CRITICAL NATIONAL NEED IDEA

Low-Cost Renewable Distributed Power Generation

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Executive Summary

The creation of a new energy paradigm that is cost-effective, sustainable, and is acceptable from an environmental and national resource perspective represents one of the greatest challenges facing America. Historically, leadership in energy technologies has been important in creating and sustaining world leadership positions for countries. Thus, in addition to the security and environmental benefits, it is vital for economic national competitiveness that the United States establishes leadership in the new energy economy.

Over the past few years the need for change in our energy supply has become abundantly clear. As the energy consumption of non-US economies have increased, the unsustainability of a situation where the United States consumes approximately 25% of the worlds oil production while producing only about 10% and possessing about 3% of the resource was drawn in stark relief. Although the global economic downturn provided a temporary reprieve, there can be little doubt that a return to economic growth will result in immense pressure on energy prices. Geo-political events have underscored the vulnerability of reliance on limited foreign resources and our further understanding of the environmental impact of carbon dioxide, both in global warming and ocean acidification, has reinforced the urgent need for change.

New technology offers a transformational opportunity in energy. Renewable energy resources, like wind and solar, are far greater than total energy consumption presently served primarily by hydrocarbon fuels. The key challenge for renewable power production is to reduce cost and be able to site the power generationnear consumption.Low cost distributed generation will be an important part of efficiently improving our aged, congested electricity infrastructure which is projected to become further stressed both by continued increase in traditional electricity consumption and potential new load resulting from changes in the transportation sector.[1]

Although many energy technologies have been advanced, and renewable power generation is growing substantially mostly in the form of large wind and solar installations, there remains a great challenge to create cost-effective distributed renewable power. This is an interdisciplinary problem that requires both technology and manufacturing advancements. It is a problem that requires new approaches, such as moving away from traditional semiconductors for photovoltaic cells or changing wind turbine designs to eliminate large wingspan blades. An example of one of these new approaches is the Compact Wind AccelerationTurbine (CWAT), where an aerodynamic structure is used to accelerate wind through smaller turbines, thereby reducing the size of the moving parts by more than a

[1] President's Council of Advisors on Science and Technology, "The Energy Imperative: Report Update", November 2008

factor of ten. Such a technology can open the mid-wind market (100 kW to 1MW distributed units), thereby allowing generation to be sited closer to consumption.

Since renewable power generation generally does not have any fuel cost and has relatively low operating cost, the driving factor for economic competitiveness is the power generation equipment's installed cost relative to the net power produced. Installed cost in dollars per watt of nameplate capacity are typically quoted for each type of device; however, a more relevant metric is dollars per watt produced which is the $/W(nameplate) divided by the capacity factor.

Table 1 Target installed cost for distributed wind and solar generation

Technology	Target $/W (net)	Typical Capacity Factor	Target $/W (nameplate)
Solar (PV)	7.00	15% to 25%	1.05 to 1.75
Wind	7.00	25% to 35%	1.75 to 2.45

Installed cost discussed here is the total cost to the end customer and thus is price as opposed to cost for the equipment manufacturer and installer. The installed cost required to be competitive depends on the local cost of electricity. Achieving the target of seven dollars per Watt (net) will produce a transformational result with broad market penetration of distributed renewable power. This goal is more likely achieved first in the mid-size distributed power market (100kW to 1MW) for powering loads such as commercial facilities, industry, government facilities, and schools.

Realization of these cost targets in sub-megawatt distributed renewable power generation requires new high-risk approaches. Successful products will likely involve a combination of novel design, new product technology, and new manufacturing technology. The high development cost and long development time, combined with the high risk associated with concurrent development of new product and manufacturing technologies, requires government investment along with industry. Although significant resources are being focused on solar power, relatively little effort has be applied to address distributed wind power.

The NIST Technology Innovation Program can play a pivotal role in addressing our nation's and the world's energy challenge by fostering and funding the development of new product and manufacturing technologies that result in cost-effective renewable power generators that are amenable to distributed electricity generations. Success will not only address an immense societal challenge, but will create a large new domestic industry with global leadership.

