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US Army Research Laboratory

Atmospheric Renewable-Energy Research, Volume 1 (Background: "To BE or not to BE")

by Gail Vaucher

NOTICES

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14. ABSTRACT

The US Army Research Laboratory (ARL) has an opportunity to manifest a decisive edge for future Soldiers in the area of operational energy. Major commitments have been made over the last 5–10 years by the Department of Defense (DOD), a Presidential Mandate, individual armed services, and the Department of Energy (DOE) to exploit renewable energy (“R-E”). As one of the largest institutional energy consumers in the world, DOD is pursuing a clean-energy solution to improve energy security, mitigate energy costs and reduce risks to the American Warfighter. This report provides a foundational document in which R-E is defined, why R-E is needed is explained, the DOD and individual armed forces R-E commitments are detailed, and a summary of the significant state-of-the-art atmospheric research being done for wind and solar power generation is given. Meteorological research and technology gaps in the current military-operational energy mission are identified, along with potential solutions. This ARL Battlefield Environment (BE) Division pioneering investigation reveals a “new” atmospheric-research opportunity for ARL BE.

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Healthy appreciation is extended to Dr Sue Ellen Haupt, Director of the National Center for Atmospheric Research’s Weather Systems and Assessment Program, for her wealth of knowledge and enthusiasm regarding the atmospheric contributions to R-E.

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Executive Summary

The US Army Research Laboratory (ARL) has an opportunity to manifest a decisive edge for future Soldiers by advancing operational energy. The 2014 Department of Defense (DOD) Directive No. 4180.01 established a policy to enhance military capability, improve energy security, and mitigate costs in energy usage and management. As one of the largest institutional energy consumers in the world, the DOD has been actively pursuing a clean-energy solution. Part of the solution is to use Renewable Energy ("R-E") resources.

R-E is energy that replenishes itself in a short period of time, such as minutes or days. Four of the more widely recognized R-E resources are solar energy, wind energy, hydro (water) energy, and geothermal energy. Section 2 provides a short history of each resource.

- Solar energy can be generated via passive (i.e., greenhouse) and active designs. Active solar designs generally include an absorbent medium, such as a photovoltaic (PV) device. The PV or solar cell produces electricity whenever photons of sunlight hit the surface.
- Wind energy is actually an indirect form of solar energy. When the sun heats the earth surface in the tropics, the warm air rises. Cooler, denser air from the polar regions advects toward the tropics, mixing in with the warm air, trying to establish an equilibrium. This endless cycle of heat transfer causes huge areas of air movement (wind) across the globe.
- Water energy (hydropower) uses naturally falling water to generate electricity. The process exploits the kinetic energy of falling water by using it to turn a turbine, which spins a generator and produces electricity. The stability of hydropower makes this resource competitive with fossil fuels; however, naturally running water is not universal, so the resource has limitations. Since solar and wind resources are generally universally available, they tend to be a more practical consideration for R-E resources.
- Geothermal energy comes from heat generated and stored by the earth. Geothermal energy is used to generate electricity via dry steam power, flash steam power, and binary cycle power stations.

The need for R-E can be summarized in 3 reasons: to save lives, improve security, and reduce costs. Section 3 explains these needs through the civilian and military perspectives.

The US armed forces commitment to R-E was defined in Public Law 109–58, *Energy Policy Act of 2005*. The 2013 Presidential Mandate further enhanced the

goals by committing the conversion of 20% of the DOD energy demand over to R-E resources by 2020. Each of the armed forces also publically announced its R-E commitment, which is summarized in Section 4.

The Army R-E investment stems from an Army Operational Energy (OE) policy to "…use energy to our greatest benefit through resilient capabilities and energy-informed operations". An Army Office of Energy Initiative (OEI) was established in September 2014 to leverage multiple acquisition approaches and partners to execute R-E projects. With this pro-active Army position, the details of the commitment were defined as deriving 25% of the total energy consumed from R-E sources and deploying 1 Gigawatt (GW) of R-E on Army installations by fiscal year (FY) 2025. The Army is committed to a 30% reduction of fossil fuel usage by FY 2015. And, the Army intends to reach net-zero energy consumption by 2030.

The diversity of Army R-E technology investments can be organized into 3 general categories, as defined by the range of power generated and their general function. R-E resources that generate power of >10 Megawatts (MW), are called by the author, the "Utility/Installation" category. This "high power" group is characterized as being in a fixed location and servicing a fixed environment.

The lowest powered group includes power production of <1.5 MW. This category has been called the "Tactical scale", since most of the technologies serviced are mobile, dynamic, of a plug and play character, and used for short-duration applications. (Active Army personnel suggested that the Tactical scale be considered <0.5 MW.)

The middle category, called "Microgrid scale", overlaps both extremes, with a range of 1–40 MW. Microgrid scale is characterized as semifixed, transportable, and most importantly, is able to connect to a larger power grid, yet also able to function independently.

The atmosphere impacts R-E in 3 areas: water, wind, and solar power generation.

- Water power relies on moving surface water. Bringing water to a ground-based moving medium (i.e., river) involves climatological and regional rain forecasting.

- Wind is indirectly associated with solar input through the heat-driven temperature gradients prompting a quest for atmospheric equilibrium. The most significant meteorological variables for wind energy include wind speed, wind direction, and turbulence.

- The atmospheric influence on solar power generation includes a diversity of atmospheric variables that cause a deviation of clear sky irradiance.

> Multiple approaches to forecasting the solar power production are underway. Clouds and aerosols are 2 major factors.

The DOE has funded major atmospheric-specific research for wind and solar power forecasting. The DOE wind and water program sponsored a project called the Wind Forecast Improvement Project (WFIP), which ran from 2011-2013. (At the time of this publication, a follow-on "WFIP2" was being negotiated.) Section 6 describes the National Oceanic and Atmospheric Administration (NOAA)-led WFIP consortium, which included 2 approaches: 1) the assimilation of additional meteorological observations into existing Numerical Weather Prediction (NWP) forecast models, and 2) the advancement of the NWP models themselves. Section 6 summarizes the WFIP Final Report, 7 specific scientific results, and 4 recommendations.

The DOE solar power forecasting effort began in 2011. The $29 million investment was divided into 4 projects aimed at improving grid connections and reducing installation costs through "plug and play" technologies ($21 million) and reliable solar power forecasts ($8 million). The latter investment was divided into 2 state-of-the-art projects intended to advance solar power forecasting. One project was led by the International Business Machines (IBM) Thomas J Watson Research Center; the second was led by the University Corporation for Atmospheric Research (UCAR). Both teams were a public-private partnership, which included industry, national laboratories and university partners. (At the time of this publication, both projects were ongoing.)

The IBM collaboration is aimed at joining powerful computers to big data processing, NWP models, and state-of-the-art machine learning technologies that determine solar and wind installation output. In a 21 July 2015 publication (Martin 2015), IBM Research Manager Hendrik Hamann stated, "Solar and wind forecasts produced by IBM's technology are as much as 30% more accurate than conventional forecasts." Hamann recognized solar forecasting is an archetypical example of the butterfly effect, where small changes can have large consequences over time and space. Thus, the IBM-led project goals are balanced with the understanding that no NWP model can be perfect, and one must be satisfied with making approximations.

The UCAR-led "Advance Solar Power Forecasting Project" (also known as "SunCast") began in 2013. Participants include national laboratories, universities, industry partners, forecast providers, USA utilities and load-balancing authorities (independent system operators). The ongoing project is aimed at advancing methods for solar-radiation measurement, observing clouds, and high resolution Nowcasts. Methods for quantifying and tracking aerosols, haze, and contrails are also being investigated. The ultimate goal is to develop short-term, cloud prediction techniques, based on observations. With solar forecasting, power-system operators will have tools for integrating more solar energy into the grid.

The atmospheric R-E research for the US armed forces is an open field of opportunity. Section 7 examines the 3 military R-E areas (utility-scale, microgrid, and tactical), focusing on Army applications. The current Army investment into utility-scale R-E (wind and solar power) is primarily as a "landlord"; therefore, the utility company partners who have the responsibility for making the investment immediately profitable will more directly benefit from the solar/wind civilian research advances, once that research matures into products.

The military microgrids service Fixed and Forward Operating Bases (FOBs). A novel feature of the military microgrid (versus civilian microgrid) is the potential for being mobile. This attribute generates several technology gaps:

1) Before R-E power resources are integrated into a military mission, the planners need to know if the R-E resource is advantageous for the particular military deployment.
2) If an R-E resource is deployed, planners need to know the optimum placement and orientation of the R-E technology.
3) Providing uninterrupted power to the users is a critical requirement. Thus, the military would benefit from a "smart microgrid" that can seamlessly integrate multiple R-E and fossil fuel resources into the Fixed or FOB power grid.

Potential solutions to these technology gaps are provided Section 7.

At the time of this publication, the tactical technology was still being developed and tested. Consequently, the author suggested using the experience gained from the proposed microgrid research to address future tactical-scale technology gaps.

