MASS CUSTOMIZATION OF WARP™ WIND POWER PLANTS

The Next Generation of Wind Power Plant

INTRODUCTION

Steady development of wind power technology and the accumulation of extensive operating experience with large clusters of electric utility connected turbines have resulted in the emergence of wind power as a viable and attractive source of electricity for utilities. A highly effective modular wind power technology, the Wind Amplified Rotor Platforms (**WARP™**) System, which utilizes many identical vertically integrated wind amplifier modules with standard propellor-type (HAWT) commodity mini-wind turbines, is proposed as the basis for mass customization (capacity and configuration) of wind power plant design and construction. WARP wind power brings the fundamentals of mass production as well as economies of scope to power plant design and construction. It can blend well with progressive engineering & construction (E&C) firm approaches which are predicated on a family of standardized designs to reduce ris k and cost, plus improve schedule, quality and reliability of units deployed. Since electricity has become the new world commodity with an imperative of low-cost, high-quality and reliability, and environmentally responsible energy, WARP Systems designs are proposed to meet these objectives through its inherent efficiency, mass customization and mass production features. WARP system's ability to integrally operate with photovoltaics, gas turbines or fuel cells provides also the opportunity to generate baseload power in an environmentally responsible manner, particularly when applied offshore.

Capturing the efficiencies of mass customized WARP wind power plant stems from years of R&D in conjunction with Rensselaer Polytechnic Institute and the New York State Energy Research & Development Authority (NYSERDA) and others such as the Technical University of Graz, and the Danish Maritime Institute which was commissioned to test WARP by NEG Micon, just prior to near insolvency due to gearbox problems (a recurring industry problem). It extends well beyond that of the conventional wind turbine approach as well as that of the engineer-constructor approach to power plant design and construction which has to date been essentially an individual tailoring of each plant as shown hereafter.

The Wind Amplified Rotor Platforms (WARP™) System

The Wind Amplified Rotor Platform (WARP™) system configuration consists of stacked aerodynamic modules about a core lattice tower. It differs dramatically from the traditional single, large-diameter horizontal-axis windmill rotor, generator with typically large gearbox mounted on a tower. Yet this world wide patented "smart tower" wind power design draws heavily on the latest technology developments of today's conventional large diameter, high-efficiency horizontal-axis wind turbines (HAWT), but without their inherent risks and drawbacks. Multiple peer reviews by numerous organizations including the IEEE have corroborated the veracity of this approach to wind power.

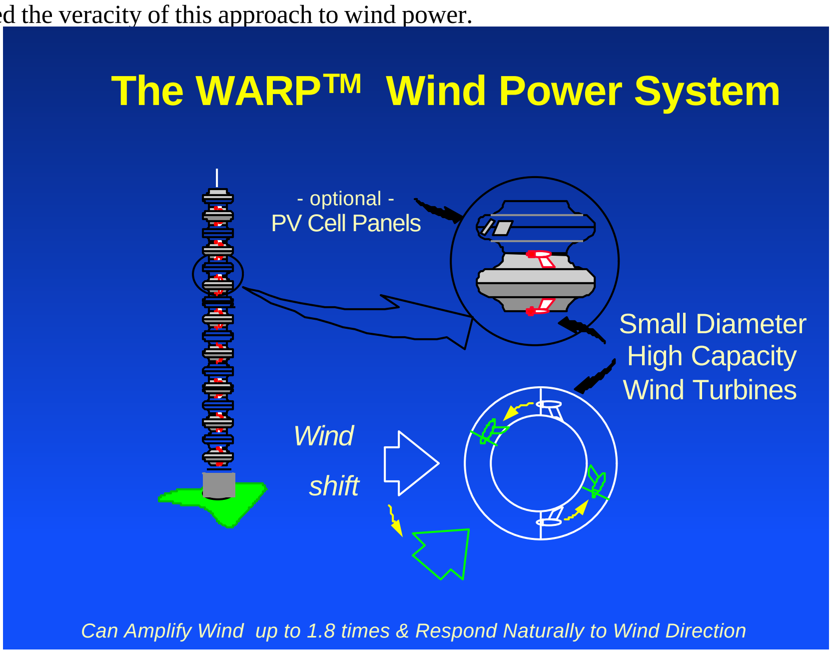


Fig. 1a The WARP Wind Power System

A WARP system is conceptually illustrated in Fig. 1. However, unlike conventional wind turbines, which stress ever larger diameter rotors for increased energy capture, a WARP system amplifies the ambient wind speed, through its multi-tasking aerodynamic modules or wind frames, to simple, standardized commodity horizontal axis (propeller-type) wind turbines.

