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Market Opportunities for Deployable Wind Systems for Defense and Disaster Response

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ABSTRACT

This report is the first public deliverable from the Defense and Disaster Deployable Turbine project, funded through the distributed wind portfolio of the U.S. Department of Energy Wind Energy Technologies Office. The objective of the project is to explore the opportunity for deployable turbine technologies to meet the operational energy needs of the U.S. military and global disaster response efforts. This report provides a market assessment that was conducted over a year using public reports, presentations at topical conferences, and direct stakeholder engagement interviews with both military and industry representatives. It begins with the high-level operational energy strategy of the Department of Defense that provides the context for alternatives to diesel fuel to meet energy needs. The report then provides an estimate of the energy use of the military in missions where a deployable turbine could potentially serve as an alternative to the baseline use of diesel fuel in generators to provide electricity in remote locations. An overview of domestic and international disaster response is provided with a focus on the role of the military in providing energy to those events. Finally, the report summarizes the technical considerations that would enable a deployable turbine to meet military and disaster response energy needs including the global wind resource, the technical design of the turbine, and the operational constraints of various military missions.

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ACRONYMS AND DEFINITIONS

Abbreviation	Definition
AMMPS	Advanced Medium Mobile Power Sources
C5ISR	Command, Control, Communications, Computers, Combat Systems, Intelligence, Surveillance, and Reconnaissance
CCDC	Combat Capabilities Development Command
CCMD	Combatant Command
CERL	Construction Engineering Research Laboratory
D3T	Defense and Disaster Deployable Turbine
DHS	Department of Homeland Security
DoD	Department of Defense
DOE	Department of Energy
E2O	Expeditionary Energy Office
E2S2	Expeditionary Energy & Sustainment Systems
ERCIP	Energy Resilience and Conservation Investment Program
ERDC	Engineer Research and Development Center
ESF	emergency support functions
FEMA	Federal Emergency Management Agency
FEMP	Federal Energy Management Program
FOB	forward operating base
FY	fiscal year
GREENS	Ground Renewable Expeditionary Energy Network System
ISB	incident support base
JFO	joint field office
kW	kilowatt
NGO	non-governmental organizations
NRF	National Response Framework
OECIF	Operational Energy Capability Improvement Fund
S&T	Science and Technology
SOCOM	Special Operations Command
USACE	United States Army Corps of Engineers
USARCENT	United State Army Central Command
USINDOPACOM	United States Indo-Pacific Command
USMC	United States Marine Corps

1. OVERVIEW

The Department of Energy's (DOE) Wind Energy Technologies Office funded a multi-laboratory research project titled the Defense and Disaster Deployable Turbine (D3T) in 2019. The overall goal of the project is to identify and publish the market opportunities for deployable wind systems for defense and disaster applications, develop minimum requirements for systems to meet those opportunities with stakeholder input and feedback, and define and publish the technology development needs associated with those opportunities based on the capabilities of commercial systems. This report supports the first part of that goal, which is to publish a report on the market opportunities for deployable wind systems in defense and disaster response applications.

Over the past year, the national laboratory team has gathered information from public documents, conferences, and direct interviews with wind industry and military stakeholders. That information has been synthesized and organized into this report to quantify and qualify the market opportunity. The report collects and integrates information from different perspectives to provide a more comprehensive and complete assessment.

The report begins with the high-level drivers for market potential distilled from the U.S. Department of Defense (DoD) Operational Energy Strategy. This strategy document establishes the DoD interest in alternatives to diesel fuel to support military missions. The historical use of fuel by DoD is summarized as an energy need benchmark including the use of diesel fuel specifically for mobile electric generators. Electrical generators serve as a proxy for applications where wind energy technology could provide an alternative.

While more difficult to quantify, a section on domestic and international disaster response is provided, with a focus on the role of the DoD in responding to such events. Because military equipment is often used to support civilian efforts to respond to disasters around the world, it is assumed that focusing primarily on the military application will simultaneously address disaster response applications.

With the need for operational energy alternatives established, the report turns to the potential of wind technology to meet that need. The primary driver for wind energy viability is the wind resource itself. The report discusses the spatial and temporal characteristics of the global wind resources and the differences between traditional commercial assessments of viability to that of a military application. Next, the report looks at what commercial systems are available today and some of the identified technical challenges associated with those technologies from a military perspective based on documents and interviews with DoD stakeholders.

The report concludes with a section on pathways to develop technology solutions, including identifying and facilitating discussions with relevant stakeholders, defining design drivers and specifications, and securing funding to support the development of new solutions to fielded products in support of the military missions.

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2. U.S. DEPARTMENT OF DEFENSE OPERATIONAL ENERGY OVERVIEW

The need for energy alternatives to diesel fuel use within the DoD comes from the Operational Energy Strategy. This section provides the high-level strategic goals established by the DoD to invest in new technologies like deployable wind turbines that help achieve the goals and support the long-term strategic missions.

2.1. Operational Energy Strategy

Starting in 2011, the DoD began publishing and updating an Operational Energy Strategy as required by law. The most recent version was published in 2016 and provides an overview of Department-wide operational energy use. Operational energy is defined as, "energy required for training, moving, and sustaining military forces and weapons platforms for military operations." [1] The document notes that in fiscal year 2014, the DoD consumed 87.4 million barrels of fuel to deploy and sustain worldwide missions. Fuel use is broken out by service and combatant command according to Figure 1. The strategy lays out three objectives to address the challenges facing operational energy needs to mission success. The objectives are:

- Increase future warfighting capability by including energy throughout future force development.
- Identify and reduce logistics and operational risks from operational energy vulnerabilities.
- Enhance the mission effectiveness of the current force through updated equipment and improvements in training, exercises, and operations.

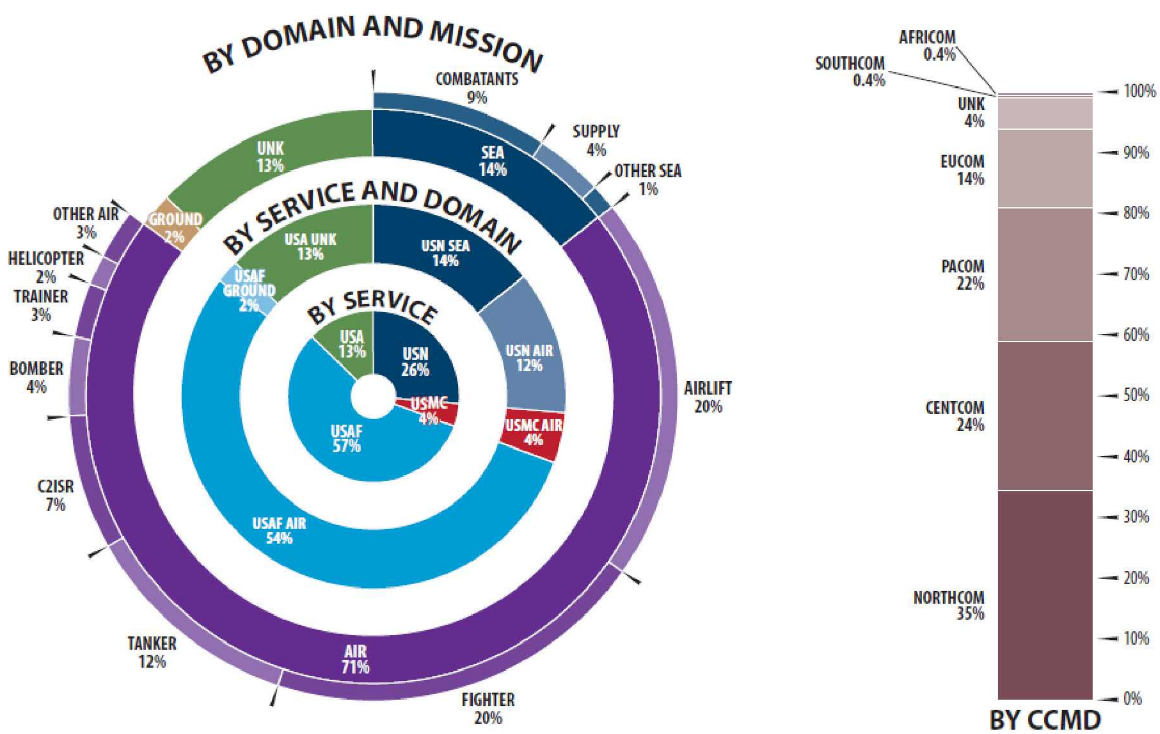

Figure 1. Operational Energy Use in fiscal year 2014 by domain and mission and by combatant command (CCMD)

The Operational Energy Strategy provides an implementation plan to address these objectives providing goals, targets, and Offices of Primary Responsibility. Under the second objective, the third goal provided is to "Diversify Energy Supplies to Reduce Risk" with one target being "By end of FY 2017, identify opportunities for harvesting energy from the surrounding environment in combatant command operations." The Office of the Secretary of Defense, Combatant Commands, and Military Services area all identified as having a primary responsibility in meeting this target. This is the high-level driver to explore the opportunity for wind energy to support the DoD operational energy strategy goals.