Societal Challenge and National Need

Energy is integral to our society and prosperity. In fact it is so fundamental that for most people, at normal times, it is hardly giving more thought than we give to the air we breath. Change occurs at glacial rates. Two critical realizations have brought energy to the forefront of our thinking. The first is that our energy economy is unsustainable and that, in healthy economic times, increasing global demand combined with limited supply resource will lead to detrimental price inflation. The second realization, prompted partially by the observation that glacial rates need not be slow, is that the environmental impact of continuing the status quo in energy will negatively impact our planet and quality of life.

The United States consumes approximately 25% of the world petroleum consumption (and about the same portion of the total energy consumption); however we produce only about 10% of the global petroleum production and have about 3% of the world's oil resource. Figure 1 shows the United States' petroleum consumption, production, and imports over the past 50 years. The rapid price increase in oil in the late 1970's is noticeable in the drop in consumption occurring at the end of the 1970's and early 1980's. Note also that this price increase did not result in greater domestic production.

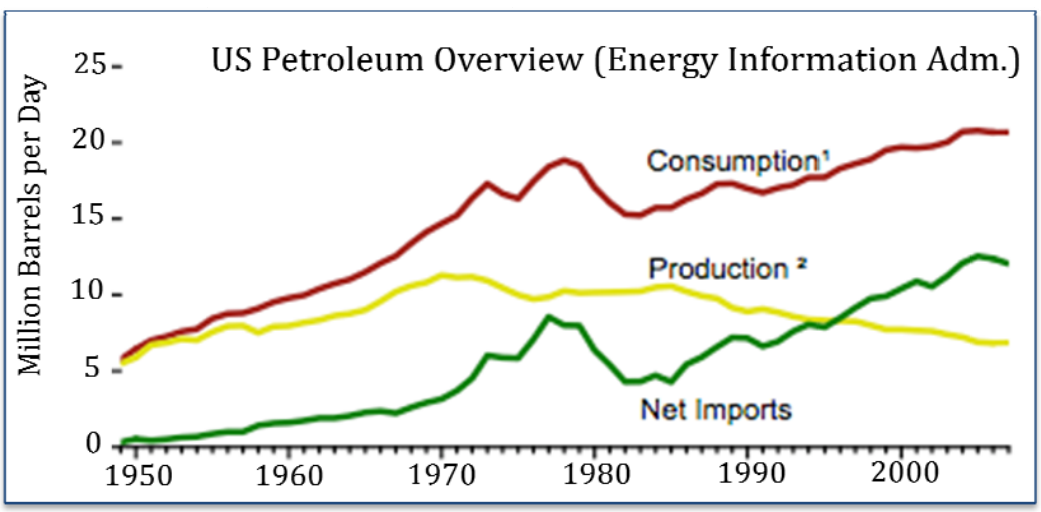
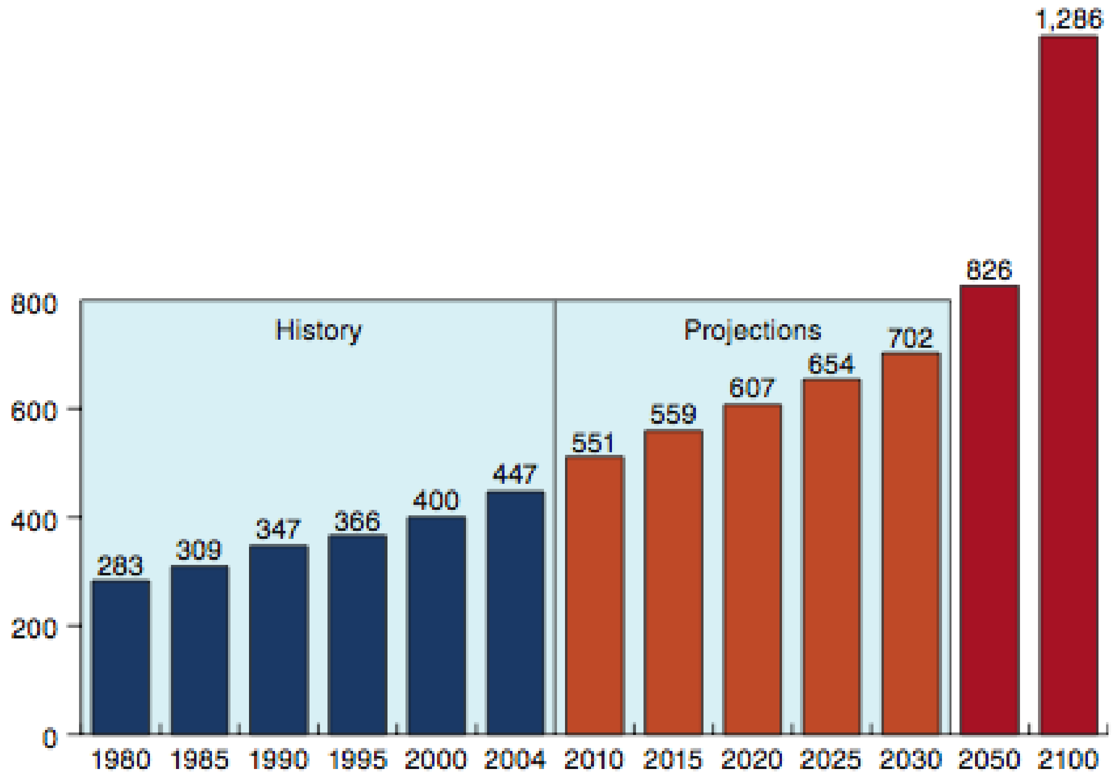


