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Federal Interagency Wind Turbine Radar Interference Mitigation Strategy

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Disclaimer

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Preface

This strategy document elaborates on and serves as the follow-on action plan to the Federal Interagency Wind Turbine Radar Interference Mitigation Strategy published in 2016.

DOE has been responsible for developing a strategy in coordination with signatory partners of the Wind Turbine Radar Interference Mitigation Working Group. In response to this requirement, DOE developed this strategy and coordinated it with the other memorandum signatories.

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List of Acronyms

AFFSA	Air Force Flight Standards Agency
BOEM	Bureau of Ocean Energy
DHS	U.S. Department of Homeland Security
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
ESG	Executive Steering Group
FAA	Federal Aviation Administration
IFT&E	Interagency Field Test & Evaluation
MOA	Memorandum of Agreement
NAS	National Airspace System
NOAA	National Oceanic and Atmospheric Agency
R&D	Research and Development
SSG	Senior Steering Group
WG	Working Group
WTRIM	Wind Turbine Radar Interference Mitigation

Executive Summary

Wind energy is one of the fastest growing sources of new electricity supply in the United States. Wind development within the line-of-sight of radar systems (and beyond the line-of-sight for coastal surface radar and over the horizon systems), however, can cause clutter and interference, which has resulted in significant performance degradation at some radar sites (Karlson et al. 2014). As wind turbines continue to be installed, older wind farms are repowered with larger wind turbines, and as advances in wind energy technology enable deployment in new regions of the country, wind development is more likely to present conflicts with radar missions. The growth driving this increase in wind-radar conflicts will impact air traffic control, weather forecasting, coastal sea-surface surveillance, homeland security, and national defense missions if not mitigated.

In 2012 – 2014, the U.S. Department of Energy (DOE), the U.S. Department of Defense (DOD), the U.S. Department of Homeland Security (DHS), and the Federal Aviation Administration (FAA) conducted three successful test campaigns to evaluate potential radar mitigation technologies under the Interagency Field Test & Evaluation (IFT&E) program. In 2014, DOD, DOE, DHS, FAA, and the National Oceanic and Atmospheric Administration (NOAA) developed the Wind Turbine Radar Interference Mitigation (WTRIM) Working Group (WG) under a Memorandum of Understanding to address wind-radar conflicts. Today, this federal working group, under a new 2023 Memorandum of Agreement (MOA), is composed of DOD, DOE, FAA, NOAA, the Bureau of Ocean Energy Management (BOEM), and DHS.

In 2016, DOE published the Federal Interagency Wind Turbine Radar Interference Mitigation Strategy (Gilman et al. 2016) with the objectives of fully addressing wind turbines' interference with critical radar missions, ensuring the long-term resilience of radar operations in the presence of wind turbines, and removing radar interference as an impediment to future wind energy development by 2025 while preserving U.S. airways, national security, the lives and property of citizens, and sensitive radar systems. While work on terminal radars and long-range radar has come a long way since 2016, with the addition of offshore and weather radar systems to the WTRIM WG's responsibilities, the timeline to accomplish the objectives of the 2016 strategy was extended to 2035 based on the technology available and tested to date. These objectives, reiterated in this updated strategy, continue to be pursued through collaboration and coordination amongst WTRIM WG agencies, with an added focus on coastal surface radar and weather radar systems.

To achieve these strategic objectives, the WTRIM WG will coordinate actions within three broad strategic themes:

Table 1. Activities and Broad Strategic Themes

Theme 1	**Improve the capacity of government and industry to evaluate the impacts of planned wind energy installations on sensitive radar systems.**
Activity 1.1	Develop improved modeling and simulation tools to aid in the siting and evaluation of planned wind facilities and assessment of potential mitigation measures.
Activity 1.2	Evaluate emerging WTRIM issues and identify effective pathways to mitigation as appropriate.
Theme 2	**Develop and facilitate deployment of mitigation measures to increase the resilience of existing radar systems to wind turbines.**
Activity 2.1	Facilitate rapid deployment of current off-the-shelf mitigation measures.
Activity 2.2	Develop and facilitate deployment of hardware and software upgrades to make existing radars more resilient to the impacts of wind turbines.
Activity 2.3	Improve the capacity of existing automation and command and control systems to mitigate wind turbine interference impacts to radars.
Activity 2.4	Explore at-the-turbine mitigation methods that reduce the radar impact of wind turbines.
Theme 3	**Encourage development of next-generation radar systems that are resistant to wind turbine-radar interference.**
Activity 3.1	Collaborate with developers of next-generation radar systems so the systems are designed to be highly robust against wind turbine interference.

While allowing for the scarcity of resources (funding and personnel) and the diversity of specific missions and authorities of each of the WTRIM WG agencies, the working group envisions its role in activities under the three above themes will vary. For example, WTRIM WG agencies are investing in research and development (R&D) to improve modeling and simulation capabilities to evaluate the impacts of proposed wind facilities on current radar systems. But with respect to improving the resilience of future radar systems, WTRIM WG efforts will focus only on outreach to the responsible programs to ensure the incorporation of WTRIM factors as key design considerations.

