboratory's (NREL's) Wind Turbine Design Cost and Scaling Model (Fingersh et al. 2006, Maples et al. 2010). "Market" indicates that NREL used current market data, with individual data sources listed in sections of this paper related to the specific cost components.

Table ES1. Summary Description of the Land-Based Reference Project Using 1.91-MW Turbines

Data Source		1.91-MW Land-Based Turbine $/kilowatt (kW)	1.91-MW Land-Based Turbine $/Megawatt-hour (MWh)
Model	Turbine capital cost	1,185	35
Model	Balance of system	349	10
Model	Financial costs	155	5
Market	Market price adjustment*	39	1
Market	**CAPITAL EXPENDITURES**	**1,728**	**51**
Market	Operating expenditures ($/kW/yr)	50	15
Market	Fixed charge rate (%)	10.2	
Model	Net annual energy production (MWh/MW/yr)	3,410	
Model	Net capacity factor (%)	38.5	
Calculated	**TOTAL LCOE ($/MWh)**	**66**	

*The market price adjustment is the difference between the modeled cost and the market price paid for the typical project in 2013.

Table ES2. Summary Description of the Fixed-Bottom Offshore Reference Project Using 4.3-MW Turbines

Data Source		4.3-MW Offshore Turbine $/kW	4.3-MW Offshore Turbine $/MWh
Model	Turbine capital cost	1,660	56
Model	Balance of system	2,697	91
Market	Financial costs	830	28
Market	**CAPITAL EXPENDITURES**	**5,187**	**175**
Market	Operating expenditures ($/kW/yr)	136	39
Market	Fixed charge rate (%)	11.7	
Model	Net annual energy production (MWh/MW/yr)	3,463	
Model	Net capacity factor (%)	39	
Calculated	**TOTAL LCOE ($/MWh)**	**215**	

Land-based wind project cost estimates were derived primarily from installed project data reported by Wiser and Bolinger (2014) and supplemented with outputs from NREL's Wind Turbine Design Cost and Scaling Model. Because of the absence of installed or operating offshore wind projects in the United States, the offshore reference project data were estimated from proposed U.S. projects and market data from the existing international offshore wind industry. The assumed wind resource regime for the offshore reference plant is comparable to that of the U.S. North Atlantic Coast. The land-based reference project was assumed to have a moderate wind resource regime and location within the interior region of the United States.

As domestic and global wind markets mature, information about component-level costs are increasingly available. To manage and organize this component-level cost data, NREL has developed a system cost breakdown structure (SCBS) for land-based and offshore wind projects. A SCBS is able to break an entire wind project into smaller, more specific components (e.g., gearbox and generator). It provides a standardized approach to characterizing total lifetime expenditures for wind projects at the component level, including both physical (e.g., materials, labor, and equipment) and financial (e.g., insurance, profit, and carrying charges) costs. Each level of the SCBS hierarchy represents an increasingly detailed look at the project components. The new SCBS is further described in Section 2 and the associated appendices. More detailed breakdowns of capital expenditures (CapEx) are shown in Figures ES1 and ES2.

The three major component cost categories and many subcategories are represented in these figures including wind turbine (e.g., wind turbine components), balance of system (e.g., development, electrical infrastructure, assembly and installation), and financial costs (e.g., insurance and construction finance). From these data, it is clear that the breakdown of wind turbine component and installation costs varies greatly between land-based and offshore turbines. For example, the majority of the land-based project cost (68%) is in the turbine itself, whereas the turbine makes up only 32% of the offshore reference project cost.

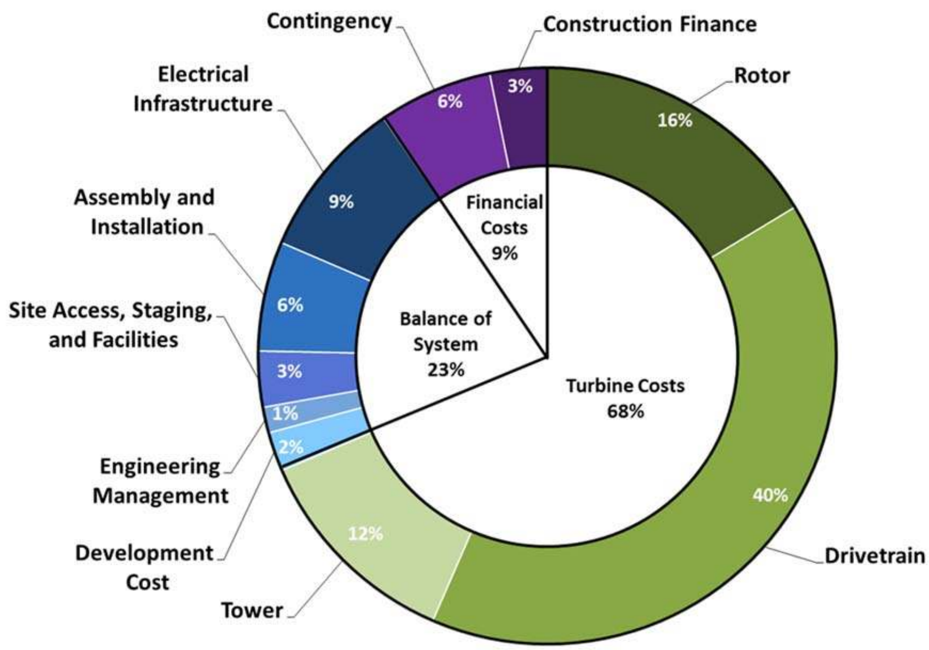

Figure ES1. Capital expenditures for the land-based wind plant reference project

Source: NREL

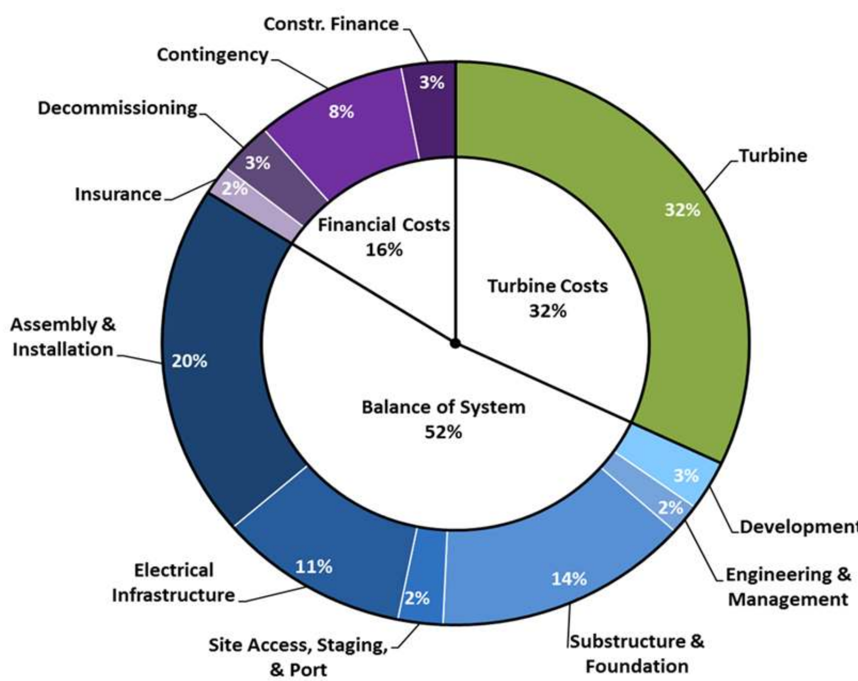

Figure ES2. Capital expenditures for the offshore wind plant reference project

Source: NREL

Figures ES3 and ES4 define the LCOE associated with the land-based and offshore reference plants along with a range of sensitivity variables affecting cost and performance. Reference project values of $66/megawatt-hour (MWh) for land-based wind and $215/MWh for offshore wind rely on inputs summarized in Tables ES1 and ES2 (and are identified by the vertical white line in these figures). Figures ES3 and ES4 also show the observed industry ranges for LCOE inputs and the resulting LCOE. To provide more detail on the fixed charge rate, the authors divided it into two principal components: discount rate and economic operational life. Annual energy production (AEP) was converted to capacity factor to help convey the full range of performance reflected by 2013 projects. As shown, the land-based net capacity factors from 2013 projects range from 25% to 50% (Wiser and Bolinger 2014), with an assumed 38.5% for the 2013 reference project. Clearly, the ranges for land-based and offshore wind LCOE inputs vary significantly (note the different axes in these figures). For example, offshore wind net capacity factor ranges from 30% to 50%, with an assumption of 39% for the reference project. Both figures show the effect capacity factor and CapEx have on the LCOE for both land-based and offshore wind projects. More detailed descriptions of the ranges and assumptions are included in the body of the report.

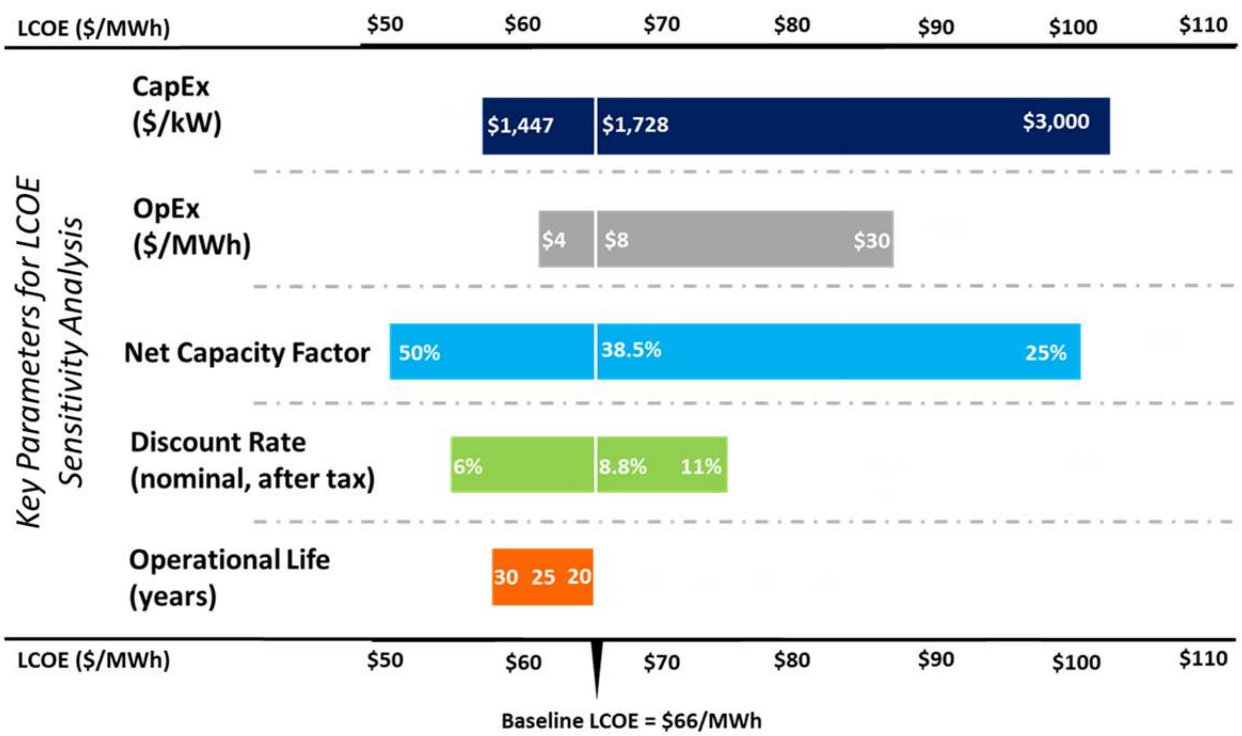

Figure ES3. Land-based wind assumptions and ranges for key LCOE input parameters

Source: NREL

Note: The reference LCOE represents the estimated LCOE for the NREL reference project. Changes in LCOE for a single variable can be understood by moving to the left or right along a specific variable. Values on the X-axis indicate how the LCOE will change as a given variable is altered, and assuming that all others are constant. For example, as capacity factor decreases toward 25%, the LCOE shown on the X-axis will increase accordingly to more than $100/MWh. As the operational life for the reference project moves toward 30 years, the LCOE will decrease to nearly $58/MWh.

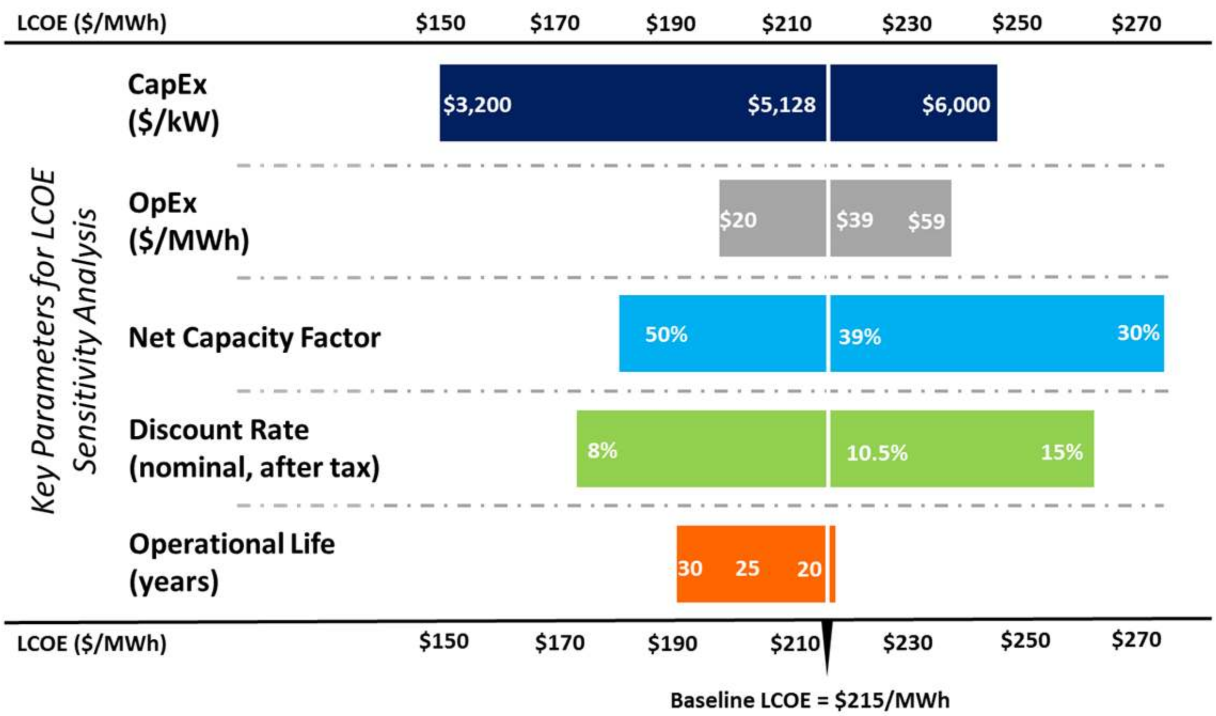

Figure ES4. Offshore wind assumptions and ranges for key LCOE input parameters

Source: NREL

Along with the reference LCOE estimates, NREL researchers created additional land-based wind project scenarios to demonstrate the impact of some project permutations: taller towers used on the project, larger rotors used to capture greater AEP, the combination of both a taller tower and larger rotor diameter, and higher average annual wind speed. Each of these scenarios resulted in a lower LCOE relative to the reference project, ranging from $63/MWh for a project with taller towers to $52/MWh combining all of the scenarios. The altered variables and their resulting LCOE are summarized in Table ES3.

Table ES3. Land-Based LCOE Cost Reduction Scenarios

	Reference	Taller Tower	Larger Rotor	Tower & Rotor	Higher Wind Speed	All Scenarios Combined
Nameplate capacity (MW)	1.91	1.91	1.91	1.91	1.91	1.91
Rotor diameter (m)	96.9	96.9	110	110	96.9	110
Hub height (m)	82.7	100	82.7	100	82.7	100
Average wind speed at 50 m (Average wind speed at hub height)	7.25 (7.79)	7.25 (8.0)	7.25 (7.79)	7.25 (8.0)	8.0 (8.6)	8.0 (8.8)
Net annual energy production (MWh/MW/yr)	3,410	3,536	3,796	3,918	3,866	4,345
LCOE ($/MWh)	**66**	**63**	**59**	**57**	**58**	**52**

From these results, researchers came to the following key conclusions:

- Final LCOE estimates continue to show a downward trend from the 2010 Cost of Wind Energy Review (Tegen et al. 2012) to 2013. Offshore turbine costs have shown similar cost reductions; however, the decrease in LCOE for the land-based projects can be attributed more to the turbine technology, and the offshore decreases to the balance-of-system costs.
- Although the reference project LCOE for land-based installations was observed to be $66/MWh, the full range of land-based estimates from the sensitivity analysis covers $50–$103/MWh.
- The reference project offshore estimate is $215/MWh, with a full range of $127–$270/MWh. This dramatic range is mostly caused by the large variation in capital expenditures ($3,200–$6,000/kW) reported by project developers.
- The sensitivity analysis shows that LCOE can vary widely based on changes in any one of several key factors; however, the variable with the most dramatic effect on LCOE is capacity factor—which is the case for both land-based and offshore projects.

Although LCOE calculations in this report do not include policy factors, it should be noted that the number of commissioned U.S. land-based wind projects was down significantly in 2013, partly because of policy uncertainty around the PTC in 2012. The expiration of the PTC forced a substantial deceleration of wind development; so much that, even with the January 1, 2013, extension of the PTC, demand for new wind projects proved to be weak. The American Wind Energy Association (2012) reported that three past expirations of the PTC resulted in a drop of 73%–93% for annual land-based wind installations in the year after expiration, and 2013 saw a 92% drop in installations compared to 2012, with the PTC expiration. The extension in 2013 that allowed for projects to meet PTC requirements is expected to bolster the industry and show an increase in land-based installations in 2014 and 2015. Observations made by Wiser and Bolinger (2014) support these expectations, showing early indications from the first quarter of 2014 which suggest a dramatic increase in the number of land-based projects installed in 2014 compared to 2013.

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1 Background

This report evaluates the levelized cost of energy (LCOE) for land-based and offshore wind projects in the United States. LCOE is a metric used to assess the cost of electricity generation and the total plant-level impact from technology design changes. LCOE can be used to compare costs of all electricity generator types, as long as the same formula and calculations are used for each type. Different methodologies have been developed to calculate LCOE; the one used for this analysis is fully described in *A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies* (Short et al. 1995).[1] Use of LCOE is especially important for technologies, where there is a constant tradeoff between maintaining or reducing capital investment and increasing energy capture, like wind and solar power.

There are four basic inputs into the LCOE equation. The first three—capital expenditures (CapEx), operational expenditures (OpEx), and annual energy production (AEP)—enable this equation to capture system-level impacts from design changes (e.g., taller wind turbine towers). The total costs of financing are represented by the fourth basic input—a fixed charge rate (FCR)—that represents the amount of revenue required to pay the carrying charges[2] on an investment during the expected project life per year.[3] For this analysis, the life of a wind project is assumed to be 20 years. All analysis and LCOE results will be in constant $2013 throughout the report unless otherwise noted.

This report provides an update to the *2010 Cost of Wind Energy Review* (Tegen et al. 2012) and an abbreviated look at the 2013 wind LCOE, turbine costs, financing, and market. Four specific areas are addressed:

- Estimate the LCOE for the reference land-based wind project located in a midwestern or "interior" site in the United States (U.S.) in 2013
- Estimate the LCOE for the reference fixed-bottom U.S. offshore wind project reflecting projects currently in late-stage development on the North Atlantic Coast
- Conduct sensitivity analyses showing the range of effects basic LCOE variables could have on the levelized cost of wind energy for land-based and offshore wind power plants
- Represent the National Renewable Energy Laboratory's (NREL's) calculated historical LCOE for land-based and offshore wind plants.

Despite addressing a number of assumptions and cost variables, this report does not capture the full spectrum of drivers that affect wind energy prices. For example, it does not consider policy incentives (such as the production tax credit, or PTC), factors from underlying economic conditions (such as an economic recession), the cost of building long-haul interstate transmission, or potential integration costs. These important variables can significantly impact wind power costs by reducing total costs, adding expenditures, delaying projects, or halting projects altogether. Nevertheless, their exclusion is consistent with past economic analysis conducted by NREL (Tegen et al. 2012, Lantz et al. 2012) and others (Bloomberg New Energy Finance 2012, Lazard

[1] For an overview of cost-of-energy calculators and models, see Gifford et al. (2011).
[2] Carrying charges include the return on debt, return on equity, taxes, depreciation, and insurance.
[3] The fixed charge rate does not allow for detailed analysis of specific financing structures; however, these structures can be represented through the use of a weighted average cost of capital as the discount rate input.

2008), as LCOE is not traditionally defined as a measure of all societal costs and benefits associated with power generation resources.

The following equation is used to calculate LCOE:

$$\text{LCOE} = \frac{(\text{CapEx} \times \text{FCR}) + \text{OpEx}}{(\text{AEP}_{\text{net}}/1{,}000)}$$

Where:

LCOE	=	levelized cost of energy [$/megawatt-hour (MWh)]
FCR	=	fixed charge rate (%)
	=	$\frac{d(1+d)^n}{(1+d)^n-1} \times \frac{1-(T \times PVdep)}{(1-T)}$
CapEx	=	Capital expenditures ($/kilowatt [kW])
AEP_{net}	=	net annual energy production (MWh/MW/yr)
	=	MW_{net} x 8760 x CF
OpEx	=	Operational expenditures ($/kW/yr)
	=	LLC + OPER + MAIN
d	=	discount rate [Weighted average cost of capital (WACC)] (%)
n	=	operational life (years)
T	=	effective tax rate (%)
PVdep	=	present value of depreciation (%)
CF_{net}	=	net capacity factor (%)
LLC	=	land lease cost ($/kW/yr)
OPER	=	pretax levelized operation cost (O&M) ($/kW/yr)
MAIN	=	pretax levelized maintenance cost (O&M) ($/kW/yr)

The following sections of this report define the approach to calculating the LCOE and introduce the new system cost breakdown structures (SCBS) to organize data and provide a common terminology across varying technologies. The report describes each component of the LCOE equation —CapEx, OpEx, AEP, and FCR— market context, and range of data for typical U.S. wind projects in the year 2013. In this *2013 Cost of Wind Energy Review*, the authors first define the 2013 LCOE components for a land-based reference project using an installed weighted average turbine sized at 1.91-megawatts (MW), which was the average nameplate capacity installed in the United States in 2013. Next, the authors describe the 2013 LCOE components for an offshore wind reference project using 4.3-MW offshore turbines, which is the average nameplate capacity installed globally in 2013.

2 Approach

The *2013 Cost of Wind Energy Review* applies the same approach as the 2010 and 2011 reports (Tegen et al. 2012, Tegen et al. 2013). The authors used a number of data sources and models in NREL's estimation of the cost of wind energy. For land-based wind technology calculations, the United States had over 61,000 MW of capacity installed and operating at the end of 2013.[4] The available data from these wind projects provided a large sample of empirical data on plant costs and performance. By contrast, no commercial offshore wind technology was deployed in the United States at the time of this study, and the market data supporting offshore cost of wind energy estimates are limited to international projects and proposed U.S. projects.

In addition to historical market data, the authors employed models to estimate disaggregated plant-level cost components. Therefore, detailed data are provided on the individual components that make up capital expenditures, operating expenditures, and estimated annual energy production for the reference projects defined here. Given the market and model data available, the general approach for estimating the levelized cost of wind energy includes:

1. Evaluating market conditions and data for projects that have been installed in the United States in a given year, to understand total installed project cost, AEP, operating costs, and representative turbine technology. The primary source for these data is DOE's *Annual Wind Technologies Market Report* (Wiser and Bolinger 2014). Accordingly, LCOE estimates reflect market conditions to the extent possible. Because of the small sample size of the 2013 commissioned projects, the projects were combined with others that were currently under construction in early 2014, with anticipated completion in 2014 per Wiser and Bolinger. The capacity-weighted averages of the U.S. installed projects were combined to yield 27 total projects, offering a larger sample size.
2. Evaluating market conditions and data for projects that have been installed in Europe and Asia when considering offshore wind technology in a given year, because no United States projects have been installed to date, to understand total installed project cost expenditures, AEP, operating expenditures, and representative turbine technology. The primary source for these data is NREL's internal Wind Database and DOE's *Offshore Wind Market and Economic Analysis* (Hamilton et al. 2014).
3. Supplementing available market data with modeled data based on a representative or reference project that reflects technology and project parameters for a given year. Principally, NREL's Wind Turbine Design Cost and Scaling Model (Fingersh et al. 2006, Maples et al. 2010) is used to estimate the capital cost and AEP of a project based on turbine rated capacity, rotor diameter, hub height, and a representative wind resource. This model uses scaling relationships at the component level (e.g., blade, hub, generator, and tower) developed with curve-fit industry data, published scaling models, and turbine models developed through the WindPACT studies (e.g., Malcolm and Hansen 2006) that reflect component-specific and often nonlinear relationships between size and cost (see Appendix C in Tegen et al. 2012). The use of this model provides additional component-level details for turbines (with user-defined parameters) and plants.