1. Introduction

The US Army Research Laboratory (ARL) is the "nation's premier laboratory for land forces that is focused on providing the decisive edge and overmatch that our future Soldiers will need to keep us safe," according to ARL Director, Dr Thomas P Russell (Russell 2015). One area in which ARL is making advances for the future Soldiers is energy. The energy topic is supported by the Department of Defense (DOD) Directive No. 4180.01, which established a policy to enhance military capability, improve energy security, and mitigate costs in energy usage and management. This DOD 10-year policy became effective on 16 Apr 2014. To fulfill Directive No. 4180.01, the document explained that DOD would

1. Improve energy performance of weapons systems, platforms, equipment, products, and their modifications; installations; and military forces.
2. Diversify and expand energy supplies and sources, including renewable energy (R-E) sources and alternate fuels.
3. Ensure that energy analyses are included in DOD requirements, acquisition, and planning, programming, budgeting, and execution (PPBE) processes.
4. Access and manage energy-related risks to operations, training, and testing, to include assets, supporting infrastructure, equipment, supplies, platforms, and personnel.
5. Develop and acquire technologies that meet DOD energy needs and manage risks; utilize appropriate resources/energy expertise in other government organizations and private sector.
6. Educate and train personnel in valuing energy as a mission-essential resource (DOD 2015).

The acceptance of R-E as a recognized resource for the armed forces follows the realization that DOD is one of the largest institutional energy consumers in the world. Over the past half century, fuel requirements to support each deployed Soldier has increased from 5 to more than 22 gallons per day (The Pew Charitable Trust 2011). High costs, increased energy security, and significant risks to the American warfighters are some of the key influences that have driven DOD toward a clean energy solution. Consequently, DOD clean energy investment increased from $400 million in 2006 to $1.2 billion in 2009, with the final target being $10 billion annually by 2030, according to a study by Pew Environment Group (Casey 2011). A snapshot of the investment is summarized in the report "From Barracks to Battlefield: Clean Energy Innovation and America's Armed Forces" (The Pew

Charitable Trust 2011). Major, new solar installations and other renewables are being added to military bases within the United States. Harvesting clean energy on site has also been tested at operating bases overseas including Afghanistan. DOD's interest in R-E has accelerated the associated technological development and deployment in 3 key areas: vehicular efficiency, advanced biofuels, and energy efficiency. Aside from the fiscal cost of transporting fossil fuels to remote bases, the key goal has been to reduce the risk to troops and loss of life caused by fuel convoys.

In Section 2, R-E will be defined, along with a short history and explanation of 4 R-E resources.

2. Renewable Energy Defined

According to Public Law 109–58, *Energy Policy Act of 2005* (issued 8 Aug 2005), R-E means "electric energy generated from solar, wind, biomass, landfill gas, ocean (including tidal, wave, current, and thermal), geothermal, municipal solid waste, or new hydroelectric generation capacity achieved from increased efficiency or additions of new capacity at an existing hydroelectric project." (US Congress 2005).

Stating the definition more simply, R-E is energy that replenishes itself in a short period of time, such as minutes or days. In contrast, nonrenewable energy either does not replenish itself, or the time needed to replenish the resource exceeds a human lifetime. The Table below provides examples for both categories. In 2012, the primary US energy sources to generate electricity were coal (No. 1), natural gas, uranium, and hydropower (National Energy Education Development [NEED] 2014). Electricity itself is neither R-E nor nonrenewable energy due to the fact that a secondary energy source is used to generate electricity.

Table US energy consumption by source, 2012: examples of nonrenewable and renewable energy resources (NEED 2014)

Nonrenewables	90.74%	Renewables	9.26%
Petroleum	34.64%	Biomass	4.61%
Natural Gas	27.44%	Hydropower	2.77%
Coal	18.23%	Wind	1.41%
Uranium	8.7%	Geothermal	0.22%
Propane	1.73%	Solar	0.25%

The inexhaustible or replaceable natural resources of R-E include a wide variety of options, as seen in the Public Law definition. Four of the more widely recognized

R-E resources are solar, wind, hydro (water) energy, and geothermal. In the next sections, a short history and explanation of these resources are provided.

2.1 Solar Energy

Solar energy can be generated via passive and active designs. A passive solar energy design uses the elements of a structure (typically a building) to heat and cool the structure’s volume, thus reducing fuel requirements. An example of a passive solar resource is a greenhouse. In a greenhouse, the closed-in glass or translucent structure warms up during the day via the penetration of the solar radiation, then releases this heat gradually throughout the night. Passive solar can also be engineered into home designs. The principle factors considered when constructing a home with passive-solar energy include: the building orientation to solar resources; proper window sizing and placement; window overhang designs (to reduce summer heat gain, yet ensure winter heat gain); and a proper thermal mass sizing. Examples of other passive solar energy applications include solar water heaters and solar cooking (Pearson 2013).

Active solar designs generally include an absorbent medium, such as a photovoltaic (PV) device. Alexandre Becquerel, a French physicist, is credited by some with first observing the PV effect in 1839, as part of his study of solar spectrum, electricity, and optics (Pearson 2013). Other historians give credit to Heinrich Hertz for first observing the photoelectric effect in 1887 (Kleissl 2013). An explanation of the PV effect was given by Albert Einstein in 1905. Sixteen years later, in 1921, Einstein was awarded the Nobel Prize in Physics “for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect” (Nobelprize.org 2015). Subsequent pro-active work on the PV technology has spanned several countries and applications. By 1972, the PV solar cells were widely used in outer space. In 1977, the US Department of Energy (DOE) was formed, advancing efforts in all renewable and nonrenewable energy fields. The National Renewable Energy Laboratory (NREL) developed a 30% efficient PV cell, in 1994. By the year 2000, Japan had installed 70,000 PV systems. In this same year, Germany enacted a robust tariff program to accelerate its grid-connected PV installation, which resulted in Germany having the largest PV market in the world. In 2011, the DOE SunShot Initiative (a play on President Kennedy’s “Moon Shot” program that put the first man on the moon) was announced. The SunShot Initiative goals included driving the solar electricity costs down, so they could be fully cost-competitive with traditional energy sources by the year 2020 (Energy.gov 2012; Pearson 2013).

How the PV converts sunlight to electricity: The PV or solar cell produces electricity whenever photons of sunlight hit the surface. The photon energy separates electrons from their atoms. These electrons then flow through the only open path, an attached wire grid on the surface, attempting to return to their atom. Their movement creates electricity in the process. Unlike most electricity generators, no fuel is used, except the solar photons.

2.2 Wind Energy

Wind energy has been utilized for centuries. Sailors have used the wind to navigate sea vessels around the world, and mechanical windmills have been used to pump water out of wells and grind grain for food.

Wind energy is actually an indirect form of solar energy. Looking at the process globally, when the sun heats the earth surface in the tropics, the warm air rises. Cooler, denser air from the polar regions advects toward the tropics, mixing in with the warm air, trying to establish an equilibrium. This endless cycle of heat transfer causes huge areas of air movement across the globe. Another contributor to the generation of wind energy is the spinning of the earth with the associated Coriolis Force (Chelius and Frentz 1978).

Good wind energy sites are characterized by their consistently strong, steady, and smooth air movement. This type of flow is found above the atmosphere’s canopy layer (above buildings, trees, and other obstacles). Consequently, wind turbines generally need to be at least 24 m (approximately 80 ft) above ground level (AGL) in a consistently windy locations (Pearson 2013).

While the United States has contributed to the wind power evolution, Germany and Spain have had the highest wind energy production in the European Union. Only recently has the Global Wind Energy Council indicated that, by the end of 2014, the global installed power capacity in Europe (134,007 MW) was surpassed by Asia, with 141,964 MW (Science Daily 2015).

According to a 2015 *Science Daily* article, “wind power industry is arguably the most mature—and fastest developing—among renewable energies. But, there is still considerable room for improvement to compete with other sources of electricity” (Science Daily 2015).

2.3 Hydro (Water) Energy

Water energy (hydropower) has been used since ancient times to perform a variety of tasks, such as grinding grain. In 1878, the world’s first hydroelectric power scheme was developed in England by William Armstrong and powered a single arc lamp. In 1881, the Schoelkopf Power Station No. 1, in the United States (near Niagara Falls), began to produce electricity. By 1889, there were 200 hydroelectric power stations in the United States (Wikipedia–Hydroelectricity 2015). Today, 70% of the Northwestern US electricity is supplied by hydropower (Pacific Northwest Waterways Association 2015). In addition to producing electricity, hydropower can be used for water supply, flood control, irrigation, and recreation.

Water energy uses naturally falling water to generate electricity. The process exploits the kinetic energy of falling water by using it to turn a turbine, which spins a generator and produces electricity.

In the context of a large power plant, such as Hoover Dam (Arizona, Nevada), the process consists of water flowing through large pipes inside a dam, which turns large turbines. The blades of a turbine turn a series of magnets (a rotor) past stationary coils of copper wire (the stator), creating a magnetic field and finally, electricity. Michael Faraday discovered this concept in 1831, when he found that electricity could be created by rotating magnets within copper coils (US Department of the Interior 2015).

Hydropower's stability of production makes this resource competitive with fossil fuels, and has been tagged as making "the most electrical energy for the cost of the system" (Pearson 2013). This accolade is due to these facts:

- Running water makes power 24 hours/day–7 days/week (24/7)—solar and wind are intermittent;
- Water, being denser than air, carries more kinetic energy than wind;
- Almost all moving water energy is usable by the turbine, with 50–70% of the water energy becoming electricity; and
- A hydropower resource intake, turbine, and generator are reliable and relatively easy to work on.

Hydroelectricity is a clean R-E source that does not result in air pollution, chemical runoff, or toxic waste, and is therefore beneficial to the environment. Construction of dams to provide hydroelectricity, however, can affect the ecology of an area. Also, access to naturally running water is not universal, so the opportunity to exploit this resource has limitations. Solar and wind resources, on the other hand, are generally universally available, making them a more practical consideration for R-E resources.

