RESOURCE POTENTIAL AND REASONABLY FORESEEABLE DEVELOPMENT SCENARIO REPORT

RESTORATION DESIGN ENERGY PROJECT

United States Department of the Interior
Bureau of Land Management
Arizona State Office

July 2011

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ACRONYMS

ARRTIS	Arizona Renewable Resource and Transmission Identification Subcommittee
BLM	Bureau of Land Management
CSP	concentrating solar power
EIS	Environmental Impact Statement
GIS	geographical information systems
GW	gigawatt
GWh	gigawatt-hour
kWh	kilowatt hour
m^2	
MW	megawatt
MWh	megawatt hour
NREL	Department of Energy's National Renewable Energy Laboratory
PV	photovoltaic
RDEP	Restoration Design Energy Project
RFD	Reasonably Foreseeable Development Scenario
RPS	Renewable Portfolio Standard
US	United States

RESOURCE POTENTIAL AND REASONABLY FORESEEABLE DEVELOPMENT SCENARIO

INTRODUCTION

The following Reasonably Foreseeable Development Scenario (RFD) has been prepared in support of the United States (US) Department of the Interior, Bureau of Land Management (BLM) Restoration Design Energy Project (RDEP) Environmental Impact Statement (EIS). The BLM action associated with the RDEP is the amendment of BLM land use plans to make disturbed or previously developed sites or areas available for renewable energy projects. Arizona has ample solar and wind resources to meet and exceed its statewide target of sourcing 15 percent of electricity sales from renewable energy by 2025 (Black and Veatch 2007). Statewide electricity sales in 2025 are estimated to be 94,295 gigawatt-hours (GWh). Taking into account energy used or lost in production and transmission (12.5 percent), Arizona would meet this target by generating 15,912 GWh from renewable energy resources. The BLM manages approximately 17 percent of lands within Arizona and is expected to be involved in a significant portion of Arizona's renewable energy future. With proactive planning, renewable energy production can be developed in a manner that minimizes impacts on natural resources and the human environment.

The RFD identifies the lands in Arizona that are likely most suitable for the development of solar and wind energy resources, and estimates the electrical energy generating capacity of those lands should they be developed. This RFD is neither a planning decision nor the "No Action Alternative" in the EIS; it serves as a technical document to be used as a reference.

The RFD process was originally designed for estimating the projected levels of fluid mineral (e.g., oil, gas, and geothermal) activity within a given area over a given timeframe (typically 15 to 20 years) to aid in the preparation of land use plans and associated environmental reviews. This RFD provides a similar purpose by assessing the potential levels of development for renewable energy resources.

Developing an RFD requires a series of assumptions about future development; these assumptions include evolution of technologies,

energy policy, economic growth, and the cost of energy in the future, among others. Uncertainties due to assumptions are amplified when dealing with unproven and yet-to-be commercialized technologies. For the purpose of this RFD, only known, proven, and currently used commercial-scale renewable energy types were considered in the estimations provided. Those technologies meeting these criteria are direct-fired biomass, biomass co-firing, landfill gas, anaerobic digestion, solar thermal electric, hydroelectric, wind, and geothermal. Of these energy types, solar (both concentrating solar power [CSP] and photovoltaic [PV] technologies) and wind are identified as having by far the greatest potential of development through 2025 (Black and Veatch 2007), and are the only energy types carried forward in this report. Other forms of renewable energy technology, such as algae-based fuel production, are currently under research and development, and have the potential to be deployed at commercial scale in the future. However, it is difficult to forecast which of these technologies will reach commercial-scale deployment and what proportion of the future energy landscape they will represent; as such, these technologies are excluded from this document.

While Arizona has potential for rooftop solar and cogeneration of renewable energy along with conventional energy production facilities, the scope of this analysis is limited to on-the-ground commercial-scale renewable energy projects.

This document provides an overview of the purpose of the RFD, an overview of wind and solar technologies assumed to be used under this RFD, a survey of similar assessments done in Arizona, the methodology used for preparing the RFD, the results of the analysis, and conclusions. Maps and acreages are provided along with descriptions identifying patterns and trends observed in the results.

PURPOSE OF RFD

This RFD was prepared for the following purposes:

- To inform policy makers. Policy makers, including land management agencies such as the BLM, develop landscape-level approaches to determine the allowable uses of lands. The RFD informs these parties of which areas are most suitable for energy projects from both technical and environmental standpoints so they are better prepared for land use planning efforts.
- To inform decision makers. Decision makers are involved at all levels of development, from large-scale planning processes all the way through site-specific project approvals. An RFD allows a decision maker to see how an

individual proposed project might fit into the energy and environmental landscape, and allows him or her to make a decision that takes into account big-picture, planning-level considerations.

