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Wind Turbine/Radar Interference:
Offshore Test Options

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Abstract

This paper attempts to describe the options to expand the scope of the current Interagency Field Test & Evaluation (IFT&E) objectives to include wind turbine encroachment on agency missions for offshore wind development in the United States.

The options described here build on the recently completed IFT&E test campaigns that took place in 2012 and 2013. Those tests, which looked at the CARSR, ASR-11, ARSR-4, and eight proposed mitigation technologies, found that wind turbines can significantly impact the ability of radars to detect aircraft and meet mission requirements above and near wind farms.

One of the more immediate successes of the IF&E Program is that today, several of the infill radar technologies which were tested, took the results of their IF&TE performance to move well beyond Technology Readiness Level 6/7 and some have been deployed and are operating at airports in the United Kingdom (UK). As well, the UK Ministry of Defense (MOD) has deployed the replacement radar which was tested to address specific concerns with especially concerning offshore wind farms. The UK MOD continues to test and hopes to refine these systems so that identified shortfalls in surveillance capability and operations which remain can be addressed. Wind energy has been steadily growing in the U.S. With a current capacity of over 60 GW today and the expectation that this capacity will need to grow to 300 GW to meet the U.S. Department of Energy's (DOE) goal of 20% wind energy in the future, offshore wind farms are gaining more attention.

The specific impacts of wind turbine interference on maritime radars have not been determined at this time. However, the DOE did fund a study conducted by the University of Texas at Austin entitled, "Assessment of Offshore Wind Farm Effects on Sea Surface, Subsurface and Airborne Electronic Systems," that focused on identifying the broader

effects of electromagnetic interference expected to be caused by offshore wind farms.[1] A review of that study would be worth the reader's time. And while no comprehensive field studies have been accomplished, it is worth noting that many mitigation solutions that were tested I the IFT&E Program are derived from short-range maritime radar systems.

The Wind and Water Power Technologies Office (WWPTO), within the DOE Office of Energy Efficiency and Renewable Energy, supports the development, deployment, and commercialization of wind and water power technologies. This report is funded by the WWPTO.

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List of Acronyms and Abbreviations

ARSR	air route surveillance radar
ASR	airport surveillance radar
ATC	air-traffic control
CMSP	Coastal and Marine Spatial Planning (process)
CODAR	coastal ocean dynamics applications radar
CONUS	continental U.S.
D-RAPCON	deployable radar approach control
dB	decibel
DHS	U.S. Department of Homeland Security
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
FAA	Federal Aviation Administration (U.S.)
ft	feet/foot
GMTI	ground moving target indictor
GW	gigawatt
HF	high frequency
HLD	homeland defense
HLS	homeland security
Hz	Hertz
IFT&E	Interagency Field Test and Evaluation (program)
kHz	kilohertz
km	kilometer
kW	kilowatt
LRR/JPO	Long-Range Radar Joint Program Office (DOD-DHS)
m	meter
MOD	Ministry of Defense (UK)
MPAR	multiple-function phased-array radar
MW	megawatt
NASA	National Aeronautics and Space Administration (U.S.)
NATS	National Air Traffic Services (UK)
nm	nautical mile
NOAA	National Oceanic and Atmospheric Administration (U.S.)
NOC	National Ocean Council (U.S.)
NWS	National Weather Service (U.S.)
OCONUS	outside the continental U.S.
OCS	outer continental shelf
OE/AAA	Obstruction Evaluation/Airport Airspace Analysis (process)
PPI	plan position indicator
PRF	pulse-repetition frequency
PSR	primary surveillance radar
RCS	radar cross-section
SAR	synthetic aperture radar
UK	United Kingdom
USAF	U.S. Air Force
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture
UTA	University of Texas at Austin
WERA	wave radar
WT/RI	wind-turbine/radar interference

1 Introduction

It is known that wind turbines present a source of interference with air-surveillance radars when they lie in the radar's line-of-sight. The effects of this wind-turbine interference are of concern to flight safety, homeland security, national defense, and protection of life and property from weather events. Even so, our national renewable-energy goals suggest that the number and size of wind turbines will grow in coming years. An Interagency Field Test and Evaluation (IFT&E) program was established in response to Congressional and White House direction to address the competing objectives of national wind-energy and air-surveillance requirements. The program investigated both long-range and short-range radar systems for onshore wind turbines.

The "20% Wind Energy by 2030" report, published in 2008 by a U.S. Department of Energy (DOE) collaborative, addressed the incentives and challenges for developing wind power plants offshore. The report assumed that offshore wind energy would account for 18% (54 GW) of total wind capacity by 2030. While these numbers come with many assumptions that may be outdated, they do illustrate the immense potential for an offshore wind industry in the U.S. It is estimated that more than 4,000 GW of potential offshore wind resource exists in state and federal waters along the U.S. oceanic and Great Lakes coasts. Currently, around 2,000 MW offshore wind projects are proposed in the U.S.[2] Figure 1 illustrates U.S. offshore wind-energy potential.

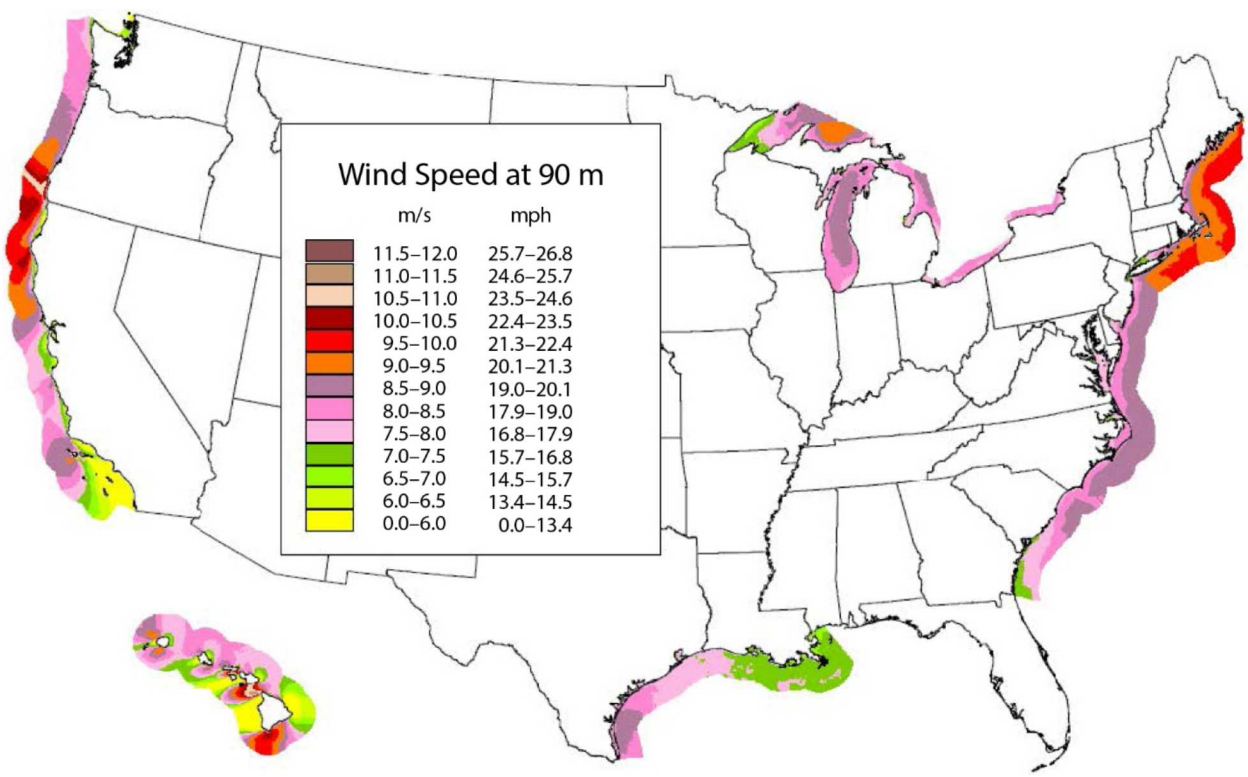

Figure 1 – U.S. offshore wind speed estimate at 90 m. (Source: National Renewable Energy Laboratory)

