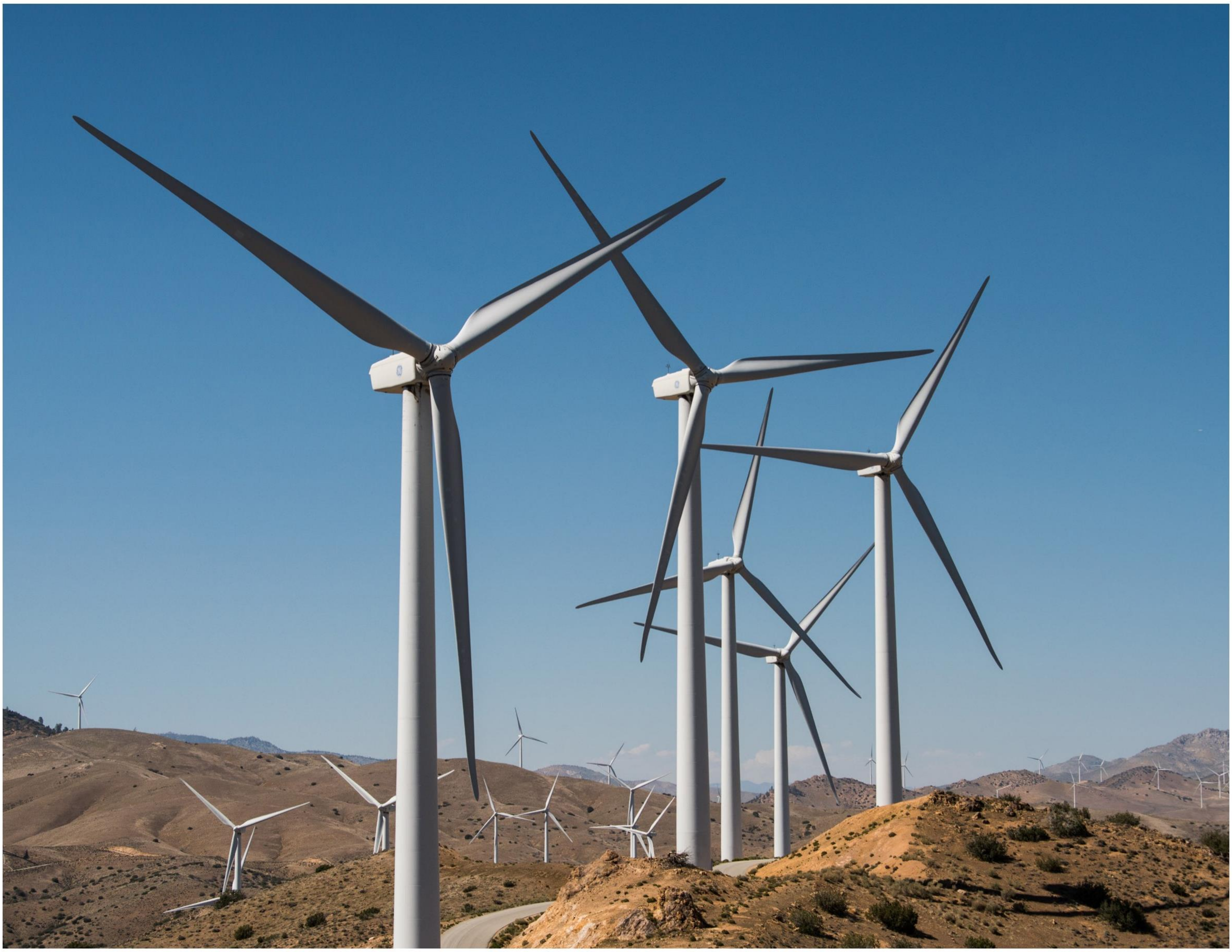

THE 8,000-ACRE LOS ANGELES DEPARTMENT OF WATER AND POWER PINE TREE WIND AND SOLAR FARM IN THE TEHACHAPI MOUNTAINS NORTH OF MOJAVE, CALIFORNIA, FEATURES 80 1.5-MEGAWATT (MW) GENERAL ELECTRIC WIND TURBINES AND IS ONE OF THE LARGEST MUNICIPALLY OWNED WIND FARMS IN THE UNITED STATES. *PHOTO BY DENNIS SCHROEDER, NATIONAL RENEWABLE ENERGY LABORATORY (NREL)*