- To inform the general public. The general public is a major force in creating political pressure that can directly affect the approval or denial of a local project proposal. An RFD allows the public to understand their local resources in the context of the state as a whole. Having this context can help local residents to submit informed opinions to political representatives or decision makers during an environmental review process or other public hearing for future projects that may be proposed in their community.
- To inform developers. Energy developers are typically looking to site a project for the maximum energy production at the lowest possible cost. An RFD shows developers a range of options for siting their projects in technically suitable locations with minimal environmental constraints. While local issues are not identified in the RFD, this document is intended to provide an initial screening of major environmental constraints. Informed developers save time, money, and are able to launch smarter outreach to communities and stakeholders.

OVERVIEW OF RENEWABLE ENERGY TECHNOLOGIES

Solar

Solar radiation may be harnessed through various technologies and transformed to usable energy, such as heat and electricity. This section examines the large-scale commercial applications of solar energy capture. Two basic solar energy technologies that produce electrical power are CSP systems and PV systems.

Concentrating Solar Power Systems

CSP technologies use mirrors to concentrate sunlight onto receivers that convert it to heat. The thermal energy is then used to drive a generator via steam turbine or heat engine to produce electricity. CSP technologies are the most suitable solar technologies for large utility-scale applications. The three main types of CSP technologies are linear concentrator, dish/engine, and power tower systems. CSP technologies require cooling of the exhaust steam so that it condenses back into water before being heated again into steam. Wet cooling is many times more efficient than dry cooling and uses 500 to 800 gallons of water per megawatt hour (MWh) (Solar Energy Industries Association 2010).

Linear Concentrator Systems

Linear CSP systems use a large field of long, rectangular, U-shaped mirrors tilted toward the sun that capture and focus solar energy onto linear receiver tubes that run along the length of the mirrors. The receiver contains a fluid (oil or water) that is heated by the sunlight and used to boil water in a steam-turbine generator to produce electricity.

The two major types of linear CSP systems are parabolic trough systems and linear Fresnel reflector systems. Parabolic trough systems are the predominant CSP systems currently operating in the US. They use collectors in which the receiver tube is positioned along the focal line of each parabolic mirror. Currently the largest individual trough systems generate 80 megawatt (MW) of electricity.

In linear Fresnel reflector systems, the receiver tube is positioned above several flat or slightly curved mirrors that are mounted on tracking structures. In some systems, a small parabolic mirror may be added atop the receiver to further focus the sun's rays.

Dish/Engine Systems

The dish/engine system produces relatively small amounts of electricity (3 to 25 kilowatts) compared to other types of CSP technologies. It uses a parabolic mirrored dish similar to a large satellite to concentrate sunlight onto a thermal receiver. The thermal receiver, mounted at the focal point of the dish, absorbs and transfers the heat to an engine or generator. The most common type of heat engine used today in dish/engine systems is the Stirling engine. A Stirling engine uses the fluid heated by the receiver to move pistons and create mechanical power. Mechanical work turns a crankshaft that drives a generator to produce electricity. To maximize the amount of solar energy captured by the dish/engine collectors, the dish assembly is mounted on a tracking structure that follows the sun across the sky.

Power Tower Systems

Power tower systems use a large field of flat, sun-tracking mirrors, known as heliostats, to focus sunlight onto a receiver, which is located atop a tower. A fluid in the receiver, either water or molten nitrate salt, is heated and used to generate steam, which, in turn, is used in a conventional turbine generator to produce electricity. The molten nitrate salt has heat-transfer and energy-storage capabilities, which allows for continued production of electricity during cloudy weather and at night.

Photovoltaic Systems

PV systems use solar cells consisting of semiconductor materials similar to those used in computer chips to capture the energy in sunlight and convert it directly into electricity. PV systems must be scaled over a

very large area in order to be effective for utility-scale applications. Due to the high cost of PV cell production, large PV electrical generating systems are less likely to be used in commercial utility application. PV systems are generally used to provide power to individual homes and small buildings. They are also found in rural areas on communication towers, water pumps, and road and traffic signs.

The process by which a PV cell converts sunlight into electricity is called the photoelectric effect. Through this process, the sunlight absorbed by the semiconductor material knocks electrons loose from their atoms, allowing them to flow through the material and generate electric current.

There are three main types of materials used for solar cells. Traditional solar cells are made from silicon. These cells are usually flat-plate and are the most efficient. The second type is the thin-film solar cell made from amorphous silicon or non-silicon materials, such as cadmium telluride. The third and newest type of solar cell is made from a variety of new materials besides silicon, including solar inks, solar dyes, and conductive plastics. Some new solar cells use plastic lenses or mirrors to concentrate sunlight onto high-efficiency PV materials. These systems are cost effective for use in utility-scale applications because they produce a significant amount of energy using smaller quantities of more efficient, albeit more expensive, materials (NREL 2010a).

