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AN OVERVIEW OF DOE'S WIND TURBINE DEVELOPMENT PROGRAMS

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Abstract

The development of technologically advanced, higher efficiency wind turbines continues to be a high priority activity of the U. S. wind industry. The United States Department of Energy (DOE) is conducting and sponsoring a range of programs aimed at assisting the wind industry with system design, development, and testing. The overall goal is to develop systems that can compete with conventional electric generation for $.05/kWh at 5.8 m/s (13 mph sites) by the mid-1990s and with fossil-fuel-based generators for $.04/kWh at 5.8 m/s sites by the year 2000. These goals will be achieved through several programs. The Value Engineered Turbine Program will promote the rapid development of U.S. capability to manufacture wind turbines with known and well documented records of performance, cost, and reliability, to take advantage of near-term market opportunities. The Advanced Wind Turbine Program will assist U.S. industry to develop and integrate innovative technologies into utility-grade wind turbines for the near-term (mid 1990s) and to develop a new generation of turbines for the year 2000. The collaborative Electric Power Research Institute (EPRI)/DOE Utility Wind Turbine Performance Verification Program will deploy and evaluate commercial-prototype wind turbines in typical utility operating environments, to provide a bridge between development programs currently underway and commercial purchases of utility-grade wind turbines. A number of collaborative efforts also will help develop a range of small systems optimized to work in a diesel hybrid environment to provide electricity for smaller non-grid-connected applications.

Background

Wind generation of electricity for delivery to the electric grid must compete with other utility sources of electricity in a complex world of financing, tax structures, avoided costs and set asides. Wind turbines must compete on a cost of energy (COE) basis with well developed infrastructures for the production of electricity that are based on fossil fuels. Wind systems can only survive by eliminating perceptions of poor reliability and availability through education, technological development, innovation and improvement. Wind turbine operators have made immense strides to eliminate these perceptions using current technology, but that is not enough. Existing wind turbines, most of which were

installed in the early 1980s, produce electricity at $.07 kWh to $.09 kWh. Decreases on the order of 50% are needed to make wind energy competitive. New advances in aerodynamics, materials, generators, controls and design tools must be incorporated into turbine designs to make wind-generated electricity competitive with conventional energy sources.

Advancing to the Future

The next five years are critical for the U.S. wind industry. Market opportunities are multiplying as utilities, state and local governments, the American public and the international community become aware of the potential for wind power. The wind industry must place itself in a position to take advantage of these opportunities. The DOE programs are designed to assist industry efforts to meet these challenges. First, existing wind plant operators and developers must remain healthy and competitive. Second, new products, which combine the best of existing designs with new research and technology, must be ready for deployment in the near-term. Third, a next-generation of utility-grade wind turbines must be developed for the year 2000 and beyond. Finally, prototype turbines must be thoroughly tested and introduced to the marketplace through utility participation.

The goal of the Value Engineered Turbine (VET) Program is to assist the U.S. wind industry in developing near-term (mid 1990s) conventional commercial wind turbines for both domestic and international markets, and strengthening domestic production of commercial turbines.

The goal of the Advanced Wind Turbine (AWT) Program is to assist U.S. industry efforts in incorporating advanced wind turbine technology into utility-grade wind turbines for the near-term (mid 1990s), and to provide the next generation of utility-grade wind turbines for the year 2000.

The goal of the EPRI/DOE Utility Wind Turbine Performance Verification Program is to deploy and evaluate commercial prototype wind turbines in typical utility operating environments in order to provide a bridge from development programs currently underway to commercial purchases of utility-grade wind turbines.

The goal of DOE's wind hybrid programs is to link wind with a range of other renewable and conventional electrical generating capabilities into stand-alone systems capable of filling the needs of remote users.

These programs will help introduce new products into the marketplace, create greater stability and strength in the wind industry by attracting utility participation, broaden the national use of wind energy, and increase competitiveness in the international marketplace.