[4] Note that data for all of these projects is not publicly available.

4. Combining the market data and modeled data described above to estimate the primary elements necessary to calculate LCOE (i.e., CapEx, OpEx, AEP, and FCR) and provide details about wind technology costs and performance that are aligned with market data but reported at a more detailed resolution.

This approach is useful in that the reference project is described with a level of detail that is based on technology specifications, whereas market conditions are preserved; however, reliance on modeled data for disaggregated component-level and energy production estimates also introduces a degree of uncertainty in some LCOE input variables. Model uncertainty is introduced principally in two areas:

- Modeled installed capital cost tends to underestimate market data that are influenced by factors not captured by the model (e.g., the relative value of the U.S. dollar, industry profit margins, foreign labor costs, underlying market conditions, and changes in warranty terms or servicing agreements that are wrapped into turbine supply agreements) that are included in the market-based CapEx that would be included in a commercial wind project.
- The modeled AEP_{net} estimate relies on estimated total losses across the reference project; however, production losses are, in reality, site- and technology-dependent, and measurements for individual projects are not available.

To address these two sources of uncertainty, model estimates for capital expenditures and capacity factor are adjusted to reflect market data by applying two terms: a "market price adjustment" factor and a generic "losses" term. These terms apply global adjustment factors (coefficients) to cost and production estimates that account for the myriad of factors that are not explicitly modeled, but that can have a significant cumulative effect. Continued efforts to improve the fidelity of NREL's bottom-up models are expected to result in greater confidence associated with individual component estimates and plant-level production; however, it is unlikely that differences between market and modeled data will ever be fully resolved.

3 System Cost Breakdown Structure

As domestic and global wind markets mature, data for component-level costs are increasingly available. To manage and organize this component-level cost data, NREL has developed a system cost breakdown structure (SCBS) for land-based and offshore wind projects. An SCBS provides the ability to view the components of a wind plant at varying degrees of cost detail. From the top down, a broad overview of plant costs is shown. From the bottom up, one can see how individual component costs are grouped into systems, and how their costs roll up to higher-level costs until reaching the plant level. The SCBS deconstructs the total expenditures of a wind project down to six levels and includes more than 300 components.

3.1 SCBS Description

The wind SCBS provides structured and consistent breakdowns of a wind project into smaller, more specific components.[5] It provides a standardized approach to characterizing total lifetime expenditures for wind projects at the component level, including both physical (e.g., materials, labor, and equipment) and financial (e.g., insurance during construction, profit, and carrying charges) costs. Each descending level of the SCBS hierarchy represents an increasingly detailed look at the project components. For example, total lifetime expenditures can be deconstructed into two "level 1" components: CapEx and OpEx. CapEx can be further deconstructed into three "level 2" components: turbine, balance-of-system (BOS), and financial costs (see Figure 1). The sum of the costs across all components at a given level should equal the cost of the components in the level above them provided that all fields have data. For example, the sum of turbine costs, BOS costs, and financial costs (level 2), should equal the CapEx for a given project (level 1).

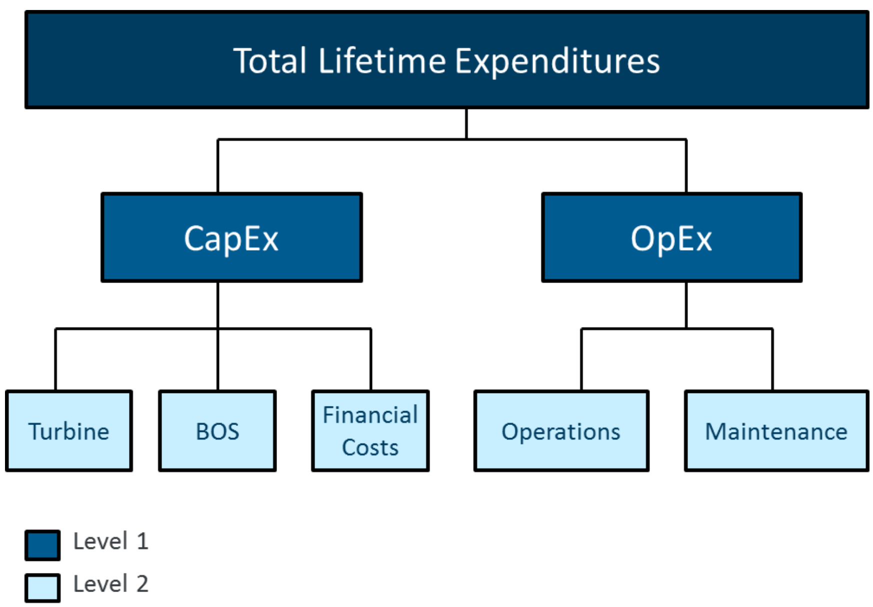

Figure 1. Levels 1 and 2 of the SCBS

Source: NREL

[5]Although the SCBS is similar to a work breakdown structure, they serve different purposes. A work breakdown structure is typically process or product oriented, whereas the SCBS is cost oriented with a focus on representing the components of a project that contribute to the capital and operational expenditures.

The wind SCBS is hierarchical and defines both the position of a component within the system and its relationship to other components. In this way, the SCBS effectively defines the bounds for the categories of data, reduces the chance of double counting or making inappropriate comparisons, and standardizes terminology to improve communication.

To be applicable and useful across a broad range of wind projects, an SCBS is designed to represent a generic project with line items to capture many possible technology configurations. Despite best efforts to define a generic SCBS, there are several reasons to expect it will not apply perfectly to any single project in the real world:

- Projects have different components depending on technical specification (e.g., a direct-drive wind turbine will not have a gearbox)
- There are many permutations of possible contractual relationships for a project, ranging from a single Engineering, Procurement, and Construction (EPC) contract to a full multi-contract approach, where a sponsor might manage all contracts internally
- Based on previous experience in collecting data from industry, various entities use different approaches for tracking the expenditures involved in a given wind project. The SCBS provides a consistent approach to organize the industry data and eliminate variations in how the industry groups its subcomponent data.

3.2 Benefits

The wind SCBS specifies well-defined categories to organize wind project expenditures and define hierarchical relationships between those categories. In this way, the SCBS provides a natural foundation for the design of the NREL wind plant database and provides several secondary benefits as well. The SCBS will simplify the collection, organization, and analysis of component-level data for projects because it:

- Offers a standard template that can be used for data collection
- Accommodates data required for both top-down and bottom-up analysis
- Enables accurate comparisons across different data sources
- Facilitates the definition of a standard approach for reporting analysis results.

The wind SCBS is also expected to enable improved analytical consistency across DOE's Wind and Water Power Technologies Office portfolio by identifying the full range of system costs for a technology and highlighting elements that might be common across similar technologies.

3.3 Approach and Limitations

The first step in developing the SCBS was to review literature describing databases, taxonomies, and models related to land-based and offshore wind projects (Table 1). The guiding documents for the definition of SCBS elements related to the wind turbine included the ReliaWind *Wind Turbine Reliability Taxonomy* (Tavner 2010) and the Sandia National Laboratory *Reliability Database* (Hill et al. 2009). The guiding documents for the definition of SCBS elements related to the BOS included BVG Associates' *Guide to an Offshore Wind Farm,* NREL's *Offshore Wind BOS Model*, NREL's *Land-Based BOS Model*, and NREL's *Wind Deployment Barriers Project.* The guiding documents for the definition of SCBS elements related to OpEx included Netherlands Energy Research Foundation *Offshore O&M Tool* and NREL's *Land-Based O&M Project*.

Table 1. Resources Referenced Prior to Developing the SCBS

Land-Based Wind
Capital Expenditures
Wind Turbine Reliability Taxonomy (Tavner 2010)
Reliability Database (Hill et al. 2009)
Land-Based BOS Model (NREL)
Wind Turbine Design Cost and Scaling Model (Fingersh et al. 2006)
Wind Deployment Barriers Project (NREL)
Operational Expenditures
Land-Based O&M data collection ([DNV GL Report] Internal Only)
Wind Turbine Design Cost and Scaling Model (Fingersh et al. 2006)

Offshore Wind
Capital Expenditures
Guide to an Offshore Wind Farm (BVG Associates 2010)
Cost Reduction Pathways Study (Crown Estate 2012)
Offshore BOS Model (NREL)
Offshore JEDI Model (NREL)
Operational Expenditures
Offshore O&M Tool (Rademaker et al. 2009)

In addition to the information provided in the literature review, the following set of basic requirements and criteria were developed to guide the development of the SCBS:

- Components in the SCBS are first grouped based on contractual relationship, then function/process, then proximity. It is clear, however, that a variety of contractual arrangements are used in the industry and the wind SCBS cannot capture them all (e.g., turbine supply agreements can include delivery of the turbine either with or without installation)
- The SCBS reflects wind project components from the perspective of the project sponsor[6] for level 3 categories, and from the perspective of original equipment manufacturers (OEMs) or EPC contractors at lower, more detailed levels of the hierarchy
- The SCBS includes wind project components through level 5; additional detail may be captured through the description of level 5 components
- The wind SCBS is flexible enough to describe projects that use many possible technology configurations (e.g., a high-voltage alternating current [HVAC] or high-voltage direct current [HVDC] export system). A consequence of this variation is that a given project will not have all possible components listed in the SCBS—nor would this be expected.

[6] To ensure that the SCBS is a relatively generic structure that can be applied broadly across all wind projects, NREL has to account for the different ownership scenarios that are possible during the project lifetime. The project could be developed, owned, or operated by the same entity, or ownership could be transferred at any point in the lifecycle.

An SCBS deconstructs the total expenditures of a wind project down to five levels and includes more than 300 components. Figure 2 and Figure 3 depict the structure of the hierarchy to level 3 for capital and operational expenditures, respectively. The full wind SCBS, including descriptions of each component category, is included in Appendix E for land-based wind plants and Appendix F for offshore wind plants.

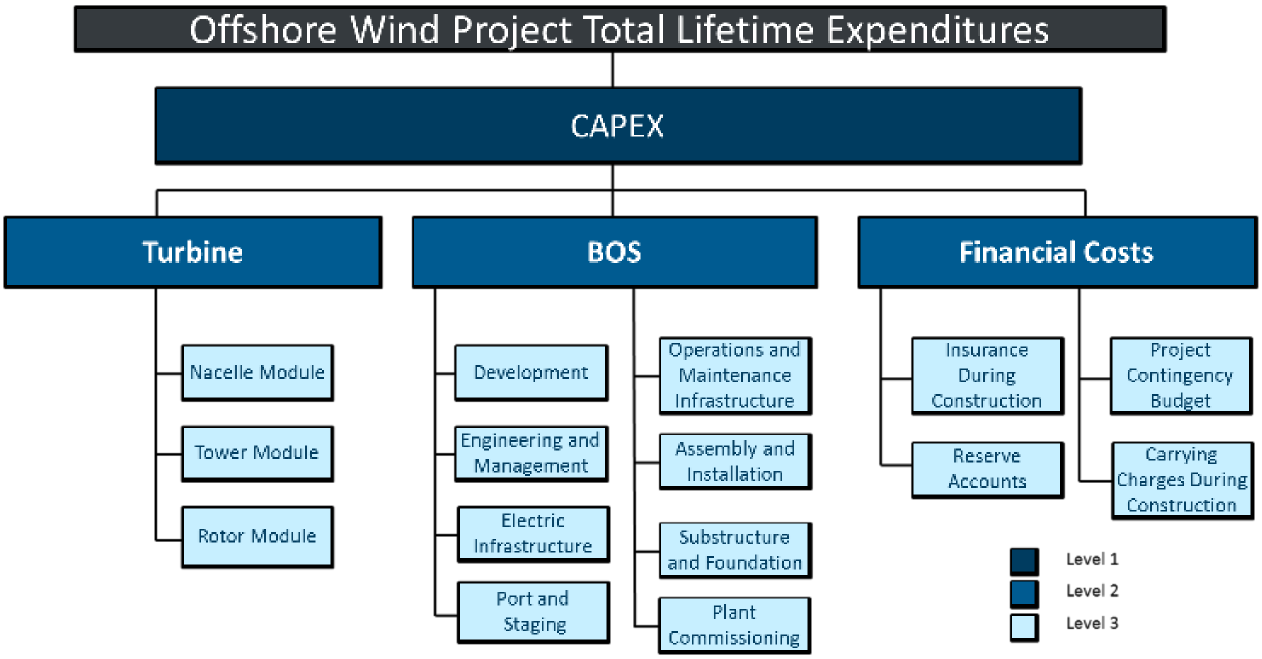

Figure 2. Wind system cost breakdown structure: CapEx levels 1 to 3

Source: NREL

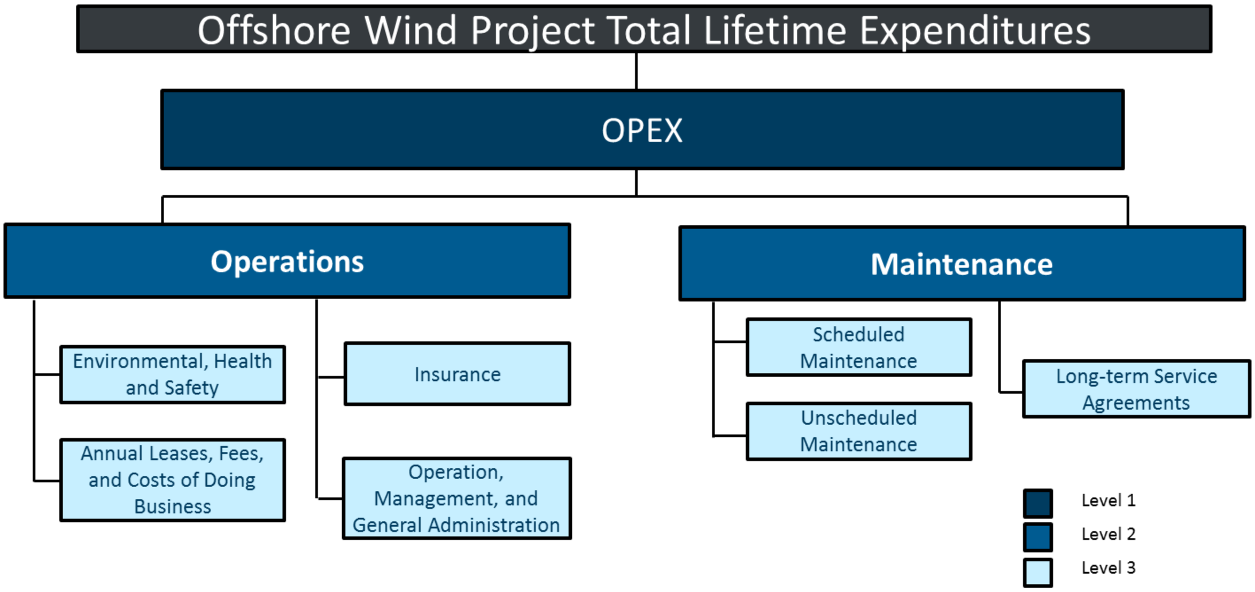

Figure 3. Wind system cost breakdown structure: OpEx levels 1 to 3

Source: NREL

Although there are many possible methods for organizing the hundreds of cost elements that make up a wind project, this structure strives to be consistent with the way that a project developer and operator might see or incur costs. That is, the authors prioritize the contractual relationships of cost elements above process or functional relationships. For example, wind turbine tower modules are often grouped with substructures and foundations as these three elements provide the same functionality. Together, they provide structural support for the wind turbine. Wind turbine supply agreements, however, have historically included the tower (the turbine manufacturer supplies both the turbine elements and the tower), making it difficult to distinguish the price of the individual components. Aligning the organizational structure of the SCBS with the way that project sponsors incur costs is expected to greatly simplify data collection and facilitate effective communication with commercial stakeholders.

The wind SCBS is not likely to perfectly capture the elements of a specific, real-world wind project. Invariably, at a very detailed level (i.e., level 4 or 5), wind projects may utilize different component breakdowns when compared to one another. Even at a less detailed level (i.e., level 3) the manner in which one sponsor tracks costs might differ from another. The guiding principle for the wind SCBS was to develop a systematic approach for organizing component information, with the flexibility to accommodate a wide variety of projects, and the specificity to clearly indicate the composition of each component line item. This approach removes uncertainty about where each component belongs and will minimize the possibility of counting components twice or making incorrect or inconsistent comparisons across different projects.

Upon completion of a preliminary wind SCBS, collaborators from NREL, DOE, and industry provided feedback on the structure to identify any gaps or redundancies and discussed suggestions for modifications and improvements.

4 Land-Based Wind

The land-based wind reference project was derived from representative characteristics of wind plants in DOE's Wind Technology Market Reports and summarized in Table 6. Reference project wind turbine and component costs are based on the most common turbine design installed in the United States in 2013, which is a three-stage planetary/helical gearbox feeding a high-speed asynchronous generator and a standard spread-foot foundation design. Operating expenditures for this project, which are considered on an annual basis, reflect estimates from 94 projects built since 2000 (Wiser and Bolinger 2014). The reference project wind regime is generally equivalent to a moderate wind resource site in the interior region of the United States, generally considered Minnesota to Oklahoma.

4.1 2012 Land-Based Cost of Wind Energy

For the year 2012, no annual cost of wind energy review was published. However, according to the *2013 Wind Technology Market Report* (Wiser and Bolinger 2014), the United States installed a record amount of new capacity totalling 13.1 gigawatts (GW) with an average installed cost of $1,940/kW. Using the reported average nameplate capacity, rotor diameter, and tower heights for the interior project, NREL calculated an AEP of 3,284 MWh/MW/yr using a 200-MW project size. Given these inputs as well as the additional variables considered to reflect the reference project, details of which are located in Appendix C and summarized in Table 2, the resulting LCOE for 2012 was $73/MWh.

Table 2. Summary of Inputs and Reference Project 2012 LCOE for Land-Based Installations

Data Source		1.94-MW Land-Based Turbine $/kW	1.94-MW Land-Based Turbine $/MWh
Model	Turbine capital cost	1,279	37
Model	Balance of system	365	11
Model	Financial costs[7]	162	3
Market	Market price adjustment[8]	135	4
Market	**CAPITAL EXPENDITURES**	**1,940**	**56**
Market	Annual OpEx ($/kilowatt/yr)	55	17
Market	Real fixed charge rate (%)	9.5	
Model	Net annual energy production (MWh/MW/yr)	3,284	
Model	Net capacity factor (%)	37.5	
Calculated	**TOTAL LCOE ($/MWh)**	**73**	

[7] Financial costs are incurred before project commissioning, primarily related to the costs that are not part of construction.
[8] The market price adjustment is the difference between the modeled cost and the price paid for the typical project in the 2013 market.

4.2 Comparison of Two Different Cost of Wind Energy Methodologies

In 2013, the United States installed 1,087 MW of wind energy, a 92% drop from the previous year. As reported in the *2013 Wind Technologies Market Report* (Wiser and Bolinger 2014), the capacity-weighted average cost for installation was $1,630/kW. The report also states that the average nameplate capacity was 1.87 MW, the average rotor diameter was 97 meters (m), and the average hub height was 80 m, resulting in an AEP of 3,424 MWh/MW/yr. The 2013 sample size was limited, with only 11 projects accounting for almost 60% of the installed projects, which could disproportionately influence the weighted averages and costs.

Early indications from a larger sample (16 projects totaling over 2 GW) at the time of writing this report that were currently under construction or anticipated completion in the first part of 2014 suggest that the capacity-weighted average was closer to $1,750/kW (Wiser and Bolinger 2014). Because of the small 2013 completed project sample size, it was determined that to better represent the market, a capacity-weighted average of the 11 projects in 2013 and the 16 anticipated commissioned projects in 2014 would be combined to yield 27 projects for the land-based wind plant cost of energy analysis for the 2013 year review. Table 3 presents a side-by-side comparison of the LCOE analysis for 2013 and the combined 2013-2014 analysis.

Table 3. Comparison of Market-Based Cost of Wind Energy, 2013 Projects to Combined 2013-2014 Projects

Parameters (Capacity-weighted averages)	2013 Projects	2013–2014 Projects
Nameplate capacity (MW)	1.87	1.91
Rotor diameter (m)	97	96.7
Hub height (m)	80	82
Modeled net capacity factor	38.5%	38.5%
CapEx ($/kW)	1,630	1,728
FCR (%)	10.2%	10.2%
OpEx ($/kW)	50	50
AEP (MWh/MW/yr)	3,425	3,386
Number of projects in sample	11	27
Total capacity (MW) in sample	650	1,919
TOTAL LCOE ($/MWh)	**63**	**66**

For the remainder of this report (and for greater clarity in presenting data) the 2013–2014 combined capacity-weighted averages will be labeled "2013," providing the basis for the 2013 reference project analysis and reporting.

4.3 2013 Land-Based Cost of Wind Energy

The land-based wind reference project was derived from representative characteristics of 2013 wind projects consisting of 105 1.91-MW turbines (200 MW total installed capacity). The capacity-weighted average of 2013 CapEx[9] costs was calculated to be $1,728/kW, with total pretax OpEx reported at $50/kW/yr. Accordingly, these values were ascribed to the land-based reference project. Given these inputs, as well as the additional variables considered to reflect the reference project and summarized in Table 4 below, the resulting LCOE is $66/MWh.

Table 4. Summary of Inputs and Reference Project LCOE for 2013 Land-Based Installations

Data Source		1.91-MW Land-Based Turbine $/kW	1.91-MW Land-Based Turbine $/MWh
Model	Turbine capital cost	1,185	35
Model	Balance of system	349	10
Model	Financial costs[10]	155	5
Market	Market price adjustment[11]	39	1
Market	**CAPITAL EXPENDITURES**	**1,728**	**51**
Market	Annual OpEx ($/kilowatt/yr)	50	15
Market	Real FCR (%)	10.2	
Model	Net annual energy production (MWh/MW/yr)	3,410	
Model	Net capacity factor (%)	38.5	
Calculated	**TOTAL LCOE ($/MWh)**	**66**	

4.4 Capital Expenditures for Land-Based Wind

The weighted-average CapEx and OpEx data are published annually by DOE in the *Wind Technologies Market Report* (Wiser and Bolinger 2014). The analysis conducted here applies the NREL Wind Turbine Design Cost and Scaling Model to estimate component-level costs that were calibrated to the market-based total cost estimates from Wiser and Bolinger (2014). This calibration was necessary because recent trends have been influenced by variables that are not captured in the current modeling approach of using national averages in a project-specific site analysis. NREL has developed a bottom-up model that associates physical parameters with cost estimates. Although this approach still under predicts the total cost, it can provide greater fidelity in component cost and relative component cost change with the size of the turbine.

[9] CapEx costs represent the cost of building a plant and do not include financing or escalation costs that can vary with risk perception, construction schedules, inflation expectations, and other factors.

[10] Financial costs are non-construction costs incurred before project commissioning, primarily related to the cost of financing.

[11] The market price adjustment is the difference between the modeled cost and the price paid for the average project in the 2013 market.

Figure 4 illustrates the breakdown of CapEx for the NREL land-based reference project. In the figure, the CapEx component percentages highlighted in shades of green capture the turbine capital cost; percentages highlighted in blue capture the BOS share of capital costs; and components highlighted in purple capture the financial capital costs. For information on the assumptions and inclusions of the individual components, see Tegen et al. (2012), Maples et al. (2010), and Fingersh et al. (2006).

