Special Report 305

Structural Integrity of Offshore Wind Turbines

Oversight of Design, Fabrication, and Installation

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TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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Committee on Offshore Wind Energy Turbine Structural and Operating Safety

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competencies and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to the procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

Although many of the world's largest wind farms are located in the United States, these installations are entirely land based. Land-based wind resources are plentiful but are located principally in the central regions of the country, remote from the major population centers where electricity demand is growing but transmission line access and capacity are limited. There are obstacles to installing an enhanced transmission system capable of connecting land-based wind farms to the highly populated areas, particularly with regard to permitting.

Costs related to installation and maintenance are significantly higher for offshore wind farms than for those located on land. However, offshore wind farms offer a number of advantages that could offset these higher costs. Offshore installations can be located close to coastal metropolitan areas, reducing transmission infrastructure requirements. The intensity of offshore wind energy is also greater, allowing the offshore wind turbine to operate at greater efficiencies than a comparable land-based installation.

There are currently offshore wind projects planned along the U.S. East Coast, the Gulf of Mexico, and the Great Lakes. To date, most offshore wind farms have been located in the waters of the European and Scandinavian nations—Germany, Denmark, and the United Kingdom being the most important. These countries have been the leaders in both technological and regulatory development related to offshore wind power generation. The international standards for offshore wind turbine design and certification established by the International Electrotechnical Commission (IEC) are formally recognized in European national regulations. Some of these national regulations also recognize the guidelines and regulations developed by classification societies.

In the United States, where offshore wind energy has been much less of a focus, regulatory development has lagged. As a result, permitting of sites in U.S. waters is proceeding without a clear set of national regulations for the design, fabrication, installation, and commissioning of offshore wind turbines. The Minerals Management Service (MMS), which has been renamed the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE), is responsible for the orderly, safe, and environmentally responsible development of offshore renewables on the outer continental shelf. BOEMRE requested that the Transportation Research Board's (TRB's) Marine Board conduct a study to guide the agency in the regulation and technical oversight of the nascent offshore wind energy industry in the United States.

A study committee consisting of 10 members from academia, national research centers, and industry was appointed by the National Research Council (NRC). Members have expertise in structural engineering, wind energy, regulation, third-party verification in offshore platforms and wind turbines, and oceanography. Biographical sketches of the committee members appear at the end of this report. The report represents the consensus opinion of the committee members and presents the committee's findings and recommendations on the standards and practices that could be used in oversight of U.S. offshore wind installations, the role of third-party reviewers and BOEMRE in overseeing of the design and construction of offshore wind turbines, the necessary qualifications of third-party reviewers, and the selection process for identifying and approving third-party reviewers.

The committee met three times over a 5-month period. These face-to-face meetings were supplemented by numerous conference calls. The committee listened to presentations from a wide range of stakeholders, including state and federal regulators, standards development organizations, wind farm developers, turbine manufacturers, and research scientists and engineers with expertise in the wind energy industry. The committee also reviewed various studies and workshop proceedings sponsored by BOEMRE. These resources proved invaluable as the committee discussed alternative approaches to oversight processes and formulated the ideas that are presented in this report.

ACKNOWLEDGMENTS

The committee acknowledges John Cushing, Lori Medley, and the other staff members of BOEMRE who provided the committee with insight into the responsibilities and workings of BOEMRE and into the various studies on offshore wind energy conducted under the auspices of BOEMRE and its predecessor, MMS. The committee also acknowledges the government and industry representatives, listed below, who took time from their busy schedules to present background information and their own ideas and opinions to the committee at its meetings, and to the others who assisted the committee by providing relevant publications and answering questions by telephone and e-mail.

The following individuals made presentations at the first committee meeting, June 28–29, 2010:

- John Cushing, BOEMRE, U.S. Department of the Interior;
- Malcolm Sharples, President, Offshore Risk and Technology Consulting, Inc.;
- Fara Courtney, Executive Director, U.S. Offshore Wind Energy Collaborative;
- Grover Fugate, Executive Director, Rhode Island Coastal Resources Management Council;
- Elmer “Bud” Danenberger, MMS (retired);
- Kenneth Richardson, Vice President for Energy Projects, American Bureau of Shipping;
- Jan Behrendt Ibsoe, Vice President for Global Renewable Energy, ABS Consulting (committee member);
- William Holley, Technical Advisor for the U.S. National Committee of the IEC, Technical Committee 88, Chief Consulting Engineer, Wind Systems, GE Energy; and
- John Dunlop, Senior Project Engineer, American Wind Energy Association.

The following individuals made presentations at the second committee meeting, August 10–11, 2010:

- Thomas Laurendine, Assistant Vice President, Liberty International Underwriters (formerly with MMS);
- Jeff Shikaze, Program Manager—Renewable Energy, Canadian Standards Association (CSA);
- Richard McNitt, Business Development Manager, CSA International;
- Peter Vickery, Principal Engineer, Applied Research Associates, Inc., IntraRisk Division; and

- Tom McNeilan, General Manager, Fugro Atlantic (on behalf of the Offshore Wind Development Coalition).

The report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

The committee thanks the following individuals for their review of the report: C.P. "Sandy" Butterfield, Boulder Wind Power Inc., Boulder, Colorado; Vice Admiral James C. Card (retired), The Woodlands, Texas; Kent Dangtran, Dangtran OTC, LLC, Cypress, Texas; John Headland, Moffatt & Nichol Engineers, New York, New York; Mary Hallisey Hunt, Strategic Energy Institute, Georgia Institute of Technology, Atlanta, Georgia; Alberto Morandi, American Global Maritime Inc., Houston, Texas; John Niedzwecki, Zachry Department of Civil Engineering, Texas A&M University, College Station, Texas; James Schneider, Department of Civil and Environmental Engineering, University of Wisconsin-Madison, Madison, Wisconsin.

Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the committee's findings or recommendations, nor did they see the final draft of the report before its release. The review was overseen by Lawrence T. Papay, PQR, LLC, and C. Michael Walton, University of Texas at Austin. Appointed by NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Madeline Woodruff, Senior Program Officer in NRC's Division on Engineering and Physical Sciences, served as study director and assisted the committee in the preparation of its report under the supervision of Stephen R. Godwin, Director, Studies and Special Programs, TRB. Suzanne Schneider, Associate Executive Director of TRB, managed the report review process. Norman Solomon edited the report, and Jennifer J. Weeks prepared the manuscript for prepublication web posting, under the supervision of Javy Awan, TRB Director of Publications. Amelia Mathis and Claudia Sauls provided assistance with meeting arrangements and communications with the committee. The committee extends its sincere gratitude to the diligent and capable staff of the National Academies. Without their efforts and support, producing a report with the depth and quality of this study in a relatively short time would not have been possible.

Acronyms and Abbreviations

Acronyms and abbreviations used in the report are listed below. A glossary provides pertinent definitions.

AASHTO	American Association of State Highway and Transportation Officials
ABS	American Bureau of Shipping
ACI	American Concrete Institute
ACP	Alternative Compliance Program
AISC	American Institute of Steel Construction
ALARP	as low as reasonably practicable
ANSI	American National Standards Organization
API	American Petroleum Institute
ASCE	American Society of Civil Engineers
ATC	Applied Technology Council
AWEA	American Wind Energy Association
BOEMRE	Bureau of Ocean Energy Management, Regulation, and Enforcement
BSH	Bundesamt für Seeschifffahrt und Hydrographie (German Federal Maritime and Hydrographic Agency)
BV	Bureau Veritas
CFR	Code of Federal Regulations
CMS	Conditioning Monitoring System
CVA	certified verification agent
DLC	design load case
DNV	Det Norske Veritas
EA	Environmental Assessment
EIS	Environmental Impact Statement
EPACT	Energy Policy Act of 20075
ESP	electric service platform
FERC	Federal Energy Regulatory Commission
GL	Germanischer Lloyd
GOM	Gulf of Mexico
GW	gigawatts
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
ISO	International Organization for Standardization
kV	kilovolts
LRFD	load and resistance factor design
MMS	Minerals Management Service
MRI	mean recurrence interval
MW	megawatts
NBS	National Bureau of Standards
NDT	nondestructive testing
NEPA	National Environmental Policy Act

NRC	National Research Council
NREL	National Renewable Energy Laboratory
NTL	notice to lessees
OCS	outer continental shelf
OEM	original equipment manufacturer
QA	quality assurance
QC	quality control
PBD	performance-based design
PBE	performance-based engineering
PE	professional engineer
PEIS	programmatic environmental impact statement
PTC	production tax credit
SCADA	supervisory control and data acquisition
SFPE	Society of Fire Protection Engineers
TA&R	Technology Assessment and Research program
TC	Technical Committee
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
USDOE	United States Department of Energy
USDOI	United States Department of the Interior
USGS	United States Geological Survey
WSD	working stress design

Glossary

A

Array – a group of wind turbines configured in a grid layout.
Array losses – see "turbine-to-turbine interference."

B

Bearing – a device to allow constrained relative motion between two or more parts, typically rotation or linear movement.

C

Capacity – the rated continuous load-carrying ability of generation, transmission or other electrical equipment, expressed in megawatts (MW). The "size" of a power plant is usually characterized by its net power generation capacity, in MW.
Certification – see Box 1.3
Class (or wind turbine class) – classifications defined by IEC for wind turbines based on three parameters: the average wind speed, extreme 50-year return 10-min averaged gust, and turbulence.
Classification – see Box 1.3
Classification society – industry associations and companies that supply services (such as certification) to the industry, evaluating the design, fabrication or installation with reference to its own rules or guidelines rather than an externally developed standard or guideline.
Code of Federal Regulations (CFR) – rules and regulations defined by the U.S. Federal government having the force of law. Title 30, part 250 (30 CFR 250) covers "Oil and Gas and Sulphur Operations in the Outer Continental Shelf." Part 285 (30 CFR 285) covers "Renewable Energy Alternate Uses of Existing Facilities on the Outer Continental Shelf."
Composite (tower or rotor) – Engineered materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure.
Condition monitoring – A process that involves a system of sensors and monitoring equipment used to remotely monitor specific properties of a mechanical or structural system (e.g., fluid temperatures or material strain) for the purpose of determining its ability to operate normally.

D

Deepwater – a water depth range for offshore facilities; typically beyond 500 feet (152 m) though there is no definitive water depth range.
Design basis – the extreme conditions under which the wind turbine is designed to operate. E.g. 50 or 100 year extreme wind and wave loading events. Also includes potential fault conditions of the turbine.

Developer – the entity in a wind project who designates and arranges for the building of an infrastructure on land or an offshore site in order to productively exploit wind energy. Analysis of the land/sea and wind resource characteristics are crucial in the development process.

Direct drive – a mechanism that takes the power coming from a motor without any reductions (such as a gearbox).

Distribution system – the part of the electrical grid infrastructure that moves electricity between local destinations either on the power generation side or the demand side (transmission systems transfer electricity over longer distances). The wind farm electric power distribution system consists of each turbine's power electronics, the turbine step-up transformer and distribution wires, the electric service platform (ESP), cables to shore, and the shore-based interconnection system.

Downwind turbine – refers to a horizontal axis wind turbine in which the hub and blades point away from the wind direction, the opposite of an upwind turbine.

Drivetrain – the transmission system of the wind turbine that converts the low speed shaft rotational power from the rotor to electrical power via either a gearbox and generator assembly or a direct drive mechanism.

E

Electric service platform – An offshore platform serving as a collection and service point for a wind farm, also called a transformer platform.

Environmental Impact Statement (EIS) – A document required by the National Environmental Policy Act (NEPA) for certain actions "significantly affecting the quality of the human environment." It is a tool for decision making, describing the positive and negative environmental effects of a proposed action and listing one or more alternative actions that may be chosen instead of the action described in the EIS.

Exploratory leases – acting under the authority granted to MMS through the Energy Policy Act of 2005, the agency initiated the Interim Policy which allows for exploratory leases in November 2007 in advance of the final regulatory framework in order to jumpstart the review and potential authorization of the renewable energy development process. The limited leases authorize a term of five years for activities on the OCS associated with renewable energy resource data collection and technology testing.

F

Federal waters – refers to U.S. territorial waters regulated by the US Federal government, as opposed to areas regulated by State authorities. Typically this is the region beyond 3 nautical miles from shore, with the exception of parts of the gulf coast.

G

Gear-driven – using a mechanical system of gears or belts and pulleys to increase or decrease shaft speed.

Goal-based standards (also known as performance-based standards) – a hierarchical standard in which the starting point is a set of high-level performance objectives, supported by a series of minimum performance criteria that are necessary to support this objective and finally a choice of methods by which satisfaction of these criteria can be demonstrated. These methods may be prescriptive in nature; rational alternative means and methods are permitted, provided that their acceptability can be verified by either analysis or tests.

Guidelines – see Box 3.1.

Gravity base (or gravity based) foundation – A type of foundation type that relies on mass and a larger base dimension to provide stability and resist overturning.

H

Helical stage – a cylindrical gear wheel which has slanted teeth that follow the pitch surface in a helical manner.

Horizontal axis turbine – a "normal" wind turbine design, in which the shaft is parallel to the ground, and the blades are perpendicular to the ground

Hydrokinetic – referring to devices which extract energy from moving water, such as rivers, ocean currents as well as waves.

I

Interconnection system – the electrical system of cabling, typically operating at medium voltage, which connects the turbines to one another as well as to the facility substation.

J

Jacket – a type of offshore structure consisting of a vertical framing system with multiple legs and a piled foundation.

Jackup rig – a floating barge fitted with supporting legs that can be lowered to the seabed.

L

Limit states design – A method of proportioning structural members, components and systems such that the design strength, defined as the product of a nominal strength and a resistance factor, equals or exceeds the required strength under the action of factored load combinations (also denoted Load and Resistance Factor Design, or LRFD, in the United States).

Load and Resistance Factor Design (LRFD) – See Limit states design.

M

Marine spatial planning – a tool that brings together multiple users of the ocean, including energy, industry, government, conservation and recreation, to make informed and coordinated decisions about how to use marine resources sustainably.

Memorandum of understanding (MOU) – a document that defines an agreement between two governmental agencies regarding how they will interact in an area of shared oversight. E.g. there is an MOU between the former MMS and the Federal Energy Regulatory Commission (FERC) which clarifies the roles each organization has in the oversight of energy projects in the OCS.

Monopole – a turbine foundation structure composed of a large steel tube driven into the seabed.
Multi-pile – see Jacket.

N

Nacelle – the portion of a wind turbine that sits atop the tower protecting the mechanical and electrical components (i.e. the drivetrain, controller, and brake) from the elements.

O

Outer Continental Shelf (OCS) – refers to all submerged lands, its subsoil, and seabed that belong to the United States and are lying seaward and outside of the states' jurisdiction, the latter defined as the "lands beneath navigable waters" in Title 43, Chapter 29, Subchapter I, Section 1301 of the U.S. code, The United States OCS has been divided into four leasing regions: Gulf of Mexico, Atlantic, Pacific, and Alaska.

P

Performance-based design – a design approach that identifies an appropriate structural system and design parameters based on the desired levels of performance (or performance targets) of the facility of which the structure is part; often used in seismic and blast-resistant design.
Pitch – the angle between the edge of the blade and the plane of the blade's rotation. Blades are turned, or pitched, out of the wind to control the rotor speed.
Planetary stage – an outer gear that revolves about a central sun gear of an epicyclic train.
Power electronics – the application of solid-state electronics for the control and conversion of electric power.
Prescriptive – a regulatory environment in which particular activities and schedules and parameters are prescribed *a priori* rather than derived from performance targets.
Prevailing wind – the predominant direction from which the wind blows.
Production tax credit (PTC) – a federal incentive program that is designed to help level the playing field of energy production where other forms of energy are subsidized. At the time of press, the PTC is currently offered to wind projects in-service by December 31, 2012 over the first ten years of operation, at a value of 2.2 cents/kWh (which increases with inflation).
Project certification – a process to verify that the wind turbine and its support structures meet the site-specific conditions. Use of a type certified wind turbine is a pre-requisite.

R

Recommended practices – a type of standard or guideline developed by a standards-development body.
Regulations – see Box 3.1.
Return period – the average interval of time between recurrences of an event such as an earthquake or storm of a certain size or intensity, used in risk analysis. A storm of a given intensity that has a return period of 10 years would have a 1-in-10 probability of being exceeded (in intensity) in any given year.

Risk-informed basis – an integrated decision paradigm in which traditional deterministic engineering evaluations are supported by insights derived from probabilistic risk assessment (PRA) methods that take into account uncertainties due to randomness, modeling and completeness. Decisions may be based on both qualitative and quantitative factors and consider traditional engineering information and the risk significance of the decision.

Rotor – s complete system of blades that supplies all the force driving a wind generator. The rotor has three blades manufactured from fiberglass reinforced epoxy, mounted on a hub. The blades are pitch-regulated to continually control their angle to the wind and are designed to optimize energy production and to generate minimal noise.

S

SCADA, Supervisory Control And Data Acquisition – the wind farm monitoring system which allows the owner and/or the turbine manufacturer to be notified of faults or alarms, remotely control turbines, and review operational data.

Scour – the effect of ocean waves and currents displacing seabed material around the base of fixed structures

Shallow water – a water depth range for offshore facilities; typically less than 200 feet (61 m), although there is no definitive water depth range.

Siting – the process of determining a suitable location for a wind project development.

Standards – see Box 3.1.

State waters – U.S. territorial waters regulated by state authority's government, as opposed to areas regulated by the Federal government, typically within 3 nautical miles of shore.

Stationkeeping (nautical) – maintaining a fixed position in the water relative to other vessels or to a stationary object or given location.

Step-up transformer – equipment designed to increase the voltage of an electric power system.

Substation – a part of an electric system where transformers are used to step up or step down the voltage in utility power lines for transition between long-distance transmission and local production or distribution lines.

Switchgear – a device within an electric system used to control the flow of electricity from one part of the system to another.

T

Transition piece – the connector between the foundation and the tower, e.g. fitted around the section of the monopole that protrudes above the waterline.

Transformer – an electrical device used to transfer power from one circuit to another using magnetic induction, usually to step voltage up or down.

Tripod – an offshore jacket structure with three legs.

Turbine spacing – the distance between wind turbines within an array.

Turbine-to-turbine interference – the aerodynamic losses experienced in a wind turbine array as the upstream turbines impact the energy capture of the turbines downstream within the array.

Type certification – obtained by the wind turbine manufacturer (from an independent body) to demonstrate that a wind turbine generator system or installation (facility) meets specified standards for key elements such as identification and labeling, design, power performance, noise emissions, and structural integrity.

U

Upwind turbine – a horizontal axis wind turbine in which the hub and blades are in front of the tower in the direction of the incoming wind, the opposite of a downwind turbine. Yaw control is required to maintain the upwind orientation.

V

Verification – see Box 1.3

W

Wind farm – a set of wind turbines or one or more turbines, when considered together with the rest of the equipment involved in transferring electricity from the turbines to shore.
Wind resource – average wind speed and direction at a range of heights on a site, required to determine viability of a wind turbine.
Wind shear – changes in wind velocity with elevation.
Wind turbine generator – a rotating machine which produces electricity from the wind.
Working stress design – a method of design in which structures or members are proportioned for prescribed working loads at stresses which are well below their ultimate values. The allowable stresses are determined by applying safety factors to the ultimate values.

Y

Yaw – to rotate around a vertical axis, such a turbine tower. The yaw drive is used to keep a upwind turbine rotor facing into the wind as the wind direction changes.

Contents

Executive Summary

The U.S. Department of the Interior's Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) is responsible for the orderly, safe, and environmentally responsible development of offshore renewable energy on the outer continental shelf (OCS). The committee that authored this report was tasked with reviewing BOEMRE's proposed approach to overseeing the design of offshore wind turbines for structural integrity. The committee was asked to review the applicability and adequacy of standards and practices that could be used for the design, fabrication and installation of offshore wind turbines. It was also asked to review the role of third-party certified verification agents (CVAs) and the expertise and qualifications needed to carry out the role of a CVA.

Because of earlier development of offshore wind energy in Europe, European countries have taken the lead in matters related to the regulation, installation, and operation of offshore wind farms. Their national regulations recognize and incorporate International Electrotechnical Commission (IEC) standards for the design of offshore wind turbines. Because the IEC standards, on their own, do not cover all aspects of the design and construction of offshore wind turbines, they have generally been supplemented by national regulatory requirements, other standards and guidelines, and recommended practices developed by industry. The committee found that even such packages of regulations, standards, and guidelines have clear deficiencies, particularly if applied to planned installations along the U.S. East Coast and Gulf of Mexico.

Safety and environmental performance are the basis for most U.S. regulations governing the offshore oil and gas, maritime, and civil infrastructure industries. The committee found that the risks to human life and the environment associated with offshore wind farms are substantially lower than for these other industries, because offshore wind farms are primarily unmanned and contain minimal quantities of hazardous substances. This finding implies that, in remedying deficiencies in standards and practices, an approach with significantly less regulatory oversight may be taken for offshore wind farms than for the other industries mentioned above. On the other hand, the U.S. government, having expressed a policy commitment to the development of alternative energy sources including offshore wind, has a vested interest in the success and performance of offshore wind turbines. On this basis, the committee recommends that the BOEMRE regulations go beyond safety and environmental risks and also consider policy consequences. Because further improvements in cost, reliability, and efficiency are needed if offshore wind is to be a competitive energy source, regulations need to allow for innovative technologies and encourage the introduction of novel concepts.

To facilitate the orderly development of offshore wind energy and support the stable economic development of this nascent industry, the United States needs a set of clear requirements that can accommodate future design development. There is a sense of urgency, because planning and design efforts for a number of offshore wind farms to be located in state waters and on the OCS are already under way. The committee recommends that BOEMRE immediately develop a set of requirements that establish goals and objectives with regard to structural integrity, environmental performance, and energy generation.

Under this approach, industry would be responsible for proposing sets of standards and recommended practices that meet the performance requirements established by BOEMRE. It is anticipated that classification societies and standards development groups will be interested in offering packages of standards and guidelines that meet the BOEMRE performance requirements. BOEMRE should be prepared to review the packages, identify their deficiencies, and approve them. The preapproved standards and guidelines will expedite the regulatory review process and provide industry with a well-defined approach for proceeding with the development of offshore wind turbines on the OCS. A developer should also be permitted to submit a package of standards and guidelines on a project-specific basis, with the understanding that a CVA first review and agree to the proposed approach.

Detailed findings and recommendations on CVAs can be found in Chapters 5 through 7. The committee was asked to review the role of CVAs (Chapter 5). The committee notes that such third-party review should be an integral part of the regulatory process. The review should include assessment of the blades, turbine control systems, towers and foundations, infield cables and export cables, and ancillary structures such as the electric service platforms. Oversight responsibility should include design, fabrication and manufacturing, transportation, and installation. Consistent with current international practice, type and project certification may be integral to the wind turbine project and used in a third-party design review.

The third-party review team should verify that the design and installation meet the BOEMRE goal-based requirements as well as the standards and guidelines applicable to that particular project. In periodic reports to BOEMRE, the third-party reviewers should describe the extent of their review, indicate the level of compliance, and clearly identify any discrepancies or concerns. Responsibility for final approval should rest with BOEMRE.

The committee was also asked to assess the expertise and qualifications needed by potential CVAs (Chapter 6). In evaluating the qualifications of potential CVAs, BOEMRE should seek organizations and individuals that are independent and objective, have the necessary expertise, have a management structure with well-defined roles and responsibilities with oversight by a registered professional engineer, and have an auditable quality plan and record-keeping processes. The committee recommends that BOEMRE approve CVAs on a project-specific basis as opposed to having a list of preapproved CVAs. BOEMRE should actively manage the CVA process for offshore wind facilities by disseminating lessons learned from the CVA process to promote best practices to the industry.

The success of offshore wind energy in U.S. waters may depend in part on how quickly and effectively BOEMRE develops the regulations and oversees compliance. It is critical that BOEMRE establish within the agency a substantial core competency with the capacity and expertise to lead the development of the performance-based standards, review the rules and guidelines submitted by third-party rulemaking bodies and developers, and review the competency of proposed CVAs. BOEMRE should be fully engaged in the national and international processes for developing standards for offshore wind turbines, particularly in standards and guidelines issued by the IEC technical committees and other relevant national and international committees. BOEMRE should also consider creating an expert panel to provide feedback and guidance for the initial offshore wind development projects as a means to fill the experience gap for both industry and regulators.

Introduction

The United States is poised to begin building its first offshore wind energy power plants. Several projects have been proposed or are under development, primarily along the Eastern Seaboard and the Great Lakes. In April 2010, the Cape Wind project, to be located off the Massachusetts coast, became the first to be approved by federal and state authorities.

Central to the project approval process is the Department of the Interior's Minerals Management Service (MMS), recently renamed the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE). The Energy Policy Act of 2005[1] assigned it responsibility for the orderly, safe, and environmentally responsible[2] development of renewable energy resources in U.S. federal waters, also known as the outer continental shelf (OCS) [3,4] (see Box 1-1). BOEMRE has exclusive jurisdiction over nonhydrokinetic projects on the OCS.

On April 29, 2009, BOEMRE published a final rule, codified at 30 CFR 285,[5] governing renewable energy project activities on the OCS. Figure 1-1 lays out the regulatory process stipulated by the rule.

The regulations require submission of several documents for BOEMRE approval of a proposed facility. Chief among them are three reports covering facility design, fabrication, and installation. The BOEMRE regulations set out in great detail what must be included in these reports—for example, structural drawings, a summary of the environmental data used in the design, a complete set of design calculations, a geotechnical report, the industry standards proposed for use in fabrication, and details on the offshore equipment to be used for installation.[6] However, the regulations do not specify standards or detailed requirements that the facility must meet for BOEMRE to approve the reports.

Instead, the regulations require that a third party, a "certified verification agent" (CVA),[7] conduct an independent assessment of the facility design on the basis of "good engineering judgment and practices" and certify to BOEMRE that the facility is designed to withstand the environmental and functional load conditions appropriate for the intended service life at the proposed location. According to the regulations, the CVA must also certify to BOEMRE that project components are fabricated and installed in accordance with "accepted engineering practices" and with the approved reports and operating plans.

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[1] P.L. 109-58, Section 288.
[2] 74 FR 81, p. 19638.
[3] On June 8, 2010, MMS was renamed the Bureau of Ocean Energy Management, Regulation, and Enforcement. For convenience, this report uses the latter name in referring to this organization, despite the fact that some of the actions discussed took place before the name change.
[4] The term "outer continental shelf" refers to those submerged lands, subsoil, and seabed that belong to the United States and lie seaward of state water boundaries (http://www.boemre.gov/AboutBOEMRE/ocsdef.htm, accessed Dec. 19, 2010).
[5] The text of this rule is given in Appendix B of this report.
[6] The list is not complete. See 30 CFR 285 (Appendix B of this report) for details.
[7] In some circumstances, BOEMRE may waive the requirement to use a CVA.

Standards and guidelines for the design, fabrication, installation, and operation of offshore wind turbines[8] have been developed by international bodies as well as by individual companies and countries, predominantly in Europe (see Chapter 3). However, none of these standards or guidelines has been accepted by U.S. agencies, nor has the United States developed its own. Standards and guidelines exist for other offshore activities in U.S. waters, such as oil and gas development and waterborne shipping. Other relevant standards cover items such as the environment and workplace health and safety. But BOEMRE has not specified any criteria that offshore wind turbine projects must meet to win approval.

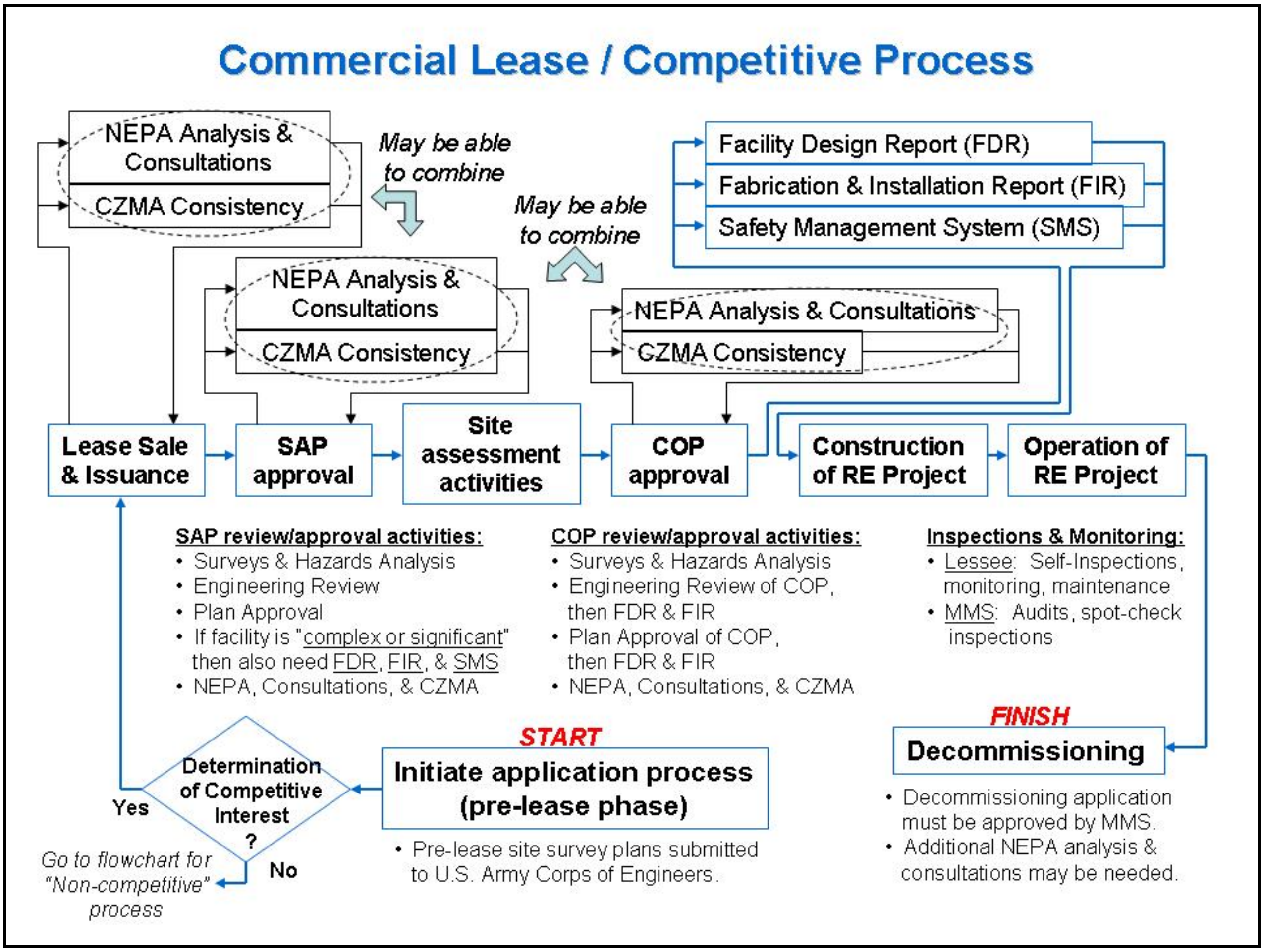

FIGURE 1-1 Approval process for offshore wind turbines set forth in 30 CFR 285. (There is also a noncompetitive path.)
(SOURCE: Presentation to the committee by John Cushing, BOEMRE.)

[8] In this report, "wind energy turbine generators" are often referred to simply as "wind turbines." A set of wind turbines is often referred to as a "wind farm." One or more turbines, when considered together with the rest of the equipment involved in transferring electricity from the turbines to shore, can also be referred to as a "wind farm" or, alternatively, a "wind energy power plant."

Box 1-1

Regulatory Timeline for Renewable Energy Development on the U.S. OCS

2005 The Energy Policy Act of 2005, Section 388, authorizes MMS to do the following, among other things:

- Act as the lead agency for federal offshore renewable energy and alternative uses of offshore public lands (also known as the OCS);
- Ensure consultation with states and other stakeholders;
  Grant easement, leases, or rights-of-way for renewable energy–related uses of the federal OCS; and
- Pursue appropriate enforcement actions in the event that violations occur.

2007 In November, MMS issued the final programmatic environmental impact statement (PEIS) in support of the establishment of a program for authorizing renewable and alternative use activities on the OCS. The final PEIS examined the potential environmental effects of the program on the OCS and identified policies and best management practices that could be adopted for the program.

In December, the Record of Decision was released, affirming that MMS would proceed with establishment of the Renewable Energy Program for the OCS on the basis of the analysis presented in the PEIS.

2007 In November, MMS announced an interim policy for authorizing the installation of offshore data collection and technology testing facilities on the OCS. The policy was designed to jump-start baseline data collection efforts in advance of final regulations.

(On June 23, 2009, five exploratory leases were granted for renewable wind energy resource assessment on the OCS offshore Delaware and New Jersey.)

2009 On April 9, MMS signed a memorandum of understanding with the Federal Energy Regulatory Commission (FERC). The memorandum clarified that MMS has exclusive jurisdiction with regard to the production, transportation, or transmission of energy from nonhydrokinetic renewable energy sources, including wind and solar. FERC has exclusive jurisdiction to issue licenses for the construction and operation of hydrokinetic projects, including wave and current, but companies will be required first to obtain a lease through MMS.

(*continued*)

Box 1-1 (*continued*)

2009 On April 29, MMS published a final rule (30 CFR Part 285, 74 FR 81, pp. 19638–19871) establishing a regulatory framework for leasing and managing renewable energy project activities on the U.S. OCS. The regulations are intended to encourage orderly, safe, and environmentally responsible development of renewable energy sources on the OCS.

Subpart G covers the technical reports that must be submitted on the final design, fabrication, and installation of facilities. It also lays out a third-party verification process that requires use of a "certified verification agent" (CVA) to verify and certify that projects are designed, fabricated, and installed in conformance with accepted engineering practices and with the submitted reports.

The regulations specify that part of the CVA's responsibility in the design phase is to conduct an independent assessment to ensure that the facility is designed to withstand the environmental and functional load conditions appropriate for the intended service life at the proposed location.

The regulations also specify that part of the CVA's responsibility in the fabrication and installation phases is to use good engineering judgment and practices in conducting an independent assessment of fabrication and installation activities. The CVA is also to ensure that these activities are conducted according to the approved applications.

2009 On August 3, MMS published its "Guidelines for the Minerals Management Service Renewable Energy Framework, July 2009." The guidelines are divided into six chapters, covering qualification requirements; definitions; and lease and grant conveyance, administration, and payments.

The guidelines state that five additional chapters will be "posted at a later date." One of them, Chapter 9, will "explain the requirements for facility design, fabrication, and installation." Chapter 10 will cover requirements for environmental and safety management, inspection, and facility assessment. Chapter 11 will discuss decommissioning requirements.