PV cells are connected into units to form PV modules, which in turn are combined to make PV arrays. The size of an array depends on the amount of sunlight and the needs of the customer. For utility-scale electricity generation, hundreds of arrays are interconnected to form a single large system. Modules and arrays are often combined with other components, such as those that convert the current within the cell material to usable electricity, batteries to store some of the electricity, and mounting structures that point them toward the sun. These components, referred to as the balance-of-system components, combined with modules and arrays create a complete PV system. There are two types of PV systems in use today: flat-plate systems and concentrated PV systems.

Water requirements for PV systems are approximately 20 gallons per MWh for the purpose of cleaning solar panels (Solar Energy Industries Association 2010). In some operations where water availability is especially limited, a PV operator may choose not to wash the panels at all, eliminating water consumption altogether.

Flat-plate Photovoltaic Systems

The most common array designs use flat-plate PV panels, which can either be fixed in place or allowed to track the sun. These panels

respond to both diffuse and direct solar radiation, making them useful even on cloudy days when the diffuse radiation accounts for nearly 100 percent of the total radiation. On a sunny day, an estimated 10 to 20 percent of the total solar radiation comes from the diffuse component of sunlight.

Generally, flat-plate PV panels are mounted on stationary structures with a tilt at a fixed angle determined by the latitude of the site, the requirement of the load, and the availability of sunlight. The fixed arrays are advantageous in that they are simple, inexpensive, and lightweight. However, because their orientation to the sun is fixed, often at a less than optimal angle, they receive less energy per unit area compared with a tracking array. The flat-plate tracking arrays are primarily mounted on one-axis tracking structures, which are designed to track the sun from east to west.

Concentrated Photovoltaic Systems

Concentrated PV systems use lenses or mirrors to concentrate sunlight on solar cells. The concentration of sunlight allows for greater efficiency and reduction in size and number of cells. These systems must track the sun to keep light focused on the PV cells. They are primarily mounted on two-axis tracking structures, which are designed to track the sun's daily and seasonal course. One-axis tracking systems are also sometimes used.

Both reflectors and lenses have been used to concentrate light for PV systems. The most promising lens for concentrated PV application is the Fresnel lens, which uses a miniature saw tooth design to focus incoming light. The best lenses, however, can transmit only 90 to 95 percent, and in practice even less, of incident light. In addition, lenses cannot focus diffuse sunlight, which makes up nearly 10 to 20 percent of the radiation on a clear day.

While concentrated PV systems lower costs by reducing PV material needs, they require sophisticated tracking devices and expensive concentrating optics. High concentration ratios also introduce an excessive heat, which can decrease cell efficiencies and damage solar cells.

Wind

A wind turbine is a mechanical assembly that converts the energy of wind into electricity. A wind turbine consists of a blade or rotor, a drive train (usually including a gearbox and a generator), a tower, and other equipment, including controls, electrical cables, ground support equipment, and interconnection equipment. The blades turn in the moving air and power an electric generator that supplies an electric current. The blades act much like an airplane wing. Blowing wind causes

a pocket of low-pressure air to form on the downwind side of the blade, which in turn causes the blade to be pulled toward that pocket. This force causes the rotor to spin like a propeller and turn a shaft. The rotational energy of the shaft turns the generator to produce electricity. Wind turbines are mounted on a tower to enable them to capture the most energy. Tower height affects the amount of power that can be extracted by a given wind turbine. At 98 feet or more above ground, wind turbines can take advantage of faster and less-turbulent wind.

Wind turbines fall into two basic groups, which include the horizontal-axis propeller-style variety, like traditional farm windmills, and the vertical-axis design, like the eggbeater-style Darrieus model. The horizontal-axis turbines are the most common, constituting nearly all the utility-scale turbines. These typically have either two or three blades. The three-blade turbines are operated upwind with their blades facing into the wind.

Wind turbines are available in a variety of sizes, and, subsequently, a variety of power ratings. Utility-scale wind turbines for land-based wind farms have rotor diameters ranging from 130 to about 395 feet, and towers that reach 130 to 425 feet high.

Utility-scale turbines range in power rating from 100 kilowatts to as large as several megawatts. Larger turbines are grouped together into wind farms, which provide bulk power to a utility power grid. Wind power plants are modular, which means they consist of small individual modules (turbines), and, depending on electricity demand, can easily modify production capacity.

BACKGROUND

While no previous known study exists that estimates the electrical generating capacity of the State of Arizona, studies do exist that estimate the lands appropriate for wind and solar development. The most recent and Arizona-specific reports are summarized below. Methodologies of other reports were reviewed and considered in the preparation of this RFD, including the BLM's 2005 Wind Energy EIS, the BLM and Department of Energy 2003 Assessment of Renewable Energy Potential on Public Lands, and the 2009 National Renewable Energy Laboratory Western Renewable Energy Zones study.