2.2. DoD Operational Energy Investments

Each fiscal year, the DoD publishes an Operational Energy Budget Certification Report that assesses how well the President's budget request supports the three objectives of the 2016 Operational Energy Strategy as noted in the previous section. The fiscal year (FY) 2020 Operational Energy Budget Certification Report notes that $3.6 billion has been requested for the execution of operational energy initiatives. [2] This budget supports a variety of operational energy investments across the DoD offices including procurement of new equipment and research, development, and testing of new technologies. One of those programs is the Operational Energy Capability Improvement Fund (OECIF) that invests in advanced technologies to mature them from concept to a prototype tested in a relevant environment. The OECIF program had a FY20 budget request of $70.5 million. The Operational Energy Budget Certification Report is a public document that describes the major investment areas broken out by the military services and serves as a good reference point for current DoD priorities.

2.2.1. Air Force

The U.S. Air Force is the largest energy consumer in the DoD, primarily in the form of fuel for aircraft. The Air Force operational energy activities are managed by the Deputy Assistant Secretary of the Air Force for Operational Energy, Office of the Assistant Secretary of the Air Force for Installations, Environment and Energy. The Air Force operational energy priorities primarily address ways to use fuel more efficiently for aircraft. While there may be specialized programs where wind energy could be applicable, the Air Force is not likely to be a big market for deployable wind systems.

2.2.2. Navy

As the second largest consumer of energy, the U.S. Navy is also responsible for transporting liquid fuel to other services at remote locations. The Navy's operational energy activities are managed by the Deputy Assistant Secretary of the Navy Energy as well as the Director of Operational Energy. The Department of Navy launched a large initiative in 2012 to acquire 50% of its energy from renewable resources. Most of that initiative has been focused on permanent installations rather than contingency basing where deployable wind would be more applicable. [3] The primary operational energy concerns for the Navy include meeting requirements of future directed energy weapons, as well as closing the gap between the growth in fuel demand and the ability to supply it to Naval and joint forces in a denied or degraded environment. Expanding the operational reach of Navy and Marine Corps Forces is also a key objective and energy use is fundamental to achieving that. Like the Air Force, there exists limited market potential for deployable wind systems for the Navy.

2.2.3. Marine Corps

The U.S. Marine Corps (USMC) operational energy efforts are coordinated through the Expeditionary Energy Office (E2O). The 2018 U.S. Marine Corps Science and Technology (S&T) Strategic Plan includes a logistics goal of "Enhanced Self-Sufficiency for Portable Electric Energy." This goal includes the development of tactically viable alternative energy solutions like solar, wind, hybrid, kinetic recovery, fuel cells, and biofuels for use at remote, austere locations by small units that can reduce the Marine combat load. [4] Typical USMC mission profiles define energy needs that could be met by a wind system in the 1-3 kilowatt (kW) power range.

2.2.4. Army

The U.S. Army operational energy efforts are led by the Office of Assistant Secretary of the Army for Installations, Energy and Environment. This office establishes policy, provides strategic direction, and supervises all matters pertaining to infrastructure, installation and contingency bases, energy, and environmental programs to enable global Army Operations. The Army invests in technology that can reduce or replace the use of diesel fuel to support mission requirements at contingency bases where the logistics of delivering fuel risks lives and adds cost. Army contingency basing is a primary opportunity for deployable wind systems due to the mission and load profiles of the contingency bases and the large number of bases as compared to the other services.

2.3. DoD Offices with Operational Energy Activities

The 2016 Operational Energy Strategy highlights that the Office of the Secretary of Defense, Combatant Commands, and Military Services all have responsibilities to meet the targets listed in the document. Table 1 lists the specific offices within the DoD with operational energy missions that are involved in setting strategy and policy, investing in research programs, conducting testing and evaluation in the field, procurement, and deployment and operations in theater. Many of these offices have staff that regularly present on their activities at conferences throughout the year with an operational energy theme. Many of the listed offices have been directly briefed on the D3T project with more meetings planned in the coming year. Some of these offices would be involved directly with wind technology providers to conduct research, development and testing activities for deployable turbines to meet their needs.

Table 1. U.S. military offices with missions relevant to energy for contingency bases

Office	Relevance to D3T project
DoD Headquarters	
Office of the Assistant Secretary of Defense for Sustainment - Energy	Oversees the Operational Energy Capability Improvement Fund (OECIF) to improve the Department's military capabilities through targeted investments in operational energy science and technology (S&T). Oversees the Energy Resilience and Conservation Investment Program (ERCIP) to fund projects that improve energy resilience, contribute to mission assurance, save energy, and reduce DoD's energy costs with a focus on domestic installations.
U.S. Army	
Office of the Assistant Secretary of the Army for Installations, Energy and Environment	Provides operational energy policy, guidance and oversight across the Army enterprise. Evaluates and nominates projects for funding through the OECIF program.
Program Executive Office Combat Support and Combat Service Support (PEO CS&CSS)	Home of the Army Project Manager, Expeditionary Energy & Sustainment Systems (PM E2S2) with a mission to provide integrated, scalable, and affordable expeditionary energy, force sustainment, and contingency basing capabilities that reduce sustainment demand for the Warfighter across the range of joint operations.

Office	Relevance to D3T project
Energy Branch, U.S. Army Corps of Engineers (USACE), Engineer Research and Development Center (ERDC) and Construction Engineering Research Laboratory (CERL)	CERL directs its research efforts toward increasing the Army's ability to more efficiently design, construct, operate and maintain its installations and contingency bases, and ensure environmental quality and safety at a reduced life-cycle cost. CERL has test and evaluation capabilities, including an experimental forward operating base where new technologies can be installed.
249th Engineer Battalion (Prime Power), U.S. Army Corps of Engineers (ACE)	Has capability to provide emergency temporary power systems in response to disasters to U.S. states and territories as well as world-wide military contingency basing.
Army Research Laboratory (ARL)	The Army's corporate research lab to discover, innovate, and transition science and technology to support Army missions. There is an Energy and Power research competency within ARL that researches storage and generation technologies.
Combat Capabilities Development Command (CCDC) C5ISR Center	Army applied research and advanced technology development center with efforts in a variety of technology areas including tactical and deployed power including renewables. It also includes the Energy Informed Operations Microgrid program to establish power system integration standards for contingency basing.
U.S. Marine Corps	
U.S. Marine Corps. Expeditionary Energy Office (E2O)	Primary office with responsibility to analyze, develop, and direct the Marine Corps' energy strategy in order to optimize expeditionary capabilities across all warfighting functions. Two programs, Ground Renewable Expeditionary Energy Network System (GREENS) and Solar Portable Alternative Communications Energy System (SPACES), are examples of renewable technologies E2O has invested in.
U.S. Navy	
Office of the Deputy Assistant Secretary of the Navy Energy (DASNE)	Provides operational energy policy, guidance, and oversight across the Navy. Current priorities include directed energy and battery storage, but there is some interest in renewable energy for forward operating bases and dismounted soldiers.
Naval Facilities Engineering Command (NAVFAC) Expeditionary Warfare Center (EXWC)	The Mobile Utilities Support Equipment (MUSE) program primarily provides diesel generator power systems to Navy and Marine Corps locations to meet utility shortcomings and for emergency response and expeditionary needs.
U.S. Air Force	
Office of the Assistant Secretary for Installations, Environment and Energy	Provides operational energy policy, guidance and oversight across the Air Force. Primary focus is on using jet fuel more efficiently and fuel logistics planning.
Air Force Research Laboratory	Primary research lab supporting the technology development needs of the Air Force. Wind turbines are generally not a good match for airfields, however AFRL has developed deployable wind technology to support remote radar sites and to support a microgrid at Joint Base Pearl Harbor Hickam.