To take advantage of steadier winds, offshore wind turbines are bigger than onshore turbines—with a rotor size of up to 160 m in diameter, and they are continuing to grow. The result of these larger machines is the potential for a larger radar cross-section (RCS) and stronger return signal to

radar systems, causing greater interference. Figure 2, below, illustrates the trends in the growth of wind-turbine technology.

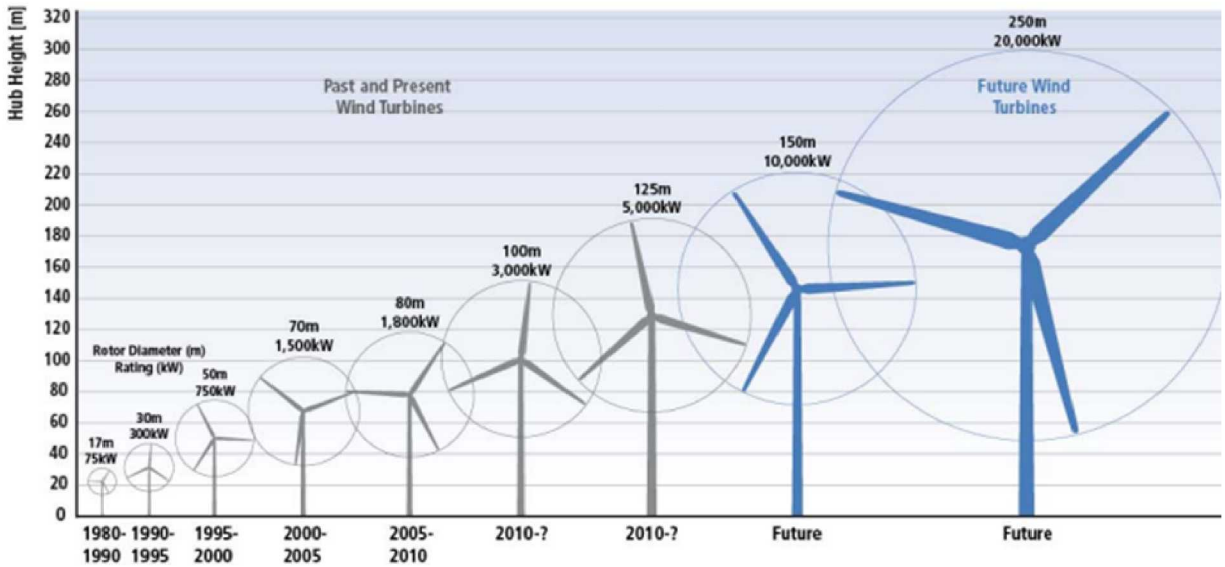

Figure 2 – Trends in wind turbine sizes. (Source: Intergovernmental Panel on Climate Change)

The increased DOE focus to overcome barriers to offshore wind development creates a potential need to investigate the radar-interference issue for offshore wind in a similar manner to the IFT&E program conducted onshore. In addition, the offshore environment has the added component of vessel navigation, in the form of shipboard radar.

The DOE has funded this whitepaper to examine the potential options, costs, and benefits of conducting a field test on military operations and radar systems in the offshore environment.

This report's Section 2 summarizes the current situation with offshore wind development in the U.S. Section 3 summarizes global trends of offshore wind energy. Section 4 describes offshore-wind-energy stakeholders and describes government agency concerns and interests. Section 5 describes the types of systems that offshore wind turbines may affect. This includes radar systems as well as other military concerns. Section 6 lists other potential interference issues that may arise due to offshore wind energy. Section 7 details potential locations where an offshore field test could take place that would be representative of the U.S. offshore environment. Finally, Section 8 provides a summary of conclusions and recommendations.

2 U.S. Offshore Wind Energy Summary

Although, currently, no commercial offshore wind-energy projects are in operation in the U.S., 12 projects, estimated at 3,824 MW of nameplate capacity, are in the development stage.[3] Those projects are listed in Table 1, below, and proposed locations are shown in Figure 3.

Table 1 – Proposed Offshore Wind Projects in Advanced Development Stages

Project Name	Location	# of Turbines	Distance Offshore (mi)	Hub Height[a] (m)	Rotor Diameter (m)	Target Completion Date[b]
Block Island Offshore Wind Farm	Rhode Island	5	3		120	2015
Icebreaker (Lake Erie)	Ohio	9	7	75/99	101	2017
Fisherman's Energy Phase I	New Jersey	5	3	90	115	2017
Cape Wind Offshore	Massachusetts	130	10	80	107	2014
Virginia Offshore Wind Technology Advancement Project	Virginia	2	23.5	100	150.95	2017
Fisherman's Energy Phase II	New Jersey	66	7	90	115	2017
Galveston Offshore Wind	Texas	55–75	7	65/80	70.65	2016
Baryonyx Rio Grande Wind Farms	Texas	100–200	7.8	—	120	2018
Garden State Offshore Energy Wind Center	New Jersey	58–70	20	—	—	2017
Deepwater ONE	Rhode Island	150–200	20	—	—	—
Principal Power Windfloat	Oregon	5	18	80/100	120/170	2017
NRG Bluewater's Mid-Atlantic Wind Park	Delaware	150	12.7	—	—	—

[a] Hub height given is from turbine manufacturer's product brochure. Actual hub height will be site specific.

[b] Dates shown are based on developer statements and may change.

The earliest estimated targeted completion date of these projects is in 2015, which could easily change based on permitting, leasing, surveying, and other development activities.

The Cape Wind offshore project was the first proposed U.S. offshore wind farm. The permitting process began in 2001, and 13 years later the project has yet to begin construction. This project illustrates the challenges and uncertainty with developing U.S. offshore wind projects.

As part of the Cape Wind environmental impact statement, a number of studies were performed including an Electric and Magnetic Fields study and a Communications: Radar, Television, Radio, Cellular, and Satellite Signals and Beacons study.[4] The U.S. Coast Guard (USCG) commissioned the radar performance study that was conducted by Technology Service Corporation. This study examined the potential impact of the Cape Wind project on several commercial off-the-shelf marine radars that vary in size and operating characteristics. The study concluded that there would likely be an impact on radar navigation and that several mitigation techniques can potentially reduce that impact.

