TRB TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Structural Integrity of Offshore Wind Turbines:

Oversight of Design, Fabrication, and Installation

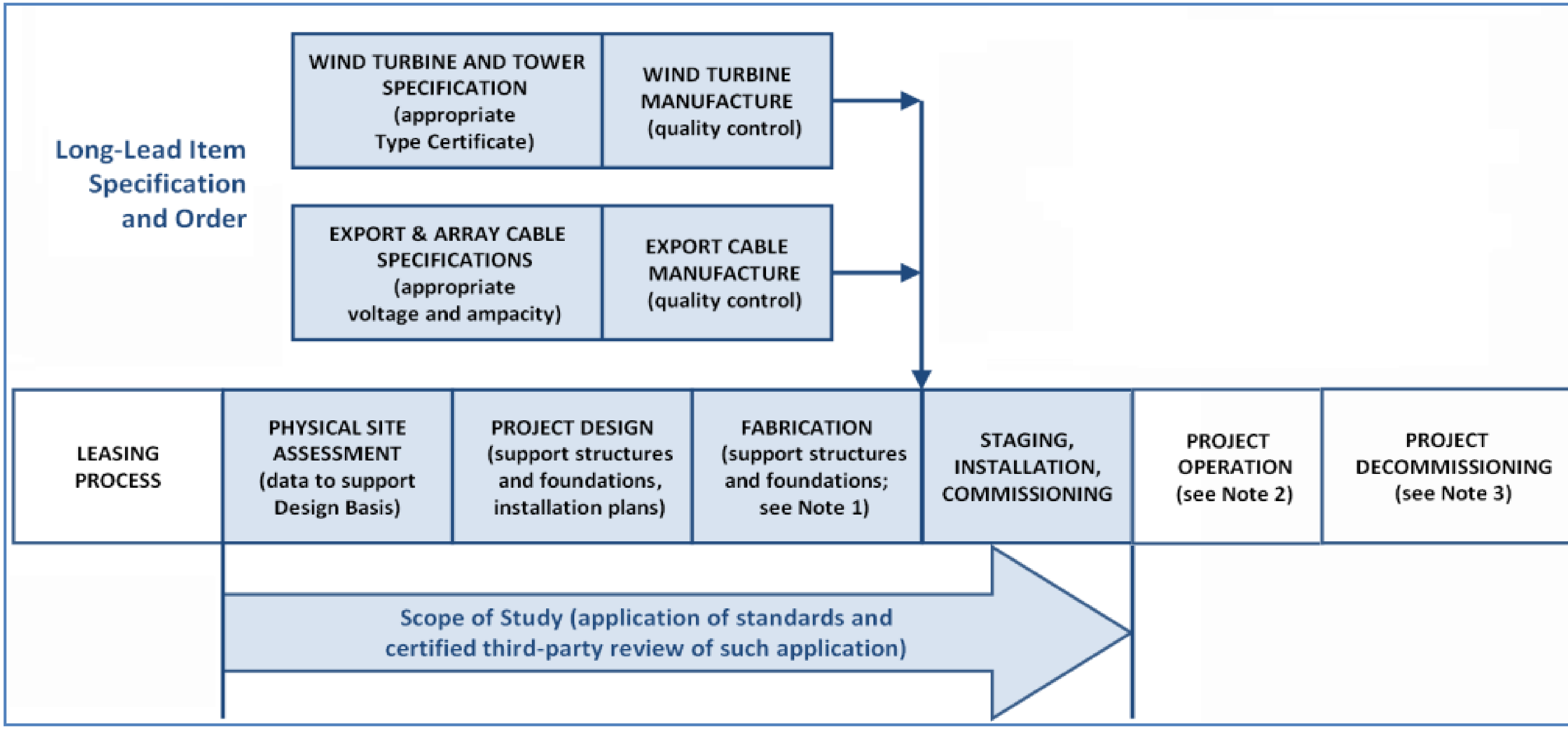
Report dated April 26, 2011

Committee

R. Keith Michel, Herbert Engineering Corporation, Alameda, California, *Chair*
Bruce R. Ellingwood, Georgia Institute of Technology, Atlanta
George M. Hagerman, Jr., Virginia Coastal Energy Research Consortium, Virginia Beach
Jan Behrendt Ibsoe, ABS Consulting, Inc., Houston, Texas
Lance Manuel, University of Texas at Austin
Walt Musial, National Renewable Energy Laboratory, Golden, Colorado
Robert E. Sheppard, Energo Engineering, Houston, Texas
Emil Simiu, National Institute of Standards and Technology, Gaithersburg, Maryland
Susan W. Stewart, Pennsylvania State University, State College
David J. Wisch, Chevron Energy Technology Company, Houston, Texas

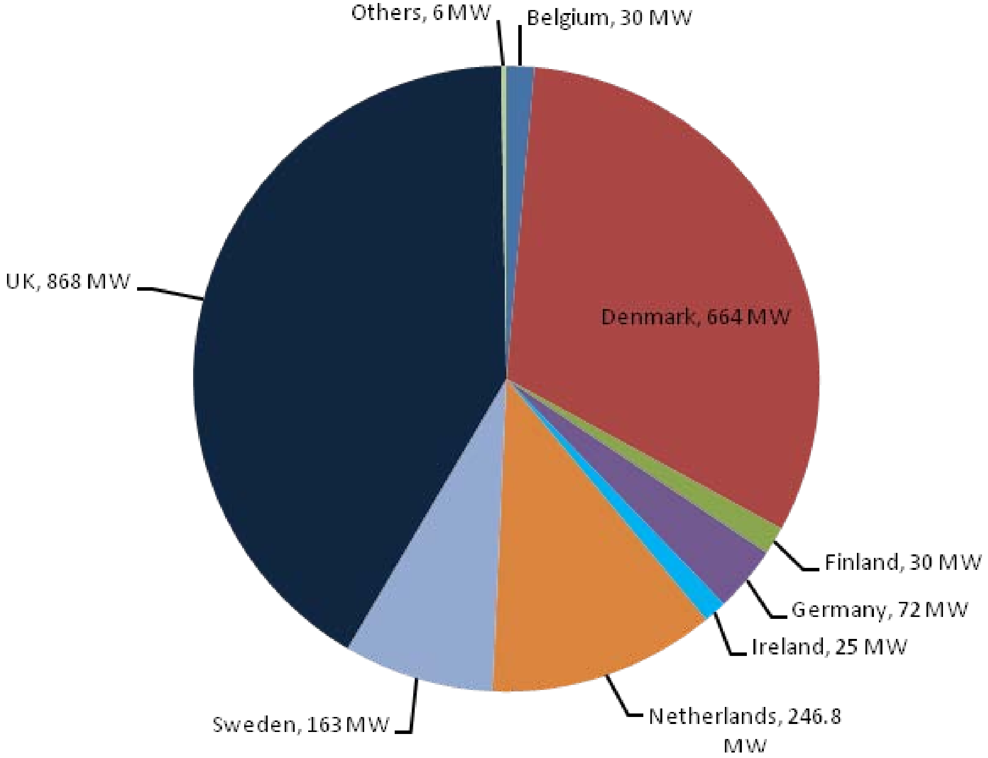
Staff Madeline G. Woodruff, Study Director