2010 MMS decided that, rather than publishing the five chapters above as part of the "Guidelines for the Minerals Management Service Renewable Energy Framework," it would develop separate guidelines for each topic and issue them as "Notices to Lessees" (personal communication, J. Cushing, BOEMRE, Oct. 1, 2010).

Source: MMS n.d.

STUDY CHARGE AND SCOPE

In the absence of such standards and guidelines for the United States, BOEMRE asked the National Research Council (NRC) to review its approach to overseeing the development and safe operation of wind turbines on the OCS, with a focus on structural safety. The charge to the study committee is given in Box 1-2.

The committee's scope was limited to structural safety, in accordance with discussions with the sponsor at the first committee meeting.[9] Hence, although the term "Structural and Operating Safety" appears in the committee's title, the committee limited its treatment of operational safety to those aspects that could be affected by structural design, fabrication, and installation. It included within its scope the design, fabrication, and installation of subsea cables. As illustrated in Figure 1-2, the committee characterized its scope as "from design to commissioning."

Box 1-2

NRC Committee on Offshore Wind Energy Turbine Structural and Operating Safety

Statement of Task

The study will provide guidance to the Minerals Management Service (MMS) on the direction and intent of its proposed approach to overseeing the development and safe operation of offshore wind turbines.
The study will provide findings regarding:

Task I. *Standards and Practices*: The applicability and adequacy of existing standards and practices for the design, fabrication, and installation of offshore wind turbines.

Task II. *Role of Certified Verification Agents (CVAs)*: The expected role of the CVA in identifying standards to be used (including determining the compatibility—the acceptability of mixing and matching—of standards from different sources), and the expected role of the CVA in conducting monitoring and onsite inspections to verify compliance with the standards.

Task III. *CVA Qualifications*: The expected experience level, technical skills and capabilities, and support equipment and computer hardware/software needed to be considered a qualified CVA.

The focus of the study will be limited to the safety of structural and operational characteristics of offshore wind turbines, including turbine design, fabrication, and installation.

[9] "Background Information and Study Goals," presentation to the committee by John Cushing, BOEMRE, July 28, 2010.

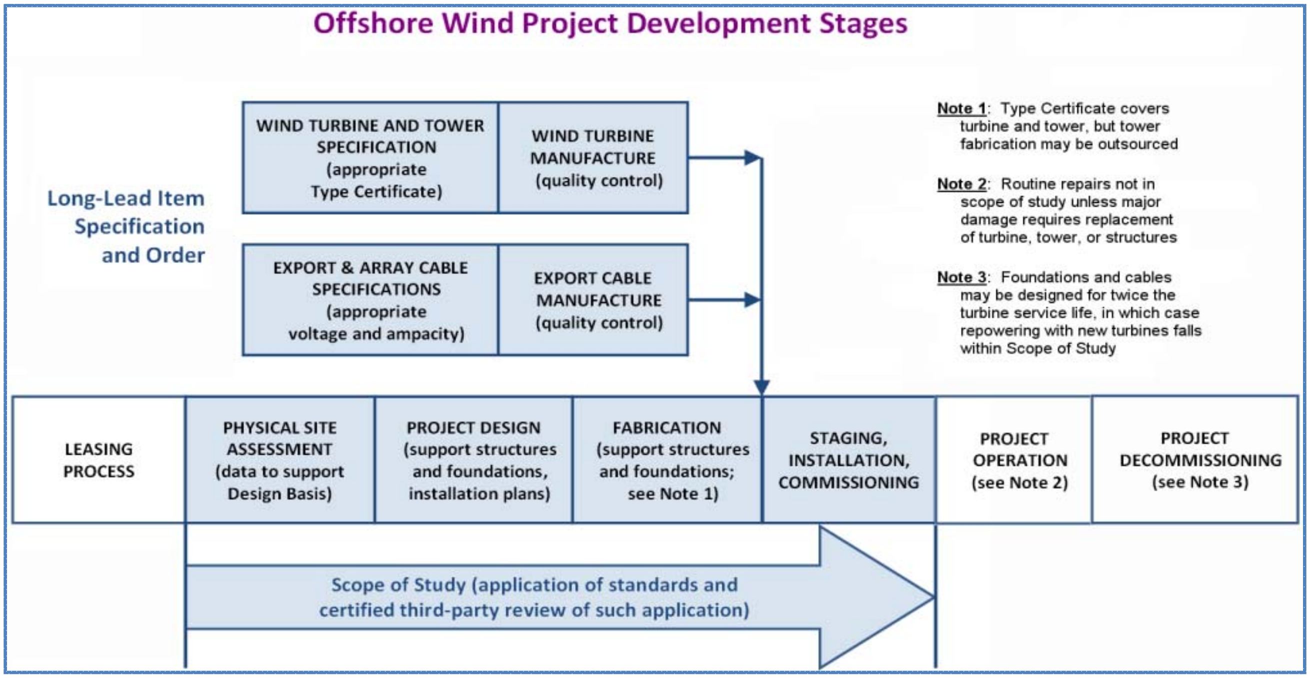

FIGURE 1-2 Scope of this study.
SOURCE: Generated by the committee.

One caveat is that structural integrity cannot be considered in isolation. In complex engineering systems such as wind turbines, there are nonstructural components and systems whose failure and malfunctioning can trigger or result in structural overload or failure. Chapter 3 notes how these interactions are accounted for.

As shown in Figure 1-1, the environmental hazards associated with the establishment and operation of offshore wind energy facilities are covered through the National Environmental Policy Act (NEPA) process. These hazards include effects on birds, other wildlife, and the seabed. BOEMRE will prepare environmental assessments (EAs) or environmental impact statements (EISs), as required by NEPA, for offshore wind project proposals.

This report does not review the environmental hazards that are assessed in EAs or EISs. As noted earlier, the committee's charge is limited to consideration of hazards resulting from structural failures.

COMMITTEE APPROACH

The committee's first task was to assess the applicability and adequacy of existing standards and practices for the design, fabrication, and installation of offshore wind turbines.

In response to this charge, the committee reviewed standards and guidance documents (the latter encompassing rules, guidelines, recommended practices, and other similar documents) that have been developed by classification societies (nongovernmental organizations and private companies), industry associations, and European governments. It identified some of the deficiencies in these standards and documents that would have to be remedied if they were to be applied in the United States.

As discussed in Chapter 3, the committee found that many existing standards and guidance documents could appropriately be applied in the United States but that no one set was complete. All have deficiencies in their coverage (for example, storms and hurricanes on the Atlantic coast and in the Gulf of Mexico) or their analysis methods that would have to be remedied before they could be used in the United States.

To respond fully to its charge, however, the committee believed that it had to do more than review existing standards and guidance and indicate their deficiencies. Other reports have identified at least some of the deficiencies, and the committee has drawn on these reports for its assessment. The committee's view was that, to provide BOEMRE with useful feedback, the committee should offer its perspectives on how BOEMRE might remedy those deficiencies. It believed that it should step back and examine not only the mechanics of remedying the deficiencies but also the underlying philosophies that could guide the development of additional standards or guidance documents for offshore wind turbines in the United States.

In applying this broader perspective, the committee reviewed the approaches to oversight of offshore wind turbines taken by European countries. It noted that current standards and guidance in Europe range from very detailed and prescriptive to high-level and less prescriptive. The committee also reviewed how the safety of engineered structures is overseen in other U.S. industries—oil and gas production, waterborne shipping, and buildings. It noted that regulation in these industries has been moving away from a detailed, prescriptive model and toward a more performance-based model.

As discussed in Chapter 4, the committee's consensus is that performance-based oversight is the most effective approach to remedying deficiencies in standards and practices for offshore wind installations. This approach will help to fulfill two government objectives:

- The safe, orderly, and environmentally responsible development of renewable energy on the OCS, which is the charge of BOEMRE; and
- The broad exploitation of the offshore wind resource, which is an objective of the U.S. Department of Energy and is in line with the administration's stated priorities.

Structural failures in offshore wind farms pose lower risk to human health and the environment than do structural failures in oil and gas platforms. In the committee's view, however, successful exploitation of offshore wind energy will require not only that turbines operate with low risk to human health and the environment but also that they prove highly reliable (to avoid negative perceptions of the industry) and become economically competitive with other sources of electricity. The committee sees performance-based oversight as the regulatory model most compatible with fostering innovation, which it views as key in developing a viable U.S. industry and bringing down the cost of electricity generated from offshore wind.

During its work, the committee was cognizant of the rapid pace at which offshore wind projects were being proposed for specific sites and of the work in several states to develop regulatory structures for projects in state waters. It recognized the need for the federal government to specify, fairly soon, how it will evaluate the acceptability of proposed projects for the OCS, so that project developers will have sufficient information to move their projects forward and to attract the necessary financing. The committee also noted that, although

BOEMRE is concerned with projects outside of state waters, federal guidance would also be of help to states as they develop their criteria for approving projects in state waters.

In recognition of BOEMRE's need to act quickly in specifying the requirements that proposed projects on the OCS must meet, the committee has set out interim measures that could be implemented soon as well as options for longer-term approaches to oversight.

In carrying out its charge, the committee met three times. At its first two meetings, it received briefings on the development of standards for offshore wind energy in Europe and on current industry efforts to develop consensus standards for the United States. Representatives from nongovernmental organizations, industry associations, and one state provided perspectives from stakeholders on the development of offshore wind energy. The committee was also able to take advantage of an NRC workshop on offshore wind energy that was held on March 25–26, 2010.

ORGANIZATION OF THE REPORT

Box 1-3 provides definitions for some key concepts that are used extensively in Chapters 3 and 4. Chapter 2 provides a brief overview of the motivation for the United States in developing offshore wind energy. It then reviews offshore wind energy production worldwide and describes the technologies involved in current offshore turbine generators.

The next two chapters address the first element of the committee's charge (Task I). Chapter 3 reviews existing standards, the differences among them, and the work under way to identify deficiencies and develop new standards. Chapter 4 sets out the regulatory philosophies underlying various oversight regimes and how they might be incorporated into standards and guidance for application in the United States. Chapter 5 targets the second part of the committee's charge (Task II) by reviewing the role of third-party oversight and CVAs. Chapter 6 assesses the qualifications needed by CVAs (Task III).

The final chapter summarizes the committee's key findings and recommendations for structural and operating safety of offshore wind energy turbine generators.

Box 1-3

Key Concepts: Verification, Certification, and Classification

Verification: Verification is the process of determining whether a design, procedure, measurement, or other activity follows a specified standard, guideline, design basis, or other definition as specified for a project. Verification can apply to design, fabrication, or installation. For instance, if the intent is that a project's turbines be designed according to the International Electrotechnical Commission 61400-3 standard, a verifier would assess whether the requirements of that standard were followed and were correctly applied, good practice was followed, and no significant deficiencies were evident. A verifier may perform independent calculations or tests.

Certification: Certification of a design, fabrication, or installation implies a higher level of responsibility on the part of the reviewer than does verification. To certify a design, for instance, independent design calculations or testing would likely be performed by the certifier as a check, rather than the certifier simply assessing whether the design was in accordance with the specified standard and design basis and whether the resulting design is accurate.

The term "certification" was likely derived from the statutory requirement in the United Kingdom that an offshore oil and gas facility receive a "certificate of fitness" from an appointed certifying authority on the basis of an independent assessment of the design, method of construction, and operations manual and associated surveys carried out by surveyors appointed by the certifying authority.

Classification: Nongovernmental organizations and private companies that establish and maintain technical rules and guidelines for the design, construction, and operation of ships and offshore structures are commonly known as "classification societies." As used in relation to a classification society, classification is a variation on the concept of certification. The difference is that the classification society is evaluating the design, fabrication, or installation with reference to its own rules or guidelines rather than an externally developed standard or guideline.

REFERENCE

Abbreviation

MMS Minerals Management Service

MMS. n.d. The Role of MMS in Renewable Energy. Fact sheet. http://www.mms.gov/offshore/renewableenergy.

2

Offshore Wind Technology and Status

Chapter 2 provides a brief overview of the motivation for the United States in developing offshore wind energy. Offshore wind energy production worldwide is reviewed, and the technologies involved in current offshore turbine generators are described.

WIND TECHNOLOGY

Land-Based Wind Energy Technology

Wind turbines convert the kinetic energy of moving air into electricity. Modern wind turbines emerged out of the U.S. government's initial push for renewable energy development in response to the oil crises of the 1970s and the corresponding sharp rises in energy prices. According to the American Wind Energy Association, at the end of 2009 more than 35,000 MW of wind energy was installed in the United States, enough to power 9.7 million homes (AWEA 2010). By the end of 2010, installed capacity had grown to more than 40,000 MW. This capacity is entirely land based, and the vast majority of it provides power at a utility scale of generation by aggregating multiple wind turbines into arrays (wind farms) to form wind power plants that can reach sizes of up to 500 MW per project.

When the commercial wind industry began, wind turbines averaged around 50 kW, corresponding to rotor diameters of about 15.2 m (50 ft). Today, land-based wind turbine sizes have reached 5,000 kW (5 MW), corresponding to rotor diameters of more than 126 m (413 ft), or nearly twice the wingspan of a Boeing 747 aircraft. This progression of scale over time is shown in Figure 2-1.

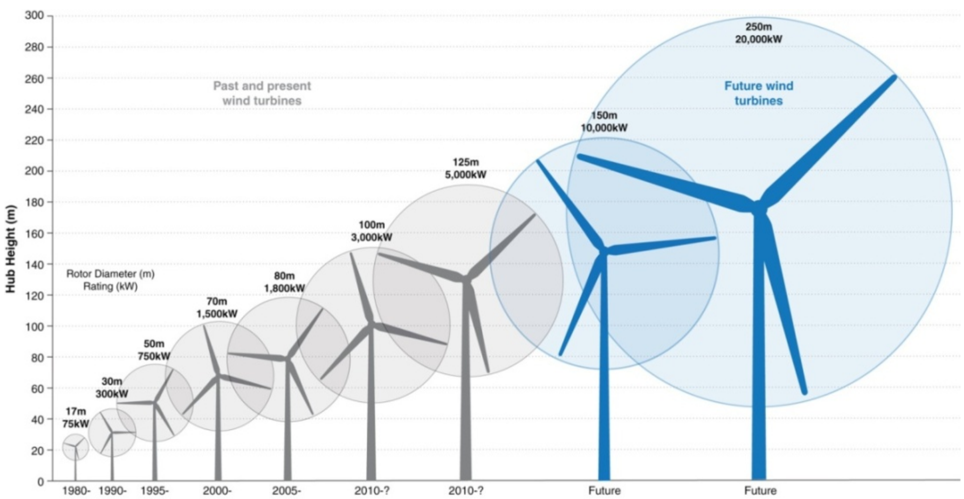

FIGURE 2-1 Wind turbine growth over time: modern wind turbine rotors exceed 400 ft in diameter, or almost twice the wingspan of a Boeing 747.

Why Go Offshore?

Renewable sources for electricity generation, such as wind and solar energy, can be exploited only where these resources are available in sufficient quantities—windy areas for wind, and so on. As demand increases for electricity generated from wind energy, additional sites with sufficient wind resources must be identified.

In the United States, land-based wind resources are abundant but are concentrated in the center of the country. Adding wind-energy capacity in these locations to service distant markets with lower wind resources is feasible but may be limited by insufficient electricity transmission access and capacity and by the cost of adding to this capacity. Moreover, the densely populated coastal energy markets do not have good sites for onshore wind, and given the lack of available land, siting new facilities in such areas can be difficult.

Offshore wind does not suffer from these drawbacks and has the advantage that offshore winds are stronger and steadier than those on land, allowing higher power output. Of the contiguous 48 states, 28 have a coastal boundary, so that transmission requirements from offshore wind to load centers in these areas can be minimized (Musial and Ram 2010). U.S. electricity use data show that these same states use 78 percent of the nation's electricity (USDOE 2008). Coastal regions pay more for electricity relative to the rest of the country, making electricity from offshore wind more economically competitive with other sources of electricity generation in these regions (Musial and Ram 2010, Section 2, 10–22).

Offshore Wind Technology

Figure 2-2 shows a schematic of a typical offshore wind turbine, and Figure 2-3 shows a photograph of a single 3.6-MW offshore wind turbine installation on a monopile foundation. Most offshore wind turbines are robust versions of proven land-based turbine designs. They are placed on freestanding steel monopiles or concrete gravity-based substructures. Although their architecture mimics that of conventional land-based turbines, offshore wind turbines incorporate significant enhancements to account for ocean conditions. The modifications include strengthening of the tower to handle the added loading from waves, pressurization of the nacelles, addition of environmental controls to keep corrosive sea spray away from critical drivetrain and electrical components, upgrades to electrical systems, and addition of personnel access platforms to facilitate maintenance and provide emergency shelter. Most exterior components of offshore turbines require corrosion protection systems and high-grade marine coatings. Most of the turbine's blades, nacelle covers, and towers are painted light gray to minimize visual impacts.

Lightning protection is mandatory for both land-based and offshore turbines. Turbine arrays may be equipped with aircraft warning lights, bright markers on tower bases, and fog signals for reasons of navigational safety. To reduce operational costs and yield better maintenance diagnostic information, offshore turbines are often equipped with condition monitoring systems (CMSs). The CMS measures vibration at various points throughout the drivetrain (including the main shaft bearings, gearbox, and generator). The CMS also monitors operational parameters such as above-nacelle wind speed and direction, generator electrical output, generator winding temperature, main shaft rotational speed, bearing temperatures, and fluid temperatures and pressures of gearbox lubricating oil and hydraulic control systems. Offshore turbines are also usually equipped with automatic bearing lubrication systems, onboard

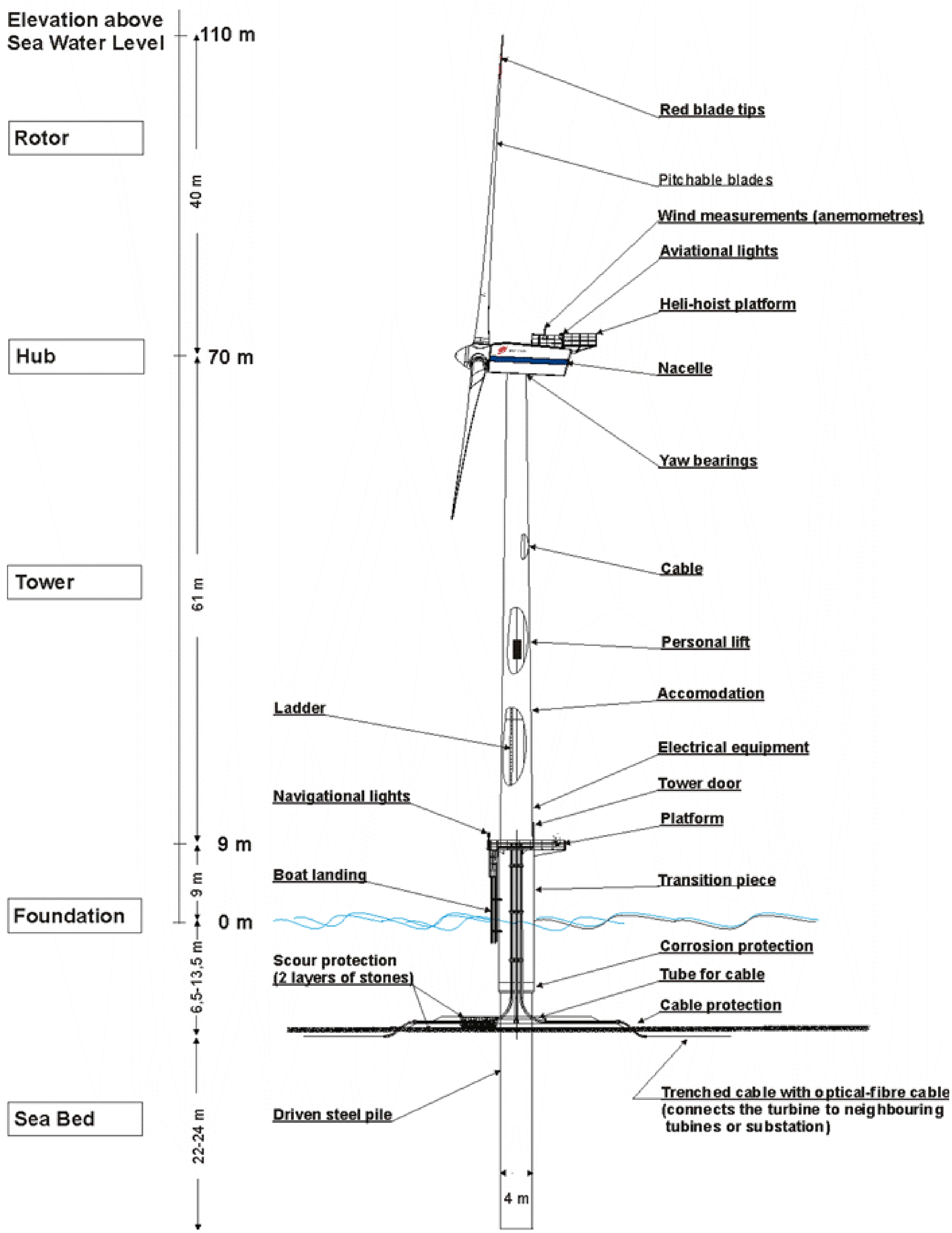

FIGURE 2-2 Horns Rev 2-MW offshore wind turbine.
(SOURCE: www.hornsrev.dk/Engelsk/Images/principskitse_UK_700.gif.)

FIGURE 2-3 View of 3.6-MW offshore wind turbine at Arklow Banks, Ireland.
(Photograph courtesy of GE Wind.)

service cranes, and oil temperature regulation systems, all of which exceed the typical maintenance provisions for land-based turbines.

Offshore substructure and foundation systems differ considerably from land-based foundations. Land-based foundations typically consist of a conventional reinforced concrete mat poured below grade with the use of conventional construction methods. In contrast, the most common substructure type offshore is the monopile—a large steel tube with a wall thickness of up to 60 mm (2.36 in.) and a diameter of up to 6 m (19.7 ft), although concrete gravity-based foundations are frequently used. Figure 2-4 shows four commonly used substructures. A less frequently used substructure, suction caissons, is shown in Figure 2-5.

In sands and soft soils, steel monopiles have been driven in water depths ranging from 5 to 30 m (16.4 to 98.4 ft). In stiff clays and other firm soils, they can be installed by boring or using a combined driven-drilled option with a pile top drill (Fugro-Seacore 2011). The embedment depth varies with soil type, but typical North Sea installations require pile embedment 25 to 30 m (82 to 98.4 ft) below the mud line. A steel transition piece is fitted around the section of the monopile that protrudes above the waterline, and the gap between the two steel pieces is grouted, which provides a level flange to fasten to the tower. The monopile foundation requires special installation vessels and equipment for driving the pile into the seabed and lifting the turbine and tower into place.

Approximately 20 percent of offshore installed wind projects use gravity-based foundations, which avoid the need to use a large pile-driving hammer and instead rely on mass and a larger base dimension to provide stability and resist overturning. Gravity-based systems require a significant amount of bottom preparation before installation and are compatible only with firm soil substrates in relatively shallow waters.

Multipile substructures such as tripods and jackets, which are more typical of offshore oil and gas platforms, have been deployed in a few projects where depths exceed 30 m (98.4 ft), around the practical limit for monopiles (Alpha Ventus 2010). Generally, the project developer

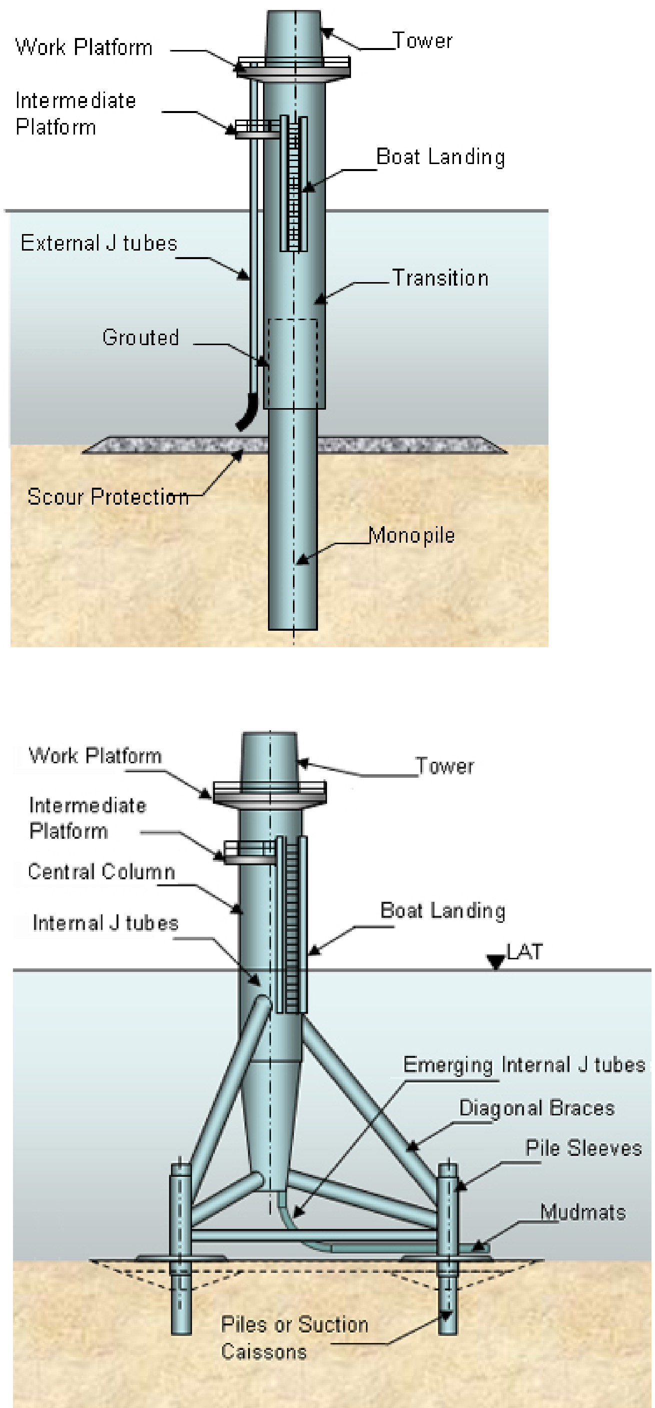

FIGURE 2-4 Four common substructure types for offshore wind: monopile (upper left), gravity base (upper right), tripod (lower left), and jacket (lower right).
(SOURCE: EWEA 2009b.)

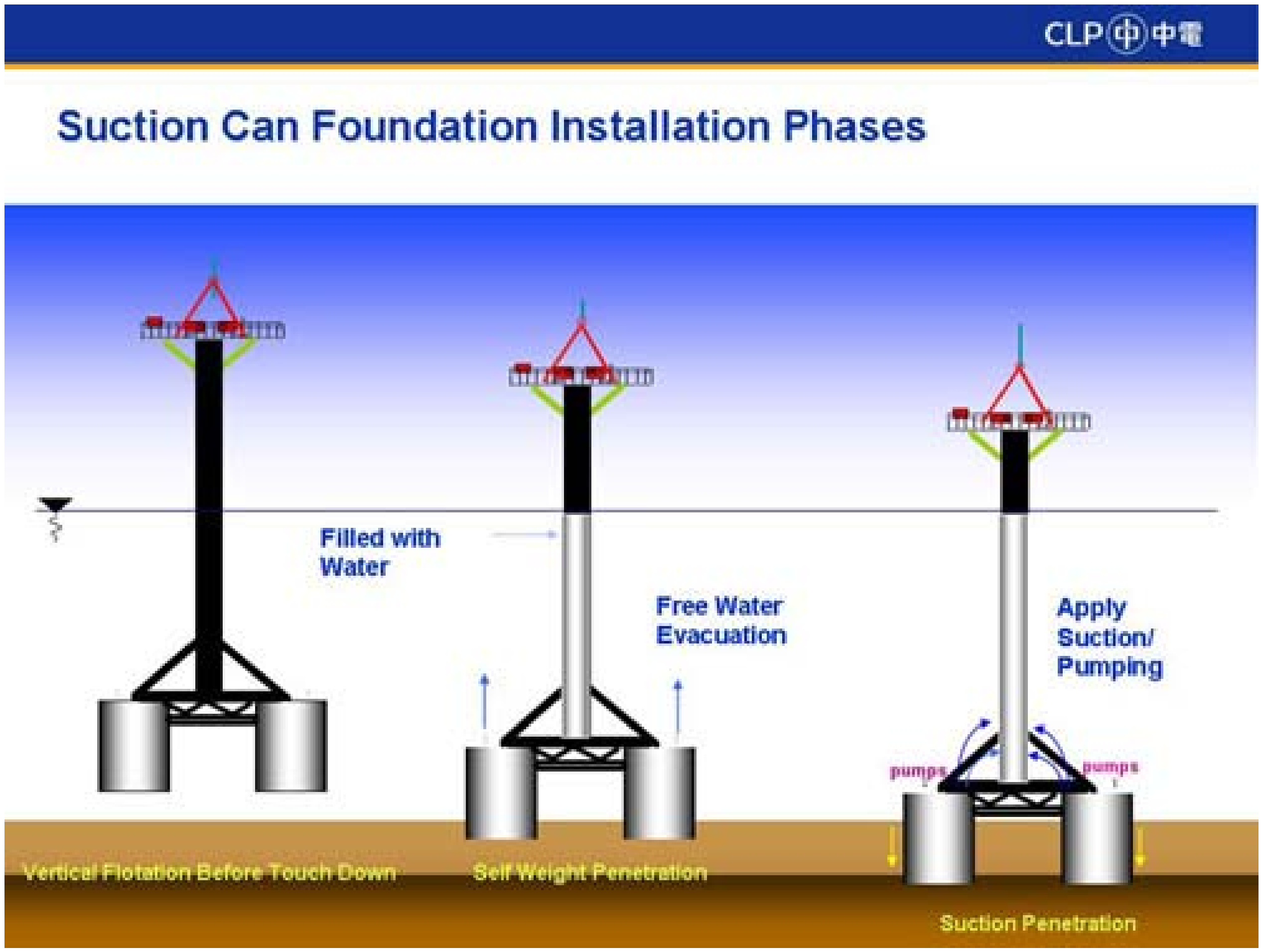

FIGURE 2-5 Installation of a suction caisson foundation. Suction caissons are inverted buckets that initially are settled partially into the seabed by the weight of the platform and then are pulled deeper by suction created when water is pumped out of the top of the caisson. (SOURCE: http://www.power-technology.com/projects/hk-windfarm/hk-windfarm2.html.)

is responsible for the substructure design, fabrication, and installation and for ensuring that the substructure is compatible with the turbine, which is usually designed for a specified International Electrotechnical Commission class. The integration of design of the substructure and the turbine is a primary concern for both developers and regulators.

Offshore wind turbine power output is greater than that of average land-based turbines. As noted earlier, this is because offshore winds are stronger and steadier than those on land and because offshore turbines can be larger. The size of onshore turbines is constrained in part by limits on the size and the weight of loads—turbine blades and towers, construction equipment, and erection equipment—that can be transported over land. Offshore turbines can be larger because larger and heavier loads can be transported over water.

Onshore turbines tend to be placed on taller towers to take advantage of the higher wind speeds that exist at higher elevations, above the influence of trees and topographic obstacles that create drag on the wind and slow it down. With vast stretches of open water offshore, higher wind speeds can exist at lower elevations, so offshore wind turbine towers can be shorter than their land-based counterparts for a given power output.

Infrastructure mobilization and logistical support for construction of a large offshore wind plant are major portions of the total system cost. The wind turbines are arranged in arrays that are oriented to minimize losses due to turbine-to-turbine interference and to take advantage of the prevailing wind conditions at the site. Turbine spacing is chosen to establish an economic balance between array losses and interior array turbulence and the cost of cabling between turbines, which increases with turbine spacing. Variations in water depth present a siting obstacle that often requires a customized approach to individual substructure design to ensure that each turbine's structural vibration modes are compatible with the turbine operating frequencies (IEC 2005; Dolan et al. 2009).

The power output from all the turbines in the wind farm is collected at a central electric service platform (ESP). The wind farm's electric power distribution system consists of each turbine's power electronics, the turbine step-up transformer and distribution wires, the ESP, the cables to shore, and the shore-based interconnection system. In U.S. projects, the cable-to-shore, shore-based interconnect, and ESP system usually are the responsibility of the developer. In some European countries such as Germany, the state-run utility is responsible for the power after it reaches the substation.

Power is delivered from the generator and power electronics of each turbine at voltages ranging from 480 to 690 V and is then increased via the turbine transformers (which can be cooled with dry air or liquid) to a distribution voltage of about 34 kV. The distribution system collects the power from each turbine at the ESP, which serves as a common electrical collection point for all the turbines in the array and as a substation where the turbine outputs are combined and brought into phase. For smaller arrays or projects closer to shore, the power can be injected at an onshore substation at the distribution voltage, and an offshore ESP is not needed. For larger projects, the voltage is stepped up at the ESP to about 138 kV for transmission to a land-based substation, where it connects to the onshore grid. An ESP substation for a 400-MW wind plant requires multiple transformers, each containing about 10,000 gallons of circulated dielectric cooling oil, which are mounted on a sealed containment compartment to prevent leakage into the environment (Musial and Ram 2010, Section 2, 10–22). In addition, each containment compartment is mounted to a secondary containment storage tank capable of capturing 100 percent of the oil should all four transformers leak. Power is transmitted from the ESP through a number of buried high-voltage subsea cables that run to the shore-based interconnection point. The voltage may need to be increased again onshore to, nominally, 345 kV for offshore power plants larger than 500 MW (Green et al. 2007).

The ESP can also function as a central service facility and personnel staging area for the wind plant, which may include a helicopter landing pad, a wind plant control room and supervisory control and data acquisition monitoring system, a crane, rescue or service vessels, a communications station, firefighting equipment, emergency diesel backup generators, and staff and service facilities, including emergency temporary living quarters. While the exact requirements for offshore safety and service have not yet been established (Puskar and Sheppard 2009), several standards set by the oil and gas industry may be applicable. Figure 2-6 shows the offshore wind turbine and how it is connected to the onshore grid system.