Regular coordination between the organizations in the WTRIM WG and coordination on WTRIM issues across the government are critical to the success of this strategy. To that end, the WTRIM WG will continue to conduct periodic teleconferences, quarterly face-to-face meetings, and periodic Technical Interchange Meetings to explore emerging WTRIM capabilities and related issues, as well as participate in other relevant government

forums, such as the National Airspace System Modernization and the Airspace Non-cooperative Surveillance Radar programs.

Given the importance of the WTRIM WG's efforts to wind energy development and vendors of mitigation measures, the WTRIM WG will also regularly distribute results from WTRIM WG-sponsored studies to wind energy groups and participate in relevant wind industry forums. The WTRIM WG will also monitor international WTRIM activities, engage with the entities performing those activities, and when appropriate, participate in international WTRIM forums.

With continued growth of wind energy installations and without adequate wind turbine-radar interference mitigations it will be a challenge to maintain the benefits of wind energy deployment while ensuring the integrity of critical radar missions. Overcoming this challenge will require continued coordination of investment in mitigation measures across the government, as well as dialogue between the wind industry and government agencies charged with carrying out critical radar missions. Through this strategy, the WTRIM WG seeks to build off the considerable progress made by the IFT&E program and other WTRIM efforts in addressing the challenge of wind turbine-radar interference.

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1 Introduction

Wind turbines can cause interference for radar systems because their large towers and moving blades reflect electromagnetic radiation. This interference affects radar systems differently, depending on whether they are air traffic control/air defense surveillance radar systems or weather radar systems. For example, in air traffic control/air defense radars, the motion of the blade resolves with similar speeds as some airborne targets and can complicate and interfere with identifying and tracking airborne targets. Atmospheric weather radar systems present a different challenge in the context of wind turbine-radar interference mitigation as they are designed to identify and resolve minute changes in air current movement and the precipitation in the air to identify and predict weather phenomena. Wind turbine radar signals can interfere with this process and cause weather radars to lose detection of these weather phenomena.

In May 2011, the White House Office of Science and Technology Policy completed an internal decision-making study at the request of the National Security Staff that found that wind turbines were interfering with government radars used for national defense, national security, aviation safety, and weather forecasting "by creating clutter, reducing detection sensitivity, obscuring potential targets, and scattering target returns. These effects on radar systems tend to inhibit target detection, generate false targets, interfere with target tracking, and impede critical weather forecasts" (Biddle et al. 2014).

As the number and size of wind turbines in the United States will continue to grow significantly over the next half century on land and offshore,[1] so could their effect on national flight safety, weather and ocean forecasting, homeland security, and national defense radars. In addition, because each next generation of more massive wind turbines will open new areas to development, more and larger areas will be impacted by wind turbine-radar interference (Zayas et al. 2015).

To preserve critical radar missions and accommodate future wind energy development, we need new technologies to mitigate wind turbine-radar interference. Moreover, because existing radar systems serve multiple missions across agencies, collaboration across the federal government will be needed to develop and gain acceptance for new wind turbine-radar interference mitigation technologies. The impact of wind turbines on radar systems may be reduced or eliminated in the near, mid, and long term. These reductions will require funding for wind turbine-radar interference R&D and for deployment of effective mitigation solutions.

History of Wind Turbine-Radar Interference

The wind turbine-radar interference issue was first brought before the U.S. Congress in 2006 in a report to the defense committees, which stated that the large size of rotating wind turbine blades result in a substantial radar cross-section target, and their rotation results in a Doppler velocity return.

In 2010, the issue gained national attention when DOD opposed construction of the Shepherds Flat Wind Farm in Oregon, because radar clutter (i.e., false targets) from the wind turbine blades would seriously impair the agency's ability to detect, monitor, and safely conduct air operations. That year, the White House asked DOD, DOE, FAA, and DHS to participate in a sub-Interagency Policy Committee called the Obstruction Evaluation Working Group to further investigate the effects of wind turbines on surveillance systems to reduce barriers to wind project installation/deployment through the application of mitigation methods.

As a result of this effort, the Interagency Field Test & Evaluation (IFT&E) program was established to conduct a series of flight tests with three goals: 1) characterize the impact of wind turbines on existing air surveillance

[1] The primary analysis of the U.S. Department of Energy Wind Program's 2015 *Wind Vision* report centers on a scenario in which wind energy serves 10% of the nation's end-use demand by 2020, 20% by 2030, and 35% by 2050.

radars; 2) assess near-term mitigation capabilities proposed by industry; and 3) collect data and increase technical understanding of interference issues to advance development of long-term mitigation strategies. Results from the IFT&E program tests are summarized in the IFT&E Industry Report (Karlson et al. 2014).

That year, Congress created the DOD Siting Clearinghouse in the Ike Skelton National Defense Authorization Act for Fiscal Year 2011. The Clearinghouse acts as a single DOD voice to provide a timely, transparent, and repeatable process to assess potential mission compatibility impacts of energy-related projects filed in the FAA Obstruction Evaluation process, and explores mitigation options while preserving military mission readiness and operations. If a major impact is identified, DOD establishes a Mitigation Response Team to evaluate mitigation options and negotiate implementation of mutually acceptable solutions to the mission compatibility challenge.