U.S. Combatant Commands	
U.S. Army Central Command (USARCENT)	USARCENT has an operational energy program that develops and deploys energy technologies to bases across the Army Central Command to improve capabilities and quality of life for the soldiers. Recent projects include solar light carts that provide photovoltaic (PV) powered hydration locations for soldiers. Wind energy projects are also under consideration.
U.S. Indo-Pacific Command (USINDOPACOM) J8 Energy Programs	The USINDOPACOM area of responsibility is very large with few logistical hubs to support the transport of personnel and fuel over long distances in areas that are increasingly contested by near-peer adversaries. These programs are looking into technologies and strategies that support a more distributed energy system.
Special Operations Command (SOCOM)	SOCOM is constantly adapting to challenging battlefield environments and is therefore always looking for new technologies to support its missions. SOCOM holds events called Technical Experimentation, where it interacts directly with prototype technologies and provide feedback. For deployable wind systems, these would probably be packable systems that a soldier could carry.
Army, Navy and Air Force Bases that have or have considered wind energy.	A variety of domestic bases have installed wind turbines, as well as bases overseas, and could provide feedback regarding potential improvements. Most of these are not deployable systems.

2.4. Summary

The DoD has an officially recognized need for new technologies to address their operational energy challenges as presented in the 2018 National Defense Strategy and Operational Energy Strategy. There are active programs at DoD headquarters, the military services, and the combatant commands to invest in research and procure fieldable technologies to reduce the dependence and logistical limitations of fuel to support military missions. Many programs are considering renewable energy, and in some cases, specifically wind energy as a potential deployable energy source.

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3. MILITARY ENERGY DEMAND

One of the primary goals in the DoD Operational Energy Strategy is to reduce the dependency on liquid fuel as the primary source of energy for contingency bases. There are good data on total fuel use across the DoD each year, but data becomes much scarcer at the scale of energy use at individual bases and especially specific equipment like generators or vehicles. Multiple efforts are underway across the services to develop energy consumption baselines to address this data gap, but most of the information is not yet public. Therefore, this section attempts to summarize a variety of public data sources that are available to arrive at an estimate of total energy use at contingency bases. These data provide a sense of the gross market potential for deployable wind systems on an energy need basis.

3.1. Liquid Fuel Use

The first approach to estimating energy use is to look at liquid fuel (e.g. diesel) consumption. The DoD has a tremendous reliance on liquid fuel and consumes more liquid fuels than many medium-sized countries. [5] In 2008, more than 68 million gallons of fuel were supplied each month to support U.S. forces in Iraq and Afghanistan alone, with most of that fuel going to supply generators. [6] A 2008 Defense Science Board Task Force report noted that Army generators alone consume about 26 million gallons of fuel annually during peacetime and 357 million gallons annually during wartime. [7]

Aside from battlefield locations operating in austere environments with minimal amenities, the U.S. military also operates many long-term bases overseas. Many of these bases are not permanent installations but are not necessarily temporary either. Many of them have been operating for over 20 years with amenities for base occupants like gyms, air conditioning, and even fast food restaurants. While these bases can often resemble small towns they often lack permanent electrical infrastructure and rely heavily on diesel generators for their access to electric power. Table 2 below shows fuel consumption for five operating bases overseas during the month of June in 2008. The fuel for base support activities is primarily consumed by diesel-powered electric generators.

Table 2: Fuel consumption (in gallons) of Forward-Deployed Base Locations for June 2008 [6]

Location	Fuel for base support activities	Fuel for air and ground operations	Total fuel consumed
Camp Lemonier	333,191	460,555	793,746
Q-West Air Base	731,449	278,769	1,010,218
Camp Arifjan	930,472	266,154	1,196,626
COB Adder	1,171,618	430,395	1,602,013
Bagram Air Field	916,911	6,155,225	7,072,136
Total	**4,083,641**	**7,591,098**	**11,674,739**

Such a high fuel demand produces an enormous logistics burden. General Paul Kern of the U.S. Army stated at the 2003 SAE World Congress that two-thirds of the Army's vehicles deliver fuel to the other third in the battlefield. [8] Transporting this fuel in a battlefield environment drives up cost and risk. Transporting fuel via truck convoy creates casualty risks from enemy activity, weather, traffic accidents, and pilferage. In June 2008 alone, a combination of these factors caused the loss of 44 trucks and 220,000 gallons of fuel. [9]

In addition to the logistical burden brought on by the high demand for fuel, there is also the financial burden. The DoD is not immune to fluctuations in fuel prices and has estimated that for every $10 increase in the price of a barrel of oil, the DoD's operating costs increase by approximately $1.3 billion per year. Fully burdened costs of fuel delivered vary wildly but some estimates reach as high as $400/gal for remote forward operating bases (FOB) where fuel is delivered by air. [10] Another report by the Defense Science Board Task Force in 2008 estimated the fully burdened cost of fuel from $15/gallon up to $42/gallon assuming no convoy protection requirements. The report also conceded that the figures are likely low estimates. [7]

3.2. Mobile Electric Generators

Fuel use provides a broad picture of operational energy needs. However, most fuel use is for ground vehicles and aircraft that are not addressable with a deployable wind turbine. A second approach to estimating energy needs for DoD that could be addressed by deployable wind systems is to look at mobile electric generator procurement and use. The Advanced Medium Mobile Power Sources (AMMPS) represent the third generation of DoD military standard generators. AMMPS are replacing second generation Tactical Quiet Generators, which have a 25-year-old design, and providing operational improvements that decrease the logistics footprint on the battlefield. The current family of AMMPS consists of five versions: the 5 kW, 10kW, 15kW, 30kW, and 60kW generators. This is the primary generator technology to support Army contingency bases. The DoD FY20 budget request contains $58.5 million for generators and associated equipment, of which $44.2 million is included for AMMPS. [11]

In September 2018, Cummins Power Generation Inc. won a $491 million contract to provide AMMPS generators to the U.S. Army. Actual funding will be determined with each order, with an estimated completion date of Aug. 28, 2022. [12] Numerous confirmed orders of these units can be found in the Federal Procurement Data System each year since the contract was awarded. [13]

The U.S. Army PEO CS&CSS researches, develops, acquires, and fields mobile electric power systems for the DoD. In a 2009 brief, the program manager reported that the DoD requires 125,125 generator sets with a total power rating of 2,104,952 kW. Of this, the Army requires 68,439 generator sets with a total power rating of 967,084 kW just for combat support and combat service support, which includes contingency bases. [14] Another program office brief from 2007 noted that the Army accounts for 76% of all tactical generators, the Air Force 15%, the Marines 7%, and the Navy 2%. The Army's 2007 requirements by generator size are listed in the following table. [15]

Table 3. U.S. Army 2007 tactical electric generator requirements

Generator Size (kW)	Qty Required for Army
2	9,576
3	19,122
5	14,779
10	12,001
15	4,370
30	3,085
60	2,950

100/200/DPGDS	568
Total	**66,451**

3.3. Summary

DoD uses over 100,000 generators with the Army alone using over 60,000 for combat support and combat services, including contingency bases. Procurements for generators are tens of millions of dollars per year to replace or upgrade these systems. These generators consume tens of millions of gallons of diesel fuel each year at a cost that can range from $15 to $42 per gallon fully burdened. While deployable wind turbines could never replace all of this fuel use, even a small fraction would represent a viable market.