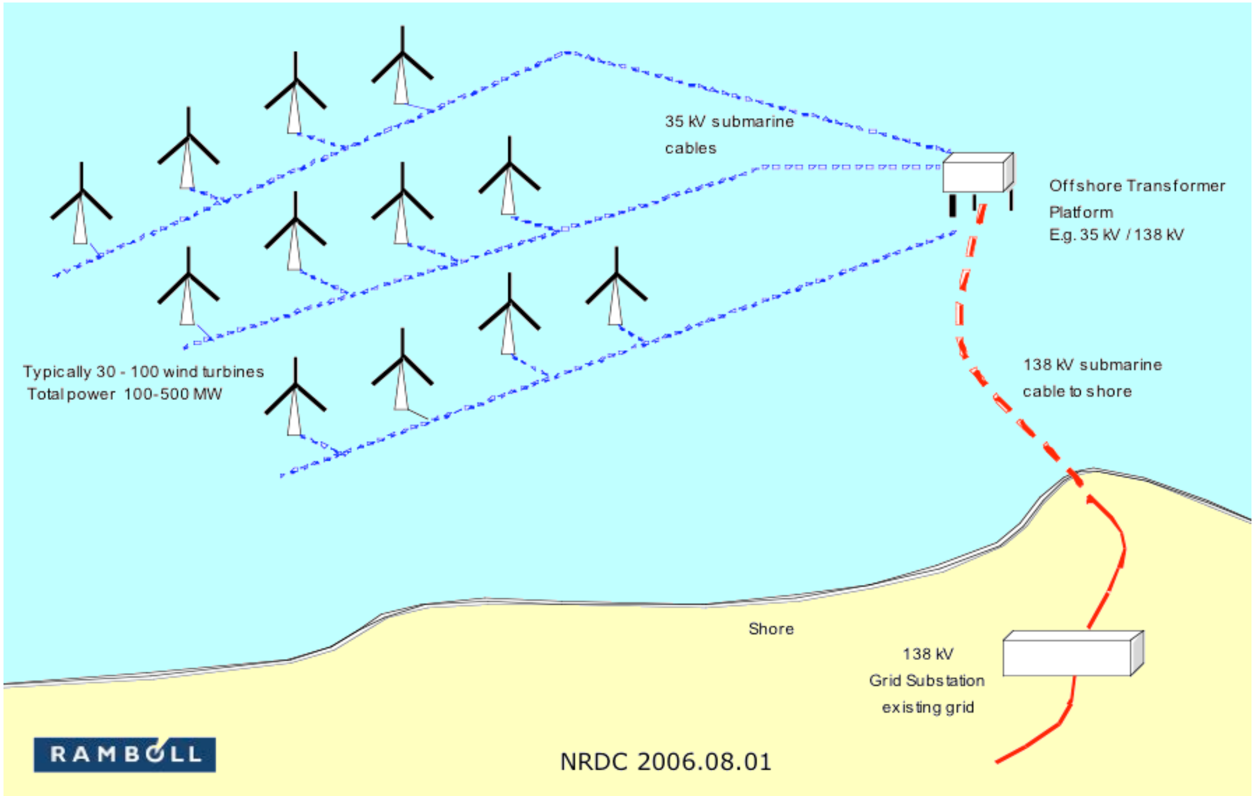

FIGURE 2-6 Offshore turbine grid connections.
(SOURCE: National Resources Defense Council)

Future Technology

Future wind technology may introduce novel concepts and advanced technology innovations for offshore wind energy that deviate significantly from the current technology (Musial and Ram 2010; Butterfield et al. 2005). Organizations such as the U.S. Department of Energy and the National Science Foundation have indicated that they plan to direct significant funding to such research. The following are among the new technology concepts:

- Foundations and substructures that allow deployment in deeper waters;
- Installation methods to automate deployment;
- Large turbines (10 MW or greater);
- Downwind rotors;
- Direct drive generators;
- Composite towers;
- “Smart” composite blades;
- Offshore high-voltage direct current transmission subsea backbones; and
- Alternative turbine designs: upwind and downwind multiple rotor concepts.

A variety of deepwater floating platforms have been proposed, but only one full-scale prototype has been installed in deep water and connected to the grid. This single-turbine demonstration prototype, called Hywind, was installed in Norwegian waters in September 2009. Such floating designs are at too early a stage to gauge properly their potential to compete cost-effectively in the energy market, although the 2.3-MW Hywind prototype was expensive compared with commercial offshore wind systems installed on fixed substructures (Statoil 2010a).

U.S. Offshore Wind Energy Potential

The resource potential for offshore wind power in the United States has been calculated by the National Renewable Energy Laboratory by state on the basis of water depth, distance from shore, and wind speed. From a gross calculation of windy water area, the capacity of installed wind power was estimated on the basis of an assumption that a 5-MW wind turbine could be placed on every 1 km^2 of windy water (Schwartz et al. 2010). The calculations show that for annual average wind speeds above 8.0 m/s, the total *gross resource* of the United States is 2,957 GW, or approximately three times the generating capacity of the current U.S. electric grid: 457 GW for water shallower than 30 m, 549 GW for water between 30 and 60 m deep, and 1,951 GW for water deeper than 60 m. This resource estimate includes significant areas where wind development would not be allowed under a range of siting restrictions and public concerns, but the studies have not yet been done to assess the viable sites from a marine spatial planning perspective and to define logical exclusion areas (CEQ 2009a; CEQ 2009b; CEQ 2009c).

STATUS OF OFFSHORE WIND INSTALLATIONS

Most offshore turbines are currently located in European waters less than 30 m in depth, in and around the North and Baltic Seas. More than 800 turbines have been installed and connected to the grid in nine countries (EWEA 2010). The market is continuing to expand, with at least 1 GW expected to be installed during 2010. Of the hundreds of wind projects that are navigating some layer of the permitting process, at least 52 have been given consent and at least 16 are under construction. As of March 2010, approximately 42 projects had been installed with an estimate of 2,377 MW in operation (4C Offshore 2010; Alpha Ventus 2010; C-Power NV 2010; Centrica Energy 2010; DONG Energy 2010a; DONG Energy 2010b; Japan for Sustainability 2004; NoordzeeWind 2010; Offshore Center Denmark 2010; Prinses Amalia Windpark 2010; Statoil 2010b; Vindpark Vänern 2010; Blue H USA 2009; E.ON UK 2009; EWEA 2009a; Ministry of Foreign Affairs of Denmark 2009; RWE npower renewables 2009; OWE 2008). Figure 2-7 shows a photograph of the 160-MW Horns Rev wind farm off the west coast of Denmark. It was one of the first large arrays and was installed in 2002.

Figure 2-8 shows the installed offshore wind capacity worldwide by year. The development of offshore wind as an energy source began in the early 1990s, but significant capacity expansion did not begin until around 2000, when project size increased from small pilot projects to utility-based wind facilities. The industry experienced a slowdown in 2004 and 2005 that can be attributed to reliability problems and cost overruns experienced at some of the first large Danish wind projects. This resulted in reduced market confidence and an industry reassessment of technology requirements, some of which may be attributed to immature

FIGURE 2-7 Photograph of 160-MW Horns Rev wind project off the west coast of Denmark.

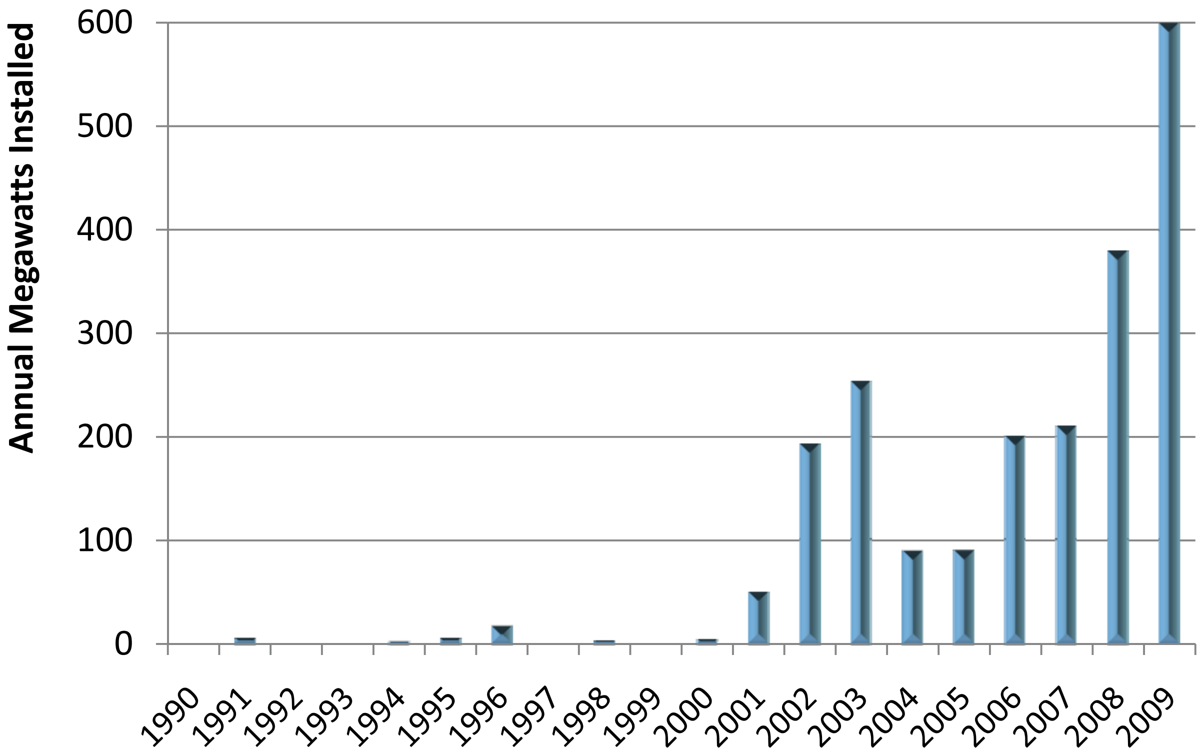

FIGURE 2-8 Installed offshore wind capacity worldwide by year, 1990–2009.
(SOURCE: Musial and Ram 2010, Section 2, 10–22.)

certification and lack of enforcement. Recently, some problems with corrosion have been discovered. For example, in late 2010 Siemens discovered that corrosion protection had failed for the pitch bearings in its 3.6-MW offshore wind turbines in four wind farms.[1] Recently, the market has regained momentum as the industry has overcome some of these problems and is trending toward more sustained growth. This is evidenced by both the increase in deployments seen in Figure 2-8 and in the long-term goals set by the European Union, which call for 150 GW of offshore wind capacity by 2030.

Figure 2-9 shows the installed capacity of offshore wind by country and indicates that the United Kingdom leads in total installed capacity, followed closely by Denmark. However, projections indicate that Germany will overtake both the United Kingdom and Denmark and become the leader in deployments. Although Europe has been the leader in offshore wind so far, several other countries have begun looking toward offshore wind to meet their energy needs, including Canada, China, and the United States.

Figure 2-10 juxtaposes *installed* offshore projects against *proposed* North American projects (reNews 2009; Daily 2008; *Wired Magazine* 2007; Sokolic 2008; Williams 2008; Garden State Wind 2010; AWS Truewind 2010). The installed projects are represented by blue bubbles and plotted to show average water depth and average distance from shore. The size of each bubble is approximately proportional to the size of the project. The red bubbles show the proposed United States projects, which are mostly in the Atlantic or the Great Lakes. Most installed projects are located close to shore and in water less than 30 m in depth. However, the proposed projects in the United States tend to be larger and will be farther from shore. This trend may be indicative of different market conditions favoring larger projects because of economies of scale. It may also reflect a general desire to move projects away from shore to areas where public concerns (over visual impacts, for example) can be minimized.

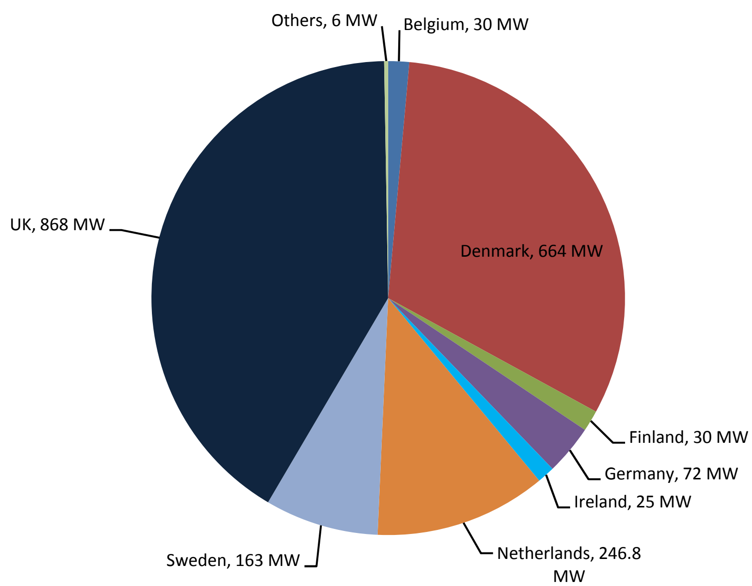

FIGURE 2-9 Installed offshore wind capacity by country, January 2010.
(SOURCE: Musial and Ram 2010, Section 2, 10–22.)

[1] http://ecoperiodicals.com/2010/08/13/siemens-hires-vessel-to-tackle-turbine-corrosion.

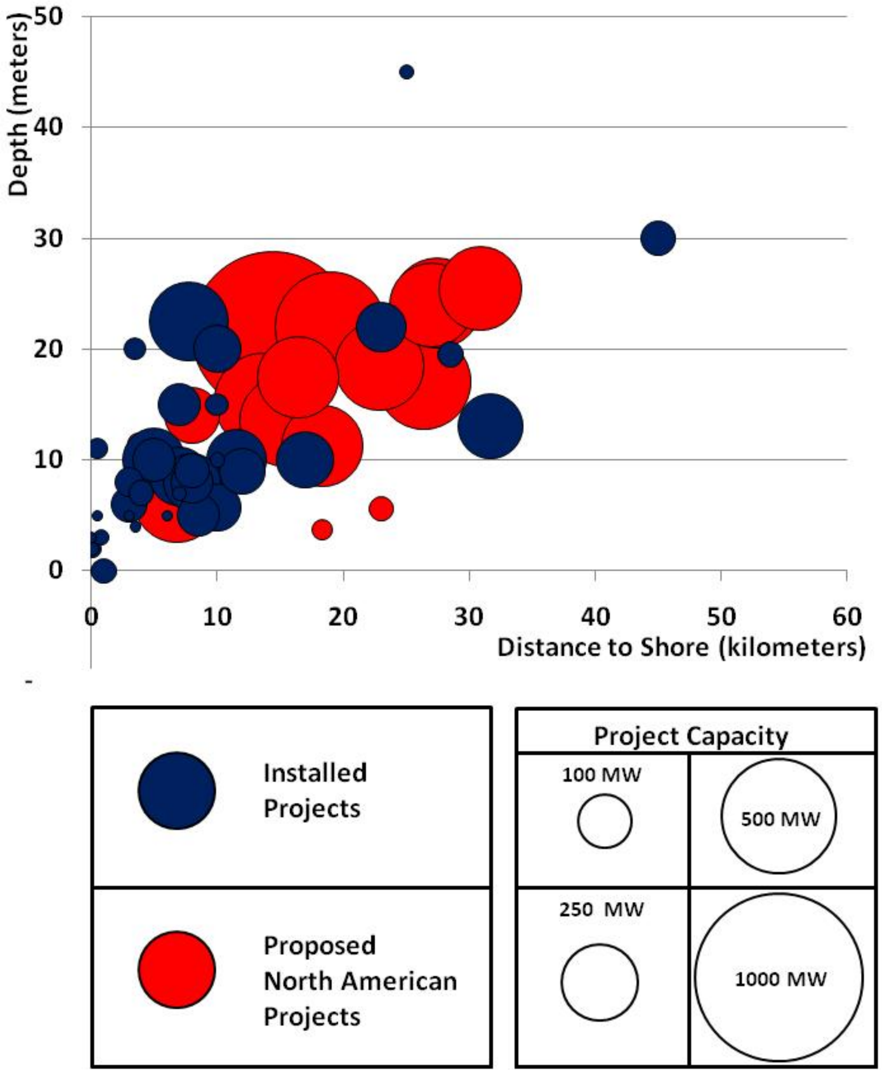

FIGURE 2-10 Offshore projects showing capacity, water depth, and distance to shore. Figure does not include experimental deepwater projects (e.g., Hywind).
(SOURCE: National Renewable Energy Laboratory.)

New technologies , as well as new construction and transport strategies, will be needed to extend this design space farther from shore and into deeper water, as indicated in Figure 2-10. They may include more robust multipile substructures and foundations capable of resisting the greater overturning forces, construction and transport strategies that maximize work at quayside, and new vessels for construction and installation that are capable of operating at greater depths. In addition, deepwater floating systems are being developed (not shown in the figure). These technologies will allow expansion of the resource area for offshore wind and increase the potential for more benign siting.

Offshore wind turbines are produced mainly by a small number of European turbine manufacturers, with some recent activity from at least one Chinese original equipment manufacturer. Table 2-1 provides a list of offshore turbines that are currently available on the market worldwide.

TABLE 2-1 Commercial Offshore Wind Turbines

Manufacturer	Model	Year Available	Rated Power (MW)	Grid Frequency (Hz)	Rotor Diameter (m)	Number of Turbines Installed Offshore[a]
AREVA Multibrid	M5000	2005	5	50	116	6
BARD	5 MW	2010	5	50	122	Prototype[b]
REpower	5M	2005	5	50	126	15
Siemens	SWT-2.3	2003	2.3	50, 60	82, 93	221
Siemens	SWT-3.6	2005	3.6	50	107	134
Siemens	SWT-3.6	2011	3.6	50	120	Prototype
Sinovel	SL3000	2010	3	50	91	34
Vestas	V80-2.0	2000	2	50, 60	80	208
Vestas	V90-3.0	2004[c]	3	50, 60	90	263
Vestas	V112-3.0	2011	3	50, 60	112	Prototype

[a] Based on projects fully commissioned through year-end 2010.
[b] The BARD Offshore 1 project will have 80 turbines, and installation began in March 2010.
[c] In early 2007, Vestas temporarily withdrew its V90-3.0 model from the offshore wind market after 72 of a total of 96 V90-3.0 turbines then operating offshore (United Kingdom and the Netherlands) developed major gearbox problems. They were corrected, and the model was offered for sale again in May 2008.
SOURCE: Adapted from NYSERDA 2010; supplemented with data from Musial and Ram 2010, Section 2, 10–22.

OFFSHORE WIND ENERGY FOR THE UNITED STATES

Offshore Wind Energy in State Waters

Many of the first offshore wind energy projects that have been proposed in the waters of the United States are small demonstration-sized wind clusters (around 20 MW or less) located close to shore (usually within 3 nautical miles). These projects are generally supported by state governments. Some state projects are likely to precede larger-scale developments in federal waters, and they may set the U.S. precedent for safe design, installation, and operation for offshore wind facilities. Performance and safety could vary among states if each is required to develop its own regulatory processes. The state projects will also provide the first U.S. experience with the regulatory processes put in place by the Bureau of Ocean Energy Management, Regulation, and Enforcement (see Box 1-1). The exception to this is the project proposed by Cape Wind Associates, LLC. The Cape Wind project is a 468-MW wind farm to be located 4.7 miles off the coast of Massachusetts. The project has been granted a site lease by the federal government but will still need to obtain approval of the plans it must submit in accordance with the process laid out in Box 1-1.

Progress in Development of U.S. Offshore Wind Facilities

As of November 2010, there were no offshore wind power facilities in the United States, but it is probable that construction activities for offshore wind energy projects will begin soon. In 2008, the U.S. Department of Energy published a report that suggested that 20 percent of the nation's electric power could be produced by wind energy by 2030 under certain scenarios that assumed "favorable but realistic" market conditions (USDOE 2008). In that report, the contribution of offshore wind was found to be a necessary component to achieve 20 percent electricity from wind energy. The scenario analyzed estimated that 54,000 MW of capacity would come from offshore sources.

Several projects that have advanced significantly in the U.S. permitting process to date are shown in Figure 2-11. As the map indicates, most of the activity is in the Northeast and Mid-Atlantic regions. However, offshore wind is being considered in most regions off the U.S. coast, including the Great Lakes, the Gulf of Mexico, and even the West Coast. (The depth of the water on the West Coast will preclude near-term development despite a good wind resource because deepwater wind turbine designs are not currently available.)

Proposed U.S. offshore wind projects can be divided into two regulatory groups: those in federal waters (i.e., outside the 3–nautical mile state boundary) and those under state jurisdiction. State projects are typically near shore and have marginally lower wind resources. In the long term, there are not enough viable sites in state waters to achieve offshore wind deployment at a scale sufficient to make a large impact on U.S. electric energy supply.

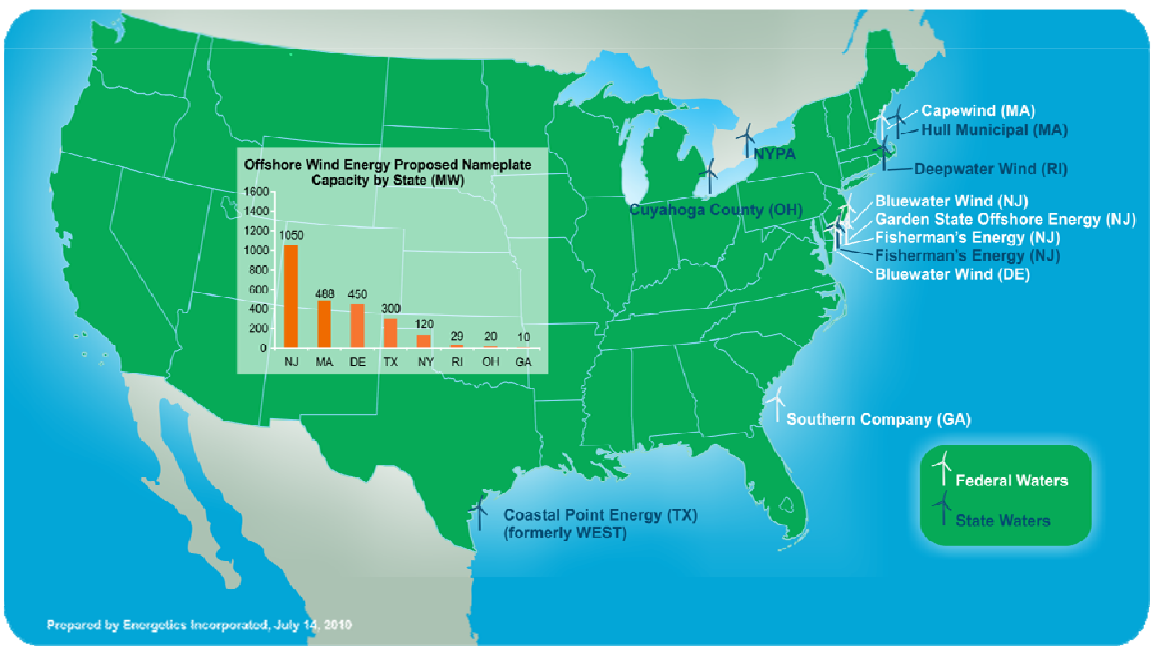

FIGURE 2-11 Proposed U.S. offshore wind projects and capacity showing projects with significant progress. (SOURCE: Musial and Ram 2010.)

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Abbreviations

AWEA	American Wind Energy Association
CEQ	Council on Environmental Quality
EWEA	European Wind Energy Association
IEC	International Electrotechnical Commission
NYSERDA	New York State Energy Research and Development Authority
OWE	Offshore Windenergy Europe
USDOE	U.S. Department of Energy

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3

Standards and Practices

This chapter addresses Task I of the committee's charge—"Standards and Practices" (see Box 1-2). It provides background on and a summary of the applicable regulations, standards, recommended practices, and guidelines that have been used in the offshore wind industry, and it describes the state of maturity of each of these documents. The terms "regulations," "standards," and "guidelines" are discussed in Box 3-1.

In its review of standards and practices, this chapter discusses technical terms related to risk assessment, strength analysis, and other areas. Definitions of these terms can be found in the glossary, and some are discussed further in Appendix A.

INTERACTIONS BETWEEN NONSTRUCTURAL FAILURES AND WIND TURBINE STRUCTURAL INTEGRITY

Although the committee's charge is limited to structural integrity (see Chapter 1), malfunction or failure of nonstructural components and systems during operation can result in structural overload or failure. This interaction is dealt with through the definition of "design load cases" (DLCs) in standards and guidelines. Such cases specify the combination of loads that a facility must be designed to resist or withstand. Although the committee has not reviewed the DLCs in detail, it notes that DLCs normally include the structural loads placed on the turbine as a result of failure or malfunction of ancillary systems such as control systems, protection systems, and the internal and external electrical networks. In such DLCs, failures in ancillary systems are normally postulated as occurring under unfavorable wind and wave conditions. For example, in International Electrotechnical Commission (IEC) 61400-3, DLC 2.3 involves both an extreme operating wind gust and loss of the electrical network. Other examples require consideration of yaw misalignment that might result from mechanical or electrical failure and consideration of what emergency procedures might be needed to cope with structural damage caused by nonstructural triggers such as overspeeding, brake failures, and lubrication defects.

In sum, the standards and guidelines that will likely be used in the structural design of offshore wind turbines for the United States and that will inform the work of certified verification agents (CVAs) consider how nonstructural components can trigger structural failures in offshore wind turbines.

Box 3-1

Regulations, Standards, and Guidelines

The use of various terms to describe technical guidance is common among engineering disciplines. Some terms have specific and generally accepted definitions, and others are less precise. The following describes the terms used throughout this document and the class of documents to which they refer, with some background on how these documents are typically developed.

Regulations
Regulations are sets of requirements promulgated by government authorities. Although they may be international and implemented by way of treaties (for example, International Maritime Organization regulations applicable to international shipping), regulations are generally established at the national and state levels. Rules and regulations developed by the various U.S. federal agencies are codified in the Code of Federal Regulations.

Standards
A standard is a document that has been developed in accordance with a protocol. Diverse interests are represented, there is a process for resolving opposing opinions, and the final version is adopted by a consensus vote of the constituencies involved. Examples of organizations that follow a recognized standards development process are the International Organization for Standardization, the International Electrotechnical Commission (IEC), the American National Standards Institute, the American Wind Energy Association, and the American Petroleum Institute (API). Standards may be international, national, or industry-specific in scope, and the term "standard" may not be present in the title. In this report, "standard" refers to any document developed according to a recognized process and subject to a vote of constituencies to establish a consensus before becoming final. Examples of standards referred to in this report are IEC 61400-3 and API RP 2A.

Guidelines
A guideline is a document that has been developed by a group or a company and that is not subject to a formal protocol or a vote of constituencies. These documents are typically vetted through an internal quality process and may be peer reviewed, but they are ultimately the product of the group or company, and no consensus is required for their completion or use. In this report, "guideline" refers to any document developed by a group or company for which no recognized protocol or consensus vote is necessary. Examples of guidelines referred to in this report are *Guideline for the Certification of Offshore Wind Turbines*, developed by Germanischer Lloyd; *Design of Offshore Wind Turbine Structures*, developed by Det Norske Veritas; and *Guide for Building and Classing Offshore Wind Turbine Installations*, developed by the American Bureau of Shipping (ABS 2010).

INTERNATIONAL ELECTROTECHNICAL COMMISSION

Background on Land-Based Wind Turbines: Historical Perspective

During the early 1990s, the wind energy industry—through IEC—began to establish international standards for land-based wind turbines. There were at least two motivations for establishing international standards:

- The existing European design standards (e.g., in Denmark, Germany, and the Netherlands) were insufficient in that they did not result in reliable performance over the 20-year design life of the turbines. Many wind turbines experienced breakdowns in major components, such as gearboxes and blades, after less than 10 years of operation, leading to excessive downtimes.
- The industry wanted to make sure that all wind turbines complied with the same standard so that price competition could take place on a uniform basis (excluding substandard wind turbine designs).

The United States saw the IEC standards activities of the 1990s as a way to provide a fair and unified approach to the emerging world wind energy market and has participated in the development of the IEC standards since their inception. Technical Committee 88 (TC 88) was established to develop and manage a suite of applicable standards for wind turbines.

Description of Relevant Standards

The primary standard for wind turbine structural design requirements is IEC 61400-1 Ed. 3 (IEC 2005). This standard defines design classes, external (environmental) conditions for each design class, DLCs, fault conditions that must be included in the design, procedures for assessing static and dynamic loads, electrical requirements, and methods for assessing the site-specific suitability of the turbine. Perhaps the most important part of the standard is a detailed definition of the turbulent wind environment. Because understanding the minute characteristics of wind is so important in assessing unsteady aerodynamic load distributions along the rotating blades, it is crucial that this part of the external conditions be defined in a manner consistent with the analytical theory used for rotor load estimation.

In 2000, TC 88 began to develop an offshore wind turbine standard, *Design Requirements for Offshore Wind Turbines*, IEC 61400-3 (IEC 2010a). It was intended to address requirements for offshore wind turbines that were not previously covered. The standard defers to IEC 61400-1 for the wind turbine aspects of the design requirements and relies on existing mature standards for setting general support structure requirements. The IEC offshore committee surveyed structural standards and guidelines for offshore oil and gas structures, including those developed by the American Petroleum Institute (API), the International Organization for Standardization (ISO), Det Norske Veritas (DNV), and Germanischer Lloyd (GL), and attempted to use them as the basis for the new IEC 61400-3 requirements. A European-funded project, “Requirements for Offshore Wind Turbines” (RECOFF), included formal comparisons of these various standards and assessed their suitability for wind turbine design. The RECOFF study concluded that, for the vast majority of support structure requirements, standards such as those of API and ISO could be used. However, the crucial deficiency was the manner in which dynamic loads were estimated. Offshore wind turbines are subject to wind and wave stochastic loadings that are nearly equal in importance with respect to dynamic excitation of the wind turbine. IEC 61400-3 is the only international standard that specifically addresses these issues. It is less mature (less fully developed) than other international standards and guidelines for land-based wind turbines, but it is based on earlier standards and therefore represents an integrated version of all the work that has preceded it. Because it is part of a series of international standards that address the broader wind industry's needs, such as verification testing for performance, structural design compliance, power quality, gearbox design requirements, and small turbines, it is the best available standard for addressing the issues of structural design for offshore wind turbines.

The IEC certification standard for type and project certification is IEC 61400-22, *Wind Turbines—Part 22: Conformity Testing and Certification* (IEC 2010b). This standard defines requirements for both type certification and project certification. The IEC 61400-22 certification standard is a further development of the previous certification standard, IEC WT 01 (IEC 2001), in particular with regard to requirements for project certification.

Turbine Type Certification Process

There are few legal requirements for structural design in land-based U.S. wind energy installations, and no single agency has full responsibility. The structures must meet local and state building codes, and the electrical systems must meet electrical standards. These codes and standards are inadequate for defining wind turbine design requirements, and there is no overarching permitting process that addresses structural design. However, this approach does not appear to have impeded the industry or become a detriment to public safety. Instead of relying on statutory regulations, the process is commercially driven. Owners and operators choose to require type-certified wind turbines for their projects. The type certification process is outlined in Figure 3-1.

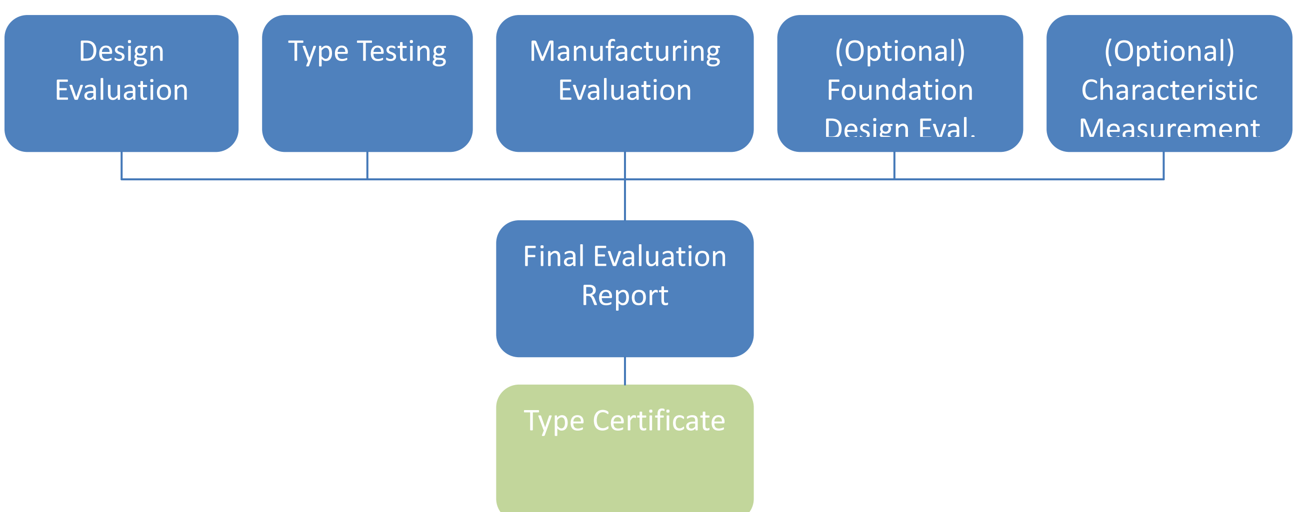

FIGURE 3-1 Type certification process under IEC 61400-22.

The turbines are usually certified to IEC or other European standards. Recognizing that the offshore certification process is unique, TC 88 has begun to draft a second edition of its wind turbine certification process, IEC 61400-22 (IEC 2010b). The new edition will rely on IEC 61400-3 for offshore technical requirements while defining the certification process. Both IEC 61400-3 and WT 01 Ed. 2 assume that the turbine will be certified to a set of design classes specified in IEC 61400-1 Ed. 3, whereas the support structure is designed to site-specific conditions. The IEC standards development process assumes that multiple parties will be responsible for different aspects of the project and offers guidance for each phase of the project. It allows for the use of other standards for the support structure, such as API RP 2A-LRFD-S1 (API 1997), DNV guidelines, and GL Windenergie Group specifications (though the latter two guidelines are heavily influenced by the API offshore standards for their offshore support structure guidance). However, some of the specifications of API RP 2A are not adequate for the design of offshore turbines, for which dynamic time-dependent behavior must be determined as accurately as possible by using, for example, modern time-domain analysis methods.

Foundation designs are integrated into the type certification for some turbines. Where this is the case, the foundation design must be evaluated for the external conditions for which it is intended. Poor geotechnical investigation and foundation design have led to delays and cost overruns at European wind farms (Gerdes et al. 2006).

Project Certification

Technical design requirements (IEC 61400-3) typically are separated from certification procedures (IEC 61400-22). The latter standard defines the certification process and relies on technical standards such as IEC 61400-3 to specify the design requirements. The overall certification quality system needed to implement the full process from design through manufacturing, installation, continuous monitoring, and decommissioning requires management procedures. Project certification is covered under IEC 61400-22 (see Figure 3-2). According to this standard, the purpose of project certification is to determine whether type-certified wind turbines and their integrated foundation designs conform to the external conditions, applicable construction and electrical codes, and other requirements of a specific site. Under this process, the external physical environmental conditions, grid system conditions, and soil properties unique to the site are evaluated to determine whether they meet the requirements defined in the design documentation for the wind turbine type and foundations.