Establishment of the Wind Turbine Radar Interference Mitigation Working Group

Formally chartered under a Memorandum of Understanding in 2014 and under a 2023 Memorandum of Agreement (MOA), the Wind Turbine Radar Interference Mitigation (WTRIM) Working Group (WG) functions to identify and develop effective mitigation solution recommendations. While these recommendations are primarily technology-driven, the WTRIM WG can also provide a forum for reviewing, discussing, and informing common policy and legislative proposals as necessary.

This federal working group is composed of DOD, DOE, FAA, NOAA, BOEM, and DHS, and supported by teams at DOE's Sandia National Laboratories and Lawrence Berkeley National Laboratory, and DOD's Massachusetts Institute of Technology Lincoln Laboratory and Air Force Research Laboratory.

The first federal WTRIM Strategy, published in 2016, advanced strategic objectives to:

- Fully address wind turbine-radar interference as an impact to critical radar missions
- Ensure the long-term resilience of radar operations in the presence of wind turbines
- Remove radar interference as an impediment to future wind energy development by 2025 while preserving our airways, national security, the lives and property of our citizens, and sensitive radar systems.

These objectives, reiterated in this updated strategy, continue to be pursued through a set of collaborative activities including, but not limited to, the coordination of each agency's investments in the wind turbine-radar interference issue, R&D of appropriate mitigation measures, and facilitating the deployment of such measures, and with an added focus on coastal surface and weather radar systems by 2035.

Updated strategic objectives are to:

- Fully address wind turbine-radar interference as an impact to critical radar missions
- Ensure the long-term resilience of radar operations in the presence of wind turbines
- Remove radar interference as an impediment to future wind energy development by continuing R&D activities
- Mature mitigation capabilities that are the most promising
- Drive the deployment of those solutions that meet government needs and mission requirements by 2035.

To guide the WTRIM WG's efforts toward achieving the strategic objectives above, this updated strategy document communicates the group's approach and presents a comprehensive overarching framework with three strategic themes through which WTRIM activities are coordinated:

Theme 1. Improve the capacity of government and industry to evaluate the impacts of planned wind energy installations on sensitive radar systems.

Theme 2. Develop and facilitate deployment of mitigation measures to increase the resilience of existing radar systems to wind turbines.

Theme 3. Encourage development of next-generation radar systems that are resistant to wind turbine-radar interference.

The ongoing activities of the WTRIM WG fall under these three strategic themes. The activities presented are differentiated by mitigation approach and relative payoff time, as some solutions may be mature enough to be put into effect immediately while others may require further exploration, development, and evaluation.

Existing Mitigation Approaches

There are several approaches to minimize wind turbine-radar interference. The most important and straightforward approach is the proper siting of wind facilities on the landscape and "micro siting" of wind turbines within planned facilities. Early siting coordination with the FAA, NOAA, and DOD's Siting Clearinghouse can help prevent an interference issue long before a facility is built. Wind development may not be viable in certain places, such as near radar systems or near military testing or training locales where activities require interference-free electromagnetic environments.

If interference issues are identified during the formal review process, several mitigation approaches can help minimize wind energy's impact on radar, including the following siting practices:

- Designing the wind farm layout to minimize the impacted area of radar coverage or to allow for maximum radar coverage within the project, such as by increasing the spacing between turbines within the project
- Terrain masking, or placing turbines on the opposite side of elevated terrain in relation to the radar so they are blocked from view
- Relocating proposed turbines or reducing their height so that they fall outside the radar line-of-sight
- Eliminating proposed turbines in areas that result in high radar interference impacts.

Siting alone may not eliminate impacts or reduce them to an acceptable level, especially in the case of oceanographic coastal surface radars that measure over the horizon beyond the line-of-sight. In these cases, other mitigation techniques, including upgrading software or hardware, and/or instrumenting the wind facility with supplementary sensors can reduce wind energy impacts on radar operations involving air traffic control/air defense radar systems and oceanographic radars. Examples include:

- Modifying the existing radar system software's constant false alarm rates, clutter maps, or other filtering and/or preliminary tracking routines
- Upgrading the hardware or software of the affected radar to implement advanced filtering techniques that can reduce or remove interference from turbines
- Installing supplementary sensors within and around the periphery of wind farms and transmitting their readings to radar operators to augment the data available to software mitigations.

In most cases, siting and other approaches have mitigated conflicts and allowed wind projects to coexist with radar missions. However, in some proposed locations, wind turbines will cause disruptive radar interference that cannot be mitigated by siting or current technical approaches.

In less straightforward cases, a mitigation agreement may be negotiated that requires changes to the wind facility's operation or that requires industry to fund upgrades to the radar system. Examples of such cases include operational curtailment agreements and funding of subsequent updates to the Common Air-Route Surveillance Radar upgrade implemented by the DOD/DHS Long Range Radar Joint Program Office (Air Combat Command 2015).

2 Strategic Themes

Theme 1: Improve the Capacity of Government and Industry to Evaluate the Impacts of Planned Wind Energy Installations on Sensitive Radar Systems

Mitigation of wind turbine-radar interference starts with ensuring that wind developers and responsible agencies have a clear understanding of the impacts to radars early in the wind project development process, preferably before substantial funds are invested in a particular site (e.g., the deployment of meteorological towers or buoys). Early engagement by wind developers with entities like the DOD Siting Clearinghouse and NOAA's Radar Operations Center (for terrestrial wind farms) and NOAA's Integrated Ocean Observing System Office and BOEM (for offshore wind areas) are critical, as are accurate tools for modeling and simulation of the effects that impact radar systems.