Project Development Stages



Wind Capacity by Country

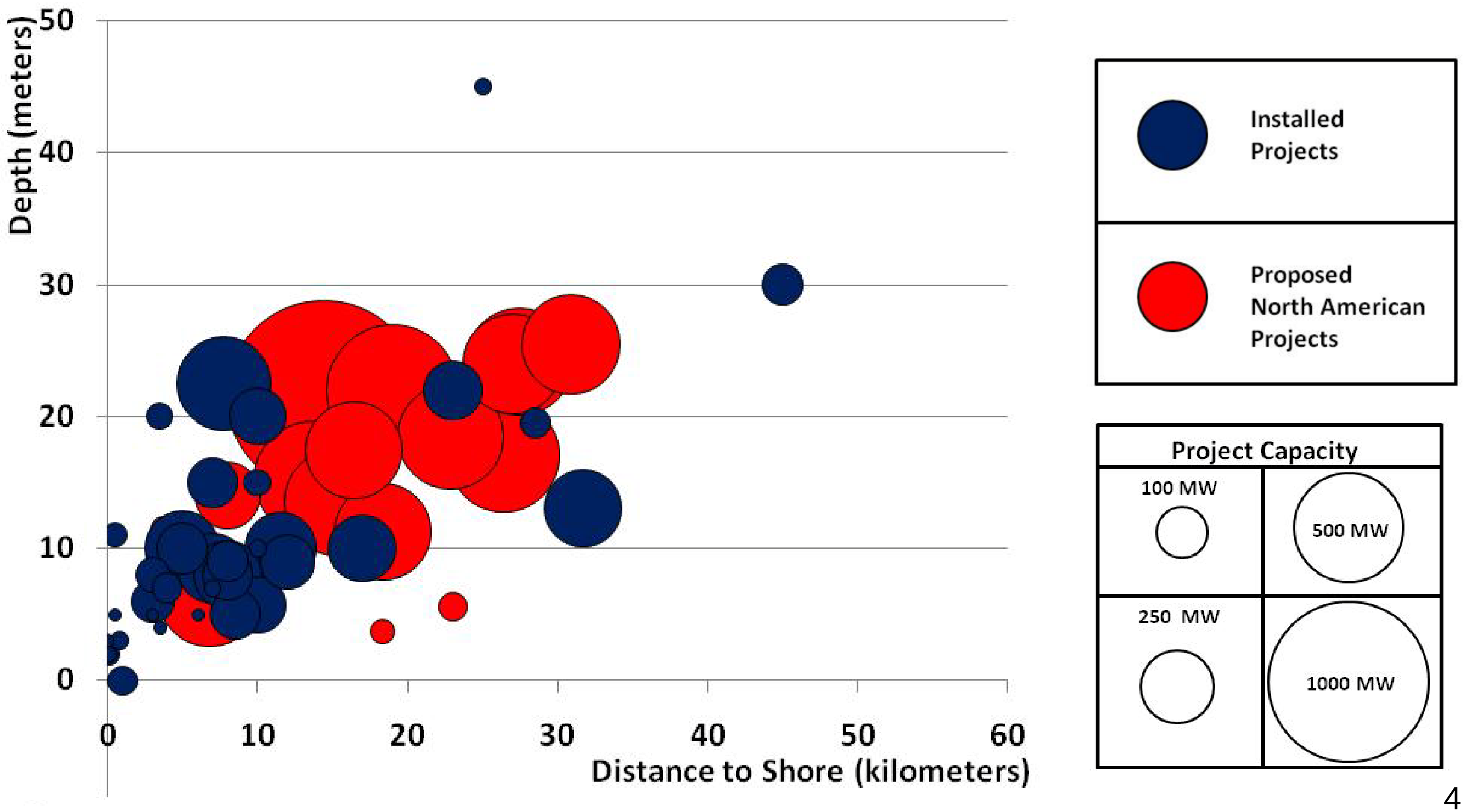
- By the end of 2010, more than 40,000 MW of wind energy had been installed in the United States (AWEA 2010). All U.S. installations are land-based.
- The large majority of offshore wind facilities are in Europe.



Source: Musial and Ram, 2010

Offshore Wind Projects

Proposed U.S. projects are typically larger and in deeper water than existing worldwide installations.



Source: NREL

Future Technology

Technical innovation to reduce costs and improve efficiency is needed to make offshore wind technology a economically competitive. New technology concepts include :

- Foundations and substructures that allow deployment in deeper water
- Install methods to automate deployment
- Large turbines (10 MW or greater)
- Downwind rotors
- Direct drive generators
- Composite towers
- “Smart” composite blades
- Offshore high-voltage DC transmission subsea backbones
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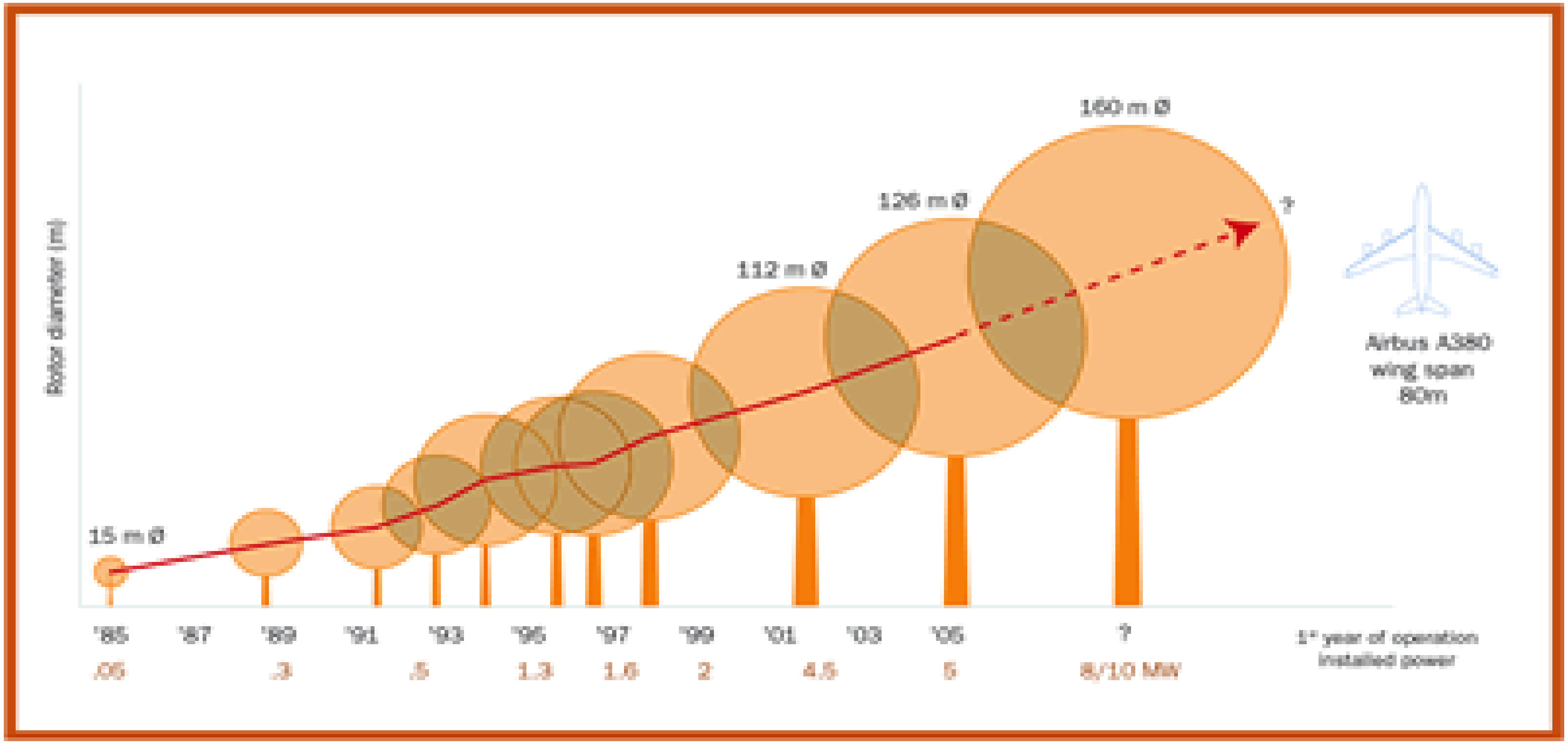
Wind Turbine Growth

Modern wind turbines exceed 400 ft in diameter, with output up to 5MW. Significantly larger turbines (10 MW and greater) are anticipated in future years.



Source: Jos Beurskens, ECN

Scope of Study

- ***TASK 1: Standards and Practices***

The applicability and adequacy of existing standards and practices for the design, fabrication, and installation of offshore wind turbines.

- ***TASK 2: Role of Certified Verification Agents (CVAs)***

The expected role of the CVA in identifying standards to be used and conducting onsite inspections to verify compliance with the standards.

- ***TASK 3: CVA Qualifications***

The experience level, technical skills and capabilities, and support equipment and computer hardware/software needed to be considered a qualified CVA.

Risk Matrix Driven by Policy Consequences of Failures

Policy Consequence:	**Low**	**High**
Scale of Impact	**Small**	**Large**

External Event Probability:	Small	Large
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Mitigate by Standards and Certified Third-Party Reviews →

QUESTIONS

DETAILED SLIDESHOW

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Background

(BOEMRE) is responsible for the orderly, safe, and environmentally responsible development of offshore renewables on the outer continental shelf.

BOEMRE requested that the NRC's Transportation Research Board'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.

Scope of Study

- ***TASK 1: Standards and Practices***

The applicability and adequacy of existing standards and practices for the design, fabrication, and installation of offshore wind turbines.