Wind turbines and their support structures are mass produced, as opposed to the customized design approach typically applied for offshore oil and gas installations. Final permitting of wind power plants results in the installation of many turbines of the same design type (hence the term “type certification” for a turbine that meets a generic design class, rather than site-specific environmental conditions). Although it is likely that the same design has operated in other sites, a new installation must integrate the environmental and physical conditions of the site into the engineering evaluation of suitability for the site. IEC recognizes that offshore turbines will be designed and tested long before most projects are even conceived. Thus, the IEC standards require and give guidance for evaluating the suitability of a type-certified turbine for specific site conditions.

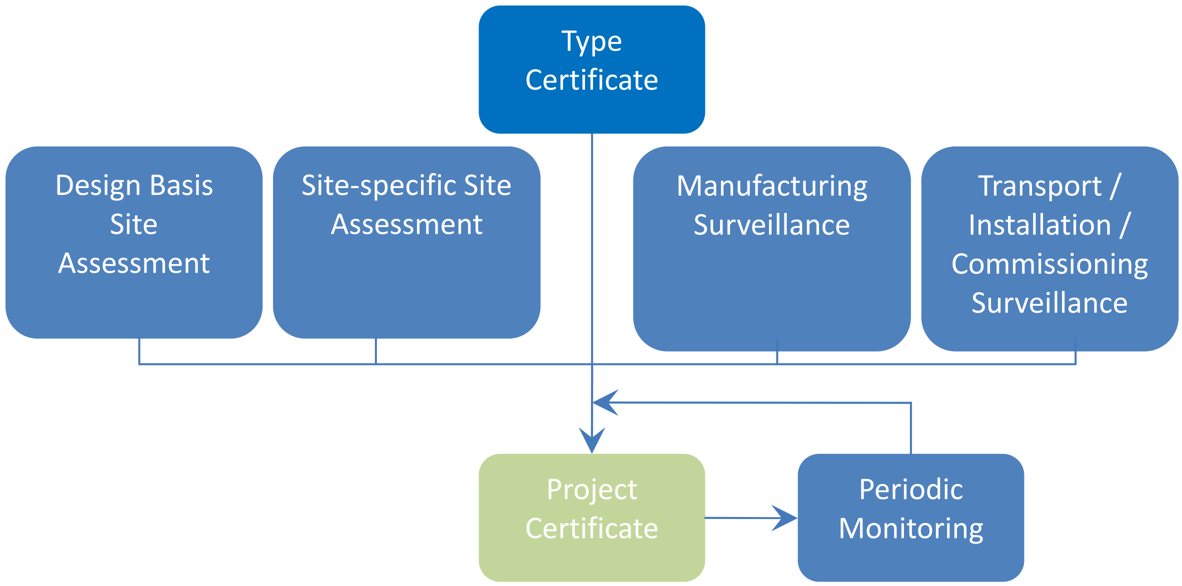

FIGURE 3-2 Project certification process under IEC 61400-22.

API STANDARDS

Background on Oil and Gas Facilities: Historical Perspective

API standards were developed with a focus on offshore facilities for oil and gas and include, among other items, wind–wave–current models, analysis approach, and structural and foundation design parameters. API RP 2A is the primary standard used by the offshore oil and gas industry for the structural design of fixed offshore structures, which are the most similar to traditional offshore wind structures, but API has additional standards for offshore floating structures, including API RP 2T, API RP 2FPS, and API RP 2SK. These standards represent more than 60 years of design experience. Although they were primarily developed to address the offshore oil industry in the Gulf of Mexico, the API series has become a comprehensive set of standards that is used internationally. In support of the recommended practices, additional documents such as 2MET (Oceanographic and Meteorological) and 2GEO (Geotechnical) have been developed to address conditions applicable to both fixed and floating structures.

API has been engaged with ISO in developing an ISO series of offshore standards using many of the API standards as their base documents. More than 80 percent of the ISO 19900 series has been published. API has restructured about 50 percent of its offshore series to match the ISO structure and incorporate the ISO standards. This integration provides for a single international set of offshore standards with U.S.-specific criteria attached to the universal core technical requirements.

Description of Relevant Standards

The API Series 2 standards are comprehensive and cover all aspects of offshore design: planning requirements, installation requirements, fixed and floating platform structural requirements, operations throughout the life of the system, and decommissioning requirements.

For structural design, API RP 2A-WSD, the commonly applied standard for fixed offshore platforms, uses an elastic component design methodology prescribing load development procedures, structural design methods, extreme load conditions, material and component safety factors, and the character and return periods for design-level extreme events for both sea states and wind conditions. The standard focuses mainly on sea states rather than wind because that is the primary source of platform loads (usually about 70 percent of the total load on a fixed platform). Detailed wind conditions are frequently characterized on the basis of a quasi-static load definition, which is generally sufficient for a statically responding facility. For dynamically sensitive facilities, wind loading is usually developed by using an offshore-specific wind spectrum model.

IEC AND API DIFFERENCES

Standards such as IEC 61400-3 and API RP 2A have some overlapping design requirements for wave and current loading conditions. However, a direct comparison of the IEC and API standards indicates differences that should be assessed in any effort to use these standards together for the U.S. offshore wind industry. The following are examples of differences between the IEC and API standards:

- IEC uses a 50-year return period for the definition of extreme environmental design conditions, while API RP 2A uses a 100-year return period for the definition of design conditions for high-consequence platforms.
- The probability of exceedance of load levels (or, equivalently, the return period of the wind–wave–current loading), for example at a 50- or 100-year return level, constitutes only one element determining the failure probability, or the probability of acceptable performance, of a facility. Equally important are the inherent safety factors accounting for knowledge uncertainties (due to incomplete or otherwise limited information concerning a phenomenon) and material factors, load combination requirements, parameters inherent in interaction equations, and so on. These aspects are often disregarded in risk discussions but can affect failure probabilities more than could a factor of two or three in the return period of the loading. Therefore, a careful assessment is needed to determine the overall failure probability in either or both of the standards.
- The definitions of DLCs are different. IEC requires the structure to be verified for normal and abnormal conditions together with specific load cases in close association with the wind turbine's operational status. API requires the structure to be verified for operational conditions, normally a 1-year storm, and extreme conditions, which are defined primarily by using environmental conditions.
- API RP 2A prescribes three levels of design based on consequence. These levels are characterized by decreasing loads for decreasing consequence. In contrast, IEC keeps the load level constant while adjusting component safety factors on the basis of the consequence of that component failing.
- API RP 2A provides a basis for the design of offshore structures subject to wave, wind, current, and earthquake loading conditions in addition to loads from drilling, production, and ongoing personnel activities. API RP 2A does not address the scope and range of all conditions relating to the design of wind turbine support structures such as blade–wind–tower

interaction and presence or absence of yaw control. Similarly, IEC 61400-3 lacks some of the detailed provisions given by API RP 2A with respect to certain offshore engineering practices.

It is important for the industry to develop a full understanding of the differences in the requirements and overall performance levels inherent in these codes. This comparison should seek to clarify the relative levels of structural reliability inherent within each code when applied to a wind turbine project at a specific location and to evaluate the similarities and differences in the consequences of failure (either loss of function or collapse of the structure) for the types of facilities.

One final issue is that floating platforms for wind turbines are explicitly not covered by IEC 61400-3. Research will be necessary to define all issues that may affect the design of such a structure. Such issues are likely to include hydrostatic and hydrodynamic stability, coupled aerodynamic loading from the rotor and wave loading, station keeping, and electrical distribution system connections for a highly compliant support structure.

ISO STANDARDS

As described previously, the ISO 19900 series of standards addresses offshore platforms for the oil and gas industries. These standards were based on existing API standards for fixed steel and floating structures and on a Norwegian standard, the leading offshore concrete standard. The oversight groups (work groups under ISO TC 67/SC 7) for these ISO standards are establishing an ongoing updating and maintenance process now that the first version of the standards has been published. To meet industry needs while the European Union standards requirements were developed, the load and resistance factor design (LRFD) version of API RP 2A was adopted as an interim ISO standard. An international committee structure with considerable U.S. and API leadership and engagement developed the second version of the Fixed Steel Platform standard (ISO 19902), as well as a suite of accompanying general offshore standards: ISO 19903 (Fixed Concrete Structures), ISO 19904 (Floating Systems), ISO 19905 (Jackups), and ISO 19908 (Arctic Structures). A full description of the ISO and API work programs is given by Wisch et al. (2010). This ISO series harmonizes international practices into a single, integrated suite of standards. The ISO standards facilitate international trade by enabling production companies to design to a single set of codes, rather than attempting to satisfy multiple national codes. A single standard also decreases the likelihood of design errors often introduced when designers use unfamiliar codes for projects in different regions.

DNV GUIDELINES

DNV is a leading contributor to research on offshore oil and gas design requirements, and its experience with wind turbine classification comes in large part through service to the Danish wind industry. DNV worked with RISØ Danish National Laboratory researchers to develop national standards for wind turbines. DNV also customized these national standards to suit its own internal practices, and it has been a key participant in developing the IEC standards. Although the IEC standards do not reflect DNV guidelines completely, there are significant similarities. The major differences are the lack of prescriptive material, welding, and component specifications in the IEC standard relative to DNV.

The first DNV offshore wind guideline, *Design of Offshore Wind Turbine Structures* (DNV-OS-J101), was issued in June 2004. The most recent version was issued in October 2007. It covers support structures and foundations for offshore wind turbines, although the foundations guideline is essentially the same as that in API RP 2A. However, the DNV guideline does not include the 2007 updates to the API standard that removed unconservative values for foundation resistance. DNV-OS-J101 does not cover structures associated with floating offshore wind turbines. The next guideline issued was DNV-OS-J102 (2006), which covers blades. The DNV-OS-J103 guideline, issued in 2008, covers design and certification of the offshore transformer station (electric service platform). Design and certification requirements are combined in the DNV documents.

The DNV offshore wind guidelines do not cover all wind turbine systems and components and so cannot stand alone. For example, design requirements for the gearbox, control system, generator, and transformer must all be addressed by using other standards, such as IEC 61400-3. DNV guidelines do not address the specific wind–wave load cases for hurricane site conditions as experienced on the U.S. East Coast and the Gulf of Mexico. Nor do the DNV guidelines address ice loading parameters for the Great Lakes, for which the DNV ice loading recommendations are likely to be unconservative. In the relatively small wave environment of the Great Lakes, freshwater ice loads tend to control design, particularly in shallower waters.

GL WINDENERGIE GUIDELINES

GL was an early leader in developing guidelines for wind turbine design. Its success has grown out of the popularity of wind energy in Germany and the country's requirement of German engineering approval. These factors gave GL exclusive certification authority on all German installations, a monopoly that still exists. GL's *Guideline for the Certification of Offshore Wind Turbines*, 2nd edition, 2005, also called the GL Bluebook, is perhaps the first to be widely used. The GL Bluebook covers all structures, systems, and components for offshore wind turbines and their support structures and foundations. However, it does not cover offshore electric service platforms, nor does it specifically cover floating support structures for offshore wind turbines. The GL Bluebook is highly prescriptive, and as such it is viewed by some in the industry as inflexible and restrictive in its applications. As with the DNV guidelines, design and certification requirements are combined.

GL has remained active in international standards development and European wind energy research. A major contributor to the IEC standards, GL continues to update its Bluebook to reflect the IEC standards while retaining requirements needed to comply with Germany's regulations. The Bluebook remains the most comprehensive guideline on land-based and offshore wind turbine requirements.

AMERICAN BUREAU OF SHIPPING GUIDELINES

The American Bureau of Shipping (ABS) has been at the forefront of developing guidelines for the offshore oil and gas energy sector since the industry's formative years, but it is a newcomer to the offshore wind field. The ABS *Guide for Building and Classing Offshore Wind Turbine Installations* was developed by harmonizing ABS experience from offshore oil and gas platforms with the guidelines provided in the IEC 61400 series of documents (ABS 2010). Requirements on the following subjects are specified in the guide for the support structure of a bottom-founded offshore wind turbine:

- Classification, testing, and survey;
- Materials and welding;
- Environmental conditions;
- Load case definitions;
- Design of steel and concrete structures;
- Foundations; and
- Marine operations.

Requirements with regard to the survey during construction and installation and the survey after construction are generally in accordance with established ABS rules for offshore structures. Alternative survey schemes are also acceptable to account for the uniqueness of offshore wind turbines, such as serial fabrication and installation.

Design environmental conditions and DLCs required by the ABS guide are generally in agreement with those required by IEC 61400-3 but have a number of amendments, mainly to account for the effects of tropical hurricanes in U.S. waters. The principle of site-specific design is addressed in the definition of the DLCs in the guide. Environmental conditions with a baseline return period of 100 years are required to be considered for the extreme storm conditions (DLCs 1.6, 6.1, and 6.2). Furthermore, the omnidirectional wind condition is required for turbines subject to tropical hurricanes, cyclones, and typhoons (DLC 6.2).

The established ABS rules and guides for offshore structures, as well as API RP 2A, have been discussed to provide a technical basis for the development of support structure and foundation design criteria. The guide specifies a set of design criteria for steel support structures by using a working stress design approach, which is still accepted as a common design practice in the United States. Allowable stress levels are defined for various design conditions, including normal, abnormal, transport, and installation on site, as well as earthquake and other rare conditions. Equivalent LRFD criteria are also specified as an acceptable alternative.

The requirements for electric service platforms are addressed in the ABS *Rules for Building and Classing Offshore Installations*. This document, the first edition of which was published in 1983, is used in the verification of bottom-founded structures worldwide.

GERMAN STANDARDS AND PROJECT CERTIFICATION SCHEME

The Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie, or BSH) is the agency in Germany that decides on the approval of offshore wind farm development projects in the North Sea and the Baltic Sea. It carries out the application procedure for offshore wind farms in the German Exclusive Economic Zone, which is the area outside the 12–nautical mile zone where most of the German offshore wind farms will likely be installed.

Part of the approval procedure is to examine whether all installations and structural components have been certified according to the BSH standard *Design of Offshore Wind Turbines*, which was issued in June 2007. This standard covers development, design, implementation, operation, and decommissioning of offshore wind farms within the scope of the Marine Facilities Ordinance and regulates the various structural components of an offshore wind farm. It refers to another BSH standard, *Standard for Geotechnical Site and Route Surveys—Minimum Requirements for the Foundation of Offshore Wind Turbines*, issued in August 2003. To develop these standards, BSH established a steering committee that included technical experts in relevant fields and representatives of three classification and certification societies (SGS, DNV, and GL).

BSH requirements for project certification are set forth for each of the following phases:

Phase I. Development,
Phase II. Design,
Phase III. Implementation,
Phase IV. Operation, and
Phase V. Decommissioning.

The certifier or registered inspector company is to be selected from a preapproved list of BSH-preapproved offshore wind energy certification companies. The list currently consists of SGS, DNV, GL, and DEWI Offshore. Companies can apply for approval as offshore wind energy certification companies.

For a given project, one certification company could cover one phase (e.g., design certification) and others could cover other phases. For example, a second company could cover implementation (manufacturing, transport, and installation), and a third could cover operation.

BSH is the final approval authority for all five phases. It reviews the design and certification documentation itself in determining whether to grant final approval of a project phase. In the process, BSH is often supported by individual external technical experts with specific knowledge of that phase—for example, a geotechnical expert for Phase I and a wind turbine expert for Phase II.

ONGOING STANDARDS DEVELOPMENT AND RELATED RESEARCH: NATIONAL AND INTERNATIONAL

American Wind Energy Association Development of Offshore Recommended Practices

In October 2009, the American Wind Energy Association (AWEA), in conjunction with the National Renewable Energy Laboratory, initiated an effort to develop a set of recommended practices for assessing the local, national, and international standards and guidelines that are being used for all wind turbines in the United States and to make recommendations on their use and applicability. The effort is aimed at three major areas where current standards (and related guidelines and other such documents) are ambiguous or have significant gaps when applied in the United States. One of these areas is offshore wind energy.

The offshore wind energy group will address all areas that are relevant to the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) project application and approval process. These areas include structural reliability; manufacturing, qualification testing, installation, and construction; safety of equipment; operation and inspection; and decommissioning.

The AWEA initiative has enlisted expert stakeholders from the offshore industry community to develop a consensus set of good practices in the use of standards for planning, designing, constructing, and operating offshore wind energy projects in U.S. waters. The group plans to prioritize its recommendations by using international standards whenever possible, followed by national standards, classification society standards, and commercial standards and guidelines.

The AWEA recommended practices will apply to all bottom-fixed structures installed on the outer continental shelf (OCS) or in near-shore locations (e.g., state waters) but will not necessarily be sufficient to ensure the structural integrity of floating offshore wind turbines.

The AWEA offshore group was divided into three subgroups. Each of the groups is working independently, but all are expected to deliver a final guideline by the end of 2011. The three subgroups are discussed below.

Group 1, Structural Reliability, is addressing design issues relating to structural reliability of offshore wind turbines. Because many wind turbines targeted for installation in the United States may have already been designed and type-certified to IEC design classes (e.g., IEC 20050), one focus of the work is establishing the appropriate interfaces between the existing IEC standards and other standards governing the structural reliability of the integrated turbine system. The group will recommend standards and practices that provide a methodology for establishing turbines at specific U.S. sites, taking into account the unique metocean and subsurface conditions.

Group 2, Fabrication, Construction, Installation, and Qualification Testing, is developing recommended practices for the safe and orderly deployment of offshore wind turbines during the construction and installation phases. Any manufacturing issues unique to offshore wind turbines will be addressed, as will issues relating to the establishment of adequate infrastructure. IEC's TC 88 is not addressing much of this phase of deployment, so this group will probably not need to mix and match existing standards as will Group 1. However, it will have to identify applicable standards from other industries and adapt them to cover these activities. Qualification testing will be treated as an overarching activity that may be applied to any project phase.

Group 3, Operation, Maintenance, and Decommissioning, is developing recommended practices for operation and inspection. The recommendations are not likely to include extensive turbine component inspection; owner–investor wind farm maintenance systems are generally more comprehensive than periodic inspections that could be carried out by BOEMRE or other federal agencies, and the consequences of failure in a secondary component are generally limited to economic risk to the wind farm itself. However, in-service structural inspection of the tower and the substructure or below the waterline will be necessary over the field service life. Conservatively, the design life of the substructure is 20 years, but designs could allow repowering scenarios where foundations could be reused. In any case, foundation and substructure design should consider removal and disposition of the system when it is no longer serviceable.

IEC Floating Wind Turbine Initiative

There is strong interest worldwide in the development of new technology for deeper water. Such technology may include floating support structures for wind turbines. Only one floating wind turbine has been deployed to date, by Statoil in Norway in 2009, but technology development is accelerating, and permits for prototypes in U.S. waters will soon be sought (Maine Public Utilities Commission 2010). There are no provisions in the work program of IEC TC 88 that specifically address floating wind structures, but a proposal to develop an IEC technical specification (IEC 2010c) has been submitted to TC88.

Bureau Veritas Guidance for Floating Offshore Wind Turbines

In January 2011, Bureau Veritas issued guidelines for the "Classification and Certification of Floating Offshore Wind Turbines." The guidelines specify the environmental conditions under which floating offshore wind turbines may serve, the principles of structural design, load cases for the platform and mooring system, stability and structural division, and design criteria for the top structure. The guidelines cover floating platforms supporting single or multiple turbines with horizontal or vertical axes.[1] The committee was not able to review these guidelines for this report.

BOEMRE Research Program

Under its Technology Assessment and Research (TA&R) Program,[2] BOEMRE carries out research in support of operational safety and pollution prevention on the OCS. The renewable energy element of the program has sponsored work on offshore wind inspection methodologies, comparisons of offshore wind standards, experience with offshore wind accidents, CVAs, and other topics. For example, BOEMRE held a workshop in October 2010 that reviewed the expected activities of CVAs.[3] It recently awarded a project to ABS covering design standards for offshore wind farms. The project focuses on governing load cases and load effects for offshore wind turbines subject to revolving storms on the U.S. OCS and on calculation methods for breaking wave slamming loads inflicted on offshore wind turbine support structures.

AREAS OF LIMITED EXPERIENCE AND MAJOR DEFICIENCIES IN STANDARDS

Generally, standards embody the collective experience of an industry, but they tend to lag the knowledge base because of the time needed for the consensus-driven standards development process to incorporate the lessons learned. The standards for offshore wind are still immature, and several shortcomings are expected when the first projects are installed in U.S. waters. Third-

[1] Bureau Veritas press release, Jan. 12, 2011.
[2] Information on projects carried out under the TA&R program for renewable energy can be found on the BOEMRE website at http://www.boemre.gov/tarprojectcategories/RenewableEnergy.htm.
[3] http://www.boemre.gov/tarprojects/633/af.pdf.

party assessments (e.g., by CVAs) can overcome the shortcomings by relying on good engineering judgment to determine adequate safety. Examples of deficiencies in offshore wind standards that were identified during this study are described below.

- Type-certified wind turbine designs may not meet the extreme wind gust criteria for some high-intensity hurricanes in the United States. Although turbines should always be type-certified to the expected site wind conditions (under Class S in IEC 61400-1 and 61400-3), the current standard does not specifically address hurricanes in the estimation of peak wind and wave heights, duration of sustained high winds, or extreme directional wind changes. In addition, IEC 61400-3 DLC 6.2 allows dependence on yaw system backup power for 6 hours, which may not be sufficient to ensure safe hurricane ride-through.
- Monopile substructures for wind turbines exceed the diameters and experience base of the oil and gas industry. Extrapolating current practice to the larger sizes can introduce unintended effects. Monopiles up to 5 m in diameter are in use today. In 2010, hundreds of offshore wind turbine installations were discovered to have excessive tilt due to failure of the grouting connection at the tower transition piece. This raises issues concerning vertical tilt tolerances and transition piece grouting practices in the current standards.
- The behavior and possible degradation of soil strength under combined dynamic loading from the wind turbine and waves are not well described in the current standards. Moreover, the empirical cyclic degradation methods specified are not appropriate. A recent paper (Andersen 2009) provides a good description of cyclic degradation of clays under shallow foundations.
- Offshore wind turbines in the Great Lakes will encounter freshwater ice, which may induce first-order loading from numerous new DLCs. Research and specification development for ice loading in the Great Lakes are needed, because the loads cannot be estimated from prior wind energy experience in the Baltic Sea.
- Extreme wave loads may result from breaking waves at some shallow-water sites. The magnitude of the loading will depend on the type of substructure used and in some instances could be a controlling factor in design. Standards require analysis of this condition to estimate (*a*) the wave characteristics and (*b*) the turbine response to the waves, for which models have not yet been validated for some substructure types.
- Gravity-based substructures are used frequently but are more poorly documented in the standards than are steel substructures, which are more commonly used by the offshore oil and gas industry. However, design of shallow-water, steel substructures for oil and gas structures is mainly concerned with preventing plastic collapse, while design of offshore wind turbines is more concerned with preventing failure due to resonance and fatigue.
- Offshore wind turbines are expected to increase in size from about 3 MW per turbine today to possibly 10 MW over the next decade. The scaling up of turbine size may introduce effects not anticipated or covered by any of the current standards.
- Significant experience has been gained since the current IEC offshore wind standards were written. The experience has improved the knowledge base with respect to design requirements for turbine support structures and has led to refinements in design methodologies. Much of this experience has not yet been incorporated into the standards. Moreover, the causes of recent technical failures in foundations and grouted connections and the design requirements to avoid such failures are still being analyzed, so they are likewise not reflected in current standards.

- Floating wind turbine systems are not addressed adequately in any of the current standards. IEC is considering a proposal to write a technical specification on floating wind turbine systems (IEC 2010a). (Bureau Veritas has just released guidelines for the "Classification and Certification of Floating Offshore Wind Turbines," but the committee was not able to review them for this project.)

FINDINGS FOR TASK I: CHAPTER 3

Findings for Chapter 3 appear below. They address Task I of the statement of task. Chapter 4 also addresses Task I. A full set of recommendations for Task I appears at the end of Chapter 4.

1. Regulations in most countries—notably in continental Europe—take a prescriptive approach, regulating in detail the design, construction, and operation of offshore wind turbines to achieve acceptable levels of safety, environmental performance, and reliability.
2. The starting points for most of the offshore wind energy regulations and guidelines (for example, those of DNV, GL, ABS, BSH, AWEA, and the Danish Energy Agency) are IEC 61400-1 (*Wind Turbines—Part 1: Design Requirements*) and IEC 61400-3 (*Wind Turbines—Part 3: Design Requirements for Offshore Wind Turbines*). The IEC standards do not cover all aspects of the design and construction of offshore wind turbines.
3. Nongovernmental organizations and private companies that establish and maintain technical rules and guidelines for the design, construction, and operation of ships and offshore structures—commonly known as classification societies—have developed guidelines. The most comprehensive industry guidelines for offshore wind turbine design, fabrication, installation, and commissioning have been developed by classification societies such as DNV, GL, and ABS. These standards are more comprehensive than are the IEC standards in the sense that they cover both the load and resistance sides, whereas the IEC standards cover explicitly only the load side. However, there are still deficiencies that must be overcome. For instance, the European society guidelines do not explicitly address environmental site conditions for the United States (e.g., storms and hurricane conditions for the Gulf of Mexico and the East Coast). Only the GL rules deal with the design and certification of wind turbine mechanical and electrical components (e.g., the gearbox, the generator, and the control systems).
4. Methodologies for strength analysis differ among the various standards and guidelines and are not always fully delineated. Some standards are based on strength or limit states design, while others are based on allowable stress design. The philosophies underlying these methods are fundamentally different, making it difficult to compare such standards against one another to ensure consistent safety levels, especially when the standards are applied to novel concepts. **There is a need for a clear, transparent, and auditable set of assumptions for strength analyses.**
5. As discussed in Chapter 1, although regulations (MMS 2009) promulgated by the U.S. Department of Interior's BOEMRE require that detailed reports for design, construction, and operation of offshore wind turbines be submitted for BOEMRE approval, they do not specify standards that an offshore wind turbine must meet. Rather, a third party (CVA) is charged with reviewing and commenting on the adequacy of design, fabrication, and installation and submitting reports to BOEMRE indicating the CVA's assessment of adequacy. Moreover, when a general level of performance such as "safe" is identified, no guidance is provided on how to

assess whether this level of performance has been met. **Hence, the BOEMRE regulations and accompanying guidance lack the clarity and specificity needed for the development of offshore wind energy on the OCS.**

6. As discussed in Chapter 2, states and private companies are developing plans for offshore wind energy projects in state waters and on the OCS. Well-defined U.S. regulations for development on the OCS are needed (*a*) to provide a resource for states as they develop requirements for projects in state waters and (*b*) to supply industry with sufficient clarity and certainty on how projects will be evaluated as companies seek the necessary financing. Further delays in developing an adequate national regulatory framework are likely to impede development of offshore wind facilities in U.S. waters. Moreover, developments in state waters could proceed in the absence of federal regulations, possibly leading to inconsistent safety and performance across projects. **The United States urgently needs a set of clear and specific standards and regulatory expectations to avoid these negative outcomes, facilitate the orderly development of offshore wind energy, and support the stable economic development of a nascent industry.**

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Abbreviations

ABS	American Bureau of Shipping
API	American Petroleum Institute
AWEA	American Wind Energy Association
IEC	International Electrotechnical Commission
MMS	Minerals Management Service

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4

A Risk-Informed Approach to Performance Assurance

Task I of the committee's charge, "Standards and Practices" (see Box 1-2), calls for the committee to review the applicability and adequacy of existing standards and practices for the design, fabrication, and installation of offshore wind turbines. Chapter 3 reviewed some of the most important standards that are in use and described some of those that are under development. It also identified some of the deficiencies that would have to be remedied and the analyses that would have to be done before these standards and practices could be used in the United States.

As discussed in Chapter 1, the committee believed that, to respond fully to this task, it had to do more than simply review existing standards and guidance and point to where the deficiencies lie. Other studies have identified at least some of these deficiencies, and the committee has drawn on these studies in developing Chapter 3 of this report. But the committee's view was that, to provide the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) with useful feedback, the committee should offer its perspectives on how BOEMRE might remedy the deficiencies. The best way to do this, it believed, was to step back and review the underlying philosophies that could guide the development of additional standards, regulations, or other guidance documents for offshore wind turbines in the United States.

In applying this broader perspective, the committee reviewed the approaches to oversight of offshore wind turbines taken by European countries. The committee also reviewed how the safety of engineered structures is overseen in other U.S. industries—oil and gas production, waterborne shipping, and buildings—and especially how regulation and other forms of oversight in these industries have evolved.

This chapter begins with a brief review of the risks to human safety and the environment posed by structural failures in offshore wind turbines. It compares these risks with those associated with other offshore industries and with land-based energy industry infrastructure. It then considers how regulation in these areas has evolved away from a detailed, prescriptive model and toward a more performance-based model, and what this suggests about approaches to overseeing wind energy development on the U.S. outer continental shelf (OCS).

RISKS TO HUMAN LIFE AND THE ENVIRONMENT POSED BY STRUCTURAL FAILURE OF OFFSHORE FACILITIES

Government regulation of offshore facilities, such as oil and gas structures and marine vessels, and of land-based infrastructure, such as buildings and bridges, focuses on mitigating risk to human life and the environment. Other risks, such as those of direct economic losses from structural damage and of indirect losses due to interruption of function, forgone opportunities, and loss of amenity, are generally not addressed in government regulations, although they may be of concern to individuals, project operators, insurers, and other stakeholder groups.

Risk to Human Life and Safety

Risk to human life from the structural failure of offshore wind installations is limited compared with risks from other offshore facilities, such as oil and gas platforms and marine vessels. Offshore wind towers are normally unmanned, so they pose limited risk to human life. The most dangerous element in the operation of an offshore wind farm is the transfer of personnel to the turbines for installation, inspection, and maintenance. Because the turbines can only be accessed by boat or helicopter, the ability to reach the turbines is highly dependent on the sea state. Personnel may find themselves stranded on a turbine structure if waves increase in magnitude while maintenance is being conducted. With the exception of wind turbine installations in regions of high seismic activity, however, it is not anticipated that humans would be on any turbine structure throughout the duration of an extreme external condition such as a powerful storm.

The transmission platform, on the other hand, might house personnel for indefinite periods of time, and this fact must be taken into account in designing for human safety in extreme conditions. The need for personnel to be stationed on a centralized transmission platform will increase as farms move farther offshore and the logistics of personnel transfer to shore become more difficult. Designs must also address the potential need for stationing personnel on transmission platforms during inclement weather.

Risk to the Environment

As stated in Chapter 1, the scope of this report is limited to oversight of structural integrity as it is affected by turbine design, fabrication, and installation. As shown in Figure 1-1, the environmental hazards associated with the establishment and operation of offshore wind energy facilities are covered through the National Environmental Policy Act (NEPA) process. These hazards include effects on birds, other wildlife, and the seabed. An environmental assessment or environmental impact statement, as required by NEPA, will be performed for each proposed offshore project (as was done for the Cape Wind project).

The most significant risk to the environment emanating from structural failure of an offshore wind turbine or transmission platform involves the release of transmission fluid or other hydrocarbon-based liquids from the wind farm structures or from the installation and service vessels that would be navigating through an offshore wind park. Proper design and construction of the turbine and transmission platform should preclude all but minor damage due to collision with a service vessel that is moving slowly. However, if the vessel suffered sufficient damage, it could leak its fuel into the ocean. In the event of a catastrophic failure of a structure or vessel, the worst-case scenario would involve discharge into the ocean of the following amounts of hydrocarbon-based fluids:

- Wind turbine (5 MW), approximately 150 gallons (Cape Wind n.d.);
- Transmission platform, approximately 40,000 gallons (Cape Wind n.d.); and
- Installation and service vessels, up to 500,000 gallons (see Box 4-1).

Box 4-1

Offshore Wind Installation and Service Vessels

Installation of the foundations (driving monopiles or setting jackets) will likely be carried out with barges and tugs. A recently delivered derrick barge has a fuel capacity of 300,000 gallons protected by inner bottom and wing tanks. Each tug typically has an aggregate fuel and lubricating oil capacity of 5,000 gallons.

Transportation and installation of turbine components may be accomplishing by using (*a*) a specially designed self-propelled vessel or (*b*) a combination of barges and barge cranes. As an example of the first case, a turbine component installer design offered by Keppel Amfels carries 500,000 gallons of diesel fuel. In the second case, the barge and crane barge described for foundation installation could be used, with the fuel capacities given above. If a lift vessel is used, fuel capacity would likely not exceed 50,000 gallons.

For reference, the amount of oil estimated to have been released into the ocean during the Exxon Valdez oil spill was 10.8 million gallons (Exxon Valdez Oil Spill Trustee Council n.d.).

Comparison with Offshore and Land-Based Fossil Fuel Facilities

Table 4-1 presents the committee's judgment, based on its experience across industries, of the relative risks of offshore wind facilities, offshore oil and gas facilities, land-based fossil fuel extraction facilities, and liquefied natural gas terminals. The table indicates the level of risk to human life and the environment under normal operating conditions. It also shows the risk levels under "design conditions," which are the conditions that the facility is designed to resist or withstand. As shown, the risks to human safety and the environment associated with structural failure of offshore wind turbines are generally lower than for structural failure in the fossil energy industries.

REGULATORY OPTIONS AND POLICY CONSIDERATIONS

Because the environmental and life safety risks of offshore wind facilities are relatively low, the form and extent of government regulation comes into question. If there are smaller safety and environmental risks associated with structural failure of an offshore wind farm, then a natural question to ask is whether the financial and insurance risk assumed by the developer is sufficient for regulating the industry. Or, to put it another way, are there reasons for overseeing the performance of offshore wind structures beyond mitigating these low risks?

TABLE 4-1 Comparison of Risks with Traditional Offshore and Land-Based Energy Industries—Safety and the Environment

	Level of Risk		
Energy Industry	Liquid Hydrocarbon Release	Life Safety: Normal Operations	Life Safety: Design Conditions
Oil and gas—shelf	M	L	M
Oil and gas—“frontier”	H	M	H
Land fossil (coal and natural gas), Texas	VL	L	M
Land fossil (coal and natural gas), Cook County, Illinois	VL	L	M
Land wind facility	VL	VL	L
Offshore wind[a]—“tower”	L	VL	L
Offshore wind[b]—central platform	L	L, M[c]	M
Offshore liquefied natural gas terminal	VL	H	H
Land liquefied natural gas terminal	VL	H	H

NOTE: VL = very low, L = low, M = moderate, H = high. Coding criteria include life safety, protection of the environment, and economic thresholds.
[a]Turbines and turbine support.
[b]Central facilities.
[c]L if evacuated prior to design condition; M if manned.

Policy Considerations

In 2010 the United States made significant strides in the offshore wind rulemaking process, and several projects proposed off the East Coast are progressing through their development phases. Currently, renewable energy development is largely driven by individual state policies and renewable portfolio standards. However, several examples, highlighted below, indicate that federal policy will promote renewable energy on a national level and that offshore wind is an essential component of this policy. National security, energy independence, and economic benefit are cited by government officials as justification for promoting offshore wind development.