Many such tools are being used today, but further work is needed to verify their performance against WTRIM data; fill gaps in modeling and simulation capabilities for weather and coastal surface radar systems so that each significant wind-radar conflict can be evaluated; and improve the capabilities of tools available to the public.

Although a great deal is understood about the effects of wind turbines on multiple types of radar and their impacts on the missions those radars support, new issues are likely to arise. The WTRIM WG must ensure that it can rapidly evaluate these new issues, identify potential mitigation measures, and prioritize investment in those mitigations against other WTRIM WG priorities.

Activity 1.1. Develop Improved Modeling and Simulation Tools to Aid in the Siting and Evaluation of Planned Wind Facilities and Assessment of Potential Mitigation Measures

The WTRIM WG identified several modeling, simulation, and analysis tools to predict the operational impacts of wind projects on particular radars and agency missions. These tools have been developed to facilitate proper siting of proposed wind turbine projects by identifying expected impacts on government radar operations in the preliminary planning stages of a project.

One area requiring additional research is that of identifying and incorporating radar wave propagation analysis features into existing and new modeling and simulation tools downwind of offshore wind turbines, as there are phenomena that differ from propagation over land masses. This research will help address accuracy in modeling and simulation.

In addition to tools that model wind turbine-radar interference, in 2018 the U.S. Geological Survey and DOE developed the U.S. Wind Turbine Database and Database Viewer in partnership with DOE's Lawrence Berkeley National Laboratory and the American Wind Energy Association (now known as American Clean Power) (Hoen et al., 2018). The database contains all onshore and offshore U.S. wind turbine locations and characteristics and is updated quarterly.

Activity 1.2 Evaluate Emerging WTRIM Issues and Identify Effective Pathways to Mitigation

Recent moves by the wind industry to advance offshore wind development in U.S. waters have resulted in the need to expand the research into wind turbine-induced interference on radar systems that surveil offshore. As more radar systems are identified for offshore wind turbine interference issues, there is an increasing need to explore the effects on these radars. For example, as described in a NOAA-commissioned working group report (Kirincich et al., 2019), scientific studies demonstrate that offshore wind turbines disrupt the signal used by coastal oceanographic high-frequency (HF) radar systems to measure surface currents and waves (Wyatt et al., 2011; Ling et al., 2013; Trockel et al., 2018a). Later BOEM-funded studies (Trockel et al., 2018b; Trockel et al., 2021) indicate that a level of mitigation for this wind turbine interference is possible by adjusting the HF-radars' operating software and measuring currents and waves with different *in-situ* sensors placed inside and around the periphery of wind farms.

As offshore wind energy developments proliferate, new concerns for coastal radar operators emerge. When the WTRIM WG learns about a new issue, it will examine it and help affected agencies determine if any technological solutions within the broader WTRIM strategy are viable pathways to addressing it. The WTRIM WG will also explore whether new technological efforts are warranted under this activity or these newly categorized sub-activities.

Advancing WTRIM-related programs and processes to ensure the protection of physical assets and federal mission capabilities is also key. Many radar systems impacted by wind turbine interference are likely to be upgraded or replaced over the next few decades. In the interim, the WTRIM WG is addressing wind turbine–induced radar interference across multiple technical lines of action as noted in the three strategic themes.

Evaluate Emerging WTRIM Issues Regarding Offshore Wind Deployment

The first step to identify mitigation measures is to characterize the impacts of offshore wind energy on nearby radars. Once characterization is complete, the next step for the WTRIM WG partners will be to follow a similar mitigation strategy that's in place in the land-based environment. These steps will ensure that unique offshore issues are considered in evaluating impacts.

Where initial efforts to characterize the unique aspects of mitigating radar interference from offshore wind turbines reveal a need for mitigation approaches specific to offshore wind development, the WTRIM WG will pursue further R&D. Characterizing unique offshore impacts will also help identify mitigation measures to address the existing radar fleet and next-generation radar systems.

Emerging issues in modeling and simulation capabilities, with respect to creating and updating accurate tools for modeling and simulating the effects of wind energy systems on radar systems, would likely include integration of parameters that coincide with relevant, unique propagation features of the offshore environment (ref Activity 1.1 for this paragraph).

Evaluate Emerging Issues for Next-Generation Weather Radar (NEXRAD) and Terminal Doppler Weather Radar (TDWR)

Characterizing the impacts of wind energy systems on NEXRAD WSR-88D and TDWR radars in land-based and marine environments is a critical first step in identifying mitigation measures. While some work has been done in these areas, more is needed to scope and quantify the impacts of wind energy systems on these radars.

Emerging issues in modeling and simulation capabilities, with respect to creating and updating accurate tools for modeling and simulating the effects of wind energy systems on radar systems, would likely include integration of parameters that coincide with relevant, unique propagation features of the offshore environment (ref Activity 1.1 for this paragraph).