Additionally, the Federal Aviation Administration (FAA) made a "Determination of No Hazard to Air Navigation" as part of the Obstruction Evaluation/Airport Airspace Analysis (OE/AAA) review process.[5] In making this determination, the FAA performed an evaluation of effect on air navigation and communication facilities. This included analyzing potential impacts to three radar systems within the Nantucket Sound area (an ARSR-4, an ASR-9, and an ASR-8[*]).

[*] ARSR = air route surveillance radar; ASR = airport surveillance radar

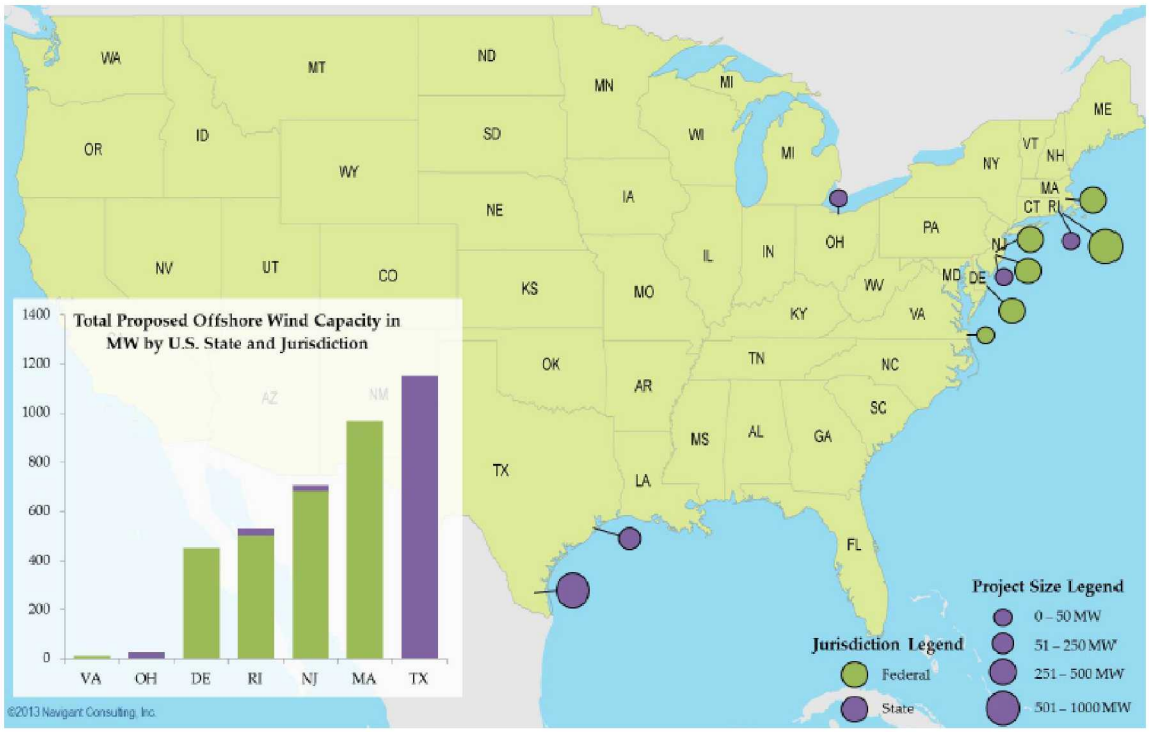

Figure 3 – Proposed U.S. offshore wind projects. (Source: Navigant Consulting, Inc.)[3]

A pilot-scale offshore wind turbine is in operation off the coast of Maine. The University of Maine installed a 20 kW turbine that sits atop a prototype floating platform. However, due to its small size, it is unlikely that this pilot turbine could be leveraged to conduct meaningful radar-interference analysis.

3 International Offshore Wind Energy Summary

Globally, ~5.3 GW of offshore wind energy is in commercial operation.[3] As seen in Figure 4, the United Kingdom (UK) hosts the majority of offshore-wind installations. With 3.65 GW installed across 22 offshore-wind sites and another 5.7 GW either under construction or with planning approval, the UK is the world leader in offshore wind energy.[6]

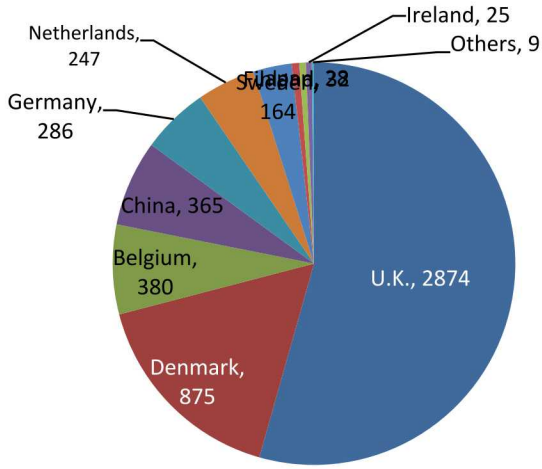

Figure 4- Nameplate generating capacity (in megawatts) of offshore wind projects as of 2013.[3]

Figure 5 shows the various locations of offshore wind installations in operation and currently under construction in the UK. It also shows a subset of layers detailing the primary surveillance radar (PSR) cover from 20–200 m. These maps were created by the UK's National Air Traffic Services (NATS) to provide wind developers with an aid to understand where potential interference with air surveillance radar is likely. The map also shows the 15 nm consultation zones for a subset of the UK's secondary surveillance radars.

Figure 5 – (Left) UK offshore wind farms in operation and under construction[7] and (right) PSR coverage[8].

Figure 6, depicting the array of European offshore wind stakeholders was presented by a NAVCOM Consult briefer in Paris (November 2007). Though dated, it provides a view of the complexity of the wind-turbine/radar interference (WT/RI) issue and could be applied to the situation in the U.S. today as well, although the names of the organizations would certainly be different.

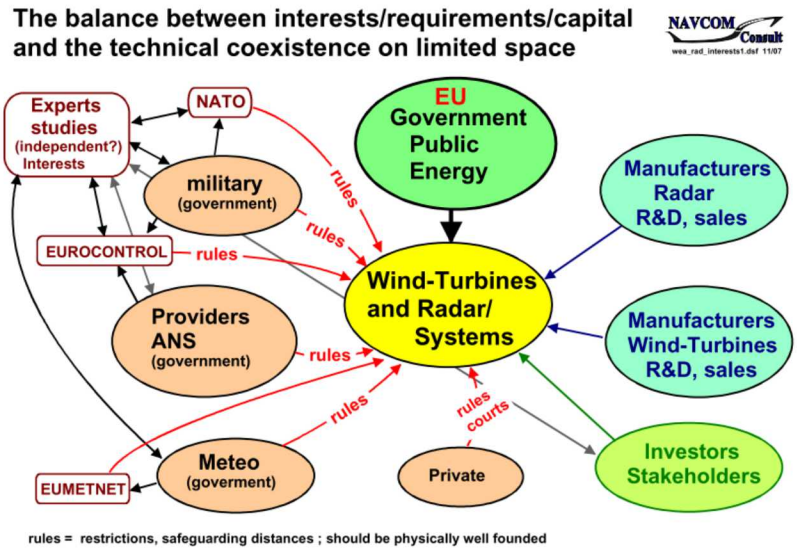

Figure 6 – The complexities of co-existence.[9]

4 Offshore Wind Energy Stakeholders: Government Agency Concerns and Interests

4.1 Bottom Line

The government and private industry organizations noted/reviewed in this section concerning offshore wind turbine induced electromagnetic interference issues are in common agreement that (1) finding technologies to mitigate or remove the electromagnetic barriers to wind-energy deployment is a national priority and (2) in order to successfully identify mitigation capabilities, comprehensive testing in each of the key areas of surveillance, navigation, and communications must be accomplished.