Creating an Offshore Wind Industry in the United States: A Strategic Work Plan for the United States Department of Energy was prepared by the U.S. Department of Energy (USDOE) Office of Energy Efficiency and Renewable Energy’s Wind and Water Power Program to outline the actions that it will pursue in supporting the development of a world-class offshore wind industry in the United States. The *Strategic Work Plan* is an action document that amplifies and draws conclusions from a companion report, *Large-Scale Offshore Wind Power in the United States* (Musial and Ram 2010).

A joint initiative between USDOE and the U.S. Department of the Interior (USDOI) titled “Smart from the Start” was announced in November 2010, with a goal of speeding appropriate commercial-scale wind energy development (USDOI 2010). A fact sheet issued on this effort by USDOI states:

> A top priority of this Administration is developing renewable domestic energy resources to strengthen the nation's security, generate new jobs for American workers and reduce carbon emissions. A major component of that strategy is to fully harness the economic and energy benefits of our nation's vast wind potential, including Outer Continental Shelf Atlantic winds, by implementing a smarter permitting process that is efficient, thorough, and unburdened by unnecessary red tape. (USDOI n.d.)

In February 2011, USDOE and USDOI unveiled the "joint National Offshore Wind Strategy: Creating an Offshore Wind Industry in the United States, the first-ever interagency plan on offshore wind energy" (USDOE 2011). As a part of this initiative, several high-priority offshore wind regions were identified to "spur rapid, responsible development of wind energy." In addition, USDOE announced a research and development program at this time to "develop breakthrough offshore wind energy technology and to reduce specific market barriers to its deployment" (USDOE 2011).

SEEKING THE RIGHT REGULATORY BALANCE

The federal government has embraced offshore wind energy as an integral component of its overarching policy of developing clean, renewable energy sources. Thus, the government has a fundamental interest not only in the safety and environmental performance of offshore wind farms but also in their reliability and cost-effectiveness. At the same time, the risks of structural failure to human safety and the environment are low.

The committee's view thus is that minimal regulation will allow market forces to guide offshore wind energy to an efficient solution. Such an approach has policy risk, since lack of a regulatory framework could lead to early project failures that negatively affect public perception and jeopardize future offshore wind development. Other countries have had this experience, with serial component failures leading to repercussions across the global offshore wind industry. For example, in Europe the Horns Rev 1 (see Box 4-2) failures and similar problems encountered by other offshore wind farm projects led to the introduction of site-specific project certification and an expanded scope for verification that extended beyond the generic type certification scheme. As discussed later in this report, it is important that a feedback mechanism be established to ensure that lessons learned are incorporated into the regulatory requirements, standards, and recommended practices.

The committee recommends that U.S. regulation be sufficient to ensure a consistent minimum standard for the design and construction of offshore wind turbines to mitigate the risk of catastrophic failure, such as the failure of a single turbine or of multiple turbines that renders repair and recovery extremely difficult or impossible.

Box 4-2

Horns Rev 1

One of the first large offshore wind farms, the 80–wind turbine, 160-MW Horns Rev 1 facility located off the coast of Denmark, was built in 2002. Early in the facility's operating life the turbines experienced numerous failures, including each of the 80 wind turbine transformers, generators, torque arms on gearboxes, lightning receptors on blades, and foundation coatings. All 80 nacelles were taken ashore for modification. The failures likely set back development of the offshore wind industry throughout Europe as industry and regulators evaluated technical risk and reliability issues. Subsequently, widespread failures in the grouting connection between the foundation and the intermediate support structures have occurred at the U.K. Dogger Bank and Gunfleet Sands wind farms, as well as at the Danish Horns Rev 2 facility (Wan 2010). If such systemwide failures are not avoided, they will negatively affect the development of offshore wind resources as they erode the confidence of both potential investors and the public.

REGULATORY EVOLUTION IN THE OIL AND GAS, MARINE, AND CIVIL INFRASTRUCTURE INDUSTRIES

As noted in Chapter 3, standards, guidelines, and regulation of offshore wind turbines in Europe are primarily prescriptive in nature.

Regulatory oversight in other U.S. industries began with such a prescriptive approach but, in some areas, has been evolving toward a more "performance-based" approach (see Box 4- 3). The following discussion illustrates this evolution by reviewing regulatory developments in the oil and gas industry, the marine shipping industry, and the civil infrastructure industry. It then turns to options for addressing the deficiencies of existing standards and regulations when applied to oversight of the U.S. offshore wind industry.

Oil and Gas Industry

As discussed in *History of the Oil and Gas Industry in Southern Louisiana* (MMS 2004), the first oil and gas structure, built in 1937, was a massive wooden platform constructed in about 15 feet of water in the Creole field in the Gulf of Mexico (GOM). This was at a time when there were no data on the response of frame structures to hurricane forces. Land-based steel design codes, principally the American Institute of Steel Construction (AISC) *Manual of Steel Construction*, were the standards most closely aligned with offshore design and construction materials. Offshore developments progressed over roughly 20 years in the GOM under a variety of operator-specific design approaches and criteria. Design conditions (conditions that the structure must be designed to withstand) were specified probabilistically, where the probability of an event occurring is expressed in terms of the percentage chance that it will occur in any given year.

The most common design condition was a 25-year return period, though other operators used return periods of up to 100 years according to their appetite for risk (MMS 2004). Data to develop the design criteria were collected on an ad hoc basis with limited cooperation between operators (MMS 2004).

Box 4-3

Performance-Based Standards and Innovation

As generally understood, a performance-based standard specifies the outcome required but allows each regulated entity to decide how to meet it. Performance standards give firms flexibility and make it possible for them to seek the lowest-cost means to achieve the stated level of performance (Coglianese et al. 2003).

By focusing on outcomes, performance-based standards accommodate technological change and innovation, which can be key to lowering costs. To the extent that they reduce the costs of power generated by using offshore wind, they increase the ability of this source to compete with other sources of electricity.

See Box 4-4 on the International Maritime Organization's goal-based standards for an example.

By the early 1960s, there were several hundred platforms in the GOM. No major storms affected areas with large numbers of offshore structures until the mid-1960s. The first significant platform failures under storm conditions came in 1964, when Hurricane Hilda destroyed 13 platforms and damaged five others beyond repair (MMS 2004). The following year, Hurricane Betsy destroyed eight platforms (MMS 2004). The storms emphasized the need for developing more consistent design approaches and for gathering better data on wind speeds, wave heights, and soil characteristics for use in the design process. Hurricane Camille in 1969 was another damaging storm, with measured waves far higher than those predicted by the use of existing data (MMS 2004; Berek 2010).

In 1966, the American Petroleum Institute (API) created the Committee on Standardization of Offshore Structures (Berman et al. 1990), and the Ocean Data Gathering Program was set up in 1968 (Ward 1974). These steps were among the first by the industry as a whole to standardize the design of offshore platform structures in the GOM, and they led to the first API design standard for fixed jacket structures, Recommended Practice 2A (RP 2A), in 1969 (Berek 2010). This standard did not specify a design return period for storm conditions. A design wave with a 100-year return period was first specified in the 7th edition of API RP 2A in 1976 (Berek 2010). The 9th edition of RP 2A (which included, among other improvements, more robust joint design guidance) was issued in 1978, and platforms designed to this or later editions are considered by the industry to be "modern." The superiority of such platforms was demonstrated in the aftermath of Hurricane Andrew in 1992, when 75 structures were destroyed, the majority of which were older platforms designed with 25-year return periods and lower decks (Berek 2010; Energo Engineering 2010).

Though storms and their damage were not the only drivers for changes to design guides and industry practice, they have had a significant effect. Figure 4-1 shows a timeline of GOM oil and gas development from its beginnings to the present along with significant storms and subsequent standards developments and changes, as well as changes in industry practice and regulations (Puskar et al. 2006). The storms of the late 1960s led directly to the establishment of the RP 2A standard and its subsequent improvement through the 1970s. Hurricane Andrew led directly to the development of revised load calculations represented in the 20th edition of RP 2A

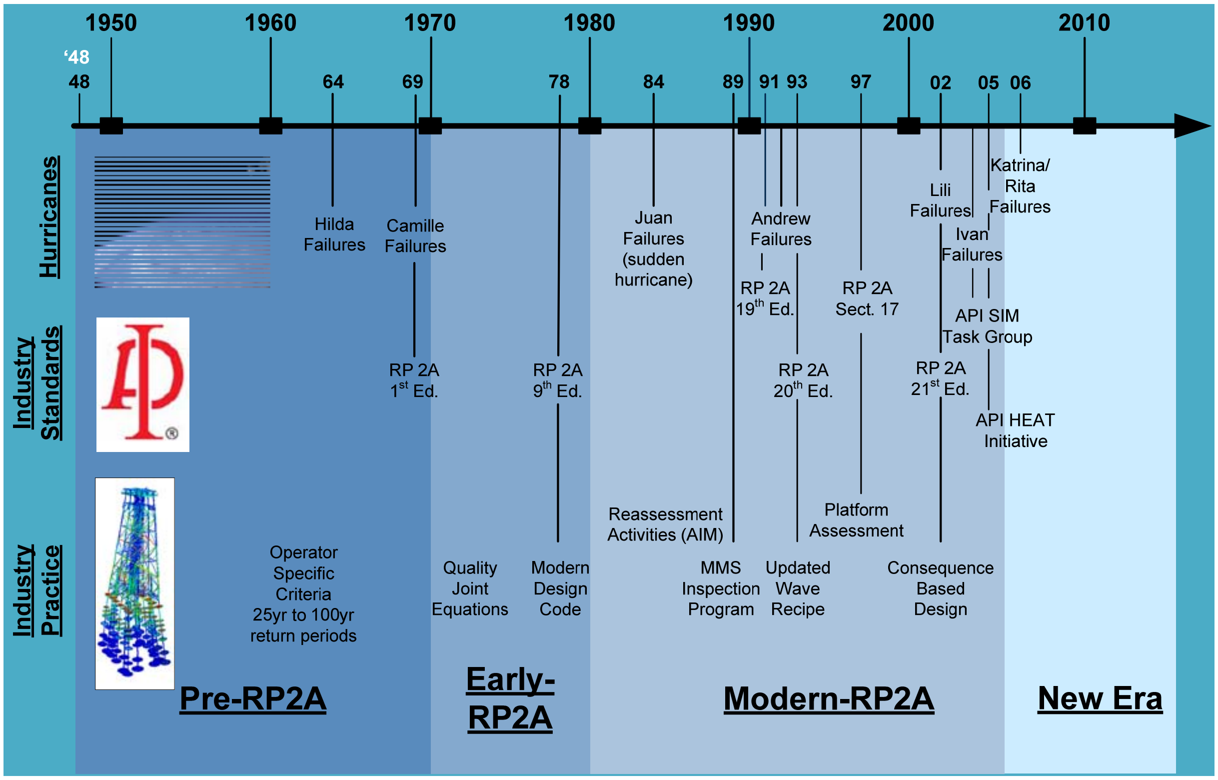

FIGURE 4-1 Timeline of GOM development, industry standards, and practices. (SOURCE: Puskar et al. 2006.)

as well as the development of guidance on reassessment of existing structures (Berek 2010; Puskar et al. 2006). The magnitude of destruction brought about by Hurricanes Ivan, Katrina, Rita, and Ike in the mid- and late 2000s has led to a reassessment of the definition of the design waves for GOM structures. The GOM has been divided into four regions, each with its own design criteria, and the use of older storm data (i.e., pre-1950 data) has been revised in formulating the statistics for calculating design waves (Berek 2010; Puskar et al. 2006).

Just as industry cooperation and standardization were limited in the early years of GOM development, the regulatory environment was limited and uncoordinated. As discussed in Chapter 1, leasing was handled by both state and federal authorities (via USDOI through the Outer Continental Shelf Lands Act of 1953); the U.S. Army Corps of Engineers had some authority, especially as related to installations in navigable waters; and the U.S. Coast Guard (USCG) was responsible for safety (MMS 2004). Setting forth and enforcing design standards were not a focus of any of these groups. The Bureau of Land Management and the Conservation Division of the U.S. Geological Survey (USGS) shared leasing and regulatory functions for USDOI until the formation of the Minerals Management Service (MMS) in 1982. MMS became BOEMRE in 2010. Its regulatory role includes the handling of permits and applications for wells, platforms, production facilities, and pipelines; environmental and safety controls; and inspections (BOEMRE n.d.).

By the late 1970s, platforms were being installed in waters nearing 1,000 ft in depth in areas subject to seafloor instability, earthquakes, and ice and in areas for which little information on the local offshore environment was available. Because of the increasing complexity and perceived risk in these areas, in 1977 USDOI requested the National Research Council to study the need for third-party oversight. The study resulted in the development and implementation of the certified verification agent (CVA) program still in use for the design, fabrication, and installation of offshore oil and gas facilities. The CVA requirements are included in Appendix B of this report.

CVA oversight is required for the more complex offshore structures located in deeper water. Assessment of compliance with the rules of a classification society is not mandatory. Some companies elect to obtain class certification; others do not. Some insurers offer reduced rates if the vessel or structure is certified by class.

API design standards are primarily experience-based and prescriptive. The design levels are well described, usually a 100-year return period loading level with associated factors of safety stated and inherent design parameters specified, such as effective length coefficients, inherent assumption of space frame load redistribution, and normal minimum steel yield to actual yield ratios. The prescriptive methodologies developed over the past six decades have proved to be robust and flexible in that they have been adjusted as experience has been gained and the knowledge base has evolved.

Maritime Industry

The maritime industry covers ocean-based shipping, including international shipping. High-level regulation of international shipping is carried out by the International Maritime Organization (IMO), an agency of the United Nations specifically dedicated to maritime affairs. The two principal IMO conventions, Safety of Life at Sea and MARPOL and MARPOL 73/78 (Prevention of Pollution from Ships), contain the safety and pollution prevention regulations. The nation of registry of a vessel, generally referred to as the flag state, can supplement the IMO regulations with additional requirements. USCG has regulatory authority for vessels registered in the United States. Regulations applicable to U.S.-flag vessels include those of IMO as well as additional safety requirements incorporated into the Code of Federal Regulations (CFR). Nations at which a vessel is calling (referred to as port states) may also implement inspection programs to ensure compliance with international regulations.

The USCG's Alternative Compliance Program (ACP) allows preapproved classification societies, which are nongovernmental and private rule development organizations, to inspect and certify vessels for compliance[1] on behalf of USCG. These classification society rules go beyond the safety and environmental regulations of IMO and cover many aspects of the design, construction, and maintenance of the vessel.

Under the ACP, the international conventions, the rules of the classification society acting on behalf of USCG, and a supplement to the rules are applied as an alternative to the USCG regulations set forth in the CFR. The supplement, which covers the gaps between the specific set of classification society rules and the CFR, is audited (reviewed) for equivalency before a classification society is authorized by USCG to administer the ACP. To date, the American Bureau of Shipping (ABS), Lloyd's Register, Det Norske Veritas (DNV), and

[1] Certain vessel types, such as towed barges, are not covered by the ACP. In such cases, vessels must comply directly with the USCG regulations. USCG Navigation and Inspection Circular 10-82 authorizes USCG to delegate to the classification societies authority to verify compliance with USCG regulations. Offshore fixed and floating structures are also not covered by the ACP.

Germanischer Lloyd (GL) have received such approval from USCG. USCG itself maintains a sufficient level of expertise to audit (review) classification society rules for compliance with international standards and the USGS regulations, to participate effectively in the rulemaking processes at IMO, and to develop additional standards when necessary.

Nearly all ships involved in international trade are "classed" by a recognized classification society. A classed ship is one that has been determined to conform with the classification society's rules. Classification is an expectation of insurance companies and is an explicit requirement of many flag states.

Historically, rules and regulations in the maritime industry have been experience-based and prescriptive, as has been the case for those developed by API. The reliance on prescriptive regulations meant that regulatory development in the maritime industry, as in the oil and gas industry, was primarily reactive, usually relying on a catastrophic event to trigger the next round of changes. This began changing in the 1970s with the introduction of probability-based methodologies for evaluating the survivability of ships. IMO has now adopted guidelines for formal risk assessment that are used in assessing new and updating existing regulations (IMO 2002). IMO has recently adopted goal-based standards applicable to ship structures. This approach is discussed later in this chapter in the section "Risk Mitigation Through Performance-Based Engineering."

Buildings, Bridges, and Civil Infrastructure

The first probability-based standards and specifications in the United States were introduced in the early to mid-1980s [American National Standards Institute Standard A58, now American Society of Civil Engineers Standard 7, and the AISC load and resistance factor design (LRFD) specification for steel buildings]. They have been followed by other specifications as the rationale of the approach has taken hold in the structural engineering community. In these standards and specification documents, the load and resistance criteria were predicated on a set of reliability targets for *member and component* limit states, expressed as a reliability index that was determined from an extensive assessment of reliabilities associated with members designed by traditional methods. Over the years, most building construction materials that have moved toward probability-based limit states design have adopted similar benchmarks, indicating a degree of professional consensus in the structural engineering standard-writing community in the United States. More recent specifications in the bridge and transportation area, typified by the American Association of State Highway and Transportation Officials *LRFD Bridge Design Specifications* (AASHTO 2007), have adopted essentially the same probabilistic methodology as that used in building structures. These first-generation probability-based limit states design standards continue to be member-based; any treatment of system effects is hidden in the member safety-checking equations in the form of effective length factors, strength or ductility factors, and similar simplifications of complex structural system behavior.

TRANSITION FROM PRESCRIPTIVE TO PERFORMANCE-BASED REGULATIONS

The performance of civil infrastructure systems, unlike that of many other common mass-produced engineered (for example, automotive and aviation) systems, is governed by codes, standards, and regulatory guidelines that represent judgments by the professional engineering community based on experience. These documents are key tools for structural engineers in managing civil infrastructure risk in the public interest, and the traditional structural design criteria they contain address the risks in structural performance as engineers have historically understood them. For the most part, these criteria have been based on judgment. This approach to performance assurance generally has served society reasonably well because construction technology has evolved slowly. As in the case of civil infrastructure, the design and construction of marine vessels date back thousands of years, and the development of design codes, standards, and practices has been gradual and deliberate. Historically, these regulations have been *prescriptive*, consisting of detailed, experience-based requirements and formulations that must be satisfied to prove compliance.

In recent years, however, innovation in technology has occurred rapidly, leaving less opportunity for learning through trial and error. New technologies have taken form not only in new concepts, materials, and manufacturing techniques but also through more sophisticated analysis and optimization tools that enable the design of more efficient structures. The public furor caused by recent disasters has made it clear that approaches to risk management based on judgment may not be acceptable and are difficult to justify after the fact. Standards for public health, safety, and environmental protection now are often debated in the public arena, and societal expectations of facility performance have increased.

Over the past several decades, regulations pertinent to the civil and marine industries have begun shifting from empirical or prescriptive formula-based (experienced-based) to performance-based (goal-oriented) standards necessitating application of first principles–based analytical techniques. Risk-based decision making provides a foundation for assessing compliance with goals and objectives and evaluating alternative solutions, and it is now applied extensively both in the development of regulations and in the evaluation of engineering solutions. The first significant offshore oil platforms were designed and constructed in the 1970s; this industry does not have the long history of the civil infrastructure and maritime industries. Experience-based codes and standards were not an option for the oil and gas industry, and therefore risk assessment has always played a fundamental role in the design of offshore structures.

In the United States, the performance concept (as it was called at the time) in building construction dates back to the late 1960s, when the U.S. Department of Housing and Urban Development sponsored a large program at the National Bureau of Standards (NBS) to develop criteria for designing and evaluating innovative housing systems. Subsequent work at NBS led to a performance criteria resource document for innovative construction (Ellingwood and Harris 1977). A set of building elements and desirable performance attributes were identified, which served as a checklist for ensuring that design professionals considered and addressed all items significant to building performance. Each provision consisted of the following:

1. A *requirement* expressing a fundamental human need qualitatively (e.g., “buildings shall be designed and constructed so as to maintain stability under extreme environmental loads”),
2. A set of *criteria* used to check that the requirement is satisfied,
3. An *evaluation* giving approved methods of supporting analysis or test procedures that demonstrate compliance, and
4. *Commentary* that explains the technical bases for each criterion and its evaluation.

RISK MITIGATION THROUGH PERFORMANCE-BASED ENGINEERING

The new paradigm of performance-based engineering (PBE) is evolving to enable new construction technologies and structural design to meet heightened public expectations, to allow more reliable prediction and control of facility performance, and to provide engineers with more flexibility in designing with nontraditional systems and materials and in achieving innovative design solutions. One common feature of most recent proposals for PBE is their distinction among levels of performance for different facility categories where life safety or economic consequences of damage or failure differ. Current codes generally make such distinctions by simply stipulating a higher design load, a step that may not lead to better performance and indeed may be irrelevant for dealing with certain low-probability events where effective design requires other considerations in addition to strength. The design objectives in PBE are often displayed in a risk matrix such as that illustrated in Figure 4-2, in which one axis describes severity of hazard (e.g., minor, moderate, severe) and the second identifies frequency of occurrence. The severity of the incident (consequence) can also be thought of in terms of performance objectives (continued function, life safety, collapse prevention). PBE might require that a critical facility remain functional under an extremely rare event (sustaining minor damage) and provide continued service without interruption under a rare event. Current prescriptive design codes for offshore oil and gas facilities, marine vessels, and civil infrastructure essentially limit their focus to life safety under rare events. The approach represented by Figure 4-2 is a more mature method for managing risk, but one that requires careful communication and mutual understanding among members of the design team rather than a simple reliance on prescriptive code provisions.

Frequency Occurrence Likelihood	Severity of Incident (or Consequences)				
	Incidental (1)	Minor (2)	Serious (3)	Major (4)	Catastrophic (5)
Frequent (5				High	Risk
Occasional (4)					
Seldom (3)					
Remote (2)	Low	Risk			
Unlikely (1)					

FIGURE 4-2 Example risk matrix driven by safety or environmental consequences. (SOURCE: TRB 2008, Figure 2-5).

Whereas the consequence of an event is often quantified in terms of loss of life and environmental damage, the implications for the success or failure of government policy are also a concern. Figure 4-3 illustrates potential policy consequences of various failure types and how regulations can be used to mitigate this risk.

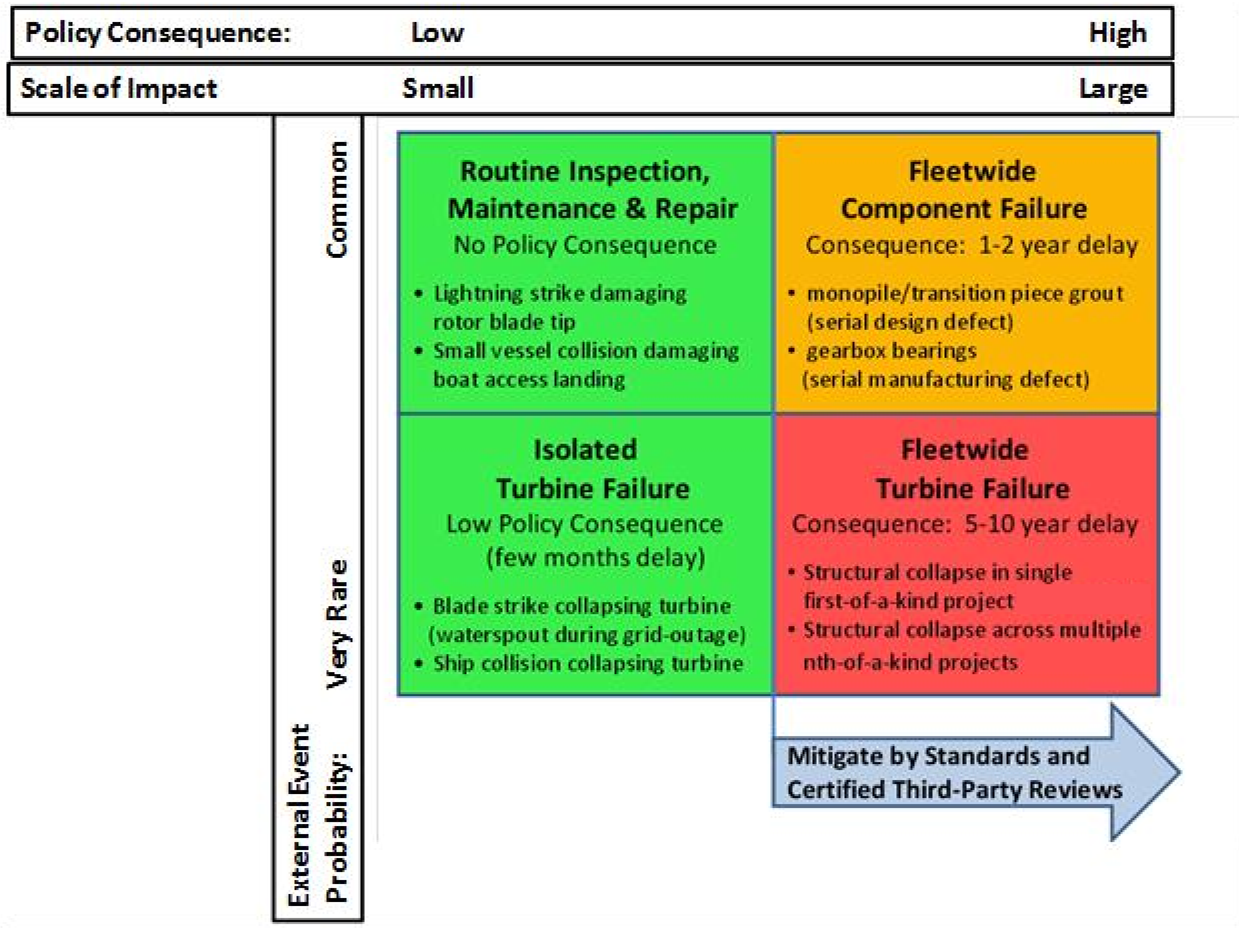

FIGURE 4-3 Example risk matrix driven by policy consequences of failures.
Policy consequences represent the implications for success or failure of government policy—in this case, a policy of supporting the development of the offshore wind resource. Not shown is the consequence of normal but subpar performance—low plant availability or higher costs than projected. These could also delay the development of the industry by making financing and public approval more difficult to obtain.
SOURCE: generated by the committee.

ALTERNATIVE APPROACHES TO REGULATING THE U.S. OFFSHORE WIND INDUSTRY

U.S. offshore wind regulations could take one of the following forms:

a. A comprehensive set of prescriptive regulations that explicitly describe design characteristics, design methodologies, materials, manufacturing standards, and installation procedures;
b. A set of regulations relying on existing national and international standards that are generally prescriptive in nature, with gaps in these regulations filled by a supplementary set of prescriptive regulations;
c. Goal-based standards that describe the overarching expectations for protection of life, environmental performance, and system reliability; or
d. Goal-based standards combined with functional requirements that establish high-level expectations for performance while providing a greater level of specificity on environmental conditions to be considered, design performance metrics, service life expectations, and so forth.

There are advantages and disadvantages associated with each of these options. The following are some of the advantages of a comprehensive prescriptive set of regulations (Option *a*):

- Prescriptive regulations are simpler and easier to implement and typically lead to lower engineering, testing, and design development costs.
- Compliance oversight is more straightforward, placing less reliance on the level of expertise and competence of the regulatory authorities and third-party reviewers.
- Prescriptive regulations are distillations of experience and are generally effective in reducing the risk of the types of accidents that have occurred in the past.

Disadvantages of prescriptive regulations include the following:

- By their nature, prescriptive regulations make suppositions about the design approach and analytical techniques to be applied and can limit the application of innovative approaches that do not suit the assumptions implicit in the regulations.
- Deficiencies in prescriptive regulations can lead to failures on multiple projects, as was the case for the grouting failures described in Box 4-2.
- Prescriptive regulations require a vigilant program of reassessment and updating by a team with a wide range of technical expertise and experience.

Option *a* requires the greatest investment by the regulatory agency with regard to the development and the maintenance of the regulations. Option *b* reduces the level of resources required of the government but has the disadvantage of relying on the expertise and diligence of an outside standards development body to maintain standards. This disadvantage is mitigated when the governmental body actively participates in the standards development and review process.

Advantages of performance-based regulations include the following:

- Performance-based regulations more readily allow for innovative solutions.
- Performance-based regulations provide the designer with greater flexibility and ability to optimize, enabling more efficient solutions.
- Performance-based regulations maintain their relevance. In contrast, prescriptive regulations tend to encompass best practices at the time they are written and eventually become outdated and can conflict with evolving technologies.
- Performance-based regulations are more readily maintained. Adjusting them to reflect evolving public and regulatory expectations is straightforward.
- Performance and safety-based regulations have greater transparency, backed up by defined goals and objectives.
- Performance-based regulations require greater involvement and buy-in by industry, leading to a better understanding of responsibility.

The following are some of the disadvantages of performance-based regulations:

- Performance standards place a greater reliance on the technical competency of the design engineer, fabricator, and third-party reviewer.
- It is more difficult to verify conformity with performance standards than prescriptive standards.

If Option *c* is implemented with only overarching performance standards, there is risk that important design concerns will be overlooked. Therefore, where goal-based standards are specified, requirements are generally further defined by functional requirements, Option *d*. Although goal-based standards are often qualitative, to maintain consistency and provide metrics for monitoring compliance the functional requirements may be performance-based quantitative standards.

When goal-based standards and functional requirements are mandated by the governmental body, prescriptive standards are frequently developed by standards bodies or industry organizations to complement the goal-based and functional requirements. The prescriptive standards are developed such that, at least for conventional structures, compliance with the standard will ensure compliance with the goal-based and functional requirements. This facilitates design and verification when the facilities and environmental conditions are consistent with the assumptions implicit in the prescriptive standards.

GOAL-BASED STANDARDS FOR OFFSHORE WIND TURBINES

The committee recommends that offshore wind turbine regulations promulgated at the federal level be goal-based standards and functional requirements that are performance-based rather than prescriptive in nature (Option *d* above). Such regulations will allow for the development of new technologies that are necessary if offshore wind farms are to develop into a cost-effective energy source. Moreover, the regulations should be risk-informed. Further background on the evolution of risk-informed approaches for regulating the safety of engineered structures is provided in Appendix A. The goal-based standards can be supplemented by prescriptive international and national standards and industry-developed guidelines where appropriate.

The committee recommends that the federal government, presumably under the auspices of BOEMRE, develop a set of goal-based standards for offshore wind turbines by using an approach similar to that applied by IMO for the maritime industry (refer to Box 4-4 for a description of IMO goal-based standards). There are parallels between the situations faced by BOEMRE in rule development for offshore wind turbines and by IMO for oceangoing ships:

1. IMO did not have the expertise or resources to develop rules with sufficient specificity. Although the committee strongly recommends that the size and capability of BOEMRE staff be enhanced, it is not envisioned that BOEMRE will have the means to develop detailed rules.
2. The classification societies had well-developed and validated rules before IMO's involvement in regulating hull structures. Similarly, international standards for offshore wind turbines (e.g., IEC 61400-3) and class rules and guides (GL, DNV, and ABS) are already in place.
3. Deficiencies and inconsistencies among the various classification society rules for shipbuilding were identified as an area of concern. Similarly, there are deficiencies and inconsistencies in the rules for offshore wind turbines, as discussed in Chapter 3.
4. In the case of both offshore wind turbines and shipbuilding, the classification societies and international standards groups are prepared to maintain the currency of their rules and regulations through continuous validation and revision.

The committee envisions the federally mandated goal-based standards for offshore wind energy installations to be a relatively short document—perhaps four or five pages. The goal-based standards should be high-level objectives expressed in terms of performance expectations. The standards will apply to the design, fabrication, and installation of offshore wind farms within U.S. waters and are intended to ensure a level of consistency meeting safety, environmental performance, and policy expectations, while being sufficiently flexible to enable introduction of new technologies and concepts.

While the committee does not have the time, the resources, or the expertise to establish a complete set of specific criteria, an example of the scope and type of evaluation criteria that should be incorporated is given below. Tier 1–type high-level general requirements are given first, followed by Tier 2–type functional requirements. In the latter, the numerical values shown as examples for various items are provided for illustrative purposes only. Actual criteria would be subject to development by BOEMRE and its consultants.

Examples of General Requirements

Structures, foundations, and nonstructural components shall be designed by analysis or by a combination of analysis and testing to provide a performance not less than as stated below when they are subjected to the influence of operating, environmental, and accidental loads. Consideration shall be given to uncertainties in loading and in resistance.

Analysis shall employ rational methods based on accepted principles of engineering mechanics and shall consider all significant sources of deformation and resistance. Assumptions of stiffness, strength, damping, and other properties of components and connections shall be based on approved test data or referenced standards.

Box 4-4

Goal-Based Standards Applicable to the Maritime Industry

As described earlier, the rules for design and construction of ships are developed by classification societies in conformance with national and international regulations. The regulatory authorities concentrated on issues of safety and environmental performance and left standards for hull structural design, materials, coatings, and construction largely in the hands of the classification societies. Comparison of the various classification rules revealed significant differences in structural requirements and expected performance. With encouragement from both national authorities who sought a more consistent level of structural reliability and safety and industry representatives who sought a more level playing field where reduced robustness in the ship's structure and acceptance of higher safety risks were not used for competitive advantage, IMO developed a set of goal-based standards (IMO 2010). These standards establish minimum objectives with which all classification rules must comply.

The standards consist of three tiers.

Tier 1: Goals
Tier 1 defines the high-level objective. An example of a Tier 1 goal is that ships shall be designed and constructed to be safe and environmentally friendly throughout their design lifetimes (when properly operated and maintained under the appropriate conditions). Further definition of terms can be given (e.g., that "*safe and environmentally friendly* means the ship shall have adequate strength, integrity, and stability to minimize the risk of loss of the ship or pollution to the marine environment due to structural failure, including collapse, resulting in flooding or loss of watertight integrity").

Tier 2: Functional Requirements
Tier 2 defines the criteria to be satisfied to conform with the goals. Examples of functional requirements are that ships have a design life of not less than 25 years; that they be suitable for North Atlantic environmental conditions; and that they comply with the structural strength, ultimate hull girder strength, and fatigue criteria after accounting for corrosion expected over the design life.

Tier 3: Verification of Conformity
Tier 3 specifies the procedures for verifying that class societies' rules and regulations for ship design and construction conform or are consistent with the goals and functional requirements.

IMO recognized that it did not have the technical expertise to develop rules with the specificity necessary to satisfy industry and regulatory needs or the resources to maintain the currency of such rules. Thus, the decision was made to keep the goal-based standards at a high level and rely on the classification societies to develop and maintain comprehensive rule sets. The Tier 3 verification process calls for parties seeking verification of rules to provide documentation demonstrating conformity with the goal-based standards. Again recognizing its technical limitations, IMO intends to use consultants with a range of expertise performing under the direction of IMO staff to audit rules submitted for verification.