4. DOMESTIC AND INTERNATIONAL DISASTER RESPONSE OVERVIEW

The scope of the D3T project includes both defense and disaster response applications for a deployable wind turbine. While most of the effort has been on the defense market, this section covers disaster response applications with a tie back to the military. Disaster response is part of a broader set of activities including disaster recovery, disaster preparation, and disaster mitigation. Disasters include events that do not necessarily involve widespread destruction of infrastructure such as disease outbreak, famine, or care of displaced persons. These events may also have energy needs.

The key difference between defense and disaster response is that the latter is civilian focused. Energy use for military installations is typically focused on the needs of the units within the base, and these bases may not be connected to the local electric grid even if one exists. In contrast, while energy is needed for the disaster response activities, a major focus of response activities is assisting the population affected by the disaster, which also requires energy. The local energy infrastructure, to the extent it exists and is functional, may be used by the response effort. The energy needs for disaster response are thus even more varied than for the military bases. Regardless, these two applications may share many common needs and characteristics that could be met by the same wind turbine design.

4.1. Domestic Disaster Response

Responsibility for U.S. domestic disaster response is shared between local, tribal, and state governments and the federal government. Response is typically handled at the lowest possible government jurisdiction, with higher level jurisdictions becoming involved only if the magnitude and/or scale of the disaster exceeds the capabilities and resources of the lower level jurisdiction. Disaster response, especially at the federal level, is governed by the National Response Framework (NRF). [16] The NRF provides a framework for responding to a wide array of catastrophic incidents including: hurricanes, floods, fires, disease, cybersecurity and terrorism. Response activities are grouped into fifteen emergency support functions (ESFs). ESF's relevant to this report are summarized in Table 4.

Table 4. Selected emergency support functions from the National Response Framework

ESF #3 – Public Works and Engineering **ESF Coordinator: DoD/U.S. Army Corps of Engineers**
Coordinates the capabilities and resources to facilitate the delivery of services, technical assistance, engineering expertise, construction management, and other support to prepare for, respond to, and recover from a disaster or an incident. Functions include but are not limited to the following: • Infrastructure protection and emergency repair; • Critical infrastructure reestablishment; • Engineering services and construction management; and • Emergency contracting support for life-saving and life-sustaining services
ESF #7 – Logistics **ESF Coordinator: General Services Administration and Department of Homeland Security**
Coordinates comprehensive incident resource planning, management, and sustainment capability to meet the needs of disaster survivors and responders. Functions include but are not limited to the following: • Comprehensive national incident logistics planning, management, and sustainment capability; and • Resource support (e.g., facility space, office equipment and supplies, and contracting services).
ESF #12 – Energy **ESF Coordinator: Department of Energy**
Facilitates the reestablishment of damaged energy systems and provides technical expertise during an incident involving radiological/nuclear materials. Functions include but are not limited to the following: • Energy infrastructure assessment, repair, and reestablishment; • Energy industry utilities coordination; and • Energy forecast.

At the federal level, the Department of Homeland Security (DHS) is responsible for planning and coordinating the overall federal response. Within DHS, many of these responsibilities are executed by the Federal Emergency Management Agency (FEMA). Several other agencies, notably DoD, also have significant domestic disaster response responsibilities. For example, the ESF Coordinator for "ESF-12 – Energy" is the DOE and the ESF Coordinator for "ESF #3-Public Works and Engineering" is the DoD/ USACE. [17] [18]

In instances where a natural disaster has damaged an area's energy infrastructure a key goal of response operations is providing power for both the response operation and the affected population. This is achieved by a combination of providing temporary power to key facilities and repairing the pre-existing infrastructure. [19] Temporary power is nearly always provided by electrical generators. Facilities requiring generators are prioritized as follows:

1. Life Saving Facilities (911 centers, police, fire stations, and medical facilities)
2. Life Sustaining Facilities (water and wastewater treatment and pumping facilities)
3. Other municipal facilities to reinstitute local command and control and post-event recovery

At the federal level, USACE is the lead entity for deploying temporary generators. These generators are a combination of government owned and contracted generators. Depending on the scale of the disaster, the number of deployed generators can be in the hundreds. For example, in 2007 USACE deployed 310 generators during the response to Hurricane Katrina. In the aftermath of the hurricanes that struck Puerto Rico in 2017, USACE had deployed 366 generators within a few weeks after the hurricane. [20]

FEMA also maintains a network of distribution centers stocked with equipment and supplies, including generators, that can be rushed to the scene of a disaster. [21]

Several types of facilities may be established as part of the disaster response effort, generally using existing buildings. Only if there is no other option will "greenfield" camps be set up. The common types of facilities supported by FEMA logistics include [22]:

> **Joint Field Office** – "The Joint Field Office (JFO) is a temporary federal multi-agency coordination center established locally to facilitate field level response activities. The JFO provides a central location for coordination of federal, state, local, tribal, non-governmental, and private sector organizations involved in incident support."
>
> **Responder Support Camps** – "When conventional lodging is unavailable, Logistics is responsible for establishing a camp for response personnel working in the disaster. Logistics supports these austere camps with shelter, food, and other basic needs. These camps are not for the disaster survivors."
>
> **Incident Support Base** – "An Incident Support Base (ISB) is a temporary location for receiving and staging resources (supplies, equipment, and teams) that may be provided to state and local governments. During incidents involving large numbers of commodities or response teams, the regional Logistics Section will stand up and staff an ISB. ISBs are normally pre-identified during response planning and may be stood up prior to a known event such as an approaching storm."
>
> **Disaster Recovery Centers** – "A Disaster Recovery Center is a readily accessible facility or mobile office where disaster survivors may go for information about FEMA or to apply for disaster assistance or for questions about their application."

Disaster planning and response at the state and local levels is generally aligned with the NRF. At the state level the National Guard often plays an important role in disaster response activities. It is unclear to what extent energy generation equipment is stockpiled at the state and local level.

In addition to government jurisdictions, numerous private sector and non-governmental organizations (NGOs) may be active in disaster response. In the latter category there are two organizations of note as follows.

4.1.1. American Red Cross

The American Red Cross is chartered by Congress to provide relief to survivors of disasters and help people prevent, prepare for, respond to, and recover from emergencies. The Red Cross has a legal status of a "federal chartered instrumentality" and maintains a special relationship with the federal government. In this capacity, the American Red Cross is the co-lead of "ESF #6–Mass Care, Emergency Assistance, Temporary Housing, and Human Services" (along with DHS/FEMA) and supports several other ESFs and the delivery of multiple core capabilities.

4.1.2. National Voluntary Organizations Active in Disaster

An association of organizations that mitigates and alleviates the impact of disasters; provides a forum promoting cooperation, communication, coordination and collaboration; and fosters more effective delivery of services to communities impacted by a disaster. This is a consortium of over 70 national organizations and 56 territorial and state equivalents.

These and other NGOs do not have a primary charter to provide power during a disaster response; however, they may require deployable power systems for their own capabilities on the ground.

4.2. International Disaster Response

International disaster response has both similarities and differences with domestic disaster response. One difference is a wider range of disaster incident types. International disasters can include events that are much less common or nonexistent in domestic disasters such as famines, civil war, and the care of large numbers of refugees and displaced persons.

With the notable exceptions of lawless areas outside of the control of any government, or areas engulfed in civil war, disaster planning response in foreign countries is coordinated by the government of the impacted country. Planning frameworks and levels of preparation can vary greatly from country to country. Depending upon the nature and scale of the disaster and the capabilities of the host government, international assistance may be requested.