4.2 Key Stakeholders

The following discussion is provided to demonstrate the level of concern and potential support for such testing one can expect from stakeholders, especially within the federal government.

4.3 Offshore Wind Energy Supporters

Literally hundreds of public wind-energy supporters are involved in the offshore wind-energy sector worldwide, so many that it would be impossible to comprehensively cover them in a white paper. Suffice it to say that public wind-energy supporters all want to promote offshore wind development and, in general, support any government initiative that reduces barriers to offshore wind-energy deployment. For this paper, we will look primarily at key government stakeholder concerns as well as identify the core planning process here in the U.S. that is currently driving U.S. offshore wind policy. That policy begins in the White House.

4.4 The National Ocean Council (White House)

The National Ocean Council (NOC) is a dual principal- and deputy- level committee that supports the President's National Ocean Policy. The following comes from the NOC website[10]:

> President Obama recognizes that America's stewardship of the ocean, our coasts, and the Great Lakes is intimately linked to national prosperity, environmental sustainability, human health and well-being, adaptation to climate and other environmental change, social justice, foreign policy, and national and homeland security. The Executive Order[11] adopts a National Policy that includes a set of overarching guiding principles for management decisions and actions toward achieving the vision of "an America whose stewardship ensures that the ocean, our coasts, and the Great Lakes are healthy and resilient, safe and productive, and understood and treasured so as to promote the well-being, prosperity, and security of present and future generations."

4.4.1 Implementation Strategy

The White House has an implementation strategy that identifies priority objectives that our nation will pursue to address some of the most pressing challenges facing the ocean, our coasts, and the Great Lakes.

4.5 Priority Objectives

The strategy notes "Nine National Priority Objectives." Objectives 2, 3, and 9 apply to potential electromagnetic interference.

- **Coastal and Marine Spatial Planning:** Implement comprehensive, integrated, ecosystem-based coastal and marine spatial planning and management in the U.S.
- **Inform Decisions and Improve Understanding:** Increase knowledge to continually inform and improve management and policy decisions and the capacity to respond to change and challenges. Better educate the public through formal and informal programs about the ocean, our coasts, and the Great Lakes.
- **Ocean, Coastal, and Great Lakes Observations, Mapping, and Infrastructure:** Strengthen and integrate federal and non-federal ocean observing systems, sensors, data-collection platforms, data management, and mapping capabilities into a national system, and integrate that system into international observation efforts.

In addition to the NOC and its objectives, one can also refer to the Coastal and Marine Spatial Planning (CMSP) process for a sense of the priority the current Administration places on offshore wind energy deployment here in the U.S.

4.6 Introduction to Coastal and Marine Spatial Planning Process

CMSP is a comprehensive, adaptive, integrated, ecosystem-based, and transparent spatial planning process. It is a planning process based on sound science, for analyzing current and anticipated uses of ocean, coastal, and Great Lakes areas. CMSP's bottom-line impact is that it provides a public-policy process for society to better determine how these areas are sustainably used and protected—now and for future generations.

The CMSP framework for the U.S. identifies the reasons for engaging in the CMSP process and describes CMSP's geographic scope. It articulates national CMSP objectives and describes how CMSP and CMS plans are regional in scope and developed cooperatively among federal, state, tribal, and local authorities, and regional governance structures, with substantial stakeholder and public input. CMSP is intended to yield substantial economic, ecological, and social benefits.

- CMSP national goals and principles[12]
- Regional planning bodies[13]
- Legal authorities relating to implementing CMSP[14]
- National Coastal and Marine Spatial Planning Workshop[15]

One can draw the conclusion from the level of effort put forth by the current Administration on developing and managing this complex and comprehensive framework that the Administration would likely be supportive of expanding the original IFT&E effort to include offshore-wind surveillance, navigation, and communication systems.

4.7 Key Government Stakeholder Concerns and Issues

Both the Bush and Obama administrations supported a framework that establishes goals for enhanced radar-surveillance capability. This framework is designed to improve capabilities of the homeland defense (HLD) and homeland security (HLS) missions across the board.[16] While this framework specifically addresses HLD/HLS missions, it does not mean that all wind-turbine-induced electromagnetic concerns are related to HLD and/or HLS missions. In fact, many federal agencies are only beginning to understand the broader impacts that wind-turbine-induced electromagnetic interference may have on their overall mission. Thus, most are reluctant to provide an agency-approved list of effects and impacts lest it be later deemed incomplete. Below is a short list of government stakeholders that have either

- officially noted concerns about the effects and impacts of terrestrial and/or offshore wind-turbine-induced interference (Sections 4.7.1–4.7.6) or
- specifically mentioned offshore wind-energy policies that could be affected by offshore wind-turbine electromagnetic interference issues (Sections 4.7.7 & 4.7.8).

4.7.1 U.S. Department of Energy

The DOE's Wind & Water Power Program is the lead for U.S. government development activities in support of national wind energy objectives. Because of the quality and magnitude of offshore wind resources, DOE has projected that offshore wind farms could supply 54 GW of generating capacity by 2030.[17] The DOE has taken an active role in addressing the broader wind-turbine-induced interference issue in order to remove a significant "barrier" to wind-energy deployment both on and offshore. The DOE Wind & Water Power Program acts as a primer organization for multiple projects that promote cross-organizational collaboration and coordination.

4.7.2 U.S. Department of Transportation

The U.S. Department of Transportation's (DOT's) primary stakeholder is the FAA. The FAA's primary concern is air safety and to some extent air security. While FAA has solid terrestrial experience with electromagnetic WT/RI issues, the offshore issues have just begun to come into focus and, due to proximity, may not necessarily fall within the confines of the FAA's OE/AAA review process. Thus, FAA representatives have noted they recognize the need for offshore WT/RI studies. The FAA is also working with the National Oceanic and Atmospheric Administration (NOAA) on a proposed multiple-function phased-array radar (MPAR) system that is being designed to replace the current land-based air-traffic control (ATC) and weather radar systems in the 2025 timeframe. Both the U.S. Department of Defense (DOD) and the U.S. Department of Homeland Security (DHS) are also interested in in the MPAR concept as a potential solution to HLD and HLS air-surveillance missions, which both involve finding solutions to offshore WT/RI issues.