Testing used to substantiate the performance capability of structural and nonstructural components shall accurately represent the materials, configuration, construction, load intensity, and boundary conditions expected. Where an approved industry standard or practice that governs the testing of similar components or materials exists, the test program and determination of design values shall be in accordance with that industry standard or practice.

Examples of Functional Requirements

The examples below are provided for illustrative purposes only.

1. Offshore wind turbines and electric service platforms shall have a service life of at least _____ years (e.g., at least 20 years).
2. Site-specific environmental conditions shall be used for design.
3. The primary structures (foundations, superstructure, platforms, blades, nacelle supports, etc.) shall be designed and constructed so that the probabilities of falling short (during their service life) of limit states associated with deflections, ultimate strength, loss of stability (buckling), and fatigue are sufficiently small for each individual structure as well as for the fleet of structures (typically installed near one another) that make up an offshore wind farm.
4. The probability, given the design-basis event, of collapse of primary structures (towers, platforms, blades, nacelle supports, etc.) within a wind energy–generating facility shall not exceed ___ (e.g., shall not exceed 10 percent).
5. Wind turbine towers and electric service platforms shall be designed with sufficient robustness that localized damage does not lead to progressive, catastrophic failure.
6. The design fatigue life shall be not less than _____ times the specified service life. For uninspectable areas, the design service life shall be not less than _____ times the specified service life (e.g., 1×, 5×).
7. The primary structures shall have protection against corrosion adequate to ensure that sufficient strength is maintained over the specified service life.
8. Wind energy generation facilities shall be designed to minimize emission of pollutants as far as practical.
9. Wherever practical, structures and equipment shall be constructed of materials that can be recycled in an environmentally acceptable manner without compromising safety.
10. The towers and other structures shall be designed to provide adequate means of access to all internal structures to facilitate close-up inspections of structures and equipment.
11. Designs shall take due consideration of the health and safety of personnel accessing offshore wind turbines and power platforms, including ready access and protection against falls, lightning, and other hazards.

Industry Compliance with BOEMRE Goal-Based Standards

Industry will be responsible for proposing a collection of national and international standards, rules, industry-developed guidelines, and recommended practices (referred to here as a "package of Guidelines") that conform to the goal-based standards established by BOEMRE. As noted later in this section, the standards, rules, industry guidelines, and recommended practices making up the packages of Guidelines could be drawn from classification societies, the International Electrotechnical Commission (IEC), or elsewhere. The packages of Guidelines will likely have prescriptive elements, which are often easier to implement than performance-based requirements. This is acceptable provided that they comply with the goals and objectives established by BOEMRE. It is anticipated that these packages of Guidelines will have as their basis the IEC standards, with additional rules, industry guidelines, and recommended practices to cover all necessary aspects of wind turbine design covered by the BOEMRE goal-based standards and to rectify any areas of nonconformance with the BOEMRE requirements.

To streamline the regulatory compliance process and provide a level of regulatory certainty to the developer, the committee recommends that BOEMRE be prepared to review the packages of Guidelines proposed by a rulemaking or standards development body in the light of BOEMRE's goal-based standards before their application to any particular project. The review process would proceed as follows:

1. The rulemaking body develops a package of Guidelines conforming to the BOEMRE goal-based standards along with the underlying documentation and analysis. Examples of standards, rules, industry guidelines, and recommended practices that could be considered are those developed by GL, DNV, and ABS, or the standards and recommended practices currently being developed by the American Wind Energy Association.
2. When it submits its package of Guidelines for approval, the rulemaking body shall provide documentation and analysis demonstrating that the standards, rules, industry guidelines, and recommended practices contained in the package fulfill all the requirements of the BOEMRE goal-based standards, or it shall clearly identify which requirements are not covered by its package of Guidelines.
3. BOEMRE reviews the package of Guidelines and the underlined documentation and analysis for conformance with the goal-based standards. Once compliance is ascertained, BOEMRE publishes notification of its approval of the package of Guidelines. If the package Guidelines does not fully cover BOEMRE requirements, any deficiencies that must be covered by other standards, rules, industry guidelines, and recommended practices should be identified in the notification.

Alternatively, a developer should be permitted to identify a package of Guidelines that will be apply to a specific project, along with the underlying documentation and analysis, and BOEMRE should be prepared to review and approve such packages on a case-by-case basis. This process is anticipated to take longer than would use of preapproved packages of Guidelines, but it will allow for the introduction of novel concepts that may not be covered in existing, preapproved packages of Guidelines. This approach would proceed as follows:

1. The developer assembles the package of Guidelines (see above) that it proposes to use for a particular project, and it prepares documentation and analysis demonstrating that all requirements of the goal-based standards are satisfied.
2. A third-party CVA reviews the developer's package of Guidelines and the underlying documentation and analysis and provides a statement indicating that the package is in full compliance with the goal-based standards. If the CVA identifies deficiencies or has concerns that are not fully reconciled by the developer, they should be explained in the CVA's report.
3. The developer submits its package of Guidelines, including the CVA's report, to BOEMRE, seeking approval for the package of Guidelines to be applied to the project. BOEMRE either approves the package or sends it back to the developer requesting revisions or further documentation and analysis , or both.

The approval of the package of Guidelines (standards, rules, industry guidelines, and recommended practices) that will be followed to ensure compliance with the goal-based standards does not imply that site-specific assessment and analysis are not required. Project certification (see Chapter 3) with on-site assessment is expected to be a standard part of the design and review process.

OVERVIEW OF PROJECTED BOEMRE ROLE

It is important that a single government agency, presumably BOEMRE, have overall responsibility for regulatory development, monitoring and maintenance of the regulations, and implementation of the verification and oversight regime.

Below is a summary of the role that BOEMRE would play under the approach recommended by the committee. The role is a large one, and BOEMRE may wish to consider creating an expert panel to assist with the initial development of the goal-based standards and then with continuous monitoring and evaluation of the standards and regulations.

a. If so decided, establish an expert panel to assist in initial development of the goal-based standards and then continuous monitoring and evaluation of the regulations (see Chapter 6).

b. Determine the scope of the regulatory standards. To ensure a level of reliability consistent with public policy expectations, the committee believes that the standards must consider design, fabrication, installation, and commissioning from the export cable through to the towers and incorporated systems.

c. By the end of calendar year 2011, develop the goal-based standards and functional requirements, including a rigorous public review process.

d. Review proposed "packages of Guidelines" (compilations of international and national standards, rules, industry-developed guidelines, and recommended practices) for compliance with the U.S. goal-based standards. (As submitted)

e. Review proposed packages of Guidelines during project assessment, where preapproved packages are not applied or where gaps in the preapproved packages are identified. (As requested)

f. By the end of calendar year 2011, establish the intent and scope of the third-party review process (see Chapter 5).

g. By the end of calendar year 2011, establish qualifications for CVAs—third-party reviewers (see Chapter 6).

h. Exercise final approval authority for design and construction in compliance with the regulations (see Chapter 5).

i. Review qualifications and approve CVAs on a project-specific basis (see Chapter 6).

j. Monitor performance of projects versus regulatory expectations and provide periodic feedback to the industry (see Chapter 6).

k. Monitor the effectiveness of the goal-based standards and periodically revise them as appropriate.

l. Monitor the effectiveness of the preapproved packages of Guidelines (national and international standards, rules, industry guidelines, and recommended practices) to ensure compliance with the latest goal-based standards.

m. Monitor the effectiveness of the third-party review process.

n. Periodically review and update the goal-based standards.

o. Serve as the U.S. representative on offshore wind standards development committees, both nationally and internationally.

IMPLEMENTATION: CAPACITY AND EXPERTISE

USDOI's Offshore Energy and Minerals Management program includes both offshore oil and gas and offshore renewable energy regulatory programs. It is staffed by roughly 900 professionals in three regional offices (GOM, Alaska, and Pacific); associated district offices; and headquarters offices in Washington, D.C., and Herndon, Virginia. The headquarters staff has one engineer with a background in civil and marine engineering and naval architecture, and the GOM regional office is supplying an engineer to support the Office of Alternative Energy Projects on an as-needed basis.

The Office of Structural and Technical Support (OSTS) is responsible for ensuring that the platforms operating on the OCS are designed, fabricated, installed, and maintained in accordance with regulations. This group is based in the GOM regional office in New Orleans, Louisiana, and serves as structural support for the Pacific region as well. On the oil and gas side, roughly 3,500 facilities are installed in the U.S. OCS (primarily GOM), and OSTS has fewer than 10 engineers to address permit applications, inspection data, repair information, and all other structural data and requests. Since Hurricane Katrina in 2005, many of the more experienced staff in OSTS, including its director, have left the organization. Remaining staff have less experience in addressing offshore structural issues and no experience in addressing issues related specifically to offshore wind structures.

To enhance its ability to oversee the offshore wind industry effectively, BOEMRE may wish to focus on obtaining staff or contractors with experience in the following areas: offshore structures design, with a preference for experience in offshore wind design; offshore installations, with a preference for experience in pile-founded structures; wind turbine hookup and commissioning, with a preference for offshore experience; and offshore structures operation and maintenance, with a preference for offshore wind facilities experience. Experience with the standards development process would also be beneficial.

FINDINGS FOR TASK I: CHAPTER 4

As noted above, the federal government has embraced offshore wind energy as an integral component of its overarching policy of developing clean, renewable energy sources. Thus, the government has a fundamental interest not only in the safety and environmental performance of offshore wind farms but also in their reliability and cost-effectiveness.

1. Improvements in the efficiency of offshore wind turbine installations and reductions in capital and operating costs are needed if offshore wind energy is to become a highly competitive renewable energy source. Performance-based (goal-based) standards, which are gradually replacing prescriptive standards in other industries including the civil infrastructure, offshore oil and gas, and shipping industries, provide the flexibility needed to accommodate new technologies. They can be administered and modified by the regulatory bodies in a straightforward way, they clarify the responsibility of industry in meeting project goals, and they result in the transparency that comes with the delineation of goals and objectives.
2. As a result of the significant uncertainties affecting facility performance under operating and extreme conditions, recent PBE standards have a risk-informed basis.
3. **Unless its staffing levels and experience are substantially enhanced, BOEMRE will be unable to provide the leadership and decision-making capability necessary for development of U.S. offshore wind standards.**

RECOMMENDATIONS FOR TASK I: CHAPTERS 3 AND 4

These recommendations flow from the findings in Chapters 3 and 4.

To enable timely development of U.S. offshore wind energy within a robust regulatory framework, the following approach is recommended:

1. BOEMRE should proceed immediately with development of a set of goal-based standards governing the structural safety of offshore wind turbines and power platforms. The regulations should be risk-informed (see Appendix A) and should cover design, fabrication, and installation. Offshore wind energy is an emerging technology; therefore, the standards should be crafted to allow and encourage introduction of innovative solutions that improve the safety, environmental performance, reliability, and efficiency of offshore wind facilities. BOEMRE should either develop these regulations within the agency in a timely manner or facilitate development through, or with the advice of, an outside group of experts. In any case, it is imperative that BOEMRE take responsibility for the process and the final product.
2. Because offshore wind projects are already under way, it is essential that BOEMRE provide industry with a well-defined regulatory framework as soon as practical. The U.S. offshore wind turbine regulations should be promulgated no later than the end of calendar year 2011, and a specific plan for meeting that target should be established as soon as possible.
3. On request of a rule development body, BOEMRE should review the rules and guidelines proposed by that body for compliance[2] with BOEMRE's goal-based standards and identify any deficiencies. Once BOEMRE deems a set of rules to be in full compliance with the

[2] A set of rules is deemed compliant if meeting those rules will be taken as sufficient evidence that the performance-based goals have been met.

goal-based standards, it should approve such rules for application to U.S. offshore wind turbines. Examples of rules and guidelines that could be considered are those developed by GL, DNV, and ABS. Preapproved rules should have the benefit of expediting the regulatory review process. However, BOEMRE should be prepared to review standards and guidelines proposed by a developer and accepted by a CVA for compliance with its goal-based regulations on a case-by-case basis.

4. It is critical that BOEMRE establish a substantial core competency within the agency with the capacity and expertise to lead the development of the goal-based standards and review the packages of standards, rules, industry guidelines, and recommended practices submitted by project developers and rules-development bodies. The section “Goal-Based Standards for Offshore Wind Turbines” in this chapter contains more details with regard to the experience and capabilities that are needed.

5. BOEMRE should take a leading role in promoting awareness of lessons learned in the offshore wind and offshore oil and gas industries among project developers, industry professionals, and standards development bodies. The goal is to help industry avoid mistakes that have been encountered elsewhere and to promote practices that have proved to be successful.

6. BOEMRE should be fully engaged in the national and international process for developing standards for offshore wind turbines and should be represented on IEC technical committees and other relevant national and international committees.

REFERENCES

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
BOEMRE	Bureau of Ocean Energy Management, Regulation, and Enforcement
IMO	International Maritime Organization
MMS	Minerals Management Service
TRB	Transportation Research Board
USDOE	U.S. Department of Energy
USDOI	U.S. Department of the Interior

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Role of Third-Party Oversight and Certified Verification Agents

Third-party review of design and construction of infrastructure has a long history. This chapter provides the historical context for infrastructure review, then progressively narrows the scope to practices for land-based energy facilities, offshore oil and gas facilities in the United States, offshore wind energy facilities, and finally to the role of a certified verification agent (CVA) for offshore wind energy facilities.

BACKGROUND

Nearly all incorporated cities and communities along with many states and counties have adopted building codes for facilities and high-consequence public infrastructure, and they have ordinances requiring compliance of design with the applicable building code and construction in accordance with the design. One of the two model building codes, as modified for unique local conditions, is usually adopted. A permit process and building inspections are coupled with the building code. Most jurisdictions issue building permits after review of plans by officials within the jurisdiction; the buildings are subject to inspection during construction.

Other types of infrastructure have third-party review or authorization processes as well. Examples of well-known processes are those developed and implemented by the Federal Aviation Administration for aircraft and those administered by the Nuclear Regulatory Commission for nuclear power plants.

The offshore oil and gas industry operates with a two-tier oversight process under the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE). For facilities of lower complexity and generally lower potential consequences due to an incident, structural plans must be stamped by a registered professional engineer, and BOEMRE staff check submittals against regulatory requirements. For facilities of greater structural complexity, the CVA program has been developed, and compliance with it is required.

Well over 200 years ago, the shipping industry began an oversight process driven by insurance brokers. A number of third-party companies that became known as classification societies developed guidelines covering design conditions, inspection scopes, and provisions for periodic inspection of vessels, which provided the insurance brokers a baseline reliability reference.

A classification society is a nongovernmental organization or private company that develops technical rules and requirements for the design and construction of ships and other marine structures (referred to as class rules) and then ensures compliance with the rules through surveys conducted during construction and throughout the life of the vessel. Classification is generally required by flag states as well as underwriters, and most oceangoing cargo ships are maintained in class.

The European practices and regulations for wind energy turbines were presented in Chapter 3. Primary oversight or review is embedded in the type certification and project certification protocols. Additional oversight may be requested by insurance or project financing entities; however, practices are not uniform.

OFFSHORE OIL AND GAS: HISTORY OF USE OF CVAs

1977 National Research Council Study

In the 1970s, oil exploration and production offshore the United States were increasing rapidly in scope and complexity. The number of wells, the number of facilities, and production volumes grew, and exploration and production extended into deeper and deeper waters. While the greatest focus was in the Gulf of Mexico, activity was under way offshore Alaska and California. Exploration was active as well off the northeast coast.

In 1977, the U.S. Geological Survey (USGS), which at the time handled the responsibilities handled today by BOEMRE, requested the National Research Council (NRC) to undertake a study to determine whether independent third-party review of offshore structures would be of benefit to the federal government. At the time, the federal regulations embodied within Outer Continental Shelf (OCS) Order 8, the forerunner of today's Code of Federal Regulations (CFR) 250, required the structural design of an offshore facility to be stamped by a registered professional engineer.

The NRC study (Marine Board 1977; Gerwick 1977) determined that a third-party review would be of value and recommended that a process be developed and implemented by USGS. Subsequently, USGS developed and implemented a process, known as the CVA program, that is still part of the facility oil and gas permitting and approval process overseen by BOEMRE. The charge to the NRC panel covered fixed offshore platforms. Today, the oil and gas CVA program covers not only fixed offshore platforms but also permanent floating facilities and deepwater production riser systems.

One of the first topics addressed by the panel was the implications of terminology. "Certification" by a "certified verification agent" had a number of perceived definitions, and specific programs were associated with the term "platform certification" in some European regulatory regimes. There was concern that certification

> might imply that the structure was certified to withstand all environmental and man-made impacts upon the structure. However, it is not possible to certify unconditionally that the platform will at all times be safe for operating personnel, or withstand the effects of all storms and seismic conditions, collisions or accidents or that the environment will not be endangered.
>
> Nevertheless, a procedure is required, whatever its designation, to assure the public, the Congress, the USGS and the owner/operator of the platform that the environmental and operating factors have been given consideration in the platform design, construction and installation. This procedure should also indicate that appropriate reviews and inspections have been conducted to document that the design, building, and installation of a platform are in conformance with the applicable performance criteria, specifications, etc. This procedure has been identified as "verification."

The study recommended that USGS, in addition to instituting a verification program, increase staff capability for assessing agent competence and approving facility permits.

The scope of a verification program was outlined. Three distinct areas—design, fabrication, and installation—were described and recommended for oversight. Because of the differing skills required in these areas, the recommendation provided that verification in each area could be performed by independent organizations.

The recommended process was outlined as follows:

1. The operator submits a plan for third-party verification of the structure to USGS.
2. USGS checks the plan, either in-house or by using a contractor.
3. USGS approves the plan if it is adequate (an appeal procedure is available in case approval is denied).
4. The plan is implemented by the third-party engineering and inspection representatives (CVAs) indicated in the plan.
5. USGS monitors implementation of the plan for compliance.
6. USGS institutes a failure reporting and analysis system.
7. An independent government board conducts or reviews investigations of major accidents (this recommendation was never implemented as envisioned).

The verification plan submitted by the operator should set forth the following:

- Environmental criteria to be used;
- Design criteria and procedures to be used;
- Fabrication procedures to be used;
- Installation procedures to be used;
- Operating procedures to be used, including postinstallation inspection and maintenance procedures;
- Techniques and procedures to be used in verification (tests, inspection procedures, etc.); and
- A list of the independent third-party verification agents proposed to be employed.

During the design phase, 30 CFR 250 specifies standards with which the facility must comply. These standards, for offshore U.S. waters, are the American Petroleum Institute (API) Series 2 standards, such as API RP 2A-WSD, 21st edition, for fixed offshore platforms and API RP 2T for tension leg platforms. They are U.S. national standards carrying the American National Standards Institute designation and comply with the institute's requirements of open development procedures, including public participation in the development, review, and approval stages. All comments to proposed standards must be addressed and resolution of comments documented. While the standards are shepherded by an industry organization, they are delivered as U.S. national standards.

Early Years of the CVA Program

In the early 1980s the Minerals Management Service (MMS) maintained a list of preapproved CVAs. An organization could petition MMS to approve it as a CVA for design, fabrication, or installation on the basis of the organization's capabilities. Approval was granted for a period of

3 years. An operator could choose from the list of preapproved CVAs or propose another organization for approval to function as a CVA on a given project. After several years, MMS discontinued the practice of preapproving CVAs because of difficulties in maintaining the list and the relatively few facilities requiring use of a CVA. Only a small subset of the approved CVAs were actually selected and used.

Initial CFR and Notices to Lessees

USGS implemented a CVA program through provisions in OCS Order 8 (later incorporated into 30 CFR 250 Subpart I) and various notices to lessees. The program initially covered structural aspects of *fixed* platforms and has been expanded to cover structural and station-keeping aspects of *permanent floating* production facilities and production risers for the floating facilities. The drilling and process systems of the offshore facilities have not been covered under the CVA program.

The CVA program can be summarized as follows:

1. Design, fabrication, and installation have been designated as distinct phases of a project, and each phase must be verified.
2. A single CVA can be approved for all three phases, or individual CVAs can be approved for each of the three phases.
3. Initially, individuals or companies could petition USGS to be approved as a CVA for a given phase or for multiple phases on the basis of competency. On acceptance by USGS, approval was granted for 3 years. USGS maintained the list of preapproved CVAs by phase.
4. Alternatively, an owner could nominate a CVA for a phase of a project if the proposed CVA was not already on the approved list. USGS reviewed the credentials of the nominee in the same manner as those of a CVA requesting preapproval. If the nominee was deemed qualified, approval as the CVA was granted for the requested project, and the nominee was added to the preapproved list.
5. The approved CVA reviewed the appropriate documentation or field activities and submitted interim reports as outlined in the CVA proposed scope of work as well as a final report to USGS.
6. USGS maintained responsibility for assessing the qualifications of a CVA, approving a CVA for a given project, and reviewing both the facility owner's documentation and the CVA reports. It made the final determination as to the acceptability of the proposed facility.

The NRC study recommended that all future facilities be included within the CVA program. When it was implemented, however, the program excluded routine facilities from the CVA scope and included only

- Platforms with natural periods greater than 3 seconds,
- Platforms installed in water depths exceeding 400 ft,
- Platforms installed in areas of unstable bottom conditions,
- Platforms having configurations and designs that have not previously been used or proven for use in the area, and
- Platforms installed in seismically active areas.

The first platforms to undergo the full CVA program addressing design, fabrication, and installation were installed off the coast of California in 1981, a seismically active area. In developing the details of the CVA program within USGS, the Shell Cognac platform, installed in 1978, was used as a test case to help develop the CVA protocols and procedures.

After implementation of the program, floating facilities were considered for U.S. offshore waters, and a new item was added to the list of those required to use a CVA: all new floating platforms.

The CVA program could be viewed as a supplement to the government staff's ability to review platform installation permits, witness on-site fabrication and installation, and verify compliance with design requirements and fabrication specifications.

The CVA program remains essentially the same as when it was conceived and implemented in the late 1970s. BOEMRE no longer maintains a preapproved list of CVA organizations, and an owner nominates CVAs for each project. Through 2009, 103 fixed platforms and 41 floating facilities have come under the CVA program.[1]

Details of the CVA program, including general requirements for platforms and details of the Platform Approval Program and the Platform Verification Program, can be found in Sections 250.900 through 250.918 of 30 CFR 250 Subpart I.

CURRENT BOEMRE REGULATORY PROPOSALS FOR OFFSHORE WIND TURBINES AND USE OF CVAs

The regulations codified at 30 CFR 285, current as of September 30, 2010, contain requirements for CVA responsibility and scope parallel to those for the offshore oil and gas industry, which have been in effect for 30 years and are described in 30 CFR 250 Subpart I. All the attention for CVA activity is focused on the structural and foundation aspects of the facilities. The key difference is the option that the offshore wind facilities have to waive the CVA elements via petition under specific circumstances. The role of the CVA as described in 30 CFR 285 is parallel to the role of the CVA for oil and gas facilities described in 20 CFR 250—to review, assess, and comment to BOEMRE. Maintaining this advisory role is a critical element of any third-party review process.

SCOPE OF REVIEWS

While the current oversight model for offshore wind energy facilities is based on the offshore oil and gas program, the scope of the latter may be considered too narrow. The offshore oil and gas industry can be partitioned easily into structural, process, and drilling segments. In view of BOEMRE's expertise and its programs for drilling and process systems, there is a logic to limiting the CVA scope to the structural segment in meeting BOEMRE objectives for offshore oil and gas governance.

The same division cannot be made as easily for offshore wind energy systems for several reasons:

[1] Presentation of Tommy Laurendine to the committee, 2010.

- The blades and nacelle assembly are critical components in maximizing the return to the U.S. government.
- A design, manufacturing, or installation flaw in any of the elements of an offshore wind facility will likely affect a significant percentage of a wind farm, not merely the one facility.
- The control elements including gearing, software and hardware systems, sensors, and power supply may be critical in the ability of a blade, nacelle, and support system to maintain integrity in severe weather conditions.
- The dynamics and relative stiffness of the supporting structural and foundation components, commonly envisaged as a monotower in shallow water (but which could be a vertical axis system, a floating system, etc.), have an interrelationship with the stiffness and rotation frequency and loads of the blades that must be carefully addressed in the design for long-term performance.

Hence, it may be desirable to make the scope of the wind energy CVA program much more comprehensive. Figure 5-1 identifies the key components of a wind energy system. For comparison purposes, Item G, the electric support platform, can be viewed as analogous to an oil and gas platform. Table 5-1 compares the scope that may be necessary to ensure coverage for a wind energy facility with that of an oil and gas facility. Table 5-1 also has a column headed "type certification." That column represents the elements that would be satisfied under a comprehensive CVA approach. As can be seen, only two elements, those of a design CVA scope, would be covered for a turbine–nacelle–blade–tower assembly that was type-certified to the International Electrotechnical Commission (IEC) process (see Chapter 3).

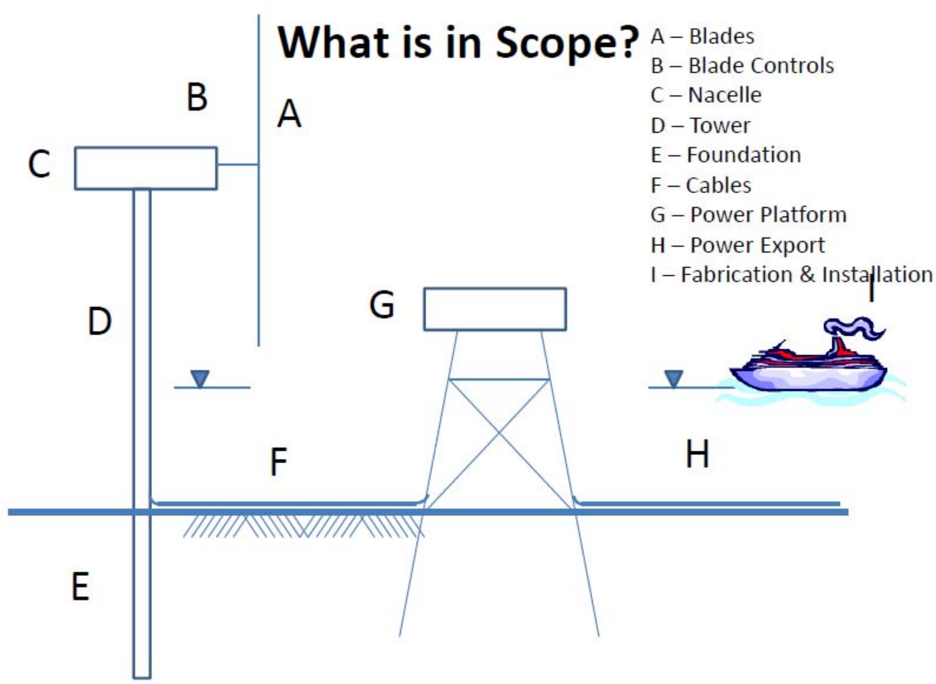

FIGURE 5-1 Key components of a wind energy system.

TABLE 5-1 Comparison of Scopes for Wind Energy and Oil and Gas Facilities

Label	Item	Type Certification	Offshore Wind Energy, 30 CFR 285	Recommended	Oil and Gas, 30 CFR 250
A	Blades	Design	No	Des/fab/inst	N/A
B	Control and protection system	Design	No	Des/fab/inst[a]	N/A
C1	Generator	No	No	No	N/A
C2	Gearbox	Design	No	No	N/A
D	Tower and structural support	Design	Des/fab/inst	Des/fab/inst	Des/fab/inst
E	Foundation	No	Des/fab/inst	Des/fab/inst	Des/fab/inst
F	Infield cables	No	No	Yes	No (infield flowlines equivalent)
G1	Electric service platform	No	Des/fab/inst[b]	Des/fab/inst	Des/fab/inst
G2	Electric service platform; transformers, controls, and so forth	No	No	Des/fab/inst	No (drilling and processing facilities equivalent)
H	Export cable	No	No	Yes	No[c] (export pipeline equivalent)

NOTE: des = design, fab = fabrication, inst = installation.
[a]If design basis requires active blade and yaw control to limit loading conditions.
[b]Implied but not explicitly stated.
[c]No for fixed structures; des/fab/inst for floating structures.

"Type certification" addresses the design of a blade–nacelle–tower subsystem in meeting a set of criteria. Physical proof testing of one manufactured blade demonstrates the product's capacity and performance (strength, deflection, etc.) in terms of the design definition. Type certification does not provide confidence that products as produced meet the design conditions. In other words, the ability to manufacture one device does not ensure that all devices will be manufactured to the same performance characteristics. Type certification is not sufficient in terms of quality assurance/quality control to provide fabrication requirements equivalent to those of CVAs or owners.

For consistency of oversight of an offshore wind farm, the scope of the CVA should be expanded beyond what is required by 30 CFR 285. Without such an expansion, gaps may exist in expected performance similar to those expected with the structural aspects. The scope of a CVA is addressed by 30 CFR 285 in a manner similar to the scope for a CVA in connection with oil and gas facilities addressed by 30 CFR 250, which covers structural and geotechnical aspects for design, fabrication, and installation. Restricting the CVA program to these areas introduces considerable gaps from a systems perspective if balanced risk is an objective.

CVAs AND GOAL-BASED STANDARDS

The use of goal-based standards is increasing, especially in areas where practice is not mature or there is great variability in design conditions. Offshore wind is a young industry with insufficient prescriptive standards and little operating experience with the environment affecting the facilities. These conditions are parallel to those in the offshore oil and gas industry during the mid-1970s. The NRC study recommended that USGS implement a third-party verification system and an advisory board to assist it in establishing a framework for the CVA program.

The use of an advisory board by BOEMRE would be valuable in identifying the interrelationship between goal-based standards and more prescriptive standards and in establishing the framework for CVA assessment to determine adequacy of design, fabrication, and installation details in meeting the goal-based standards.

The use of goal-based standards does not alter the intent or the scope of a CVA; instead, it introduces an additional set of high-level targets that can be used by the CVA as a framework providing consistency in evaluating prescriptive standards and elements within a basis of design and the construction and installation documents.

SUMMARY

In the late 1970s, the development of oil and gas facilities in offshore environments began accelerating in areas posing more severe challenges (e.g., deeper water, earthquake zones, and unstable seafloor sediments) and in areas with little or no historical operating experience. Similarly, in the past 20 years, wind energy facilities in Europe have spread from land to offshore environments. In both of these situations, regulators have used third-party review protocols to assist in the oversight of design, fabrication, and installation of facilities and to provide a higher level of assurance that the interests of the public and the regulations governing these facilities are being met.

FINDINGS AND RECOMMENDATIONS FOR TASK II

The findings and recommendations for Task II of the statement of task are given below.

Findings

1. Wind turbine type certification in accordance with IEC 61400 provides effective oversight and third-party review for
   a. Design of the nacelle;
   b. Design of the blades if the type certification criteria match the installation conditions; and
   c. Design of the tower provided the foundation stiffness matches the design assumptions and specifications of the tower, blades, and nacelle.
2. Type certification does not cover fabrication, transportation, or installation activities.

3. Type certification of blades addresses only design conditions and requires testing of only one blade. There are no fabrication quality assurance/quality control requirements for production.

4. The CVA program defined in 30 CFR 250 may be used as a model for offshore wind projects.

5. The regulations of 30 CFR 285 provide a good definition of the role of a CVA.

Recommendations

1. The responsibility for proposing a comprehensive set of national and international standards, rules, industry guidelines, and recommended practices (referred to here as a "package of Guidelines"), and the underlying documentation and analysis, should rest with the developers. The CVA's role should be to review and comment on the adequacy of the proposed package of Guidelines in meeting the goals and objectives defined in the BOEMRE goal-based standards. Although BOEMRE should consider the documentation and analysis provided by the developer and the report of the CVA, responsibility for approval of the proposed package of Guidelines and for determination of their conformance with the goal-based standards should rest solely with the agency.

2. The scope of the BOEMRE-mandated third-party review process should include
   a. Blades,
   b. Blade controls (if reliance on active controls is required for load reduction),
   c. Tower and structural support,
   d. Foundation and station keeping,
   e. Infield cables and connectors,
   f. Other structural and electrical systems, and
   g. Export cables.

The third-party review should ensure the following:

a. *Design*: The design adheres to good industry practice, the basis of the design is appropriate for the location and stated objectives of the project, site-specific conditions have been appropriately addressed, and the identified codes and standards are adhered to.

b. *Fabrication and manufacturing*: Quality assurance/quality control processes are in place to ensure that fabrication and manufacturing comply with the design and the identified codes and standards.

c. *Installation*: All transportation and field installation activities are performed in a manner ensuring that the facility meets the design intent.

The third-party reviewer should provide periodic reports to BOEMRE with regard to the review findings and should note any deviations or concerns.

3. Type certification of a wind turbine may be substituted for portions of third-party design review subject to the type certification matching site conditions.

4. BOEMRE should retain responsibility for final approval. It is essential that BOEMRE have staff competent to select qualified third parties (see Chapter 6) and to approve projects.

REFERENCES

Gerwick, B. 1977. Verification of Offshore Platform Design and Installation: The Marine Board Panel View. *Proc., Offshore Technology Conference*, Houston, Tex.

Marine Board. 1977. *Verification of Fixed Offshore Oil and Gas Platforms: An Analysis of Need, Scope, and Alternative Verification Systems.* National Research Council, Washington, D.C.

6

Qualifications Needed by Certified Verification Agents

As discussed in Chapter 5, the certified verification agent (CVA) is responsible for ensuring that the design, fabrication, and installation of offshore wind turbine facilities are in accordance with accepted and approved plans and compilations of national and interanational standards, rules, industry guidelines, and recommended practices (referred to here as "packages of Guidelines"). To perform this work, the CVA must have certain capabilities and experience. This chapter explores qualifications required of third-party reviewers, evaluates various approaches to accrediting a CVA, addresses the qualifications necessary for an offshore wind turbine CVA, and discusses the potential gaps in the process in the initial years of CVA implementation in the U.S. offshore wind industry.

SURVEY OF QUALIFICATIONS FOR OTHER THIRD-PARTY REVIEWS

Third-party reviews and verification activities are undertaken for various engineered systems, among them offshore oil and gas, marine, and land-based structural design (including wind turbines). This section explores the qualifications necessary for organizations undertaking these verification activities to provide a background for evaluating what qualifications should be required for the offshore wind turbine industry. The qualifications described in this section are presented as examples from other third-party review systems, which have informed the committee's deliberations on the recommended qualifications for CVAs.