2.4 Geothermal Energy

Geothermal energy comes from heat generated and stored by the earth. This perpetual thermal resource originates from the planet's formation and an ongoing radioactive decay of internal materials. Power generated by geothermal energy is associated with atmospheric thermodynamic concepts in that it extracts heat from a fuel source in the ground to heat a second fluid (water). This second fluid is then used to turn a generator turbine, which produces electricity. The second fluid is cooled and returned to the heat source. Since the heat extracted is small with respect to the earth's total heat content, the process qualifies as a "renewable energy" (Wikipedia–Geothermal Energy 2015).

An example of early uses of geothermal energy would be the hot springs used for bathing in the Paleolithic times. In the Roman times, this energy resource was also used for space heating. Today, geothermal energy is used to generate electricity. (Wikipedia–Geothermal Energy 2015). There are 3 basic designs for generating geothermal electricity (California Energy Commission 2015):

1) Dry steam power: steam goes directly into a turbine, which drives a generator that produces electricity.

2) Flash steam power: fluid sprayed into a tank at a much lower pressure, causing a portion of the fluid to rapidly vaporize or "flash"; vapor drives the turbine, which produces electricity.

3) Binary cycle power: hot geothermal fluid and a second ("binary") fluid at a much lower boiling point pass through a heat exchanger, causing the second fluid to flash to vapor, which turns the turbines to generate electricity.

The largest group of geothermal power plants in the world is located at The Geysers in California (Calpine 2015). More than 20 other countries generate geothermal power. Examples of countries whose percentage of national production is greater than 14% include Kenya, 51%; El Salvador, 25%; the Philippines, 27%; Iceland, 30%; New Zealand, 14.5%; and Costa Rica, 14% (Wikipedia–Geothermal Electricity 2015).

3. Why Renewable Energy is Needed

The need for R-E can be summarized in 3 reasons: save lives, strengthen security, and improve economics.

From a civilian perspective, integrating R-E power resources into the utility grid has the potential of saving lives by lowering the environmental impacts that would have been created with conventional energy technologies. Examples of environmental impacts include air (coal) and water (nuclear) pollution. The US security concerns are eased when more R-E resources are used, due to a reduced dependency on imported, foreign oil. In terms of the economy, as the supply runs low, costs go up—but R-E does not run out since, by definition, the resource replenishes itself. An added economic benefit is that the installation of R-E systems tends to require a local workforce; thus, R-E investments also create local jobs, fueling the local economics (versus outsourcing overseas).

From a DOD perspective, operational energy affects a wide range of military capabilities, including maneuverability, sustainability, communications, intelligence, surveillance, and reconnaissance. Military missions require secure and uninterrupted access to energy. Consequently, the value of integrating R-E into the armed forces mission can be summarized by the same 3 reasons described in Section 2.4.

- <u>Saving lives</u>: The mobilized armed forces are required to transport all of their power supply resources. With a heavy dependency on fossil fuels, the logistics alone put Soldiers at risk, as they convoy fossil fuels between sites. One solution: integrate R-E into the operational energy mission. In 2010, the *Army Operational Energy Strategy* document (US Army 2010) reported that a 1% reduction of fossil fuel consumption in the Iraq or Afghanistan theatre could mean roughly 60 fewer long-distance fuel convoys per year. A fuel convoy typically involves 50–100 Soldiers. Thus, replacing even 1% of the fossil fuel requirements with R-E resources would reduce Soldier risk, meaning fewer Soldier casualties and fatalities.

- <u>Security</u>: The benefits to replacing even a portion of the fossil fuel requirements with R-E resources improve security. When R-E is integrated into the operational energy mission, the lengthy convoy of fossil fuels can be shortened and fuel storage areas reduced, making a smaller target for the enemy. Another benefit is that the military gains a diversity of options for providing its critical, uninterrupted electrical power requirements. For security, the diversity of resources cascades into a “plus” for all 6 capability areas (see paragraphs above) supported by operational energy.

- <u>Economics</u>: Reduced dependence on the single-use fossil fuels (versus the R-E’s perpetual provision) automatically results in reduced fiscal requirements. The reduction may not be linear, since R-E technology comes with its own maintenance requirements. However, the fiscal feedback has a trend toward supporting the US taxpayer, as explained from a civilian perspective.

4. The Armed Forces Commitment to Renewable Energy

Public Law 109–58 *Energy Policy Act of 2005* (US Congress 2005) and a subsequent Presidential mandate have helped frame the future R-E commitments for the DOD. The following sections summarize the key commitments and milestones by DOD and each of the armed forces (American Council on Renewable Energy [ACORE] 2015).

4.1 DOD R-E Commitment

As per the Presidential Mandate of 5 Dec 2013, DOD has committed to meet at least 20% of the DOD energy demand with R-E resources by Fiscal Year (FY) 2020 (Obama 2013). By this same year, DOD will be building 10 landfill or wastewater treatment facilities that recover biogas for DOD usage. The use of petroleum products in nontactical vehicle fleets will be reduced by 30% over the 15-year period ending in FY 2020. The DOD facility Energy Use Intensity (EUI) will be reduced by 30% from FY 2003 to FY 2015, and 37.5% from FY2003 to FY 2020. The Environmental Protection Agency (EPA) uses EUI as the basis for "Energy Star" scores: A low EUI signifies good energy performance (US EPA 2015). EUI quantifies a building's energy usage as a function of the building size or other characteristics. (EUI is measured in energy per square foot per year and is calculated by dividing the total energy consumed by a building in 1 year in kiloBtu or Gigajoule by the building's total gross floor area.)

Finally, by FY 2020, the DOD is committed to reducing indirect emissions by 13.5%, as well as, decreasing noncombat greenhouse gas emissions by 34% (ACORE 2015).

4.2 Navy R-E Commitment

Secretary of the Navy, the Honorable Ray Mabus, captured a portion of the Navy perspective when he stated: "Simply put, we as a military rely too much on fossil fuels. That dependence creates strategic, operational and tactical vulnerabilities for our forces and makes them susceptible to price and supply shocks caused by either man-made or natural disasters in the volatile areas of the world where most fossil fuels are produced" (US Navy Energy Security 2012).

The Navy has subsequently issued one of the more progressive plans toward integrating R-E resources. The Navy is committed to having 50% of their total Department of the Navy (DON) energy consumption generated from alternative sources by 2020. They intend to produce at least 50% ashore-based energy requirements from alternate sources; 50% of DON installations are to be net zero; and 1 Gigawatt (GW) of R-E will be deployed on Navy installations—all by FY 2020.

Within their 50% goals, the Navy will include alternative fuels. In 2012, the Navy's progress was demonstrated by a Green Strike Group (fleet of Navy vessels), which participated in the world's largest international maritime exercise called "Rim of the Pacific" (RIMPAC). In 2016, the Navy will be deploying a "Great Green Fleet".

The Navy is committed to a 50% reduction of its non-tactical commercial fleet petroleum usage by 2015. They have also stated that the evaluation of energy factors will be mandatory when awarding system and building contracts (ACORE 2015; US Navy 2015).

4.3 Air Force R-E Commitment

The Air Force has committed to increasing facility consumption of R-E to 25% of their total electricity usage by 2025. A 1-GW onsite capacity is to be developed by 2016, with a 1% on-base R-E production achieved by 2013. Beginning in 2020, all new Air Force building designs are to achieve net-zero energy by 2030.

The Air Force will be increasing the use of cost-competitive drop-in alternative aviation fuel blends for noncontingency operations to 50% of the total consumption by 2025. By 2013, the Air Force committed to certifying 100% of the aviation fleet for a biobased alternative aviation fuel blend. By 2015, all new light-duty vehicles were to be alternative or flex-fuel vehicles, where commercially available and economically feasible. Also, between 2008 and 2015 there was to be an increased use of alternative fuel in ground vehicles of 10%, compounded annually.

Starting in 2008, petroleum consumption by all Air Force ground vehicles was to be reduced by 2% annually through 2020. Aviation energy efficiency is to improve 10% by 2020. Total facility energy consumption is to decrease by 15% by 2020. By 2015, the energy intensity was to have been reduced by 30%, using 2003 as the "baseline", and by 1.5% annually through 2020 using 2015 as the baseline (ACORE 2015).

4.4 Army R-E Commitment

Before detailing specific Army commitments to R-E investment, 2 relatively recent Army policies toward energy are worthy of note. In the document *Strategy 2025*, the Assistant Secretary of the Army for Installations, Energy and Environment presented 3 "Key Business Drivers": installations, energy, and environment. The outcome for Key Business Driver “energy” is to “provide a ready and resilient Army, strengthened by secured access to *energy* [emphasis added], water. …” (Office of the Assistant Secretary of the Army for Installations, Energy and Environment 2015).

The Army Operational Energy (OE) policy includes the requirement to “…use energy to our greatest benefit through resilient capabilities and energy-informed operations”. An Office of Energy Initiative (OEI) was established to leverage multiple acquisition approaches and partners to execute R-E projects. Six major objectives with respect to energy are to 1) make energy-informed decisions—use energy resources wisely; 2) optimize energy use—improve energy efficiency; 3) assure energy access; 4) build resilience; 5) drive innovation by encouraging new concepts, institutionalizing continuous process improvements, and communicating best practices to maximize resource effectiveness; and 6) advance the Army ability to provide scalable capabilities (Office of the Assistant Secretary of the Army for Installations, Energy and Environment 2015).

With this pro-active policy position, the Army R-E commitment details include deriving 25% of the total energy consumed from R-E sources, and deploying 1 GW of R-E on Army installations by FY 2025. Using alternative fuel is included in the 25% goal. (In 2013, the Army intended to launch a “Green Warrior Convoy” of vehicles. This event had to be canceled due to a congressionally ordered sequestration of the government, which removed the funding for the event.) The Army is committed to a 30% reduction of fossil-fuel usage by FY 2015 (FY 2003 baseline). And, finally, the Army intends to reach net-zero energy consumption by 2030 (ACORE 2015).