Like in the U.S., international disaster response can involve myriad government agencies, NGOs, and other private sector organizations. A sample of entities that conduct international relief operations follow.

4.2.1. The Office of Foreign Disaster Assistance (OFDA):

As a part of the U.S. Agency for International Development (USAID), "The OFDA is responsible for leading and coordinating the U.S. government's response to disasters overseas. In the wake of a large-scale disaster, OFDA can deploy a Disaster Assistance Response Team (DART) to coordinate and manage an optimal U.S. Government response, while working closely with local officials, the international community, and relief agencies. OFDA also maintains stocks of emergency relief supplies in warehouses worldwide and has the logistical and operational capabilities to deliver them quickly." [23]

4.2.2. The International Federation of Red Cross and Red Crescent Societies (IFRC)

The IFRC "coordinates and directs international assistance following natural and man-made disasters in non-conflict situations. The IFRC works with National Societies in responding to catastrophes around the world. Its relief operations are combined with development work, including disaster preparedness programs, health and care activities, and the promotion of humanitarian values." [24]

4.2.3. The International Committee of the Red Cross (ICRC)

The ICRC is a legally separate and distinct organization from the IFRC. "The International Committee of the Red Cross (ICRC) is an impartial, neutral and independent organization whose exclusively humanitarian mission is to protect the lives and dignity of victims of war and internal violence and to provide them with assistance. During situations of conflict, the ICRC is responsible for directing and coordinating the Movement's international relief activities. It also promotes the importance of international humanitarian law and draws attention to universal humanitarian principles. As the custodian of the Geneva Conventions, the ICRC has a permanent mandate under international law to visit prisons, organize relief operations, reunite separated families and undertake other humanitarian activities during armed conflicts. The ICRC also works to meet the needs of internally displaced persons, raise public awareness of the dangers of mines and explosive remnants of war and trace people who have gone missing during conflicts."

Similar to domestic disaster response, international disaster relief requires energy resources for both relief operations and the affected population. The exact requirements will depend on the location and nature of the disaster. There is interest in using renewable energy for disaster response and recovery, especially in remote areas where fuel resupply is challenging. An example of this is in Dominica, where in the aftermath of Hurricane Maria, a solar powered "nanogrid" was installed in a remote community to supply power for a medical clinic and water purification. [25]

4.3. Summary

In both domestic and international disaster relief, energy supply for both the relief operation and the affected population is a key need. Specific requirements for deployable energy sources are not well defined, but often draw from DoD equipment. Domestic disaster response appears to offer a better-defined procurement path via government agencies. However, with generally good access to fuel supplies and the existence of extensive electrical infrastructure, there is less of a need for renewable energy systems in general and wind energy in particular. International disaster relief, which more likely involves operations in less developed areas, offers a more obvious possible opportunity for wind energy. However, the procurement path is ill-defined and likely to be fragmented between numerous entities. Given the role of DoD offices in both domestic and international disaster response efforts, there is reason to think that a deployable turbine developed for military missions could include disaster response applications without the need for a special design consideration.

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5. WIND ENERGY POTENTIAL

Wind energy resources vary substantially around the world, within a country, and even within a small geographical area. Wind resources are also variable in time with diurnal and seasonal variation in most locations. In commercial applications, wind resources are identified through databases, maps, and often direct measurements at a site for a year or more. Wind turbines are then installed at sites where the wind resource is sufficient to meet the financial requirements. For a deployable turbine in a military application, the wind resource is unlikely to ever be taken into consideration when locating a contingency base. It is therefore necessary to take a different approach and consider the global wind resource to identify where wind energy could be viable.

5.1. Wind Resource Classification

Wind resources have been traditionally classified based on an average annual wind speed at a given height above the ground. [26] In Table 5, the wind resource at two heights, 10 m and 50 m, is divided into 7 classes. Deployable turbines are likely to have hub heights between 10 m and 50 m, so this classification is applicable. Companies have improved wind turbines over the past decades to achieve economically viable installations at lower wind power classes. This is beneficial for defense and disaster response applications because, on average, the global land area is class 1 and 2.

Table 5. Classes of wind power density at 10 m and 50 m(a)

Wind Power Class	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density (W/m^2)	Speed(b) m/s (mph)	Wind Power Density (W/m^2)	Speed(b) m/s (mph)
1	0	0	0	0
	100	4.4 (9.8)	200	5.6 (12.5)
2				
	150	5.1 (11.5)	300	6.4 (14.3)
3				
	200	5.6 (12.5)	400	7.0 (15.7)
4				
	250	6.0 (13.4)	500	7.5 (16.8)
5				
	300	6.4 (14.3)	600	8.0 (17.9)
6				
	400	7.0 (15.7)	800	8.8 (19.7)
7				
	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.
(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/1000 m (5%/5000 ft) elevation.

5.2. Wind Resource Data

Average global wind resource data is freely available online via a World Bank and the Technical University of Denmark program. The resource is called the Global Wind Atlas. [27] Figure 2 shows a screenshot from The Atlas representing average annual wind speed at 50 m above ground. Referencing the wind classification table above, class 3 and higher wind resources would be the warm colors of orange, red and purple, while class 1 and 2 are represented by the yellow, green, and blue areas that are less commercially viable. It is clear that most of the earth's surface does not have commercially viable wind resource. However, this does not imply that wind is not viable as an energy source for defense and disaster response applications. Some design changes are likely required to make wind energy viable in more locations such as larger rotors that have better performance in lower wind speed resources.

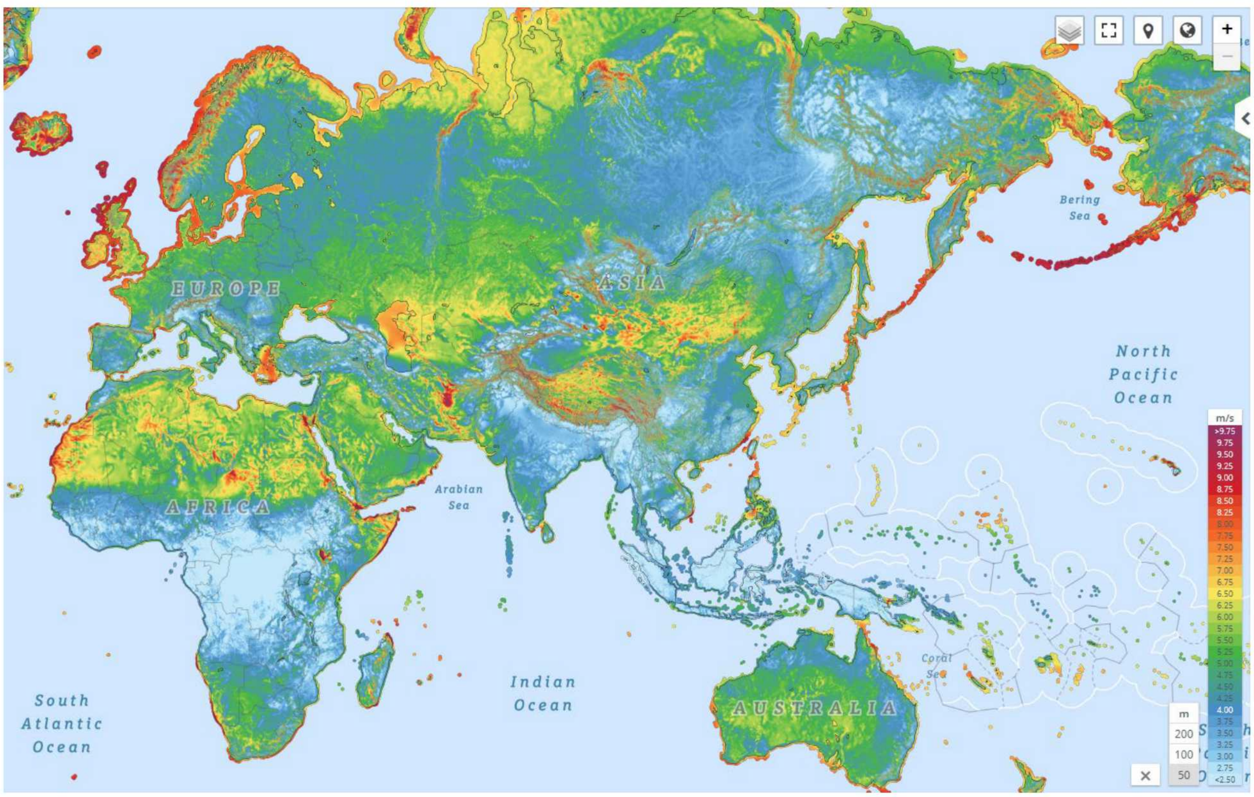

Figure 2. Screenshot from the Global Wind Atlas showing color-coded annual average wind speeds at 50 m height above ground