2009 Arizona Renewable Resource and Transmission Identification Subcommittee Final Report

The Southwest Area Transmission Planning Group developed the Arizona Renewable Resource and Transmission Identification Subcommittee (ARRTIS), which produced a final report in 2009. The 2009 ARRTIS Final Report identified potential constraint areas for Arizona renewable resource development. A collaborative process was

undertaken involving representatives from state and federal government, utilities, Native American tribes, environmental organizations, and development and technology companies. The report used geographical information systems (GIS) data, which involves layering maps of different data sets to provide visuals of resource distribution and potential overlaps, from state and federal government sources and from the Western Governors' Association's Western Renewable Energy Zone Initiative (Southwest Area Transmission Planning Group 2009).

The ARRTIS analysis looked at all lands with either solar or wind resource potential within Arizona and then excluded areas using various GIS data layers that would preclude the development of solar or wind projects due to either technical or environmental factors on those lands such as low wind speeds, steep slopes, wetlands, conflicting uses, or environmental protection areas. Remaining lands were further classified into "High", "Moderate", or "Low" sensitivity through the application of other GIS data layers. The final report included separate maps for wind and solar resource potential, and separate maps for wind and solar that show exclusion areas and resource sensitivity areas.

The ARRTIS report considered lands with slopes greater than five percent to be too steep to be developable with existing solar technologies and lands with slopes greater than 15 percent to be too steep to be developable with existing wind technologies.

2007 Arizona Renewable Energy Assessment

Black and Veatch Corporation completed this in-depth assessment of renewable energy generation potential for three Arizona utilities (Arizona Public Service, the Salt River Project, and Tucson Electric Power) that must comply with Arizona's Renewable Energy Standard. The purpose of the report was to assess the prospects for significant renewable energy development in Arizona. The study includes a review of the current status of renewable energy in Arizona, characterization of renewable power generation technologies, and an assessment of Arizona's renewable resources.

2007 Arizona Wind Energy Assessment

In 2007, the Arizona Wind Working Group produced Arizona Wind Energy Assessments for eight Arizona counties. Each report determined the amount of "developable windy land." The analysis used the TrueWind map acquired by Northern Arizona University in 2003. Similar to the ARRTIS report, the working group undertook a process of excluding lands via the application of GIS data layers. The exclusions were both technical and environmental in nature, and once applied, resulted in a remaining set of lands categorized as "developable windy

land." The report examined longer-term potential, taking into consideration advances in wind technology that would enable production on steeper slopes. Lands with slopes of 20 percent or less were considered developable over the long term (Arizona Wind Working Group 2007), in comparison to the slope of 15 percent, which was used as the maximum slope in the ARRTIS analysis.

2010 Solar Energy Development Programmatic Environmental Impact Statement

At the time of this writing, the BLM is preparing a Programmatic EIS to "evaluate utility-scale solar energy development, to develop and implement Agency-specific programs that would establish environmental policies and mitigation strategies for solar energy projects, and to amend relevant BLM land use plans with the consideration of establishing a new BLM solar energy development program."

The Programmatic EIS covers six states and includes a two-tiered RFD approach for Arizona. The first RFD approach employed the solar component of Department of Energy's National Renewable Energy Laboratory's (NREL) Regional Energy Deployment System model, which estimated the role of all energy types in the US through 2050. The second RFD approach used the Arizona Renewable Portfolio Standard (RPS). The Arizona RPS requires that 15 percent of energy produced in the state be from renewable sources by 2025. This RPS-based approach uses this 15 percent renewable energy generation as a starting point and calculated how many acres of land would be required for solar projects to satisfy this mandate.

Throughout the development of the RDEP RFD and EIS, the project team has stayed in close communication with the Solar PEIS project management team, sharing methodologies, resources, and lessons learned, and ensuring that the solar energy zones being identified in the Solar PEIS are included within the RDEP RFD area.

METHODOLOGY

This report provides resource potential summaries and RFDs for solar and wind energy on lands within the State of Arizona. Resource potential and RFDs are provided both for the State as a whole, regardless of land ownership, and for BLM-managed lands only. This report serves as both a guide for solar and wind energy development in Arizona and as a basis for the environmental analysis in the RDEP EIS.

Resource Potential Summaries

Resource potential maps for solar and wind were developed for both the State of Arizona and for BLM-administered lands within the State.

Given the broad presence of solar energy resources across the State of Arizona, this analysis assumes production can occur anywhere and therefore focuses upon identifying lands with the greatest suitability for development. Wind resources are much more limited than solar within Arizona, so the traditional approach of pinpointing these known resource areas is employed with the same focus on identifying which lands in those areas are most suitable for development.