Value Engineered Conventional Technology

Over the past ten years U.S. wind plant operators have gained considerable knowledge and operating experience with the current generation of wind turbines in the California wind farms and have developed an understanding of the most dependable features in current wind turbine designs. Many wind turbines of this generation have achieved the minimum levels of reliability sought by wind plant operators, but the COE produced by many of these turbines is still higher than the levels necessary for long-term survival in an increasingly competitive global energy market. The VET program will support these U.S. wind plant operators in the value analysis, manufacturing, and commercialization of these turbines and assure that highly reliable, economically competitive U.S.-built wind turbines are available to meet near-term market demands. The value engineering of proven designs will provide a fast transition to more economic wind systems, with low technical and financial risk. The concept of value engineering focuses on removing unnecessary costs from a design while assuring that its quality, reliability and performance are maintained.

The primary objectives of the VET Program are to: 1) support U.S. organizations that have demonstrated expertise in wind energy to improve the cost effectiveness, reliability and manufacturing quality of proven conventional wind turbine configurations for near term market opportunities, 2) expand the domestic production of commercial wind turbines, and 3) accelerate the maturation of existing U.S. wind energy businesses by promoting the development of sustained engineering and manufacturing capabilities.

The VET program was initiated by a Request for Proposal (RFP) in late 1992. Negotiations are underway with three potential participants. Subcontractors selected under this program must be capable of rapidly developing a manufacturing capability to produce a utility-grade wind turbine generator in the near-term. These value engineered turbines will be of a conventional design, and will not depart from the turbine upon which they are modeled in any radical way. For example, rotor swept areas will not be increased significantly. Value-engineered turbines will be based on reliable, proven configurations with a demonstrated capacity factor of at least .20 and a multi-year operating history with at least 20 MW of cumulative installed capacity worldwide. Wind turbine development projects similar to the VET Program already are underway within the wind energy industry at various stages of progress. To accommodate this diversity, the VET Program is considering a range of project types to assist wind plant operators in implementing their existing wind turbine development plans.

Project teams under the VET Program will characterize the performance of the proposed turbine or configuration and perform value engineering analysis of wind turbine components and sub-systems. Subcontractors will prepare detailed engineering designs of final wind turbine configurations, develop business plans, fabricate and install one value-engineered prototype turbine system, and conduct field tests.

Near-Term Innovative Products

The AWT Program is assisting U.S. industry in exploring and developing new wind

turbine products. The first projects to be conducted under the AWT Program were Conceptual Design Studies. The purpose of this early effort, which began in 1990, was to: 1) study improvements to existing baseline wind turbine configuration, designs, and manufacturing methods that would make wind energy a significantly more competitive electricity source in the mid 1990s, and 2) initiate conceptual studies of advanced wind turbine configurations that would be competitive for bulk electricity generation at moderate wind speeds over large geographic regions by the year 2000. Results of the conceptual design studies show promising performance and reliability enhancements and cost-of-energy reductions for improved next-generation wind turbine designs.

Concepts identified as key elements for improving existing designs included: 1) increased rotor sizes that take advantage of advanced NREL airfoils, 2) flow-through rotor structures, 3) aileron controls, and 4) integrated gearboxes and mainframes. In many cases the application of new engineering can result in simple design changes which greatly improve reliability and performance.

The final task of the conceptual design studies required introduction of innovations and major architectural changes to overcome problems associated with the baseline turbines. Concepts developed by subcontractors to significantly improve the performance of the next-generation of wind turbines include: 1) aerodynamically-shaped, wood/epoxy rotating towers, 2) totally integrated drivetrain configurations that are directly mounted to tower top castings, 3) improved thin and thick airfoils, optimized for new aero-controls, and 4) taller towers.

Ideas developed by these subcontractors represent only the tip of the iceberg in innovative potential. Numerous ideas arose in the 1970s and 1980s that were not fully developed due to lack of funding, resources or time. Many other promising ideas were prematurely implemented on wind turbine designs, and as a result were discredited. History has shown that the understanding of many wind engineering concepts was, at best, intuitive, and that many assumptions about performance and reliability of materials and equipment were incorrect. A rigorous iterative process of designing, building and testing prior to commercialization is a key component for future success.