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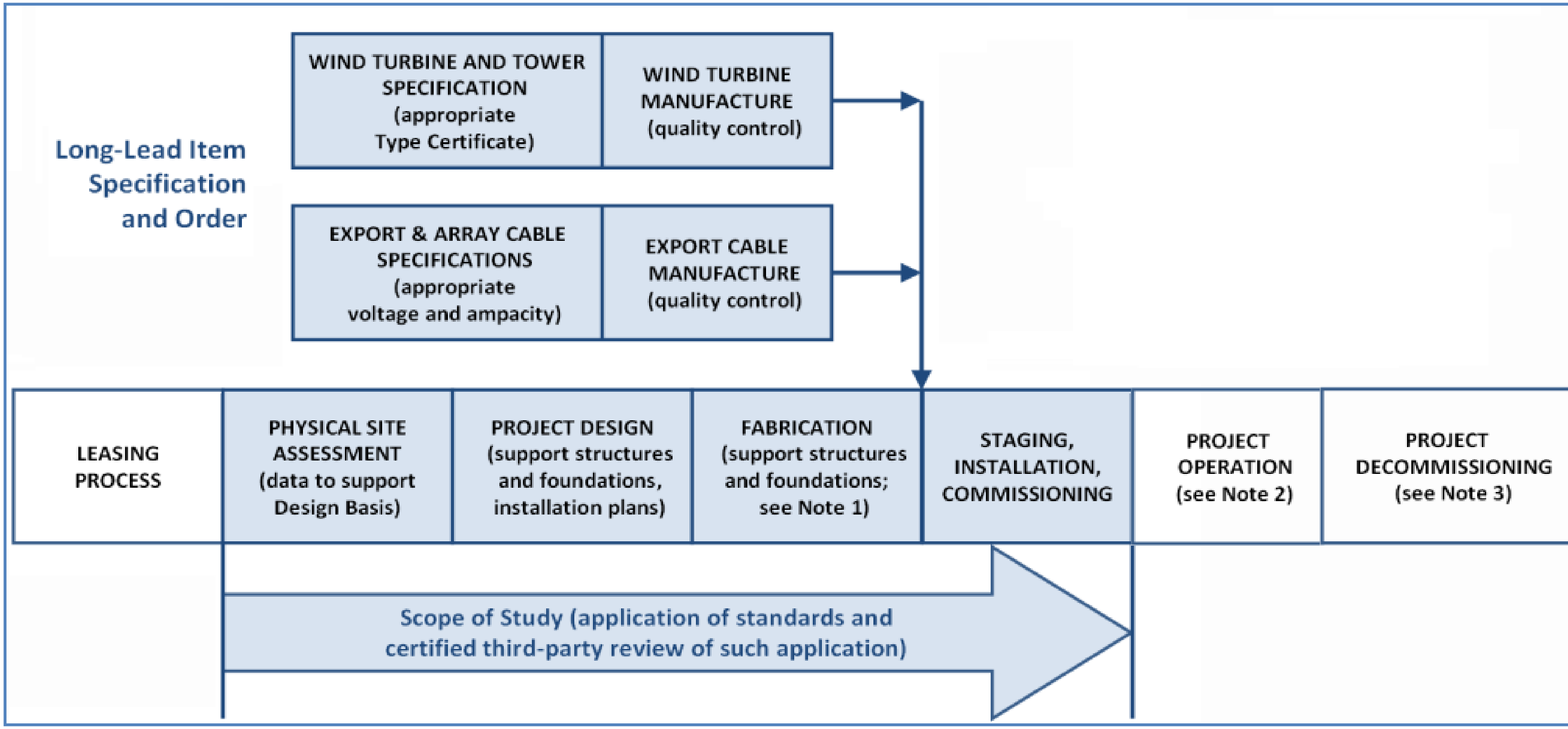
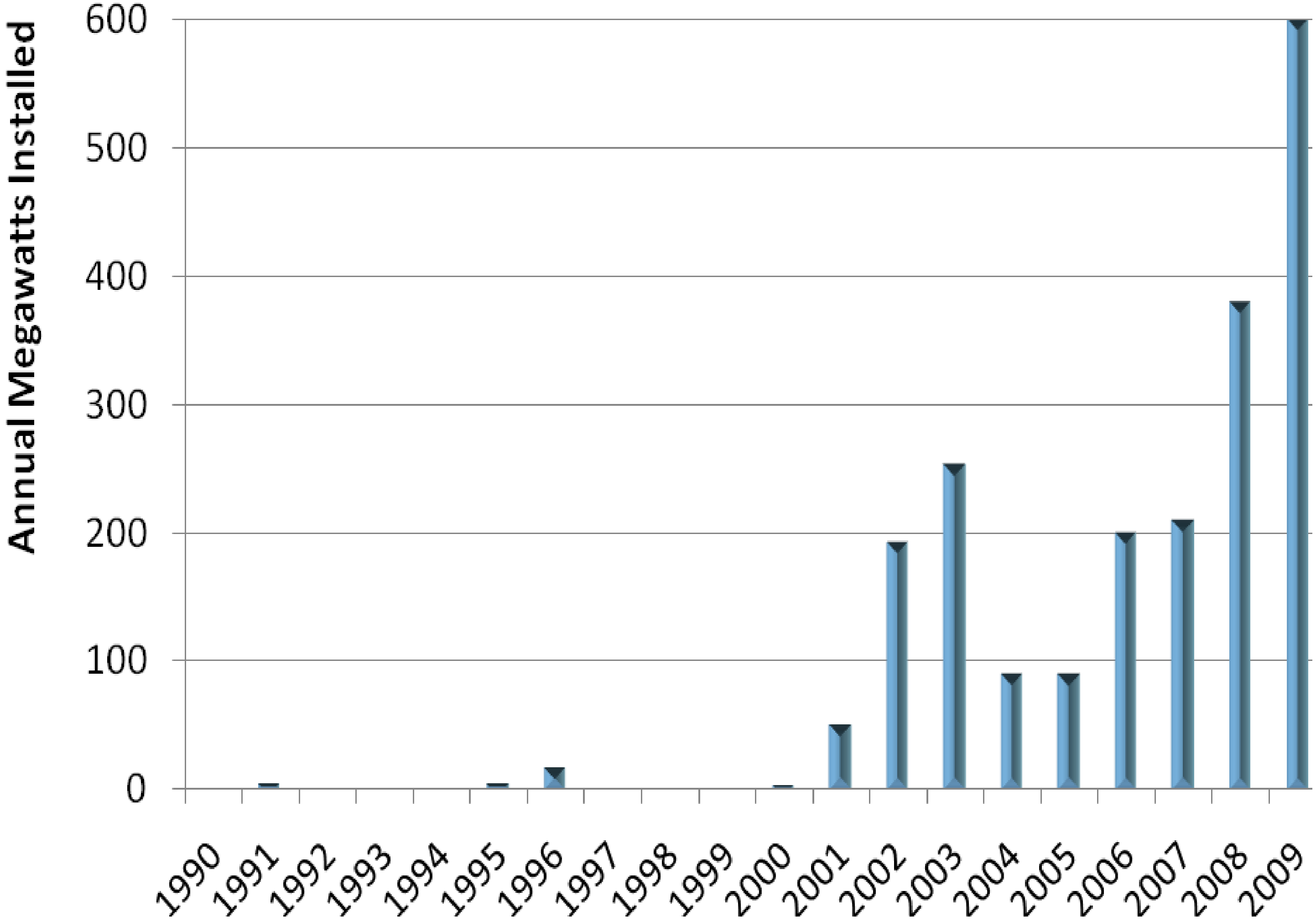


Offshore Wind Technology and Status

The following slides describe the status of offshore wind deployment, and some of the existing and future technologies.

Refer to Chapter 2 for further information.

Installed Offshore Wind Power Worldwide by Year



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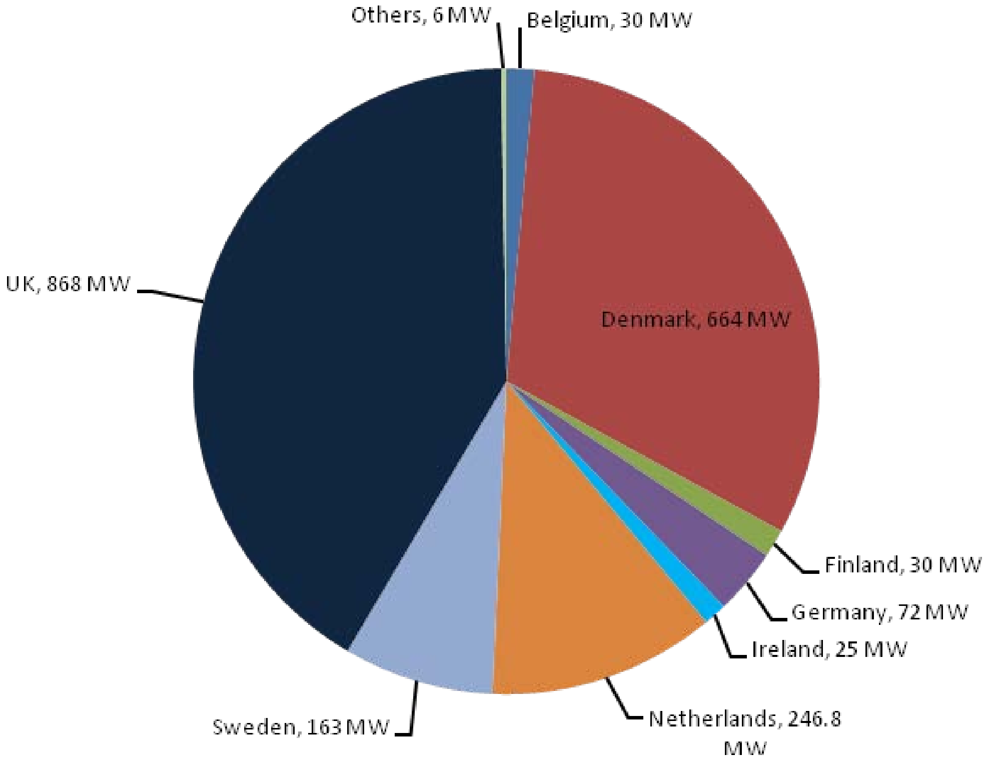