Solar

For solar energy, existing solar intensity data maps produced by NREL were examined for Arizona. It was determined that the entire state receives enough solar radiation for development, with annualized Direct Normal Irradiance levels of six or higher. Using GIS data layers, areas with slopes of five percent or greater were eliminated from the project map as these areas are generally considered to be undevelopable for solar energy projects using existing technologies. The remaining lands are considered to be the solar potential area of Arizona and were recorded on the Statewide Solar Potential map (**Figure 1**). The remaining lands were then narrowed down to BLM-administered lands only, resulting in the BLM Solar Potential map (**Figure 2**).

Each of the remaining acreages was then divided by an industry-standard factor of generation capacity per acre, resulting in an estimate of solar electricity generation capacity for both the entire State and BLM-administered lands within the State. These numbers are presented in the Results section, below.

Wind

For wind energy, existing wind resource class GIS data produced by NREL were used as a starting point. Areas with Wind Resource Class 3 ("Fair") or greater were retained as being considered developable. Using GIS data layers, areas with slopes of 15 percent or greater were then eliminated from the project map as these areas are generally considered to be economically unfeasible for wind energy projects using existing technologies. The remaining lands are considered to be the wind potential areas of Arizona and were recorded on the Statewide Wind Potential map (**Figure 3**). The remaining lands were then narrowed down to BLM-administered lands only, resulting in the BLM Wind Potential map **(Figure 4**).

Each of the remaining acreages was then divided by an industry-standard factor of generation capacity per acre, resulting in an estimate of wind electricity generation capacity for both the state as a whole, and for BLM-administered lands within the state. These numbers are presented in the Results section, below.

POTENTIALLY DEVELOPABLE LANDS

Potentially developable lands are those lands that have no known regulatory or technical restrictions on which energy projects could potentially be sited. These lands were identified to give an idea of the maximum electrical generation capacity of lands in Arizona that are free from such known restrictions. Methodologies to identify such lands were reviewed from the following sources:

- 2009 ARRTIS (Southwest Area Transmission Planning Group 2009);
- 2007 Arizona Wind Energy Assessment (Arizona Wind Working Group 2007); and
- Solar Energy Development Programmatic EIS (BLM 2010).

Four separate pairs of maps and acreages were developed, including two for solar (one for all lands in Arizona and one for BLM-managed lands) and two for wind (one for all lands in Arizona and one for BLM-managed lands).

Potentially Developable Lands with Solar Potential

Potentially developable lands were identified as a subset of lands with solar potential. Lands were then excluded if they were considered to be undevelopable due to technical or regulatory restrictions. The screens applied to these lands include:

- Areas greater than 50 miles[1] from existing transmission lines of 230 kilovolts or greater;
- Airports;
- Designated Wilderness Areas;
- Wilderness Study Areas;
- Established Research Natural Areas;
- Inventoried Roadless Areas;
- Military Range/Installation;

[1] The 2009 ARRTIS report considered areas within 30 miles from transmission to be "technically ideal for utility-scale generation development." This RFD has a wider scope than the ARRTIS report and assumes a wider inclusion corridor of 50 miles, which is consistent with previous BLM and Department of Energy evaluations of renewable energy potential areas.

- National Conservation Areas;
- National Historic Trails;
- National Monuments;
- National Park System units;
- Wild and Scenic Rivers;
- State Designated Habitat Conservation Areas;
- State Designated Natural Community Conservation Areas;
- Wetlands;
- Fish and Wildlife Service lands;
- Urban/Developed Areas; and
- Water bodies (including seasonal and dry lakes).

The remaining lands, recorded on **Figure 5**, are considered to be potentially developable, as they have no known technical or regulatory restrictions. The remaining lands were then narrowed down to BLM-administered lands only, resulting in Potentially Developable BLM Lands with Solar Potential (**Figure 6**).

Potentially Developable Lands with Wind Potential

Potentially developable lands were identified as a subset of lands with wind potential. Lands identified in the Statewide Wind Potential Map were screened out using GIS. Lands were excluded if they were considered to be undevelopable due to technical or regulatory restrictions.

The remaining lands are considered to be developable, as they have no known technical or regulatory restrictions. Potentially Developable Lands with Wind Potential are recorded on **Figure 7**. The remaining lands from the previous step were then narrowed down to BLM-administered lands only, resulting in Potentially Developable BLM Lands with Wind Potential (**Figure 8**).