The objective of the current activities under the Near-Term Product Development project of the AWT focuses on products for introduction to an expanded market place in the 1995 time frame. The introduction of the Federal $0.015 kWh tax incentive opens a wide range of possibilities for introduction of wind technology into still untapped wind resource areas. New machines that can produce electricity at $.05 kWh will be well suited to take advantage of both the tax credit for new capacity as well as the empty or replacement space for units in wind farms still covered under active Standard Offer 4 contracts.

During 1992 an RFP was issued for the development of improved near-term products based on existing designs. Four subcontracts have been awarded under this project, with durations of two to three years. These subcontractors will develop prototype turbines that will implement numerous improvements to units currently running in a production

environment. Initial subcontractors began their efforts during the summer of 1992 to design, fabricate and test prototypes based on these baseline designs. Eight principal design tasks make up the scope of work for each of the subcontractors: 1) assess a baseline turbine for design improvements, 2) determine the potential of candidate improvements, 3) analyze the effects of proposed improvements on the preliminary advanced wind turbine system design, 4) fabricate critical components and subsystems and perform qualification tests, 5) develop a final prototype advanced wind turbine design, 6) develop manufacturing, maintenance, and commercialization plans, 7) fabricate two prototype advanced wind turbine systems, and 8) install two prototype advanced wind turbine systems and perform field tests for a minimum of one wind season. Careful application of improved design techniques and tools integrated with thorough testing is a key element in these projects. Field tests of pre-prototype turbines and qualification tests of improved components and subsystems under this project began as early as January of 1993 and will run through early 1995. DOE will support the refinement of these turbines through research, testing and other cooperative efforts.

A Next-Generation of Technology

The objective of the Next-Generation Phase of the AWT is to stimulate U.S. industry to explore new concepts and apply cutting-edge technology for the development of commercial utility-grade wind turbines for the 2000 time frame. These innovative wind turbines are expected to produce electricity for the grid at $0.04/kWh at 5.8 m/s (13 mph) wind sites. Primary factors which must be addressed to reach this COE goal include reduced turbine capital cost, increased performance and reliability, and decreased operations and maintenance expense.

The development of advanced utility-grade designs cannot be accomplished by step-wise or incremental improvements to old designs, even though incremental advancements may offer important insights into performance and reliability problems. The Next-Generation Phase will encourage participants to broaden their vision and emphasize innovation. By starting with a blank sheet of paper and taking an overall systems view of wind energy, new ideas and concepts will be fostered. Participants will explore high-risk, high-reward components and configurations. Uncoupling designers from current ideas is critical to making a quantum jump in improved performance.

The Next-Generation Phase will consist of two project efforts. The Innovative Subsystems Project is the first. This project was initiated with an RFP in early 1993. Five subcontracts are anticipated. Subcontractors under this project will 1) complete a detailed design of an innovative subsystem, 2) fabricate and test this component in a shop environment, 3) test the subsystem on an existing operating wind turbine, and 4) assess the subsystem's performance and impact on COE. By focusing the first project on subsystems or components, developers will push the technology further than if they were attempting to develop an entire turbine. Subsystems developed under this project will be available for incorporation into existing wind turbine designs, or for inclusion in the next-generation of turbines to be developed under the Next-Generation Turbine Development project.

The second effort in the Next-Generation Phase is the Turbine Development Project, which will support industry to design and test a new generation of wind turbines incorporating the most recent technology in all aspects of wind turbine operations. It will build extensively on all that has been learned from the VET, Conceptual Design Studies, and the Near-Term Product and Next-Generation Innovative Subsystems projects. Subcontractors selected for this effort will be required to 1) develop their concepts into fully documented preliminary designs, 2) fabricate and perform qualification tests on components, either in the field or on a bench scale, and 3) fabricate and test full scale prototype turbines.

This cycle of Innovative Subsystems, followed by full scale Turbine Development, will be repeated in 18 months to two years following the start of the first Innovative Subsystems project. A third cycle of Innovative Subsystems and Turbine Development is planned 18 months to two years after the start of the second cycle. This continuing cycle of design and development will allow participants to envision new designs and evolve them into working prototypes for testing. The first solicitation for Next-Generation Innovative Subsystems project began with an RFP issued in February, 1993. This RFP included specifications and evaluation criteria developed with input from members of the wind and utility industries.