4.5 Army R-E Investment

The diversity of Army R-E technology investments can be organized into 3 general categories. These categories are defined by the author, as a function of the range of power generated and their general function:

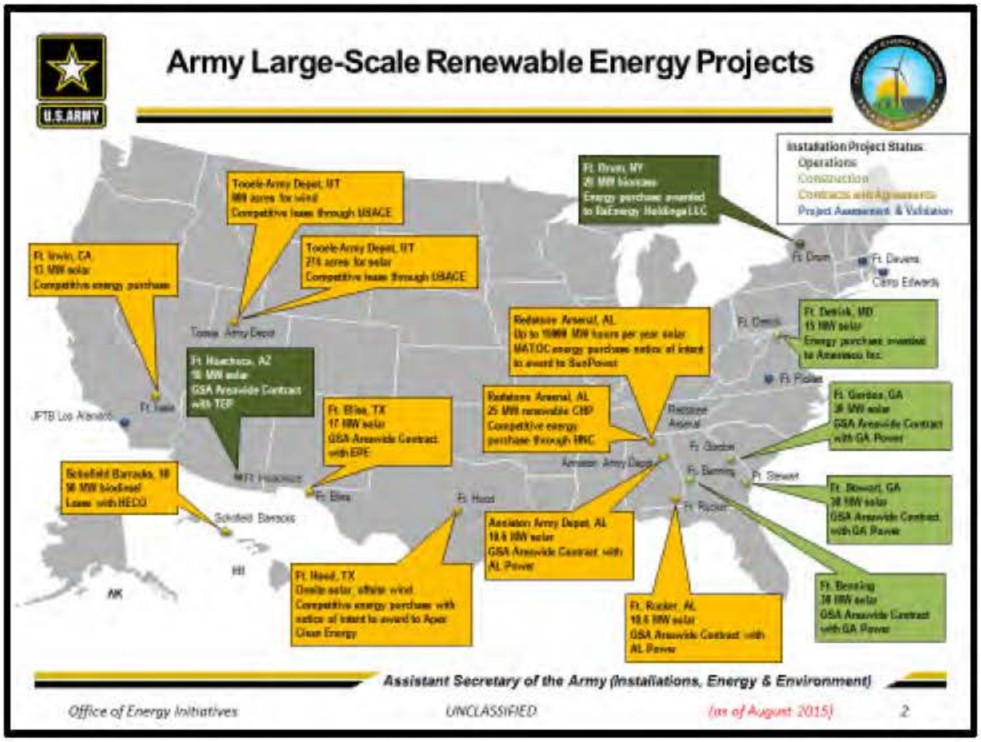
1) R-E resources that generate power greater than or equal to 10 MW are labelled the “Utility/Installation” category. This “high power” group is characterized as being in a fixed location, servicing a fixed environment.

2) The lowest-powered group includes power production of less than 1.5 MW. This category has been called the “Tactical scale” since most of the technologies serviced are mobile (mainly hand-held devices), dynamic, of a plug-and-play character, and used for short-duration applications. These power resources tend to service direct current (DC) supported devices

(Berman 2015). After discussing these categories with active Army personnel, it was suggested that the power range of the Tactical Scale be considered as less than 0.5 MW.

3) The middle category overlaps both extremes, with a range of 1–40 MW. This group has been called the "Microgrid scale". While the overlapping power may pose some confusion, the function is what clarifies the grouping. Microgrid scale is characterized as semi-fixed, transportable, and—most importantly—is able to connect to a larger power grid, yet also able to function independently (Berman 2015).

The magnitude of Army investment in the Utility/Installation scale has been so significant that an Army OEI office was initiated on 1 Sep 2014. The function of this office is for the development, implementation, and oversight of all third-party financed, large-scale (≥10 MW) renewable and alternative energy projects. Note that there are some significant third-party investments, such as the White Sands Missile Range (WSMR) 4.1-MW tracking Solar Power Farm, which functions much like a Utility asset. However, by the power-scaling numbers, these sites do not fall within the OEI mission. Examples of facilities that are within OEI purview are mapped in the following figure.



Army Large-Scale Renewable Energy Projects

Assistant Secretary of the Army (Installations, Energy & Environment)

Office of Energy Initiatives UNCLASSIFIED (as of August 2015) 2

Fig. Army Large-Scale R-E Projects falling within the OEI mission[1]

At the time of this publication, the OEI was showing rapid progress in their move forward with large-scale R-E projects. Consequently, to read of their latest achievements in energy security, financial predictability, and their R-E goals set by Congress, the Secretary and the President, the author recommends consulting the following website:

http://www.asaie.army.mil/Public/ES/oei/index.html

The Army Microgrid and Tactical categories are both evolving and showing technical advances. (Due to the potentially sensitive nature of these areas, elaboration on their progress will be reserved for other publications.)

5. R-E Areas that Involve Atmospheric Science

The 3 R-E areas that are most directly impacted by the atmosphere include water, wind, and solar-power generation. How each R-E area links to the atmosphere is described next. (Geothermal energy is associated with atmospheric thermodynamic concepts, but is not directly dependent on atmospheric contributions.)

1) Water power relies on moving ground water. While the atmosphere does not directly impact the process, bringing water to a ground-based moving medium (such as a river or stream) does. Thus, long-term (climatological) and regional-rain forecasting becomes important to this R-E resource. Ocean tides and currents, hurricanes, severe storms, and general air–sea interactions impact these power-generating sources.

2) Wind is indirectly associated with solar input through the heat-driven temperature gradients prompting a quest for atmospheric equilibrium. The meteorological variables that have the most direct impact on wind energy include wind speed, wind direction, and turbulence. Other atmospheric qualities affect the wind energy production, but the 3 variables mentioned have a significantly strong impact.

3) For solar power, the atmospheric influence cannot be avoided. The diversity of atmospheric variables causing a deviation of clear sky irradiance has prompted multiple approaches to forecasting the solar power production. Clouds and aerosols are just 2 major factors. The solar energy variability over space and time that cascades from dynamic cloud evolution alone is significant.

In the next Section, a sample of the research and operational forecasting work being done will be highlighted.

6. R-E Atmospheric Research

In 1974, the *Solar Energy Research Development and Demonstration Act* established the “Solar Energy Research Institute”. In 1991, the name was changed to the “National Renewable Energy Laboratory” or NREL. The NREL mission is to develop 1) renewable energy and energy efficiency technologies and practices, 2) advances related to science and engineering, and 3) to transfer knowledge and innovations that address the nation’s energy and environmental goals. While atmospheric research is a part of the NREL mission, a more noted strength of this DOE-funded resource is in the testing of R-E technologies and its ability to answer specific customer-funded R-E questions (US NREL 2015).

For atmospheric-specific research, the DOE created separately funded areas that addressed wind and solar power forecasting. The DOE wind and water program sponsored a project called the “Wind Forecast Improvement Project” (WFIP), which ran from 2011 to 2013. (A follow-on WFIP2 was being negotiated at the time of this publication.)

The DOE solar power forecasting effort began in 2011, with the creation of the SunShot Initiative: a national collaborative effort to make solar energy more cost-competitive with other electrical energy forms by the end of the decade. The $29-million investment was divided into 4 projects aimed at improving grid connections and reducing installation costs through “plug and play” technologies ($21 million) and reliable solar power forecasts ($8 million). The latter investment was subdivided into 2 state-of-the-art projects intended to advance solar power forecasting at sub-hourly, hourly, and day-ahead timeframes. One program was led by the International Business Machines (IBM) Thomas J. Watson Research Center; the second was led by the University Corporation for Atmospheric Research (UCAR). Both teams were a public–private partnership that included industry, national laboratories, and universities. At the time of this publication, both projects were ongoing[2] (Energy.gov 2011, 2012; Martin 2015).

A description of the 3 state-of-the-art, atmospheric forecasting projects follows.

6.1 WFIP

From February 2011 to October 2013, DOE funded WFIP, a multi-million dollar, public–private partnership for improving short-term, wind energy forecasts and quantifying the benefits of utility operations (Office of Energy Efficiency and Renewable Energy [OEERE] 2011; Wilczak 2014). The National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) led the consortium, as they worked to better inform utility-grid operators of the anticipated electrical output of a wind plant. (Utility operators are responsible for integrating wind power into the main grid.) When the project began, the industrial power forecasts contained large uncertainties. These uncertainties required operators to keep in reserve more energy than needed, due to the risk of falling short of the energy demand. Unfortunately, the operators also ran a risk of not getting paid for any surplus of power stored. Consequently, the WFIP project was established (OEERE 2011).

The following information is extracted from the very detailed 2013 *WFIP Final Report* (Wilczak 2014):

Two approaches were used by WFIP: First, they assimilated additional meteorological observations into existing Numerical Weather Prediction (NWP) forecast models. These new measurements facilitated a more precise depiction of the model's initial atmospheric state, and were installed in 2 general US locations: the Great Plains and Western Texas. The locations coincided with the 2 primary utility companies associated with WFIP. The measurements also characterized a deep atmospheric layer over a sufficiently broad area, in support of NWP forecasts predicting up to 6 hours of lead time. The observing systems included 12 wind profiling radars, 12 sodars, and several lidars. Atmospheric observations from proprietary tall towers in 184 locations, and 411 wind turbine nacelle anemometers from the wind energy industry were acquired and assimilated, after being quality controlled (Wilczak 2014).