USA

Wind power capacity in the United States grew at a record pace in 2020, adding 16.8 gigawatts (GW) [1]. Wind continues to be the top source of renewable energy production in the United States [2]. The U.S. Energy Information Administration (EIA) states that wind accounted for 9.2% of U.S. electric sales or 8.3% of U.S. generation in 2020 [3].

U.S. DEPARTMENT OF ENERGY'S WIND ENERGY TECHNOLOGIES OFFICE, NATIONAL RENEWABLE ENERGY LABORATORY

The United States had 121,985 megawatts (MW) of operating wind power capacity [1], with 67,814 wind turbines operating across 42 states and two U.S. territories at the end of 2020 [5]. Wind energy companies employed 116,817 workers in 2020 [6]. Project developers and power purchasers reported power purchase agreement activity totaling 5,444 MW in 2020 [4].

At the end of December, the Bureau of Ocean Energy Management (BOEM) had issued 15 active commercial

TABLE 1. KEY NATIONAL STATISTICS 2020: UNITED STATES

Total (net) installed wind power capacity*	121,985 GW
Total offshore capacity	0.030 GW
New wind power capacity installed	16.8 GW
Decommissioned capacity (in 2020)	0.120 GW
Total electrical energy output from wind	337.510 terawatt-hours
Wind-generated electricity as percent of national electricity demand	9.2%
Average national capacity factor**	33.8%
Target	
National wind energy R&D budget	104 million USD (85.07 EUR)

*Installed wind power capacity: Use nameplate power ratings of the installed wind turbines.

Average national capacity calculation. Only include turbines in operation the whole year: **(MWh production/8,760 hrs) / MW installed capacity. MWh total electrical production from wind turbines operating 1 January through 31 December divided by 8,760 hrs divided by the total installed wind capacity (in MW) at the beginning of the year. [You can also use an estimate based on the average installed capacity during the year: (installed 1 Jan + installed 31 Dec)/2. But in that case, state that it is how the estimate is calculated.]

leases [7] for the development of offshore wind energy projects, and there were 25.5 GW of offshore wind projects in various stages of development off the East Coast and in the Great Lakes regions [8].

Market development

Targets and policy

The U.S. Department of Energy's (DOE's) Wind Energy Technologies Office has established research goals to reduce the levelized cost of energy (LCOE) by 2030, as follows:

1. Fixed-bottom offshore wind: 40% to 50% LCOE reduction—from 0.086 USD (0.07 EUR) per kilowatt-hour (kWh) in 2020 to 0.07 USD (0.057 EUR) per kWh in 2025 and 0.05 USD (0.04 EUR) per kWh in 2030.

2. Floating offshore wind: 40% to 50% LCOE reduction —from 0.135 USD (0.11 EUR) per kWh in 2020 to 0.095 USD (0.077 EUR) per kWh in 2025 and 0.07 USD (0.057 EUR) per kWh in 2030.

3. Land-based wind: 40% to 45% LCOE reduction—from 0.037 USD (0.03 EUR) per kWh in 2020 to 0.032 USD (0.026 EUR) per kWh in 2025 and 0.023 USD (0.018 EUR) per kWh in 2030.

4. Distributed wind: 50% LCOE reduction for a reference 100-kilowatt wind turbine—from 0.105 USD (0.085 EUR) per kWh in 2020 to 0.072 USD (0.058 EUR) per kWh in 2025 and 0.05 USD (0.04 EUR) per kWh in 2030 [9].