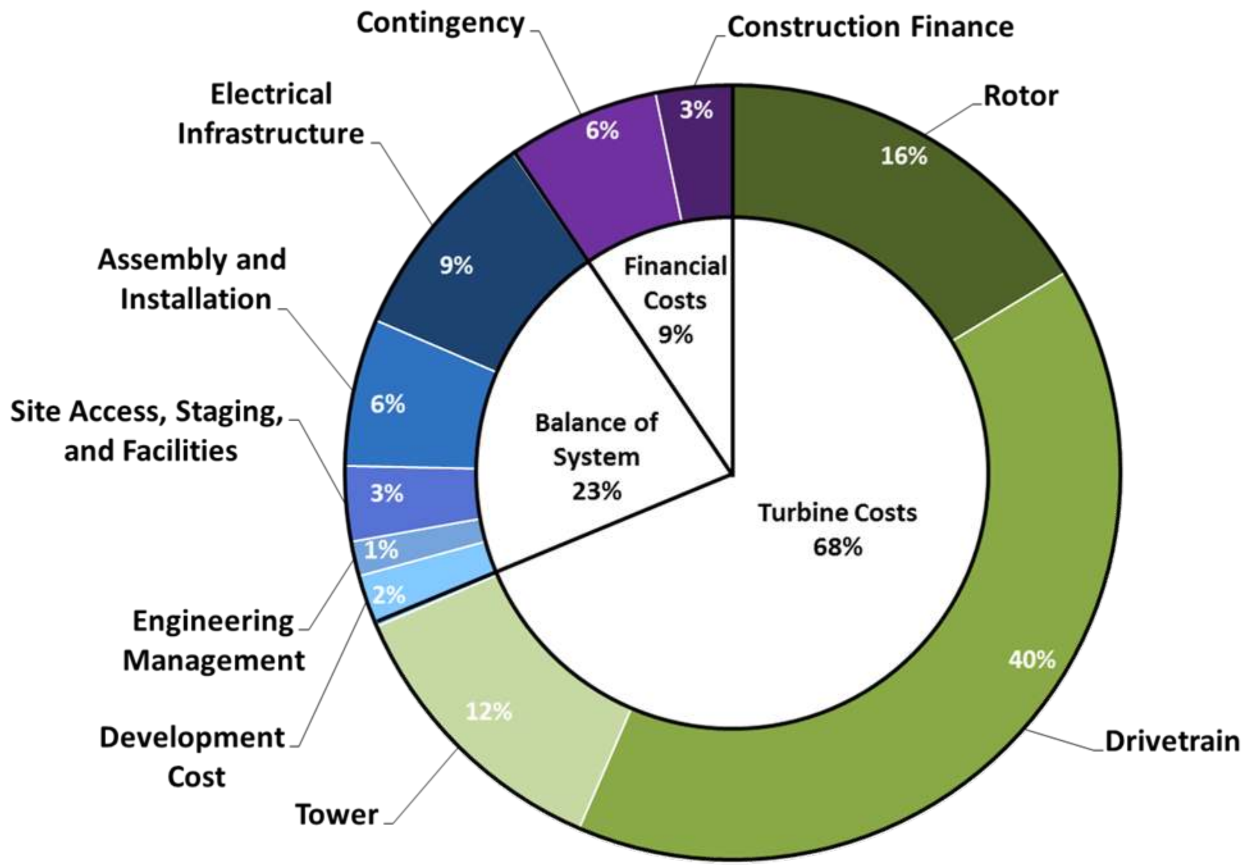

Figure 4. Capital expenditures for the land-based wind reference project

Source: NREL

Table 5 summarizes the costs for individual components (including their contribution to LCOE) for average turbine characteristics used in the reference project, based on a project that uses 1.91-MW turbines. Data sources for this table are described in Appendix B.

Table 5. Land-Based LCOE and CapEx Breakdown

	1.91-MW Land-Based Turbine $/kW	1.91-MW Land-Based Turbine $/MWh
Rotor Module	**282**	**8**
Blades	169	5
Pitch assembly	65	2
Hub assembly	48	1
Nacelle Module	**695**	**21**
Nacelle structural assembly	139	4
Drivetrain assembly	235	7
Nacelle electrical assembly	283	8
Yaw assembly	38	1
Tower Module	**208**	**6**
TURBINE CAPITAL COST	**1,185**	**35**
Development Cost	32	1
Engineering Management	19	1
Foundation	58	2
Site Access and Staging	48	1
Assembly and Installation	43	1
Electrical Infrastructure	150	4
BALANCE OF SYSTEM	**349**	**10**
Market Price Adjustment	39	1
Construction Financing Cost	50	2
Contingency Fund	105	3
FINANCIAL COSTS	**194**	**6**
TOTAL CAPITAL EXPENDITURES	**1,728**	**51**

Wind turbine costs for projects installed in 2013 ranged from $900/kW to $1,300/kW for utility-scale wind projects (Wiser and Bolinger 2014), with many factors driving these differences (such as terrain, site access, and regional labor costs). Because of CapEx variability, estimates for the component costs were established using the NREL Wind Turbine Design Cost and Scaling Model, and a market price adjustment was added to bring the CapEx cost in line with the industry average. The market price adjustment accounts for fluctuations in component costs, profit margins, foreign exchange rates, supply chain constraints, and other market conditions. This analysis does not attempt to predict which capital cost components are influenced by the market price adjustment, as these impacts can vary from project to project.

BOS costs were estimated using new scaling relationships and costs from detailed data obtained through a major EPC firm active in the wind industry. These new relationships provided a basis for understanding the underlying impacts of turbine component designs on the BOS costs as well as the impacts of innovative BOS concepts. This additional cost information enabled a more detailed breakdown of BOS categories than was available in previous years. Construction financing was estimated at 3% of hard costs, which is consistent with industry reporting.

4.5 Operating Expenditures for Land-Based Wind

OpEx typically include land lease costs (LLC), operations wages and materials (OPER), and maintenance (MAIN). OpEx costs are generally expressed in two categories: fixed operations, which includes discrete, known operations costs (e.g., scheduled maintenance, rent, land leasing, taxes, utilities, and insurance payments) and typically does not change depending on how much electricity is generated (called OPER in this report), and variable OpEx, which includes unplanned maintenance and other costs that may vary throughout the project life depending on how much electricity is generated (called MAIN in this report). For simplicity, annual OpEx can be converted to a single term and expressed as either dollars per kilowatt per year ($/kW/yr) or dollars per megawatt-hour ($/MWh). This analysis uses the $/kW/yr convention.

Annual MAIN estimates are calculated from recent estimates of operating costs for projects built since 2000. Wiser and Bolinger (2014) reported a pretax average MAIN value of $28/kW/yr that generally incorporates the costs of wages and materials associated with maintaining the turbines of a facility, but likely excludes other elements such as general operations, insurance, taxes, or depreciation.[12]

The OpEx values reported here include the average estimated property tax payments from NREL's Jobs and Economic Development Impact (JEDI) model and the MAIN for major turbine components from Cohen et al. (2008), which are referred to as levelized replacement costs (LRC). Property tax costs and MAIN bring the total pretax OpEx to $50/kW/yr and are summarized in Table 6. It should be noted that, given the scarcity and unpredictable quality of the data, OpEx can vary substantially among projects (Wiser and Bolinger 2014), and the data presented here may not fully represent the challenges that operating expenditures present to the wind power industry. In addition, researchers across NREL and other laboratories in the wind industry have worked together over the past year to validate the $50/kW/yr calculation and support these pricing levels.

[12] Alternatively, if expressed in $/kWh terms, O&M estimates in 2013 ranged from $5 to $20/MWh (based on plants with a commercial operation date of 2010), with the 2013 O&M baseline estimate of $9/MWh (Wiser and Bolinger 2014).

Table 6. Land-Based Wind Reference Project OpEx

	1.91-MW Land-Based Turbine	1.91-MW Land-Based Turbine
Operations (OPER)	\$14/kW/yr	\$4/MWh
Maintenance (MAIN)	\$28/kW/yr	\$9/MWh
Land lease cost	\$8/kW/yr	\$2/MWh
OPERATIONAL EXPENDITURES	**\$50/kW/yr**	**\$15/MWh**

4.6 Annual Energy Production and Capacity Factor for Land-Based Wind

Annual energy production (AEP) for this analysis is computed using the NREL wind turbine design cost and scaling model. The model computes annual energy capture and other related factors, such as capacity factor, for a wind project that is specified by generic input parameters, presented in Table 7. These input parameters have been chosen as default values to be held constant for the annual LCOE calculations, allowing the differences in turbines and financing to influence the results and not project variability. The input parameters can be grouped into three general categories: turbine parameters, wind resource characteristics, and losses.

Table 7. Reference Land-Based AEP Input Assumptions

Turbine Parameters	
Turbine rated power (MW)	1.91
Turbine rotor diameter (m)	96.7
Turbine hub height (m)	82.5
Maximum rotor tip speed (meters per second [m/s])	80
Tip-speed ratio at maximum coefficient of power (C_p)	8
Drivetrain design	Geared
Rotor peak power coefficient (C_p)	0.47
Wind Resource Characteristics	
Annual average wind speed at 50-m height (m/s)	7.25
Weibull K	2
Shear exponent	0.143
Elevation (above sea level [m])	450
Losses	
Losses (i.e., array, energy conversion, and line)	15%
Availability	98%

4.6.1 Turbine Parameters

Turbine parameters are characteristics that are specific to the turbine and independent of the wind characteristics. These parameters consist not only of turbine size (such as rated power, rotor diameter, and hub height), but also of turbine operating characteristics such as coefficient of power [C_p], maximum tip speed, maximum tip-speed ratio (TSR), and drivetrain design). Because the geared drivetrain topology dominates the U.S. market, a geared drivetrain was selected for the baseline turbines used in this analysis. For specific approaches used regarding additional turbine parameters (e.g., power curves), see the *2010 Cost of Wind Energy Review*.

4.6.2 Wind Resource

The annual average wind speed chosen for the reference project analysis was 7.25 meters per second (m/s) at 50 m above ground level (7.75 m/s at hub height of 80 m). This wind speed is representative of a Class 4 wind resource (7–7.5 m/s) and is intended to be generally indicative of the wind regime for projects installed in moderate quality sites in the "interior" region of the United States (Minnesota to Oklahoma). An elevation above sea level of 450 m was used based on the representative "interior" site. The elevation above sea level coupled with a hub height of 80 m results in an average air density of 1.163 kg/m^3.

4.6.3 Losses

Although some losses can be affected by turbine design or wind characteristics, losses are treated as independent of any other input in this simplified analysis. Types of losses accounted for in this analysis include array wake losses, electric collection and transmission losses (from the substation to the point of interconnection), and blade soiling losses, totaling 15%. An availability of 98% was used, indicating that the wind farm is ready to produce power between wind turbine cut-in and cut-out wind speeds 98% of the time. Net annual energy production (AEP_{net}) is calculated by applying all losses to the gross AEP. Table 8 shows the AEP, capacity factors, losses, and availability for the land-based reference turbine operating in 2013.

Table 8. Land-Based Wind Turbine AEP and Capacity Factor Summary

	1.91-MW Land-Based Turbine
Gross AEP (MWh/MW/yr)	4,094
Gross capacity factor (%)	46.1
Losses and availability (%)	17
AEP_{net} (MWh/MW/yr)	3,410
Net capacity factor (%)	38.5

4.6.4 Land-Based Wind Finance

Throughout the majority of 2013, the financing environment was not conducive for installing land-based wind projects. The 92% drop in projects completed in 2013 compared to 2012 can be directly attributed to the expiration of the production tax credit (PTC), which required projects to be completed by December 31, 2012. The PTC, under the American Taxpayer Relief Act of 2012, was reinstated in January 2013. This reinstatement allows projects to be eligible as long as they meet the Internal Revenue Service's designation of "Physical Works" and "under construction" before January 1, 2014; however, the delay in the PTC enactment had already negatively affected financing and discouraged projects from being completed in 2013.

The cost of capital for both term debt and tax equity investment in 2013 departed slightly from 2010 and 2011 levels as the benchmark interest rates in the United States rose. The 20-year treasuries that closely approximated the lifetime of a modeled wind project rose from 2.67% in December 2011 to 3.63% in December 2013. Similarly, 30-year treasuries rose from 2.98% in December 2011 to 3.89% in December 2013. With a rise in benchmark interest rates, the authors would expect to see higher debt interest rates for wind energy projects generally as well as the associated required rate of return.

In 2013, both the tax equity and term debt yields were relatively steady with tax equity on an after tax, unlevered basis of 8%, whereas the 15-year CapEx, pretax basis, debt interest rates held below 6% (Wiser and Bolinger 2014). For this analysis, the discount rate was calculated as the after-tax weighted average cost of capital (WACC) for land-based wind energy projects. The base-case assumptions used in estimating the WACC include a debt ratio of 50%, an after tax, levered tax equity yield of 11.5%, a pretax debt interest rate of 6.5%, and an effective marginal corporate tax rate of 38.9%. Under these assumptions, the nominal, after tax WACC for land-based wind energy projects in 2013 was estimated at approximately 8.8% (nominal). Assuming a 2.2% rate of inflation in 2013, the real after tax discount rate was estimated at 6.5%.[13]

4.7 Land-Based Wind Reference Project Summary

Table 9 captures the full array of variables that reflect the land-based reference project as well as the values (for each variable) that underlay the basic LCOE inputs. The CapEx for the project was assumed to be nearly $345 million, or $1,728/kW. A $20.9 million contingency fund was assumed to cover any possible increases in capital costs, and OpEx was estimated at $15/MWh. A 20-year project operational economic life was assumed, with a nominal discount rate of 8.8%.

Table 9. Land-Based Reference Project Assumptions Summary

General Assumptions	
Project capacity (MW)	200
Number of turbines	105
Turbine capacity (MW)	1.91
Site	
Location	U.S. Interior
Elevation (meters above sea level)	450
Layout	Grid
Wind speed (m/s at 50-m height above ground)	7.25
Wind speed (m/s at 80-m height above ground)	7.75
Net capacity factor	38.9%
Technology	
Rotor diameter (m)	96.7
Hub height (m)	82.5
Gearbox	Three stage
Generator	Asynchronous
Foundation	Spread foot

[13] Converted using the standard Fisher equation. The 2.2% rate of inflation is based on the *2014 Annual Energy Outlook* by the Energy Information Administration (EIA 2014).

Cost	
Capital cost (millions)	$345
Contingency (6%) (millions)	$20.9
OpEx ($/MWh)	$15
Discount rate (real)	6.5%
Discount rate (nominal)	8.8%
Economic operating life (years)	20
FCR (real)	10.2%

Note: The nominal discount rate may be generally equated with the weighted average cost of capital and is distinguished from the real discount rate in that it includes an inflation factor. The discount rate constitutes a principal input into the FCR, which allows for the estimation of capital recovery on an annualized basis.

4.8 Land-Based Wind LCOE Calculation

Based on the NREL land-based baseline project inputs—CapEx, AEP, OpEx, and FCR—and using the LCOE equation, a land-based wind LCOE is computed to reflect the 2013 reference wind plant described above. Table 10 summarizes the costs for the primary components (including their contribution to LCOE). Data sources for this table are located in Appendix B. Figure 5 provides a graphical representation of the land-based reference project LCOE by line item.

Table 10. Land-Based Wind Reference Project LCOE Cost Breakdown

	1.91-MW Land-Based Turbine	1.91-MW Land-Based Turbine
CAPITAL EXPENDITURES	**$1,728/kW**	**$51/MWh**
OPERATIONAL EXPENDITURES	**$50/kW/yr**	**$15/MWh**
Net 7.25 m/s AEP (MWh/MW/yr)	3,410	
Net capacity factor	38.5%	
FCR (real, after tax)	10.2%	
LEVELIZED COST OF ENERGY ($/MWh)	**$66**	

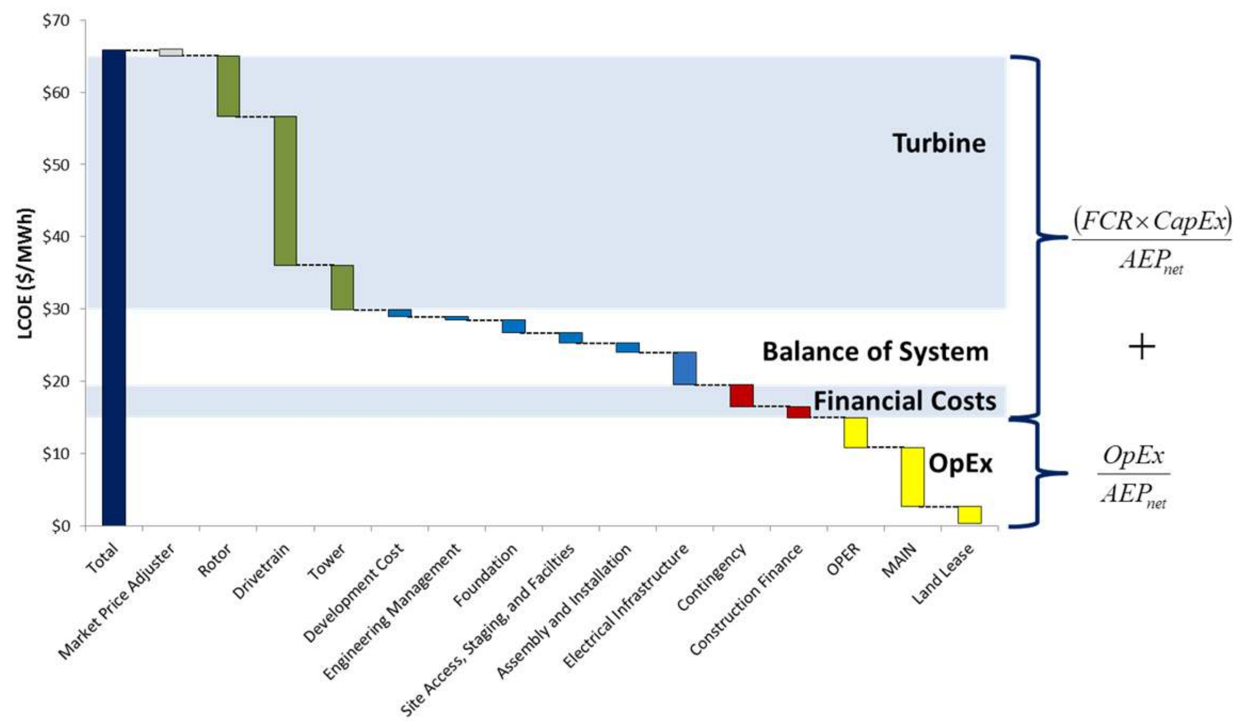

Figure 5. Component level cost breakdown for the 2013 land-based wind reference project

Source: NREL

4.9 LCOE Sensitivities

The input parameters described above reflect the land-based reference wind project; however, input parameters for a near-term, land-based wind project are subject to considerable uncertainty. As a result, it is beneficial to investigate how this variability may impact LCOE. The sensitivity analysis shown in Figure 3 focuses on the basic LCOE inputs: 1) CapEx, 2) OpEx, 3) capacity factor (a surrogate for AEP), and 4) FCR, although in Figure 6, FCR is broken into its principal elements—discount rate and economic operational lifetime. Sensitivities to these variables are tested across the ranges of market data reported in previous sections.

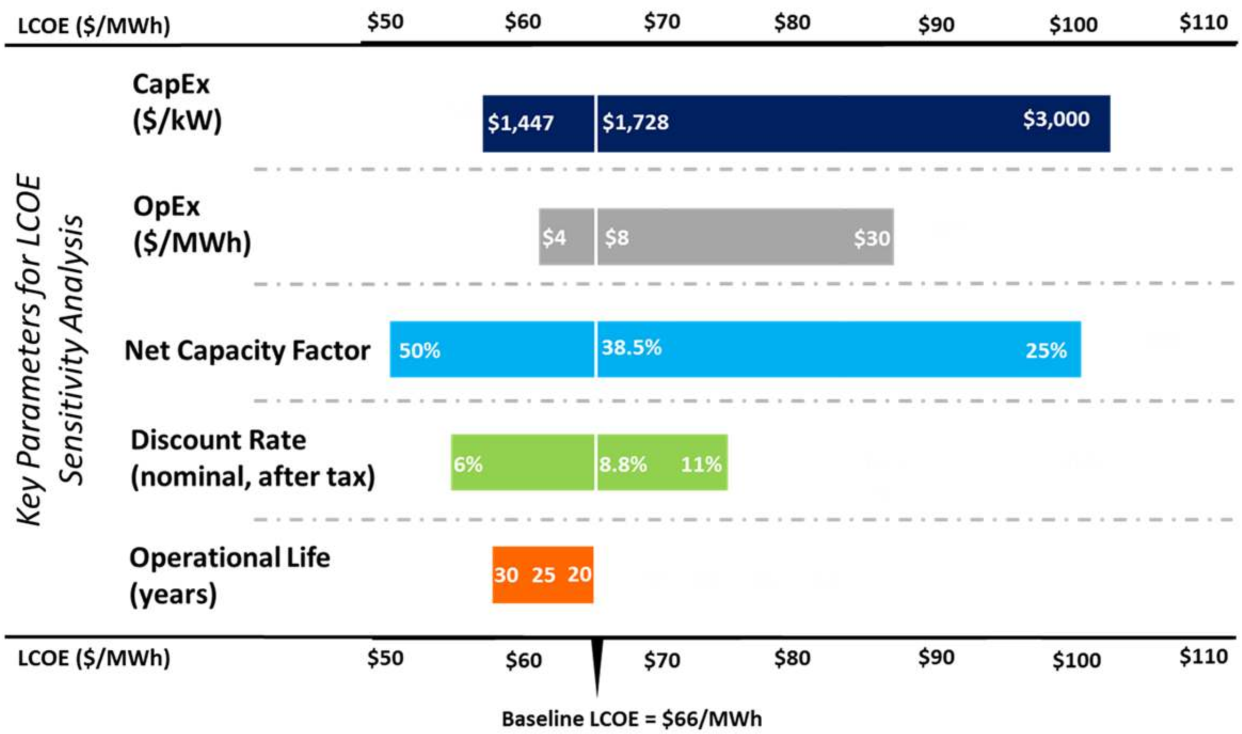

Figure 6. Sensitivity of land-based wind LCOE to key input parameters

Source: NREL

Note: The reference LCOE reflects a representative industry LCOE. Changes in LCOE for a single variable can be understood by moving to the left or right along a specific variable. Values on the X-axis indicate how the LCOE will change as a given variable is altered and all others are assumed constant (i.e., remain reflective of the reference project).

Sensitivity analyses were conducted by holding all reference project assumptions constant and altering only the variable in question. Sensitivity ranges were selected to represent the highs and lows observed in the industry. This selection of ranges provides insight into how real-world ranges influence LCOE. The sensitivity analysis yields ranges in LCOE from a low of $50/MWh to a high of $103/MWh—a low-to-high increase of nearly double the lower bound. Within the ranges shown, CapEx and capacity factor are the two factors that appear to have the greatest impact on LCOE; however, the capacity factor and discount rate appear to have the greatest influence with respect to decreasing the LCOE relative to the reference project.

Although the ranges provided here for the selected variables are grounded in actual 2013 plant costs and performance data; the high and low LCOE ranges should not be taken as absolute. These variables are generally not independent, and it is unlikely for changes to occur only in a single variable. Moreover, each individual wind project has a unique set of characteristics. Accordingly, the sensitivities shown here are not universal.

4.10 Cost Reduction Scenarios

For the 2013 reference project installations, additional scenarios were modeled: 1) increasing the hub height, 2) increasing the rotor diameter, 3) combining the technology changes of taller towers and larger rotors, 4) increasing annual average wind speed, and 5) combining all three independent scenarios. Although there is a link between changes in cost and energy production, this analysis was performed by holding all reference project assumptions constant and changing only the necessary variables to demonstrate the relative impacts of isolated changes for illustrative purposes.

4.10.1 Increasing Turbine Characteristics

Wiser and Bolinger (2014) noted that average wind turbine characteristics, nameplate capacity, rotor diameter, and hub height, have been increasing. The industry is trending toward taller towers, with many geographic areas preferring 100-m-tall towers to increase AEP. Assuming the CapEx remains constant, the reference project LCOE with a 100-m-tall tower would be expected to decrease to $64/MWh (Table 9). In addition, the increase in rotor diameter has outpaced all other technological advancements, increasing up to 103% in size since 1998–1999 (Wiser and Bolinger 2014). Similar to the findings for taller towers, if the project costs remain constant, the 11% increase in AEP resulting from the increased rotor diameter would amount to an LCOE of $60/MWh.

Both of these advancements impact the capacity factor and AEP of projects. By combining both technology changes—increasing the hub height and rotor diameter—the LCOE would decrease to $58/MWh for the reference project (assuming constant capital costs).

4.10.2 Increasing Annual Average Wind Speed

A number of factors, such as policy influences, siting impacts, and technology changes, have led to the recent trend in siting wind projects in areas with lower wind resource quality (Wiser and Bolinger 2014). There is still a surplus of high-quality wind resource project sites that are undeveloped in the United States and an effort to place more projects in these areas could lower the project LCOE. Table 11 presents the change in LCOE that is a direct result of switching from a Class 4 wind resource (annual average hub-height wind speed of 7.79 m/s) to a Class 5 wind resource (annual average hub-height wind speed of 8.6 m/s), thereby decreasing the LCOE to $59/MWh. It is important to note that the decrease in LCOE resulting from the better wind resource is approximately equivalent to the LCOE reductions achieved with a taller tower or a larger rotor for the same turbine power rating ($59/MWh versus $58/MWh, respectively). If both of these technological advances can be implemented without a concurrent increase in either CapEx or OpEx (using advanced controls or design innovations), in combination with a higher average wind speed, the net effect would be to reduce the LCOE to $52/MWh in the reference project scenarios.

