CRITICAL NATIONAL NEED IDEA

Technology Innovation Program

Mail Stop 4750
National Institute of Standards and Technology
100 Bureau Drive
Gaithersburg, MD 20899-4750
Att. Critical National Needs Ideas
Email: tipwhitepaper@nist.gov

Critical National Need Idea Title: 10 MW Class Wind Turbine Technologies

Submitting Organization: American Superconductor Corporation

Contributing Organizations:

Contacts:

American Superconductor Corporation
64 Jackson Road
Devens MA 01432

Att: Bruce Gamble

Email: bgamble@amsc.com

Phone: 978-842-3522

Fax: 978-842-3024

Key words (90 character limit)

wind turbine, superconductors, HTS, blades, foundation, power conversion, nacelle, bearings, generator

10 MW Class Wind Turbine Technologies

White Paper Submitted

to

The Technology Innovation Program (TIP)
National Institute of Standards and Technology
Gaithersburg, MD 20899

by

American Superconductor Corporation
64 Jackson Road
Devens MA 01432
January 2009

There is a national imperative to reduce fossil fuel use through expanding the use renewable energy. Wind energy is the most cost-effective and widely used renewable energy source. However, higher wind turbine ratings (~10 MW) are needed to open up the huge offshore wind opportunity, and conventional technology has hit a wall around 5 MW, due to generator size, weight and efficiency limitations. High temperature superconductor (HTS) technology for large electric machines provides major reductions in size and weight, and improvements in efficiency, as recently demonstrated through the successful testing in the US of a large (36.5 MW) HTS motor.[ref. 1]. Applying this technology to 10 MW-class wind generators will provide the needed breakthrough to enable practical 10 MW rated wind turbines for the offshore (and some onshore) market. The effective introduction of such systems requires investment in the demonstration of full-scale 10 MW-class HTS generators, but also in other essential components of the wind turbine system including foundations, blades and nacelles. These component advancements represent a unique opportunity for US companies to recapture the lead in advanced wind turbines.

AN AREA OF CRITICAL NATIONAL NEED

US companies have the opportunity to lead the world in the development and manufacture of large generators for offshore wind power to reduce green house gases and lower dependence on foreign oil for energy production. By 2020, global offshore wind power is predicted to grow by 200,000 GWh/year compared to its present position (see Fig. 1). However, with the current trajectory of technology development, <u>the US is not expected to play a significant role in offshore wind power generators and offshore wind farms are at risk of not being commercially viable even with substantial subsidy (ref. [2]).</u>

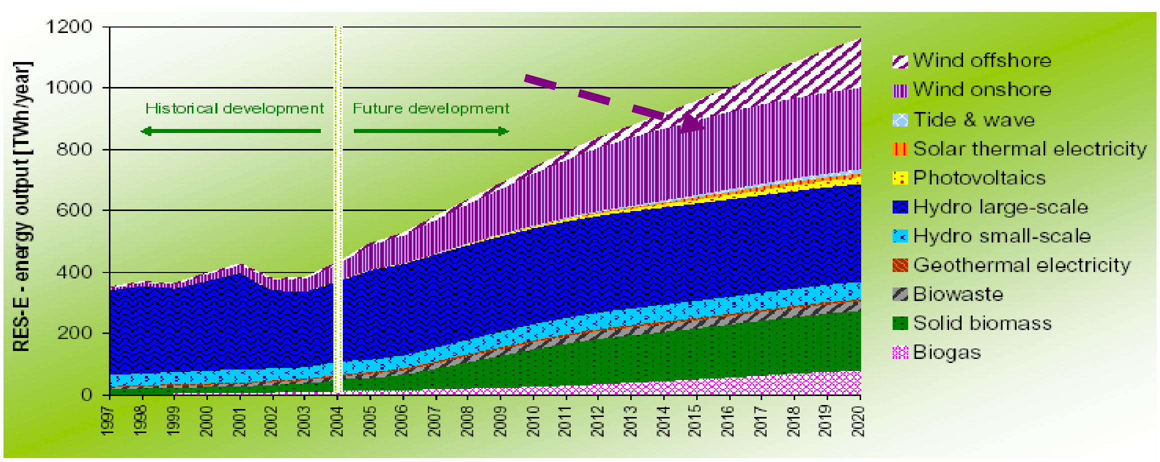

Fig. 1. Projections for growth of renewable energy sources to 2020. Offshore wind is expected to grow by 200 TWh/yr (about 23 GW). ref. [2]

Wind power generation is needed in a massive way in the US to enable a reduction in CO_2 emissions and dependence on foreign energy sources. For example, by 2020 wind power generation in the US could result in the avoidance of a staggering 4 trillion tons of CO_2 per year! Hence, the importance to our environmental future cannot be overstated.