The variation of wind resource by location is highlighted in Figure 3 where plots of the average wind speed by percent of land area are shown. As a point of comparison, the windiest 10% of global land area has an average wind speed of at least 4.87 m/s (class 1) whereas the windiest 10% of land area in Afghanistan has an average wind resource of 8.9 m/s (class 7c). This can also be considered from the other direction. Commercially available wind turbines can produce reliable power even at class 2 wind speeds of 5.6 m/s and higher. This occurs in over 76 % of the land area in Afghanistan but in less than 2% globally.

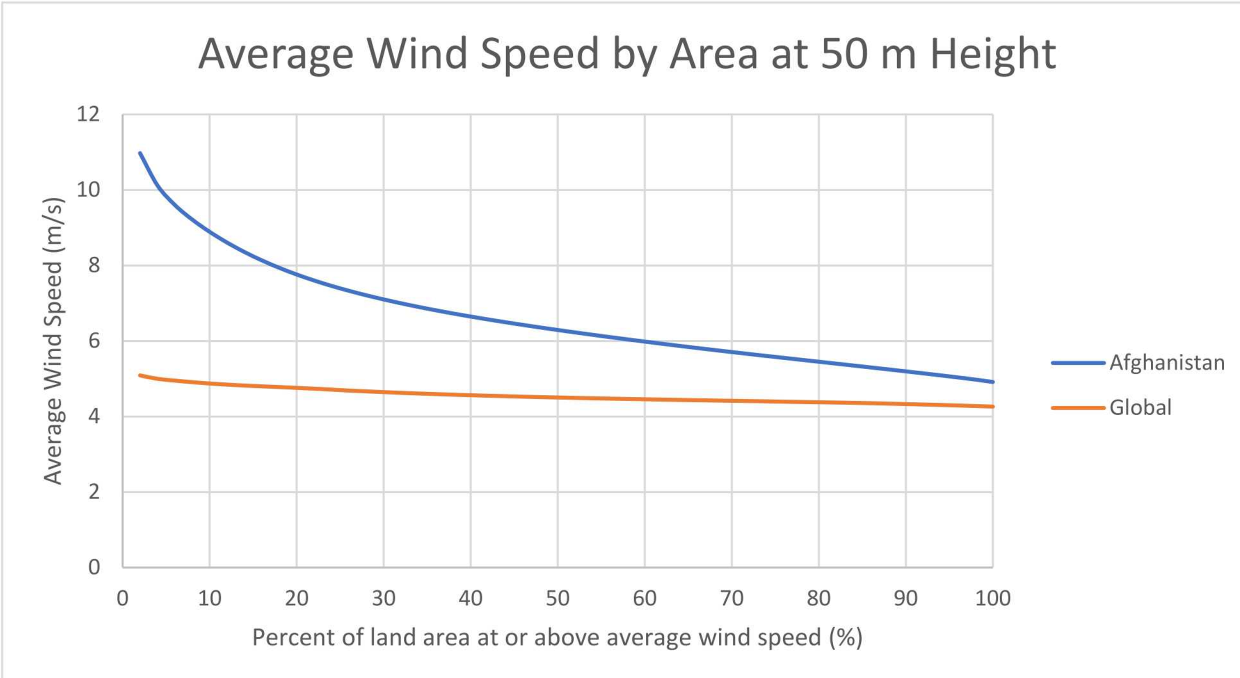

Figure 3. Average annual wind speed at 50 m above ground by percent of land area

Average annual wind speed is a good initial metric for assessing the viability of wind energy for a specific location. The daily and seasonal variability is equally important to consider for military contingency bases because they are generally operated as isolated microgrids where there is no external grid to provide power if the wind speed is too low. For this reason, wind turbines are not envisioned as a sole or even primary energy source for contingency bases, but rather to augment the diesel generators and reduce their fuel use when the wind does blow. Incorporating batteries in the system could also address the temporal mismatch between wind availability and load. Still, it is important to understand that there are many locations where there is a windy season and a relatively calm season, which are not represented by the average annual wind speed. Likewise, daily fluctuations occur as well. The most recent version of the Global Wind Atlas (GWA 3.0 October 2019) includes a new feature called the "Energy yield calculator" that is capable of estimating the annual energy production of a given wind turbine design as provided by the user based on the resource of a selected area on the map. This new feature also provides estimates of the variability of the wind resource between years, within a year, and within a day. Figure 4 shows an example plot of the wind speed variability over the 24 hours of an average day for each month of the year. The wind speed index is the multiplier of the average annual wind speed. In this example, it is clear that April and May (months 4 and 5) are well below the average annual wind speed while November through January (months 11, 12, 1) are well above the annual average.

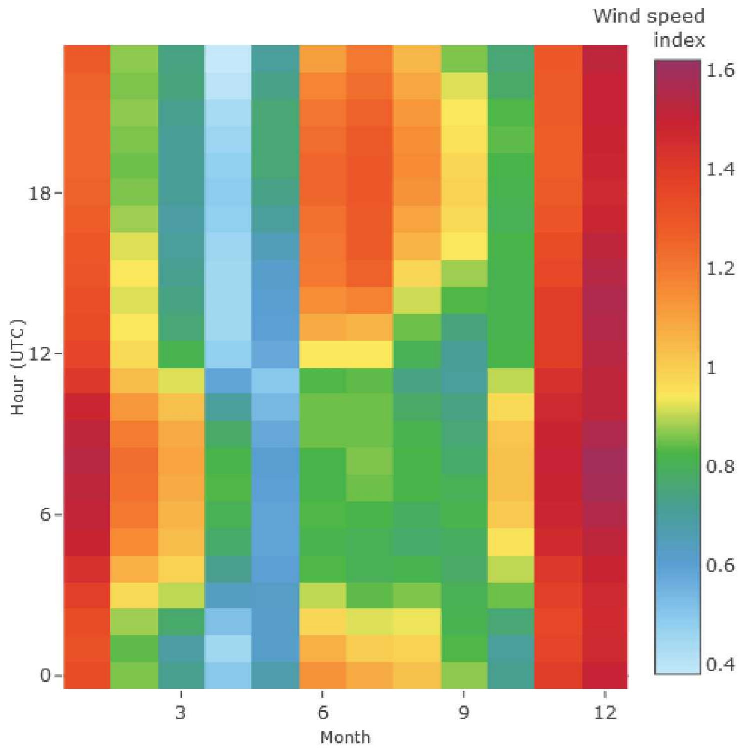

Figure 4. An example of the wind speed variability for the 24 hours and 12 months of a year for a given site as provided by the Global Wind Atlas Energy Yield Calculator feature

The Global Wind Atlas is an effective tool to estimate wind energy output as a starting point. For more detailed studies of a specific location, there exists other commercial products for a fee from companies like AWS Truepower and Vaisala.

5.3. Summary

The global wind resource is highly variable both spatially and temporally. While this presents some potential limitations to wind energy as a technology to support military contingency bases, it also does not categorically exclude it. It is critical to understand how wind turbines can be designed to match the resource where they will be installed. Most commercially available turbines are designed for medium to high wind resources. However, design choices in the wind turbine can increase the viable land area for wind energy to be effective including lower wind speed sites where commercial turbines will perform poorly. Larger rotors on turbines to create low and ultra-low specific power turbines are one avenue to explore. Some companies are also exploring airborne turbines that access better and more consistent wind resources high up in the air using a tether to transport power back to the ground. Ultimately, enough opportunities exist to warrant continued exploration of a deployable wind turbine for defense and disaster response applications.