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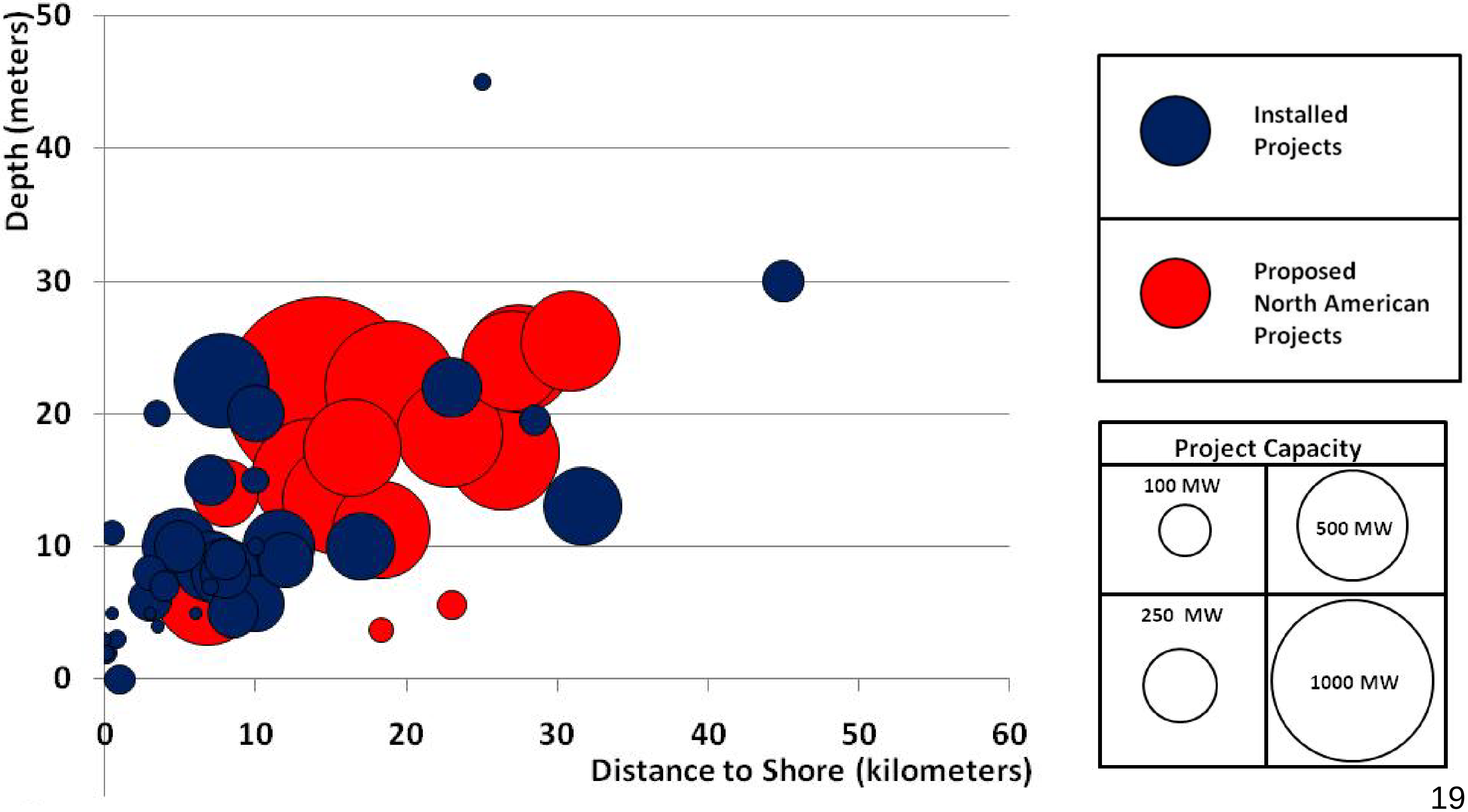
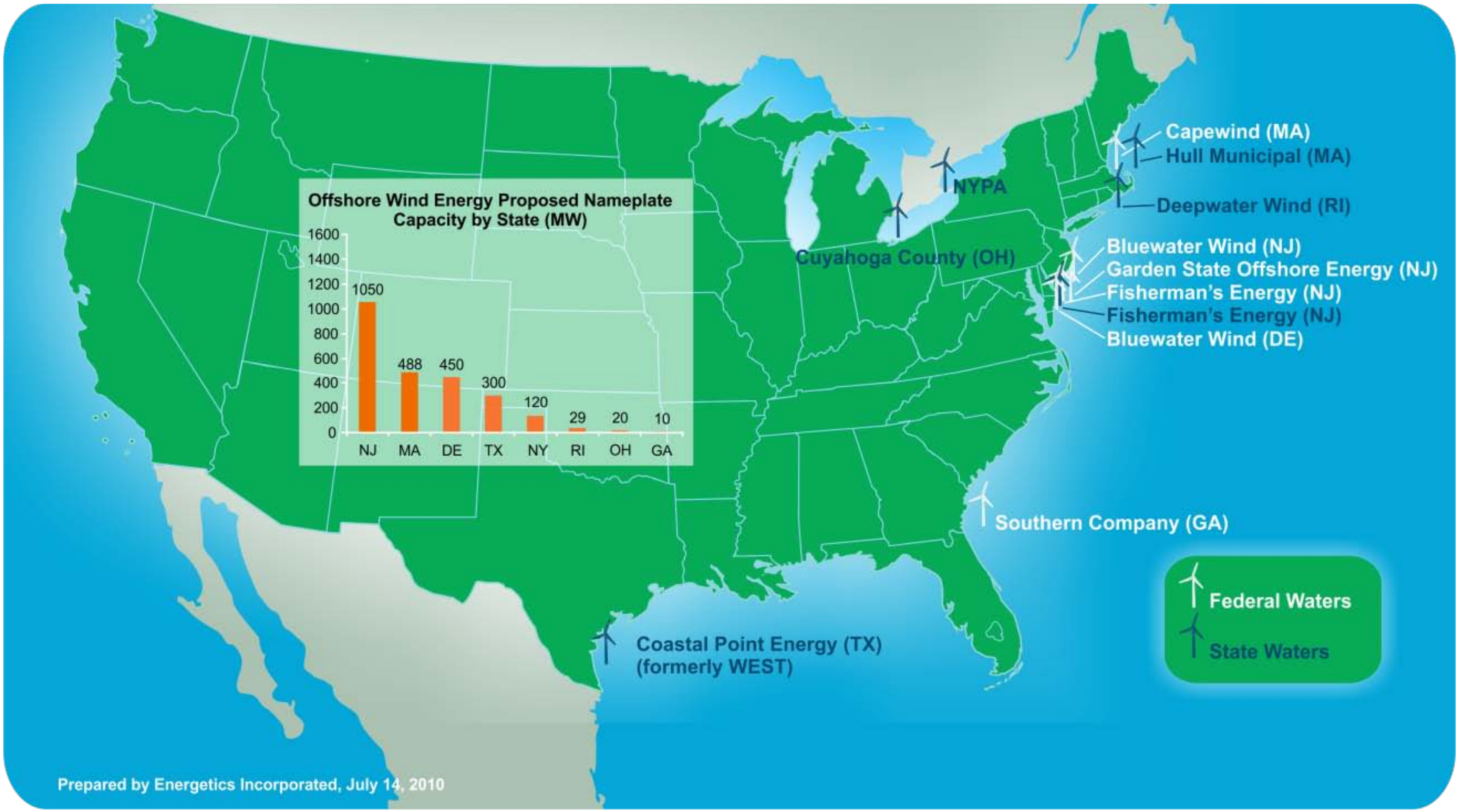