MAGNITUDE OF THE PROBLEM

A recent market analysis in Fig. 3 shows that there is a huge untapped market for offshore wind near the coasts of the USA. There are several key technical, financial, and political bottlenecks that are currently slowing the development of offshore wind power. In particular, site requirements represent a substantial fraction of the total cost per kW-hr. There is evidence from the European developers that a 10 MW class of wind generator will have the greatest market impact but, there is no conventional technology that can achieve the 10 MW goal. The USA does not play a key role in offshore development as shown in Fig. 4.

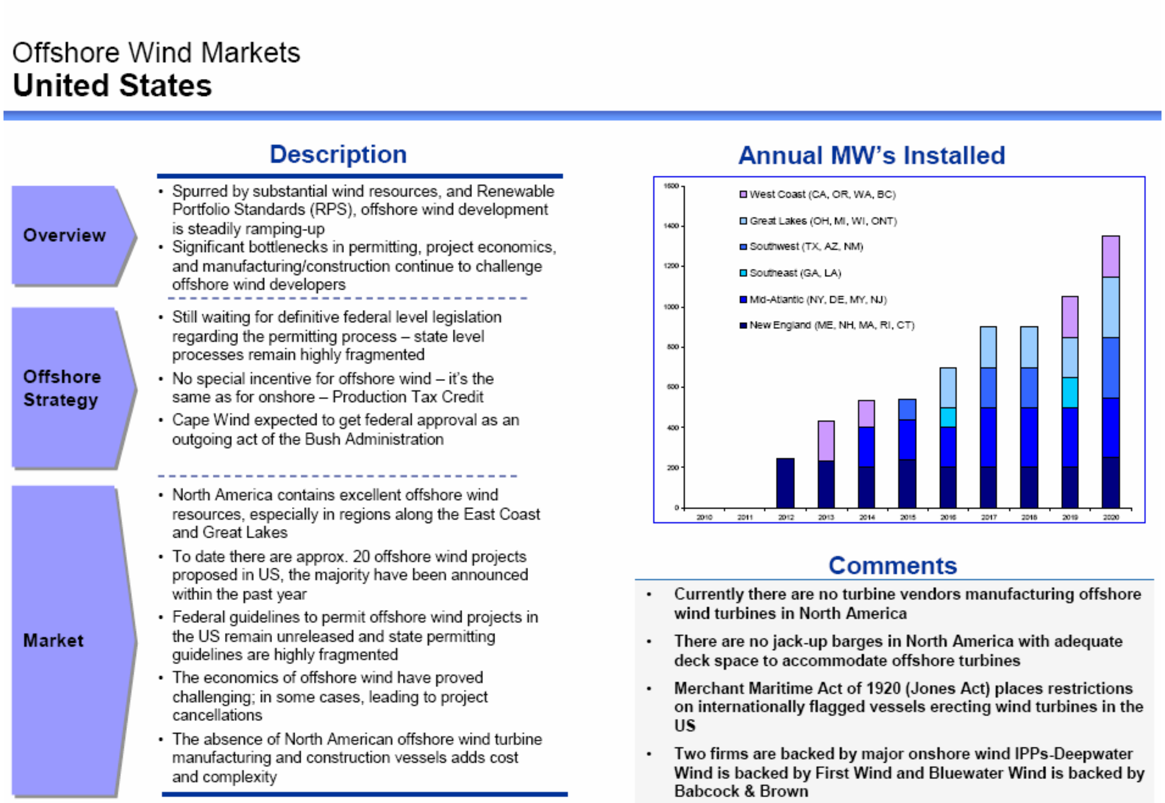

Fig. 3. A summary of the present state of the USA Offshore market [3].