Policies driving wind energy development include the U.S. production tax credit (PTC), a per-kilowatt-hour credit for electricity generated by eligible renewable sources. Congress extended the PTC, which was set to expire on 31 December 2020, at 60% of the full credit amount, or 18 USD (14.7 EUR) per megawatt-hour. Qualifying wind energy projects must begin construction by 31 December 2021 [10]. The Business Energy Investment Tax Credit addresses offshore wind facilities and small wind and other distributed energy resources [11].

Progress and operational details

Because of significant design innovation in wind turbine scaling—such as larger rotors and taller towers to boost energy capture and capacity factor—wind's per-megawatt costs have declined [12]. The average hub height of U.S. utility-scale turbines installed in 2020 was 90 meters (m), nearly the same as in 2019. However, rotors increased in size from an average 2019 rotor diameter of 121.2 m to 124.5 m, increasing the average total turbine height to more than 150 m. Meanwhile, the rated capacity of wind turbines also continued scaling up—from 2.6 MW in 2019 to 2.8 MW in 2020 [1].

U.S. offshore wind energy projects announced in 2020 include Vineyard Wind [14], Ørsted's Skipjack Wind Farm [15] (using 13-MW General Electric [GE] Haliade-X turbines), and Dominion Energy's Virginia Beach project (using SG 14-222 DD turbines) [16].

> Wind reaches 9.2% of electricity generation

The United States has over 87,000 wind turbines in distributed wind applications across 50 states, the U.S. Virgin Islands, Puerto Rico, and Guam. In 2020, the United States added 14.7 MW of distributed wind capacity, roughly a 41 million USD (33.53 million EUR) investment serving residential, industrial, agricultural, commercial, government, and utility customers. Total distributed wind capacity in the United States installed from 2003 to 2020 is just over 1 GW [17].

Partial wind power plant repowering projects completed in 2020 totaled 2,899 MW, led by GE Renewable Energy repowering 2,086 MW. Vestas repowered 774 MW and Siemens Gamesa repowered 39 MW [18].

Matters affecting growth and work to remove barriers

Apart from uncertainty about long-term policy support, a variety of factors could slow U.S. wind energy growth. These include economic factors (tariffs, exchange rates, interest rates), other low-cost energy options, modest electricity growth in most regions, inadequate transmission, and siting and environmental challenges. Adding battery storage will ease the challenges of large amounts of variable energy on the grid [12].

DOE funding helps overcome barriers to U.S. wind energy growth by facilitating several approaches that address potential impacts on wildlife and radar systems and enable efficient siting and operation of wind power plants [9]. DOE-supported approaches to protecting wildlife at wind plants include a bat deterrent system that uses nacelle-mounted, ultrasound-generating devices [19]; a 3D-thermal-tracking system of birds and bats developed by DOE's Pacific Northwest National Laboratory (PNNL) [20]; and research by Purdue University and the University of Minnesota exploring eagle physiology to improve the effectiveness of deterrents used around wind energy facilities [21]. A National Renewable Energy Laboratory (NREL) study of wind development's impacts on U.S. rural communities found that 80% of operation and maintenance workers spend money in the communities in which they work, demonstrating their positive economic impact [22].

RD&D activities

National RD&D priorities and budget

DOE funds research to reduce the cost of wind energy, enable the integration of substantial amounts of wind energy into the national energy system, and create siting solutions to reduce environmental impacts [9].

In 2020, the federal research budget for wind energy research and development was 104 million USD (85.07 EUR)—an increase of 12 million USD (9.816 million EUR) over 2019 [23].

DOE organized its 2020 wind energy research priorities into several categories [9]:

Offshore wind: DOE support included 21 million USD (17.17 million EUR) for three projects on offshore wind technology demonstration and resource characterization [24]. The National Offshore Wind R&D Consortium, a public-private partnership supported by DOE and focused on R&D activities to reduce offshore wind LCOE, selected 12 new research projects, bringing the consortium's total to 20 awards and 17.3 million USD (14.15 million EUR) invested [25].