Figure 1 - US petroleum consumption, production, and imports[2]

Figure 2 shows the historical trend and projected future energy consumption. When one considers that our energy sources are primarily non-renewable with limitations on production increase, a doubling of energy demand in 50 years and a tripling in 100 years is an enormous challenge.It is clear that withouta positive shift to a new energy paradigm, supply limitations will negatively impact future productivity and quality of life.
Figure 2 – World energy consumption in quadrillion BTU[3]

[2] Energy Information Administration, Energy Outlook 2008



The Energy Information Administration is projecting that world electricity demand will nearly double between 2005 and 2030.[4] Although the projected increase in domestic consumption is less, it has been pointed out by the President's Council of Advisors on Science and Technology that changes to the transportation sector like the introduction of plug-in hybrid and electric vehicles will add new load to the electricity grid.[5]

Our challenge is not just how to supply cost-effective energy in the face of rapidly increasing demand, but also involves creating a energy system that does not negatively impact the environment and quality of life. Even if hydrocarbon fuel were not limited, we now appreciate that a doubling or tripling of the use of coal and oil would have potentially catastrophic ramifications. The National Academies of Science and Engineering have provided a call to action in stressing the importance

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[3] Ray L. Orbach, U.S. Department of Energy, "Basic Research and America's Energy Future," presentation at the Summit on America's Energy Future on March 14, 2008; data on consumption through 2030 from EIA (2007) and after 2030 through 2100 from IPCC (2000; Figure 8)

[4] Energy Information Administration, International Energy Outlook 2008, DOE/EIA-0484 (2008)

[5] President's Council of Advisors on Science and Technology, "The Energy Imperative: Report Update", November 2008

of addressing global warming as we address our energy challenge.[6] Carbon dioxide emissions resulting from power generation with traditional hydrocarbon fuels is contributing to global warming and ocean acidification. Over the past few years, public opinion has caught up with scientific understanding that it is imperative that CO2 emissions are addressed in our future energy solutions.