Theme 2: Develop and Facilitate Deployment of Mitigation Solutions to Increase the Resilience of Existing Radar Systems to Wind Turbines

The IFT&E campaigns identified several possible off-the-shelf solutions that showed promise in mitigating impacts on air traffic control/air defense radars, particularly infill radars. These short-range high-resolution radars are added around wind farms to increase the coverage in areas that would be lost to the existing radar[2]. The WTRIM WG is working to develop approaches to use these solutions over the next few years. The WTRIM WG is also investing in mitigation measures with longer-term payoffs, such as software and hardware upgrades to existing radars, along with command and control/automation system improvements to filter out turbine clutter or "fuse" radar pictures together where multiple radars cover airspace over a wind facility.

Early on, the WTRIM WG explored potential mitigation solutions that might have been applied to individual wind turbines or across multiple turbines in a wind facility rather than the radar. For example, Sandia National Laboratories studied the option of embedding materials into the structure of a blade to incorporate radar-absorbing materials. While this showed promise in reducing the radar cross-section of a blade, the cost proved to be prohibitive to the commercialization of the process. The WTRIM WG remains vigilant in the search for other turbine-based solutions.

Activity 2.1 Facilitate Rapid Deployment of Current Off-the-Shelf Mitigation Measures

A variety of candidate infill radars were tested under the Interagency Field Test & Evaluation campaign.

To deploy these systems and ensure that they meet federal requirements, the WTRIM WG continues to pursue pilot mitigation projects and other studies to enable government-industry partnerships that facilitate wind energy development, as well as the operational deployment and long-term onsite testing of solutions.

One such study, the Cannon AFB Analysis of Alternatives Project, was conducted by subject matter experts for a single site. This project determined the Air Force Base's initial WTRI mitigation solution and identified follow-on enhancement activities.

WTRIM WG–supported pilot mitigation projects have included the Travis Air Force Base (AFB) FAA STARS Infill Radar Integration Project and the FAA-Air Force Flight Standards Agency (AFFSA) Infill Radar Certification Project. The Travis AFB project, led by the Airforce Research Lab, was a precursor to the FAA's work in developing a pathway for infill radars to be certified and incorporated into the NAS. The FAA-AFFSA Infill Radar Certification Project is another step in that process.

Pilot mitigation projects are key to WTRIM activities because they help manage the risk to stakeholders while achieving the following:

- Maintaining the quality of air surveillance, weather, oceanographic, or other data products from the radar system
- Reducing the time required to implement mitigation solutions
- Minimizing the cost of delivering effective air surveillance, weather and ocean forecasting, and other radar-derived services to government users

[2] Several infill radar systems have been evaluated as potential mitigation solutions as of the publishing of this document. None of these systems have met FAA requirements for integration into the National Airspace System (NAS). Each infill radar system tested was intended to mitigate air traffic control/air defense type radar systems and should not be assumed to be applicable in the weather radar or coastal surface radar system environment.

- Meeting renewable energy goals.

Activity 2.2: Develop and Facilitate Deployment of Hardware and Software Upgrades to Make Existing Radars More Resilient to the Impacts of Wind Turbines

Another approach is to improve the wind turbine interference mitigation capabilities of existing radars through signal-processing software upgrades and hardware modifications. These modifications are likely to result in lower-cost solutions compared to wide-scale deployment of short-range infill radar systems. An upgrade that significantly improves the radar's resolution in range, Doppler, or altitude might yield performance like that of a new radar installation. Software-based improvements to target detection and clutter processing may also help for systems where resolution cannot be increased due to hardware constraints.

The WTRIM WG is exploring technology transition paths for these types of mitigation techniques. Retrofits to implement these techniques on existing radar systems can be cost-prohibitive given legacy hardware and processing capabilities, but these techniques could be considered in future radar designs and acquisitions.

Activity 2.3: Improve the Capacity of Existing Automation and Command and Control Systems to Mitigate Wind Turbine Interference Impacts to Radars

Each radar site sends data to different automation and command and control systems based on the missions being performed by that radar. The output of the automation system is what human users typically monitor and base decisions on. Therefore, the performance of the automation system, how it behaves around wind farms, and how it deals with mitigation systems are crucial to the overall surveillance mission.

The WTRIM WG continues to study the impact of wind turbines on these automation systems as well as study new command and control mitigation approaches. Of particular interest is "radar fusion," which could be promising in areas where there is overlapping coverage from multiple radars above wind farms. If the wind turbines are not visible to at least one radar because of the Earth's curvature and/or terrain masking, then the automation system tracker can, in theory, maintain nominal performance above a certain altitude (depending on the geometry) by ignoring detections from the impacted radars and displaying only detections from the unimpacted radar(s) over wind facilities.

Activity 2.4: Explore At-the-Turbine Mitigation Methods That Reduce the Radar Impact of Wind Turbines

New design operational methods for future wind turbines deployed near vital radar assets could reduce radar impacts either independently or in conjunction with mitigation measures applied at the impacted radar systems. With an emphasis on blade fabrication, Sandia National Laboratories demonstrated the technical feasibility of integrating radar-absorbing materials into the standard construction methods currently used for manufacturing wind turbines (McDonald et al. 2012). The study identified multiple pathways to apply radar-absorbing material to a blade that could minimize the cost, leading to an economically viable mitigation option for the wind industry. Vestas, one of the largest global wind turbine manufacturers, developed a "stealth blade" based on a similar concept (Douet, 2014), but there is no independent technical evaluation of its technology or effectiveness.