Table 11. Example of Land-Based LCOE Reduction Scenarios

Parameters	Reference Project	Taller Tower	Larger Rotor	Taller Tower and Larger Rotor	Higher Wind Speed	Scenario Combination
Nameplate (MW)	1.91	1.91	1.91	1.91	1.91	1.91
Rotor diameter (m)	96.9	96.9	110	110	96.9	110
Hub height (HH) (m)	82.7	100	82.7	100	82.7	100
Avg. speed at 50 m (Avg. speed at HH) (m/s)	7.25 (7.79)	7.25 (8.0)	7.25 (7.79)	7.25 (8.0)	8.0 (8.6)	8.0 (8.8)
AEP (MWh/MW/yr)	3,410	3,536	3,796	3,918	3,866	4,345
Net capacity factor	38.5%	40.4%	43.3%	44.7%	44.1%	49.6%
CapEx ($/kW)	1,728	1,728	1,728	1,728	1,728	1,728
OpEx ($/MW/yr)	50	50	50	50	50	50
Tax rate (%)	39	39	39	39	39	39
FCR (real, after tax)	10.2%	10.2%	10.2%	10.2%	10.2%	10.2%
LCOE ($/MWh)	**66**	**64**	**60**	**58**	**59**	**52**

5 Offshore Wind

Although there is much enthusiasm about the potential of offshore wind development in the United States, no projects have been installed to date. The lack of domestic experience with offshore wind technology has contributed to considerable uncertainty in estimates of the potential cost of domestic offshore wind energy. The *2010 Cost of Wind Energy Review* (Tegen et al. 2012) offers a detailed analysis of offshore wind cost trends in Europe as well as projections for the United States to develop input assumptions for a reference project based on commercial-scale, fixed-bottom offshore wind technology.

This report provides an update to the 2010 report including trends in capital costs observed outside of the country as well as recent market conditions; however, as no major differences from the 2010 report have been observed in offshore costs for projects under development in the United States, the cost estimates utilized in this report are a result of the annual *Offshore Wind Market and Economic Analysis* (Hamilton et al. 2014) completed by Navigant Consulting, Inc. (Table 12). The offshore wind reference project uses the average global turbine characteristics from the Navigant report including 4.3 MW of capacity, a rotor diameter of 119.4 m, and an 89.5-m-tall tower. Although information on floating offshore wind projects is not included here, it is planned to be covered in future iterations of this report.

Table 12. Summary of Inputs and Results for the Fixed-Bottom Offshore Wind Project

Data Source		4.3 MW Offshore Turbine $/kW	4.3 MW Offshore Turbine $/MWh
Model	Turbine capital cost	1,660	56
Model	Balance-of-system costs	2,697	91
Model	Financial costs	830	28
Market	**CAPITAL EXPENDITURES**	**5,187**	**175**
Market	OpEx ($/kW/yr)	136	39
Market	FCR (%)	11.7	
Model	AEP_{net} (MWh/MW/yr)	3,406	
Model	Capacity factor (%)	39.0	
Calculated	**TOTAL LCOE ($/MWh)**	**215**	

5.1 2013 Market Developments

In 2013, 1,567 MW of offshore wind capacity were installed worldwide (GWEC 2014). To date, offshore wind development has been highly concentrated geographically, with over 93% of cumulative capacity installed in Europe and 56% located in the United Kingdom (GWEC 2014). Installations in Asia are starting to accelerate, with two commercial-scale projects installed in

China and three demonstration projects installed in South Korea and Japan. Global markets are poised for growth with aggressive goals in both Europe and Asia; however, deployments have been affected by uncertainty in the form and value of incentives (United Kingdom), delays in grid development (Germany), and local and national government concerns (China). In the United States, the three principle hurdles are:

- **An uncertain timeline for permitting**. The Bureau of Ocean Energy Management (BOEM) has made considerable progress in leasing and permitting projects since the 'Smart from the Start' initiative was announced in 2010. BOEM has awarded commercial leases in three wind energy areas and is moving forward with an additional four, as well as two unsolicited lease request areas. Despite this progress, the duration of the timeline for permitting still remains to be seen.
- **The scheduled expiration of federal tax credit incentives**. The PTC and investment tax credit (ITC), the principle federal incentives for wind energy generation, expired at the end of 2013.[14] Uncertainty over the availability of these incentive programs creates significant market risk and makes investors hesitant to commit capital for essential activities in the development phase. Furthermore, this uncertainty is likely to slow the development of the offshore wind industry because the multiyear development horizons for projects tend to exceed the typical periods when the PTC/ITC are active.
- **The lack of a defined market for offshore wind power**. The biggest near-term challenge for the offshore wind energy industry is the lack of a defined market. Federal incentives are generally not sufficient enough to attract investment in offshore wind projects by themselves given the current cost structure, and there is significant ambiguity as to the continued availability of these incentives. Developers are therefore working through state representatives to augment the federal incentives and achieve financial viability; either through offshore wind-specific revenue streams (Offshore Renewable Energy Credits) or by negotiating long-term power purchase agreements. Although this approach is allowing a number of projects to move forward, it is very complicated and resource intensive for developers.

5.2 CapEx for Fixed-Bottom Offshore Wind Reference Project

For the *2011 Cost of Wind Energy Review* (Tegen el al. 2013), NREL developed the offshore CapEx estimate by conducting several parallel assessments: 1) analyzing global market data, 2) reviewing published literature, and 3) interviewing active offshore wind developers in the United States. This multipronged approach yielded an average capital cost of $5,120/kW across the industry (for operational and proposed plants worldwide), and resulted in a U.S. reference cost estimate of $5,600/kW (consistent with the expected CapEx reported by the proposed Cape Wind offshore project located off Cape Cod in Nantucket Sound). The 2011 reported range of installed capital costs (again for operational and proposed projects) varied from $2,500/kW to $6,500/kW.[15]

[14] Offshore wind projects that started construction before the expiration of the tax credits—the 468-MW Cape Wind project and the 30-MW Block Island wind farm—have announced that they have met the 'safe harbor' criteria defined by the U.S. Internal Revenue Service and expect to qualify for the investment tax credit (Broehl and Ernst 2014).
[15] Offshore wind capital costs may vary widely as a result of water depth, distance from shore, turbine size, and other factors.

In 2012, a DOE analysis of LCOE for offshore wind plant technology used the average global installed cost from the *Offshore Wind Market and Economic Analysis* report, which was $5,384/kW (Hamilton et al. 2014). For the LCOE analysis, the same technology was used in the 2012 analysis as in the 2010 and 2011 cost of wind energy reviews. Details on the 2012 analysis are located in Appendix C and resulted in an LCOE of $225/MWh.

According to the *2013 Offshore Wind Market and Economic Analysis* report (Hamilton et al. 2014), the global offshore CapEx may be stabilizing; however, there is little data on projects to be installed after 2016. Figure 7 shows the capital cost trends since 1994 inflated to 2012 currency and converted to U.S. dollars using 2012 average exchange rates. Globally, projects commissioned in 2013 had a capacity-weighted average capital cost of $5,187/kW, almost $200/kW lower than the average cost of a project installed in 2012.

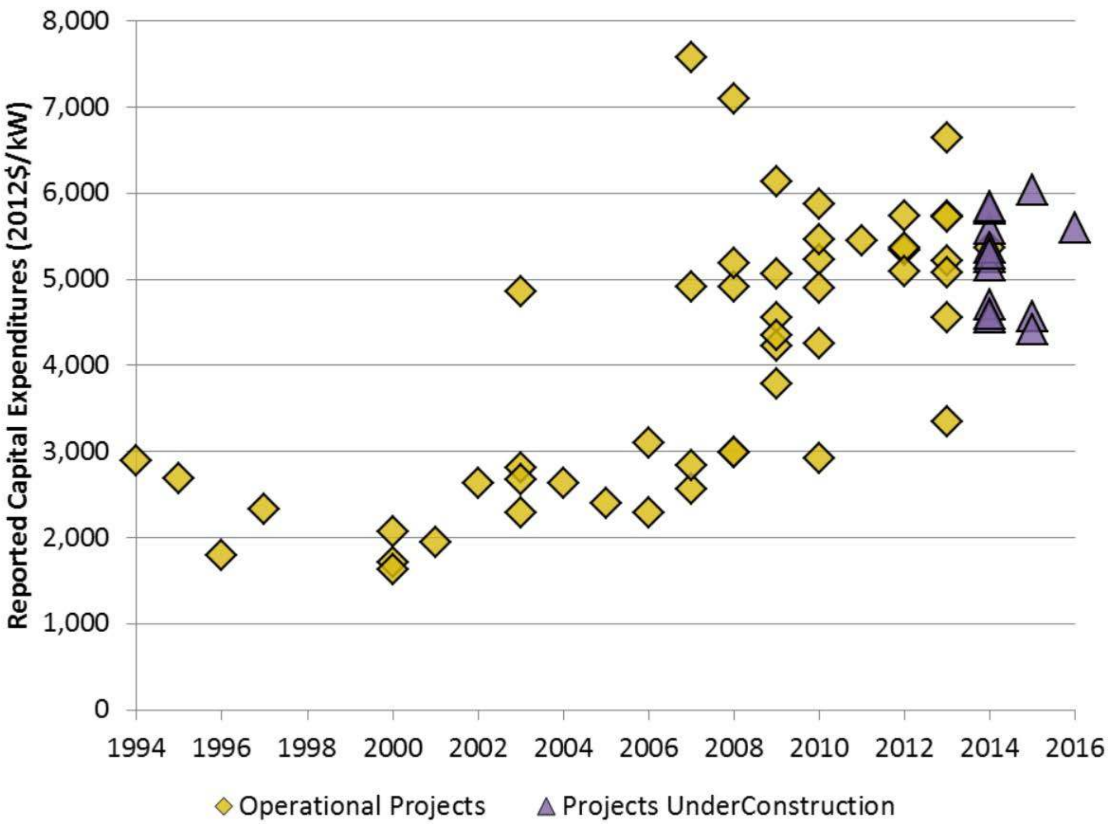

Figure 7. Reported capital costs for installed, under construction, contracted, and approved offshore wind projects in $2012 (2000 to 2016)

Source: Hamilton et al. 2014

Figure 8 shows the percentage contribution of each component to total capital cost for the reference offshore wind project. Percentage estimates were based on the NREL Wind Turbine Design Cost and Scaling Model (Fingersh et al. 2006, Maples et al. 2010); several recent publications (Douglas-Westwood 2010, BVG Associates 2011, Deloitte 2011); and conversations with U.S. offshore wind project developers. In Figure 8, the segment in green represents the turbine cost, shades of blue represent BOS costs, and shades of purple represent financial costs.

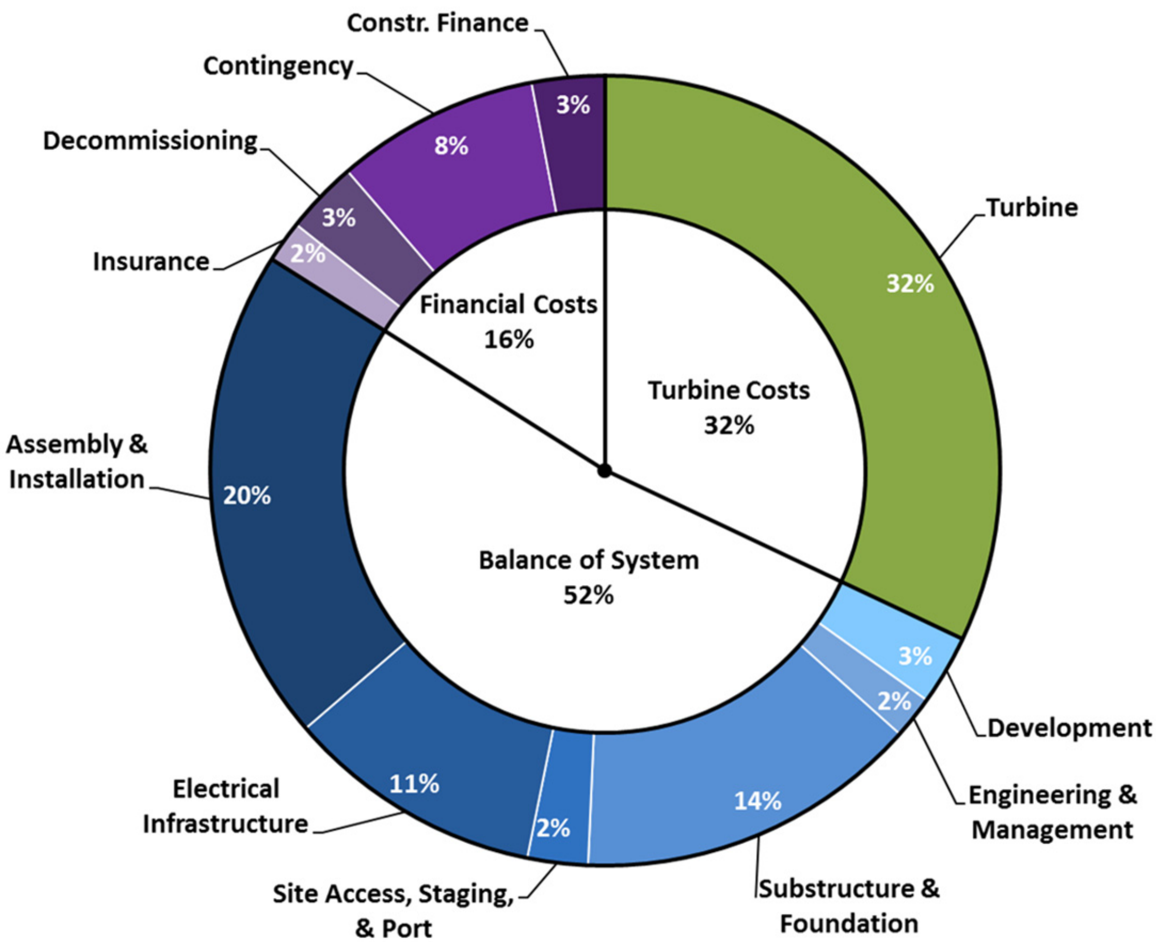

Figure 8. Capital expenditures for the 2013 offshore wind reference project

Source: NREL

The percentage estimates in Figure 8 were applied to the global industry average CapEx estimate of $5,187/kW to generate individual component costs in dollars per kilowatt for the 2013 reference project. This dollar-value component cost breakdown is shown in Table 13. As stated, there is a notable difference between the cost components that make up the land-based and offshore projects. In the land-based project, 68% of the cost is related to the turbine, whereas the turbine makes up only 32% of the CapEx for the offshore project.

Table 13. Fixed-Bottom Offshore LCOE Component Cost Breakdown

	4.3 MW Offshore Turbine $/kW	4.3 MW Offshore Turbine $/MWh
TURBINE CAPITAL COST	**1,600**	**56**
Development Cost	149	5
Engineering Management	90	3
Substructure and Foundation	730	25
Site Access, Staging, and Port	128	4
Electrical Infrastructure	546	18
Assembly and Installation	1,053	36
BALANCE OF SYSTEM	**2,697**	**91**
Insurance	87	3
Decommissioning (surety bond)	115	5
Construction Financing Cost	156	5
Contingency	432	15
FINANCIAL COSTS	**830**	**28**
CAPITAL EXPENDITURES	**5,187**	**175**

5.3 Operating Expenditures for Offshore Wind

There has been no indication that expected operating expenditures for offshore wind projects have shifted between 2010 and 2013. The OpEx baseline for 2013 was assumed to be $40/MWh, equivalent to $136/kW/yr, with a range extending from $20/MWh to $70/MWh. The equivalent range on a $/kW/yr basis extends from $68/kW/yr to $239/kW/yr. Operating costs are broken down into MAIN, OPER cost,[16] and the Outer Continental Shelf (OCS) lease payments.[17]

5.4 Offshore Annual Energy Production and Capacity Factor

Hamilton et al. (2014) reported that installed European offshore wind projects typically achieve capacity factors between 35% and 50%. Rødsand II, a Danish project installed in 2010, reported a capacity factor of 55% in its first year of operation. U.S. developers have announced capacity factor expectations for nine project sites currently under development. Data collected by NREL suggests that net capacity factors at these projects may range from 32% to 50%, with a capacity-weighted average of 38% (NREL 2013).

[16] O&M cost for offshore wind projects is assumed to include labor, vessels, equipment, scheduled maintenance, unscheduled maintenance, land-based support, and project administration.
[17] Lease payments are expected to range between 2% and 7% of operational revenue. Cape Wind will pay 2% of operational revenue in years 1 to 15. The lease payment increases to 7% of operational revenue from year 16 until the plant is decommissioned (BOEMRE 2010).

Because net AEP and the corresponding net capacity factor will vary with the wind resource and project design, the authors assumed specific site characteristics that are common to the North Atlantic Coast for the reference offshore wind project. AEP for this analysis was calculated using the NREL Wind Turbine Design Cost and Scaling Model and a Class 6 wind resource. Table 14 shows the assumptions used to calculate the net AEP for the reference project.

Table 14. Fixed-Bottom Reference Offshore AEP Input Assumptions

Turbine Parameters	
Turbine rated power (MW)	4.3
Turbine rotor diameter (m)	119.4
Turbine hub height (m)	90
Maximum rotor tip speed (m/s)	90
Tip-speed ratio at peak coefficient of power (C_p)	8
Drivetrain design	Geared
Rotor peak power coefficient Cp	0.47
Wind Resource Characteristics	
Annual average wind speed at 50 m (m/s)	8.4
Weibull K	2.1
Shear exponent	0.1
Losses	
Losses (array, energy conversion, line)	15%
Availability	96%

For this report, the authors assumed that offshore wind projects will experience losses from array wake impacts, availability, and inefficiencies in power collection and transmission. Assuming 19% total losses, AEP_{net} was estimated for offshore wind projects using commercially available technology and the NREL wind turbine design cost and scaling model. Table 15 shows the impact of losses on AEP and capacity factor.

Table 15. Offshore Wind Turbine AEP and Capacity Factor Summary

	4.3-MW Offshore Turbine
Gross AEP (MWh/MW/yr)	4,241
Gross capacity factor (%)	45
Losses and availability (%)	19
Net AEP (MWh/MW/yr)	3,463
Net capacity factor (%)	39.5

These data show that the 2013 baseline project will deliver 3,463 MWh/MW of installed capacity annually, which is equivalent to a net capacity factor of 39.5%. The range of AEP estimates around this baseline extends from 2,600 to 4,820 MWh/MW/year, which corresponds to the range of capacity factors (30%–50%) observed in Europe and for planned projects in the United States.

5.5 Financial Parameters for Offshore Wind

There has been no indication that financial parameters for domestic offshore wind projects have changed between 2010 and 2013. The reference project discount rate for 2013 is assumed to be 10.5%, with a range extending from 8% to 15%, based on data reported by Tegen et al. (2012).

5.6 Offshore Wind Reference Project Summary

The databases and analysis described above informed the creation of the reference project shown in Table 16. The 2013 reference project is defined with 116 turbines on monopile foundations and an average water depth of 15 m. Reference project costs for 2013 were based on estimates for a site located 20 km from shore. In addition, turbines rated at 4.3 MW, with a 119-m rotor diameter and a 90-m hub height were assumed. The average wind speed at the project site was assumed to be 8.4 m/s at 50 m and 8.9 m/s at the 90-m hub height (Class 6 wind regime).[18] In the reference project layout, the turbines are spaced in a grid formation at 8 rotor diameters apart and connected to the substation using a radial 33-kilovolt (kV) collection system design.

The capital expenditures of the project were assumed to be $2.6 billion, or about $5,187/kW, including a contingency estimated at 10% of hard costs. After tax, annual operational expenditures are equivalent to $39/MWh, or $577,600 per turbine per year.

The weighted average cost of capital (WACC), or discount rate, used to finance the project was estimated to be 10.5% nominal (equivalent to 8.3% real). Although this discount rate could represent a number of different financial structures, the specific financial structures were not examined in this analysis. The reference project was assumed to have an operating life of 20 years from the date of commissioning; the FCR under these assumptions is 11.7%.

[18]Average wind speed based on a Weibull (k = 2.1) probability distribution.

Table 16. Fixed-Bottom Offshore Reference Project Assumptions Summary

General Assumptions	
Project capacity (MW)	500
Number of turbines	116
Turbine capacity (MW)	4.3
Site	
Location	North Atlantic Coast (U.S.)
Depth (m)	15
Distance from shore (km)	20
Wind speed (m/s at a 50 meters above mean sea level [MASML])	8.4
Wind speed (m/s at a 90 MASML)	8.9
Net capacity factor	39.5%
Technology	
Rotor diameter (m)	119
Tower height (m)	90
Gearbox	Three-stage
Generator	Asynchronous
Foundation	Monopile
Cost	
Capital cost (millions)	$2,600
Contingency [6.5% of hard costs](millions)	$217
OpEx ($/MWh)	$39
Discount rate (real)	8.3%
Discount rate (nominal)	10.5%
Operating life (years)	20
Fixed charge rate (real)	11.7%

5.7 Offshore Wind LCOE Calculation

Table 17 summarizes the offshore wind technology reference project by providing the component cost categories for the 4.3-MW turbines in the project as well as the LCOE calculation results. A comprehensive summary of assumptions can be found in Appendix B. Estimates of the percentage contribution of individual project components to total capital costs were developed for each component based on the aforementioned publications and conversations. These estimates were applied to the total capital expenditure estimate to generate individual component costs. NREL plans to continue to collect market data and develop bottom-up cost models in 2014. These data and models will enable the development of an improved understanding of scaling relationships and opportunities for technology improvement, and reflect current market data in 2014.

Table 17. Fixed-Bottom Offshore Wind LCOE and Reference Project Cost Breakdown

	4.3-MW Offshore Turbine	4.3-MW Offshore Turbine
CAPITAL EXPENDITURES	$5,187/kW	$175/MWh
Operations (OPER)	$45/kW/yr	$13/MWh
Maintenance (MAIN)	$85/kW/yr	$24/MWh
OCS lease cost	$6/kW/yr	$2/MWh
OPERATING EXPENDITURES	**$136/kW/yr**	**$39/MWh**
Net 8.0 m/s AEP (MWh/MW/yr)	3,463	
Net capacity factor	39.5%	
FCR (real, after tax)	11.7%	
LEVELIZED COST OF ENERGY ($/MWh)	**215**	

The 2013 NREL reference offshore wind project has an LCOE of $215/MWh. Figure 9 shows the cost breakdown for the project.

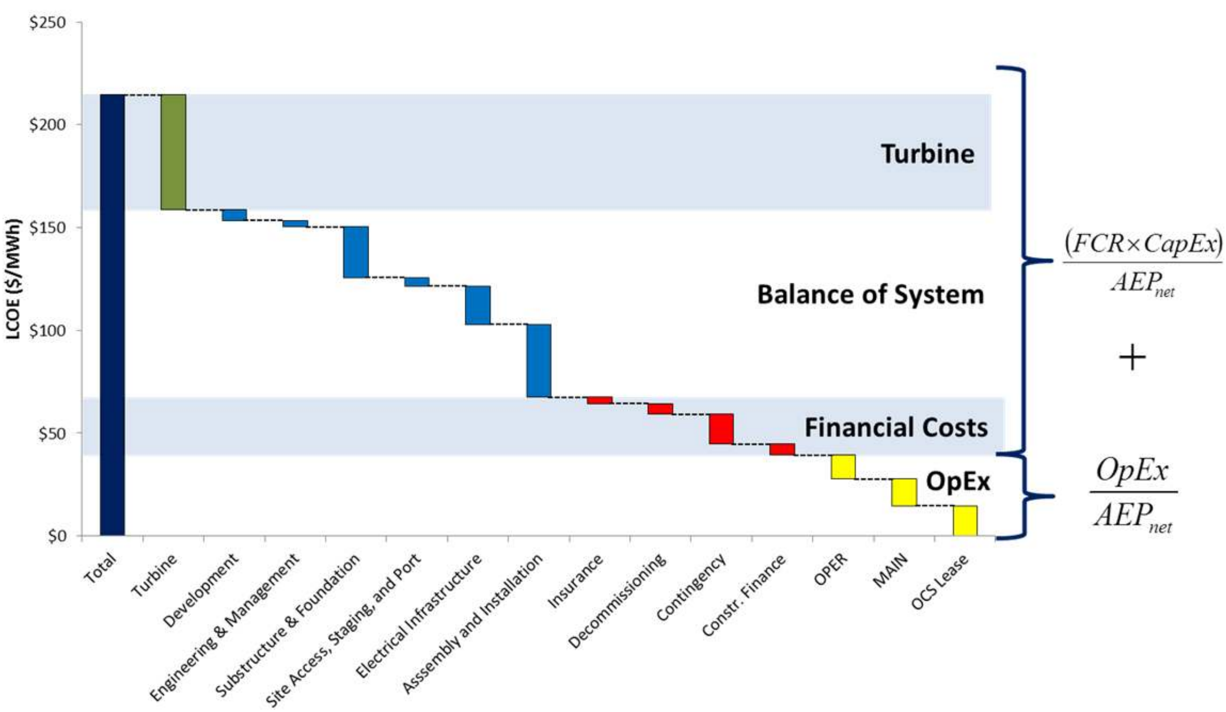

Figure 9. Cost breakdown for the 2013 offshore wind reference project

Source: NREL

5.8 Offshore Wind LCOE Sensitivities

Although the input parameters used for the LCOE calculation in the reference project represent reasonable estimates for the costs and operational parameters of a near-term offshore wind project, as was the case for land-based projects, these inputs are subject to considerable uncertainty. The sensitivity analysis shown in Figure 10 focuses on the basic LCOE inputs: 1) capital expenditures, 2) operating expenditures, 3) capacity factor (a surrogate for AEP), and 4) FCR, although in Figure 10, discount rate and operational lifetime represent FCR. Sensitivities were tested using the observed ranges described above and by holding all other variables constant. In Figure 10, the reference estimate for each parameter is represented by the vertical white line within each bar, and specific high and low values are shown within each colored bar.