In addition to consuming fuel and emitting carbon, traditional power generation also consumes vast quantities of another limited resource - fresh water. A transition to in the United States to 20% wind energy is estimated to save 450 billion gallons of water annually.[7]

Another important challenge associated with a new energy paradigm is energy distribution. The US electricity grid is old, with capacity limitations that have led to reliability problem during periods of peak demand. Further increase in demand, particularly in more densely populated, geographically constrained regions such as the coasts, will likely overstress the existing infrastructure. Many envisioned scenarios, like substantial increases in large central wind farms, will add new stresses to the electricity grid. In fact the DOE estimates that the addition grid investment required for a 20% wind scenario, where most of that wind power is in the form of central large wind farms, will cost $20 billion (seefig.3).[8] Bringing low-cost renewable power into the energy mix in the form of distributed power generation reduces the stress on the electricity grid. The congressional budget office has stated, following EIA forecasts, "But there are reasons to expect that distributed generation could meet a significantly greater

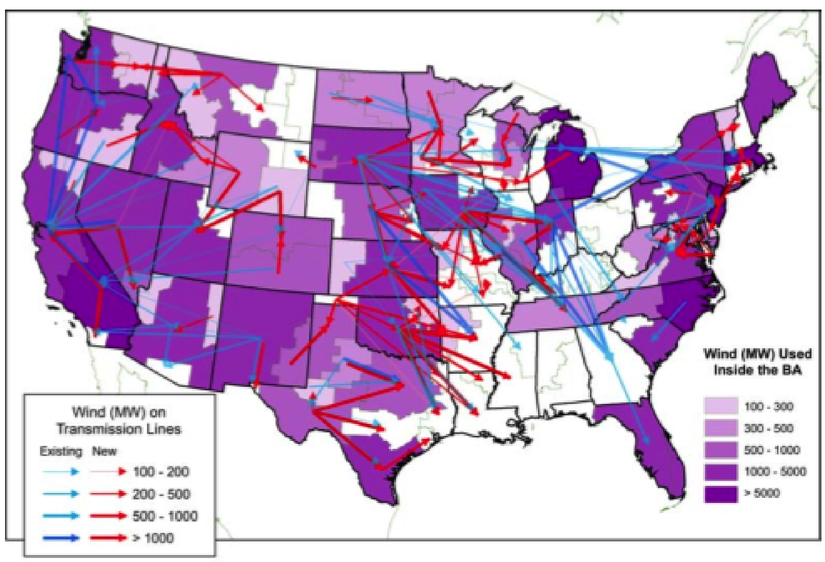

Figure 3 – A grid scenario for 2030 assuming 20% wind for large wind farms.[8]

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[6] The National Academies Summit on America's Energy Future: Summary of a Meeting (March 2008)

[7] US Department of Energy – 20% Wind Energy by 2030, DOE/GO-102008-2567, July 2008

[8] Hand etal., "Power System Modeling of 20% Wind-Generated Electricity by 2030", NREL/CP-500-42794, June 2008

portion of future electricity demand in the United States, at costs that could compete with those of generation from new central power plants."[9]

Low-cost, renewable, distributed power generation addresses these important societal challenges. The United States has an opportunity to establish global leadership in this import new industry, thereby increasing our economic competitiveness, enhancing our domestic economy, and creating numerous, much discussed, "green jobs." Creating the required breakthrough technology and manufacturing processes should be a national priority and warrants significant government attention. A discussion of research, technology development, and manufacturing development needed to address these challenged is found in the next section (Solution Path). The magnitude of the research challengesare large and the timeframe is critical, requiring public/private cooperation. Many companies have efforts underway; however, due to the high risk, long timeframe and high capital intensity of development in the energy industry, these efforts are smaller and more diffuse than is appropriate. Although a number of government entities are funding research in renewable, distributed power generation, NIST TIP can make an important contribution. This is because funding for novel concepts likely to break the cost barrier has been small and the problem is highly interdisciplinary, requiring a perspective of technology and manufacturing.

[9] Congressional Budget Office, "Prospects for Distributed Generation" 2003

Solution paths

Widescale application of distributed, renewable power generation will have a transformational positive effect to our energy system. The key barrier to broad market penetration is achieving sufficiently low capital equipment and installation cost so that the realized electricity cost is competitive with the existing grid (cost of central power generation plus distribution cost).