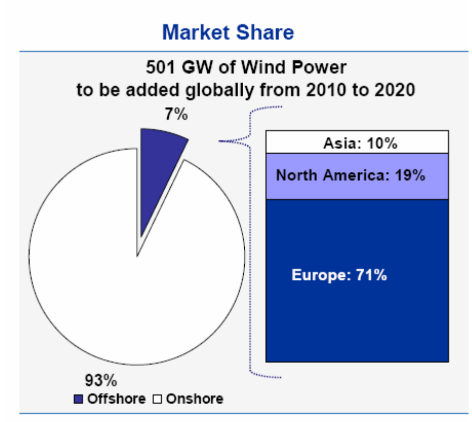

Fig. 4. Global offshore is rapidly developing but the USA is not playing a key role [3].

The critical technologies that are needed for a commercially successful 10 MW class wind turbine system include:

- Direct drive generator meeting practical size, weight, efficiency requirements
- Advanced blade development
- Advanced rotor development
- Direct power conversion
- Tower and foundation
- Nacelle

High temperature superconductor technology provides the needed breakthrough for achieving the 10 MW class direct drive generator meeting the wind turbine requirements. A recent successful demonstration including full load testing for the US Navy of a 36.5 MW (50000 hp) motor has confirmed the major size and weight advantages as well as efficiency (factor of two reduction in losses). This technology provides the necessary foundation for application to direct-drive (10-15 rpm) generator for wind application.

Under a program funded by the NIST-ATP program, ref. [4], the key technologies for a 10 MW class HTS generator are already in development. However, this program only addresses core generator components, but does not address the construction and demonstration of the first full-scale prototype. Nor does it address the significant advancement required in the areas of blade, rotor, tower, foundation, power conversion and nacelle to enable the full 10 MW wind turbine system.

SOCIETAL CHALLENGES

The USA has clearly lost the leadership position for the development of high rating wind generators for offshore applications. The development of a 10 MW class technologies for offshore capable wind turbines including large high temperature superconducting (HTS) generators can place the USA back in a leadership position. This will reduce the cost-of-energy produced with advanced HTS based ultra low-speed generators for offshore wind power, making clean and green offshore power a major contributor to this fundamental national imperative (FIG. 5. and ref. [5]). A reduction in the cost of energy produced is fundamental to wider acceptance of offshore wind generators. This supports a primary goal of reduction of fossil fuel consumption and the associated reduction in green-house gasses.

This was effectively summarized in the following quote from an HSBC report ref. [5] and is supported by the data in Fig. 5 also from that report.

> *"To date, the offshore market has been slow to develop, since the economics are not as attractive as for onshore projects. Larger, more efficient and reliable turbines are required to make the economics of offshore projects more attractive. Such turbines will help drive down foundation costs per MW and should reduce operation and maintenance (O&M) costs, while optimizing electricity generated."*