Source: NREL

Proposed U.S. Offshore Wind Projects & Capacity



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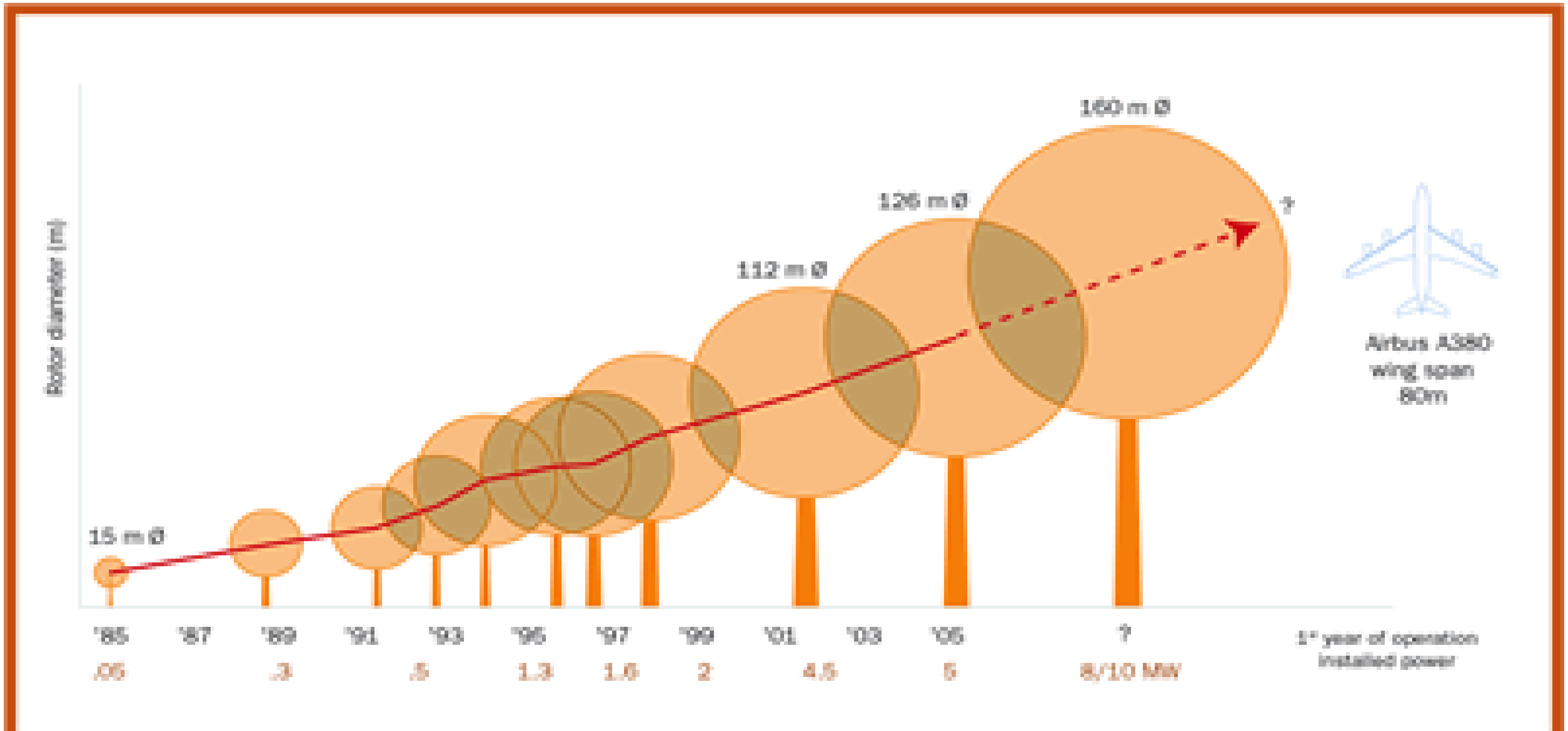
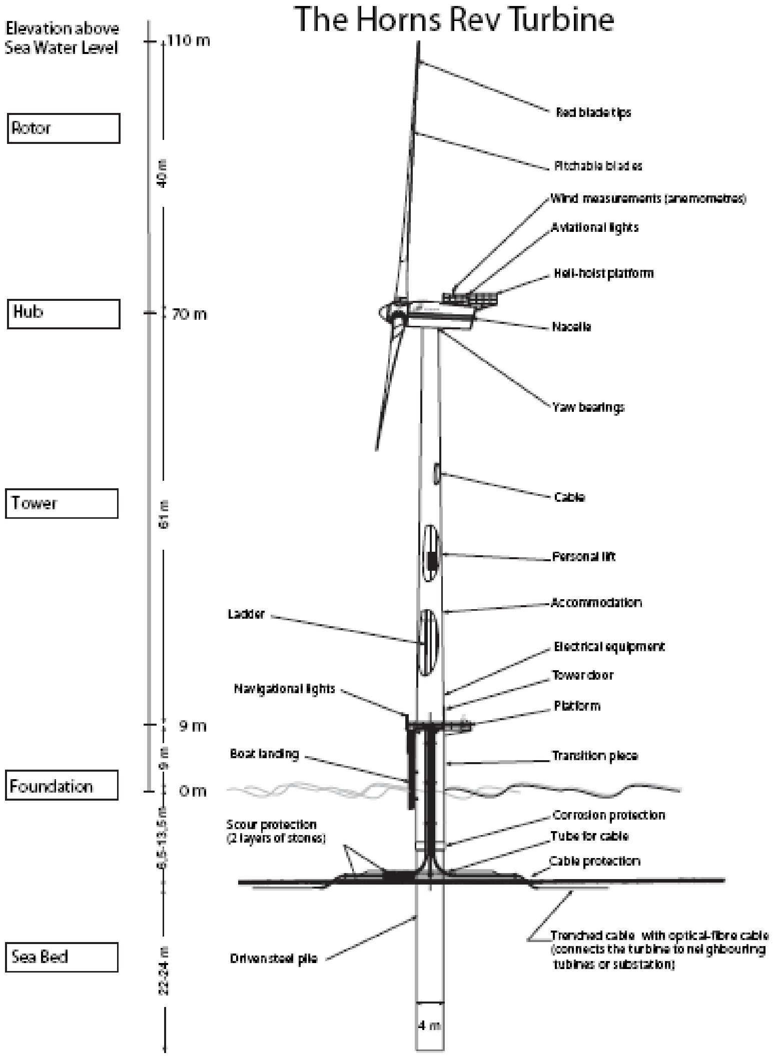


Source: Jos Beurskens, ECN

Offshore Wind Turbines

Most offshore wind turbines are robust versions of proven land-based designs, placed on freestanding steel monopiles or concrete gravity-based foundations.

The figure shows a 2 MW offshore wind turbine on a monopile foundation.