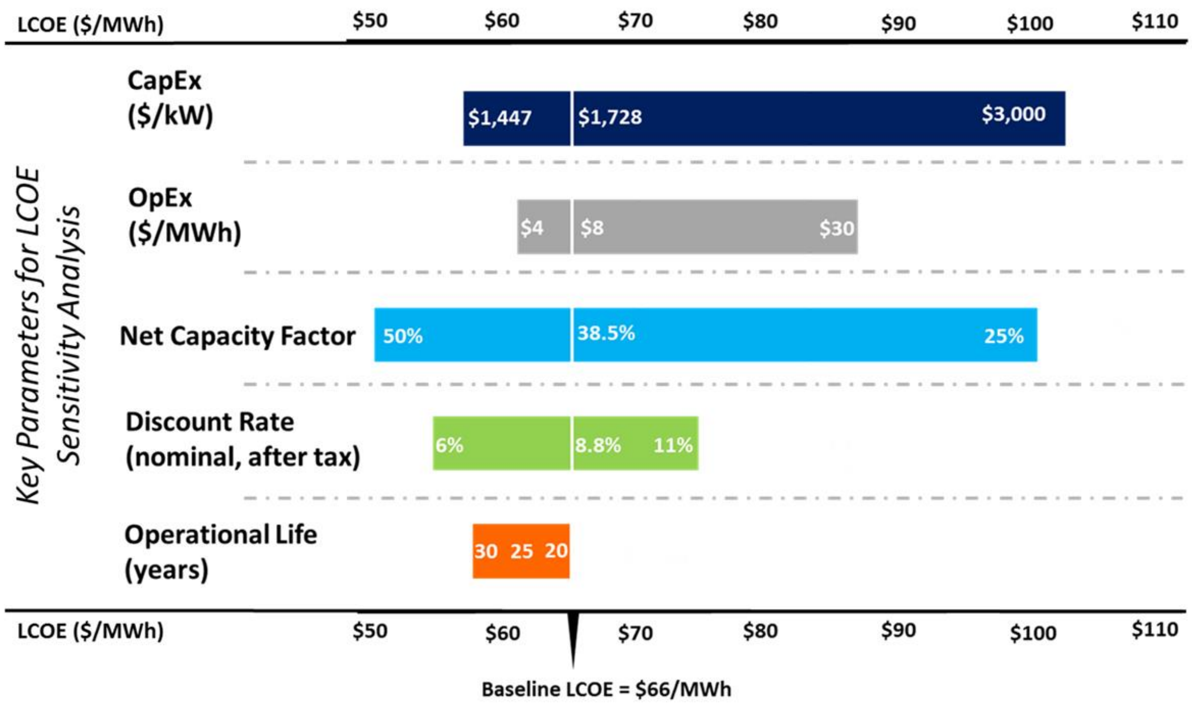

Figure 10. Sensitivity of offshore wind LCOE to key input parameters

Source: NREL

Note: The reference LCOE provides a representative estimate of the offshore wind LCOE, assuming commercial-scale fixed-bottom technology. Changes in LCOE for a single variable can be understood by moving to the left or right along a specific variable. Values on the X-axis indicate how the LCOE will change as a given variable is altered and assuming that all others are constant (i.e., the variables remain reflective of the reference project).

During the analysis, sensitivity ranges were selected to represent the highs and lows seen in the industry. This selection of ranges provides insight into how real-world ranges influence LCOE. Figure 10 shows a very wide range of LCOE outcomes, extending from $147 to $282/MWh; however, as noted above in the discussion of land-based sensitivities, the high and low LCOE ranges should not be taken as absolute because these variables are not typically independent. For offshore wind projects, cost of energy is most sensitive to capital expenditures, capacity factors, and discount rate, and appears to be less sensitive to operating life and operating expenditures.

6 Historical Levelized Cost of Wind Energy

DOE set goals in 2010 for LCOE for 2020 and 2030. NREL has been assessing the LCOE since that time. Table 18 and Table 19 summarize the trends of land-based LCOE and offshore LCOE, respectively, in nominal dollars, over time and include the primary LCOE inputs driving these results.

In Table 18, LCOE results in 2010 and 2011 differ from the official reports for the given years because of the changes in methodology for OpEx. In the previous cost of wind energy reviews, the authors used an after-tax operational expenditure that affected the labor, equipment, and facilities portion of the OpEx. The methodology of using only a pretax value was established in 2012 because rules and regulations differ based on the specific project location. To compare the historical LCOE values and represent the trends, the 2010 and 2011 OpEx were modified to align with the current methodology. Appendix D provides additional detail on the historical LCOE, DOE's LCOE goals in 2010 dollars, and a graph showing the historical land-based LCOE in constant 2010 dollars with the DOE goals.

Table 18. Historical Land-Based LCOE in Nominal Dollars

Parameters	2010 COE	2011 COE	2012 COE	2013 COE
Nameplate capacity (MW)	1.5	1.5	1.94	1.9
Rotor diameter (m)	82.5	82.5	93.5	96.9
Hub height (m)	80	80	80	82.7
Modeled net capacity factor	38.0%	37.0%	37.5%	38.5%
CapEx ($/kW)	2,155	2,098	1,940	1,728
FCR (%)	9.5%	9.5%	9.5%	10.2%
OpEx ($/kW)	55	55	55	50
AEP (MWh/MW/yr)	3,345	3,263	3,284	3,410
LCOE ($/MWh)	**78**	**78**	**73**	**66**

Table 19. Historical Offshore LCOE in Nominal Dollars

Parameters	2010 COE	2011 COE	2012 COE	2013 COE
Nameplate capacity (MW)	3.6	3.6	3.6	4.3
Rotor diameter (m)	107	107	107	119.4
Hub height (m)	90	90	90	89.5
Modeled net capacity factor	39.0%	39.0%	39.0%	39.0%
CapEx ($/kW)	5,600	5,600	5,384	5,187
FCR (%)	11.7%	11.7%	11.7%	11.7%
OpEx ($/kW)	136	136	136	136
AEP (MWh/MW/yr)	3,406	3,406	3,406	3,463
LCOE ($/MWh)	**232**	**232**	**225**	**215**

7 Conclusions

The results and analysis in this technical report lead to the following conclusions:

- Final LCOE estimates continue to show a downward trend from the 2010 Cost of Wind Energy Review to 2013. Offshore turbine costs have shown similar cost reductions; however, the decrease in LCOE for the land-based projects can be attributed more to the turbine technology, and the offshore decreases to the balance-of-system costs.
- Although the reference project LCOE for land-based installations was observed to be \$66/MWh, the full range of land-based estimates covers \$50–\$103/MWh.
- The reference project offshore estimate is \$215/MWh, with a full range of \$147–\$282/MWh. This dramatic range is mostly caused by the large variation in capital expenditures (\$3,200–\$6,000/kW) reported by project developers.
- The sensitivity analysis shows that LCOE can vary widely based on changes in any one of several key factors; however, the variable with the most dramatic effect on LCOE is capacity factor—which is the case for both land-based and offshore projects.

This analysis presents a picture of the levelized cost of land-based and offshore wind energy using real and modeled data that represents 2013 market conditions. Scenario planning and modeling activities often focus on one number (or cost) for land-based LCOE and one for offshore LCOE. In reality, the cost of land-based wind energy varies greatly across the United States and offshore wind LCOE varies significantly across Europe and Asia (Table 20).

The LCOE analysis presented in this report is only one way to measure the cost of wind energy and it does not include other costs and price issues that influence a given wind project's viability, such as transmission, environmental impacts, military constraints, or other areas of consideration (e.g., public policy, consumer costs, energy prices, or public acceptance). In addition, these LCOE estimates do not reflect the value of electricity, incentives, or other policy mechanisms (such as production tax credits or investment tax credits) that affect the sales price of electricity produced from wind projects.

Table 20. Ranges of LCOE and Elements for U.S. Land-Based and Offshore Wind in 2013

	Land-Based Wind Projects	Offshore Wind Projects
Capital expenditures	\$1,447–\$3,000/kW	\$3,200–\$6,000/kW
Operational expenditures	\$4–\$30/MWh	\$20–\$59/MWh
Capacity factor	25%–50%	30%–50%
Discount rate	6%–11%	8%–15%
Operational life	20–30 years	20–30 years
Range of LCOE	<\$50–>\$103/MWh	<\$147–>\$282/MWh

8 Related and Future Work

NREL continues to work to gain a better understanding of costs associated with many components of land-based wind turbines and systems. Ongoing collaboration with industry could lead to better data, enhanced modeling capabilities, and increased awareness of current and future wind power system component costs. For offshore wind, this analysis provides a best estimate for potential domestic wind power projects.

NREL intends to update this review of wind energy costs on an annual basis. These updates are intended to help maintain a perspective on costs that is grounded in real-time market changes as well as offer greater insight into the costs and performance of individual components related to the wind generation system. In addition, these reports are intended to provide greater clarity regarding wind energy costs and the effects of changes in specific variables on the LCOE. The data and tools developed from this work will be used to help inform projections, goals, and improvement opportunities. As the industry evolves and matures, NREL will continue to publish current representative project data and LCOE estimates for scenario planning, modeling, and goal setting.

Future work entails three primary objectives: 1) continue to enhance data representing market-based costs, performance, and technology trends to reflect actual wind industry experience, 2) enhance the fidelity of bottom-up cost and performance estimation for individual wind plant components, and 3) understand sensitivities to factors such as regional differences, site characteristics, and technology choices. In 2015 and going forward, NREL will continue to work with industry and national laboratory partners to obtain project-specific data to validate and improve models. NREL's ongoing wind analysis efforts include:

- Creating a model to better represent offshore non-turbine project costs, such as foundations, electrical cabling, and installation, across a range of turbine and project sizes
- Developing a wind energy systems engineering model to conduct enhanced analysis of new innovation impacts on turbine cost and performance.

In addition, NREL plans to:

- Update the NREL cost and scaling model with improved, turbine-specific data
- Estimate the effect on LCOE from anticipated improvements to O&M in both land-based and offshore wind projects
- Continue work on computational fluid dynamics models to determine the magnitude and impact of wake losses
- Quantify the effect of potential technology pathways on system LCOE for land-based and offshore wind technology
- Collect data and examine key issues involved in wind power deployment, such as transmission, radar, wildlife issues, and public acceptance, to better understand their impacts on the cost of wind energy and potentially developable land
- Investigate and estimate the cost of offshore wind energy on floating platforms and compare to fixed-bottom foundation substructures.

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Appendix A. Present Value of Depreciation Calculations

Land-Based Wind

Table A1. Present Value of Depreciation Calculation for Land-Based Wind Reference (*d* = 8.8%)

Year	Net Book Value	5-Year MACRS Depreciation Schedule	Depreciation	Present Value Depreciation	Accumulated Present Value Depreciation
1	100	20.00%	20	18.4	18.4
2	80	32.00%	32	27.0	45.4
3	48	19.20%	19.2	14.9	60.3
4	28.8	11.52%	11.52	8.2	68.5
5	17.28	11.52%	11.52	7.6	76.1
6	5.76	5.76%	5.76	3.5	79.6

MACRS: Modified Accelerated Cost Recovery System

Offshore Wind

Table A2. Present Value of Depreciation Calculation for Offshore Wind Reference (*d* = 10.5%)

Year	Net Book Value	5-Year MACRS Depreciation Schedule	Depreciation	Present Value Depreciation	Accumulated Present Value Depreciation
1	100	20.00%	20	18.1	18.1
2	80	32.00%	32	26.2	44.3
3	48	19.20%	19.2	14.2	58.5
4	28.8	11.52%	11.52	7.7	66.3
5	17.28	11.52%	11.52	7	73.3
6	5.76	5.76%	5.76	3.2	76.4

MACRS: Modified Accelerated Cost Recovery System

Appendix B. Summary of Assumptions for 2013 Reference Projects

Land-Based Wind Project Assumptions

Table B1. Comprehensive List of Assumptions for 2013 Land-Based Reference Project Cost of Energy

Assumption	Units	Value	Notes
Project Information			
Capacity	megawatts (MW)	200	Calculation
Number of turbines	#	105	Representative of commercial-scale projects
Turbine capacity	MW	1.91	Average turbine size installed in United States
Net capacity factor	%	38.6	Class 4 wind resource [7.25 meters per second (m/s) at 50 m], assumed losses (17%)
Rotor diameter	meters (m)	96.7	Average rotor size installed in United States
Tower height	m	82.5	Average hub height installed in United States
Operational life	years	20	Standard business case assumption
Capital Expenditures (CapEx)			
CapEx (million)	$	344.7	Calculation
Capital expenditures	$/kilowatt (kW)	1,728	Average CapEx of 2013 U.S. projects
Market price adjustment	$/kW	39	Calculated to bring CapEx in line with market conditions
Hard costs			Estimated based on the National Renewable Energy Laboratory's (NREL's) Wind Turbine Design Cost and Scaling Model (Fingersh et al. 2006, Maples et al. 2010), NREL's new balance-of-system model, and NREL's conversations with developers of land-based wind projects in the United States
Turbine	$/kW	1,185	
Balance of system	$/kW	349	
Soft costs			
Construction finance	$/kW	50	
Contingency	$/kW	105	
Operating Expenditures (OpEx)			
OpEx costs	$/megawatt-hour (MWh)	15	Representative of published literature and NREL's conversations with U.S. land-based wind developers
OpEx costs (pretax)	$/kW/yr	50	
Operation (OPER)	$/kW/yr	14	
Maintenance (MAIN)	$/kW/yr	28	
Land lease	$/kW/yr	8	
Financing Costs [d, Fixed Charge Rate (FCR)]			
Inflation rate	%	2.2	Assumption in the *Annual Energy Outlook 2013* (Energy Information Administration [EIA] 2013)
Discount rate (nominal)	%	8.8	2013 land-based weighted average cost of capital averages
Discount rate (real)	%	6.5	
FCR (nominal)	%	12.2	Calculation
FCR (real)	%	10.2	
Cost recovery factor (CRF) (nominal)	%	10.8	
CRF (real)	%	9.0	
Taxes (T)			
Effective	%	38.9	Calculation
Federal	%	35	Standard federal corporate tax rate
State	%	6	Representative state tax rate
Present Value Depreciation (PVDep)			
Depreciable basis	%	100	Simplified depreciation schedule
Depreciation schedule	5-yr Modified Accelerated Cost Recovery System (MACRS)		Standard for choice for renewable energy projects
PVDep	%	79.6	Calculation
Levelized cost of energy	**$/MWh**	**66**	**Calculation**

Offshore Wind Project Assumptions

Table B2. Comprehensive List of Assumptions for 2013 Offshore Reference Project Cost of Energy

Assumption	Units	Value	Notes
Project Information			
Capacity	megawatts (MW)	500	Representative of commercial-scale projects
Number of turbines	#	116	Calculation
Turbine capacity	MW	4.3	Average turbine size installed globally
Depth	meters (m)	15	Representative of proposed U.S. projects
Distance from shore	(kilometers (km)	20	Representative of proposed U.S. projects
Net capacity factor	%	39	Class 6 wind resource (8.4 m/s at 50 m), assumed losses (18%)
Rotor diameter	m	119.4	Average rotor size installed globally
Tower height	m	89.5	Average hub height size installed globally
Operational life	years	20	Standard business case assumption
Capital Expenditures (CapEx)			
CapEx ($)	$ millions	2,587.3	Calculation
CapEx	$/kilowatt (kW)	5,187	Average global installed capital expenditures (Hamilton et al. 2014)
Hard Costs			Values estimated based on the NREL Wind Turbine Design Cost and Scaling Model (Fingersh et al. 2006, Maples et al. 2010), new balance-of-system model, several recent publications (Douglas-Westwood 2010, BVG Associates 2011, Hamilton et al. 2014), and NREL's conversations with developers of offshore wind projects in the United States; percentage estimates applied to CapEx estimate to obtain dollar-per-kilowatt values
Turbine	$/kW	1,660	
Development	$/kW	149	
Engineer and management	$/kW	90	
Substructure and foundation	$/kW	730	
Port and staging	$/kW	128	
Electrical infrastructure	$/kW	546	
Transportation and installation	$/kW	1,053	
Soft Costs			
Insurance during construction	$/kW	87	
Decommissioning bond	$/kW	155	
Construction finance	$/kW	156	
Contingency	$/kW	432	
Operating Expenditures (OpEx)			
OpEx	$/megawatt-hour (MWh)	39	Representative of published literature and NREL's conversations with U.S. offshore wind developers
OpEx costs (pretax)	$/kW/yr	136	
OPER (pretax)	$/kW/yr	40	Representative of published literature and NREL's conversations with U.S. offshore wind developers
MAIN	$/kW/yr	75	
Outer Continental Shelf (OCS) Lease	$/kW/yr	21	Cape Wind OCS lease—2% operational revenue in years 1–15, 7% of operational revenue in years 15–20
Financing Costs (d, FCR)			
Inflation rate	%	2.2	Assumption in *Annual Energy Outlook 2010* (EIA 2010)
Discount rate (nominal)	%	10.5	Approximate weighted average cost of capital for Cape Wind and Block Island wind projects
Discount rate (real)	%	8.1	
FCR (nominal)	%	13.9	Calculation
FCR (real)	%	11.7	
Cost Recovery Factor (CRF)/nominal	%	12.2	
CRF (real)	%	10.3	
Taxes			
Effective	%	38.9	Calculation
Federal	%	35	Standard federal corporate tax rate
State	%	6	Representative state tax rate
Present Value Depreciation (PVDep)			
Depreciable basis	%	100	Simplified depreciation schedule
Depreciation schedule	5-yr Modified Accelerated Cost Recovery System		Standard choice for renewable energy projects
PVDep	%	76.4	Calculation
Levelized cost of energy	**$/MWh**	**215**	**Calculation**

Appendix C. Summary of Assumptions for 2012 Reference Projects

Land-Based Wind Project Assumptions

Table C1. Comprehensive List of Assumptions for 2012 Land-Based Reference Project Cost of Energy

Assumption	Units	Value	Notes
Project Information			
Capacity	megawatts (MW)	200	Calculation
Number of turbines	#	103	Representative of commercial-scale projects
Turbine capacity	MW	1.94	Most common turbine size in the United States
Net capacity factor	%	37.5	Class 4 wind resource [7.25 meters per second (m/s) at 50 m], assumed losses (17%)
Rotor diameter	meters (m)	93.5	Most common rotor size of GE-1.5
Tower height	m	83.8	Average U.S. hub height
Operational life	years	20	Standard business case assumption
Capital Expenditures (CapEx)			
CapEx (million)	$	387.7	Calculation
CapEx	$/kilowatt (kW)	1,940	Average CapEx of 2012 U.S. projects
Market price adjustment	$/kW	195	Calculated to bring CapEx in line with market conditions
Hard costs			Estimated based on the NREL Wind Turbine Design Cost and Scaling Model (Fingersh et al. 2006, Maples et al. 2010), NREL's new balance-of-system model, and NREL's conversations with developers of land-based wind projects in the United States
Turbine	$/kW	1,279	
Balance of system	$/kW	365	
Soft costs			
Construction finance	$/kW	54	
Contingency	$/kW	108	
Operating Expenditures (OpEx)			
OpEx costs	$/megawatt-hour (MWh)	17	Representative of published literature and NREL's conversations with U.S. land-based wind developers
OpEx costs (pretax)	$/kW/yr	55	
OPER (pretax)	$/kW/yr	14	
MAIN	$/kW/yr	33	
Land lease	$/kW/yr	8	
Financing Costs [d, Fixed Charge Rate (FCR)]			
Inflation rate	%	2.2	Assumption in the *Annual Energy Outlook 2012* (EIA 2012)
Discount rate (nominal)	%	8	2010 land-based weighted average cost of capital averages
Discount rate (real)	%	5.7	
FCR (nominal)	%	11.4	Calculation
FCR (real)	%	9.5	
Cost recovery factor (CRF) (nominal)	%	10.2	
CRF (real)	%	8.5	
Taxes (T)			
Effective	%	38.9	Calculation
Federal	%	35	Standard federal corporate tax rate
State	%	6	Representative state tax rate
Present Value Depreciation (PVDep)			
Depreciable basis	%	100	Simplified depreciation schedule
Depreciation schedule	5-yr Modified Accelerated Cost Recovery System		Standard for choice for renewable energy projects
PVDep	%	81.1	Calculation
Levelized cost of energy	**$/MWh**	**73**	**Calculation**

Offshore Wind Project Assumptions

Table C2. Comprehensive List of Assumptions for 2012 Offshore Reference Project Cost of Energy

Assumption	Units	Value	Notes
Project Information			
Capacity	megawatts (MW)	500	Representative of commercial-scale projects
Number of turbines	#	139	Calculation
Turbine capacity	MW	3.6	Representative of turbine size planned for Cape Wind
Depth	Meters (m)	15	Representative of proposed U.S. projects
Distance from shore	kilometers (km)	20	Representative of proposed U.S. projects
Net capacity factor	%	39	Class 6 wind resource (8.4 meters per second at 50 m), assumed losses (18%)
Rotor diameter	m	107	Representative of turbine size planned for Cape Wind
Tower height	m	90	Representative of turbine size planned for Cape Wind
Operational life	years	20	Standard business case assumption
Capital Expenditures (CapEx)			
CapEx ($)	$ millions	2,694.2	Calculation
CapEx	$/kW	5,384	Average global installed capital expenditures (Hamilton 2013)
Hard Costs			Values estimated based on the NREL Wind Turbine Design Cost and Scaling Model (Fingersh et al. 2006, Maples et al. 2010), several recent publications (Douglas-Westwood 2010, BVG Associates 2011, Deloitte 2011, Hamilton 2013), and NREL's conversations with developers of offshore wind projects in the United States; percentage estimates applied to the total CapEx estimate to obtain dollar-per-kilowatt values
Turbine	$/kW	1,723	
Development	$/kW	155	
Engineer and management	$/kW	94	
Substructure and foundation	$/kW	758	
Port and staging	$/kW	133	
Electrical infrastructure	$/kW	566	
Transportation and installation	$/kW	1,093	
Soft Costs			
Insurance during construction	$/kW	90	
Decommissioning bond	$/kW	161	
Construction finance	$/kW	162	
Contingency	$/kW	448	
Operating Expenditures (OpEx)			
OpEx	$/MWh	39	Representative of published literature and NREL's conversations with U.S. offshore wind developers
OpEx costs (pretax)	$/kW/yr	136	
MAIN	$/kW/yr	40	Representative of published literature and NREL's conversations with U.S. offshore wind developers
OPER (pretax)	$/kW/yr	75	
Outer Continental Shelf (OCS) Lease	$/kW/yr	21	Cape Wind OCS lease—2% operational revenue in years 1–15, 7% of operational revenue in years 15–20
Financing Costs (d, FCR)			
Inflation rate	%	2.2	Assumption in *Annual Energy Outlook 2010* (EIA 2010)
Discount rate (nominal)	%	10.5	Approximate weighted average cost of capital for Cape Wind and Block Island wind projects
Discount rate (real)	%	8.1	
FCR (nominal)	%	13.9	Calculation
FCR (real)	%	11.7	
Cost recovery factor (CRF)/ nominal	%	12.2	
CRF (real)	%	10.3	
Taxes (T)			
Effective	%	38.9	Calculation
Federal	%	35	Standard federal corporate tax rate
State	%	6	Representative state tax rate
Present Value Depreciation (PVDep)			
Depreciable basis	%	100	Simplified depreciation schedule
Depreciation schedule	5-yr Modified Accelerated Cost Recovery System		Standard choice for renewable energy projects
PVDep	%	76.4	Calculation
Levelized cost of energy	**$/MWh**	**225**	**Calculation**

Appendix D. Summary of Historical Levelized Cost of Energy Using Reference Projects

Table D1. Historical Land-Based Wind Plant Levelized Cost of Energy as Calculated by NREL