Each modular wind frame provides highly amplified wind flow fields from over 50% to 80% over free air wind speed to each conventional, small diameter wind turbine of no more than 1 meter to 3 meters in diameter. Each module also serves as a support for the wind turbines, a yaw assembly and protective housing for the core support tower and other internal sub-systems.

WARP systems can be flexibly and incrementally deployed into multi-megawatt size wind power plants without turbine redesigns. While heavily building on proven windmill technology, WARP systems may be shown to surpass current technology windmills in all aspects of system characteristics. WARPs have improved performance as a result of amplified gearless and shrouded turbine operation capability. Other benefits include greater tower heights for access to higher energy winds. It is user-friendly in operation and maintenance characteristics and has high reliability and low risk features due to its small, simple and robust turbine components.

Environmental benefits include an order of magnitude less land requirement compared with conventional windmill wind farm installations of equal energy capacity; less susceptibility to lightning damage; virtual absence of bird kill potential, attractive appearance, lower far field noise and EMI/TV interference, and improved rotor safety through optional containment means.

Operation under extreme icing is improved due to both rotor shielding and inherent self-sustaining tower anti-icing capability. Destructive rotor imbalance and ice shedding predicaments possible with large rotor conventional windmills are thereby avoided. System components are well suited for low cost mass production, ease of transportation, erection and servicing. Also, spare parts can be easily stored within the tower base housing structure.

Another extraordinary feature is that WARP turbine generators can be made internal to modules. This can isolate rotor thrust and vibratory loads from the generator and it can also allow optimizing rotor to generator speed matching through very small RPM step-up. It also provides ready internal access to the generator for ease of servicing. The ability to link a set of rotors to a single internal generator opens further cost and operational benefits.