NREL will continue to support industry during these efforts with direct engineering and parallel research activities. Other DOE Cooperative Research Programs will provide a means to continue the refinement of these prototype turbines beyond the AWT program.

Entering the Marketplace

The primary market for products developed under DOE's wind turbine development program is the utility industry. Successful utility market penetration will depend on factors such as low COE to compete with conventional energy sources, high reliability to reduce technical and financial risks, and minimal environmental impact. Utility acceptance of wind-generated electricity will increase as the performance and reliability of new wind turbine products is demonstrated. The EPRI/DOE Utility Wind Turbine Performance Verification Program is being developed with the goal of deploying and evaluating commercial prototype wind turbines in typical utility operating environments. This will provide a bridge between development programs currently underway and commercial purchases of utility-grade wind turbines. The foundation for the EPRI and DOE collaborative venture in wind power development is to hasten wind power commercialization and the realization of wind power's environmental and energy-security benefits.

From this foundation the following program objectives have been set: 1) establishment of deployment and testing projects with at least four host utilities to provide statistically valid performance, operation, and maintenance experience with commercial-prototype, utility-grade turbines (three of these projects have already begun), and 2) documentation of these projects between 1993 and 1997 for the benefit of utilities, turbine suppliers, and others in the wind power development and user communities. Another round of

solicitations is anticipated in 1994.

Each host utility under this program will select the installation site, specify operating conditions, solicit bids from wind power vendors, and establish agreements with selected vendors. With EPRI and DOE assistance, the host utility will establish a test program, evaluate turbine performance and reliability, and assist in transferring information to the utility and wind power industries. Benefits to the host utility will include first-hand experience with demonstration wind power plant of at least 6 MW using the latest technology; recognition of leadership in renewables development; influence on technological development, and early access to information on other demonstration wind power plants.

Non-Grid-Connected Environments

Electrical generation demand at remote locations is growing as fast as utility-grid-connected applications. Remote villages require generation that is reliable and cost effective. Wind hybrid systems that combine the best of renewable technology are in demand to fill these needs. Hybrid systems link wind turbines, photovoltaics, new electrical storage systems and diesel generators to provide an integrated and dependable power system for non-grid-connected systems. Potential advantages of hybrid systems include low life-cycle costs, moderate operating costs, utility-grade power output, and the ability to meet varying loads. DOE sponsors research and development that will directly impact the performance and capabilities of wind hybrid systems.

To enhance the performance of hybrid systems, NREL selected a subcontractor to develop a family of improved inverters and power processing units. As part of DOE's Advanced Wind Turbine program to reduce the cost of wind energy, NREL selected a subcontractor to design, develop and test a 50-kW wind turbine. This size of turbine is designed to meet the electrical loads of larger, remote village applications, in many cases as part of a wind/diesel hybrid system. As part of its balance-of-system technology program, Sandia National Laboratory is co-sponsoring (along with the Alaska Science and Technology Foundation and NREL) the development of a wind hybrid power system for use in remote applications. The system is designed to drastically reduce engine run time and thereby reduce fuel consumption and maintenance while increasing genset lifetime. The USDA and DOE are cosponsoring research on "all renewables" wind hybrid electrical generation systems for rural areas. Such systems could be powered completely from renewable sources such as wind, solar, and vegetable oils. These and other efforts are creating a strong technical backbone of equipment and know-how for remote power applications.

Conclusion

The combined activities under the AWT, VET, EPRI/DOE Utility Wind Turbine Performance Verification Program and Hybrid Systems Development comprise a broad approach to expanding U.S. competitiveness in wind turbine technology, engineering skill

and manufacturing capability. Without such a diversified approach the U.S. wind industry is not able to compete with aggressive international programs and firms. The wind turbine development programs supported by DOE, EPRI and various utilities will support U.S. industry in development of the wind technology needed to prosper in the 1990s and 21st century.