Parameters	2010 COE	2011 COE	2012 COE	2013 COE
Nameplate capacity (megawatts [MW])	1.5	1.5	1.94	1.91
Rotor diameter (meters [m])	82.5	82.5	93.5	96.9
Hub height (m)	80	80	80	82.7
Modeled net capacity factor	38.0%	37.0%	37.5%	38.5%
Capital expenditures ($/kilowatt [kW])	2,155	2,098	1,940	1,728
Fixed charge rate (%)	9.5%	9.5%	9.5%	10.2%
Operational expenditures ($/kW)	55	55	55	50
Annual energy production (megawatt-hour (MWh)/MW/yr)	3,345	3,263	3,284	3,410
Levelized cost of energy ($/MWh)	**78**	**78**	**73**	**66**

Table D2. Historical Land-Based Average Wind Plant Turbine Specifications

Respective Market Turbine Parameter Averages	2010	2011	2012	2013
Nameplate Capacity (MW)	1.79	1.97	1.94	1.91
Rotor Diameter (m)	79.8	89	93.5	96.9
Hub Height (m)	84.3	81	83.8	82.7

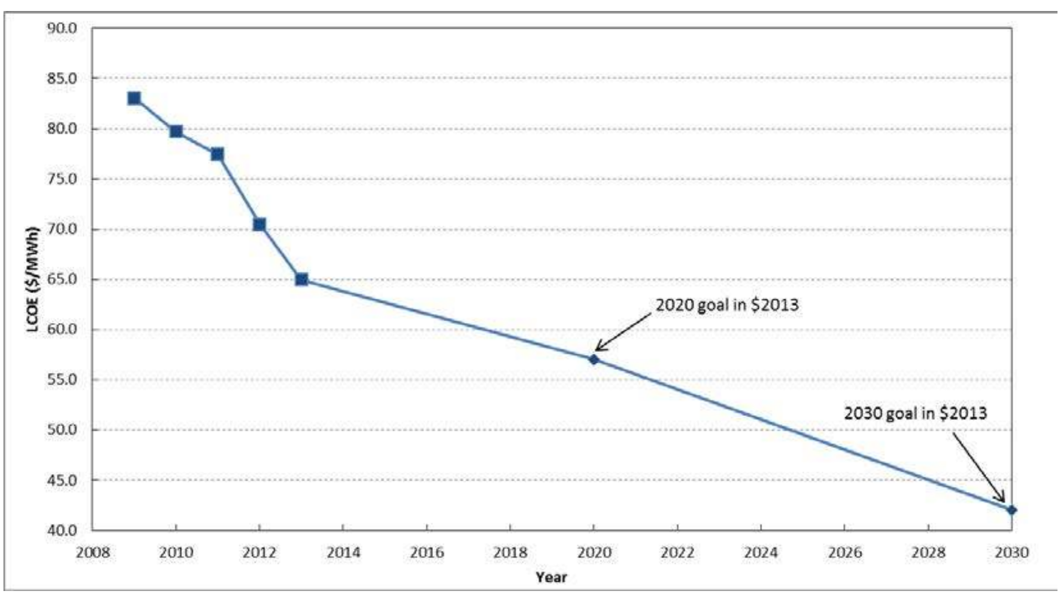

Figure D1. Historical land-based wind plant levelized cost of energy (LCOE) as calculated by NREL including the U.S. Department of Energy's LCOE goals

Table D3. Historical Offshore Wind Plant Levelized Cost of Energy as Calculated by NREL

Parameters	2010 COE	2011 COE	2012 COE	2013 COE
Nameplate capacity (megawatts [MW])	3.6	3.6	3.6	4.3
Rotor diameter (meters [m])	107	107	107	119.4
Hub height (m)	90	90	90	89.5
Modeled net capacity factor	39.0%	39.0%	39.0%	39.0%
CapEx ($/kilowatt [kW])	5,600	5,600	5,384	5,187
FCR (%)	11.7%	11.7%	11.7%	11.7%
OpEx ($/kW)	136	136	136	136
Annual energy production (MWh/MW/yr)	3,406	3,406	3,406	3,463
Levelized cost of energy ($/MWh)	**232**	**232**	**225**	**215**

Table D4. Department of Energy's Cost Goals for Land-Based and Offshore Wind Power

DOE Goals	2020	2030
Land-Based LCOE ($/MWh)	57	42
Offshore LCOE ($/MWh)	167	136

Appendix E. Summary of Land-Based System Cost Breakdown Structure

Table E1. Land-Based Wind System Cost Breakdown Structure Terms and Definitions

Level	Term	Definition
1	**Capital expenditures (CapEx)**	**Includes all installed costs incurred prior to the commercial operations date (COD). CapEx components include turbine, balance-of-station (BOS), and soft costs.**
2	**Wind turbine**	**Converts kinetic energy from wind into three-phase AC electrical energy**
3	Nacelle module	Provides structural interface between tower module, drivetrain module, and rotor module; provides housing for sensitive electrical and mechanical components and equipment; enables access by maintenance personnel
4	Nacelle structural assembly	Provides the structure interface between the tower, drivetrain, and rotor and shelters sensitive equipment
5	Enclosure	Includes the fiberglass shell, hatches, latches, anchors, and venting
5	Drivetrain and generator support structures	Contains the bedplate, framing, flooring, and anchors, including welded steel and fasteners
5	Coatings	Provides coatings to protect from weather
4	Drivetrain assembly	Includes the main power conversion system in the wind turbine, where energy captured by the rotor is transferred to drive the generator via the main shaft system, with or without a gearbox
5	Gearbox	Provides speed and torque conversion between the rotor (low speed) and the generator (high speed); only applicable for geared designs
6	Gears	Include the planet carrier, planet gear, ring gear, sun gear, spur gear, and hollow shaft
6	Bearings	Include the planet bearing, carrier bearing, and shaft bearing
6	Housing	Contains the bushing, case, mounting, and torque arm system
6	Sensors	Include debris sensors, oil level sensors, pressure 1 and pressure 2 sensors, and temperature sensors
6	Lube system	Contains the primary filter, secondary filter, primary motor, primary pump, hose/fitting, seal, and reservoir
6	Cooling system	Consists of the pump, radiator, and hoses
5	Low-speed shaft and main bearing system	Transfers torque from the rotor to the gearbox (if applicable) or generator (if direct drive)
6	Low-speed shaft	Contains the low-speed shaft, compression coupling, rotor lock, connector plate, and slip ring assembly
6	Main bearing	Consists of the main bearing upwind, main bearing downwind, and main bearing seals
6	Sensors	Include the main bearing temperature sensors, low-speed shaft rpm, and position sensors
5	High-speed shaft and braking system	Contains the high-speed shaft, coupling, rotor lock, and transmission shaft

Level	Term	Definition
6	High-speed shaft	Includes the high-speed shaft, coupling, rotor lock, and transmission shaft
6	Braking system	Consists of the brake disc, brake calipers, brake pads, and transmission lock
6	Sensors	Include high-speed shaft rpm sensors and position sensors
4	Nacelle electrical assembly	Contains the power off-take system elements located in the nacelle
5	Generator	Converts mechanical energy to electrical energy (based on the gearbox-generator system)
6	Cooling system	Includes hoses, the filter, cooling fan, motor, pump, and radiator
6	Lubrication system	Consists of the pump, pump motor, and the reservoir
6	Rotor	Includes the commentator, exciter, resistance controller, rotor lamination, rotor winding, slip ring, rotor magnets, and brush
6	Sensors	Include core temperature sensors, encoders, and watt meters
6	Stator	Contains stator magnets, stator lamination, and stator windings
6	Structural and mechanical	Includes the front bearing, rear bearing, silent block, housing, and shaft
5	Frequency converter	Converts variable frequency from an asynchronous generator to grid-compliant power of the right 'quality.' and with a stable frequency of either 50 hertz (Hz) or 60 Hz
6	Converter auxiliaries	Include the power supply, cabinet, heating system, cabinet sensor, communication and interface unit, control board, generator side fan, grid side fan, measurement unit, power supply, power supply (24 volts [V]), tachometer adapter, and thermostat
6	Converter power bus	Contains the branching unit, capacitors, contactors, generator side converter, generator side power module, grid side converter, grid side power module, inductor, load switch, and precharge unit
6	Power conditioning	Includes the common mode filter, crowbar system, DC chopper, generator side filter, line filter assembly, and voltage limit unit
5	Power electrical system	Converts generator voltage to array cable system voltage for collection
6	Power circuit	Includes the insulated-gate bipolar transistor (IGBT) module, rectifier bridge, crowbar system, driver/control board, cables, machine contractor, Mbusbar/isolator/circuit breaker, M switchgear/disconnect, motor contractor, soft starter, and grounding system
6	Main transformer (nacelle)	Main transformer when located in the nacelle (also located on the ground outside tower)
6	Measurements	Equipment to measure the function of the power electric system
6	Switchgear	Located in the base of a tower (transformer up tower) or as part of a ground-based transformer external to the tower
5	Control and communication system (supervisory control and data acquisition [SCADA])	Connects the wind turbines with the operations center and utility off taker; provides the wind project operator with information about the status of wind turbine systems; and allows remote control of some functions
6	Wind turbine controller	Includes the rotor controller, nacelle controller, tower controller (all comprised of numerous level 6 components)

Level	Term	Definition
6	Communication system	Contains the analog I/O unit, digital I/O unit, Ethernet module, field bus master, field bus slave, frequency unit, and the controller internal communication system
6	Condition monitoring system	Comprises sensors, cables, data logger, and the protocol adapter card for the data logger
6	Ancillary equipment	Includes cables, connectors, and the contactor/circuit breaker fuses
6	Wind plant control equipment	Includes any advanced wind plant control equipment installed on the turbines (e.g., nacelle-mounted lidar) or distributed throughout a wind plant (e.g., ground-mounted lidar)
5	Auxiliary nacelle electrical system	Other equipment necessary for the function of the nacelle electrical system
6	Nacelle electrical services	Include a 24-DC feeder, the auxiliary transformer, breaker, cabinet, fan, fuse, grid protection relay, light, mechanical switch, power point/supply, protection cabinet, push button, relay, space heater, surge arrester, thermal protection, and Uninterruptible Power Supply (UPS)
6	Nacelle lightning protection system	Contains air termination, the bonding element, earth connector and termination, sliding contact, spark gap system, and the surge arrester
4	Yaw assembly	Provides the structure interface between the tower, drivetrain, and rotor and shelters sensitive equipment
5	Brake	Comprises yaw brake calipers, the disc, path, and hoses
5	Drives and bearings	Include the motor, gear, pinion, bearing, and damper
5	Hydraulics	Contain the accumulator, pump, hoses, valves, and motor
5	Yaw sensors	Include the wind-up counter, yaw encoder, and position sensor
4	Nacelle auxiliaries	Consist of the other equipment within the nacelle necessary for the necessary for the function of the wind turbine
5	Nacelle sensors	Includes the anemometer, wind vane, and temperature sensors
5	Internal environment	Consists of high-voltage alternating current (HVAC), nacelle vent, and nacelle lighting
5	Federal Aviation Administration (FAA) lighting	Comprises navigational lights (requirements set by FAA in the United States)
5	Walking/climbing infrastructure	Includes cat walks, cables, ladders, people hatch, crane hatch, and anchors
5	Safety system	Consists of the tie-off system, firefighting system, fall arrester, down conductor, service crate, beacon, nacelle cover metallic mesh, and lighting protection
5	Lightning protection system	Protects the turbine from damage resulting from lightning strikes by passing currents to the ground and includes air termination, the bonding element, earth connector and termination, sliding contact, spark gap system, and surge arrester
5	External maintenance crane	Lifts small components (<2 mT) from the ground into the nacelle or vice versa and includes tools, supplies, and replacement equipment
4	Nacelle transportation	Includes the costs of transporting the nacelle components from the manufacturing facility to the staging area

Level	Term	Definition
3	Tower module	Provides a support structure element that connects the nacelle, drivetrain and rotor modules with the substructure and foundation, and has the ability to house electrical conversion equipment and provide emergency shelter
4	Tower system	Provides the primary structural component
5	Tower structure	Includes tower sections that generally consist of rolled steel sections (though other options are being considered)
5	Fasteners	Connect individual tower elements (e.g., bolts) to other tower elements, the nacelle module, and substructure
5	Coatings	Protect from corrosion
4	Tower electrical assembly	Consists of the electrical system, from the nacelle to the switchgear/transformer connection to the array
5	Drop cables	Off-take power from the drivetrain (or main transformer, if located up tower) and transport it down tower to the main transformer (if located at the tower base) or switchgear
5	Frequency converter	Converts variable frequency from thee asynchronous generator to grid-compliant power of the right 'quality' and with a stable frequency of either 50 or 60 Hz
6	Converter auxiliaries	Include the power supply, cabinet, heating system, cabinet sensor, communication and interface unit, control board, generator side fan, grid side fan, measurement unit, power supply, power supply (24 V), tachometer adapter, and thermostat
6	Converter power bus	Includes the branching unit, capacitors, contactors, generator side converter, generator side power module, grid side converter, grid side power module, inductor, load switch, and precharge unit
6	Power conditioning	Consists of the common mode filter, crowbar system, DC chopper, generator side filter, line filter assembly, and voltage limit unit
5	Power electrical system	Converts generator voltage to array cable system voltage for collection
6	Power circuit	Comprises the IGBT module, rectifier bridge, crowbar system, driver/control board, cables, machine contractor, M Busbar/Isolator/Circuit Breaker, M Switchgear/Disconnect, motor contractor, soft starter, and grounding system
6	Main transformer (tower)	Main transformer when located in the tower base (can also be mounted in the nacelle)
6	Measurements	Includes equipment that measures the function of the power electric system
5	Auxiliary tower electrical system	Includes other equipment necessary for the function of the nacelle's electrical system
6	Tower electrical services	Include the 24-DC feeder, auxiliary transformer, breaker, cabinet, fan, fuse, grid protection relay, light, mechanical switch, power point/supply, protection cabinet, push button, relay, space heater, surge arrester, thermal protection, and UPS

Level	Term	Definition
6	Tower lightning protection system	Consists of air termination, the bonding element, earth connector and termination, sliding contact, spark gap system, and surge arrester
4	Ancillary equipment	Includes other equipment within the tower necessary for the function of the wind turbine
5	Personnel access and survival equipment	Includes climb assist, elevators, hatches, ladders, landings, lighting, and doors
5	Electrical system	Comprises wiring to support tower auxiliaries
5	Tower internal lighting	Provides a safe working environment
5	Equipment support	Includes other equipment necessary for the function of the wind turbine
5	Aerodynamic accessories	Consist of passive accessories on the tower to improve energy capture (likely applicable for downwind designs only)
5	Tower-mounted damping system	Reduces the transfer of unwanted torque from the nacelle through the tower
5	Internal hoist/lifting device/elevator	Consists of a hoisting system (e.g., hoist, other lifting device, and internal elevator/lift system) within the tower used to lift tools and supplies during maintenance activities
4	Tower transportation	Includes the costs of transporting the tower components from the manufacturing facility to the staging area
3	Rotor module	Captures wind energy and transfers it to the drivetrain (through the low-speed shaft)
4	Blade	Captures the kinetic energy in the wind and transfers the torque and other unwanted loads to the drivetrain module and rest of the turbine
5	Root structure	Provides the interface between the main composite section of the blade and the blade bearing
5	Sandwich core	Consists of the low-density core material between laminates
5	Spar/spar box	Includes the spar cap and spar web
5	Bond	Provides the bonds for leading edge and trailing edge
5	Fasteners	Include the T-bolt/root insert and others
5	Laminates	Consist of internal structural laminates and skin laminates
5	Paint and coatings	Protect the outside of the turbine and its components from erosion
5	Lightening protection	Includes termination and down-conductor
5	De-icing system	Consists of sensors, heaters, wiring, and thermal conductors
5	Ballast	Adjusts the center of gravity and weight of the blades to make matching sets for a wind turbine
5	Aerodynamic accessories	Include active and passive blade accessories such as aileron, tip brakes, and so on
4	Pitch assembly	Adjusts the pitch angle of the blades to control power output from the turbine, minimize loads, and start/stop turbine as needed; blades are attached to the hub through the pitch systems

Level	Term	Definition
5	Pitch drive	Includes the motor, motor cooling fan, pitch bearing, motor brake, pitch gear, gear reducer, pinion, power electronics/drive, cabling, contractor/circuit breaker fuse, encoder, power supply, heater, accumulator, and pump
5	Pitch cabinet	Consists of the switchboard/limit switch, battery, battery charger, heater, position controller, and load controller
5	Sensors	Include the temperature sensor, voltmeter, and position sensor
5	Miscellaneous	Includes seals, auto lube system, pitch cylinder linkage, bushing, proportional valve, and hose/fitting
	Hub assembly	Connects the blades and pitch system to the low-speed shaft within the drivetrain module
5	Hub	Connects the blades and pitch system to the low-speed shaft within the drivetrain module
5	Nose cone	Consists of a protective cap fitted on the hub, largely aesthetic
5	Exit hatch	Provides access to and exit from the hub system
4	Rotor transportation	Includes the costs of transporting the rotor components from the manufacturing facility to the staging area
2	**Balance of station**	**Consists of the balance of equipment, labor, and material costs (other than wind turbine) incurred prior to COD**
3	Development	Includes all activities from project inception to financial close (where financial close is the date in which project and financing agreements have been signed and all required conditions have been met)
4	Permitting and leasing	Consists of acquisition of permits and leases required for site assessment, construction, and operation at the project site
5	Permit acquisition activities	Include the activities necessary to obtain permits from relevant authorities
5	Lease acquisition activities	Include the activities necessary to obtain a commercial or research lease to operate the project from relevant authorities
5	Public outreach	Consists of stakeholder education, marketing, and other efforts to facilitate public acceptance of a project
4	Professional advisory services	Include legal support, external consultants, accounting, and so on during development
4	Engineering	Includes engineering studies to specify the design of the project (e.g., technology and layout) and better understand economics and risks associated with the design
5	PreFront End Engineering Design (FEED)	Includes preliminary engineering design studies to develop the general design of project, identify a short list of technologies for further evaluation, and identify fatal flaws
5	FEED	Consists of engineering activities to develop final design specification, address areas of risk/uncertainty, determine technical and economic feasibility, and develop necessary specifications to begin the procurement process
5	Engineering certification	Consists of a review by a third party, independent verification agent to assess the feasibility of the design basis, resulting in a certification report

Level	Term	Definition
4	Site characterization	Includes the equipment, material and labor costs required for collecting/analyzing a wind resource, ocean conditions, and geological data at a project site; defines parameters for engineering assessments as data becomes available
5	Siting and scoping	Consists of the initial desktop-level studies to select a project location, develop a conceptual design, identify regulatory requirements, and create a preliminary business case
5	Studies and surveys	Include the climatic, environmental, and social surveys/studies required by regulators or that are otherwise necessary for the project
5	Meteorological (met) station and installation	Consists of the met tower, instrumentation, data acquisition system, and associated equipment rental and installation
5	Wind resource analysis	Includes the collection, cleaning, and analysis of data to develop a wind resource profile and power production estimates for a selection of turbine types at a project site; might include array layout optimization surveys
5	Geotechnical and geophysical surveys	Perform surveys for project site and each turbine location
4	Interconnection and power marketing	Includes activities that are intended to gain access to the transmission grid and negotiate contracts to sell or otherwise market power
5	Interconnection studies and fees	Include the activities required to obtain a Large Generator Interconnection Agreement from the Federal Energy Regulatory Commission (FERC), prepared in coordination with the transmission system operator. Studies cover the technical considerations of an interconnecting project with the grid while maintaining system balance and will operate within grid operating limits
5	Transmission rights of way	Includes the costs of obtaining or expanding transmission rights of way for any land-based electric infrastructure (e.g., overhead transmission lines), as well as any costs to permit land-based transmission
5	Power marketing	Includes efforts to develop power marketing strategies and forecast pricing and negotiate power purchase agreements
4	Project management during development	Consists of managing the project from the start of the development phase to the financial close
5	Procurement	Consists of the preparation of tenders for each work package, evaluation of bids, and negotiation with suppliers
5	Salaries	Include salaries for management and support staff on the developer's payroll; some overlap with the categories above is expected, depending on the amount of work that is completed internally versus through a contract
5	Sales, general, and administrative	Include the overhead for the project company including administrative salaries and benefits, rent, utilities, depreciation, insurance, and so on
5	Profit (if private developer)	Consists of any margin earned by the developer upon the sale of the project at financial close; does not include the cost to a new owner of any stake that a developer might retain in the project

Level	Term	Definition
4	Financing and incentives	Consists of fees, closing costs, and staff and consultant efforts to arrange and secure equity, debt financing, and government incentives
5	Due diligence	Includes activities performed by potential investors to investigate the technical and economic aspects of the project and estimate its value prior to executing a financial commitment (typically conducted by third party technical consultant[s] hired by investor[s])
5	Incentives	Include efforts performed by the developer to secure and demonstrate qualification for local, state, and federal incentives
5	Closing costs	Consist of administrative costs incurred by investors (debt and equity) during the evaluation of the investment
5	Legal support	Consists of legal support provided to developers during financial negotiations
3	Engineering management	Includes management activities from the financial close to the COD
4	Detailed design and construction engineering	Includes costs related to detailed design and construction engineering activities for the project
4	Procurement management	Includes bid management, purchasing, negotiations, and contract management
4	Construction management	Includes quality control and assurance
5	Salaries	Include salaries for management and support staff on the project owner's and/or construction manager's payroll
5	Sales: general and administrative	Consist of overhead for the project company and/or construction manager including administrative salaries and benefits, rent, utilities, depreciation, insurance, and so on
5	Profit	Includes any margin earned by an independent construction management firm
4	Project certification	Consists of review by a third party, independent verification agent to assure that a project is in compliance with the design basis as well as technical standards and regulatory requirements, resulting in a project certificate
4	Health, safety, and environmental monitoring	Includes coordination and monitoring activities to ensure compliance with health, safety, and environment (HSE) requirements during construction
5	Health and safety monitoring	Includes coordination and monitoring activities to ensure compliance with health and safety requirements during construction
5	Environmental monitoring	Includes coordination and monitoring activities to ensure compliance with environmental requirements during construction
3	Electrical infrastructure	Includes equipment and system installation to extract power from turbines via the array and transfers that power to the substation and then to the grid
4	Array cable system	Collects power generated by the turbines and transports it to the substation
5	Medium Voltage (MV) power cables	Provide the MV collection system that is buried within the project boundaries
5	Grounding transformer	Includes the supply, Dissolved Gas Analysis (DGA) testing, and installation of the grounding transformer at the substation

Level	Term	Definition
5	Pad mount transformer	Includes the supply, DGA testing, installation, and River Interference Voltage (RIV) testing of the transformer at the turbine (if applicable)
5	Switchgear	Provides the termination point between the collection system and the turbine
5	Low Voltage (LV) cables	Provide the LV collection system buried within the project boundaries
5	Backfill	Includes the engineered backfill to cover up the collection system and communication cabling system
5	Ground system	Includes the lightening protection and grounding system supplied by the original equipment manufacturer (OEM) to be installed with the foundation
5	Ancillary equipment	Includes other elements that provide necessary functions to the export cable system
6	Termination kit	Consists of the necessary components to connect the cable to substation and electric infrastructure for communication, LV, and MV systems
6	Connectors	Connect individual sections of cable together, in the event of long cable runs or damage
5	Array cable system commissioning	Assures that all array cable systems and components are operational through a predefined series of tests and checks
5	Array cable system transportation	Includes the costs of transporting the array cable components from the manufacturing facility to the staging area
4	Ancillary systems	Include other optional elements that provide functions to a project
5	Diesel generator back up	Provide power to the substation if the grid connection is lost
5	Fuel tanks	Consist of the fuel tanks and pumping equipment for the generator
5	Safety and security systems	Include access control, to safeguard personnel from hazards arising from the installation, maintenance, or operation of substation equipment
5	Spare parts	Include spares for the substation
4	Transmission infrastructure	Connects the onsite substation to the utility substation
5	Land leases/Right-of-Way	Consist of the land lease or right-of-way payments for the transmission corridor
5	Transmission lines and poles	Include the overhead transmission lines
5	Switchyard	Interconnect switchyard at the utility substation
5	Land-based transmission infrastructure transportation	Includes the costs of transporting the land-based transmission infrastructure components from the manufacturing facility to the staging area
4	Underground cable system	Include any underground cables required for connecting export cables to the land-based substation
5	Underground cables	Connect export cables to the land-based substation directly or via overhead lines
5	Ancillary equipment	Includes the equipment required for the underground cable system including ducts
4	Substations	House the electric conversion equipment to transform or convert power from the export voltage to the grid voltage