Beyond radar-absorbing materials, there are additional at-the-turbine solutions that the WTRIM WG could explore:

- Reduced radar impact lightning protection systems, materials, and structures, which are especially important for over-the-horizon radar systems
- New operational methods in which data from individual turbines are combined with radar data in real time as a potential mitigation method for current or newly deployed wind farms
- Developing publicly available, validated design tools for wind turbine designers to evaluate the impacts of their proposed turbine designs on radar systems to enable new technology solutions to be more rapidly and cost-effectively developed and deployed.

Theme 3: Encourage Development of Next-Generation Radar Systems That Are Resistant to Wind Turbine-Radar Interference

Many of today's radar systems impacted by wind turbine interference are likely to be significantly upgraded or replaced by next-generation radars over the next few decades.

The WTRIM WG is committed to ensuring that resilience after wind turbine interference becomes a key design requirement for next-generation systems. Accordingly, the WTRIM WG will continue to engage in outreach and R&D to ensure that relevant radar development and acquisition programs are aware of the wind turbine-radar interference issue and continue to provide the information necessary for these programs to build wind-radar mitigation into system design.

Even as the WTRIM WG focuses more on addressing wind-turbine radar interference, there is no single solution. Radar target size, material (i.e., aircraft components), and elemental (i.e., air/water) composition are only parts of the problem that new radar systems will need to solve. Other issues include turbine blades that rotate 360-degrees, spin to induce multiple Doppler bin detections, and produce turbulent air with varying amounts of water vapor. Wind turbine-radar interference issues are complex, and a full resolution may be difficult to achieve.

Activity 3.1: Collaborate with Developers of Next-Generation Radar Systems So They Design the Systems to Be Highly Robust Against Wind Turbine Interference

Replacing the National Airspace System and weather radar fleet with radars that are more robust to wind turbines is a long-term solution to wind turbine-radar interference. The WTRIM WG has provided information or technical input to multiple groups and programs working to address next-generation radar systems. Examples include the NOAA National Severe Storms Laboratory Advanced Technology Demonstrator dual-polarization phased array radar program[3] and the Airspace Non-Cooperative Radar program.

A key role of the WTRIM WG is to ensure these systems include requirements for wind turbine interference mitigation at early stages of the development and acquisition cycle. The WTRIM WG continues to search for and evaluate resilience techniques for inclusion in these new systems that can mitigate wind turbine data contamination.

[3] https://www.nssl.noaa.gov/tools/radar/atd/

3 WTRIM WG: Structure and Activities

An outgrowth of the IFT&E program was the recognition of a need for a more comprehensive interagency approach to mitigating wind turbine-radar interference. The signatory agencies in the original WTRIM WG—DOD, DOE, FAA, and NOAA—worked to identify common outcomes and leverage intellectual and fiscal capital to invest in mutually beneficial activities. Their goal was to reduce redundancies in R&D and mitigate wind turbine-radar interference over time. This strategy, produced under a new 2023 MOA, again outlines seven specific activities, under three broad strategic themes, which the WTRIM WG will pursue to meet the goals of the new WTRIM signatories—DOD, DOE, FAA, BOEM, and DHS. These activities will also be facilitated and strengthened by two vital, associated actions—intergovernmental coordination and public and industry outreach.

WTRIM WG Organization Structure

The WTRIM WG is made up of three levels of authority and responsibility:

- **Executive Steering Group (ESG) -** Representatives of the signatory agencies to the MOA. The ESG is composed of executive-level representatives from the agencies that provide oversight and strategic direction to the Senior Steering Group and Working Group.
- **Senior Steering Group (SSG)** - ESG-appointed organizational representatives that provide the WTRIM WG program management and synchronization across WTRIM WG activities.
- **Working Group (WG)** – Action team that handles day-to-day operations and management, project tasks and deliverables, and administrative tasks, reporting to the SSG. The WG is composed of representatives from within and outside the agencies, as approved by the SSG, including federal government scientists, engineers, and agency analysts, who will be responsible for executing project tasks as approved and directed by the SSG.

Intergovernmental Activities

The activities outlined in section 2 will require the WTRIM WG agencies to coordinate their investments and work together to support the following activities:

- **Periodic Teleconferences.** DOE will convene WTRIM WG teleconferences on a monthly or more frequent basis to update members on constituent activities relevant to the group's progress, including upcoming events, reviewing assigned outstanding action items, updating current laboratory tasks, and introducing new developments in the wind-radar community.
- **In-Person Federal WG Meetings.** The WTRIM WG will hold periodic meetings in which the SSG members from each of the agencies will conduct progress reviews to ensure that the spirit and purpose of the MOA is being satisfactorily pursued. A portion of the meeting may be structured for the ESG to provide strategic course corrections and hear updates on key activities. The ESG will meet at least once per fiscal year.
- **Technical Interchange Meetings.** The WTRIM WG may coordinate and schedule technical meetings to compile and exchange information related to emerging R&D initiatives. These meetings will be supported by agency science and technology advisors, including select national laboratories. This is a way to anticipate or explore technology areas that may offer an advantage to assessing, mitigating, or facilitating the group's understanding of the impact of renewable energy projects on missions and infrastructures.