Land-based wind: DOE funded the Big Adaptive Rotor project to enable the next generation of land-based wind turbines with rotors that measure over 200 m in diameter [26]. DOE awarded GE Renewables 5 million USD (4.09 million EUR) to design and demonstrate a 140 m wind turbine with a 10-m, 3D-printed concrete pedestal [27]. DOE and Lawrence Berkeley National Laboratory, in partnership with the U.S. Geological Survey and the American Clean Power Association, made significant improvements to the U.S. Wind Turbine Database, which contains data from nearly 68,000 wind turbines [5].

Distributed wind: DOE's Tools Assessing Performance project aims to improve wind resource characterization, thereby reducing the uncertainty of project performance and financing costs, increasing consumer confidence, and lowering the levelized cost of distributed wind energy [28]. The Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL) project leverages research capabilities across four national laboratories and enables research, development, and industry validation of distributed energy resource design and planning tools, components, and hybrid energy systems [29].

Systems integration: DOE's goal is to enable cost-effective, cybersecure, reliable, and resilient operation of the energy system with increasing levels of wind [9]. Projects include a wind cybersecurity road map and MIRACL [30].

National research initiatives and results

- The NREL-led Interconnections Seam Study, sponsored by DOE's Wind Energy Technologies Office and the DOE Office of Electricity, determined that strengthening the connections between the Eastern and Western U.S. power grids could create a more integrated power system, drive economic growth,