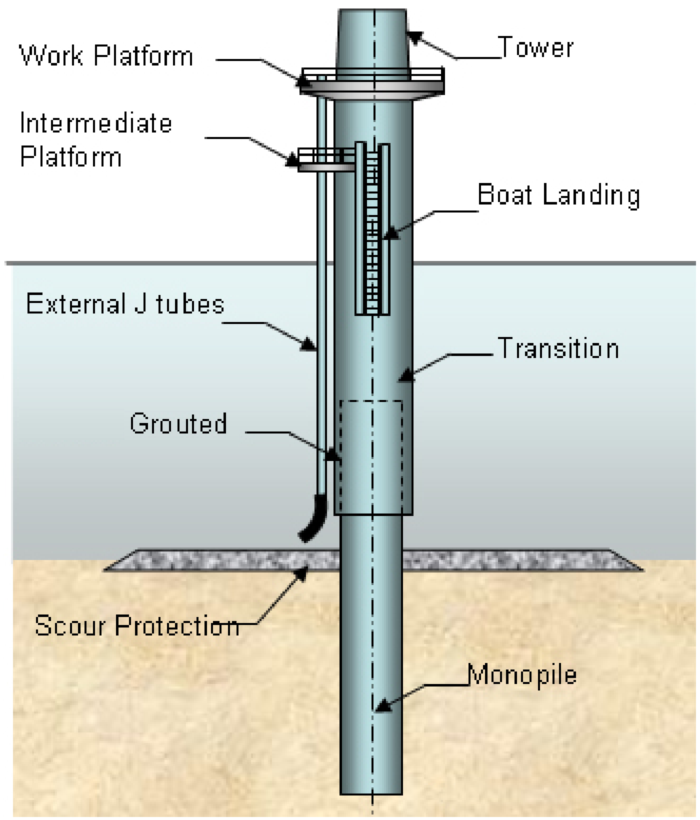


Principal Components and Dimensions of an Offshore Wind Turbine

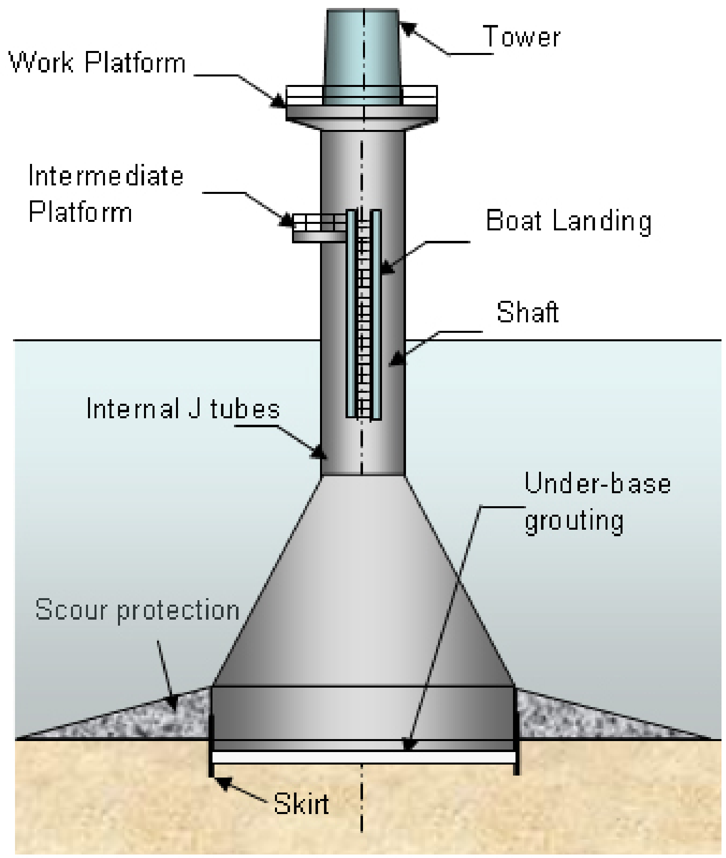
Graphic courtesy of Horns Rev wind project, Denmark (http://www.hornsrev.dk). Copyright Elsam A/S.

Types of Substructures

Monopile



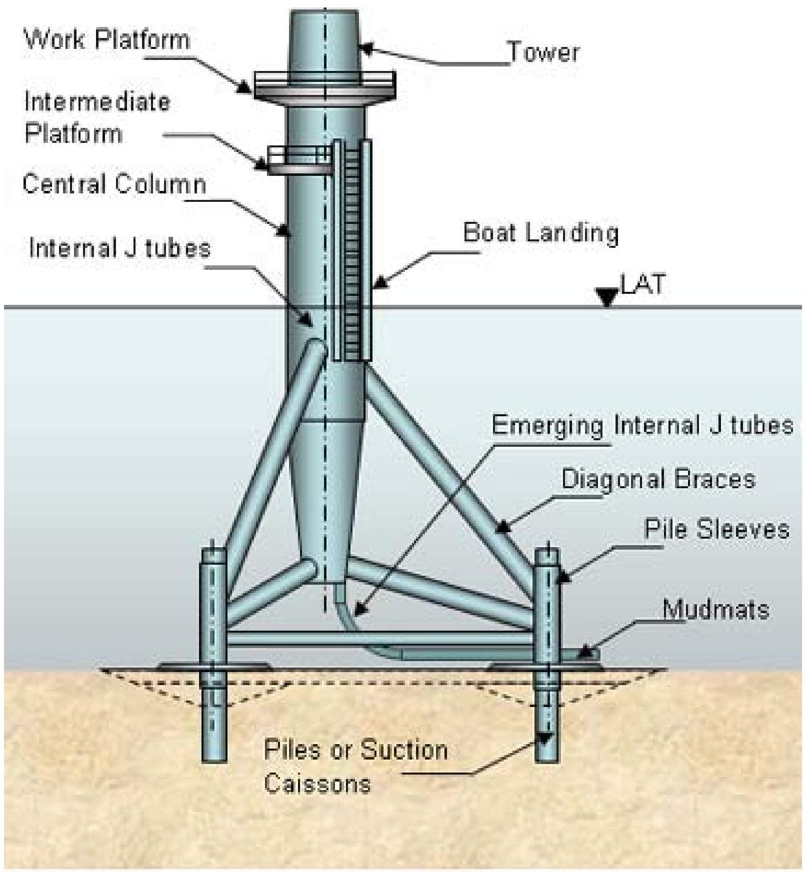
Gravity Base



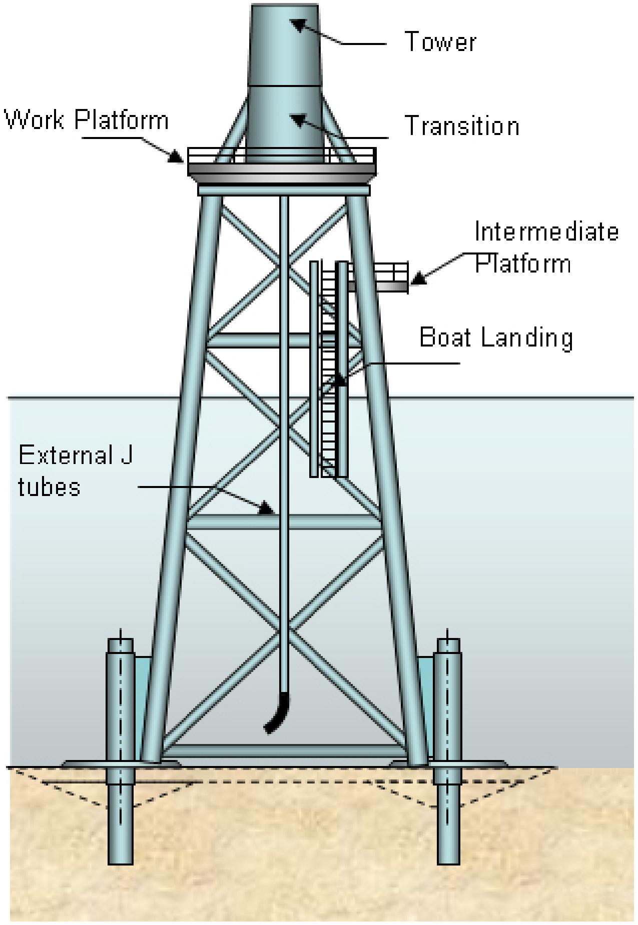
Source: EWEA "Wind Energy – the Facts", 2009

Types of Substructures

Tripod



Jacket



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Task 1
Standards and Practices

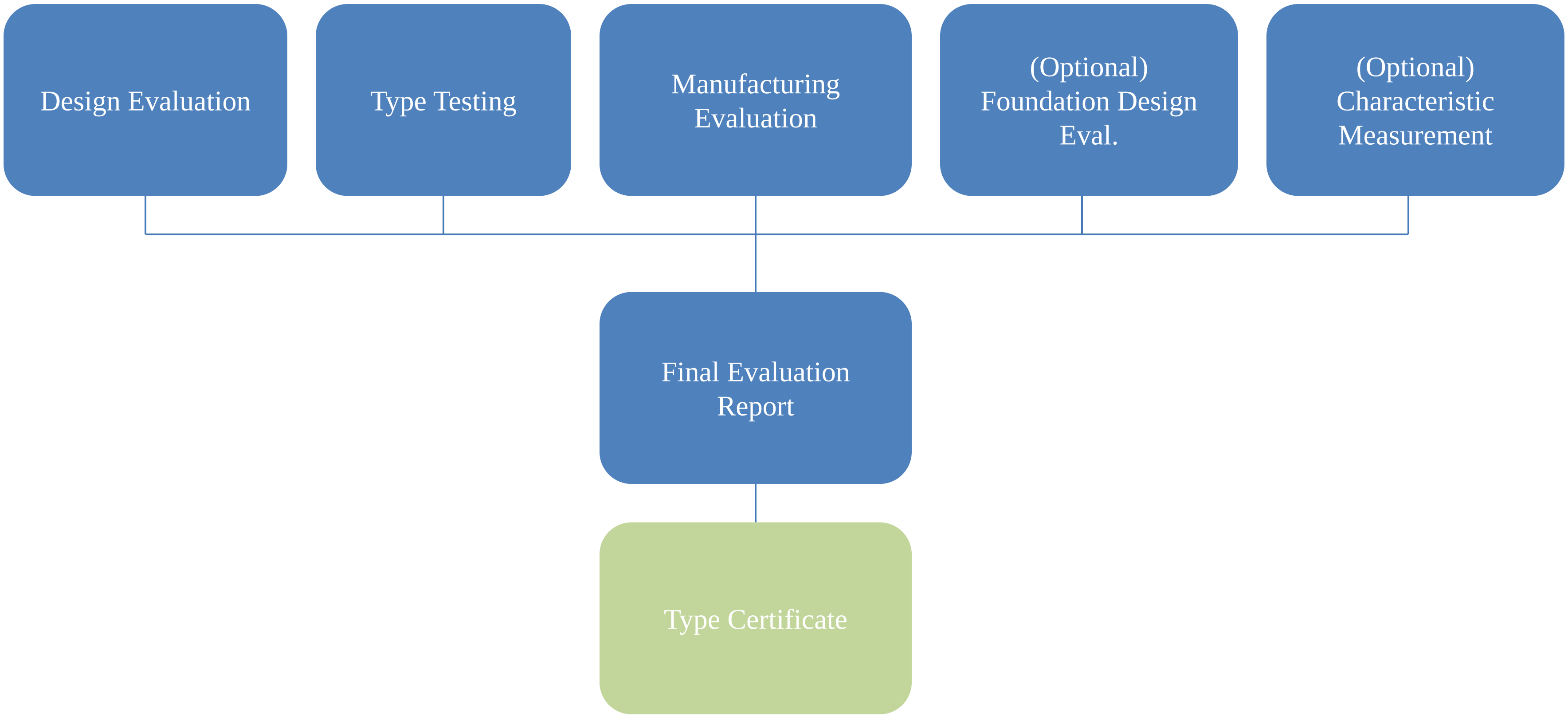
An evaluation of the applicability and adequacy of existing standards and practices for the design, fabrication, and installation of offshore wind turbines.