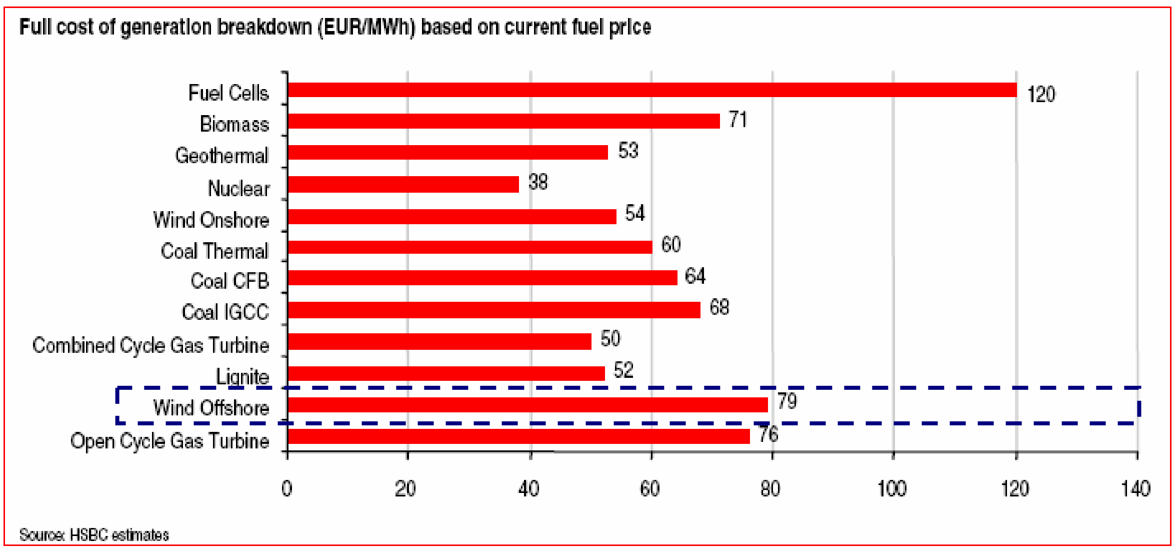

Fig. 5. Comparison of Cost-of-energy (COE) among various power generation technologies. Presently, offshore wind costs 46% more than onshore wind. [5]

MAPPING TO NATIONAL OBJECTIVES

A 10 MW class HTS generator and wind turbine system for use offshore is pivotal to achieving the required cost reduction. This technology will result in broad implementation of this green energy production solution. Large, lightweight, efficient, and reliable; these are the identified requirements for economic attractiveness:

- Large - For power generation the cost-of-energy is reduced with larger generators through the economies of scale.

- Lightweight - For economical deployment of turbines, lightweight generators are a key component to drive the reduction of first cost. The size and weight of the generator significantly impacts other components.

- Efficient - The need for higher efficiency electricity production throughout the life of the wind turbine points in the direction of high efficiency HTS-based rotors and advanced air-core stators.

- Reliable - A direct-drive generator, one without the complexities of a gearbox, will have lower maintenance requirements and greatly reduced costly downtime.

Fig. 6. Photograph of the Enercon 4.5MW wind turbine. The generator and hub weight 440 tonnes, compared to an estimated 118 tonnes for an 8MW HTS design.[6]

A direct-drive generator rated at 8 to 10 MW will be an enabling technology for offshore wind power. A turbine of this power will require a rotor diameter of approximately 140 meters, and with current blade technology the nominal speed of the direct-drive generator will be 11 rpm.

To illustrate the scale of the unit, Fig. 6 shows photos of the world's largest direct-drive wind turbine demonstrator (note: it is less than half of the power of the class of generator under consideration). It uses a copper annular generator (over 300 tonnes and 12 meters in diameter) and its blades sweep 112 meters in diameter. This technology cannot be scaled to 8MW and used offshore; the generator becomes too massive, thus a solution requiring new technology must be developed.

To summarize, the compelling business opportunity is to position US industry to capitalize on the expected explosive growth in offshore wind power generation by developing the fundamental technology enabling a large ultra low-speed generator with a size and weight compatible with practical wind turbine construction. The national economic importance is to enable US companies to win in this market, and also to reduce reliance on foreign imported oil and reduce CO2 emissions by increasing the amount of electricity generated by renewable, offshore wind.

MEETING TIMELY NEEDS NOT MET BY OTHERS

There is urgency in meeting the requirements for the 10MW class wind turbine since the U.S. is facing a future major reduction in fossil fuel sources of energy. Wind turbine technology has demonstrated the potential for contributing to the energy needs of the United States. Wind energy could supply about 20% of the nation's electricity, according to Battelle Pacific Northwest Laboratory, a federal research lab (ref. [7]). As the ultimate penetration level will be driven by the cost of energy that is produced and the cost of energy is dependent on the size oft the wind turbines (the initial costs of larger wind energy turbines and the annual costs for maintenance and operation in comparison to standard turbines are below proportional to their enhanced output). Larger wind turbines may thus significantly increase the penetration level. The downward cost trend of large-scale wind turbines is expected to continue as larger multi-megawatt turbines are mass-produced. Not many facilities can produce larger turbines and their towers and foundations, and to date production or even prototype for 10 MW class wind turbines exists. These constraints emphasize the need for the development of a larger, 10MW wind turbine class.

The market competition (Fig. 7) is trying to push toward a 10 MW solution but, the time to commercialization will be unacceptably long without accelerated development.