Public and Industry Outreach

Organizations outside the WTRIM WG share an interest in or involvement with the wind turbine-radar interference issue. Connecting with these national and international organizations at conferences or through digital communications, such as via email or a webinar, creates and supports a knowledge network in which

WTRIM WG items can be publicly promoted, stakeholder feedback can be received, and the WTRIM WG can gain exposure to new developments in technical and political areas that exist outside of the WTRIM WG.

Event Participation

The WTRIM WG will assess and make itself available to government, industry, and public meetings to educate and encourage an open dialogue with the audience about its purpose, progress on its mission, and to obtain feedback. The following are examples of forums in which the WTRIM WG will routinely consider participating in as resources allow:

- The DOD/FAA National Airspace System Interagency Working Group (previously referred to as the National Airspace System Modernization Working Group): This DOD- and FAA-led interagency team meets quarterly to coordinate activities related to modernizing the NAS.
- American Clean Power Conferences: These offer opportunities to keep the wind industry abreast of federal progress in developing affordable WTRIM solutions while networking with leaders in the wind energy industry.
- International Energy Agency Topical Experts Meetings and Canadian Wind Energy Association Annual Conference and Exhibition: These expose the WTRIM WG to international developments in technical and policy areas outside the United States.

International Information Exchanges

Wind turbine-radar interference manifests around the world and has driven a strong investigative reaction within our allied community. As appropriate, the WTRIM WG will use existing international technical exchange agreements, as well as more informal fact-finding activities, to gather information on useful mitigation solutions developed outside the United States.

4 Conclusion

This updated Federal Interagency WTRIM Strategy links mutual goals and objectives established under a new MOA between DOD, DOE, FAA, NOAA, BOEM, and DHS to ongoing collaboration efforts to mitigate technical and operational impacts of wind turbine projects on critical radar missions. The WTRIM WG activities outlined under the strategic themes of this document encompass the WTRIM WG's broader approach to implementing the strategy.

Realizing the substantial benefits of continued wind energy deployment while ensuring the integrity of critical radar missions is a substantial challenge. Overcoming this challenge will require continued coordination of investment in mitigation measures across the whole of government, as well as dialogue between the wind industry and government agencies charged with carrying out critical radar missions. Through this strategy, the WTRIM WG seeks to build off the considerable progress made by the IFT&E program and other WTRIM efforts in addressing the challenge of wind turbine-radar interference.

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Appendix A. The 2023 Memorandum of Agreement (MOA)

MEMORANDUM OF AGREEMENT
Establishment of the Wind Turbine Radar Interference Mitigation Working Group

Between the Following U.S. Federal Government Agencies

DEPARTMENT OF DEFENSE (DoD)
DEPARTMENT OF ENERGY (DOE)
FEDERAL AVIATION ADMINISTRATION (FAA)
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)
BUREAU OF OCEAN ENERGY MANAGEMENT (BOEM)

I. PURPOSE

A. All Federal agencies having a stake in resolving wind turbine radar interference issues should, where opportunities present themselves, develop a shared vision and framework to coordinate activities. This Memorandum of Agreement (MOA) supersedes the 2014 Memorandum of Understanding, *Establishment of the Wind Turbine Radar Interference Mitigation Working Group* (WTRIM) and establishes a general framework to encourage cooperation and coordination between the signatory agencies (the Parties, or, individually, a Party). The purpose of this MOA is to identify and develop the means to mitigate the potential technical and operational effects of wind turbine projects on critical radar missions within the jurisdiction of the Parties, including offshore regions. The goals of the interagency effort include:

a. Developing near-term (5 years), mid-term (10 years), and long-term (20 years) goals focusing on technology-driven mitigation solutions. These will be primarily technology-driven, but may also extend to policy and legislative proposals, as necessary.
b. Creating and executing a plan to implement workable solutions that includes a process for the Parties, in accordance with each Party's authorities and limitations on the use of appropriations, to commit funding necessary to execute the near, mid, and long-term mitigation, as outlined in Section II.

The Department of Defense enters into this memorandum of understanding in furtherance of its statutory requirements set forth in section 183a of title 10 of the U.S. Code and

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Department of Defense Instruction 4000.19, change 2, August 31, 2018 (https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/400019p.pdf?ver=2019-02-26-085841-693).

II. REQUIREMENTS

A. Whereas all Parties have been empowered by internal management, and in some cases additionally by Congress, to identify wind turbine radar interference mitigation solutions, their representatives will coordinate the development of an interagency Research and Development Plan, as well as commitments of funding required for all associated studies, field tests, or other agreed-to expenditures to be cost-shared commensurate with meeting agency equity needs, in accordance with each Party's authorities and limitations on the use of appropriations.

B. Department of Energy: Whereas DOE supports research and development to reduce the cost of wind energy and overcome challenges to its adoption nationwide, including, but not limited to, wind turbine radar interference, DOE will:

a. Commit senior departmental oversight and leadership.
b. Participate in the budget process by helping identify required studies, field tests, or other agreed-to expenditures.

C. Department of Defense, Federal Aviation Administration, and the National Oceanic and Atmospheric Administration: Whereas these agencies and sub-agencies have critical radar systems that are threatened by wind turbine interference and need to identify workable and affordable mitigation measures, they will:

a. Commit senior departmental oversight and leadership.
b. Help identify required studies, field tests, or other agreed-to activities.
c. Help identify resources to support WTRIM activities commensurate with meeting their agency needs and in accordance with their authorities and limitations on the use of appropriations.