4.7.3 U.S. Department of Defense

The DOD's primary stakeholder is the DOD Siting Clearinghouse as they are the "One-stop-shop" set up by DOD, per Congressional mandate, to address electromagnetic wind-turbine-interference effects on military mission. DOD has long acknowledged the impacts/effects of large wind turbines on radars and specifically identified that studies needed to be conducted to find solutions in a 2006 DOD report entitled, "The Effect of Windmill Farms on Military Readiness." The graphic on military

flight-training routes and special-use airspace that follows this paragraph clearly underscores DOD's need to resolve offshore wind-turbine electromagnetic interference issues. Additionally, international military concerns have been noted in NATO studies entitled: Impact of Wind Turbines on Radar (SET-128) that began on 1-May-07 and continued thru 1-Dec-11. Other key DOD stake-holders include the

- DOD Assistant Secretary of Defense (Homeland Defense);
- Deputy Under Secretary of Defense, Acquisition Technology & Logistics, Science & Technology;
- North American Aerospace Defense Command and U.S. Northern Command/J36R, Headquarters U.S. Air Force (USAF)/A3O;
- DOD-DHS Long-Range Radar Joint Program Office (DOD-DHS LRR/JPO);
- 84th Radar Evaluation Squadron;
- USAF Flight Standards Agency;
- Hanscom AFB Electronic Systems Center;
- U.S. Air Force Research Laboratories; and
- a number of sub-organizations with specific evaluative and/or mission requirements that span the nation's armed services (U.S. Air Force, U.S. Navy, U.S. Army, & U.S. Marine Corps).

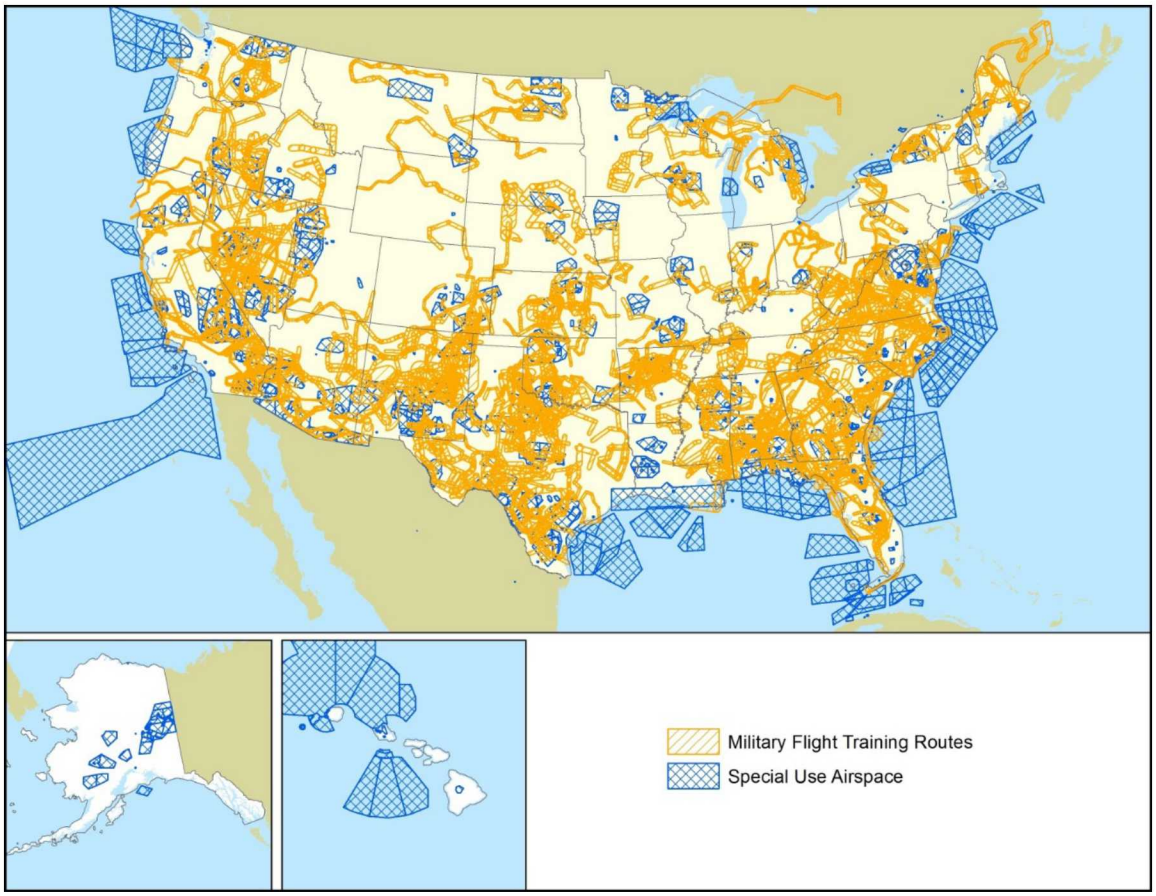

Figure 7 – U.S. military flight-training routes and special-use areas.

4.7.4 U.S. Department of Homeland Security

Key stakeholders in DHS include the DHS Science & Technology Directorate, Air & Marine Operations Center, U.S. Customs and Border Protection, U.S. Immigration & Customs Enforcement, U.S. Secret Service, DOD-DHS LRR/JPO, and USCG—with the USCG carrying the bulk of the burden for offshore surveillance and security. The USCG also maintains a robust counterintelligence service and has the only signals-intelligence capability within DHS. DHS missions are performed by dozens of agencies who leverage surveillance, navigation, and communications operations coordinating with hundreds of law-enforcement agencies, military organizations, and international partners. DHS is one of three agencies, DHS, DOT (FAA), and DOD, responsible for securing and defending our sea and air approaches. In order for each of these organizations to successfully perform their missions, each depends upon offshore surveillance systems to detect, track, identify, and prosecute suspected targets.

Five core HLS missions could be impacted by offshore wind-turbine electromagnetic interference issues, four of which require specific radar capabilities.[18] They are to

- prevent terrorism and enhance security,[19]
- secure and manage our borders,[20]
- enforce and administer our immigration laws,[21]
- ensure resilience to disasters,[22] and
- safe-guard and secure cyberspace.[23] (This mission has no direct radar role.)

The USCG derives their key authorities here from the Ports and Waterways Safety Act, as amended (33 USC et. seq.). This act

> Authorizes the USCG to implement, in water subject to the jurisdiction of the U.S., measures for controlling or supervising vessel traffic or for protecting navigation and the marine environment. Such measures may include but are not limited to reporting and operating requirements, surveillance and communications systems, routing systems, and fairways.[24]

4.7.5 U.S. Department of Commerce

The U.S. Department of Commerce has four key agencies that are concerned with offshore wind-turbine electromagnetic interference issues: NOAA, the National Weather Service (NWS), the National Telecommunications and Information Administration, and the National Marine Fisheries Service. NOAA, in particular, is concerned with offshore wind development, and while the ties may not be obvious to the casual observer, many of the missions of NOAA, require some sort of wind-turbine electromagnetic interference mitigation (marine, coastal, and airborne radar systems) in order to safely and efficiently leverage offshore energy sources.