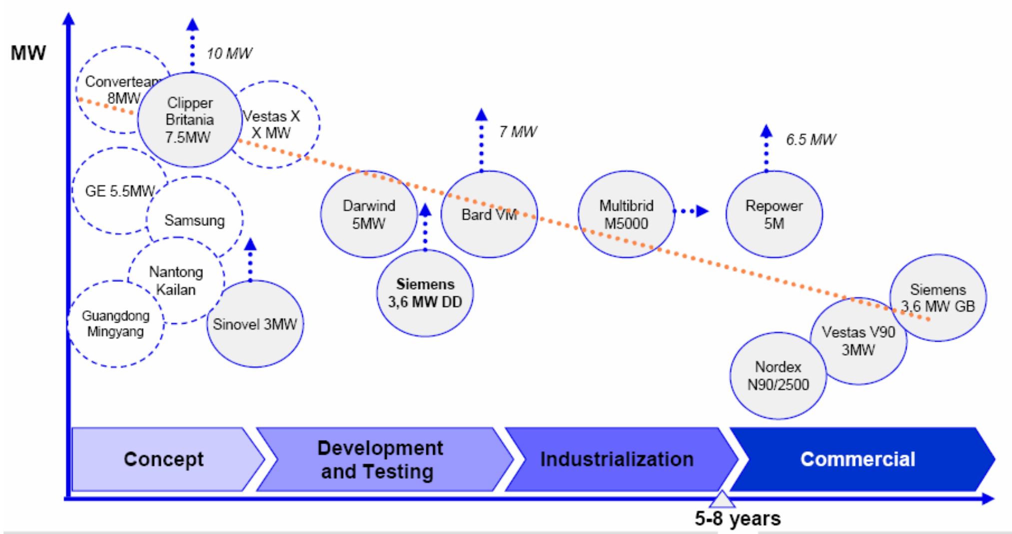

Fig. 7 – Competitors effort to compete in the higher rating wind generator market [8]

There are key gaps in the technology for larger turbines. The achievement of this goal without costly and inefficient trial and error requires certain critical research and development. The technology areas to be addressed and the subsystems to be defined include the development of the rotor blades, the foundation, power conversion, the nacelle integration and the direct drive generator.

1. *Rotor blades*
2. *Foundation*
3. *Power Conversion*
4. *Nacelle Integration*
5. *Direct drive generator*

New technologies for power conversion will be introduced, but the major advance must come through the design of larger rotor blades. A new, large-scale wind turbine system will take advantage of advances in materials technology of rotor blades. Moreover, the concept and design must meet the need to manufacture a consistently high-quality product at reasonable cost.

1. Blades

The design of larger wind turbines puts new demands on materials technology of rotor blades. Advanced materials as well as a new structural design must be developed to ensure sufficient stiffness while simultaneously preventing above proportional weight gain. To this end for example glass fiber materials may be substituted by carbon fiber materials. In order to meet lifetime requirements means must be researched to counteract blade erosion.

2. Foundation

The cost-effectiveness of foundations for offshore wind turbines depends to a large extent on manufacturing, transportation and the actual installation process at the location. Considering these factors, there is a significant demand for cost optimized, on-site, large-sized support structures.

A variety of structures is available on the market that needs to be assessed with regard to their suitability for the 10MW class of wind turbines. The most widely used and most cost-effective system consists of monopiles simply rammed into the ground. However, this concept is contingent on radial dimension and thus may only be utilized if certain rotor diameters and power ratings of the turbine apply. An upgraded version dubbed “tripile” was developed for series production that combines monopile installation advantages with multi-megawatt wind turbine requirements. Further structure variants are gravity foundations with the disadvantage of a very big concrete structure especially for transport. Steel structures like jackets are capable of multi-megawatt wind turbine requirements and have a significantly lower weight but suffer from complexity in design verification and manufacturing and are poor in grounding on the seabed.

A very different approach to the topic of support structures has been recently developed with floating structures where a floating platform is anchored to the seabed providing the weight support to the wind turbine mounted on it. This system is highly influenced by sea currents and waves resulting in low stiffness. Moreover the numerical verification for such a structure is still in the development phase. Further investigations have to be conducted before a reliably statement can confirm floating structures as a real alternative to concrete or steel structures, viewed both from the technical and the economical side.