RFDs Based on State Renewable Portfolio Standard

To complete the estimate of the level of development that is reasonably expected to occur on BLM lands, the State of Arizona RPS of 15 percent renewable electrical generation by 2025 was used as a starting point. Total electricity sales in Arizona in 2025 are estimated to be 94,295 GWh. Fifteen percent of that represents 14,144 GWh of renewable energy sales. The amount of generation required to satisfy this level of sales requires an additional 12.5 percent to account for internal use and line losses (US Energy Information Administration

2008). This brings the estimated renewable generation capacity for in-state consumption in 2025 to 15,912 GWh to meet the 15 percent RPS. Arizona, given its abundance of solar energy resources, is expected to be a net exporter of renewable energy, and so, for the purposes of this RFD, it is assumed that by 2025 Arizona will generate 15,912 GWh for in-state consumption, and will generate a further 15,912 GWh for export to neighboring states. Thus, the estimated renewable electrical energy generation capacity for in-state consumption and out-of-state export in 2025 is 31,824 GWh.

The following individual solar and wind RFD calculations will use 31,824 GWh as the estimated overall renewable electrical energy generation in 2025. The goal of these calculations is to determine how much energy is expected to be produced by solar and wind, how much installed capacity would be required to produce these levels of output, and how much land disturbance would be associated with these levels of capacity.

Solar RFD

While solar energy is currently Arizona's greatest renewable energy source, wind and other renewable resources will contribute to meeting the estimated overall renewable electrical energy generation in 2025. For the purposes of this RFD, it is estimated that solar will comprise 90 percent of the state renewable energy portfolio. Reducing the 31,824 GWh to 90 percent of its value leaves 28,642 GWh of electricity generation to be met by solar sources.

Of the 28,642 GWh estimated to be generated by solar energy, some of this demand would be met through rooftop solar installations. The Western Governors' Association 2006 Solar Task Force Report identifies Arizona's 2005 rooftop solar capacity to be 5.7 gigawatts (GW) for residential, 3.8 GW for commercial (an average of 3.3 GW for tilted panels and 4.4 GW for flat panels), for a state total of 9.5 GW. Full development of this capacity would result in approximately 26,000 GWh per year of production[2], representing nearly 90 percent of 2025 estimated solar output; however, it is not expected that all rooftops will be covered with solar panels by 2025 and, for the purpose of this RFD, a more conservative estimate of 10 percent is used for the portion of solar energy output that will be met by rooftop solar. After the removal of this 10 percent, or 2,864 GWh, due to rooftop solar, 25,778 GWh remain to be satisfied by utility scale solar projects.

Divided by the number of hours in a year (8,766), 25,778 GWh translates into an installed capacity of 2.94 GW for a technology with a theoretical capacity factor of 100 percent. Depending on the technology

[2] GWh per year of production = 9.5 GW x 7.5 hours/day (average hours of available sunlight/day) x 365 days.

used, solar capacity factors–the amount of time in a 24 hour period that the technology produces electricity at its rated capacity–range from 23 percent for utility-scale PV applications to 38 percent for utility-scale parabolic trough applications (Frisvold et. al. 2009). For the purposes of this RFD, the mid-point of 31 percent was used. Dividing 2.94 GW by 31 percent (0.31) reveals that 9.48 GW of installed utility scale solar projects would be required to produce 25,778 GWh to help meet the 28,642 GWh of total electricity generation by solar resources in 2025.

To determine the amount of land necessary to meet this production capacity, the final figure of 9.48 GW was then multiplied by 8,000, an estimate of how many acres are required to create one GW of solar energy capacity.[3] This calculation resulted in a statewide project installation area of 75,840 acres. Of the potentially developable lands with solar capability, 15.5 percent of them are managed by the BLM. While different readers may make different assumptions regarding the proportion of projects that would occur on BLM-managed lands versus other lands, this RFD assumes that projects would be evenly distributed across available lands, with 15.5 percent of such projects (11,755 acres) occurring on BLM lands .

For the land disturbance associated with the development scenario, 100 percent of the lands associated with solar projects are assumed to be disturbed since this is often the reality of on-the-ground projects. Therefore, 75,840 acres (11,755 acres of BLM land) would be disturbed by developing solar projects to meet production capacity.

Wind RFD

The majority of the acreage identified as having wind potential occurs in the lowest commercially viable wind class, Class 3. The acreage breakdown for all of Arizona is as follows:

- Class 3 (Fair) – 885,941 acres
- Class 4 (Good) – 44,852 acres
- Class 5 (Excellent) – 10,801 acres
- Class 6 (Outstanding) – 3,591 acres
- Class 7 (Superb) – 396 acres

The acreage breakdown for BLM-managed lands by wind class is as follows:

[3] An "acres per megawatt" factor of 8 was calculated from dividing the total acres of disturbance by the sum nameplate capacity for 20 solar energy facilities across the Western US. Seventeen of the 20 projects were CSP, and the remaining three were PV.