The key NOAA radar network that is expected to be significantly affected by wind-turbine electromagnetic interference includes their portion of the continental U.S. (CONUS) high-frequency (HF) radar system depicted, in part, in Figure 8.[25] Multiple agencies contribute the assets that make up this CONUS HF radar system. Agency missions are varied and include operations such as USCG search and rescue, fisheries and ecosystem management, water-quality monitoring, rip-current prediction, marine navigation, and oil-spill response (for both NOAA & U.S. Department of State). The

primary HF radar types that make up the NOAA part of the network include coastal ocean dynamics applications radar (CODAR) and wave radar (WERA) sensors used to monitor the open-ocean surface current out to ~250 km. These and other HF systems register larger wind turbines on the order of the electromagnetic wavelength used. Expectations are that resonant scattering is likely to be a significant issue with HF systems, even more so than the high probability already noted with most terrestrial the L-, X-, and S-band systems used to meet today's surveillance needs.

The NWS performs a key function in developing wind energy, both onshore and offshore, and provides depth to many NOAA missions. A short list of NWS services includes weather, hydrologic, and climate forecasts and warnings for the U.S., its territories, adjacent waters, and ocean areas to protect life and property and enhance the national economy. NWS data and products form a national information database and infrastructure and are also used by other governmental agencies, the private sector, the public sector, and the global community.[26]

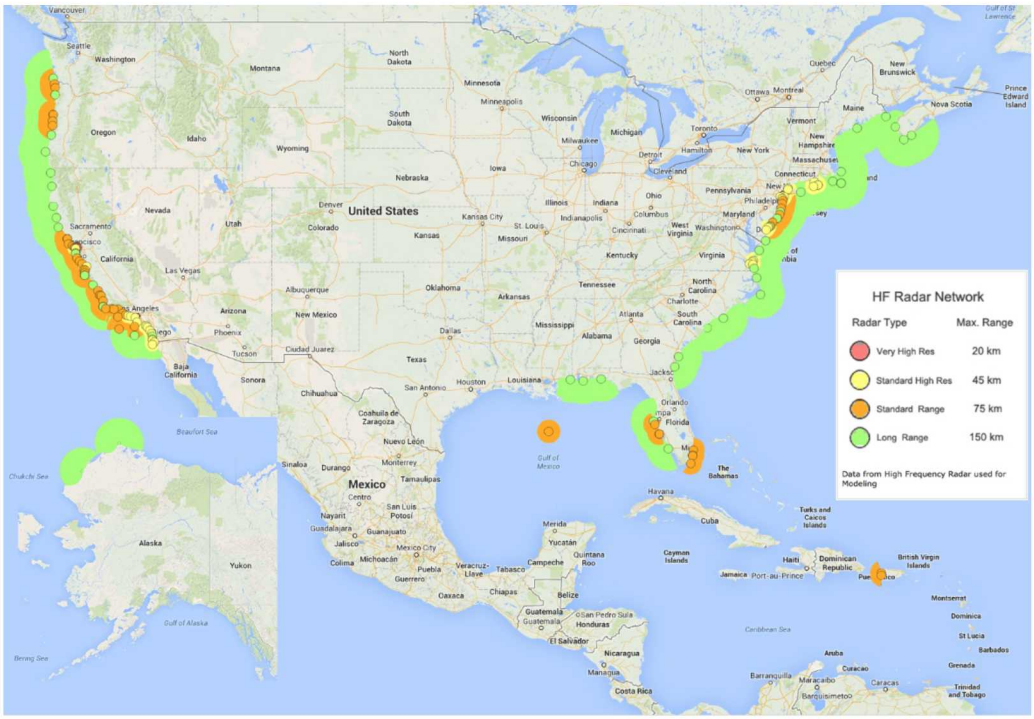

Figure 8 – CONUS marine HF radar system. (Source: NOAA)

4.7.6 U.S. Department of the Interior

The U.S. Department of the Interior's (DOI's) key stakeholder for offshore wind energy is the Bureau of Ocean Energy Management. DOI promotes an energy mission much like the DOE, but from another perspective. Their mission statement says that the DOI, "*protects America's natural resources and heritage, honors our cultures and tribal communities,* ***and supplies the energy to power our future****.*"

4.7.6.1 Key Elements Presented in DOI's Offshore Renewable Energy Argument[27]

The outer continental shelf (OCS) holds significant renewable energy resources that can contribute to meeting the nation's energy needs. Offshore renewable energy resources include many thermal and mechanical forms of energy. However, it is likely that in the foreseeable future, only ocean wind,

wave, and current resources will be economically developable. Offshore-wind development technology is more advanced than ocean wave and current technology, and OCS wind development is expected to contribute to the nation's energy portfolio before wave and current development.

4.7.7 U.S. Department of Agriculture

The U.S. Department of Agriculture (USDA) has an on/offshore wind-energy development perspective which simply stated is: "The proper siting of wind farms on public lands, tribal lands, and the outer continental shelf is a key issue for the USDA."

4.7.8 National Aeronautics and Space Administration

A report completed by the University of Maryland's Center for Integrative Environmental Research, published in October 2010, suggests that the National Aeronautics and Space Administration (NASA) would be concerned for their radar systems along the East Coast.[28] The report notes:

- "…the potential for diminished radar functionality exists at NASA's Wallops Flight Facility, which would impact many stakeholders."
- "A deficit of literature on how mobile radar devices interact with wind turbines is a hurdle to identifying potential conflicts."

Much like the areas around DOD training and test & evaluation facilities, NASA's concerns center on critical capabilities that cannot be readily moved or replaced. Even if they could be moved, these missions would very likely take decades or more to do so, due to political, environmental, and technical studies that are required by current regulations.

5 Interagency Systems Expected To Be Impacted by Offshore Wind-Turbine Electromagnetic Interference

Table 2 offers a summary of key systems and programs used in support of federal missions that are known or suspected to be affected wind-turbine electromagnetic interference issues.

Table 2 – Potential Missions that May Be Affected by Wind-Turbine Electromagnetic Interference

Air Safety
Air traffic control
Airborne weather forecasting/operations
Terminal/airway airspace clearance
Navigational aids
Special-use airspace (onshore and offshore areas)
Automatic dependent surveillance–broadcast
Next-generation system implementation
Surface target discrimination and control systems at major airport facilities
Maritime Navigation
Maritime radar monitoring navigation routes (offshore vessels)
Air Security (Aerospace Surveillance)
Homeland security
Homeland defense
Weather Operations
Air traffic safety and control
Public weather safety (hurricane, tornado, severe weather [rain/snow/thunderstorm] warning, etc.)
Communications Facilities
Radio (AM/FM/HF [short wave])
Television (analog/digital)
Navigation capabilities:
Aviation & maritime communication systems
Global positioning systems

Note: Many of the systems affected in this table directly impact industry operations as well. They may also be tied to, and significantly impact, U.S. economic health.

5.1 Terrestrially-Based Turbines vs Offshore Turbines

This section contains notes from multiple discussions between dozens of government representatives at interagency-sponsored conferences over the past two years concerning offshore wind energy and electromagnetic interference. For the operational stakeholders, six key differences must be considered when looking at terrestrially-based vs offshore wind turbines as research is performed on wind-turbine-induced electromagnetic interference.