Since renewable power generation generally does not have any fuel cost and has relatively low operating cost, the driving factor for economic competitiveness is the power generation equipment's installed cost relative to the net power produced. Installed cost in dollars per watt of nameplate capacity are typically quoted for each type of device; however, a more relevant metric is dollars per watt produced which is the $/W(nameplate) divided by the capacity factor.

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Installed cost discussed here is the total cost to the end customer and thus is price as opposed to cost for the equipment manufacturer and installer. The installed cost required to be competitive depends on the local cost of electricity. These goals are exceptionally challenging for residential power production in the near-term, but are potentially achievable in mid-size range distributed power devices (100kW to 1MW size). Achieving the target of seven dollars per Watt (net) will produce a transformational result with broad market penetration of distributed renewable power by creating a substantial portion of our power inexpensively, cleanly, and locally at industrial, commercial, and government facilities.

A number of new technologies have the potential to be developed into low-cost renewable distributed power generators. Although wind and solar technology are leading candidates, many technologies should be considered. It is likely that novel approaches will be required as more established renewable power generators, such as three-blade wind turbines and silicon photovoltaic, are not well suited to achieve the cost goals in distributed applications. Examples of candidate technologies include:

1. Novel distributed wind turbine designs for the mid-wind market. For example Compact Wind Acceleration Turbines (CWATs) that are devices that utilize aerodynamics structural design to accelerate wind through smaller turbines.
2. Thin film solar technology utilizing new materials and/or application technology and novel concentrated solar technologies.

3. Novel low-grade heat to electricity technologies like some versions of organic Rankine cycle technologies.

Although the particular research programs are unique to the technology, manufacturing processes, and products being developed, a NIST TIP program in this area will stimulate the Nation's scientific frontiers in the areas of advance materials and manufacturing technologies. Taking the development of CWATs as an example, we see that numerous material and manufacturing advancements are involved. A number of companies and research organizations are pursuing accelerated wind turbine technology. The Optiwindconcept is shown in figure 4. By accelerating available winds around its structure and harnessing that enhanced power with a series of individually mounted 5-bladed fans, the CWAT enables customers located in wind areas as low as Class 2 to economically deploy wind turbines for distributed generation. And, with roughly 20% of the US land area located in Class 2 winds, this significantly enhances the size of the available market for wind energy. To realize the installed cost targets in Table 1, numerous material and manufacturing advancements are required. New high strength-to-weight ratio materials and designs are important to reducing cost. These include metals, plastics, and composites. Manufacturing technologies include new molding and forming processes, such as forming parts out of high strength steels, making unique structural shapes from low cost polymers, and extending the size capability of injection molding. As an aside, it is interesting to note that the manufacturing technology for large wind turbines was developed in Europe, giving market dominance to European companies and resulting in the American companies still importing blades from Europe. Other advancements likely to be developed in manufacturing technology by a CWAT program include new assembly technologies to automate steel and plastic fabrication. This research leverages US technology leadership position in areas like fans and aircraft engines, helping to develop this new technology and potentially advancing those fields. Other technologies that are likely to be advance by distribute power programs include thin film manufacturing, low cost optics, semiconductors, and electronics.

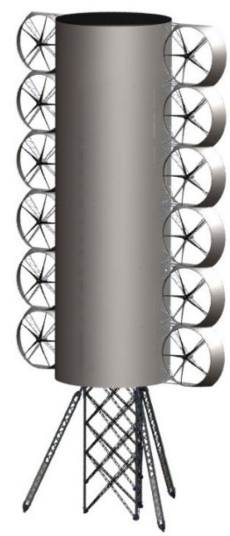

Figure 4 – Optiwind CWAT

NIST is in a unique position to accelerate the technology and manufacturing innovations required to develop and deploy low-cost, renewable, distributed power generation. A NIST Technology Innovation Program in this area will advance key technologies and, if successful, will result in US leadership in a vital new industry with vast benefits ranging from energy security, improved environment, stable low-cost domestic electricity, an economic vitality through the creation of green jobs.