- Class 3 (Fair) – 68,308 acres
- Class 4 (Good) – 3,746 acres
- Class 5 (Excellent) – 277 acres
- Class 6 (Outstanding) – 69 acres
- Class 7 (Superb) – 0 acres

Given the low acreage of high quality windy lands, it is estimated that wind would not contribute more than five percent to the state's renewable energy production. Reducing the anticipated statewide 2025 output of 31,824 GWh to five percent results in 1,591 GWh of electricity generation to be met by wind sources. For the purposes of this RFD, it is assumed that 10 percent of this capacity will be met through small scale wind projects, leaving 1,432 GWh to be satisfied by utility scale wind projects.

Divided by the number of hours in a year (8,766), 1,432 GWh translates into an installed nameplate capacity of 163 MW for a technology with a theoretical capacity factor of 100 percent. Wind capacity factors (i.e. the amount of time in a 24 hour period that the technology produces electricity at its rated capacity) typically range from 20 to 40 percent. For the purposes of this RFD and given the general lack of high quality wind resources, the capacity factor of 20 percent was used. Dividing 163 MW by 20 percent (0.20) reveals that 815 MW of installed, nameplate, utility scale wind projects would be required to produce 1,432 GWh to help meet the 1,591 GWh of total electricity generation by wind resources in 2025.

This final figure of 815 MW was then multiplied by 28, an estimate of how many acres are required to create one MW of wind energy capacity. The number of acres required per MW of generation capacity was determined assuming the use of 295 feet diameter, 3.0 MW capacity turbines spaced apart by 2,215 feet (7.5 times the turbine diameter[4]). A theoretical grid layout of 12 turbines with a total capacity of 36 MW would require a site that is 1,013 acres, resulting in a final factor of 28 acres per MW[5]. Therefore, projects with a total installed capacity of 815 MW are expected to occur over a project area of 22,820 acres across the state. Since BLM manages approximately 15.5 percent of the lands in Arizona, and it is assumed that projects would be similarly distributed across land ownership, it is estimated that 3,537 acres of BLM lands would be developed for wind projects.

[4] Turbine space of 7.5 times turbine diameter was the mid-point in the NREL-provided range of "5 to 10" turbine diameters that are required (NREL 2010b).

[5] A grid of twelve turbines arranged 3 by 3 with 675 meters between each turbine would have sides of 2,025 meters (i.e. 675 m multiplied by 3). The area of this grid would be 4,100,625 m^2, or 1,013 acres.

For the land disturbance associated with the development scenario, 10 percent[6] of the acres per MW of capacity are assumed to be disturbed. With wind projects, there is little ground disturbance outside of the actual turbine foundations, access roads, and ancillary facilities; lands between the turbines often remain undisturbed. This translates into an estimated area of disturbance of 2,282 acres statewide, and 354 acres across BLM lands from developing wind projects to meet production capacity.

RESULTS

Tables 1 and 2, included in the sections for solar and wind summarize key numerical results from the analyses of acreages and electrical generation capacity.

Solar

It is estimated that there are 38,315,000 acres of high potential solar lands across Arizona with slopes of less than five percent, regardless of land ownership, or technical or regulatory restrictions (refer to **Figure 1**). This estimate represents 53 percent of all lands in the State. When considering BLM-managed lands, 5,847,000 acres of high potential solar lands with slopes less than five percent were estimated; representing 48 percent of all BLM-managed lands in Arizona (refer to **Figure 2**).

Lands without known technical or regulatory restrictions comprised 30,116,000 acres for the State as a whole (refer to **Figure 5**). If fully developed, these lands could provide 3,765 GW of electrical capacity through a combination of PV and parabolic trough technologies. When considering only BLM-managed lands, 4,680,000 acres were identified as having no known technical or regulatory restrictions (refer to **Figure 6**). If fully developed, these BLM-managed lands could provide 585 GW of capacity. These numbers represent 41 percent of all state lands, and 38 percent of all BLM-managed lands in Arizona, respectively.

The RFD, as based on a doubling of the Arizona RPS (15 percent renewable energy by 2025), estimates that 76,000 acres of lands across Arizona will be developed for 9.5 GW (nameplate capacity) of utility scale solar development, and that 12,000 of those acres (and 1.5 GW of that capacity) would be on BLM-managed lands.

Disturbed lands nominated during scoping for the RDEP EIS comprise 166,000 acres, 29,000 of which are located on BLM lands. These lands could produce an estimated 20.8 GW and 3.6 GW of solar energy, respectively. These RDEP-Nominated Disturbed Lands are shown in **Figure 9**.

[6] The Office of Utility Technologies estimates that land disturbance occurs at a rate of 5 to 10 percent for 50-MW turbines (Office of Utility Technologies et. al. 1997).