The second method for improving wind energy forecasts was to advance the NWP models themselves. These advancements included updating the model physics, improving numerical calculations, and adding new data-type assimilation, as well as improving the operational hourly update model version from the Rapid Updated Cycle (RUC) NWP model to the Rapid Refresh (RAP) model. Infrastructural improvements, to accommodate the large data amounts required to support the models, were also developed.

The evaluation of pseudo-power forecasts was done by converting the 60–80-m tall tower and model wind speeds into equivalent power, using a standard International Electro-technical Commission Class 2 (IEC2) power curve. WFIP forecast skill analysis compared model forecast at tower locations for an individual wind plant, within a single model grid cell. Spatially averaged forecast outputs were also investigated. A ramp metric tool was developed that identified wind ramp events, matched forecast and observed ramps, and calculated a forecast skill score. Ramping events are fundamentally periods when the power generated quickly increases or decreases. To better understand the physical processes, the relationship of hub-height winds on surface heat and momentum fluxes, and the applicability of flux-dependent wind profiles laws at replicating the wind profiler through wind turbine rotor layer, were also investigated.

A summary of 7 specific, scientific WFIP results included the following:

1) RUC to RAP NWP Model: “Percent (Mean Absolute Error) MAE improvements between the National Weather Service (NWS) RUC operational hourly-updated forecast model and the real-time NOAA/ESRL RAP hourly-updated forecast model, calculated over the first 6 months of the WFIP field campaign, were significant. In the Northern Study Area (NSA) a 13% power improvement at forecast hour 01 was found, decreasing to a minimum improvement of 6-7% for forecast hours 7-15. In the Southern Study Area (SSA) a 15% power improvement at forecast hour 01 was observed, decreasing to a minimum improvement of 5% at forecast hour 15. This improvement reflects the combined effects of the better RAP model versus the RUC model, as well as the contribution from assimilation of the WFIP observations into the research RAP model” (Wilczak 2014).

2) Using Additional Observations: To quantify the assimilation of additional WFIP observations only, data denial (DD) experiments were run with the RAP and North American Model (NAM) models. In these experiments, the RAP model control simulations were run that did not assimilate any of the special WFIP observations. These results were then compared to an experimental simulation that assimilated the WFIP observations. “Six DD episodes were run, each from 7-12 days long, spanning all four seasons of the year. Using conventional statistical analysis with the tall tower data sets for verification, the experimental simulations were found to improve the average MAE power forecast skill at the 95% confidence level for the first seven forecast hours in the NSA, and through forecast hour 03 in the SSA. This improvement ranged from 8% at forecast hour 1 to 3% at forecast hour 6 in the NSA, and from 6% at forecast hour 1 to 1% at forecast hour 6 in the SSA. Positive forecast skill improvement remained until the last forecast hour 15 in both study areas, but at levels less than 2%. Although the NAM DD simulations were only run for two episodes (December and January) the results are fully consistent with the findings from the RAP model over the larger data set” (Wilczak 2014).

   “The forecast skill improvement due to assimilation of the new WFIP observations was also found to be dependent on the location of the verifying site. Verifying tower sites that were on the periphery of the NSA and SSA domains had smaller improvements than those located within the core observing network area, demonstrating the increased benefit of having more observations spread over a larger geographic area” (Wilczak 2014).

3) Forecast Skills, as a Function of Season, Time, and Observed Power: No clear seasonal trends across the NSA and SSA were found. In contrast, the forecast improvement was found to be strongly dependent on the hour of the day at which the forecast was verified. The NSA observed the largest improvements during the daytime hours, with considerably smaller improvements during the nighttime hours. The SSA improvements showed a less clear diurnal variation. Though, the results displayed 2 maxima, one in the early morning and the other at night. A strong diurnal signature was found in the power MAE. For both the NSA and SSA, the lowest MAE was associated with forecasts that were initialized and verified during the daytime hours. The MAE was significantly greater (up to a factor of 2) during the night. This result was consistent with the fact that the stable boundary layer and nocturnal low level jet are still poorly understood within the atmospheric research community. The power forecast improvement had only a small variation, with slightly larger improvement for larger observed power.

4) Forecast-Error Size Dependency: For positive forecast errors (when the model forecasts more power than actually occurs), no obvious dependence on forecast error was found. For negative forecast errors (when the model under-forecasts the power), the improvement was greatest for smaller forecast errors, decreased with increasing size of the error, and became negative for the most negative errors. Since the negative impact of the assimilated data on the largest power under-forecasts was not understood, WFIP recommended additional research in this area.

5) Impact of Spatial Averaging: The degree of precomparison between spatial averaging of the forecasts and observations was found to have a profound impact on the forecast skill. The power MAE decreased by more than a factor of 2, as the spatial averaging went to the maximum. This demonstrated the advantage of having spatially distributed generation, not only because it provides less generation variability, but also because the generation produced can be better forecast. Surprisingly, the impact of assimilating the new WFIP observations measured as a percent improvement was either constant or increased with the degree of spatial averaging, up to domains on the order of 400 km × 600 km.

6) Wind-Ramp Events: The RAP model skill at forecasting ramp events was studied with the ramp tool developed for WFIP, using data from 6 DD episodes for which 15-minute model output was available. The model had greater forecast skill for longer duration ramps, and was marginally dependent on the ramp magnitude. The poor short duration ramp forecasting skill was, in part, due to the fact that these events span a small spatial scale, making it difficult for the model data assimilation scheme to represent them in the model initialization. Additional research was recommended to improve the small scale, short duration ramp events.

   The ramp forecast skill improved when the special WFIP observations were assimilated. Averaging over the first 9 forecast hours, the NSA improved by more than 10%; the SSA improved only 3.5%. The 2 study area results were consistent with the conventional MAE statistics. The greater NSA impact from the special WFIP observations was explained by 1) the NSA had more observations (more tall tower and nacelle anemometer observations, and wind profiler observations); 2) the spatial distribution of the new observations was spread over a wider geographic area in the NSA than in the SSA—which was thought to have allowed the model's initial field improvements to be more robust, affecting a wider area, and thereby having a more lasting positive impact before atmospheric events advected out of the study area; and 3) the NSA had a larger number of synoptic scale systems, which may have contributed to the larger impact of the new observations in the NSA (versus SSA).

   The ramp forecast skill improvement varied considerably between DD episodes, especially in the SSA. Most improvements were found from correctly forecasting up-and-down ramp events, as opposed to decreasing the penalty for a forecasted ramp event of the opposite sign. The lack of improvement for these opposite sign forecasts may be due to the short duration and small spatial scale of the events, which makes them difficult to assimilate into the models. Consequently, the models have little skill in forecasting them.

7) Predicting Hub-Height Wind Speeds: WFIP efforts produced significant improvements to hub-height wind forecasts and in model assimilation of hub-height wind measurements. Foundational ground work for ingesting the 'new' observations into the operational RAP and NAM models was laid with WFIP. In stable conditions, estimating hub-height wind speeds using

stability dependent, flux-profile relationships was problematic. This challenge was, in part, due to hub-height winds decoupling from surface forcing in stable environments.

A sample of the WFIP recommendations included the following (Wilczak 2014). Additional work is needed to

1) Improve the accuracy of meteorological observations, and develop inexpensive sensors that can provide the required measurements.
2) Evaluate the impact of new observations in complex terrain or coastal areas, and compare with the Great Plains analyses.
3) Determine which instrument type has the largest impact, and what is the optimal sensor deployment density.
4) Improve the models: The stable nocturnal boundary layer is a forecast weakness. Low-level jets contribute to the high wind resource of the Great Plains. The inability to forecast these jets generates large model errors for nighttime cases. Improving the nocturnal boundary layer forecast will require new physical parameterization schemes for atmospheric processes such as turbulent mixing, and more representative model initial conditions. To advance model initial conditions requires not only better observations, but also, better methods to assimilate observations in the stable boundary layer.

6.2 Solar Power Forecasting—IBM Project

The IBM collaboration with the DOE SunShot Initiative is ongoing. The collaboration is aimed at joining powerful computers to big data processing, NWP models, and state-of-the-art machine learning technologies that determine solar and wind installation output. IBM incorporates a great number of weather and solar energy prediction models that are blended with historical data as a function of the weather situation, forecast horizon and location. The final product has been called a “supermodel”. This system is being designed to continuously monitor weather conditions (including satellite observations), analyze that data, and to forecast the availability of solar energy at different locations and times. One of the project novelties is the machine learning and advanced data analytics (“self-adjusting voting algorithms”) that give utilities, plant managers, and grid operators improved guidance on various forecasting models, and what their R-E arrays will generate in the future. The 2 main customers, as of July 2015, were utility companies and independent system operators (ISOs) (Altenergymag.com 2015).

In a 21 July 2015 publication, IBM Research Manager Hendrik Hamann stated, “Solar and wind forecasts produced by IBM’s technology are as much as 30% more accurate than conventional forecasts.” (Martin 2015). This claim is a product of combining the multiple models together into a “supermodel”, weighing the results against historical performance and tailoring the output for user needs. To achieve the day-ahead forecasting, the article explained that the computing technology corrects for systematic errors in the NWP models. These improved model outputs are then integrated with power generation resources, using cloud-based computing networks. The resulting virtual power plants are projected to automatically dispatch power in the most efficient manner. The vision consists of achievable technological advances; however, as Hamann recognized, solar forecasting is an archetypical example of the “butterfly effect”, where small changes can have large consequences over time and space. Thus, the goals are balanced with the understanding that no NWP model can be perfect, and one must be satisfied with making approximations (Martin 2015).