1. Offshore winds blow stronger and steadier than on land, and may result in larger Doppler returns.
2. The larger turbines employed in offshore wind farms produce larger RCSs.
    a. Larger turbines will remain in line of site farther off the horizon, lack of geomasking.

3. Clutter picture complicated by sea surface conditions:
   a. additional reflectivity and multiple-path issues not experienced in/around terrestrial wind farms are expected and
   b. surface targets ignored onshore will be part of the required target ID and tracking set[29].
4. Coastal air/sea defense, ATC, and weather radar concerns persist for offshore wind farms. Particularly due to expected siting, the location will have very large effects on the HLD mission.[30]
   a. The best places to locate offshore wind farms are near population centers.
   b. U.S. wind conditions are most favorable along the Northeast coastline, near those key population centers.
   c. Thus, optimally siting offshore wind farms for energy production and delivery will make sea and air approaches to those key population centers more difficult to defend (and increase defense costs).
5. Expectations are that resonant scattering is likely to be a significant issue with HF radar systems (e.g., NOAA CODAR & WERA sensors used to monitor the open ocean surface current out to 250 km) even more so than exist in high probabilities already identified with most L-, X-, and S-band systems used for today's typical terrestrial surveillance needs.[31]
6. Sonar (underwater radar) concerns become an issue.
   a. Turbine tower vibrations in the water will drive a different set of concerns not addressed in this review.
   b. Potential electromagnetic concerns as electromagnetic fields in/around water near wind turbines, and produced by wind turbines, have not been substantially measured.

6 Potential Interference Issues

In order to fully leverage the resources that would be expended for an expansion of the IFT&E program to the offshore wind-energy realm, one must cast a wider net to capture the variety of potential offshore wind-turbine-induced electromagnetic interference impacts. The specific impacts of wind-turbine interference on maritime radars and other electromagnetic systems have not been determined at this time. However, the study conducted by the University of Texas at Austin (UTA) focused on identifying the broader effects of electromagnetic interference expected to be caused by offshore wind farms.

Findings from the UTA report included the following (excerpted from the report).[1]

> ***Potential Interference with Electromagnetic Systems***
>
> **For marine navigation**, it was found that wind farm scattering could produce a confusing navigational picture if a boat being tracked is inside a wind farm. There would be minimal interference to tracking of vessels operating outside the wind farm. These findings confirm the earlier U.S. Coast Guard determination on the Cape Wind project that "the Coast Guard's assessment of impact on navigation safety falls within the moderate impact level." The case when the radar is inside the wind farm was not studied. In addition, higher order electromagnetic effects such as multiple scattering between turbines and turbine interaction with the ocean surface were not considered in the PPI [plan position indicator] simulation and further study is needed to fully characterize their effects.
>
> **For sensitive airborne sensors**, modeling was performed for a generic class of airborne radars onboard aircraft and operating at X-band under the SAR [synthetic aperture radar] and ground moving target indictor (GMTI) modes. When a wind farm falls within the coverage area of the radar beam, it was found that wind farm scattering could produce serious artifacts in SAR imagery and GMTI range-Doppler chips generated by airborne sensors. This could potentially impact the performance of identification and tracking algorithms. Possible mitigation based on signal filtering was also investigated. It was found that median filtering of the signatures may be a viable approach to mitigate the effect of dynamic wind turbine clutter. Assuming such a mitigation algorithm is properly tested and implemented, the impact on recognition and tracking could be reduced to within an acceptable level.
>
> **For ocean monitoring sensors**, the effect of offshore wind farms on HF radars located on the coast line such as CODAR and WERA systems was modeled. The radar backscattering clutter and forward electromagnetic shadow generated by a typical wind farm in the HF frequency range was simulated using the computer code FEKO. It was found that the overall shadowing effect of a wind farm is not strong and is localized to the region immediately behind the farm from the radar. The strength of the wind farm clutter is estimated to be 18 dB below the scattered power from the ocean surface being mapped by the radar. However, the turbine clutter may be comparable to weaker Bragg lines from the ocean surface that are also of interest. Moreover, the turbine clutter will be aliased in Doppler due to the slow PRF [pulse-repetition frequency] (2 or 4 Hz) that is typically used in these radars.
>
> **For communications systems**, the effect of offshore wind farms on vessel-to-vessel, vessel-to-shore and vessel-to-space links was modeled. Given the small degree of the signal fade (< 6 dB) and the finiteness of the electromagnetic shadow found around wind farms, the effect on com-

munications systems is expected to be low. When more than one turbine is lined up with respect to the transmitter line-of-sight, the fading risk is elevated. The disruption on phase due to wind farms may cause some concerns on those applications where phase information is used, such as direction finding and precise global positioning system (GPS) techniques based on carrier phase measurements.

In summary, the findings for the electromagnetic systems studied are as follows:

(i) Communications systems in the marine environment are unlikely to experience interference as the result of typical wind farm configurations, except under extreme proximity or operating conditions.

(ii) Marine navigation radars and ocean monitoring HF sensors may experience interference under certain proximity and operating conditions as the result of typical wind farm configurations. Pre-deployment investigation is warranted. Mitigation measures may be required.

(iii) Sensitive airborne radars may experience serious interference. However, the degree of interference may be system specific and dependent on whether wind farms are located within the operational area of the radar. Pre-deployment investigation is warranted. Mitigation measures may be required and will need to be further investigated.

Potential Interference with Underwater Acoustical Sensors

The underwater sound from a single wind turbine exhibits a relatively simple tonal structure, consisting of several frequencies between 100 and 1000 Hz, the amplitudes of which generally decrease with frequency. Local bathymetry and seabed composition determine the rate at which such sound is attenuated as it propagates away from a wind farm. This attenuation rate determines the range at which the sound pressure level is reduced to the ambient noise level. For example, along the continental shelf off the east coast of the U.S. it is anticipated that sound radiated by wind farms located near the coast should usually be reduced to ambient noise levels before it propagates beyond the shelf and into open ocean. In the event that hydrophones or seismic sensors are within the range where sound from the wind farm is above the ambient level, it is anticipated that conventional signal processing such as filtering and beam-forming can mitigate the potential interference.

Thus, due to the virtual absence of noise exceeding background levels radiated underwater by wind turbines at frequencies above 1 kHz, interference with underwater acoustical systems is deemed to be unlikely at such frequencies. At frequencies below 1 kHz, the tones radiated by wind turbines may cause interference with certain acoustical systems when placed in close proximity to a wind farm. The definition of "close proximity" depends on many factors, both environmental and specific to the wind farm itself.

The UTA report also recommended the following actions (excerpted from the report) be considered for future studies.[1]

First, it is highly recommended that measurement data on electronic systems be collected both before installation and after installation of the new Advanced Technology Demonstration projects funded by the DOE wind program. These new facilities, which should become operational between 2015 and 2017, will provide an excellent testing ground to collect in situ electromagnetic and acoustic data in order to confirm the modeling predictions.