Refer to Chapters 3 & 4 for further information.

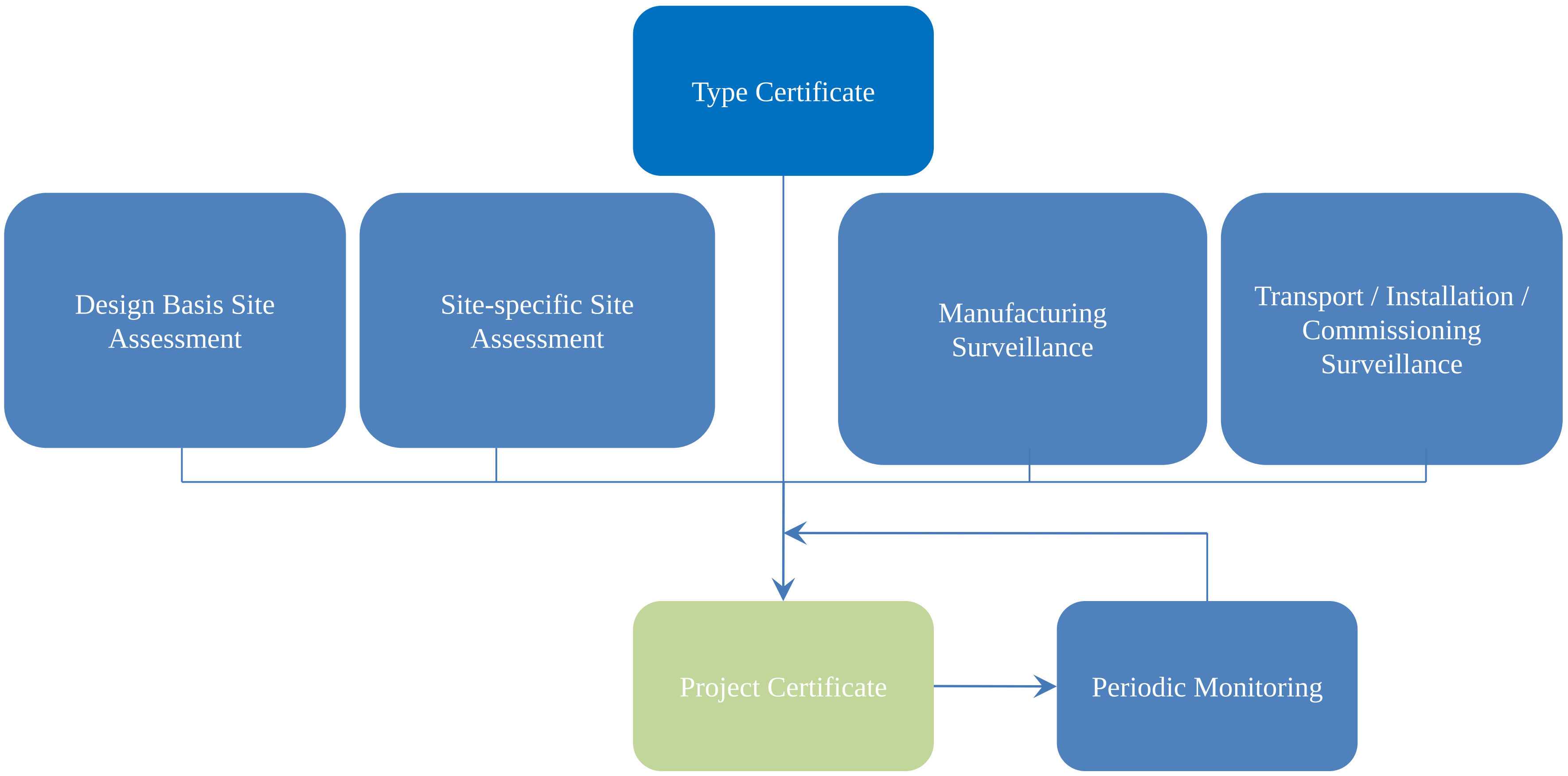
Regulations, Standards, and Guidelines for Offshore Wind

- **Regulations** are requirements promulgated by governments. Examples include the offshore wind regulations developed by Denmark, Germany and the Netherlands.
- **Standards** are documents developed by a consensus process following an established protocol. Examples include IEC 61400-1, 61400-3, 61400-22, and API RP 2A.
- **Guidelines** are documents developed by a group or company which is not subject to a vote of constituencies. Examples include the offshore wind guidelines developed by GL, DnV, and ABS.

Type Certification (IEC 61400-22)



Project Certification (IEC 61400-22)



Gaps in Existing Standards

- "Type certified" (IEC 61400-22) wind turbines may not be specifically designed for wind gust criteria for high energy hurricanes.
- Extrapolation of standards to significantly larger turbines raises concerns.
- Cyclic degradation of soil strength not considered.
- Fresh water ice loading not considered (e.g. Great Lakes).
- Extreme wave loads from breaking waves not specifically considered.
- Gravity based structures not as well documented as steel substructures.
- Recent experiences not yet introduced into IEC standards.

Findings – Task 1: Standards

1. Most existing offshore wind regulations take a prescriptive approach.
2. The starting point for most regulations is IEC 61400-1 and IEC 61400-3.
3. The more comprehensive guidelines have been developed by the classification societies (e.g. DNV, GL, ABS).
4. Methodologies for strength analysis differ amongst the various standards and guidelines, and lack transparency.
5. The BOEMRE regulations lack the clarity and specificity needed for development of offshore wind in the OCS.
6. The U.S. urgently needs a clear set of regulatory expectations to facilitate the orderly development of offshore wind.

Comparison of Level of Risk

Offshore wind farm pollution and safety risks are relatively low.

Energy Industry	Level of Risk: Liquid Hydrocarbon Release	Level of Risk: Life Safety: Normal Operations	Level of Risk: 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

Appropriate Level of Regulatory Oversight

- Because the environmental and life safety risks of offshore wind facilities are relatively low, the form and extent of government regulation should be considered.
- The U.S. commitment to exploiting offshore wind as a key component of its renewable energy policy raises the question of whether regulations should be crafted to ensure a minimum level of system reliability.

Risk Matrix Driven by Policy Consequences of Failures

Policy Consequence:	Low	High
Scale of Impact	**Small**	**Large**

External Event Probability:		
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Mitigate by Standards and Certified Third-Party Reviews

Alternative Approaches to Regulating Offshore Wind Industry

a. A comprehensive set of prescriptive regulations that explicitly describe design characteristics, methodologies, materials, and manufacturing & installation procedures.

b. A set of regulations relying on existing national and international standards that are prescriptive in nature, with gaps filled by supplementary prescriptive regulations.

c. Goal-based standards that describe the overarching expectations for protection of life, environmental performance, and system reliability.

d. Goal-based standards combined with functional requirements that establish high-level expectations for performance while providing a greater level of specificity on design assumptions and expectations.

Prescriptive Regulations

Prescriptive regulations describe in detail methods and formulations to obtain the design objective and demonstrate compliance. Advantages of prescriptive regulations include:

- 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.

Performance-Based Regulations

Performance-based regulations describe the desired outcome rather than the means to achieve the outcome. Advantages of performance-based regulations include:

- 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.

Advantages of Performance-Based Regulations (continued)

- 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.

Suggested Approach for Regulating the U.S. Offshore Wind Industry

- The committee recommends that BOEMRE develop a set of goal-based standards backed by functional requirements. These regulations should be performance-based and risk-informed.
- A set of standards, rules, recommended practices, guidelines, and so on is deemed compliant, or in conformance, if meeting them is sufficient evidence that the performance-based goals have been met.
- To facilitate compliance by developers, BOEMRE should be prepared to pre-approve guidelines developed by rulemaking bodies (e.g. classification societies) as compliant with the goal-based standards.
- The rulemaking body should be expected to demonstrate to BOEMRE compliance of their rules with the goal-based standards, and to fill any gaps identified by BOEMRE.

Findings – Task 1
Regulatory Approach

1. The federal government has an interest not only in safety and environmental performance of offshore wind installations but also their reliability and efficiency.