6.3 Solar Power Forecasting—UCAR Project

The 3-year, UCAR-led “Advance Solar Power Forecasting Project” (also known as SunCast) began in February 2013. Participants include 3 national laboratories, 6 universities, industry partners, 4 forecast providers, 6 utilities across the United States, and 4 balancing authorities (ISOs). The ongoing project is aimed at advancing methods for measuring solar radiation, observing clouds, and high resolution Nowcasts. Methods for quantifying and tracking aerosols, haze and contrails that affect cloud formation are also being investigated. The ultimate goal is to develop short-term cloud prediction techniques, based on observations. With solar forecasting, power system operators will have the tools for integrating more solar energy into the grid (Energy.gov 2012).

The Advance Solar Power Forecasting Project approach was built on the concept that predicting irradiance requires different forecast timescales. Two general forecast time scales of 0–3 hours and 3–48 hours were defined. Nowcast models support the short term forecasts, and NWP models, such as the High Resolution Rapid Refresh (HRRR), Global Forecast System (GFS) and Weather Research and Forecasting (WRF)-Solar, address the 6–48 hour predictions. Four Nowcast models are being investigated, which include StatCast, Total Sky Imager (TSI) Cast, Cooperative Institute for Research in the Atmosphere (CIRA) Cast and Multi-sensor Advection Diffusion (MAD) foreCast WRF Nowcasting. Results from the WRF-Solar model will be blended into the final results of the Nowcast effort, as well. A short description of each Nowcast approach, as described in Haupt and Drobot (2014) follows:

StatCast: An operational StatCast Model produces a clearness index persistence forecast. The method begins by analyzing observed data to identify cloud regimes via clearness index on a solar radiation data time series. Artificial Intelligence (AI) techniques train on past cloud regime data to make a prediction. Local irradiance observations assess whether each 10 minute interval is defined as "clear sky" or not. The ratio of an identified "clear sky" to the atmosphere top (extraterrestrial) irradiance is calculated, forming a clear-sky attenuation factor (Kt). The Kt is the ratio of observed Global Horizontal Irradiance (GHI), to the expected irradiance at the atmosphere's top. With an initial clear sky prediction, a cloud identification and expert system forecasts irradiance attenuation from clouds. The first step in analyzing cloud regimes is to classify days into clear, partly cloudy and cloudy, based on a clearness index. Low clearness indices indicate cloudy skies (overcast is $Kt<0.2$); high values indicate clearer skies ($Kt>0.6$); partly cloudy is anything between these values. In situ meteorological observations are used in an Artificial Neural Network (ANN) to predict the GHI at the surface due to the attenuation from clouds. Multiple ANN are used to capture nonlinear relationships among predictors for each cloud regime. Examples of GHI time series can be viewed in Haupt and Drobot (2014). The prediction scale is in the order of 15 minutes (Haupt and Drobot 2014).

Total Sky Imager (TSI) Cast: Brookhaven National Laboratory (BNL) has developed algorithms for cloud identification, taking into account TSI image distortion corrections. Stereoscopic algorithms were also developed that identify cloud location characteristics (latitude, longitude, and height). The use of multiple TSIs has contributed to the determination of cloud height. In 2014, the TSI technology was been able to perform short-term (1–5 minutes) low level cloud forecasts. Higher-level clouds yielded 30 minute forecasts. TSI has focused on 15-minute forecasts, but is pursuing a longer (30-minute) forecast capability (Haupt and Drobot 2014).

CIRACast: CiraCast is a satellite-derived insolation forecast developed by Colorado State University (CSU), CIRA. The forecast uses Geostationary Operational Environmental Satellite (GOES) observations and collocated winds from the GFS model. To identify coherent cloud groups, CIRACast uses a cloud mask and several retrieved cloud properties (cloud optical depth, cloud-top height, etc.) from the Pathfinder Atmospheres–Extended (PATMOS-x) retrieval algorithm applied to GOES-East and GOES-West. These cloud groups are then advected forward in time, using wind values derived from the GFS for that group. Note that individual cloud elements move with the local flow, according to their vertical location, as opposed to the entire cloud propagating as a single unit. Surface insolation is calculated for each time step, based on solar geometry and a simple radiative transfer model. In 2014, the forecast technique generated a 3-hour forecast at 5-minute resolutions for any site within the GOES scan areas. The processing time delay was about 15–20 minutes. This technique has shown potential for forecasting ramps within a 0–2-hour lead time (Haupt and Drobot 2014).

Multi-sensor Advection Diffusion foreCast (MADCast): The MADCast system is being developed by National Center for Atmospheric Research (NCAR). This system uses multiple satellite infrared (IR) sensors and a simplified version of WRF with data assimilation. The foundational element is a Multivariate Minimum Residual (MMR) scheme. The scheme compares satellite IR-radiance observations with a numerical model equivalent. A WRF data assimilation system computes the "departures" between observations and model equivalents for multiple channels, which are sensitive to different atmospheric altitudes. The MMR then quickly solves a variational problem for each satellite field of view and retrieves a cloud profile. At every vertical level, the control variable is reduced to the cloud fraction (Haupt and Drobot 2014).

As of 2014, the MADCast system was working on the interpolation of cloud columns from the satellite fields of view to the model grid points. The WRF dynamical core provided dynamical advections and diffusion of clouds over time. Since WRF is run without physics packages, the net result is a faster (than a full NWP model) processing system; the 3-dimensional gridded cloud fraction is treated as a dynamical tracer. The last step of the MADCast system is the implementation of a RUC. The goal is to reduce the 1-hour runs to 15-minute intervals. To ensure the most recent input data, new data are overwritten and nonobservation areas remain unchanged. Each updated state is the initial point for a new forecast, which helps reduce the model spin-down errors. This option is selected, since clouds are treated as tracers that do not interact with model physics (Haupt and Drobot 2014).

WRF-Solar Model: The DOE project core objective is to advance the science and NWP applications for solar power forecasting. The contemporary NWP forecast model during this tasking was WRF. Consequently, improving WRF physics packages for solar power forecasting was a major focus of the DOE project.

The foundational WRF version for the task was Advanced Research WRF (WRF ARW), version 3.5.1. The NCAR scientists pursued several major areas for advancement, including 1) cloud physics parameterization, 2) shallow convection parameterization, 3) radiation parameterization, and 4) satellite data assimilation. The cloud physics parameterization was advanced by improving the consistency between microphysics particles and radiation. The microphysics particles were made more dependent on ambient water and ice-nucleation aerosols (Haupt and Drobot 2014).

The shallow convection parameterization was improved by Pennsylvania State University, which integrated a shallow convection scheme with the WRF planetary boundary layer schemes, and connected sub-grid fractional clouds to the radiation scheme (Haupt and Drobot 2014).

The radiation parameterization was modified by Jimy Dudhia and Jose Rivas Arrias. Clear sky solar radiation can now interact with given aerosol optical depth and specified aerosol properties. And, high-frequency solar output of surface GHI, with direct normal and diffuse components, are now provided (Haupt and Drobot 2014).

Satellite data assimilation techniques from the MADCast capability now advances the way WRF assimilates multiple satellite images and sounders using the MMR scheme, which improves the cloud analysis (Haupt and Drobot 2014).

<u>SunCast System</u>: The architecture for integrating the above tools consists of a 2-pronged approach. The data from the Nowcast models and WRF-Solar are coupled with observations, and blended to produce a short-range, solar irradiance forecast. The longer-range forecasting system (publically available models and WRF-Solar) are blended using the Dynamic Integrator (DICast). DICast is an automated forecast system that examines NWP model data and generates forecasts based on empirical relationships developed from historical model and observational data. This tool, under development by NCAR, is a critical assessment step for reducing forecast errors. Results from the Nowcast and DICast integrators are combined to provide a seamless irradiance prediction forecasts. The irradiance, which includes GHI, Direct Normal Irradiance (DNI), and Diffuse Irradiance (DIF), is converted to power for transmittance to utility and ISO partners. (One of the early hurdles concerned varying model-generated irradiance time scales.) Consequently, NCAR developed code for each model to extract predictors of hourly average GHI. Using an empirical formula, the DNI was estimated and the DIF components were calculated. These were used to estimate the final Plane of Array irradiance (Haupt and Drobot 2014).

The prediction uncertainty is determined with an Analog Ensemble (AnEn) approach. The AnEn uses an historical set of predictions and observations, which are similar to the current deterministic forecast (Haupt and Drobot 2014).

Utility partners working with the SunCast Team have guided forecasting priorities and are active in the testing of this evolving forecasting tool. The project has been designed to have a long-term impact: WRF-Solar is being developed so that it can be implemented in the operational HRRR model; the consortium includes forecast provider partners who are able to provide persistent access in the marketplace; all newly developed software will become "open source"; and, research results are being widely published to encourage peer review and input (Haupt and Drobot 2014).

7. Atmospheric R-E Technical Gaps

The atmosphere has the greatest impact on solar and wind power generation; consequently, the "technical gap" discussion will focus on just these applications.

7.1 Civilian Atmospheric R-E Technical Gaps

After reviewing various atmospheric R-E research programs, the DOE-sponsored programs appear to be exploring the civilian utility-scale wind and solar power issues in a thorough and well-thought out manner. It is important to note that atmospheric R-E research is still in the early stages. New tools and insights are very dynamic, with "lessons learned" formulating subsequent research efforts. A significant strength to the DOE approach is their choice to make the material open source. This attribute enables the international community to integrate their longer-term experience into the evolving discipline.