6. DEPLOYABLE WIND TURBINE TECHNOLOGY CONSTRAINTS

The wind resource of a location represents the upper bound of energy production for a wind turbine. The design and operation of the turbine determines how much of that available wind energy can be converted into usable electricity. A deployable wind turbine that can power military bases and disaster response applications must consider design and operational constraints that can be significantly different than current commercial products. Defining these specifications is a major deliverable of the D3T project in the coming year. However, there are some general observations regarding the characteristics of a deployable wind turbine that could limit the market potential.

One of the biggest concerns raised from direct conversations with DoD stakeholders and indirectly from industry stakeholders is that wind turbines are a large visible target for adversaries. Wind turbines must operate in a viable wind resource, and the resource generally improves with increasing height above ground. This is a performance tradeoff that can be evaluated with more specific designs, and it may be that wind turbines are not a good fit at some forward bases. However, many other bases are in well-known places where a visual presence is not a primary concern. This constraint will need to be quantified more but does not appear to rule out wind turbines entirely.

Related to the visual signature concerns, DoD stakeholders have also mentioned concerns that wind turbines impact surveillance and communications systems, especially radar. Wind turbine interference with electromagnetic signals is well-characterized in the U.S. commercial market and mitigation options are under development. The proximity of a deployable wind turbine to a radar or communication system at a contingency base may present unique challenges. Proper siting of the wind turbines, operational limits, and reduction of the turbine signature or the radar system are all possible mitigation options. Even with the best mitigation, there may be bases where wind turbines are severely limited or even excluded in application. On the other hand, one company is developing a deployable airborne wind turbine system specifically for military bases and taking advantage of the high-altitude operation to include communications and surveillance systems installed on the airborne turbine. Like other technical constraints, this issue will have to be better quantified and weighed against the benefits of a wind system but does not appear to totally exclude deployable wind turbines as a viable technology. Neither visible target nor impact on surveillance concerns apply to disaster response applications. However, disaster response has its own set of concerns such as often shorter deployment times and more challenging deployment logistics. More work is needed to develop a good understanding of the range of needs or challenges for disaster response.

There are other technical, operational, and logistical constraints that limit the overall market potential for deployable wind turbines. Given the size of the overall DoD operational energy opportunity, even if a small percentage was addressable by deployable wind energy, there is good justification to continue more detailed exploration of the technology as a solution for military bases and disaster response.

6.1. Commercially Available Wind Technology

An initial task of the D3T project was to survey the wind industry to gather information on the capabilities of wind turbine technologies that might be adaptable for deployable applications. Questions posed to the companies included their level of interest in the deployable wind market, concepts or products that are already in development or available that could supply this market, any prior experience supplying or interacting with DoD, and any sense of what a minimum viable market would be to attract investment in a new technology.

A total of thirteen companies were interviewed that manufacture or are developing distributed wind turbine products and were interested in the D3T market space. Five were in production (one closed since) and five were in advanced stages ready to start production or with prototypes under test. Three were in early stages and not yet to the point of building prototypes. Their level of involvement with deployable turbines ranged from being the focus of the company to not thinking it was a market they fit well. The size range was from 20 W to 300 kW. Table 6 provides a high-level summary of the responses.

Table 6. Summary of wind turbine technology provider discussions

Company	Production stage	Rating (kW)	Interest in D3T	Deployable Design	Minimum new product market
Company 1	Pre-prototype	2.5	Yes	Concept development	No response
Company 2	Preorders	0.02	Primary focus	Inherent at this size	No response
Company 3	Yes	15	Yes	Design development underway	No response
Company 4	Starting production	300	Yes	Looking for orders to start	Depends on price
Company 5	Prototype testing	3.5	Some	Concept development	No response
Company 6	Prototype testing	70	Maybe	None	No response
Company 7	Production	0.20	Yes	Inherent at this size	No response
Company 8	Production	20	Maybe	None	No response
Company 9	Production	0.6; 2.4	Yes	Marketing as deployable	100 units
Company 10	Starting production	10	Their focus	Marketing as deployable	No response
Company 11	Pre-prototype	25; 100	Maybe	Minimal	25 units
Company 12	Closed	2.1; 10.4	NA	Concept development	No response
Company 13	Pre-prototype	6; 20; 100	Primary focus	Pre-prototype	No response

It proved difficult to get responses on minimum viable market for developing a new product. The answer for most companies would depend on several factors that were not specified in this hypothetical question. Even when they gave an answer it included caveats. For one company, the answer was based on developing a new product using an existing blade for which they already had tooling. Another company felt that it depends on the price available in the market for the new product. For many companies, a major concern was the level of confidence in the long-term market potential. It is one thing to have an order for a few turbines in a market that may stop there, and entirely another to have an order for a few turbines in a market that they have a high confidence will grow and extend for many years. Some companies were willing to develop a new product specifically for military deployable applications if funding sources are available to cover most of the cost. Developing a new military turbine was also mentioned as a good opportunity to transition to a commercial product and one company even mentioned that a "military grade" turbine would help with marketing to other rugged applications.

Most companies expressed a significant desire to have a better idea of what the potential market was and the market requirements. Several companies expressed uncertainty about the application requirements and the size of the market as reasons they were not considering a military product. Navigating the DoD to find the right customers was also a common challenge. The D3T project has objectives to address most of these challenges.

6.2. Summary

Most industry members that were interviewed had an interest in the defense and disaster response markets for deployable wind systems. Many of the companies already have specific concepts or even prototypes for deployable systems and a few are actively involved with DoD programs to develop their technology. Many of the identified challenges to developing technology solutions are the focus of the D3T project in the coming year.

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7. DEVELOPING D3T ENERGY TECHNOLOGY SOLUTIONS

One of the primary objectives of the D3T project is to identify and facilitate discussions between wind technology providers and decision makers within the DoD whose missions include operational energy for contingency bases and other missions. These discussions will help to better identify the needs of the military application for operational energy and the pathways to develop and deploy the technology to meet those needs. A list of most of the relevant DoD offices to D3T are listed in Section 2.3. Many of these offices have been briefed on the D3T project and a few have provided more extensive feedback via interviews and email correspondence. That information is summarized in the following sections. This provides a "snapshot" of the variety of views on wind and renewable energy across the DoD and is not intended to be exhaustive.

7.1. DoD Energy Events

One of the most effective ways to engage with relevant DoD stakeholders is by participating in events that are generally held every year. The following sections summarize the events that have the largest participation of DoD stakeholders that are engaged with operational energy. Many of the conversations regarding D3T have been held during networking time at these events, and these would also make a good venue for industry members interested in meeting DoD staff and learning about funding and procurement programs to support the development of their technologies and products.

7.1.1. Expeditionary Power & Energy Summit

The Expeditionary Power & Energy Summit took place May 15-16, 2019 in Washington, DC, where around 50 people attended from DoD, federal research entities, industry and academia. The event is organized and facilitated by the Defense Strategies Institute, but it is not necessarily held every year. This event is small and focused on energy technologies to meet DoD mission needs and offers targeted networking opportunities with top DoD staff across the department.