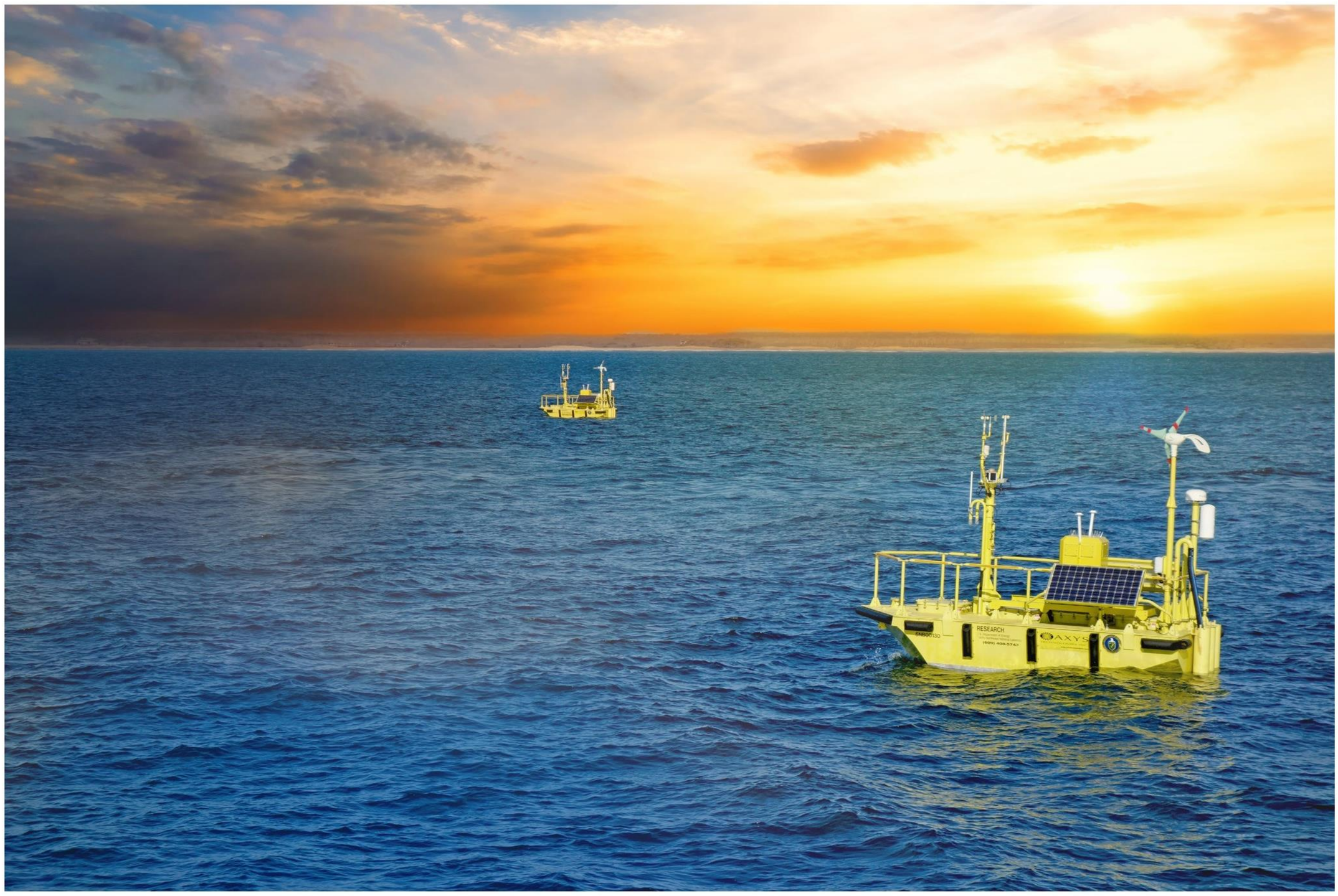

FIGURE 1. PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL) RESEARCHERS UPGRADED THE INSTRUMENTATION ON TWO LIDAR BUOYS USED TO CAPTURE DATA AT NEARLY TWICE THE HEIGHT OF PREVIOUS INSTRUMENTATION, HELPING MEET THE DATA NEEDS FOR TODAY'S MUCH TALLER WIND TURBINES.
IMAGE: OCEAN TECH SERVICES AND PNNL

and increase efficient development and use of the nation's abundant energy resources, including solar, wind, hydropower, and natural gas [29].

- With funding from BOEM, PNNL deployed two offshore wind research buoys off the California coast in September 2020 (see Figure 1). The buoys are gathering meteorological and oceanographic measurements to support BOEM decisions on potential leasing of wind energy sites [31].

- DOE announced eight new Competitiveness Improvement Project awards to receive 2.6 million USD (2.126 million EUR) to make distributed wind energy more cost competitive, improve its interoperability with other distributed energy resources, and increase the number of small- and midscale wind turbine designs certified to national testing standards [32].

- As part of DOE's efforts to develop advanced materials and processes for wind energy technologies, Oak Ridge National Laboratory and NREL researched how additive manufacturing and advanced materials could benefit wind turbines as they increase in size and efficiency [33]. Researchers at NREL also demonstrated that using thermoplastic resin to manufacture wind turbine blades could make them more recyclable, lighter weight, and less expensive [34].

> 2020 breaks annual wind capacity installation records with 16.8 GW new capacity

- ExaWind, a suite of high-performance-computing codes developed by NREL, provides simulations of wind turbines and power plants to enable engineers to test designs in real time, minimizing industry risk and ensuring optimized performance [35]. Lawrence Livermore National Laboratory developed a wind power plant modeling framework that is the first to simulate plant performance under complex atmospheric conditions [36].

Test facilities and demonstration projects

DOE and NREL commissioned infrastructure, including the Distributed Integrated Energy Laboratory, for the Advanced Research on Integrated Energy Systems (ARIES) research platform. ARIES will allow NREL researchers and the scientific community to address the fundamental challenges of integrated energy systems at the 20-MW scale [37].