7.2 Armed Forces Atmospheric R-E Technical Gaps

The atmospheric R-E research for the US armed forces is an open field of opportunity. The following subsections examine the topic via the 3 areas defined earlier: utility-scale, microgrid, and tactical R-E power resources.

7.2.1 Utility Scale

The current military, Army in particular, investment into utility-scale R-E (wind and solar power) is primarily as landlords. Therefore, the need for cost-effective, efficient R-E systems at this scale is not a direct responsibility of the armed forces. Consequently, bringing the civilian utility-scale research successes to the armed forces community has been met with an interested but, for practical reasons, neutral attitude. The utility-scale partners who have the immediate responsibility of making the investment profitable will certainly benefit from the civilian research advances, once that research matures into tested, off-the-shelf products.

7.2.2 Microgrid Scale

Military microgrids (1–40 MW) primarily service fixed sites and Forward Operating Bases (FOBs). A novel feature of the military microgrid (versus civilian microgrid) is the potential for being mobile. This attribute alone generates several technology gaps. For example:

1) Before R-E power resources are integrated into a military mission, the planners need to know if the R-E resource is advantageous for the particular military deployment.
2) If an R-E resource is deployed, planners need to know the optimum placement and orientation of the R-E technology.
3) Providing uninterrupted power to the users is a critical requirement. Thus, the military would benefit from a "smart microgrid", which can seamlessly integrate multiple R-E and fossil fuel resources into the fixed-site or FOB power grid.

To solve these technology gaps, the author suggests the following:

1) For R-E mission application: Develop an R-E Assessment Decision Aid that evaluates not only the technology availability and logistics, but the applicability. The atmospheric input on the applicability would involve using historical climatology for the military fixed site or FOB, as well as current and projected weather conditions for the area. An evaluation of the site morphology would be part of this pre-deployment decision aid, to ensure adequate room and optimal placement of the R-E technology. The decision aid would also need a function that incorporates lessons learned from previous missions. Fielding military R-E is novel, so on-the-job learning will be expected and needs to be integrated.

2) For seamless integration of multiple R-E (and non-R-E) resources: The multiple-energy-resource microgrid is vulnerable when the power resource transitions from one resource to another. The power transition can be called "power ramping". To solve the atmospheric portion of this technological gap, the author proposes the following theses: 1) atmospheric forecasting tools/techniques can be developed to anticipate microgrid ramping up and down periods, and 2) integrating atmospheric forecasting tools/techniques into a microgrid improves military power resource reliability.

   Being more specific, the author proposes the following approach to solving the latter technology gap: Define microgrid ramping events and causality; correlate microgrid power ramping events with atmospheric variables;

investigate relevant atmospheric-forecasting techniques; integrate atmospheric predictive techniques into microgrid simulations; and, assess system efficiency. Once the background research is completed, develop automated software to integrate in situ and predictive environmental assessments into the microgrid operation. The author's vision is for this "smart grid" to use "live" and predictive atmospheric information to automatically operate a power resource that is seamless to the end user. Since the microgrid involves power, a human in the loop will always be needed for safety and operational management requirements. However, for the uninterrupted power supply to the user, the informed, future "smart grid" is a proposed technology gap solution.

7.2.3 Tactical Scale

At the time of this publication, the tactical technology was still being tested for applications. Consequently, the technology gaps remain vague. It is the opinion of the author, however, that the microgrid solutions proposed above will provide a healthy foundation for addressing the future tactical scale, technology gaps.

8. Summary and Recommendations

The ARL is tasked to provide a decisive edge and overmatch that our future Soldiers will need to keep America safe. One area in which ARL can make advances for the future Soldiers is operational energy. The energy topic is supported by the 2014 DOD Directive No. 4180.01, which established a policy to enhance military capability, improve energy security, and mitigate costs in energy usage and management. DOD is one of the largest institutional energy consumers in the world. Key influences that drive DOD to clean energy solutions include economics, energy security, and the risks to American Warfighters that stem from this energy consumption.

What is R-E? R-E is energy that replenishes itself in a short period of time, such as minutes or days. In contrast, nonrenewable energy either does not replenish itself or the time needed to replenish the resource exceeds a human lifetime. Four of the widely recognized R-E resources include solar, wind, hydro (water) energy, and geothermal. (Section 2 presented a short history of each resource.)

Solar energy can be generated via passive (i.e., greenhouse) and active designs. Active solar designs generally include an absorbent medium, such as a PV device. The PV or solar cell produces electricity whenever photons of sunlight hit the surface. The photon energy separates electrons from their atoms. These electrons then flow through the only open path, an attached wire grid on the surface, attempting to return to their atom. Their movement creates electricity in the process. Unlike most electricity generators, no fuel is used, except the solar photons.

Wind energy is actually an indirect form of solar energy. When the sun heats the earth surface in the tropics, the warm air rises. Cooler, denser air from the polar regions advects toward the tropics, mixing in with the warm air, trying to establish an equilibrium. This endless cycle of heat transfer causes huge areas of air movement (wind) across the globe.

Water energy (hydropower) uses naturally falling water to generate electricity. The process exploits the kinetic energy of falling water by using it to turn a turbine, which spins a generator and produces electricity. The stability of hydropower production makes this resource competitive with fossil fuels; however, naturally running water is not universal, so the opportunity to exploit this resource has limitations.

Geothermal energy comes from heat generated and stored by the earth. This energy resource is used to generate electricity via dry steam power, flash steam power, and binary cycle power stations.

The need for R-E can be summarized in 3 reasons: to save lives, improve security, and reduce costs.

From a civilian perspective, integrating R-E power resources into the utility grid has the potential of saving lives by lowering the environmental impacts (i.e., air pollution) that would have been created with conventional energy technologies. The US security concerns are eased when diverse resources are used, due to a reduced dependency on imported oil. In terms of the economy, as the supply runs low, costs go up. With R-E the supply is continual, by definition. An added benefit is that installation of R-E systems tends to require employing a local workforce.

From a DOD perspective, the value of integrating R-E into the mission can be summarized by the same 3 reasons: 1) The mobilized armed forces are required to transport all of their power supply resources. A 1% replacement of fossil fuels with R-E resources is projected to result in 60 fewer convoys per year. With 50–100 Soldiers per convoy, this strategy would put fewer Soldiers at risk; thus, saving lives. 2) The benefits to replacing a portion of the fossil fuel requirements with R-E resources improves security, due to shorter fossil fuel convoys and a smaller fossil fuel storage footprint. Having a diversity of operational energy options also strengthens security. 3) Reduced dependency on the single-use fossil fuels automatically generates better fiscal requirements.

The US armed forces commitment to R-E was initially defined in Public Law 109–58, *Energy Policy Act of 2005* (US Congress 2005) and enhanced by the 2013

Presidential mandate, which committed 20% of the DOD energy to be converted to R-E resources by 2020. (The individual armed force commitments were summarized in Section 4.)

The Army R-E investment stems from an Army OE policy to "…use energy to our greatest benefit through resilient capabilities and energy-informed operations". The OEI was established in 2014, to leverage multiple acquisition approaches and partners to execute R-E projects. Six major Energy objectives include to 1) make energy-informed decisions; 2) optimize energy usage; 3) assure energy access; 4) build resiliency; 5) drive innovation by encouraging new concepts, institutionalizing continuous process improvements, and communicating best practices to maximize resource effectiveness; and 6) advance the Army ability to provide scalable capabilities.

With this pro-active policy position, the details of the Army R-E commitment includes deriving 25% of the total energy consumed from R-E sources and deploying 1 GW of R-E on Army installations by FY 2025. The Army was committed to a 30% reduction of fossil fuel usage by FY 2015. And, the Army intends to reach net-zero energy consumption by 2030.

The diversity of Army R-E technology investments can be organized into 3 general categories, as defined by the range of power generated and their general function:

1) R-E resources that generate power ≥10 MW, are categorized as "Utility/Installation". This "high power" group is characterized as being in a fixed location, servicing a fixed environment.

2) The lowest powered group includes power production of <1.5 MW. (Active Army suggest Tactical scale be considered less than 0.5 MW.) This category has been called the "Tactical scale", since most of the technologies serviced are mobile and dynamic, have a plug-and-play character, and are used for short-duration applications.

3) The middle category, called "Microgrid scale", overlaps both extremes with a range of 1–40 MW. Microgrid scale is characterized as semi-fixed, transportable, and—most importantly—is able to connect to a larger power grid, yet also able to function independently.

The magnitude of Army investment in the Utility/Installation scale has been so significant that an Army OEI was initiated in September 2014. The function of this office is for the development, implementation, and oversight of all third-party financed, large-scale (≥10 MW) renewable- and alternative-energy projects. At the time of publication, the rapid OEI progress in their move forward with large-scale

R-E projects prompted the author to recommend their website for current information (see Section 4).

The 3 R-E areas most directly impacted by the atmosphere include water, wind and solar power generation.

1) Water power relies on moving surface water. While the atmosphere does not directly impact the process, bringing water to a ground-based moving medium (such as a river) does. Thus, long-term (climatological) and regional rain forecasting becomes important to this R-E resource.

2) Wind is indirectly associated with solar input through the heat-driven temperature gradients prompting a quest for atmospheric equilibrium. The most significant atmospheric variables for wind energy include wind speed, wind direction, and turbulence.

3) The atmospheric influence on solar power generation includes a diversity of atmospheric variables that cause a deviation of clear sky irradiance. Multiple approaches to forecasting the solar power production are underway. Clouds and aerosols are just 2 major factors.