Table 1
Solar Potential and RFD Results

Land Description (all lands have Direct Normal Irradiance ≥ 6.5 kWh/m²/day)	Acres	Generation Capacity[7] (MW)
Statewide, Slope ≤ 5%	38,315,000	4,789,000
Slope ≤ 5% without Known Restrictions	30,116,000	3,765,000
BLM-managed, Slope ≤ 5%	5,847,000	731,000
BLM-managed, Slope ≤ 5% without Known Restrictions	4,680,000	585,000
RDEP Nominated	166,000	20,800
BLM-managed, RDEP Nominated	29,000	3,600
RFD (9.5 GW)	76,000	9,500
BLM-managed, RFD (9.5 GW)	12,000	1,500

Wind

It is estimated that there are 1,061,000 acres of high potential windy lands of slopes less than 15 percent across Arizona, regardless of land ownership, or technical or regulatory restrictions (refer to **Figure 3**). This estimate represents 1.5 percent of all lands in the State. When considering only BLM-managed lands, 96,000 acres of high potential windy lands with slopes less than 15 percent were estimated, representing 0.8 percent of all BLM-managed lands in Arizona (refer to **Figure 4**).

Lands without known technical or regulatory restrictions comprised 946,000 acres for the State as a whole (refer to **Figure 7**). If fully developed for wind energy, these lands could provide 33.8 GW of electrical capacity.

When considering only BLM-managed lands, 72,000 acres were identified as having no known technical or regulatory restrictions (refer to **Figure 8).** If fully developed, these BLM-managed lands could provide 2.6 GW of capacity. These numbers represent 1.3 percent of all state lands, and 0.6 percent of all BLM-managed lands in Arizona, respectively.

[7] Calculated by dividing lands in RFD acreage by a factor of 8 acres per megawatt. Results have been rounded.

Table 2
Wind Potential and RFD Results

Land Description (all lands of Wind Class ≥3)	Acres	Generation Capacity[8] (MW)
Statewide, Slope ≤ 15%	1,061,000	37,900
Slope ≤ 15% without Known Restrictions	946,000	33,800
BLM-managed, Slope ≤ 15%	96,000	3,400
BLM-managed, Slope ≤ 15% without Known Restrictions	72,000	2,600
RFD (820 MW)	23,000	820
BLM-managed, RFD (820 MW)	3,600	130

The RFD, as based on the Arizona RPS of 15 percent renewable energy by 2025, estimates that 23,000 acres of lands across Arizona will be developed for utility scale wind development, resulting in 820 MW of capacity, and that 3,600 of those acres and 130 of those MW would be on BLM-managed lands. Of the 3,600 acres of wind projects on BLM lands, approximately 360 of those acres are expected to be disturbed in the development process.

None of the RDEP nominated sites occurred within areas that were of Wind Class 3 or greater, so no estimate has been provided of the wind generating capacity of those sites.

CONCLUSIONS

The majority of BLM-managed land that is developable for solar energy projects occurs in the western half of Arizona with smaller areas identified to the east around Safford and smaller scattered parcels throughout the Tucson Field Office and in the northern portion of the Safford Field Office. Large tracts of land with no known technical or regulatory conflicts are identified along Highways 8 and 10 to the west of Phoenix, and in the north, south, and west of Highway 389.

Relatively few areas of BLM-managed lands are considered developable for wind energy projects across Arizona. These areas occur in several locations within the Arizona Strip Field Office in the northwestern corner of the state, west of Kingman near the California border, an area in the northern portion of the Tucson Field Office, and a scattering of

[8] Calculated by dividing lands in RFD acreage by a factor of 28 acres per megawatt. Results have been rounded.

areas in the northern portion of the Safford Field Office, south of Highway 40. No BLM-managed lands were found to contain the highest class of wind resources (Class 7) and only 69 acres were found to contain the second highest class resources (Class 6).

Arizona has a vast potential to produce renewable energy for both in-state use and out-of-state sale. This report identifies that, if all lands without known technical or regulatory restrictions are utilized to generate renewable power, approximately 3,800 GW of electrical capacity could be brought online.

When looking at disturbed sites nominated during the scoping process for the RDEP EIS, the 166,000 acres of disturbed lands statewide could produce an estimated 21 GW if they were developed with solar energy projects. The 29,000 acres of BLM-managed nominated lands could produce an estimated 3.6 GW if they were developed with solar energy projects. Because none of the nominated sites are classified as Class 3 or greater wind potential, it is estimated that no wind-generated electrical power would be produced on any of these sites.

Assuming that Arizona will meet its RPS of 15 percent renewable energy by 2025 two times over, allowing half of the renewable energy in the state to be exported to other states, and assuming that 15.5 percent of that generation occurs on BLM public lands (in proportion to the percentage of lands without known restrictions that BLM manages), the RFD estimates that 1.5 GW of solar energy capacity would be developed on 12,000 acres of BLM-managed lands and that 130 MW of wind energy would be produced on 3,600 acres of BLM public lands.

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