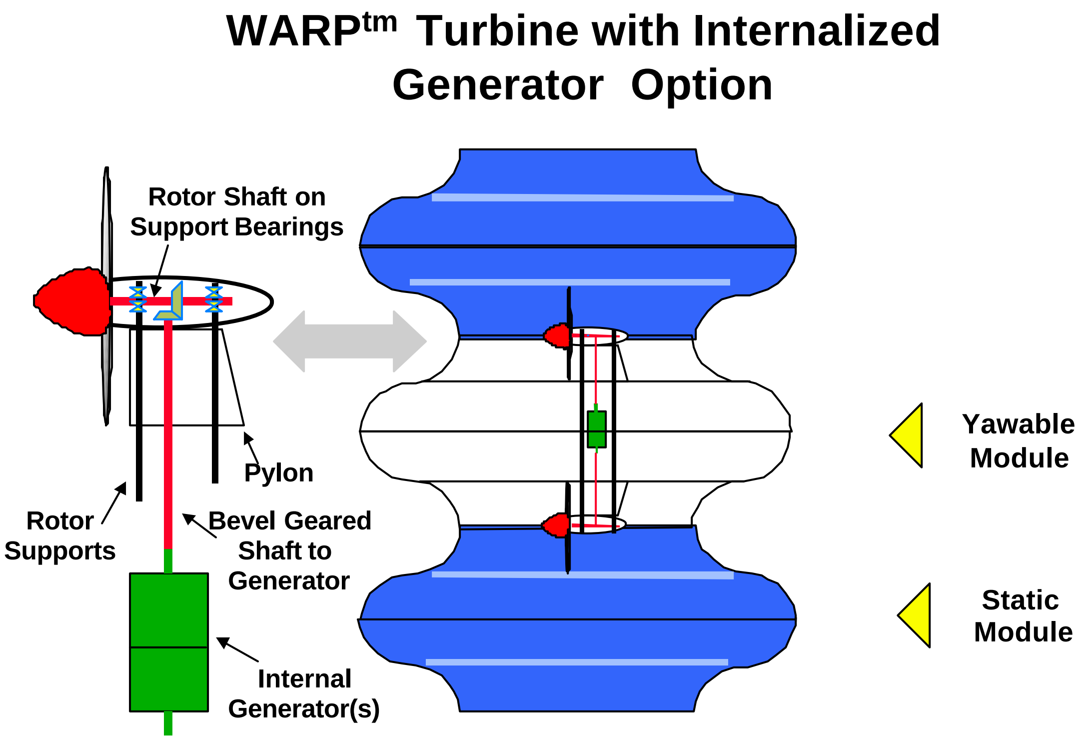


Fig. 1b Internal WARP Generators Can Provide Added Optimization, Access & Cost Benefits

The combination of wind amplification, multi-tasking use of its structure, and low cost mass production of manageable size components projects WARP to be an exceptionally economical system.

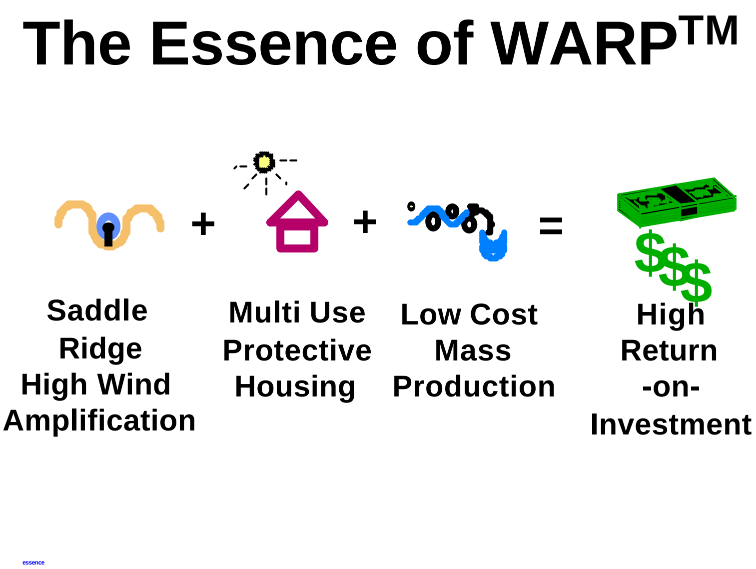


Fig. 2 The Essence of WARP Wind Power Leads to Excellent Rates of Return

WARP MASS PRODUCTION DESIGN

The increasing power demands of the new global economies around the world is resulting in electricity becoming the new world commodity, presenting enormous opportunities for many companies. Consequently, a common business imperative has emerged for the need of environmentally responsible low-cost, high-quality energy that provides operators and developers with the greatest potential for a return on equity. One solution to this challenge is predicated chiefly on the design and construction of reliable, low-cost generating plants; in other words, the concept of "mass customization." Along this line of reasoning, WARP wind power systems emerge as a uniquely qualified power plant design for mass customization whereby one can achieve the economies of mass production and also provide the flexibility needed to individual plants and owners.

Allegedly recognizing the beneficial features of the WARP system design, including the efficiencies of mass production, Garrad Hassan & Partners, Ltd., the prestigious and highly recognized wind energy consulting firm in the UK, has recently presented the WARP™ windpower system design to at least one leading wind turbine manufacturing client for consideration as a next generation wind power plant. Although GH&P, to remain objective as a consultancy, cannot be expected to endorse any technology and, therefore, qualifies its presentation with the proviso that the "jury is still out" on WARP, however they appears to recognize the extraordinary and common sense features and benefits of this exceptionally versatile technology.

Mass production has long been recognized as an effective means of reducing a product's unit cost. It has enabled manufacturing companies around the world to produce high-quality products that leverage the economies of scale based on division of labor and automated, standardized components and processes. The principle drivers are the learning curve and the bulk purchasing power afforded by large quantity of identical components. Cost and cycle time can be reduced even further by extending the approach to suppliers and also incorporating the buying power of bulk material procurements.