Second, it is recommended that a more complete risk assessment on individual systems be made by combining the results from our study with detailed system-specific information. These are best performed by stakeholders who not only hold such information but have the expertise to make a holistic risk assessment. For underwater acoustics, it is recommended that a future study be conducted that focuses on specific acoustical systems that operate at frequencies below 1 kHz, which was not addressed in the present report. Such a study should include further engagement with stakeholders, including a classified forum in which the Department of Defense may voice its concerns.

Third, it is recommended that research and development into approaches to mitigate the impact of offshore wind farms on electronic systems be initiated through new research funding. The systems to be addressed, in order of their sensitivity to wind farm interference, are (1) airborne radars operating in high-resolution sensing modes, (2) coastal HF radars, (3) marine radars, and (4) acoustical sensors operating below 1 kHz. For radar systems, particular focus should be placed on low-cost solutions such as those based on signal filtering algorithms or modified navigation practices. In the case of underwater noise, one might investigate possibilities for expanding techniques currently focused on pile driving operations (such as bubble screens, pile sleeves, and hydrodynamic sound dampers) to entire wind farm installations.

Fourth, it is recommended that a government working group focusing on the new offshore scenario be established to encourage sharing of information from various agencies and help set protocols for addressing the offshore wind farm interference problem.

Fifth, it is recommended that the development of electromagnetic and acoustic simulation capabilities be continued. Currently, no end-to-end simulation tool exists that can address the various offshore wind farm interference scenarios. An accurate, user-friendly prediction tool will benefit future site-specific assessment tasks. Anomalous propagation effects over the ocean and higher order electromagnetic effects such as those due to multiple scattering, interactions with the ocean surface and non-conducting turbine materials should be further examined.

Sixth, it is recommended that ambient underwater noise measurements be made at potential offshore wind farm sites or, if possible, collected from available databases, and then catalogued for use in future modeling studies aiming to determine acoustical impact.

Seventh, it is recommended that the acoustic source model for underwater noise radiated by submerged wind turbine towers, which was developed under this project, be extended from cylindrically symmetric monopile towers to more complicated but geometrically similar constructions such as tripods, and that a new approach be developed to model noise radiated from floating platforms. Similarly, the implications of new tower constructions should be examined for their above-surface electromagnetic scattering effects.

Finally, another potential challenge with offshore wind turbines is the interference from electromagnetic fields created by the electric cables running from the turbines underwater to the shore that could affect orientation and navigation of ships.

Each of these items should be reviewed for potential inclusion to better leverage the expenses associated with any extension initiative put forward for the IFT&E program that includes an offshore IFT&E events.

7 Options for Offshore Wind Turbine/Radar Interference Testing

A key challenge in carrying out a test is finding a suitable venue because the U.S. currently lacks any utility-scale offshore wind farms. One possibility is partnering with the DeepCwind Consortium, a University of Maine research initiative funded by the DOE and the National Science Foundation looking at the development of floating offshore wind-farm technologies. The DeepCwind Consortium installed one 20 kW floating wind turbine in the Gulf of Maine. It is a one-eighth pilot-scale test turbine, ~65 ft in height. In situ electromagnetic and data collected at these facilities will certainly be valuable to better understand phenomenology and improve impact models; however, the findings may not fully characterize potential operational impacts due to the turbine's smaller scale when compared to the current turbine sizes deployed in commercial offshore wind farms.

Other options for a U.S.-based offshore test would rely on the completion of any of the projects listed in Table 1.

Alternatively, a test could be held OCONUS (outside the continental U.S.) near an operational offshore farm. As noted in Section 3, the UK is the global leader in commercially operational offshore wind farms, and the UK Ministry of Defense (MOD) is experienced with field trials and evaluations around these farms. An example is the recent Technology Demonstration Trials of Wind Turbine Mitigation for MOD ATC Radars, which took place in 2013 and assessed the impact on their existing Tactical Watchman ATC radar and six mitigation technologies. These trials were held at the MOD Eskmeals range in Cumbria in the northwest of England.

If the UK is deemed a promising venue for an offshore test, it is recommended that the existing four memorandums of understanding between DOD and MOD be leveraged to facilitate information exchange and begin planning discussions. It would be especially valuable to obtain technical information and results from the aforementioned technology demonstration trials. It is our understanding that some mitigation systems tested during the IFT&E program also participated in the UK trials. It would be worthwhile to understand the performance of these systems in a maritime environment, as well as being in proximity to larger offshore turbines with an increased RCS.

Several of the mitigation-system vendors who participated in the IFT&E program were polled as to how they might engage in such a test in the waters around the UK, specifically the infill radar vendors. All noted that due to the coverage volumes of their systems, wind farms far from the mainland would best be served by placing an infill system in or around the wind farm out at sea. All have ideas on how they would set up operationally, and all showed interest in participating in an offshore test program.

Key items of concern that must be considered to properly bound the costs of performing an IFT&E event in the UK (or elsewhere) include

- ensuring that the team would have access to government or private aircraft and/or vessels for the test,
- ensuring that the airspace and/or waterway control of a test box could be appropriately protected,

- ensuring that we send the appropriate personnel (balancing costs vs value to the team onsite),
- determining the availability and cost of securing billeting and an operations center for the test team, and
- determining the availability and transportation for U.S. systems of interest.

A transportable radar system that could be OCONUS is the Raytheon deployable radar approach control (D-RAPCON) system for ATC. D-RAPCON is similar to the ASR-11 domestic radar that was tested during the second IFT&E campaign.

Testing commercial mitigation technologies, particularly short-range infill radar systems, at a UK venue may be less burdensome in terms of cost and logistics. Many of the infill radar systems evaluated during the IFT&E program have been deployed at various sites across the UK and European Union.

8 Conclusions

The large potential for offshore wind energy in the U.S. coupled with the fact that wind turbines are known to cause interference on air-surveillance and weather radar systems is cause to begin to study and understand the likely intersection of these systems. With at least 12 projects, estimated at 3,824 MW of nameplate capacity, in the development stage, it is recommended that all potential issues with offshore wind energy and national security be examined and understood.

Because the U.S. doesn't have any existing commercial offshore wind turbines in operation, it is recommended that we look to our allies in the UK to learn from their experience and partner with them on any offshore testing. The following is a list of recommendations to begin this process:

- Engage with UK MOD to understand work to date.*
  - What have they tested? What are the gaps and value added from our potential test?
  - Leverage existing DOD MOU's where possible.
  - DOD Siting Clearinghouse should oversee discussions and to identify and control information exchanged.
  - Obtain copies of reports (e.g., technology demonstration for MOD ATC radars, TPS-77 testing) for review by Sandia and Massachusetts Institute of Technology–Lincoln Laboratory.
- Engage with key operational stakeholders.
  - What are their big concerns, and how do we address them in the test?
  - Identify systems of interest and prioritize based on expected mission impact from interference.
  - Determine feasibility of transporting system for OCONUS testing, or identify suitable surrogate system or measurements to characterize the impact.

Engage with the UK's Civil Aviation Authority, NATS, and other ATC agencies in Europe to garner support for an offshore test program that leverages their experience with regulatory agencies to help develop system integration requirements into the study.

* This team originally intended on reaching out to the UK MOD but received instruction from the DOD Siting Clearinghouse that any communication should follow protocols through existing agreements between the DOD and MOD.

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