2. Improvements in efficiency are needed to make offshore wind cost competitive. Performance-based regulations allow for the introduction of new technologies.

3. As a result of the significant uncertainties affecting performance under extreme conditions, performance-based criteria have a risk-informed basis.

4. BOEMRE staffing levels and experience must be enhanced if it is to effectively provide the leadership and decision-making capability needed for developing U.S. offshore wind regulations.

Recommendations: Task 1

1. BOEMRE should develop a set of goal-based standards governing the structural and operational safety of offshore wind turbines and power platforms.
2. BOEMRE should provide a well-defined regulatory framework as soon as practical (not later than YE 2011).
3. BOEMRE should be prepared to review rules of other bodies for compliance with its goal-based standards.
4. BOEMRE should establish a substantial core competency within the agency with the capacity and expertise to lead the development of the goal-based standards, and review compliance.
5. BOEMRE should consider creating an expert panel to assist in development of the goal-based standards.

Recommendations: Task 1 (continued)

6. BOEMRE should take a leading role in promoting awareness of lessons learned in the offshore wind industry.

7. BOEMRE should be fully engaged in the national and international process for developing standards for offshore wind turbines.

Task 2
Role of CVAs

The expected role of the CVA in identifying standards to be used, and, the expected role of the CVA in conducting onsite inspections to verify compliance with the standards.

Refer to Chapter 5 for further information.

Examples from Other Industries

Examples from other industries:

- Local communities and states adopt building codes for facilities and public infrastructure. Most jurisdictions issue permits after plan review, and inspect during construction. Compliance verification is generally carried out by officials of the jurisdiction.

- Ocean shipping is subject to national and international regulations. Compliance verification is the responsibility of the flag state (national authority). Compliance verification is often contracted out to classification societies. Classification societies also develop guidelines (called class rules) for the design and construction of ships, and provide verification through plan review, inspection during construction, and periodic inspections during the vessel's life.

CVAs for Oil & Gas Facilities

The U.S. oil and gas industry operates with a two-tier oversight process as administered by BOEMRE. For facilities of lower complexity, plans are stamped by a professional engineer and checked by BOEMRE for regulatory compliance. For more complex structures, the Certified Verification Agent (CVA) program has been adopted.

Key features of the CVA process as currently implemented:

- Covers design, fabrication and installation.
- A single CVA can be approved for all three phases, or separate CVAs can be approved for each phase.
- BOEMRE approves CVAs on a project basis.
- BOEMRE reviews owner's documentation and CVA reports, and makes final determination of acceptability.

BOEMRE Regulations using CVAs for Offshore Wind

30 CFR 285 provides for a CVA process similar to that applied for offshore oil and gas facility oversight.

- Focuses on structural aspects and foundations.
- The specified role of the CVA is to review, assess, and comment to BOEMRE.

A key difference from the offshore oil & gas certification process and that specified for offshore wind is that the offshore wind developer has the option to petition for a waiver of CVA elements under special circumstances.

BOEMRE Regulations using CVAs for Offshore Wind

The committee believes that limiting CVA oversight to structural aspects is too narrow a focus:

- A design, manufacturing or installation flaw in any component of an offshore wind facility could readily affect a significant percentage of the wind farm.
- Dynamic response of the structure and foundation is influenced by the harmonics and loading of the blades.
- The control systems may be critical to maintaining integrity during severe weather conditions.
- Proper design, fabrication and installation of components including the blades and nacelle assembly are critical to achieving high reliability and efficiency.

Scope of CVA Verification: Wind vs. Oil & Gas

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.

Findings – Task 2
Role of the CVA

1. Wind turbine certification in accordance with IEC 61400 provides effective third party review for design of the nacelle, blades, and tower, provided the type certification criteria matches the site specific conditions.
2. Type certification does not cover fabrication, transportation, or installation.
3. For example, type certification of blades requires testing of only prototype blade. Fabrication quality assurance and control procedures for production are not addressed.
4. The CVA program for offshore oil & gas as defined in 30 CFR 250 is an appropriate model for offshore wind.
5. 30 CFR 285 provides a good definition of the CVAs role, but should be enhanced per the committee's recommendations.

Recommendations: Task 2

1. The responsibility for proposing a comprehensive package of standards, rules, guidelines and recommended practices that conform** with the goal-based standards should rest with the project developer. The CVA should review them and comment to BOEMRE on the adequacy of the proposed standards.

2. The scope of BOEMRE mandated third party review should include: blades, blade controls, tower and structural supports, foundation, infield cables and connectors, export cables, and other structural and electrical systems.

**A set of standards, rules, recommended practices, guidelines, and so on is deemed compliant, or in conformance, if meeting them is sufficient evidence that the performance-based goals have been met.

Recommendations: Task 2 (continued)

3. The third-party review should ensure the following:

- *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.

- *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.

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

Recommendations: Task 2 (continued)

4. The third-party reviewer should provide periodic reports to BOEMRE with regard to the review findings and should note any deviations or concerns.
5. Type certification of a wind turbine may be substituted for portions of third-party design review subject to the type certification matching site conditions.
6. BOEMRE should retain responsibility for final approval. BOEMRE should have staff competent to select qualified third parties and to approve projects.

Task 3
CVA Qualifications

The experience level, technical skills and capabilities, and support equipment and computer hardware/software needed to be considered a qualified CVA.

Refer to Chapter 6 for further details.

Qualifications Needed by CVAs

Section 706 of 30 CFR 285 contains the proposed CVA nomination process for offshore wind projects. Similar to offshore oil & gas facilities, a qualification statement is to include 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.

Qualification Statement
(continued)

- 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.
- Level of work to be performed.
- Unlike 30 CFR 250, the offshore wind turbine regulations require that the verification work be directed by a registered professional engineer.

Design CVA

The design CVA should have expertise in the following:

- Identification, specification and implementation of design limit states.
- Fatigue and strength design approaches.
- Determination of adequacy of proposed design environmental conditions.
- Evaluation of foundation design.
- Interaction between foundation and turbine system.
- Determination of adequacy of geotechnical assessment.
- Ability to perform independent design calculations as necessary.

Fabrication CVA

The fabrication CVA should have expertise in the following:

- Fabricator quality control.
- Material quality evaluation.
- Welder qualifications.
- Nondestructive testing.
- Destructive testing (e.g. full-scale blade tests).
- Blade materials and fabrication.

Installation CVA

The installation CVA should have expertise in the following:

- Evaluation of installation plans and procedures.
- Witnessing of installation operations including loadout, towing, launching, uprighting, submergence, etc.
- Marine operations, from loadout to sea fastening and transportation to site.
- Subsea cabling activities including trenching, burial, and connections.
- Offshore construction activities.
- Installation equipment.

Pre-Approved List of CVAs vs. Project-Specific Approval of CVAs

- The advantages of pre-approved lists are that they provide clarity for the developer/operator and avoid possible delays due to the approval process.
- The advantages of project-specific approval is that it helps ensure that qualification information is current, and that the qualification process is transparent for each project.
- MMS found it difficult to maintain an approved list of CVAs for offshore oil & gas, and abandoned this approach in favor of project specific-approvals.
- The committee recommends the approval of CVAs be on a project-specific basis.

Findings – Task 3
Qualifications Need by the CVA

1. A qualified CVA must be:

- Independent and objective.
- Experienced in performing scopes of work similar to that being reviewed, with a knowledge base of the standards and the necessary technical expertise and engineering judgment to verify assumptions, results and conclusions.
- Direction to be provided by a registered professional engineer (or international equivalent).

2. Detailed lists of expertise that should be required for CVAs providing certification for the design stage, the fabrication stage, and the installation stage are provided in the committee's report.

Findings – Task 3
(continued)

3. The CVA for design, for fabrication, and for installation need not be the same organization or person. It is unlikely that a single person would have sufficient expertise to perform effectively as CVA for all phases.

4. It would be beneficial, though not essential, for a CVA to have experience in third-party reviews and in interacting with regulatory agencies.

5. The CVAs experience should be related to the installation location.

6. 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 3

1. When evaluating CVAs, BOEMRE should seek organizations and individuals that:

- Are independent and objective
- Have experience, expertise, and engineering judgment sufficient to verify assumptions, conclusions, and results.
- Have experience with the dominant environmental effects for the project location.
- Have experience in the areas described in the report for the CVA tasks.
- Have clearly defined roles and responsibilities with adequate oversight by a PE (or international equivalent).
- Have an auditable quality plan for the processes and record keeping involved.

Recommendations – Task 3
(continued)

2. BOEMRE should hire sufficient staff to oversee the development of offshore wind farms in the OCS.

3. BOEMRE should approve CVAs on a project-specific basis as opposed to maintaining an approved list of qualified CVAs.

4. BOEMRE should take a leading role in 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 projects as a means to fill the experience gap for both industry and regulators.

Recommendations – Task 3 (continued)

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.

QUESTIONS