While theories of mass production have guided the manufacturing industry for decades, engineering, procurement and construction (EPC) firms in the power industry have remained in large measure a custom business. Most EPC firms continue to approach plants as one-of-a-kind efforts, designed by project teams that are assembled and disbanded as jobs open and close. In some states and countries deregulation and a more competitive environment are forcing change rapidly, including consolidation among EPC firms.

The modular WARP systems design., in contrast to today's typical power plant and megawatt size windmills, is ideally suited to provide not only standardized sub-components and modular repetitive sub-assemblies for mass production and procurement benefits, but also brings a significant measure of value in terms of environmentally clean power to both customer and locale in which it is being operated.

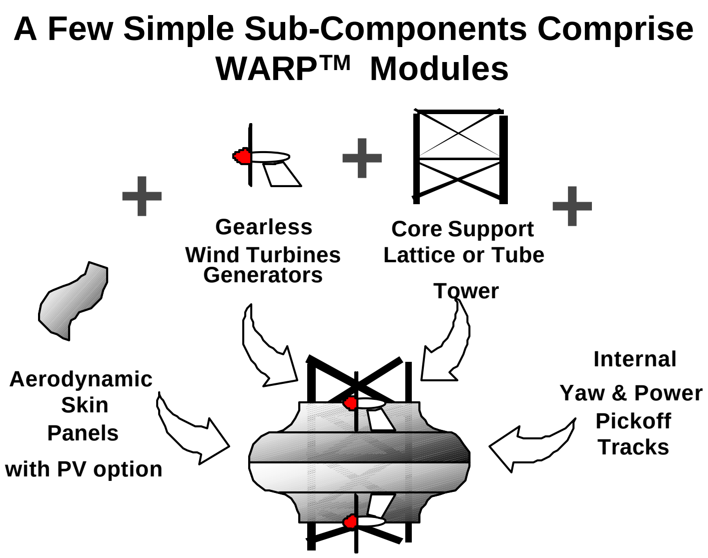


Fig. 3 Mass Producibility of WARP Systems

This system design meets one of the prized key principals of mass customization criteria; namely, modular design. Its mass production will find economies in production of large number of deliverables that are essentially identical - i.e.; the WARP windframe modules with standardized wind turbine rotors. ***Effectively no redesign is required for producing differing capacity systems!***

Production definition can be deconstructed into smaller, standard modules that can be aggregated rapidly to define the overall power plant given the site specific energy needs and wind and solar resource characteristics.

It is worthwhile to invest considerably in configuring the base design to achieve the lowest cost both with respect to life-cycle as well as capital cost. This is achieved by investing in those components that directly contribute to the efficiency or availability of the plant, such as the aerodynamic WARP windframe and the turbines, while optimizing the plants physical size for accommodating all the necessary equipment. For example, one can conceivably have the same WARP power capacity resident in a relatively short, stocky tower assembly versus a higher slenderness ratio taller WARP tower which may be less material intensive. The favorable trade for the latter comes in large part from the added wind energy resource available at higher elevations.

It is also important to recognize that base designs in themselves are continuously updated as improvements are fed back from lessons learned from operational projects or as unique requirements are imposed as they might for extraordinary environments such as those having high salt air, or arctic or high particulate conditions.

A WARP wind power system also provides the opportunity to operate autonomously or in a baseload manner in conjunction with fuel cells or gas or micro-turbines or other generators *within its base* with large fuel and O&M savings along with little or no emissions.

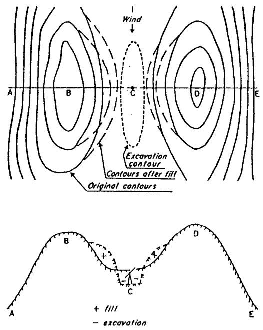
Fundamental WARP Performance Check:

The following calculation is provided to assess the performance of a WARP turbine system in a modest wind site. A fundamental and conservative approach is used which does not account for the added benefits of partial tip shrouding and WARP flow field shear which can enhance typical power coefficients over free air turbines. Instead, by using conventional wind turbine parameters, it projects the WARP system to operate conservatively within the bounds of the Betz limit.