7.1.2. Defense TechConnect Innovation Summit & Expo

This event is held every year, generally in the fall in Washington, DC, and has a strong focus on energy technologies for defense applications. The event features speakers from DoD offices that provide insight into their current needs and also sources of funding and how to work with them. There are funding mechanisms specifically targeted at small businesses with a goal of reducing the timeline and paperwork to get access to funding. A unique aspect to this event is a series of topical sessions where industry members have 10-15 minutes to present their technology to a panel of DoD representatives relevant to their topic (e.g. energy) and get immediate feedback on their ideas, as well as contacts across DoD they should talk to. There is also an exposition hall where companies can set up booths and network with DoD and other participating industry members. In 2019, there was a special half-day workshop specifically targeted at providing technology innovators with an introduction on how to work with DoD to develop technology solutions. [28]

7.1.3. Operational Energy Summit

The Operational Energy Summit, organized by the Institute for Defense and Government Advancement is held every year, currently in January in Washington, DC. This event is organized around the DoD Operational Energy Strategy and the investments made across the offices to implement that strategy. The event features speakers from the DoD operational energy offices and many networking breaks throughout the schedule. The 2020 event has a specific session on renewable energy.

7.1.4. Energy Exchange

The Energy Exchange conference is organized annually by the Federal Energy Management Program (FEMP) within the DOE, generally in August with a rotating location each year. FEMP has a mission to enable federal agencies to meet energy-related goals, identify affordable solutions, facilitate public-private partnerships, and provide energy leadership to the country by identifying and leveraging government best practices. This event brings together representatives from across the federal agencies, including broad participation from DoD, for training, presentations, and opportunities to network and learn about new technologies from national laboratories, industry and others.

7.2. Direct Military Stakeholder Discussions

More extensive and detailed discussions have been conducted with specific military stakeholders. These will be expanded upon in the following sections.

7.2.1. U.S. Marine Corps Expeditionary Energy Office

An interview was conducted in June 2019 with the USMC E2O as a follow-up to a brief discussion at the Expeditionary Power & Energy Summit in May 2019.

The USMC E2O office mission is to "analyze, develop, and direct the Marine Corps' energy strategy in order to optimize expeditionary capabilities across all warfighting functions." They accomplish this through two different functions. The Combat Development office sets requirements for USMC operational energy while the Systems Command office interfaces with operations, sets maintenance schedules, acquires equipment, and other operational responsibilities.

The current focus of development for the E2O is small unit power, roughly 1-4 kW systems at the point of use. The smaller end would be for the dismounted soldier while the upper end is mounted on a small vehicle (e.g. all-terrain vehicle). These are envisioned to be hybrid systems where a battery, small diesel generator, a controller, and renewable systems (solar and potentially wind) are integrated to make a power system. Previous attempts at such systems (e.g. GREENS [29]) were underutilized in the field because they were too large and did not provide enough continuous power. Adequate requirements were not established ahead of time with input from the soldiers who would eventually use the systems, so future efforts will need to take this into consideration.

The primary deployment focus for the USMC is any coastal area, especially in the Pacific. The Middle East remains relevant in the near term as well.

The E2O emphasized that there are no true "hard" constraints on energy systems and that it is generally interested and open to any technology that supports its missions. However, there are many strong preferences like limiting the size and weight of equipment that a soldier must carry, having something that is portable and simple to deploy and use. The typical patrol is around 72 hours for a dismounted soldier, so equipment must be quick to setup, use, and dismantle.

The E2O office is currently undertaking a power study of its units to better quantify capability gaps that would drive future requirements. Prior studies only examined the bulk energy use of the USMC, but the accuracy of those results was found to be inadequate for unit level deployments where a 10% error in energy supply would be critical. This information is planned for release publicly in 2020. In addition to this study, participation from industry in developing requirements was noted as desirable.

Regarding technology development and testing, the E2O office does coordinate demonstration of new technologies in the field, in addition to providing direct support of research and development. No specific test evaluation criteria were offered, but metrics, like ability to recharge batteries that the soldier must carry, were mentioned.

For fielding technologies, the USMC has a tool called IPOWER that takes load requirements as inputs and offers combinations of battery and generator systems that would meet those loads. The tool is used for acquisition to calculate optimum system specifications like generator sizes, but also as a mission planning tool given a fixed set of components available to deploy. Without such decision support tools, soldiers rely on previous experience to select equipment to take on a patrol or mission.

E2O did not have input regarding specific wind turbine tower types or foundations, other than it must be temporary and pack up quickly. Direct current (DC) power output was preferred as charging batteries is the primary need. Previous experience with wind systems included seeing a mockup of an airborne system at a conference, a presentation on a smaller system, but no direct experience with either in a development or testing scope.

Overall, the USMC E2O is open to any technology that can improve their mission effectiveness and is open to adopting new ideas rapidly. Its focus on small systems (1-4 kW) offers up the opportunity for novel wind system designs and rapid design iteration.

7.2.2. US Indo-Pacific Command (USINDOPACOM)

A contractor supporting the J8 Energy Program at USINDOPACOM attended the Defense TechConnect conference and was briefed on the D3T project. The feedback provided included:

- The weather in the area, especially typhoons, is too destructive for the types of contingency bases that are commonly deployed in Afghanistan and Iraq.
- Typical exercises last about 2 weeks, and some missions are only 24-48 hours, so any energy system would need to be set up and broken down quickly.
- Consider the mission cost of a deployable wind system as compared to a diesel generator. Compare the size, mass, and cost of the system that would need to be replaced and the equivalent amount of energy from diesel fuel.

7.2.3. US Army Corps of Engineers Construction Engineering Research Laboratory

A program manager from USACE CERL attended the Defense TechConnect conference and was provided an overview of the D3T project. The feedback provided included:

- USACE CERL is facilitating the installation of a microgrid at Fort Hunter Liggett, located 2-3 hours south of San Jose, CA. The base-wide microgrid will provide power when utility service is down. It also is intended to help Fort Hunter Liggett achieve net zero energy with installation of solar and energy storage.
- The Tactical Microgrid Standard was mentioned, which is being developed to address inefficient spot generators typically deployed at contingency bases. Deployable wind systems could be connected into those types of systems.

- USACE has programs that can provide matching funds in the range of a few hundred thousand dollars to support field test and evaluation of new technologies like deployable wind systems hosted at their testing facilities.

7.2.4. *Office of the Assistant Secretary of the Army for Installations, Energy and Environment*

The Special Assistant for Energy and Sustainability from the OASA (IE&E) office was briefed on D3T and provided the following feedback:

- The OECIF program developed a performance standard for PV systems after early prototypes failed or underproduced compared to company claims. A testing specification was developed. Something similar could be devised for wind systems to evaluate them for military use.
- Two studies were provided from the Center for Naval Studies regarding renewables in expeditionary energy applications. The general conclusions of the reports were that the wind speed was generally too low at most locations to be viable with current wind technology:
    - Solar and Wind Power in Expeditionary Environments: Summary for DSB Energy and Environmental Research Group, Center for Naval Analyses
    - USMC Expeditionary Energy Cost Analysis: Summary for DSB Energy and Environmental Research Group, Center for Naval Analyses.

7.2.5. *Deputy Assistant Secretary of the Navy, Energy, U.S. Navy*

The Director of Operational Energy was provided an overview of the D3T project and offered the following feedback:

- The operational energy offices across the services coordinate their investments and share technologies with each other. For example, the U.S. Navy is currently focused on battery technologies while the U.S. Army is doing most of the advanced microgrid activities.
- The biggest concern with wind is the intermittency and lack of predictability of production. PV is easy to estimate with existing commercial software tools, but good wind resource data is lacking.

7.3. Summary

Thus far, the information provided through formal presentations and from direct interviews with military stakeholders provides a general picture that there is much interest in energy alternatives to diesel generators to meet mission needs. The specific feedback regarding the use of a deployable wind system to address some of those operational energy challenges has been mostly neutral with some specific technical requirements provided for various applications or locations. There appears to be sufficient opportunity to demonstrate the potential value of deployable wind systems to warrant further development and engagement with certain DoD offices. The DoD is a large organization with a wide range of missions and energy needs that vary across offices and also change year-to-year. One way to navigate opportunities to provide technology solutions to the DoD is through targeted events such as those mentioned previously. Not only do these events bring together a wide range of DoD stakeholders and other companies for networking opportunities, but the formal presentations and workshops provide valuable guidance for companies to understand the current technology development opportunities.

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