Level	Term	Definition
5	Buildings/facilities	Consist of climate-controlled structures that house electric conversion equipment
5	Civil infrastructure	Provides improvements to a construction site (e.g., roads) necessary for substation construction and operation
5	Electric conversion equipment	Transforms generated power from the export cable voltage to the interconnection voltage and/or converts that power from DC to AC (e.g., AC transformers, switchgears, shunt reactors, and DC converters)
5	Ancillary systems	Consist of other elements that provide necessary functions to the substation during operations (e.g., metering equipment, safety and security systems, fire protection, and gas detection)
5	AC transformers	Consist of power convertors that step up generated power from the array cable voltage to the export voltage
5	High-voltage switchgear	Controls, protects, and disconnects the high-voltage connection
5	Medium-voltage switchgear	Controls, protects, and disconnects the medium-voltage connection
5	Shunt reactors	Consist of onboard reactive compensation equipment
5	DC converter	Converts power from high-voltage AC (HVAC) to high-voltage DC (HVDC) for export to shore
5	Filtering system	Uses filters to address harmonics generated by HVDC converters
5	Substation Integration, Assembly, Test and Checkout (IATC)	Consists of activities performed by the turbine manufacturer to integrate, assemble, test, and verify the substation substructure and foundation before delivering to the customer (does not include commissioning activities)
5	Substation transportation	Includes costs of transporting the substation components from the manufacturing facility to the staging area
3	Plant commissioning	Includes the cost incurred by the owner or prime contractor to test and commission the integrated power plant
3	Site access, ports, and staging	Includes the activities and physical aspects of a staging area; elements needed to support the delivery, installation, storage, handling, and deployment of wind plant components
4	Facilities	Consist of temporary facilities (trailers) supplied by subcontractors for supporting the construction of a wind plant; area needs to be leveled and compacted
5	Laydown area	Includes the space at the staging area used to store turbine components and conduct any pre-assembly work on the ground; also stores other subcontractor components prior to delivering to the pad
5	Utilities	Include the temporary power, restrooms, and water located at a facility to be used by subcontractors during the construction phase
3	Assembly and installation	Include assembly and installation activities conducted at the project site; assume that financial costs related to warranties, contractor insurance, SG&A, profit margin, and so on are loaded in rates for labor and equipment

Level	Term	Definition
4	Roads	Includes modifying public roads as required, creating site entrances, and constructing site roads per the layout, OEM transportation guidelines, and engineering drawings
4	Erection	Includes costs of equipment and labor to assemble wind turbines on individual pads
5	Cranage	Includes cranage fees to use and operate crawler cranes, topping cranes, and stabilizing cranes used for the assembly of a wind turbine; includes the number of cranes, day rates, mobilization and demobilization on site, and breakdowns as required for relocating crawler cranes over long distances
5	Fasteners	Provides hardware to secure connections between the foundation structure, tower components, nacelle, and rotor elements
5	Grout, grout lines, and seals	Consist of grout and ancillary equipment to secure connections between foundation elements
4	Commissioning	Process of testing the mechanical components of a turbine and commissioning it for energy production; complete when 100 kilowatts per turbine are supplied to the grid
3	Foundation	Provides the structural foundation for a wind turbine
4	Excavation	Creating wind turbine pads and locating the structural foundation
4	Primary structure	Consists of rebar and concrete (spread foot, P&H, or modified P&H)
4	Batch plant	Provides a temporary onsite facility to create concrete for a project
4	Foundation transportation	Involves the transportation of foundation materials to the staging area
3	Operations and maintenance (O&M) infrastructure	Includes the capital investment in facilities, equipment, and other assets required for O&M
4	Permanent facilities	Include O&M facilities, offices, warehouse, parking, the SCADA server, restrooms, and so on
4	O&M equipment purchases	Include other purchases necessary for operating the wind project after COD; examples include: safety equipment (e.g., harnesses), equipment to store replacement parts (e.g., climate control for spare electric cables), and vehicles to support operations (e.g., fork trucks)
2	**Financial costs**	**Consist of financial expenditures for which the project owner is responsible prior to COD, related to either payments for financial products, carrying charges on loans, or setting up financial instruments**
3	Project contingency budget	Provides a liquid financial instrument set up to respond to "known unknown" costs that arise during construction; does not include contingences set by manufacturers and contractors as part of supply contract pricing

Level	Term	Definition
3	Insurance during construction (IDC)	Consists of insurance policies held by the owner during the construction period, which may include construction all risk, cargo, commercial general liability, workers compensation, environmental site liability, pollution liability, and so on; does not include insurance held by contractors
3	Carrying charges during construction (construction financing costs)	Include carrying charges of expenditures on equipment and services incurred before COD
3	Reserve accounts (maintenance expenditures [MRAs], debt service expenditures [DSRAs])	Provide financial arrangements in which payments (before commissioning) are deposited into reserve accounts; generally required by either financiers or regulators
4	Maintenance reserve accounts	Include payments (before commissioning) into reserve accounts set up to cover major MRAs, often required by debt service providers
4	Debt service reserve accounts	Include payments (before commissioning) into reserve accounts set up to cover DSRAs, often required by debt service providers
4	Decommissioning reserve account	Include payments (before commissioning) into reserve accounts to fund project decommissioning obligations (e.g., surety bonds)
1	**Operational expenditures**	**Consist of expenditures required to operate the project and maintain availability, generally annualized**
2	**Operations**	**Include nonequipment costs of operations for a project**
3	Environmental, health, and safety	Includes coordination and monitoring activities to ensure compliance with HSE requirements during construction
4	Health and safety monitoring	Includes coordination and monitoring activities to ensure compliance with health and safety requirements during operations
4	Environmental monitoring	Includes coordination and monitoring activities to ensure compliance with environmental requirements during operations
3	Business-related annual leases, fees, and costs	Consist of payments for permission to operate at a project site, terms defined within a lease, any payments to transmission system operators for rights to transport generated power, any payments to infrastructure owners for the right to operate power facilities, and
4	Land leases	Consist of payments to land owners for rights to operate transmission lines, the substation, or other facilities
4	Transmission charges/rights	Include any payments to transmission system operators or transmission asset owners for rights to transport generated power
4	FERC fees	Include fees paid to FERC during operations
3	Insurance	Consist of insurance policies held by the project company or operations manager during the operational period
3	Operation, management, and general administration	Consist of activities necessary to determine, dispatch, sell, and manage the plant's power production; includes staff and equipment both on and off site

Level	Term	Definition
4	Generation planning and integration	Includes efforts spent on forecasting, selling, and dispatching the power generated by the facility
4	Operating facilities	Include co-located offices, parts store, maintenance sheds, and so on
4	Operating equipment	Includes lease payments for operating equipment held by the project to support operations (e.g., cranes and fork trucks)
4	Sales: general, and administrative	Includes financial reporting, public relations, procurement, parts and stock management, HSE management, training, subcontracts, and general administration of project site
4	Turbine power consumption	Consists of charges for power drawn from the grid by the wind project (e.g., turbine and substation) during operation
4	Weather forecasting	Provides a daily 96-hour forecast of wind conditions that is used to plan maintenance visits and project power production
4	Operations management	Includes coordination of equipment and personnel to carry out maintenance and inspections of generation and transmission equipment
4	Condition monitoring	Consists of monitoring SCADA data from wind turbine components to optimize performance and identify component faults
4	Operating margin	Includes any margin earned by an independent operations management company
4	Professional advisory services	Consist of legal support, external consultants, accounting, and so on during operation
2	**Maintenance**	**Includes labor and equipment costs of operations for the project**
3	Long-term service agreement	Consists of the annualized cost of a contract between the project owner and a third party to maintain the project at a guaranteed level of availability for a defined period; will likely replace scheduled and unscheduled maintenance categories below for the duration of the contract
3	Scheduled maintenance	Consists of planned, routine activities to ensure that equipment, systems, and structures are operating correctly and at optimal efficiency, and to minimize unscheduled breakdowns/ downtime; includes cost of labor, equipment, spare parts, and consumables
4	Wind turbine scheduled maintenance	Consists of planned maintenance activities for turbine systems
5	Nacelle module	Includes planned maintenance related to the drivetrain modules
5	Rotor module	Includes planned maintenance related to the rotor modules
5	Tower module	Includes planned maintenance related to the tower modules
4	BOS scheduled maintenance	Includes planned maintenance activities for BOS
5	Electrical transforming equipment inspection	Consists of inspecting the switchgears, transformers, and back-up power supply
5	DC converter inspection	Consists of inspecting the DC converter equipment and filtering equipment
5	Land-based electric infrastructure	Includes inspections of the switchgear, transformers, and any connections
3	Unscheduled maintenance	Involves interventions and other activities to respond to random failures; costs include equipment, labor, replacement parts, and consumables (also known as corrective maintenance)

Level	Term	Definition
4	Wind turbine unscheduled maintenance	Consists of performing unscheduled maintenance for turbine systems
5	Nacelle module	Includes corrective maintenance related to the drivetrain modules
5	Rotor module	Includes corrective maintenance related to the rotor modules
5	Tower module	Includes corrective maintenance related to the tower modules
4	BOS unscheduled maintenance	Includes unscheduled maintenance for BOS
5	Foundation	Includes corrective maintenance related to the substructure and foundations
5	Electrical infrastructure	Includes the corrective maintenance related to the electric infrastructure
5	Other infrastructure	Includes the corrective maintenance related to other infrastructure
5	Electric infrastructure	Includes servicing and repairs to the switchgear, transformers, and any connections (infrequent)
4	Unscheduled maintenance contingency	Consists of a liquid financial instrument set up to respond to "known unknown" costs that arise during maintenance

Appendix F. Summary of Offshore System Cost Breakdown Structure

Table F1. Offshore Wind System Cost Breakdown Structure Terms and Definitions

Level	Term	Definition
1	**Capital expenditures (CapEx)**	**Consist of all installed costs incurred prior to the COD; CapEx components include the turbine, BOS, and soft costs**
2	**Wind turbine**	**Converts kinetic energy from wind into three-phase AC electrical energy**
3	**Nacelle module**	**Provides a structural interface between the tower module, drivetrain module, and rotor module; Also provides housing for sensitive electrical and mechanical components and equipment, and enables access by maintenance personnel**
4	Nacelle structural assembly	Provides the structural interface between the tower, drivetrain, and rotor, and shelters sensitive equipment
5	Enclosure	Includes the structure, exit hatch, hatch, latches, and helicopter landing pad
5	Drivetrain and generator support structures	Include the bedplate and generator frame (can be a single unit), including welded steel and fasteners
5	Coatings	Protect the outside of the wind turbine from corrosion in a marine environment
4	Drivetrain assembly	Consists of the main power conversion system in the wind turbine, where energy that is captured by the rotor is transferred and drives the generator via the main shaft system, with or without a gearbox
5	Gearbox	Provides speed and torque conversion between the rotor and the generator (only applicable for geared designs)
6	Gears	Include the planet carrier, planet gear, ring gear, sun gear, spur gear, and hollow shaft
6	Bearings	Include the planet bearing, carrier bearing, and shaft bearing
6	Housing	Consists of the bushing, case, mounting, and torque arm system
6	Sensors	Include the debris sensors, oil level sensors, pressure 1 and pressure 2 sensors, and temperature sensor
6	Lube system	Consists of the primary filter, secondary filter, primary motor, primary pump, hose/fitting, seal, and reservoir
6	Cooling system	Includes the pump, radiator, and hoses
5	Low-speed shaft and main bearing system	Transfers torque from the rotor to the gearbox (if applicable) or generator if direct drive
6	Low-speed shaft	Includes the low-speed shaft, compression coupling, rotor lock, connector plate, and slip ring assembly
6	Main bearing	Includes the main bearing upwind, main bearing downwind, and main bearing seals
6	Sensors	Include the main bearing temperature sensor, low-speed shaft rpm, and position sensor
5	High-speed shaft and braking system	Consists of the high-speed shaft, coupling, rotor lock, and transmission shaft
6	High-speed shaft	Includes the high-speed shaft, coupling, rotor lock, and transmission shaft

Level	Term	Definition
6	Braking system	Consists of the brake disc, brake calipers, brake pads, and transmission lock
6	Sensors	Include the high-speed shaft rpm sensor and position sensor
4	Nacelle electrical assembly	Consists of the power off-take system elements located in the nacelle
5	Generator	Converts mechanical energy to electrical energy
6	Cooling system	Includes the hoses, filter, cooling fan, motor, and radiator
6	Lubrication system	Includes the pump, pump motor, and reservoir
6	Rotor	Consists of the commentator, exciter, resistance controller, rotor lamination, rotor winding, slip ring, rotor magnets, and brush
6	Sensors	Include the core temperature sensor, encoder, and watt meter
6	Stator	Include stator magnets, stator lamination, and stator windings
6	Structural and mechanical	Consist of the front bearing, rear bearing, silent block, housing, and shaft
5	Frequency converter	Converts the variable frequency from the asynchronous generator to grid-compliant power of the right 'quality' and with a stable frequency of either 50 or 60 Hz
6	Converter auxiliaries	Consist of the power supply, cabinet, heating system, cabinet sensor, communication and interface unit, control board, generator side fan, grid side fan, measurement unit, power supply, power supply (24 V), tachometer adapter, and thermostat
6	Converter power bus	Includes the branching unit, capacitors, contactors, generator side converter, generator side power module, grid side converter, grid side power module, inductor, load switch, and precharge unit
6	Power conditioning System	Consists of the common mode filter, crowbar system, DC chopper, generator side filter, line filter assembly, and voltage limit unit
5	Power electrical system	Converts the generator voltage to the array cable system voltage for collection
6	Power circuit	Consists of the IGBT module, rectifier bridge, crowbar system, driver/control board, cables, machine contractor, M busbar/isolator/circuit breaker, M switchgear/disconnect, motor contractor, soft starter, and grounding system
6	Main transformer (nacelle)	Consists of the main transformer when located in the nacelle (can also be mounted in the tower)
6	Measurements	Use equipment to measure the function of the power electric system
6	Switchgear	Provides the termination point between the collection system and the turbine. It is either located in the base of the tower (transformer up tower) or or as part of a ground-based transformer that is external to the tower
5	Control and communication system (SCADA)	Connects wind turbines with a land-based operations center, providing wind project operators with information about the status of wind turbine systems and allowing for the remote control of some functions
6	Wind turbine controller	Consists of the rotor controller, nacelle controller, and tower controller (all comprised of numerous level 6 components)
6	Communication system	Consists of the analog I/O unit, digital I/O unit, Ethernet module, field bus master, field bus slave, frequency unit, and controller internal communication system
6	Condition monitoring system	Includes sensors, cables, a data logger, and protocol adapter card for the data

Level	Term	Definition
		logger
6	Ancillary equipment	Consists of cables, connectors, and the contactor/circuit breaker fuse
6	Wind plant control equipment	Includes any advanced wind plant control equipment installed on the turbines (e.g., nacelle-mounted lidar) or distributed throughout the plant (e.g., ground-mounted lidar)
5	Auxiliary nacelle electrical system	Includes the other equipment necessary for the function of the nacelle electrical system
6	Nacelle electrical services	Consist of the 24-DC feeder, auxiliary transformer, breaker, cabinet, fan, fuse, grid protection relay, light, mechanical switch, power point/supply, protection cabinet, push button, relay, space heater, surge arrester, thermal protection, and UPS
6	Nacelle lightning protection system	Consists of air termination, bonding element, earth connector and termination, sliding contact, spark gap system, and surge arrester
4	Yaw assembly	Provides the structure that interfaces between the tower, drivetrain, and rotor, and shelters sensitive equipment
5	Brake	Includes the yaw brake calipers, disc, path, and hoses
5	Drives and bearings	Consist of the motor, gear, pinion, bearing, and damper
5	Hydraulics	Include the accumulator, pump, hoses and valves, and motor
5	Yaw sensors	Include the wind-up counter, yaw encoder, and position sensor
4	Nacelle auxiliaries	Consist of the other equipment within the nacelle necessary for the function of the wind turbine
5	Nacelle sensors	Include the anemometer, wind vane, and temperature sensors
5	Internal environment	Consists of the HVAC, nacelle vent, and nacelle lighting
5	FAA lighting	Consists of the navigational lighting lights (requirements set by the FAA in the United States)
5	Walking/climbing infrastructure	Consists of the cat walks, cables, ladders, landing, people hatch, crane hatch, and anchors within the turbine tower
5	Safety system	Consists of the tie-off system, firefighting system, fall arrester, down conductor, service crate, beacon, metallic mesh nacelle cover, and lighting protection
5	Lightning protection system	Protects the turbine from damage caused by lightning strikes by passing currents to the ground; includes the air termination, bonding element, earth connector and termination, sliding contact, spark gap system, and surge arrester
5	External maintenance crane (Davit)	Lifts small components (e.g., <2 metric Tons (mT)) from the support structure or maintenance vessel into the nacelle
4	Nacelle transportation	Includes the costs of transporting the nacelle components from the manufacturing facility to the staging area
3	**Tower module**	**Consists of a support structure element that connects the nacelle with the substructure and foundation, and can house electrical conversion equipment and provide emergency shelter**
4	Tower system	Consists of the primary structural component

Level	Term	Definition
5	Tower structure	Includes the tower sections, generally consisting of rolled steel sections (though other options are being considered)
5	Fasteners	Consist of bolts the connect individual tower elements to other tower elements, the nacelle module, and the substructure
5	Coating	Protect from corrosion in the marine environment
4	Tower electrical assembly	
5	Drop cables	Consist of cables to off-take power from the drivetrain (or main transformer, if located up tower) and transport down tower to the main transformer (if located at tower base) or the array cable interface
5	Frequency converter	Converts variable frequency from the asynchronous generator to grid-compliant power of the right 'quality' and with a stable frequency of either 50 or 60 Hz
6	Converter auxiliaries	Consist of the power supply, cabinet, heating system, cabinet sensor, communication and interface unit, control board, generator side fan, grid side fan, measurement unit, power supply, power supply (24 V), tachometer adapter, and thermostat
6	Converter power bus	Includes the branching unit, capacitors, contactors, generator side converter, generator side power module, grid side converter, grid side power module, inductor, load switch, and precharge unit
6	Power conditioning system	Consists of the common mode filter, crowbar system, DC chopper, generator side filter, line filter assembly, and voltage limit unit
5	Power electrical system	Converts the generator voltage to the array cable system voltage for collection
6	Power circuit	Includes the IGBT module, rectifier bridge, crowbar system, driver/control board, cables, machine contractor, M busbar/isolator/circuit breaker, M switchgear/disconnect, motor contractor, soft starter, and grounding system
6	Main transformer (tower)	Consists of the main transformer when located in the tower base (can also be mounted in the nacelle)
6	Measurements	Use equipment to measure the function of the power electric system
5	Auxiliary tower electrical system	Includes other equipment necessary for the function of the nacelle's electrical system
6	Tower electrical services	Include the 24-DC feeder, auxiliary transformer, breaker, cabinet, fan, fuse, grid protection relay, light, mechanical switch, power point/supply, protection cabinet, push button, relay, space heater, surge arrester, thermal protection, and UPS
6	Tower lightning protection system	Consists of the air termination, bonding element, earth connector and termination, sliding contact, spark gap system, and surge arrester
4	Ancillary equipment	Other equipment within the tower necessary for the function of the wind turbine
5	Personnel access and survival equipment	Includes the climb assist, elevators, hatches, ladders, landings, lighting, doors, food and fresh water storage
5	Electrical system	Consists of the wiring needed to support tower auxiliaries
5	Tower internal lighting	Consists of the lighting within the tower to provide a safe working environment

Level	Term	Definition
5	Equipment support	Includes the other equipment necessary for the function of the wind turbine
5	Aerodynamic accessories	Include the passive accessories on the tower to improve energy capture (likely applicable only for downwind deigns)
5	Damping system (tower mounted)	Reduces the transfer of unwanted torque from the nacelle through the tower
5	Internal hoist/lifting device/elevator	Consists of the hoisting system (e.g., the hoist, other lifting device, and internal elevator/lift system) within the tower used to lift tools and supplies during maintenance activities
4	Tower transportation	Includes the costs of transporting the tower components from the manufacturing facility to the staging area
3	**Rotor module**	**Captures wind energy and transfers it to the drivetrain (through the low-speed shaft)**
4	Blade	Captures the kinetic energy in the wind and transfers torque and other unwanted loads to the drivetrain module and rest of the turbine
5	Root structure	Provides the interface between the main composite section of the blade and the blade bearing
5	Sandwich core	Consists of the low-density core material between laminates
5	Spar/spar box	Includes the spar cap and spar web
5	Bond	Provides the bond for the leading edge and trailing edge
5	Fasteners	Includes the T-bolt/root insert and others
5	Laminates	Include the internal structural laminates and skin laminates
5	Paint and coatings	Protect the outside of the turbine and its components from erosion
5	Lightening protection	Consists of termination and the down conductor
5	De-icing system	Includes sensors, heaters, wiring, and thermal conductors
5	Ballast	Adjusts the center of gravity and weight of the blades to make matching sets for a wind turbine
5	Aerodynamic accessories	Include active and passive blade accessories such as aileron, tip brakes, and so on
4	Pitch assembly	Adjusts the pitch angle of the blades to control power output from the turbine, minimize loads, and start/stop the turbine as needed; blades are attached to the hub through the pitch systems
5	Pitch drive	Includes the motor, motor cooling fan, pitch bearing, motor brake, pitch gear, gear reducer, pinion, power electronics/drive, cabling, contractor/circuit breaker fuse, encoder, power supply, heater, accumulator, and pump
5	Pitch cabinet	Consists of the switchboard/limit switch, battery, battery charger, heater, position controller, and load controller
5	Sensors	Includes the temperature sensor, voltmeter, and position sensor
5	Miscellaneous	Include the seals, auto lube system, pitch cylinder linkage, bushing, proportional valve, and hose/fitting
4	Hub assembly	Connects the blades and pitch system to the low-speed shaft within the drivetrain module

Level	Term	Definition
5	Hub	Connects the blades and pitch system to the low-speed shaft within the drivetrain module
5	Nose cone	Consists of a protective cap fitted on the hub that is largely aesthetic
5	Exit hatch	Provides access to and from the hub system
4	Rotor transportation	Includes the costs of transporting the rotor components from the manufacturing facility to the staging area
2	**Balance of system**	**Consists of the balance of equipment, labor, and material costs (other than the wind turbine) incurred prior to COD**
3	**Development**	**Includes all activities from project inception to financial close (financial close is the date in which the project and financing agreements have been signed and all the required conditions have been met)**
4	Permitting and leasing	Involves the acquisition of permits and leases required for site assessment, construction, and operation at the project site
5	Permit acquisition activities	Includes the activities necessary to obtain permits from relevant authorities
5	Lease acquisition activities	Include the activities necessary to obtain a commercial or research lease (from relevant authorities) to operate the project
5	Public outreach	Includes stakeholder education, marketing, and other efforts to facilitate public acceptance of a project
4	Professional advisory services	Consist of legal support, external consultants, accounting, and so on during project development
4	Initial engineering	Consist of engineering studies to specify the design of the project (e.g., technology and layout) and understand the economics and risks associated with the design
5	Pre-FEED	Consist of preliminary engineering design studies to develop the general design of a project, identify a short list of technologies for further evaluation, and identify fatal flaws
5	FEED	Include engineering activities to develop final design specification, address areas of risk/uncertainty, determine technical and economic feasibility, and develop the necessary specifications to begin the procurement process (20% to 30% design level); additional engineering activities (e.g., preliminary, detailed, and final) are covered in engineering and management
5	Engineering certification	Includes the review by a third-party, independent verification agent to assess the feasibility of design basis, resulting in a certification report
4	Site characterization	Consists of the equipment, material, and labor costs required for the collecting/analysis of wind resource, ocean conditions, and geological data at a project site; defines parameters for engineering assessments as data becomes available
5	Siting and scoping	Consist of the initial desktop-level studies to select the project location, develop a conceptual design, identify regulatory requirements, and create the preliminary business case
5	Studies and surveys	Include the environmental and social surveys/studies required by regulators or that are otherwise necessary for the project