With support from DOE, researchers from NREL, Avangrid Renewables, the California Independent System Operator, and GE conducted a series of tests showing that wind resources can be used to actively manage the electric grid with higher levels of renewable generation [38].

> Wind technician still ranks as the nation's fastest-growing job, with a 61% growth rate expected

Collaborative research

U.S. representatives participated in research for 15 of the International Energy Agency Wind Technology Collaboration Programme (IEA Wind) tasks in 2020. Participation in these international research efforts provides U.S. researchers an opportunity to collaborate with international experts in wind energy, exchange recent technical and market information, and gain valuable feedback for the U.S. industry [39].

Through this participation, NREL developed the IEA Wind 15-MW offshore reference turbine; an open-access design of a complete wind turbine system that researchers use to evaluate the performance and cost of proposed system modifications (Figure 2). The reference turbine features two modules; one for fixed-bottom wind turbines in shallow water and another for floating wind turbines in deep water [29]. U.S. delegates in IEA Wind Task 36 led publication of an article offering an ecological risk-based approach to lessening wind energy development's potential damage to wildlife, habitats, and communities [40].

Impact of wind energy

Environmental impact

In 2020, 337.510 terawatt-hours of wind generation represented 9.2% of total U.S. net generation [3] and displaced approximately 295.3 million metric tons of carbon dioxide, 214,447 metric tons of sulfur dioxide, and 220,826 metric tons of nitrogen oxide emissions. Wind power also saved approximately 140.8 billion gallons of water that would otherwise have been used to cool thermal power plants [4].

Economic benefits and industry development

All 50 states are home to either a wind project or a wind-energy-related manufacturing facility, and 116,817 Americans have jobs in the wind industry [6]. The U.S. wind industry is a major economic development driver, investing more than 30.69 billion USD (25.1 billion EUR) in new wind projects in 2020 [4]. Wind technician ranked as the nation's fastest-growing job, with a 61% growth rate expected between 2019 and 2029 [41]. Throughout the COVID-19 pandemic, wind energy provided immediate economic relief for communities by bringing in new tax revenue for local services [2].

For recently installed U.S. wind projects, domestically manufactured content is highest for nacelle assembly (>85%), towers (60%-75%), and blades and hubs