Qualifications Required of Offshore Oil and Gas CVAs

The verification process for offshore oil and gas facilities is the one most closely associated with the process envisioned for offshore wind turbines, because they are both mandated by U.S. Department of the Interior regulations as published in the Code of Federal Regulations (CFR) and directed by the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE), formerly the Minerals Management Service (MMS). Title 30 of the CFR addresses minerals resources, and Parts 250.909 through 250.918 describe the Platform Verification Program (30 CFR 250.909–918) (see Chapter 5).

A list of qualifications necessary for the nominated CVA to be approved by the BOEMRE regional supervisor, such as 10 years or more of experience with offshore fixed platform design or active involvement in three or more fixed jacket installations, is not given by 30 CFR 250. However, a review of the nomination requirements and expected activities of the CVA provides a sense of the necessary qualifications.

The CVA nomination process for oil and gas facilities is addressed in 30 CFR 250.914. Section (b) lists the information that must be included in the CVA "qualification statement," including the following:

- Previous experience with third-party verification;
- Previous experience with design, fabrication, or installation of fixed or floating offshore structures; similar marine structures; and related systems and equipment;
- Previous experience with BOEMRE requirements and procedures;
- Technical capabilities for the specific project and staff availability;
- Size and type of the organization;
- Access to necessary technology such as analysis tools and testing equipment; and
- Level of work to be performed.

The CFR does not include minimum acceptable levels for any of these qualifications, and the evaluation of a CVA's qualifications is subjective and ultimately the responsibility of the regional supervisor. The following is an overview of what, according to the CFR, is expected of the CVA for each of the three project phases: design, fabrication, and installation.

Expectations of CVAs for the Design Phase

The primary design phase activity (30 CFR 250.916) is to perform an independent review of the design on the basis of "good engineering judgment" to determine whether the design is suitable and will allow the system to withstand "environmental and functional load conditions appropriate for the intended service life at the proposed location." The CFR indicates specific areas that must be subjected to the CVA's independent review for both fixed and floating offshore structures; among them are loading, stresses, and foundations. The design CVA must produce a report of findings that identifies how and by whom the independent review was conducted.

Expectations of CVAs for the Fabrication Phase

The primary fabrication phase activity (30 CFR 250.917) is to perform an independent review of the fabrication on the basis of "good engineering judgment" to determine whether the structure matches the design documents and plans. Periodic site visits to where the fabrication is taking place are necessary. The CFR specifies several items that must be verified by the CVA during this phase for both fixed and floating offshore structures, including fabricator quality control, material quality, welder qualifications, and nondestructive testing. The fabrication CVA must produce a report of findings that identifies how and by whom the independent review was conducted.

Expectations of CVAs for the Installation Phase

The primary installation phase activity (30 CFR 250.918) is to perform an independent review of the installation on the basis of "good engineering judgment." This entails reviewing installation plans and procedures and witnessing the installation operations from loadout and towing to launching, uprighting, submergence, and so forth. The CVA is also responsible for evaluating the equipment used and the record keeping that is done. The installation CVA must produce a report of findings that identifies how and by whom the independent review was conducted.

In each phase, the CFR emphasizes the use of "good engineering judgment." While there is no definition of this term, its use indicates a preference for personnel with enough experience to form the basis for exercising good engineering judgment. Given the range of activities required for each of the phases, it is clear that to perform the role of a CVA competently, those involved and certainly the person in charge of the process must have direct experience with the activities of that phase.

Wind Turbine Project Certification

As described in Chapter 3, project certification is a process used to ensure that the equipment and supporting structure are adequate for conditions at the site and meet the site's requirements. It involves monitoring of activities during manufacturing, transportation, installation, and commissioning. Project certification also considers the life cycle of the facility and includes provisions for periodic monitoring, inspection, and maintenance.

The qualifications for a certification agent vary with the regulator in the area where the wind turbines are to be installed. In some cases, there is no regulatory requirement for project certification, but the operator or developer may need certification to obtain financing or for other reasons. In these cases, certification is generally provided by an organization, such as Germanischer Lloyd or Det Norske Veritas, that has developed its own set of guidelines for designing, installing, and maintaining wind turbine facilities. The organization will certify that the project has met its guidelines and any local jurisdictional requirements. Other organizations, such as Bureau Veritas, that have not developed their own guidelines may also provide certification. In such cases, the qualification for the certifier is its institutional knowledge of the topic through development of detailed guidelines and through its work with the industry.

As described in Chapter 3, where such certification is required, it is typically provided by an organization that has been accredited to provide these services. For instance, the German Federal Maritime and Hydrographic Agency accredits organizations to provide certification on projects in Germany. Accreditation is based on evaluations of professional competence, independence, impartiality, and integrity. Accreditation is generally valid for a period of time, after which the review process is repeated to ensure that the organization remains in compliance.

Qualifications Required for Performance-Based Design Peer Review

Standard building codes and industry practice use a prescriptive design approach that does not always lend itself to the design of atypical or unusual structures such as high-rise buildings or buildings with unique architectural features. As noted in Chapter 4, building codes and industry practice generally do allow the use of alternative means and methods, one of which is performance-based design (PBD). A peer-review process in support of PBD approaches is used as a means of determining whether a design meets the intent of basic code requirements, is equivalent in terms of safety to a code-compliant structure, and meets project-specific design criteria and performance expectations for the facility.

A peer review is not intended to be a critique of the design concept developed by the engineer of record. In some cases, such as for structures in areas of high seismic activity, especially where the design is atypical, the peer review is mandated by regulators, but it may also be implemented by the developer to satisfy expectations of insurers or financiers.

One description of this type of peer review comes from the Los Angeles Tall Building Structural Design Council in its publication *2008 Alternative Design Criteria*. The council proposes that each project convene a seismic peer-review panel to provide an "independent, objective, technical review of those aspects of the structural design" related to seismic performance. Its recommendation is for a panel of at least three members with "recognized expertise in relevant fields" to be selected by the building official of the jurisdiction. (See http://www.tallbuildings.org.)

Others

Peer-reviewed designs are becoming more common in the assurance of fire protection of buildings as well. The Society of Fire Protection Engineers (SFPE) has developed guidelines for the peer-review process in fire protection design (*Guidelines for Peer Review in the Fire Protection Design Process*, October 2002). With regard to qualifications, the society emphasizes independence and technical expertise. It gives a specific example of how one can demonstrate technical expertise: the peer reviewer should have the knowledge to prepare an "acceptable design that is similar in scope to the design being reviewed." This definition is attributed to Section 1.2.1 of the *SFPE Engineering Guide to Fire Protection Analysis and Design of Buildings*.

This document also describes peer reviewers as those who are "qualified by their education, training and experience in the same discipline, or a closely related field of science, to judge the worthiness of a design or to assess a design for its likelihood of achieving the intended objectives and the anticipated outcomes."

U.S. REGULATIONS FOR OFFSHORE WIND TURBINE CVA QUALIFICATIONS

Language in the current CFR addresses requirements for offshore wind turbines. Sections 705 through 714 of 30 CFR 285 are related to CVAs for offshore renewable energy. Three areas may be covered by the CVA process: the facility design report, the fabrication and installation report, and the modification and repair report.

Section 705 describes when a CVA must be used and provides guidance on when BOEMRE may waive the use of a CVA for any or all of the three phases (design, fabrication, and installation). Section 706 addresses the CVA nomination process. As in the case of offshore oil and gas facilities, a qualification statement is required that includes the following:

- Previous experience with third-party verification;
- Previous experience with design, fabrication, repair, or installation of offshore energy facilities;
- Previous experience with BOEMRE requirements and procedures;
- Technical capabilities for the specific project and staff availability;
- Size and type of the organization;
- Access to necessary technology such as analysis tools and testing equipment; and
- Level of work to be performed.

Unlike the regulations of 30 CFR 250, the offshore wind turbine regulations require that the verification work be directed by a registered professional engineer. Each U.S. state implements its own professional engineer registration process to provide a specific minimum level of work experience and competency, although the experience and competency may not be directly related to offshore wind facilities. BOEMRE would determine whether an organization having international engineers with credentials equivalent to those of a U.S. registered professional engineer would be considered acceptable for providing CVA services.

The guidance on activities to be performed at each stage of the project is similar to that provided in Part 250 and summarized in the section on offshore oil and gas CVA above.

EVALUATION OF ACCREDITATION APPROACHES

Generally, there are two approaches in determining whether a person or organization is qualified to perform CVA activities: project-specific and authorized list. Some of the advantages and disadvantages of each approach with regard to offshore wind turbines are examined below.

Project-Specific Accreditation

This approach is used by BOEMRE for offshore oil and gas CVA selection and is inherent in the proposed CFR language for offshore wind turbines. A CVA is nominated by the operator for each project and must be approved by the BOEMRE regional director.

The regional director is responsible for evaluating the qualifications of the proposed CVA and determining whether the nominee is suitable. This can be cumbersome if the regional director does not have sufficient time, expertise, or staff to devote to these evaluations and could lead to delays in projects as they await approval or to rubber-stamping of nominees without proper consideration of their qualifications. However, this approach has the advantage of producing current qualification information from the potential CVA, and the qualification process is readily auditable for each project.

No process and no objective criteria are available for use by the regional director in determining whether a nominee is qualified for a given project and scope, and there is no way to estimate how long the determination will take. The process should be clearly defined, and operators should have an expectation of the time required to approve the nominee.

Authorized CVA List

When the CVA process was introduced to the offshore oil and gas industry, the authorized list approach was used. Preapproved CVA organizations were identified, and an operator could select one from the list without further approvals or reviews. This had the advantage of clarity and timeliness for the operators and freed regulators from reviewing qualifications for each project that required a CVA.

However, the authorized list must be kept current, since personnel available at the time of approval may not be available when the projects get under way. Periodic auditing of the list is required to ensure that it represents qualified organizations. Furthermore, the list creates a barrier to participation for individuals and organizations that are not on the list, although they may be qualified.

To implement an authorized list effectively there should be

- A regular review of the authorized organizations,
- A process for removal from the list,

- A regular opportunity to add new organizations to the list, and
- An auditing process to ensure that personnel performing CVA duties are those whose qualifications were cited to get on the list.

An authorized list can be advantageous, although it may be just as burdensome for the regulator, given the work required to maintain the list and ensure that it is used properly.

The committee heard from a former director of the MMS Office of Structural and Technical Support, who described how the oil and gas CVA process was implemented. He expressed the opinion that the maintenance of an approved list was impractical given how personnel moved from company to company and the inability of MMS to monitor effectively the expertise of the companies on the list. This led to the abandonment of the list and the move to project-specific approvals of CVAs.[1] The difficulty in maintaining an approved list would be similar for the offshore wind industry. This difficulty, coupled with the successful use of project-specific approvals for the oil and gas CVA process, makes project-specific lists the preferred approach for CVA approval.

The International Electrotechnical Commission (IEC) is revising its standard 61400-22 for conformity testing and certification of wind turbines. It has established an advisory committee of certification bodies to provide advice on, among other things, harmonization of certification requirements and interpretation of technical requirements. Involvement of BOEMRE with this committee would be useful as a means of interacting with other regulators facing similar issues and staying informed on issues relating to wind turbine certification and the accreditation of CVAs.[2]

OFFSHORE WIND TURBINE CVA QUALIFICATIONS

In addition to being independent and demonstrating good engineering judgment, a third-party reviewer should have technical expertise related to the work being reviewed. In evaluating the qualifications of CVA candidates for offshore wind turbines, their expected areas of expertise should be identified. As the preceding sections show, however, they are not usually identified. The following sections outline the committee's suggested expectations for a CVA qualified to perform each of the three review phases. The expectations are based on the direct experience of the committee members, reviews of existing guidance documents for offshore wind turbines, and CFR requirements.

Design CVA

A design CVA should have expertise in the following areas:

1. Identification, specification, and implementation of design limit states. These are especially important for offshore wind turbine designs given the variety of load cases that must be considered under the IEC standards and other relevant guidance and the need to incorporate load conditions not generally encountered for offshore European facilities, including hurricanes and earthquakes.

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[1] Presentation of Tommy Laurendine to the committee, August 10, 2010.
[2] "Report from MT22." http://wind.nrel.gov/public/TC88/Report%20from%20MT22.pptx.

2. Fatigue and strength design approaches, including the effects of coupled wind–wave dynamics. The CVA must be able to understand the techniques used in the analysis and design process and identify whether design assumptions are valid and the conclusions are supported by the results.

3. Determination of the adequacy of proposed design environmental conditions. A CVA must understand the prevalent environmental conditions affecting the site and be able to assess whether the site-specific criteria developed for the project have been adequately considered in the design approach and the final design.

4. Evaluation of foundation design. Within U.S. waters, a variety of soil types and factors affect foundation design (e.g., scour). The CVA must be able to identify whether the design approach is suitable for local conditions and verify that long-term effects such as cyclic degradation and scour have been adequately addressed.

5. Interaction between the foundation and the turbine system. In contrast to the case for offshore oil and gas permanent structures, the interaction between the wind turbine's above-water structure and the substructure and foundation has a dynamically driven response that must be considered in the design and understood by the CVA to ensure that it has been adequately addressed.

6. Determination of the adequacy of the geotechnical assessment. The quality of soil data can vary greatly depending on who does the investigation, where the borings are taken in relation to the foundation, and the age of the data and their interpretation. The CVA must understand these factors and be able to determine whether the soil data are suitable for the foundation design.

7. Performance of design calculations similar to those provided in the design reports. This is not a requirement that independent calculations be performed but that the CVA be able to perform them as necessary.

Fabrication CVA

A fabrication CVA should have expertise in the following areas:

1. Fabricator quality control. The CVA should be familiar with quality control processes and be able to perform audits of the fabricator's systems to determine compliance specific to the project.

2. Material quality evaluation. The CVA should understand material traceability procedures and be able to determine whether project requirements are suitable and whether the manufacturer is effectively managing these processes for the project.

3. Welder qualifications. The CVA must have a working knowledge of welder qualifications and how they relate to the project and be able to determine whether project qualification requirements are suitable and are being met by the fabricator.

4. Nondestructive testing. Tests for welds and other fastenings, blades, and other structural systems are done to help ensure that fabrication is proceeding according to the design documents. The CVA should be familiar with the project requirements and how such tests are carried out and interpreted.

5. Destructive testing (e.g., full-scale blade tests). In some cases, destructive testing may be called for in project documents to demonstrate that equipment and systems meet specifications (e.g., blades may be tested to failure under certain loading conditions). The CVA

should understand the project requirements and how such tests are to be carried out and interpreted.

6. Blade materials and fabrication. Blade fabrication is a specialized process with unique use of skin materials and substructure to achieve the desired aerodynamics and strength. The CVA should have experience with the materials used and the fabrication process so that the CVA can evaluate the suitability of the blade manufacturing process and results and determine whether the manufacturer's quality control process can be relied on to produce blades to the desired specification.

Installation CVA

An installation CVA should have expertise in the following areas:

1. Evaluation of installation plans and procedures. The CVA must be familiar with how offshore installation activities are carried out and be able to review project procedures and plans for correctness and suitability for site-specific conditions.
2. Witnessing of installation operations including loadout, towing, launching, uprighting, submergence, and so forth. The CVA must have experience with offshore installation activities and have knowledge sufficient to document the activities and identify any anomalous conditions.
3. Marine operations. The CVA should be familiar with marine operations from loadout to sea fastening and transportation to the site. This will enable the CVA to document the process and identify any anomalous conditions encountered.
4. Subsea cabling activities including trenching, burial, and connections. The transmission cables used to interconnect the turbines within a field and to connect to shore-based facilities require attention during installation to ensure that they are properly trenched or buried according to the design of the system and that connections are properly completed. The CVA should be familiar with these operations.
5. Offshore construction activities. The CVA must understand how typical offshore construction activities (e.g., launching, lifting, and erecting the facility) are carried out and be able to document that they were implemented successfully and where deviations occurred.
6. Installation equipment. The CVA should have an understanding of the equipment to be used in the installation process and be able to determine that it is being used as intended for the project in a safe and reliable manner.

In addition, the CVA should be able to define the amount of attendance required by the CVA at various offshore activities in conjunction with the installation contractor and BOEMRE. The amount of attendance required should be based on the complexity of the activity and the contractor's experience with similar activities.

Other Aspects of CVA Qualifications

The experiences of some committee members and information provided to the committee by presenters indicate that having CVAs for the design phase different from those for the fabrication and installation phases is acceptable in current offshore oil and gas practice. No restrictions on the assignment of CVA responsibilities to different organizations for different phases are imposed by 30 CFR 250. In practice, organizations with expertise in design do not necessarily have expertise in fabrication or installation activities. Thus, it is expected that different CVAs will be responsible for different phases unless it can be demonstrated that a single individual or organization has sufficient expertise as outlined above to direct all or a combination of the phases.

Local environmental, soil, and marine traffic conditions vary greatly throughout U.S. coastal waters. The variations affect loads that control tower, foundation, and turbine designs; installation conditions such as local sea swells; pile-driving requirements; and a variety of other factors. Expertise with conditions in one location may not be directly applicable to other locations. In some cases, knowledge unique to a particular location (e.g., seismic effects offshore California) may be required. The expertise of the CVA should be considered in relation to the location of the project to determine whether that expertise is applicable to local requirements.

Finally, in the committee's opinion, a CVA should have a quality assurance plan that addresses the processes used in the CVA activities and the record-keeping ability necessary to track the project adequately and document results. Such plans may, but are not required to, adhere to International Organization for Standardization or other standards for quality assurance, but they should be maintained in such a way that a compliance audit could be conducted and passed. Adherence to such a plan helps ensure that data are properly tracked (e.g., nondestructive evaluation test reports and project interim reports) and that the CVA activities capture all necessary aspects of the project.

FILLING THE EXPERIENCE GAP

To date, no large-scale offshore wind turbine projects have been designed for or installed in U.S. waters. As described in Chapter 3, while a number of projects have been installed in European countries, the local design conditions (e.g., hurricanes) expected for U.S. facilities have not been addressed in detail, and potential fabrication and installation obstacles have not been encountered. Thus, there is a potential gap in experience that will affect the ability of a CVA to review the activities of designers, fabricators, and installers effectively, because the CVA will be learning side-by-side with the principal participants in the projects.

Experience in regulating the offshore wind industry is lacking. BOEMRE has a long history of regulating the U.S. offshore oil and gas industry, and its familiarity with operators, designers, fabricators, and installation contractors is invaluable in evaluating the expertise and qualifications of potential CVAs. This familiarity does not exist for the offshore wind industry, and BOEMRE lacks staff with experience in regulating, designing, installing, or operating such facilities.

The lack of experience within BOEMRE with regard to offshore wind turbine facilities could inhibit its ability to provide effective regulation. One of its roles within the CVA process for offshore renewable projects is to determine whether a CVA is required and whether the proposed CVA is suitable for the tasks assigned. This role is difficult to accomplish without experienced, dedicated staff. It is vital that BOEMRE act in a timely fashion to hire staff as described in Chapter 4 in the section "Implementation: Capacity and Expertise" to fulfill its regulatory role.

The committee believes that the CVA process can produce valuable information for BOEMRE with regard to the design and installation of wind turbine projects in the United States. The details provided through CVA reports during the course of the projects should be carefully reviewed by BOEMRE and evaluated for information that may lead to better regulation or better guidance documents for the industry. This would not place additional burdens on the CVA or on developers and contractors, but it would require BOEMRE to dedicate staff to this task.

BOEMRE may also wish to consider creating a panel of industry experts to advise it for the duration of the first several projects. Such a panel could provide BOEMRE with feedback and guidance on the submitted design documents and the plans for fabrication and installation. This group of experts would also benefit BOEMRE and the industry as they implement the first several offshore wind turbine farms in U.S. waters. The panel would supplement the CVA for the project and would bridge the experience gap for both the industry and the regulator. It would also help disseminate lessons learned throughout the industry if the panel were tasked with documenting its findings and recommendations at the completion of its mandate. Such a panel would need a range of expertise similar to that described in the section on offshore wind turbine CVA qualifications. Ideally, the panel would have expertise in design of offshore wind or oil and gas structures; offshore transportation and installation, particularly for fixed structures; and structural engineering and fabrication with a preference for experience specific to offshore wind. Panelists could come from a variety of backgrounds and could include developers, designers, representatives from academia, and representatives from regulatory bodies. While establishing a panel that meets all those requirements may be impractical, the broader the range of expertise, the more effective the panel will be.

In Chapter 4 in the section “Overview of Projected BOEMRE Role,” the committee noted that BOEMRE may wish to use such an expert panel to assist in the initial development of the goal-based standards and then in the continuous monitoring and evaluation of the standards and regulations. If desired, a single panel could serve all of these purposes.

To eliminate concerns about conflict of interest, controls would be needed to ensure that those impaneled did not use their appointment as a means to promote their business or gain leverage for future work as CVAs or as principals in offshore wind farm work. This is essentially an administrative detail that BOEMRE would need to address and implement.

FINDINGS AND RECOMMENDATIONS FOR TASK III

Task III of the statement of task calls for the committee review the expected experience level, technical skills and capabilities, and support equipment and computer hardware/software needed to be considered a qualified CVA.

Findings, Task III

On the basis of a review of the implementation of the CVA process for offshore oil and gas facilities, the proposed CFR language for an offshore wind CVA, and how other engineered systems implement third-party reviews, the following are the committee’s key findings with regard to CVA qualifications.

1. A qualified CVA must be
    a. Independent and objective, with no involvement in the scope of work being reviewed (i.e., design, fabrication, or installation);
    b. Experienced in performing scopes of work similar to that being reviewed, with detailed knowledge of the codes and standards being applied; familiarity with the approaches proposed by the developer; and the technical expertise and engineering judgment to verify assumptions, conclusions, and results independently; and
    c. Directed by a registered professional engineer (or international equivalent). The intent of this requirement is to establish a baseline level of experience and qualifications for the CVA lead. It is the opinion of the committee that this goal can be achieved through both U.S. and non-U.S. professional registrations.
2. A CVA for the design stage must have expertise in
    a. Identification, specification, and implementation of design limit states;
    b. Fatigue and strength design approaches, including the effects of coupled wind–wave dynamics;
    c. Determination of the adequacy of proposed design environmental conditions for the site;
    d. Evaluation of foundation design;
    e. Evaluation of interaction between the foundation and the turbine system;
    f. Determination of the adequacy of the geotechnical assessment; and
    g. Performance of design calculations similar to those provided in the design reports.

This is not a requirement that independent calculations be performed but that the CVA be able to perform them as necessary.

3. A CVA for the fabrication stage will need expertise in
    a. Fabricator quality control,
    b. Material quality evaluation,
    c. Welder qualifications,
    d. Nondestructive testing,
    e. Destructive testing (e.g., full-scale blade tests), and
    f. Blade materials and fabrication.
4. A CVA for the installation stage will need expertise in
    a. Evaluation of installation plans and procedures;
    b. Witnessing of installation operations including loadout, towing, launching, uprighting, submergence, and so forth;
    c. Marine operations;
    d. Subsea cabling activities including trenching, burial, and connections;
    e. Offshore construction activities; and
    f. Installation equipment.
5. The CVA for design, for fabrication, and for installation need not be the same organization or person, and it is unlikely that a single person would have sufficient expertise to perform effectively as CVA for all phases.
6. It would be beneficial, though not essential, for a CVA to have experience in third-party reviews and in interacting with regulatory agencies.

7. Given the variety of controlling environmental loads (e.g., hurricanes, seismicity, icing) and installation requirements (e.g., mudslide areas, tidal erosion effects) in U.S. waters, the CVA's experience should be related to the installation location.
8. Experience with the use of project-specific CVA approvals in the offshore oil and gas industry indicates that project-specific approval of CVAs is better than maintenance of a list of BOEMRE-accepted CVAs.

Recommendations, Task III

The committee recommends the following with regard to CVA qualifications:

1. In evaluating potential CVAs, BOEMRE should seek organizations and individuals that
   a. Are independent and objective;
   b. Have experience, technical expertise, and engineering judgment sufficient to verify assumptions, conclusions, and results independently;
   c. Have experience with the dominant environmental effects for the project location (e.g., earthquake-resistant design experience for offshore West Coast locations);
   d. Have experience in the areas described in the findings section above for the CVA tasks (i.e., design, fabrication, and installation) for which they are nominated;
   e. Have clearly defined roles and responsibilities with adequate oversight by a registered professional engineer (or international equivalent); and
   f. Have an auditable quality plan for the processes and record keeping involved in the CVA activities.
2. BOEMRE should hire sufficient staff with adequate expertise (as described in Chapter 4 in the section "Implementation: Capacity and Expertise") to oversee the development of wind farms in U.S. waters by the end of calendar year 2011.
3. BOEMRE should approve CVAs on a project-specific basis as opposed to maintaining an approved list of qualified CVAs.
4. BOEMRE should actively manage the CVA process for offshore wind facilities by disseminating lessons learned from the CVA process to promote good practices to the industry.
5. BOEMRE should consider creating an expert panel to provide feedback and guidance for the initial offshore wind development projects as a means to fill the experience gap for both industry and regulators.
6. BOEMRE should actively participate in the IEC Wind Turbines Certification Bodies Advisory Committee as a means of staying informed on issues relating to wind turbine certification and the accreditation of CVAs.

7

Summary of Key Findings and Recommendations

The charge of this committee was to review the proposed approach of the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) in overseeing the structural safety of offshore wind turbines. It was to consider the design, fabrication, and installation of these turbines. Specifically, the committee was charged with providing findings in three areas: standards and practices, the role of certified verification agents (CVAs), and the qualifications needed by CVAs. Specific findings and recommendations in these areas are given at the ends of Chapters 3, 4, 5, and 6 of this report. Those chapters should be consulted for details. The sections below summarize the committee's key findings and recommendations.

During its review, the committee noted that the U.S. government, having committed to exploiting the offshore wind energy resource, has an interest in industry performance for reasons beyond its statutory mandate to ensure the safe, orderly, and environmentally responsible use of the outer continental shelf (OCS). For policy reasons, it also wants to foster the growth of the nascent U.S. offshore wind industry (see the Chapter 4 section "Regulatory Options and Policy Considerations"), which will require setting clear regulatory expectations soon and encouraging the innovation that will help make offshore wind power generation more economically competitive with other sources of electricity.

FINDING: SAFETY AND THE ENVIRONMENT

The risks to life safety and the environment and the consequences associated with those risks are much lower for offshore wind plants than for offshore oil and gas platforms, ships, and land-based civil structures such as buildings. Oversight of offshore wind development should take this into account but will also need to reflect the importance of successful and reliable operation of offshore wind turbines to policy goals.

FINDINGS AND RECOMMENDATIONS: STANDARDS AND PRACTICES (TASK I)

The committee was tasked with reviewing the applicability and adequacy of existing standards and practices for the design, fabrication, and installation of offshore wind turbines. In response to this charge, the committee reviewed the standards and guidance documents (the latter including guidelines, recommended practices, and similar documents) that have been developed or are under development by nongovernmental organizations, classification societies, standards-development bodies, and government entities. It also considered ways in which BOEMRE might address deficiencies in existing standards and guidance documents.

Applicability and Adequacy

- ***In reviewing existing sets of standards and guidance documents, the committee found that many could be applied in the United States but that no one set was complete.***

Many sets of standards and guidance documents for offshore wind turbines are available from standards organizations, classification societies, and at least one government. Many, if not most, have elements that are relevant to the United States and can be applied to installations in U.S. waters.

Most of these standards and guidance documents—notably, those used in continental Europe—are detailed and prescriptive. However, they are incomplete in that no one set covers all aspects of structural design, fabrication, and installation. All existing standards and guidance documents have shortcomings that will have to be overcome if they are to be applied in the United States.

The following are some of the most important areas where existing standards need more work for use in the United States:

– *Environmental site conditions* for the United States, especially storm and hurricane conditions for the Gulf of Mexico and the East Coast. These and other conditions—such as ice loading (for the Great Lakes) and seismic activity (especially on the Pacific coast)—would need to be covered appropriately.

– *Transparency*. Methodologies for strength analysis[1] differ among the standards and guidance documents and are not always fully delineated, making it difficult to compare the standards and guidance documents against one another to determine whether they provide equivalent safety levels, especially when applied to novel concepts. The methodologies, assumptions, and data used for strength analysis must be laid out clearly to provide the necessary transparency.

- ***BOEMRE's own regulations (published in 30 CFR 285) and accompanying guidance are inadequate in that they do not identify specific criteria that a proposed project must meet to be approved and gain the necessary permits.***

Although regulations[2] promulgated by BOEMRE require that detailed reports for design, construction, and operation of offshore wind turbines be submitted for BOEMRE approval, they do not specify standards that an offshore wind turbine must meet. Rather, a third party (CVA) is asked to comment on the adequacy of design, fabrication, and installation and provide reports to BOEMRE indicating the CVA's assessment of adequacy. Moreover, when a general level of performance such as "safe" is stipulated, no guidance is provided on how to assess whether this level of performance has been met.

- ***The United States urgently needs a set of clear and specific standards to reduce uncertainty in the requirements that projects must meet, facilitate the orderly development of offshore wind energy, and support the stable economic development of a nascent industry.***

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[1] Some standards and guidance documents are based on strength or limit states design; others are based on allowable stress design. The philosophies underlying these methods are fundamentally different. See Chapter 4.

[2] 30 CFR Part 285, 74 FR 81, pp. 19638–29871.

States and private companies are developing plans for offshore wind energy projects in state waters and on the OCS. Well-defined U.S. regulations for development on the OCS are needed (*a*) to provide a resource for states as they develop requirements for projects in state waters and (*b*) to supply industry with sufficient clarity and certainty on how projects will be evaluated as companies seek the necessary financing. Further delays in developing an adequate national regulatory framework are likely to impede development of offshore wind facilities in U.S. waters. Moreover, developments in state waters could proceed in the absence of federal regulations, possibly leading to inconsistent safety and performance across projects.

Filling the Gaps

- ***Performance-based standards are a regulatory framework that best meets two government objectives: (a) fulfilling BOEMRE's mission of overseeing the safe, orderly, and environmentally responsible development of the OCS and (b) fostering innovation and competitiveness.***

Improvements in the efficiency of offshore wind turbine installations and reductions in capital and operating costs are needed if offshore wind energy is to become a highly competitive renewable energy source. Performance-based (goal-based) standards, which are gradually replacing prescriptive standards in other industries (such as civil infrastructure, offshore oil and gas, and shipping), provide the flexibility needed to accommodate new technologies. They can be administered and modified by the regulatory bodies in a straightforward way, they clarify the responsibilities of industry in meeting project goals, and they result in the transparency that comes with the delineation of goals and objectives.

Recommendations

To enable timely development of U.S. offshore wind energy within a robust regulatory framework, the following approach is recommended:

1. BOEMRE should proceed immediately with development of a set of goal-based standards governing the structural safety of offshore wind turbines and power platforms. These regulations should be risk-informed (see Appendix A) and should cover design, fabrication, and installation. Offshore wind energy is an emerging technology; therefore, the standards should be crafted to allow and encourage introduction of innovative solutions that improve the safety, environmental performance, reliability, and efficiency of offshore wind facilities. BOEMRE should either develop these regulations within the agency in a timely manner or facilitate development through, or with the advice of, an outside group of experts. In any case, it is essential that BOEMRE take responsibility for the process and the final product.
2. Because offshore wind projects are already under way, BOEMRE should provide industry with a well-defined regulatory framework as soon as practical. The U.S. offshore wind turbine regulations should be promulgated no later than the end of calendar year 2011, and a specific plan for meeting that target should be established as soon as possible.

3. On request of a rule development body, BOEMRE should review the rules and guidelines proposed by that body for compliance[3] with BOEMRE's goal-based standards and identify any deficiencies. Once BOEMRE deems a set of rules to be in full compliance with the goal-based standards, it should approve such rules for application to U.S. offshore wind facilities. Examples of rules and guidelines that could be considered are those that have been developed by Germanischer Lloyd, Det Norske Veritas, and the American Bureau of Shipping. Preapproved rules should have the benefit of expediting the regulatory review process. However, BOEMRE should be prepared to review standards and guidelines proposed by a developer and accepted by a CVA for compliance with its goal-based regulations on a case-by-case basis.

4. BOEMRE should take a leading role in promoting awareness of lessons learned in the offshore wind and offshore oil and gas industries among project developers, industry professionals, and standards development bodies. The goal is to help industry avoid mistakes that have been encountered elsewhere and to promote practices that have proved to be successful.

FINDINGS AND RECOMMENDATIONS: ROLE OF THE CVA (TASK II)

1. The responsibility for proposing a comprehensive set of standards, guidelines, and recommended practices should rest with the developers. The CVA's role should be to review and comment on the adequacy of the proposed standards and rules in meeting the objectives defined in the BOEMRE goal-based standards. Although BOEMRE should consider the documentation provided by the developer and the report of the CVA, the responsibility for approval of the proposed standards and guidelines and for determination of their conformance with the goal-based standards should rest solely with the agency.
2. The scope of the BOEMRE third-party review process should include the following:
   - Blades,
   - Blade controls (if reliance on active controls is required for load reduction),
   - Tower and structural support,
   - Foundation and station keeping,
   - Infield cables and connectors,
   - Other structures—structural and electrical systems, and
   - Export cables.

The third-party review should ensure the following:

Design: The design adheres to good industry practice, the basis of the design is applicable for the location and stated objectives of the project, site-specific conditions have been appropriately addressed, and the identified codes and standards are adhered to.

Fabrication and manufacturing: Quality assurance/quality control processes are in place to ensure that fabrication and manufacturing comply with the design and the identified codes and standards.

[3] A set of rules is deemed compliant if meeting those rules will be taken as sufficient evidence that the performance-based goals have been met.

Installation: All transportation and field installation activities are performed in a manner ensuring that the facility meets the design intent.

The third-party reviewer should provide periodic reports to BOEMRE with regard to the review findings and should note any deviations or concerns.

3. Type certification of a wind turbine may be substituted for portions of third-party design review subject to the type certification matching site conditions.
4. BOEMRE should retain responsibility for final approval. It is essential that BOEMRE have staff who are competent to select qualified third parties (see Task III) and to approve projects.

FINDINGS AND RECOMMENDATIONS: CVA QUALIFICATIONS (TASK III)

Findings

The committee's key findings with regard to CVA qualifications, which are based on a review of the implementation of the CVA process for offshore oil and gas facilities, the proposed Code of Federal Regulations language for an offshore wind CVA, and how other engineered systems implement third-party reviews, are as follows:

1. A qualified CVA must be
   a. Independent and objective, with no involvement in the scope of work being reviewed (i.e., design, fabrication, or installation);
   b. Experienced in performing scopes of work similar to that being reviewed, with detailed knowledge of the codes and standards being applied; familiarity with the approaches proposed by the developer; and the technical expertise and engineering judgment to verify assumptions, conclusions, and results independently; and
   c. Directed by a registered professional engineer (or international equivalent).
2. A CVA for the design stage must have expertise in
   a. Identification, specification, and implementation of design limit states;
   b. Fatigue and strength design approaches, including the effects of coupled wind–wave dynamics;
   c. Determination of the adequacy of proposed design environmental condition for the site;
   d. Evaluation of foundation design;
   e. Evaluation of interaction between the foundation and the turbine system;
   f. Determination of the adequacy of the geotechnical assessment; and
   g. Performance of design calculations similar to those provided in the design reports. This is not a requirement that independent calculations be performed but that the CVA be able to perform them as necessary.
3. A CVA for the fabrication stage will need expertise in
   a. Fabricator quality control,
   b. Material quality evaluation,

c. Welder qualifications,
d. Nondestructive testing,
e. Destructive testing (e.g., full-scale blade tests), and
f. Blade materials and fabrication.