The DOE has funded major atmospheric-specific research for wind and solar power forecasting. The DOE-sponsored WFIP ran from 2011 to 2013. (A follow-on WFIP2 was being negotiated at the time of this publication.) Section 5 described the NOAA/ESRL-led consortium, which included 2 approaches: 1) they assimilated additional meteorological observations into existing NWP forecast models, and 2) they worked to advance the NWP models themselves. (Section 6 summarizes the WFIP, 7 specific scientific results, and 4 recommendations.)

In 2011, the DOE solar power forecasting effort began. The large investment was divided into 4 projects aimed at improving grid connections and reducing installation costs through “plug and play’ technologies ($21 million) and reliable solar power forecasts ($8 million). The latter investment was subdivided into 2 state-of-the-art, advance solar power forecasting projects. One program was led by IBM; the second was led by the UCAR. Both teams were a public–private partnership that included industry, national laboratories, and universities. At the time of this publication, both projects were ongoing.

The IBM collaboration is aimed at joining powerful computers to big data processing, NWP models, and state-of-the-art machine learning technologies that determine solar and wind installation output. In a July 2015 publication, IBM Research Manager Hendrik Hamann stated, “Solar and wind forecasts produced by IBM's technology are as much as 30% more accurate than conventional forecasts.” (Martin 2015). Hamann recognized solar forecasting is an archetypical example of the “butterfly effect”, where small changes can have large consequences over time and space. Thus, the goals are balanced with the understanding that no NWP model can be perfect, and one must be satisfied with making approximations.

In February 2013, the UCAR-led Advance Solar Power Forecasting Project (also known as SunCast) began. Participants include 3 national laboratories, 6 universities, industry partners, 4 forecast providers, 6 utilities across the USA, and 4 ISO balancing authorities. The ongoing project is aimed at advancing methods for measuring solar radiation, observing clouds, and executing high-resolution Nowcasts. Methods for quantifying and tracking aerosols, haze, and contrails that impact cloud formation, are also being pursued. The ultimate goal is to develop short-term cloud prediction techniques, based on observations. With solar forecasting, power system operators will have the tools for integrating more solar energy into the grid.

SunCast is built on the concept that predicting irradiance requires 2 general forecast time scales of 0–3 hours and 3–48 hours. Nowcast models support the short-term forecasts, and NWP models address the 6–48 predictions. Four Nowcast models are being investigated: StatCast, Total Sky Imager Forecast (TSICast), Cooperative Institute for Research in the Atmosphere (CIRACast), and MADCast. Results from the WRF-Solar are also blended into the final results of the Nowcast effort. (A short description of each Nowcast model is in Section 6.)

The SunCast architecture for the 2-pronged approach couples observation data with the Nowcast and NWP models. The 2-scale results are first independently integrated, using Nowcast and Dynamic Integrators; then the 2 are blended. A prediction uncertainty is determined with an AnEn approach, which calls on similar historical scenarios for comparison. Utility partners working with the SunCast Team have guided forecasting priorities and are active in the testing of this evolving forecasting tool. The project results will be open source to encourage peer review and input.

The atmospheric R-E research for the armed forces is an open field of opportunity. Section 7 examined the 3 military R-E areas: utility-scale, microgrid, and tactical-scale. The current military, Army in particular, investment into utility-scale R-E (wind and solar power) is primarily as landlords. Therefore, the need for cost-effective, efficient R-E systems is not a direct responsibility of the armed forces. The utility company partners who have a direct responsibility for a profitable investment, however, will benefit from the civilian research advances, once that research matures into off-the-shelf products.

The military microgrids primarily service fixed sites and FOBs. A novel feature of the military microgrid (versus civilian microgrid) is the potential for being mobile. This attribute generates several technology gaps:

1) Before R-E power resources are integrated into a military mission, the planners need to know if the R-E resource is advantageous for the particular military deployment.
2) If an R-E resource is deployed, planners need to know the optimum placement and orientation of the R-E technology.
3) Providing uninterrupted power to the users is a critical requirement. Thus, the military would benefit from a "smart microgrid" that can seamlessly integrate multiple R-E and fossil-fuel resources into the fixed or FOB power grid.

To solve these technology gaps, the author suggested the following:

1) For R-E mission application: Develop an R-E Assessment Decision Aid that evaluates not only the technology availability and logistics, but the applicability. The atmospheric input on the applicability would involve using historical climatology for the military fixed sites or FOBs, as well as current and projected weather conditions for the area. An evaluation of the site morphology would be part of this pre-deployment decision aid, to ensure adequate room and optimal placement of the R-E technology. The decision aid would also need a function that incorporates lessons learned from previous missions. Fielding military R-E is novel, so on-the-job learning will be expected and needs to be integrated.

2) For seamless integration of multiple R-E (and non-R-E) resources: The multiple energy resource microgrid is vulnerable when the power resource transitions from one resource to another. The power transition is called "power ramping". To solve the atmospheric portion of this technological gap, the author proposes the following theses: 1) atmospheric forecasting tools/techniques can be developed to anticipate microgrid ramping up and down periods and 2) integrating atmospheric forecasting tools/techniques into a microgrid improves military power resource reliability. The author also included a multistep process to prove the theses and to contribute to the development of a mobile, armed forces "smart microgrid".

At the time of publication, the tactical technology was still being tested for applications. Consequently, the author suggested that building upon the microgrid solutions proposed earlier would provide a constructive foundation for addressing future tactical-scale, technology gaps.

9. Notes

1. Personal communications (email), Amanda Simpson and Caroline Harrover to Gail Vaucher, 2015 Aug 18.
2. Personal communications (email), Dr Sue Ellen Haupt to Gail Vaucher, 2015 July 29.

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List of Symbols, Abbreviations, and Acronyms

24/7	24 hours/day–7 days/week
ACORE	American Council on Renewable Energy
AGL	above ground level
AI	Artificial Intelligence
AnEn	Analog Ensemble
ANN	Artificial Neural Network
ARL	US Army Research Laboratory
BE	Battlefield Environment
BNL	Brookhaven National Laboratory
CIRA	Cooperative Institute for Research in the Atmosphere
CSU	Colorado State University
DC	direct current
DD	data denial
DICast	Dynamic Integrator Forecast
DIF	Diffusive Irradiance
DNI	Direct Normal Irradiance
DOD	Department of Defense
DOE	Department of Energy
DON	Department of Navy
EPA	Environmental Protection Agency
ESRL	Earth System Research Laboratory
EUI	Energy Use Intensity
FOB	forward operating base
FY	fiscal year
GFS	Global Forecast System
GHI	Global Horizontal Irradiance

GOES	Geostationary Operational Environmental Satellite
GW	gigawatt
HRRR	High Resolution Rapid Refresh
IBM	International Business Machines
IEC2	International Electro-technical Commission Class 2
IR	infrared
ISO	independent system operator
Kt	clear sky attenuation factor
MADCast	Multi-sensor Advection Diffusion foreCast
MAE	mean absolute error
MMR	Multivariate Minimum Residual
MW	megawatt
NAM	North American Model
NCAR	National Center for Atmospheric Research
NEED	National Energy Education Development
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NSA	Northern Study Area
NWP	Numerical Weather Prediction
NWS	National Weather Service
OE	Operational Energy
OEERE	Office of Energy Efficiency and Renewable Energy
OEI	Office of Energy Initiative
PATMOS-x	Pathfinder Atmospheres – Extended
PPBE	planning, programming budgeting and execution
PV	photovoltaic
RAP	Rapid Refresh

R-E	renewable energy
RIMPAC	Rim of the Pacific
RUC	Rapid Update Cycle
SSA	Southern Study Area
TSI	Total Sky Imager
TSICast	Total Sky Imager Forecast
UCAR	University Corporation for Atmospheric Research
WFIP	Wind Forecast Improvement Project
WRF	Weather Research and Forecasting
WRF ARW	Advanced Research WRF
WSMR	White Sands Missile Range

1 DEFENSE TECH INFO CTR
(PDF) DTIC OCA

2 US ARMY RSRCH LAB
(PDF) IMAL HRA MAIL & RECORDS MGMT
RDRL CIO LL TECHL LIB

1 GOVT PRNTG OFC
(PDF) A MALHOTRA

1 ARMY JOINT SUPPORT TEAM
(PDF) SFAE IEW&S DCGS A
H CARTER

1 ARMY OFC OF ENERGY INITIATIVES (AOEI)
(PDF) HQDA ASA ALT
A SIMPSON

1 US ARMY INTLLGNC CTR OF EXCELLENCE
(PDF) ARMY WEATHER PROPONENT OFC INTEGRATION
1 SYNCHRONIZATION AND ANYS (CDID)
(CD) J STALEY (1 CD)

1 HQDA ASA ALT
(PDF) W05R USA ELE SPE OP A
M OWENS

2 NAVAL POSTGRADUATE SCHOOL
(PDF) A HERNANDEZ
P DURKEE

1 NAVAL RSRCH LAB
(PDF) DR J MCLAY

1 HQ AIR FORCE WEATHER AGENCY (2WG)
(PDF) AFWA/WXN R CRAIG DAF CIVILIAN

1 NATL CENTER FOR ATMOS RSRCH
(PDF) DIR WEATHER SYS & ASSSESSMENT PROG RSRCH
APPLICATIONS LAB
S E HAUPT

5 US ARMY RSRCH LAB
(PDF) RDRL CIE M J A SMITH
RDRL CIE M D KNAPP
RDRL CIE D R RANDALL
RDRL CIE D G VAUCHER
RDRL CIE D S G O'BRIEN

4 US ARMY RSRCH LAB
(PDF) RDRL CIE D C KLIPP
RDRL CIE G MCWILLIAMS
RDRL CIE P CLARK
RDRL CIO LL N FAGET