D. Bureau of Ocean Energy Management: Whereas BOEM is the regulatory authority and primary permitting agency for offshore wind energy development on the Outer Continental Shelf and has need to identify critical radar interference and workable mitigation measures, BOEM will:

a. Commit senior management oversight and leadership.
b. Participate in the budget process by helping to identify required studies, field tests, or other agreed-to expenditures based on the principles of cost sharing commensurate with meeting their equity needs.

E. The interagency team will collaborate as appropriate with other federal government groups and organizations, including, but not limited to:

The DoD/FAA National Air Surveillance (NAS) Modernization Working Group, the joint working group responsible for addressing common NAS information assurance needs.

III. **STIPULATIONS** (subject to applicable Federal laws, regulations, and policies)

Now, therefore, the Parties agree that the undertaking will be implemented with the following stipulations:

A. Management of the WTRIM Working Group will be carried out in the manner of a three-tiered team:

a. Executive Steering Group (ESG): The ESG will be composed of executive level representatives from each of the Parties to provide oversight and strategic direction to the Working Group. The ESG will:

i. Approve a 5-year plan for studies, field tests or other agreed-to activities on which agency funding requirements can be determined, based on the principle of cost-sharing and commensurate with the intent of the MOA and respective agency equity needs, in accordance with each Party's authorities and limitations on the use of appropriations.

ii. Prepare a yearly progress report at the end of each calendar year. The report should also include objectives for the following years.

iii. Lead, or designate a Senior Steering Group (SSG) representative to lead quarterly progress review briefings held by the WTRIM, provide executive oversight, and ensure that the spirit and purpose of the MOA is being satisfactorily pursued.

iv. Appoint representatives to an SSG that is composed of management level representatives from each of the Parties who will carry out ESG approved tasks.

b. Senior Steering Group (SSG) – The ESG will appoint organizational representatives to the SSG. The SSG's purpose will be to provide the WTRIM Working Group (WG) program management and synchronization across WTRIM WG activities. When necessary, the SSG may invite government representatives from non-parties to participate in meetings.

c. WTRIM WG – The WG will be composed of representatives from within as well as outside the Parties, as approved by the SSG. The WG will normally include federal government scientists, engineers, and agency analysts, who will be responsible for executing project tasks, as approved and directed by the SSG. The WG may, as necessary, be augmented at the approval of an SSG member.

IV. **MUTUAL UNDERSTANDINGS**.

A. This MOA describes the general terms upon which the Parties will cooperate. Performance by each Party under the terms of this MOA is subject to the

availability of appropriated funds and personnel resources through their respective funding procedures. This MOA is neither a fiscal nor a funds obligation document. Any endeavor involving reimbursement or contribution of funds or transfer of anything of value between Parties to this MOA will be handled in accordance with applicable laws, regulations, and procedures. Any such endeavors by the SSG will be outlined in separate agreements, such as work plans or statements of work, which will be made in writing by representatives of the Parties and independently authorized by appropriate authority.

B. This MOA is a voluntary agreement and does not create any rights or benefits, either substantive or procedural, enforceable by law or equity, by persons who are not party to this agreement, against the Parties, or their officers or employees. This MOA does not apply to any person, agency, or entity outside those of the Parties. This MOA does not impose any legally binding requirements on the Parties, the regulated community, or the public and does not restrict the authorities of the Parties to exercise their discretion in making regulatory decisions based upon their judgment about specific facts and application of relevant statutes and regulations.

C. Nothing in this MOA is intended to diminish, modify, or otherwise affect the statutory or regulatory authorities of the Parties or relieve them of their obligations under Federal Law.

D. Nothing in this MOA will be construed as an indication of a financial commitment by the Parties for the expenditure of funds, except as authorized in specific appropriations.

Each Party is responsible for all costs of its personnel, including pay and benefits, support, and travel. Each Party is responsible for supervision and management of its personnel.

It is expressly understood and agreed that this MOA embodies the entire agreement between the Parties regarding the MOA's subject matter.

E. This MOA may only be modified or amended by mutual agreement of all Parties in writing.

This MOA takes effect beginning on the day after the last Party signs.

F. Additional Federal organizations may become Parties to the MOA by the approval of the ESG.

This MOA will be reviewed annually on or around the anniversary of its effective date for financial impacts and triennially in its entirety.

Any disputes relating to this MOA will, subject to any applicable law, Executive order, directive, or instruction, be resolved by consultation between the Parties or

in accordance with Parties' applicable regulations or directives pertaining to interagency agreements.

G. This MOA may be terminated at any time by the mutual written agreement of all Parties or individual Parties may withdraw upon 90 days written notice to the other Parties.

H. This MOA will remain in force for a period of five years from the date of its execution.

V. **POINTS OF CONTACT**. The following individuals will be the working level points of contact for this MOA:

DEPARTMENT OF DEFENSE
Robbin Beard
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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Bill Ward
Radar Operations Center
National Weather Service
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EFFECTIVE DATE. The Parties have by their signatures on the following pages executed this MOA as of this date:

January 4, 2023

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Figure A-1. Copy of the official memorandum of agreement for this work.

U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

For more information, visit:
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