Level	Term	Definition
5	Met and ocean monitoring stations	Includes the meteorological tower and the substructure (fixed or floating), buoys, benthic node, acoustic Doppler current profilers, instrumentation (meteorological and oceanographic), and data acquisition systems
5	Met and ocean monitoring installation	Includes the vessels, labor, and equipment required to install the met station, instrumentation, and data acquisition system
5	Wind resource analysis	Involves the collection, cleaning, and analysis of data to develop the wind resource profile and power production estimates for a selection of turbine types at a project site; might include array layout optimization surveys
5	Geotechnical and geophysical surveys	Include the vessels, labor, and equipment required to establish bathymetry, seabed features, water depth, stratigraphy, and identify hazards on the seafloor; performed for the project site and potential cable routes to interconnection
4	Interconnection and power marketing	Consist of activities performed to gain access to the transmission grid and negotiate contracts to sell or otherwise market power
5	Interconnection studies and fees	Include activities required to obtain a Large Generator Interconnection Agreement from FERC, prepared in coordination with the transmission system operator; studies cover technical considerations of the interconnecting project with the grid while maintaining system balance and grid operation within specified limits
5	Transmission rights of way	Include costs of obtaining or expanding the transmission rights of way for any land-based electric infrastructure (e.g., overhead transmission lines); includes any costs to permit transmission on land
5	Power marketing	Includes efforts to develop a power marketing strategy, forecast pricing, and negotiate power purchase agreements
4	Project management during development	Managing the project from the start of the development phase to the financial close
5	Procurement	Preparing tenders for each work package, evaluation of bids, and negotiations with suppliers
5	Salaries	Include salaries for management and support staff on the project developer's payroll; some overlap with categories above is expected, depending on the amount of work that is completed internally versus contracted
5	Sales: general and administrative	Consists of overhead for the project company including administrative salaries and benefits, rent, utilities, depreciation, insurance, etc.
5	Profit (if private developer)	Includes any margin earned by the developer upon sale of the project at financial close; does not include the cost to a new owner of any stake that a developer might retain in the project
4	Financing and incentives	Include fees, closing costs, and staff and consultant efforts to arrange and secure equity, debt financing, and government incentives
5	Due diligence	Involves activities performed by potential investors to investigate the technical and economic aspects of the project and estimate its value prior to executing a financial commitment; typically conducted by third-party technical consultant(s) hired by investor(s)
5	Incentives	Consist of efforts performed by the developer to secure and demonstrate qualification for local, state, and federal incentives

Level	Term	Definition
5	Closing costs	Include administrative costs incurred by investors (debt and equity) during the evaluation of the investment
5	Legal support	Consists of developer's legal support during negotiations to arrange financing
3	**Engineering and management**	**Consists of management activities performed from financial close through COD**
4	Detailed design and construction engineering	Include the detailed design and construction engineering costs
4	Procurement management	Consists of bid management, purchasing, negotiations, and contract management
4	Construction management	Includes quality control and assurance
5	Salaries	Consist of salaries for management and support staff on of the project owner’s and/or construction manager’s payroll
5	Sales: general and administrative	Consists of the overhead for the project company and/or construction manager including administrative salaries and benefits, rent, utilities, depreciation, and insurance
5	Profit	Includes any margin earned by an independent construction management firm
4	Project certification	Consists of review by a third party, independent verification agent to assure that the project is in compliance with the design basis as well as technical standards and regulatory requirements; results in a project certificate
4	Health, safety, and environmental monitoring	Consists of coordination and monitoring to ensure compliance with HSE requirements during construction
5	Health and safety monitoring	Consists of coordination and monitoring to ensure compliance with health and safety requirements during construction
5	Environmental monitoring	Includes coordination and monitoring to ensure compliance with environmental requirements during construction
3	**Electrical infrastructure**	**Consists of all electrical infrastructure to collect power from the generators and deliver to the grid**
4	Array cable system	Collects power generated by the turbines and transports it to the offshore substation
5	Array cables (high or medium voltage)	Connect turbines with the offshore substation or export turbine
5	Protection	Consists of equipment and materials used to protect cables from damage (e.g., strikes, overbending, and so on)
6	Scour protection	Includes rock fill, sand bags, or concrete mattresses to protect from scouring; used where burial is not possible
6	Seabed protection mats	Consist of concrete, sand bags, and polyurethane mats to route cables over existing electric/telecommunications cables
6	Ducting system	Provides a protective sheath that can be fitted around cables where burial is not an option

Level	Term	Definition
6	J-tube seals	Provide a seal to the ends of the J-tube to keep sea water out; can be active or passive
6	Bend restrictors	Prevents the overbending of static cables during installation and operation
6	Bend stiffeners	Limit bending stresses and maintain an acceptable curvature for dynamic cables at the hang-off point and touch down
5	Ancillary equipment	Include other elements that provide necessary functions to the array cable system
6	Termination kit	Consists of the necessary components to connect the array cable to each turbine transformer
6	Connectors	Connect individual sections of cable together, in the event of long cable runs or damage
6	Buoyancy modules	Manage buoyancy in some dynamic cable configurations and control load transfer
6	Anchorage	Maintains the station of dynamic cable at the touchdown point
6	Messenger lines and buoys	Include the ancillary equipment used during the installation of static and dynamic cable systems
6	Portable diesel generators	Provide power to turbines if the grid connection is not established before commissioning, including generators, fuel tanks, fuel, fueling, and maintenance during deployment
6	Array cable system commissioning	Assures that all array cable systems and components are operational through a predefined series of tests and checks
5	Array cable system transportation	Includes costs of transporting the array cable components from the manufacturing facility to the staging area
4	Export cable system	Connect turbines or offshore substations with the land-based electric infrastructure or offshore converter station (if DC); includes IATC
5	Export cables (High or medium voltage)	Connect turbines or offshore substations with the land-based electric infrastructure or offshore converter station (if DC); includes IATC
5	Protection	Includes the equipment and materials used to protect the cable from damage (e.g., strikes and overbending)
6	Scour protection	Includes the rock fill, sand bags, or concrete mattresses to protect from scouring; used where burial is not possible
6	Seabed protection mats	Include the concrete, sand bags, and polyurethane mats to route cables over existing electric/telecommunication cables
6	Ducting system	Provides a protective sheath that can be fitted around cables in which burial is not an option
6	J-tube seals	Seal the ends of the J-tube and keep sea water out; can be active or passive

Level	Term	Definition
6	Bend restrictors	Prevents the overbending of static cables during installation and operation
6	Bend stiffeners	Limit bending stresses and maintain an acceptable curvature for dynamic cables at the hang-off point and touch down
5	Ancillary equipment	Includes other elements that provide necessary functions to the export cable system
6	Termination kit	Consist of necessary components for connecting the cable to the substation and to land-based electric infrastructure
6	Connectors	Connect individual sections of cable together, in the event of long cable runs or damage
6	Buoyancy modules	Manage buoyancy in some dynamic cable configurations and control load transfer
6	Anchorage	Maintains the station of dynamic cable at the touch down point
6	Messenger lines and buoys	Consist of the ancillary equipment used during the installation of static and dynamic cable systems
5	Export cable system transportation	Includes the costs of transporting the export cable components from the manufacturing facility to the staging area
4	Offshore substation(s)	Includes the electric conversion equipment required to step up or convert power for export to the land-based grid and support structure; also includes onboard work platforms, accommodation, equipment storage, and helicopter access
5	Topside	Provides support and climate-controlled housing for the electrical conversion equipment; can also provide work platforms, accommodation, equipment storage, and helicopter access
6	Structure	Includes material, equipment, and labor costs of fabricating structural steel or concrete structure
6	Helicopter deck	Provides the onboard helicopter landing platform
6	Accommodations	Include the refuge, temporary, or permanent accommodations for project personnel
6	Outfitting steel	Includes additional nonstructural elements attached to the primary structure
6	Topside marine systems	Consist of the ancillary systems required for marine operations
6	Substation topside and foundation IATC	Consists of activities performed by the manufacturer to integrate, assemble, test, and verify the substation topside before delivering to the customer (does not include commissioning activities)
6	Substation topside transportation	Includes costs to transport the substation topside from the manufacturer to the staging port
5	Substructure and foundation	Includes all elements of the offshore substation below the point of connection with the topside
6	Foundation	Consists of the main structural interface that transfers the loads into the seabed
6	Substructure	Connects the foundation to the substation topside

Level	Term	Definition
6	Substructure marine systems	Consist of ancillary systems for marine operations; the major element is the ballast system for floating offshore substations
6	Scour protection	Includes rock fill or concrete mattresses to protect substructures from scouring at the point of connection to the seafloor
6	Substation substructure and foundation IATC	Consists of activities performed by the manufacturer to integrate, assemble, test, and check out the substation substructure and foundation before delivering to the customer (does not include commissioning activities)
6	Substation substructure and foundation transportation	Includes costs to transport the substation substructure and foundation from the manufacturer to the staging port
5	Electrical conversion equipment	Steps up power from the array cable voltage to the export voltage and/or converts power to DC
6	AC transformers	Step-up generated power from the array cable voltage to the export voltage
6	High-voltage switchgear	Controls, protects, and disconnects the high-voltage connection
6	Medium-voltage switchgear	Controls, protects, and disconnects the medium-voltage connection
6	Shunt reactors	Consist of the onboard reactive compensation equipment
6	DC converter	Converts power from HVAC to HVDC for export to shore
6	Filtering system	Filters to address harmonics generated by HVDC converters
6	Substation electrical conversion equipment IATC	Includes activities performed by the manufacturer to integrate, assemble, test, and check out the substation electrical conversion equipment before delivering to the customer (does not include commissioning activities)
6	Substation electrical conversion equipment transportation	Includes costs to transport the substation electrical conversion equipment from the manufacturer to the staging port
5	Ancillary systems	Consist of other elements that provide necessary functions to the offshore substation during operations
6	Diesel generator back up	Provides power to the substation if the grid connection is lost
6	Fire protection system	Includes fire alarms and fire response equipment
6	Water tanks	Include fresh water tanks and pumping equipment
6	Fuel tanks	Consist of fuel tanks and pumping equipment For the generator and possibly emergency fueling of service/crew transfer vessels
6	Control and communication system	Connects the substation with an operations center on land; provides the project operator with information about the status of substation systems; and allows remote control of some functions
6	Safety and security systems	Include access control to safeguard personnel from hazards arising from the installation, maintenance, or operation of substation equipment
4	Land-based transmission infrastructure	Include any land-based transmission or conversion equipment required to connect a project to the grid

Level	Term	Definition
5	Land leases	Consist of land lease or right-of-way payments for the transmission corridor prior to COD
5	Underground cable system	Includes any underground cables required for connecting export cables to the substation on land
6	Underground cables	Connect export cables to the land-based substation directly or via overhead lines
6	Ancillary equipment	Consists of the ancillary equipment required for the underground cable system including ducts
5	Self-supporting towers with insulators	Support any overhead lines required for connecting export cables to the land-based substation
6	Foundations	Include support tower structures, typically reinforced concrete
6	Transmission towers	Support overhead transmission lines
6	Insulators	Attach overhead transmission lines to the towers
5	Overhead lines	Transmit power and enable communications with the offshore wind project
6	Conductors	Transmit power between the export cable and land-based substation (three-phase system)
6	Communications	Consist of the fiber optic wire routed to the control center that transmits information from the data acquisition system (DAS) and Conditioning Monitoring System (CMS), and allows land-based control of project systems
6	Shield wire	Provides a grounded conductor to protect phase conductors from surges (lightning)
5	Onshore substations	House electric conversion equipment to transform or convert power from the export voltage to the land-based grid voltage
6	Buildings/facilities	House electric conversion equipment (climate controlled)
6	Civil infrastructure	Provide necessary improvements to the construction site (e.g., roads) for substation construction and operation
6	Electric conversion equipment	Transforms generated power from the export cable voltage to the interconnection voltage and/or converts power from DC to AC (e.g., AC transformers, switchgears, shunt reactors, and DC converters)
6	Ancillary systems	Include other elements that provide necessary functions to the substation during operations (e.g., metering equipment, safety and security systems, fire protection, and gas detection)
5	Land-based transmission infrastructure transportation	Includes the costs of transporting the land-based transmission infrastructure components from the manufacturing facility to the staging area
3	**Plant commissioning**	**Includes the cost incurred by the owner or prime contractor to test and commission the integrated power plant**
3	**Site Access, port, and staging**	**Consist of activities and physical aspects of a staging port; elements needed to support the delivery, storage, handling, and deployment of offshore wind plant components**

Level	Term	Definition
4	Facilities	Include port facilities or space leased to support the installation of a project
5	Laydown area	Consists of the leased space at the staging port to store turbine components and foundations
5	Assembly areas	Consist of the leased space at the staging port with a high load bearing capacity to perform land-based assembly activities
5	Utilities	Include temporary power, restrooms, and water located at facilities to be used by subcontractors during the construction phase
5	Fabrication facilities	Support fabrication, construction, or assembly of components
4	Cranage	Includes cranage fees to use and operate crawler cranes, tower cranes, harbor cranes, and self-propelled modular transporters for the land-based assembly of components and loading onto installation vessels
4	Port improvements	Consist of any improvement to the existing port infrastructure that is paid for by the project owner (e.g., quayside reinforcement)
4	Port fees	Include fees for vessel access, docking, and loading/unloading
5	Entrance/exit fees	Consist of charges levied upon entry of vessels into the port, generally calculated using a standard formula basis upon gross registered ton
5	Quayside docking fees	Include charges levied for the use of a berth either occupied by a vessel or by preassembly activities
5	Wharfage fees	Include charges for loading or unloading cargo from vessels, generally calculated by tonnage and equipment requirements for loading/unloading the cargo
3	**Assembly and installation**	**Consists of assembly and installation activities conducted at the staging port and at the project site; assume that financial costs related to warranties, contractor insurance, SG&A, profit margin, and so on, are loaded in day rates for vessels, labor, and equipment**
4	Substructures and foundations	Include vessel, labor, and equipment costs to complete installation of foundations and substructures
5	Foundation	Includes vessel, labor, and equipment costs to complete installation of the foundation
5	Substructure	Includes vessel, labor, and equipment costs to complete installation of the substructure
5	Scour protection	Includes vessel, labor, and equipment costs to complete installation of scour protection
4	Turbines	Include vessel, labor, and equipment costs to complete turbine installation for the entire project
5	Towers	Include vessel, labor, and equipment costs to complete tower installation
5	Nacelle	Includes vessel, labor, and equipment costs to complete nacelle installation
5	Blades	Include vessel, labor, and equipment costs to complete blade installation
4	Electrical infrastructure	Includes vessel, labor, and equipment costs to install electrical infrastructure
5	Array cables	Include installation of the subsea array cable system

Level	Term	Definition
6	Laying	Includes vessel, labor, and equipment costs to lay array cables
6	Trenching	Includes vessel, labor, and equipment costs to bury array cables
6	Protection	Includes vessel, labor, and equipment costs to protect array cables
6	Terminations	Include vessel, labor, and equipment costs to pull array cables through J-tubes and connect to transformers
5	Export cables	installation of subsea export power cable system from offshore substation to land-based substation
6	Laying/trenching	Includes vessel, labor, and equipment costs to lay and bury export cables
6	Protection	Includes vessel, labor, and equipment costs to protect export cables
6	Terminations	Includes vessel, labor, and equipment costs to pull export cables through J-tubes and connect to transformers
6	Landfall operations	Include vessel, labor, and equipment costs to transition export cable from the subsea trench to the land-based jointing pit
5	Offshore substation(s)	Include costs of installing offshore substations at a project site
6	Substructure	Includes vessel, labor, and equipment costs to install substation substructure(s)
6	Topside	Includes vessel, labor, and equipment costs to install substation topside(s)
5	Offshore accommodations platform(s)	Include costs of installing offshore accommodations platforms at a project site
6	Substructure	Includes vessel, labor, and equipment costs to install offshore accommodations platform substructure(s)
6	Topside	Includes vessel, labor, and equipment costs to install offshore accommodations platform topside(s)
5	Land-based electric infrastructure	Includes costs of installing land-based electric infrastructure
6	Underground cable system	Includes labor and equipment costs to install underground cables on land
6	Overhead transmission lines	Include labor equipment costs to install overhead transmission lines
6	Land-based substation	Includes labor and equipment costs to install land-based substation
3	**Other infrastructure**	**Includes other capital investments made by the project company prior to COD**
4	Offshore accommodations platform(s)	House project personnel during operations
4	Dedicated O&M vessel(s)	Includes new-build vessels owned by the project company that will be used exclusively to support operations at a project site
4	Land-based O&M facilities	Consist of facilities on land, owned by the project company, to support the operation of the project
4	O&M equipment purchases	Include other purchases necessary for the operation of the wind project after COD; examples include safety equipment (e.g., harnesses and floatation devices), equipment to store replacement parts (e.g., climate control for spare electric cables), and vehicles to support operations (e.g., fork trucks)
3	**Substructure and foundation**	**Includes all elements of the offshore wind turbine support structure below the point of connection with the tower**

Level	Term	Definition
4	Substructure	Connects the foundation to the tower
5	Primary structure	Consists of structural steel or concrete (e.g., jacket, tripod, floating platform, and gravity base)
5	Transition piece	Provides the main structural interface between the primary structure and point of connection with the tower
5	Fasteners	Secure connections between the substructure and foundation elements
5	Grout, grout lines, and seals	Secure connections between the substructure and foundation elements
5	Marine coatings	Provide anti-corrosion protection for substructure elements
4	Foundation	Provides the main structural interface that transfers loads into the seabed
5	Bedding stones	Provide a stable and level surface on which to place gravity-based structures or anchors
5	Piles	Consist of steel pipes driven into the seabed to provide support and transfer loads acting on the structure into seabed
5	Anchors	Transfer loads from floating platforms into the seabed (installed below the mudline)
5	Mooring lines	Include chain, wire, or synthetic fiber ropes to connect floating platforms with anchors on the seabed
5	Mooring tendons	Consist of synthetic fiber ropes or welded steel pipers to connect floating tension-leg platforms with anchors on the seabed
5	Connecting hardware (required)	Attach the mooring lines/tendons to anchors and to the platform
5	Messenger lines and buoys	Provide the ancillary equipment used to install the mooring system
4	Outfitting steel	Includes additional nonstructural elements attached to substructure elements
5	Vessel landing	Provides the interface between the maintenance vessels and the substructure to enable safe access for personnel
5	Service platforms and decks	Provide access to the inside of the turbine and a work platform for maintenance activities
5	J-tube	Routes array cable from the trench to the point of connection with the turbine and protects the cable from dynamic loads
5	Ladders	Provide access from the vessel landing to the deck
5	Railings	Enclose the deck to provide a safe working environment for personnel
5	Marine coatings	Provide anti-corrosion protection to any outfitting steel elements
4	Marine systems	Consist of ancillary systems for marine operations
5	On-board crane	Consists of a Davit crane installed on deck to lift small components; used for maintenance
5	Cathodic protection system	Consists of an active (impressed current) or passive (anodes) cathodic protection system

Level	Term	Definition
5	Personnel access system	Consists of equipment installed on the vessel landing, ladders, and deck to facilitate safe access to the turbine
5	Ballast system	Controls draft/stability of floating systems; can be fixed or variable (active or passive)
5	Condition monitoring system	Monitors and controls substructure systems (e.g., variable ballast)
4	Scour protection	Consists of rock fill or concrete mattresses to protect substructures from scouring caused by currents
4	Substructure and foundation IATC	Include activities performed by the manufacturer to integrate, assemble, test, and check out the substructure and foundation before delivering to the customer (does not include commissioning activities)
4	Substructure and foundation transportation	Includes costs of transporting other substructure and foundation components from the manufacturing facility to the staging area
2	**Financial costs**	**Consist of financial expenditures for which the project owner is responsible prior to the COD, related to either payments for financial products, carrying charges on loans, or setting up financial instruments**
3	**Project contingency budget**	Consists of a liquid financial instrument set up to respond to "known unknown" costs that arise during construction; does not include contingencies set by manufacturers and contractors as part of supply contract pricing
3	**Insurance during construction**	Consist of insurance policies held by the owner during the construction period, can include construction all risk, marine cargo, commercial general liability, workers compensation, environmental site liability, pollution liability, and so on; does not include insurance held by contractors
3	**Carrying charges during construction (construction financing costs)**	Include carrying charges of expenditures on equipment and services incurred before COD
3	**Reserve accounts**	**Involve payments (before commissioning) into reserve accounts; generally required by financiers or regulators**
4	Maintenance reserve accounts	Involve payments (before commissioning) into reserve accounts set up to cover major MRAs, often required by debt service providers
4	Debt service reserve accounts	Involve payments (before commissioning) into reserve accounts set up to cover DSRAs, often required by debt service providers
4	Decommissioning reserve account	Involve payments (before commissioning) into reserve accounts to fund project decommissioning obligations (e.g., surety bonds)
1	**Operational expenditures (OpEx)**	**Consist of expenditures required to operate the project and maintain availability, generally annualized**
2	**Operations**	**Include nonequipment costs of operations for the project**
3	**Environmental, health, and safety monitoring**	Consist of coordination and monitoring to ensure compliance with HSE requirements during construction
4	Health and safety monitoring	Consist of coordination and monitoring to ensure compliance with health and safety requirements during operations
4	Environmental monitoring	Consist of coordination and monitoring to ensure compliance with environmental requirement during operations; includes postconstruction survey

Level	Term	Definition
		activities
3	**Annual leases, fees, and other costs of doing business**	Consist of ongoing payments, including but not limited to: payments to a regulatory body for permission to operate at a project site (terms defined within lease); payments to transmissions systems operators or transmission asset owners for rights to transport generated power
4	Submerged land-lease	Involve payments to the state or federal regulatory authorities for rights to operate an offshore wind project on a publicly owned seabed or lakebed
4	Onshore land-lease	Involve payments to land owners for rights to operate transmission lines, a land-based substation, or other facilities
4	Transmission charges/rights	Consist of any payments to transmissions systems operators or transmission asset owners for rights to transport generated power
4	FERC fees	Consist of fees paid to FERC during operations
3	**Insurance**	Consists of insurance policies held by the project company or operations manager during the operational period
3	**Operation, management, and general administration**	Consist of the activities necessary to forecast, dispatch, sell, and manage the production of power from the plant; includes both on-site and off-site personnel, software, and equipment to coordinate high-voltage equipment, switching, port activities, marine activities, and weather forecasting
4	Generation planning and integration	Include efforts to forecast, sell, and dispatch power generated by the facility
4	Operating facilities	Consist of co-located offices, parts store and quayside facility, helicopter facilities, and so on
4	Operating equipment	Include lease payments for operating equipment held by the project to support operations (e.g., cranes and fork trucks)
4	Sales: general and administrative	Includes financial reporting, public relations, procurement, parts and stock management, HSE management, training, subcontracts, and general administration
4	Turbine power consumption	Include charges for power drawn from the grid by the wind project (e.g., turbine, foundation, and substation) during operation
4	Weather forecasting	Provides a daily 96-hour forecast of metocean conditions used to plan maintenance visits and project plant power production
4	Marine management	Involves the coordination of port equipment, vessels, and personnel to carry out maintenance and inspections of generation and transmission equipment
4	Condition monitoring	Involves monitoring of SCADA data from wind turbine components to optimize performance and identify component faults
4	Operating margin	Includes any margin earned by an independent operations management company
4	Professional advisory services	Include legal support, external consultants, accounting, and so on during operation
2	**Maintenance**	**Includes vessel, labor, and equipment costs of operations for the project**

Level	Term	Definition
3	**Long-term service agreement**	Includes the annualized cost of a contract, generally between the owner and turbine OEM or third party, to maintain the offshore wind project at a guaranteed level of availability for a defined period; will likely replace scheduled and unscheduled maintenance categories below for duration of contract
3	**Scheduled maintenance**	Includes planned and routine activities to ensure that turbines, substructures, and all related systems are operating correctly and at optimal efficiency, and to minimize unscheduled breakdowns/ downtime; includes cost of vessels, labor, equipment, spare parts, and consumables (sometimes referred to as preventative maintenance)
4	Wind turbine scheduled maintenance	Includes planned maintenance activities for turbine systems
5	Nacelle module	Involves planned maintenance related to drivetrain modules
5	Rotor module	Involves planned maintenance related to rotor modules
5	Tower module	Involves planned maintenance related to tower modules
4	BOS scheduled maintenance	Involves planned maintenance activities for BOS
5	Regular cable surveys	Involves conducting surveys of array and export cable routes to ensure coverage and determine cable burial depth
5	Foundation inspections	Consist of inspections that cover above- and under-water aspects of the substructure and foundation as well as the integrity of the cathodic protection system maintenance
5	Electrical transforming equipment inspection	Involves inspections of switchgears, transformers, and the back-up power supply
5	DC converter inspection	Includes inspection of DC converter equipment and filtering equipment
5	Land-based electric infrastructure	Includes inspections of switchgear, transformers, and any connections
3	**Unscheduled maintenance**	Includes interventions and other activities needed to respond to random failures; costs include equipment and vessels, labor, replacement parts, and consumables; also known as corrective maintenance
4	Wind turbine unscheduled maintenance	Involves unscheduled maintenance for turbine systems
5	Nacelle module	Involves corrective maintenance related to drivetrain modules
5	Rotor module	Involves corrective maintenance related to rotor modules
5	Tower module	Involves corrective maintenance related to tower modules
4	BOS unscheduled maintenance	Involves unscheduled maintenance for BOS
5	Substructure and foundation	Involves corrective maintenance related to the substructure and foundations
5	Electrical infrastructure	Involves the corrective maintenance related to the electric infrastructure
5	Other infrastructure	Involves the corrective maintenance related to other infrastructure
5	Land-based electric infrastructure	Involves servicing and repairs to the switchgear, transformers, and any connections (infrequent)
4	Unscheduled maintenance contingency	Consists of a liquid financial instrument set up to respond to "known unknown" costs that arise during maintenance