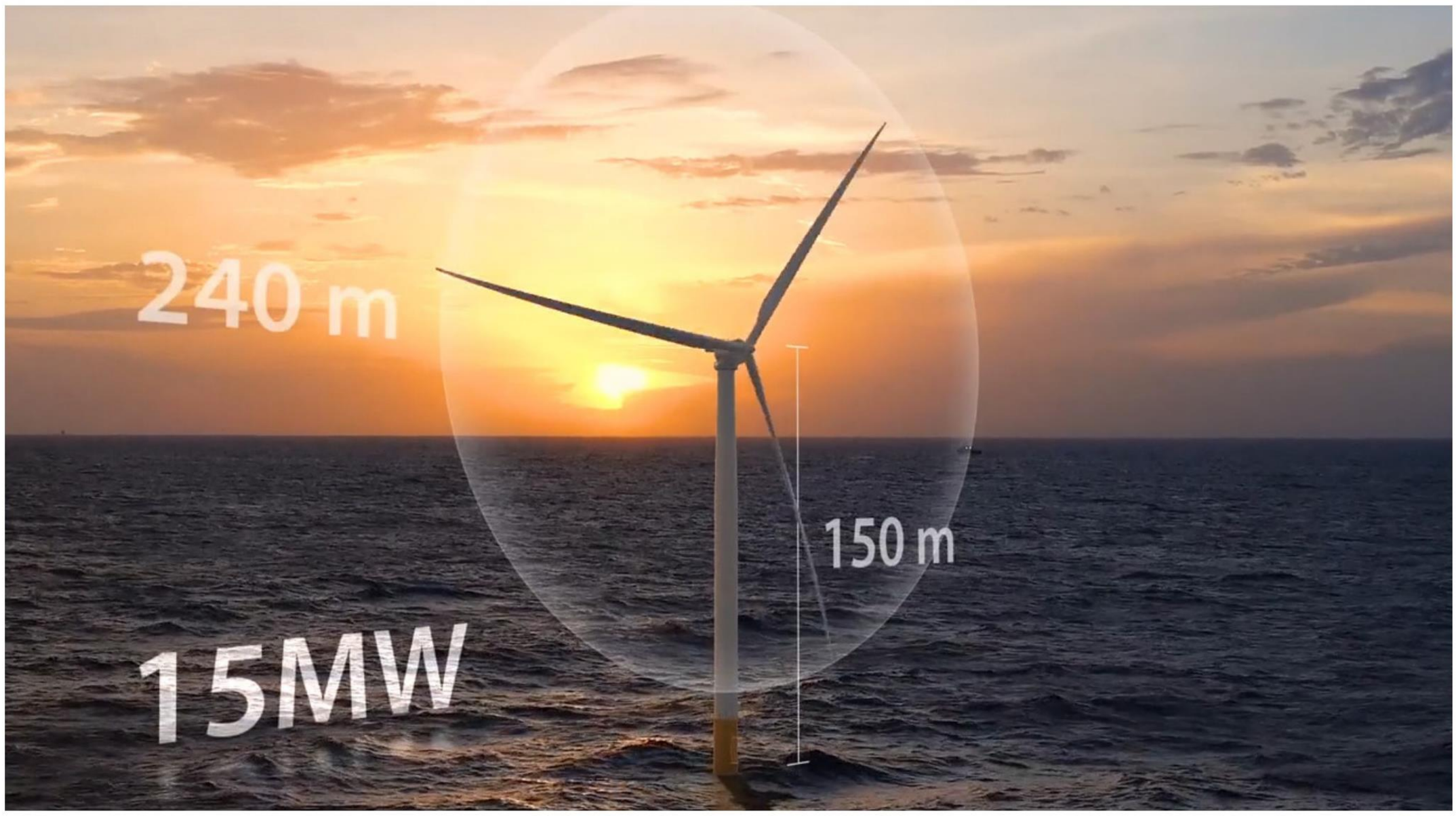

FIGURE 2. NREL DEVELOPED THE IEA WIND 15-MW OFFSHORE REFERENCE TURBINE—AN OPEN-ACCESS DESIGN OF A COMPLETE WIND TURBINE SYSTEM WITH A HEIGHT OF 150 METERS AND A ROTOR DIAMETER OF 240 METERS. *GRAPHIC BY JOSHUA BAUER, NREL*

(30%-50%) , though domestic content for blades has declined in recent years [1]. Dominion Energy began construction of the first Jones-Act-compliant offshore wind turbine installation vessel, which will provide American jobs and a local installation solution in support of U.S. offshore wind supply chain and economic development. A federal law that regulates U.S. maritime commerce, the Jones Act requires goods shipped between U.S. ports to be transported on ships that are built, owned, and operated by U.S. citizens or permanent residents [42].

Next term

EIA expects wind's share of electricity generation to increase to 10% in 2021 [13]. By the end of 2021, project developers and grid operators plan to add another 12.2 GW of new wind capacity to the U.S. electric grid [43].

In December 2020, 43,575 MW of new U.S. wind energy projects were either under construction or in advanced development—and offshore wind projects represented 21% of this project pipeline [2].

In the 2020 presidential election, the United States elected President Joseph R. Biden and Vice President Kamala D. Harris. The Biden Administration priorities include addressing climate change while revitalizing the U.S. energy and manufacturing sectors. To help achieve the president's goal of ensuring that the United States builds a 100% clean energy economy and reaches net-zero emissions no later than 2050 [44], the U.S. Departments of Energy, Interior, and Commerce set a national goal to deploy 30 GW of offshore wind energy by 2030 [45].

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