Calculations are made on the basis of a one rotor level (RL) (i.e.; includes two turbines with adjacent associated aerodynamic WARP module amplifier structure for energy capture). This single 'RL-module' approach is used to avoid introduction of and compensation for the significant non-linear wind shear benefit on performance over an entire WARP system height. Since each module can be handled discretely (separately), total WARP system performance is merely the sum of the performance of individual RL-modules at each level (elevation) location.

Each WARP module level is effectively a customized omni-directional saddle ridge site. In nature, saddle ridges are known to be great amplifiers of the wind. Fig. 4 is a proposed tailoring of such a natural site.

Nature's Ideal Wind Turbine Site
Per the Mitre Corporation



PROPOSED TYPE OF TERRAIN MODIFICATION FOR THE PURPOSE OF AUGMENTING AVERAGE WIND SPEEDS

Source: NSF RANN Report, Oct 1975

Fig. 4 A WARP Improves on Nature's Desirable Saddle Ridge Site for a Wind Turbine

For this example, a WARP system height of 60 m is assumed with turbines of 9.85 ft. (~3 m) diameter and module configuration of d/D=0.42, where d=wind turbine rotor diameter and D=the WARP module minimum ('waist') diameter.

In general, the energy available to any wind energy recovery device is directly proportional to the area of the system in question and the local wind speed cubed.

Power in the wind (kW) = 0.5 * density of air * projected area * wind velocity cubed

A WARP "RL-module" projected area, with two ~3 m (actually 9.85 ft.) turbines on a toroid shape amplifier module with d/D=0.42 and module height =1.66d (where d = the rotor diameter and D = the minimum waist diameter of the module) includes the shroud projection area plus the 2 rotor disk areas. This projected area of a "RL-Module" and two turbines amounts to:

$$\mathbf{A = 671\ ft^2 = 62.34}$$

Rated Wind Speed Energy Availability: Assuming a 20 m reference height and site mean wind speed of 6.0 m/s, the rated wind speed impacting the WARP ***system*** [RL-module] at an average "hub height" of the specified system module with turbines [taken to be at ~60% of total system height or at ~35.8 m (118 ft.) height] with 0.16 wind shear factor, is:

$$\textbf{Rated } V_{\text{hub height}} = V_{\text{ref}} \textbf{ * Shear factor to height * Rated wind speed factor}$$

where the Rated Wind Speed Factor is typically known to be ~2 to 2.5 times mean wind speed (assume 2.2 here) for best energy capture.

$$\textbf{Rated } V_{\text{hub height}} = \textbf{6.0 m/s * 1.10 * 2.2 = 14.52 m/s}$$

<u>Power in the Wind</u>: At rated hub height wind, using these values in the above power output in kilowatt (kW) in the wind relationship yields (assuming density of air = 1.226 kg/m3)

$$P_{\text{in wind}} = \textbf{117 kW}$$

Power Output Calculated for the noted "Hub Height" Turbine on "RL-Module": The rated power output in kilowatt (kW) of each ~3m diameter WARP conventional horizontal axis type propeller turbine, assuming a rated turbine power coefficient of O.2, which is subjected to system hub height winds amplified by the WARP module 1.7 times, or:

$$[V_{hub\ height} * 1.7] = [1.7*14.52]$$

yields:

<u>WARP Turbine Rated Power</u> (kW) = Cp_{rated}*0.5 * density of air * Turbine Disc Area * Velocity to Turbine cubed

$$= 0.2*0.5*1.226*0.25*pi*3^2 * [1.7*14.52]^3 = \sim 13 \text{ kW (single turbine)}$$

Since a "RL-Module" has 2 Turbines on a single level:

$$P_{RL\text{-"Module"}} = 2 * P_{turbine} = 2 * 13 = 26 \text{ kW}$$

The effective efficiency (Cp) is given as:

$$\text{WARP "RL-Module" Efficiency (Cp)} = [P_{RL\text{-"Module"}}]/[P_{in\ wind}] = 26/117 = .22$$

This is a typical <u>rated</u> (i.e.; at rated wind condition) level wind turbine efficiency or power coefficient (Cp) value and also well within the Betz limit.