4. A CVA for the installation stage will need expertise in
   a. Evaluation of installation plans and procedures;
   b. Witnessing of installation operations including loadout, towing, launching, uprighting, submergence, and so forth;
   c. Marine operations;
   d. Subsea cabling activities including trenching, burial, and connections;
   e. Offshore construction activities; and
   f. Installation equipment.
5. The CVA for design, for fabrication, and for installation need not be the same organization or person, and it is unlikely that a single person would have sufficient expertise to lead an effective CVA for all phases.
6. It would be beneficial, though not essential, for a CVA to have experience in third-party reviews and in interacting with regulatory agencies.
7. Given the variety of controlling environmental loads (e.g., hurricanes, seismic activity, ice loads) and installation requirements (e.g., mudslide areas, tidal erosion effects) in U.S. waters, the CVA's experience should be related to the installation location.
8. Experience with the use of project-specific CVA approval in the offshore oil and gas CVA industry indicates that project-specific approval of CVAs is better than maintenance of a list of BOEMRE-accepted CVAs.

Recommendations

The committee recommends the following with regard to CVA qualifications:

1. In evaluating potential CVAs, BOEMRE should seek organizations and individuals that
   a. Are independent and objective;
   b. Have experience, technical expertise, and engineering judgment sufficient to verify assumptions, conclusions, and results independently;
   c. Have experience with the dominant environmental effects for the project location (e.g., earthquake-resistant design experience for offshore West Coast locations);
   d. Have experience in the areas described in the findings section above for the CVA tasks (i.e., design, fabrication, and installation) for which they are nominated;
   e. Have clearly defined roles and responsibilities with adequate oversight by a registered professional engineer (or international equivalent); and
   f. Have an auditable quality plan for the processes and record keeping involved in the CVA activities.
2. BOEMRE should hire sufficient staff with adequate technical expertise (as described in Chapter 4 in the section "Implementation: Capacity and Expertise") to oversee the development of offshore wind farms in U.S. waters.
3. BOEMRE should approve CVAs on a project-specific basis as opposed to maintaining an approved list of qualified CVAs.

4. BOEMRE should actively manage the CVA process for offshore wind facilities by disseminating lessons learned from the CVA process to promote best practices to the industry.

5. BOEMRE should actively participate in the IEC Wind Turbines Certification Bodies Advisory Committee as a means of staying informed on issues relating to wind turbine certification and the accreditation of CVAs.

FINDINGS AND RECOMMENDATIONS: IMPLEMENTATION

- ***In the committee's view, unless BOEMRE's staffing levels and experience are substantially enhanced, the agency will be unable to provide the leadership and decision-making capability necessary for development of U.S. offshore wind facility standards.***
- ***It is essential that BOEMRE establish a substantial core competency within the agency with the capacity and expertise to lead the development of the goal-based standards, review the rules and guidelines submitted by the third-party rule developers, and review the qualifications of proposed CVAs.***

The committee's findings and recommendations on standards and practices, the role of the CVA, and the qualifications needed by a CVA call for BOEMRE to take a leadership role in developing new, goal-based standards; to review sets of standards and guidance documents put forward by industry for preapproval, identify gaps and deficiencies, and determine whether they have been sufficiently addressed; to review the full set of standards and guidance documents submitted for specific projects; and to select CVAs who can take part in all these functions as necessary.

The expertise required to carry out these tasks is substantial. Moreover, the critical advisory roles that the CVA could play in these tasks could require that BOEMRE make a more detailed appraisal of CVA nominations than in the past, which also implies in-depth expertise. BOEMRE will likely be asked to apply this expertise extensively and in the near future, both because regulatory expectations need to be established soon and because several offshore wind projects are already being developed and many more will likely be entering the pipeline for review and approval.

- ***As a means of filling the experience gap for both industry and regulators, BOEMRE should consider creating an expert panel to provide it with guidance and feedback for the development of goal-based standards, for the review of proposed standards and guidelines for compliance with the goal-based standards, and for the initial wind development projects.***

Such an expert panel could help BOEMRE in developing goal-based standards expeditiously. It could also advise BOEMRE on how CVAs can assess compliance with goal-based standards and on how the agency and industry can learn from the deficiencies and other concerns that CVAs identify in projects. Finally, for the initial offshore wind development projects, such an expert panel could help BOEMRE review the packages of Guidelines—standards, rules, industry guidelines, and recommended practices—submitted for application to a particular project or submitted for preapproval for use in future projects.

- ***BOEMRE should be fully engaged in the national and international process for developing standards for offshore wind turbines, and it should be represented on the International Electrotechnical Commission's technical committees and on other relevant national and international committees.***

Appendix A

Risk-Informed Approaches to Safety Regulation

In risk-informed regulation, insights from risk assessment are considered together with other engineering insights. This appendix summarizes basic concepts of modern risk-informed safety regulation as they are currently used in the design of civil infrastructure, focusing on their use in the United States.

RISK-INFORMED ANALYSIS AND DESIGN OF CIVIL INFRASTRUCTURE FACILITIES

Risk-informed approaches to analysis, design, and condition assessment have reached a state of maturity in many areas of civil infrastructure during the past three decades, particularly in codes, standards, and regulatory guidelines that govern design and construction. These documents are key tools for structural engineers in managing civil infrastructure risk in the public interest, and the traditional structural design criteria they contain address risks in performance as engineers have historically understood them. For the most part, these criteria have been based on judgment. In recent years, however, innovation in technology has occurred rapidly, leaving less opportunity for learning through trial and error (as is the case in the wind energy industry today). Standards for public health, safety, and environmental protection now are often debated in the public arena, and societal expectations of civil infrastructure have increased. Questions concerning alternative or innovative projects and structural solutions are better answered from a risk-informed perspective. Such a perspective continues to include a significant component based on judgment: the use of a 50- or 100-year mean recurrence interval (MRI) for the design wind effect is an example. However, modern structural reliability tools have increased the contribution of risk analysis to the rational development of design criteria, which, owing to current computational capabilities, can be far better differentiated and realistic than their 1970s counterparts.

This appendix summarizes basic concepts of modern risk-informed safety regulation as they are currently utilized in the design of civil infrastructure and discusses their application to structural design requirements for mitigation of risk in the built environment.

FUNDAMENTALS OF RISK ASSESSMENT FOR NATURAL AND MAN-MADE HAZARDS

Risk analysis and assessment tools are essential in measuring compliance with performance objectives, in comparing alternatives rationally, and in highlighting the role of uncertainty in the decision process. This section outlines a framework for modern risk-informed decision making, providing the background for the implementation of structural design requirements for civil infrastructure facilities in the current construction and regulatory climate.

Risk and Its Analysis: Hazard, Consequences, Context

Risk involves *hazard*, *consequences*, and *context* (Stewart and Melchers 1997; Vrijling et al. 1998; Faber and Stewart 2003). The hazard is a potentially harmful event, action, or state of nature. The potential for the occurrence of a hurricane or earthquake at the site of a structure is a hazard. The occurrence of such a hazardous event has potential consequences—building damage or collapse, loss of life or personal injury, economic losses, or damage to the environment—which must be measured in terms of a value system involving some metric. Finally, there is the context of the risk assessment, which is related to what is at risk, what individuals or agencies are measuring and assessing the risk and how risk-averse they might be, the necessity for or feasibility of risk management, and how additional investment in risk reduction can be balanced against available resources.

Risk Benchmarks in Current Structural Codes

Structural codes and standards and design practice historically have striven to deliver structural products and systems with risks that the public finds acceptable. In the vast majority of studies to date involving structural performance and reliability, the term "risk" is used more or less interchangeably with "probability" or is thought of as the complement of "reliability" (Ellingwood 1994). Consequences (e.g., economic losses; morbidity and mortality) are included only indirectly, if at all; low target probability goals are typically assigned, somewhat arbitrarily and on the basis of judgment, to high-consequence events. While current codes and standards as well as code enforcement keep failure rates at a low level, no one knows exactly what a socially acceptable failure rate for buildings, bridges, and other structures might be, although structural engineers believe that current codes and standards deliver civil infrastructure with risks that are acceptable in most cases. At the other extreme, the de minimis risk below which society normally does not impose any regulatory guidance is on the order of 10^{-7}/year (Paté-Cornell 1994). Failure rates for buildings, bridges, dams, and other civil infrastructure that may be calculated through the use of classical reliability analysis (Ellingwood 2000) fall in a range between 10^{-3}/year and 10^{-7}/year, a gray area within which risk-reduction measures are traded off against increments in the cost of risk reduction. The notion of having risks "as low as reasonably practicable" (Stewart and Melchers 1997), which is common in industrial risk management, is based on this concept. In sum, what constitutes acceptable risk is relative and can be established or mandated only in the context of what is acceptable in other activities, what investment is required to reduce the risk (or socialize it), and what losses might be entailed if the risk were to increase.

The following section considers how the general concepts of risk assessment and management summarized above have been implemented for several types of civil infrastructure. The unique nature of each infrastructure type determines how specific risk-informed decision concepts have been implemented.

PROBABILITY-BASED LIMIT STATES DESIGN

Load and Resistance Factor Design

Structural codes and standards applicable to the design of civil infrastructure traditionally have been concerned primarily with public safety (preventing loss of life or personal injury) and, in this context, the collapse of a structure or a large portion of it. The probability of structural collapse is a surrogate for all other metrics, and limiting that probability addresses the fundamental goal. Most first-generation probability-based structural design codes focus on that performance objective. Other performance metrics—direct economic losses from structural damage, indirect losses due to interruption of function, forgone opportunities, and loss of amenity—have not been addressed in current construction regulations but may be of concern to certain stakeholder groups in certain types of infrastructure facilities.

The use of classical structural reliability principles and code calibration has historically formed the basis for the development of load combinations in American Society of Civil Engineers (ASCE) Standard 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE 2010); Eurocode 1, *Actions on Structures* (CEN 1994); and structural strength criteria found in most standards and specifications (e.g., AASHTO 2007; ACI 2005; AISC 2010). Such codified procedures gloss over the issue of consequence and context by presuming that "risk" and "probability of collapse" are identical. However, these procedures avoid the difficulty of selecting appropriate risk (loss) metrics and transform the analysis of risk into a problem amenable to solution by principles of structural reliability theory (Ellingwood 1994; Melchers 1999), which is an essential step in first-generation probability-based structural design.

In modern probability-based limit states design codes, the requirement that the reliability equal or exceed a target reliability is transformed into a traditional safety-checking equation:

$$\text{Required strength } (Q_d) < \text{ design strength } (R_d) \qquad \text{(A-1)}$$

The required strength to resist loads, shown on the left-hand side of the equation, is determined from structural analysis by using *factored* loads, while the design strength (or factored resistance) on the right-hand side is determined by using nominal material strengths and dimensions and partial resistance *factors*. The load and resistance factors are functions of the uncertainties associated with the load and resistance variables and the target reliability index. The target reliability index, in turn, may depend on the failure mode (e.g., brittle or ductile) and the consequences of a member failure (e.g., local damage, possibility of global instability). The most common representation of Equation A-1 in the United States is as follows:

$$\Sigma\, \gamma_i\, Q_{ni} < \varphi\, R_n \qquad \text{(A-2)}$$

where R_n is a specified nominal (characteristic) strength, φ is a resistance factor, Q_{ni} is the nominal (characteristic) load, and γ_i is the associated load factor for load type *i*. The design format suggested by Equation A-2 is transparently deterministic, but the load and resistance factors are in fact based on explicit reliability benchmarks (reliability indices) obtained through a complex process of code calibration.

Existing Implementation of Load and Resistance Factor Design; Measures of Reliability

Buildings

The first probability-based design specification in the United States [denoted as load and resistance factor design (LRFD) for steel structures] was introduced in 1986 and has since been followed by several other specifications. LRFD is now a mature concept and has been widely used in structural design practice for the past two decades.

The required strength, $\Sigma\gamma_i Q_{ni}$, is determined, in all cases, from the set of load combinations stipulated by ASCE Standard 7-10. In first-generation LRFD (Galambos et al. 1982; Ellingwood et al. 1982), the benchmark target reliability index (β) for a *member* limit state involving yielding of a tension member or formation of the first plastic hinge in a compact beam was set equal to approximately 3.0 for a service period of 50 years, corresponding to a limit state probability of approximately 0.0013 in 50 years; annualized, this probability is on the order of 10^{-5}. The value of β equal to 3.0 was selected following an extensive assessment of reliabilities associated with members designed by traditional methods and is applicable to load combinations involving gravity loads but not wind or earthquake loads (Galambos et al. 1982).[1] Reliability indices for other limit states were set relative to 3.0 (e.g., reliability index values for connections are on the order of 4.0 to ensure that failure occurs in the member rather than in the connection; because the cost of connection design is determined primarily by fabrication rather than materials, providing the additional conservatism has little economic impact). Similar benchmarks have been adopted for most other building construction materials.

Bridges

The American Association of State Highway and Transportation Officials (AASHTO) *LRFD Bridge Design Specifications* dates from 1994, with the 2007 edition being the latest. The probabilistic design methodology adopted there is essentially the same as that used for building structures. The supporting study (Nowak 1995) focused on the strength of individual bridge girders, with truck loads applied to the individual girders through empirically derived girder distribution factors for moment and shear. AASHTO uses essentially the same LRFD format as is used for ordinary buildings and other structures. The load and resistance factors in the *LRFD Bridge Design Specifications* (AASHTO 2007) were developed in such a way that bridge girders achieve a reliability index, β, equal to 3.5 at the inventory or design level for a service period of 75 years. No distinction is made between steel, reinforced concrete, and prestressed concrete girders in terms of their target reliabilities, nor is the target reliability index dependent on the girder span or on whether the girder is simply supported or continuous over internal supports.

Offshore Platforms

Formal design guidance for offshore structures originated in 1967 with the release of American Petroleum Institute (API) RP 2A (API 1967). This standard used a working stress approach, consistent with the prevailing steel design practice for land structures. In 1979, work began on development of an LRFD version of API RP 2A. The format was parallel to that developed by

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[1] The annual probability of partial or total collapse of a properly designed redundant structural frame is approximately one order of magnitude less, or on the order of 10^{-6}/year.

Galambos et al. (1982). The calibration strategy focused on developing partial factors for identified components that would yield a platform design having members and connections equivalent to those resulting from use of the existing working stress code. This approach was summarized by Moses and Larrabee (1988):

> The traditional one-third allowable stress increase for environmental loading found in working stress design (WSD) has been replaced in the Draft RP2A-LRFD by separate load factors (γ) for dead load, live load, wind–wave–current load, earthquake load and wave dynamic load. Resistance factors (φ) vary for pile capacity, beam bending, axial compression, hydrostatic pressure, etc. Together, these load and resistance factors provide a level of safety close to present practice, yet provide more uniform safety and economy.

Calibrated β-values ranged from 2.0 to 2.8 for a 20-year service life with a 100-year loading event used as the reference load level. Similar values for the North Sea were developed by Turner et al. (1992). Recently, ISO 19902:2007, Fixed Offshore Steel Structures, which was based on API RP 2A-LRFD and expanded to include loading specifics for international locations, became available and is referenced in the International Electrotechnical Commission (IEC) offshore wind turbine design standard (i.e., IEC 61400-3) as the offshore structural guidance document.

Other Civil Infrastructure Applications

As noted above, probability-based design of buildings and bridges has focused on member or component limit states and has measured reliability by making use of the reliability index β. More recent applications of risk-informed decision making to civil infrastructure, brought about in part by the move toward performance-based engineering, have considered system behavior and expressed performance through limit state probabilities rather than through use of the reliability index. These developments have been made possible through advances in structural computation, which now make nonlinear dynamic analysis of complex building and bridge structures feasible in design. Several standards and guidelines have begun to adopt such concepts.

ASCE 7-10 Commentary 1.3.1.3 ASCE Standard 7-10 has implemented a new general design requirement for performance-based procedures. The commentary to these procedures contains two tables with acceptable reliability levels: the first stipulates annual limit state probabilities and reliability indices for nonseismic events, and the second provides anticipated probabilities of structural failure for earthquakes. These acceptable reliability levels are dependent on the risk category of the structural facility and the nature of the structural failure involved. In nonseismic design situations, the acceptable annual probability of failure ranges from 3×10^{-5}/year for failures that are benign to 7×10^{-7}/year for failures that are sudden and lead to widespread damage or collapse. In seismic situations, the acceptable probabilities are conditioned on the design-basis event; for ordinary building structures, this conditional probability (given occurrence of the design-basis event) is 10 percent for total or partial collapse.

ASCE Standard 43-05 Standard 43-05 (ASCE 2005) addresses seismic design criteria for nuclear facilities. Like ASCE Standard 7-10, it adopts a uniform risk approach to earthquake-resistant design rather than a uniform hazard approach. Table 1-2 of this standard stipulates target performance goals in terms of the annual probability of failure for facilities requiring different levels of protection. For facilities requiring confinement of highly hazardous materials with high confidence, the target probability is 10^{-5}/year or less, and the structure must be designed to remain essentially elastic under such conditions.

CRITICAL APPRAISAL OF EXISTING RISK-INFORMED ANALYSIS AND DESIGN PRACTICES FOR APPLICATION TO OFFSHORE WIND TURBINES

Component Versus System Reliability Analysis

Most codified reliability-based design for civil infrastructure has focused on individual buildings, bridges, and other industrial facilities for which the hazard can be identified at a point (e.g., Ellingwood 2007). A distinguishing and essential feature of risk-informed decision tools for wind turbine farms in coastal and offshore environments is their ability to account for the spatial correlation in the intensity of the hazard (such as from a hurricane) over geographic scales on the order of tens of kilometers within the region affected (Vickery and Twisdale 1995); multiple wind turbine units experience correlated risks under such conditions. In addition, the presence (or lack) of advanced warning systems and the effect on risk-mitigation options should be considered (Lakats and Paté-Cornell 2004).

Design MRIs of Joint Wind Effects

MRIs of design wind effects for strength design have typically been specified with consideration for knowledge uncertainties. Such uncertainties influence, for example, estimates of wind effects associated with a 50- or 100-year MRI. For typical building occupancies, ASCE Standard 7-10 specifies a 700-year MRI wind speed. Similar MRI estimates are needed for wave and current effects or for combined wind, wave, and current effects. Note that the MRI is insufficient to establish the structural reliability. The associated load factor also plays a key role; for example, the probability of exceedance of some load level, $1.6W$, with W determined on the basis of a 50-year MRI wind speed, is about the same as the probability of exceeding $1.0W$ when W is defined on the basis of a 700-year wind speed. This is also the reason why the reliabilities associated with an IEC-based offshore wind turbine design, which stipulates use of a 50-year wind speed with a load factor of 1.3, might yield essentially the same reliability as an alternative factored load that uses a 100-year wind speed (as in API RP 2A) with a wind load factor of 1.0.

Whereas a typical MRI for an offshore oil and gas platform design is 100 years, a 50-year MRI is commonly used for offshore wind turbines in Europe. Although the combination of the MRI and an associated load factor can lead to similar reliability levels with either the 50- or the 100-year MRI, the 50-year MRI used for offshore wind turbines in Europe partly reflects the thinking that consequences of a turbine failure typically do not lead to loss of life or grave environmental effects (see Chapter 4). The selection of MRI for the design-basis event of a facility is not sufficient to determine the risk for that facility.

Finally, to account explicitly for economic consequences or the consequences of an unreliable energy supply, approaches similar to those presented briefly in this appendix may be used to establish appropriate alternative design MRIs, rather than an approach based on engineering judgment with regard to structural performance.

Time-Domain Methods

Computer-intensive time-domain methods similar to those recently developed by Simiu and Miyata (2006) and Long et al. (2007) can allow rigorous estimates of (*a*) combined load effects, with any mean recurrence interval, from Monte Carlo simulations of simultaneous time histories of wind, wave, current, and storm surge effects; and (*b*) attendant uncertainties in those estimates. Such methods will help to sharpen significantly estimates of combined load effects used for allowable stress design, strength design, limit states design, and design for fatigue, and to define geographical areas whose environmental conditions are compatible with the use of specified classes of turbine designs.

REFERENCES

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
API	American Petroleum Institute
ASCE	American Society of Civil Engineers
CEN	Comité européen de normalisation

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Appendix B

Text of Pertinent Regulations

This appendix contains the pertinent text of regulations from 30 CFR 250 cited in the body of the report. Only the regulations concerning certified verification agents (CVAs) referenced in Chapter 5 are included.

REQUIREMENTS FOR CVAS IN BOEMRE REGULATION

§ 250.916 What are the CVA's primary duties during the design phase?

a. The CVA must use good engineering judgment and practices in conducting an independent assessment of the design of the platform, major modification, or repair. The CVA must ensure that the platform, major modification, or repair is designed to withstand the environmental and functional load conditions appropriate for the intended service life at the proposed location.

b. Primary duties of the CVA during the design phase include the following:

Type of facility . . .	The CVA must . . .
(1) For fixed platforms and non-ship-shaped floating facilities	Conduct an independent assessment of all proposed:
	(i) Planning criteria;
	(ii) Operational requirements;
	(iii) Environmental loading data;
	(iv) Load determinations;
	(v) Stress analyses;
	(vi) Material designations;
	(vii) Soil and foundation conditions;
	(viii) Safety factors; and
	(ix) Other pertinent parameters of the proposed design.
(2) For all floating facilities	Ensure that the requirements of the U.S. Coast Guard for structural integrity and stability, e.g., verification of center of gravity, etc., have been met. The CVA must also consider:
	(i) Drilling, production, and pipeline risers, and riser tensioning systems;
	(ii) Turrets and turret-and-hull interfaces;
	(iii) Foundations, foundation pilings and templates, and anchoring systems; and
	(iv) Mooring or tethering systems.

c. The CVA must submit interim reports and a final report to the Regional Supervisor, and to you, during the design phase in accordance with the approved schedule required by §250.911(d). In each interim and final report the CVA must:

1. Provide a summary of the material reviewed and the CVA's findings;
2. In the final CVA report, make a recommendation that the Regional Supervisor either accept, request modification, or reject the proposed design unless such a recommendation has been previously made in an interim report;
3. Describe the particulars of how, by whom, and when the independent review was conducted; and
4. Provide any additional comments the CVA deems necessary.

§ 250.917 What are the CVA's primary duties during the fabrication phase?

a. The CVA must use good engineering judgment and practices in conducting an independent assessment of the fabrication activities. The CVA must monitor the fabrication of the platform or major modification to ensure that it has been built according to the approved design and fabrication plan. If the CVA finds that fabrication procedures are changed or design specifications are modified, the CVA must inform you. If you accept the modifications, then the CVA must so inform the Regional Supervisor.
b. Primary duties of the CVA during the fabrication phase include the following:

Type of facility . . .	**The CVA must . . .**
(1) For fixed platforms and non-ship-shaped floating facilities	Make periodic onsite inspections while fabrication is in progress and must verify the following fabrication items, as appropriate:
	(i) Quality control by lessee and builder;
	(ii) Fabrication site facilities;
	(iii) Material quality and identification methods;
	(iv) Fabrication procedures specified in the approved plan, and adherence to such procedures;
	(v) Welder and welding procedure qualification and identification;
	(vi) Structural tolerances specified and adherence to those tolerances;
	(vii) The nondestructive examination requirements, and evaluation results of the specified examinations;
	(viii) Destructive testing requirements and results;
	(ix) Repair procedures;
	(x) Installation of corrosion-protection systems and splash-zone protection;
	(xi) Erection procedures to ensure that overstressing of structural members does not occur;
	(xii) Alignment procedures;

	(xiii) Dimensional check of the overall structure, including any turrets, turret-and-hull interfaces, any mooring line and chain and riser tensioning line segments; and
	(xiv) Status of quality-control records at various stages of fabrication.
(2) For all floating facilities	Ensure that the requirements of the U.S. Coast Guard floating for structural integrity and stability, e.g., verification of center of gravity, etc., have been met. The CVA must also consider:
	(i) Drilling, production, and pipeline risers, and riser tensioning systems (at least for the initial fabrication of these elements);
	(ii) Turrets and turret-and-hull interfaces;
	(iii) Foundation pilings and templates, and anchoring systems; and
	(iv) Mooring or tethering systems.

c. The CVA must submit interim reports and a final report to the Regional Supervisor, and to you, during the fabrication phase in accordance with the approved schedule required by §250.911(d). In each interim and final report the CVA must:

1. Give details of how, by whom, and when the independent monitoring activities were conducted;
2. Describe the CVA's activities during the verification process;
3. Summarize the CVA's findings;
4. Confirm or deny compliance with the design specifications and the approved fabrication plan;
5. In the final CVA report, make a recommendation to accept or reject the fabrication unless such a recommendation has been previously made in an interim report; and
6. Provide any additional comments that the CVA deems necessary.

[70 FR 41575, July 19, 2005, as amended at 73 FR 64547, Oct. 30, 2008.]

§ 250.918 What are the CVA's primary duties during the installation phase?

a. The CVA must use good engineering judgment and practices in conducting an independent assessment of the installation activities.
b. Primary duties of the CVA during the installation phase include the following:

The CVA must . . .	**Operation or equipment to be inspected . . .**
(1) Verify, as appropriate	(i) Loadout and initial flotation operations;
	(ii) Towing operations to the specified location, and review the towing records;
	(iii) Launching and uprighting operations;

	(iv) Submergence operations;
	(v) Pile or anchor installations;
	(vi) Installation of mooring and tethering systems;
	(vii) Final deck and component installations; and
	(viii) Installation at the approved location according to the approved design and the installation plan.
(2) Witness (for a fixed or floating platform)	(i) The loadout of the jacket, decks, piles, or structures from each fabrication site;
	(ii) The actual installation of the platform or major modification and the related installation activities;
(3) Witness (for a floating platform)	(i) The loadout of the platform;
	(ii) The installation of drilling, production, and pipeline risers, and riser tensioning systems (at least for the initial installation of these elements);
	(iii) The installation of turrets and turret-and-hull interfaces;
	(iv) The installation of foundation pilings and templates, and anchoring systems; and
	(v) The installation of the mooring and tethering systems.
(4) Conduct an onsite survey	Survey the platform after transportation to the approved location.
(5) Spot-check as necessary to determine compliance with the applicable documents listed in §250.901(a); the alternative codes, rules and standards approved under §250.901(b); the requirements listed in §250.903 and §250.906 through 250.908 of this subpart and the approved plans.	(i) Equipment; (ii) Procedures; and (iii) Recordkeeping.

c. The CVA must submit interim reports and a final report to the Regional Supervisor, and to you, during the installation phase in accordance with the approved schedule required by §250.911(d). In each interim and final report the CVA must:

1. Give details of how, by whom, and when the independent monitoring activities were conducted;
2. Describe the CVA's activities during the verification process;
3. Summarize the CVA's findings;
4. Confirm or deny compliance with the approved installation plan;
5. In the final CVA report, make a recommendation to accept or reject the installation unless such a recommendation has been previously made in an interim report; and
6. Provide any additional comments that the CVA deems necessary.
7.

[70 FR 41575, July 19, 2005, as amended at 73 FR 64547, Oct. 30, 2008.]

Study Committee Biographical Information

R. Keith Michel, C*hair*, is former President and current Board Chairman of Herbert Engineering Corporation. In more than 25 years with the company, he has worked on design, specification development, and contract negotiations for containerships, bulk carriers, and tankers. Mr. Michel has served on numerous industry advisory groups developing guidelines for alternative tanker designs, including groups advising the International Maritime Organization and the U.S. Coast Guard. His work has included development of methodology, vessel models, and oil outflow analysis. He was a project engineer for the U.S. Coast Guard's report on oil outflow analysis for double-hull and hybrid tanker arrangements, which was part of the U.S. Department of Transportation's technical report to Congress on the Oil Pollution Act of 1990. He has also worked on the development of salvage software used by the U.S. and Canadian Coast Guards, the U.S. Navy, the National Transportation Safety Board, the Maritime Administration, the American Bureau of Shipping, Lloyd's, and numerous oil and shipping companies. Mr. Michel was Chair of the Transportation Research Board's Marine Board from 2002 through 2004 and has served on several National Research Council committees. Mr. Michel received a BS in naval architecture and marine engineering from the Webb Institute of Naval Architecture.

Bruce R. Ellingwood (Member, National Academy of Engineering) is Professor in the School of Civil and Environmental Engineering at the Georgia Institute of Technology. He is recognized for leadership in the use of probability and statistics in the design of structures and in the development of new design criteria. His main research and professional interests concern the application of methods of probability and statistics to support the practice of structural engineering. The role of structural design codes is to manage risk arising from the uncertainties inherent in structural engineering and thereby ensure adequate public safety. Thus, the focal points of Dr. Ellingwood's research have included probabilistic modeling of structural loads, statistical studies of the performance of structures, development of safety and serviceability criteria for structural design, studies of the response of structures to severe fires and other abnormal loads, and risk assessment of civil infrastructure projects. Dr. Ellingwood received a BS, an MS, and a PhD in civil engineering from the University of Illinois at Urbana–Champaign.

George M. Hagerman, Jr., is a research faculty member at Virginia Polytechnic Institute and State University's Advanced Research Institute and Director of Offshore Wind Research for the Virginia Coastal Energy Research Consortium, a public–private–university partnership. Mr. Hagerman has almost 30 years of experience in evaluating and optimizing the design, performance, and economics of marine renewable energy systems, including offshore wind power, wave power, tidal power, and ocean thermal energy conversion. Mr. Hagerman served as an oceanographer on the Electric Power Research Institute's Ocean Energy Team. He received a BS in zoology and an MS in marine sciences, both from the University of North Carolina at Chapel Hill.

Jan Behrendt Ibsoe was recently named Vice President for Global Renewable Energy at ABS Consulting. Earlier, he served as global director of renewable energy at Société Général de Surveillance in Germany and worked for 8 years at Det Norske Veritas (DNV) in Denmark.

DNV is heavily involved in international standards development for offshore wind turbines. It has provided project certification for offshore wind turbines throughout Europe and in China and type certification for onshore wind turbines. Dr. Ibsoe's focus in these positions has been offshore and onshore wind and solar energy. Previously, he worked in the offshore oil and gas industry. Dr. Ibsoe received an MS in civil engineering and a PhD in fatigue and fracture mechanics analyses of offshore welded structures, both from the Technical University of Denmark.

Lance Manuel is Associate Professor in the Department of Civil, Architectural, and Environmental Engineering at the University of Texas at Austin. His areas of research are structural reliability, structural dynamics, probabilistic seismic hazard analysis, and wind engineering. He has worked with Sandia National Laboratories on the statistical analysis of inflow and loads data for wind turbines, on characterization of the spatial coherence in inflow turbulence for wind turbines, and on the development of turbine design loads using inverse reliability techniques. He received a BS in civil engineering from the Indian Institute of Technology (Bombay), an MS in civil engineering from the University of Virginia, and a PhD in civil engineering from Stanford University.

Walt Musial is a Principal Engineer at the National Renewable Energy Laboratory (NREL). He leads the offshore wind research at NREL, including offshore technology characterization, resource assessment, and technology development. He started at NREL as a test engineer on the unsteady aerodynamics experiment. Mr. Musial led the testing team at NREL's National Wind Technology Center and was responsible for building and operating NREL's full-scale component facilities for testing wind turbine blades and drivetrains. Before joining NREL, he worked for 5 years in the commercial wind energy industry in California. He holds a BS and an MS in mechanical engineering from the University of Massachusetts at Amherst.

Robert E. Sheppard is a Principal Consultant with Energo Engineering, an engineering consulting firm specializing in advanced analysis, integrity management, and risk and reliability. He has more than 20 years of experience in structural engineering with a focus on assessment and repair of offshore structures and structural integrity management. He has extensive experience with design certification of offshore structures in addition to third-party reviews of design and installation of offshore facilities. Mr. Sheppard has developed guidelines for the inspection of offshore wind turbine facilities, including the substructure, tower, nacelle, and blades. These projects blended the existing operating experience from offshore oil and gas facilities with the unique requirements of wind turbine facilities. Mr. Sheppard holds a BS in civil engineering from Rice University and an MS in structural engineering from the University of California, Berkeley.

Emil Simiu is a Fellow at the National Institute of Standards and Technology (NIST), Structures Group. His research has included the estimation of wind and wave effects on buildings, bridges, and deepwater offshore platforms; structural reliability; and structural, fire, and chaotic dynamics. He has developed the database-assisted design concept and pioneered its systematic use for structures subject to wind loads. Dr. Simiu is a Fellow of the American Society of Civil Engineers (ASCE); served as chairman of its Committees on Wind Effects, Dynamic Effects, and the Reliability of Offshore Structures; and is a distinguished member of the ASCE Standard

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Susan W. Stewart is a Research Associate in the Aerospace Engineering and Architectural Engineering Departments at the Pennsylvania State University. She was formerly with the Applied Research Laboratory at Pennsylvania State University as well as the Strategic Energy Institute at the Georgia Institute of Technology. Her research focuses on wind energy, energy efficiency, hybrid renewables systems, SmartGrid analysis, and renewable energy workforce development. She has performed technology assessments involving economic and efficiency analysis of offshore wind energy and has worked on wind energy resource assessment and offshore wind farm design, particularly in the South Atlantic Bight. She holds a BS in mechanical engineering from Pennsylvania State University and an MS and a PhD in mechanical engineering from the Georgia Institute of Technology.

David J. Wisch is a Chevron Fellow at Chevron Energy Technology Company (ETC), Facilities Division. He currently is the Technical Team Lead of the Integrity Management Team in ETC's Civil, Structural, and Marine Engineering Unit. He was previously the engineer of record for the first platform in the United States to undergo certification by a certified verification agent and provided engineering oversight for the world's deepest self-standing structure. Mr. Wisch has been engaged for more than 30 years in industry standards development at the American Petroleum Institute (API) and the International Organization for Standardization (ISO). He chaired the API committee on fixed platforms and led the U.S. delegation to the ISO offshore standards committee. After Hurricanes Ivan, Katrina, and Rita (2004–2005), he led an API task force to develop a consensus interim industry standard for mooring of floating drilling vessels. He served for 6 years on the Marine Board. Mr. Wisch received an MS in civil engineering from the University of Missouri–Rolla and has done postgraduate work in civil and structural engineering at Tulane University.

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