3. Power Conversion

Actual frequency converters for power conversion from the variable frequency generator output to the fixed frequency grid are state of the art but working on low voltage level. This would result in relatively high currents causing big losses and therefore a reduced power efficiency.

Thus in order to ensure an efficient system there is a demand for medium voltage frequency converters. Additional requirements on high torque dynamics on the generator side are present for drive train damping. New developments have to consider strict requirements for grid connections like low voltage ride through and must be capable of handling several grid conditions which vary highly within the national grids all over the world.

For good grid compatibility filter systems may be installed, but these systems generate a certain level of losses especially at no load conditions. For handling these effective higher switching frequencies semiconductor modules are used requiring optimization on test runs.

Because of the reduced space in the nacelle of a wind turbine the frequency converter is commonly situated in the tower. Since the design of the tower is thus highly influenced by converter requirements for mounting, maintenance, safety purposes and cooling efforts further research on the tower structure has to be carried out.

4. Nacelle Integration

The direct drive poses challenges in the integration of the main bearing, the machine support and the design of the high-temperature superconducting (HTS) generator. Since the main bearings with + 5m in diameter are not state-of-the-art, technical problems of dimensioning and surface hardening have to be overcome. The machine mount needs to be as stiff as possible to support the applied loads. The HTS generator is integrated into the structure.

In order to ensure a reasonable price and meet shipping constraints a modular main frame concept for production and transportation has to be developed. The HTS generator has to be adapted to meet the needs of the wind power application in terms of vibrations and corrosion protection especially for offshore applications. Moreover the special cooling equipment to achieve the required temperatures for the HTS wires needs to be designed for these conditions. The HTS generator stator needs to be supported during transport and testing.

5. Direct drive generator

As introduced in previous sections, the 10 MW class direct drive generator is prohibitively large and inefficient without HTS technology. Although and ATP program is currently addressing the advanced technologies needed for the HTS rotor winding, cooling and stator coils, technologies for ultra low cost production is required to address the ultimate goal of low cost. Introduction of advanced technology often initially results in manufacturing cost which can only be successful in niche markets. Over time manufacturing cost reduction increases market penetration. The urgency of the reduction in fossil fuel use makes this slow cost reduction unacceptable.

A targeted effort is required to address cost reduction for large electric machines and in particular HTS generators. The electric machine industry in the US has been moving offshore. This focused effort would have benefit for a broad range of electric machine applications and strengthen the electric machines industry in the US.

Manufacturing technologies required to accelerate the goal include HTS wire, coil and support volume manufacturing cost reduction. The basic cost of the cryogenic coolers to be used with the HTS rotor is another area where accelerated manufacturing cost reduction is imperative. Finally the advanced, high efficiency medium voltage stator coils required for these large high torque generators must be produced at low cost.

CONCLUSION

The urgency of the goal of fossil fuel use reduction can be addressed by larger offshore wind turbines and in particular by the 10 MW class HTS wind turbine. NIST is currently funding advanced technology for a direct drive generator for this class of turbine. The accelerated introduction of this technology requires full scale demonstration leading to volume generator production. It also will require a focused effort on other key elements of the wind turbine system and on manufacturing cost reduction. This focused effort will strengthen and create jobs in critical industries needed to address the broader power generation needs of the US.

References

[1] American Superconductor announced on January 13, 2009 that the full load testing of the 36.5 MW motor as successful, http://www.amsc.com/newsroom/pr.html?id=311

[2] "Renewable Energy Roadmap," published by the Commission of the European Communities, January 2007, COM(2006) 848 final.

[3] Emerging Energy Research under a consulting agreement with American Superconductor

[4] The NIST ATP program funded a program titled "Technical Innovations Enabling a New Direct Drive Wind Turbine Generator " that is a joint partnership of American Superconductor and TECO-Westinghouse.

[5] "Power for a New Generation," HSBC Report, March 2007

[6] "Offshore Wind Technology Overview," presentation by Mike Robinson and Walt Musial (NWTC), October 2006.

[7] American wind energy association http://www.awea.org/faq/wwt_potential.html

[8] Emerging Energy Consulting under a consulting agreement with American Superconductor