Required Real Estate Reduction:

A WARP wind farm may require about 70% to 80% less real estate compared to that of a large bladed conventional windmill wind farm with an equal quantity of energy output. It also has a less animated (annoying disco effect) appearance. Land reduction comes from large energy capture capability with tall WARP units and the associated smaller unit spacing needs as a result of shortened downstream flow perturbation from its small rotors. The ability to deploy WARP structures much taller than is possible with conventional windmills is a paramount benefit. WARPs can be as tall as any HDTV tower and can have greater safety margin with equal core tower structure due to lower survival wind loads resulting from its aerodynamically faired structure and weathervaned turbines. In Fig. 5, WARP

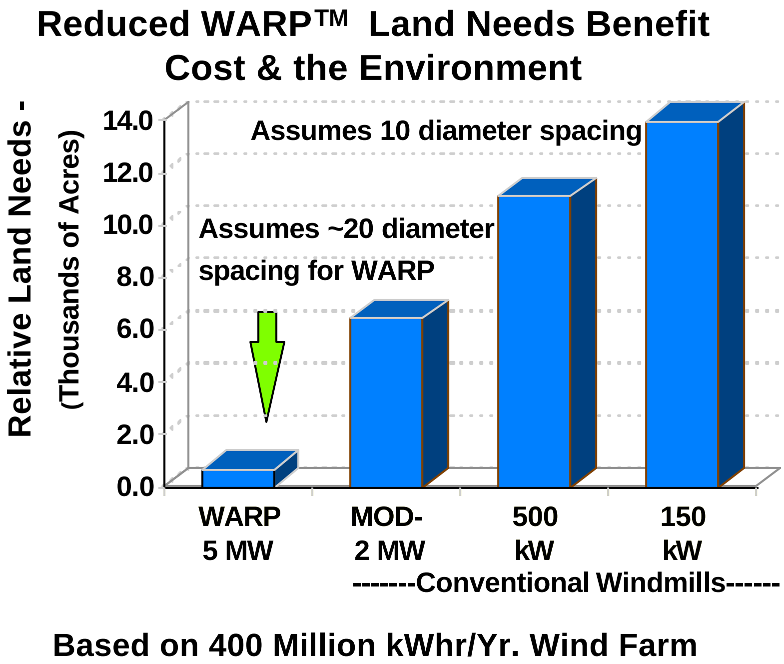


Fig. 5 WARP Reduces Land Requirements

spacing is assumed a conservative 20 times the maximum module diameter. WARP construction and maintenance can be accomplished by moderately skilled labor. This can provide added cost benefits and aid local economies for added community support.

Performance & Cost Parametrics:

Below are performance curves based on a 6 ft. (~3m) WARP turbine diameter and the stated assumptions. The WARP costs shown in the figures are based on US labor rates.

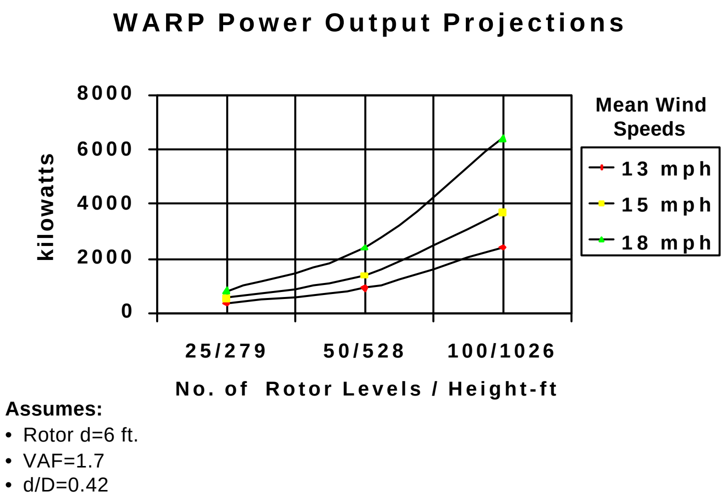


Fig. 6 WARP Power Capacity can be Readily Tailored Without New Turbine Designs

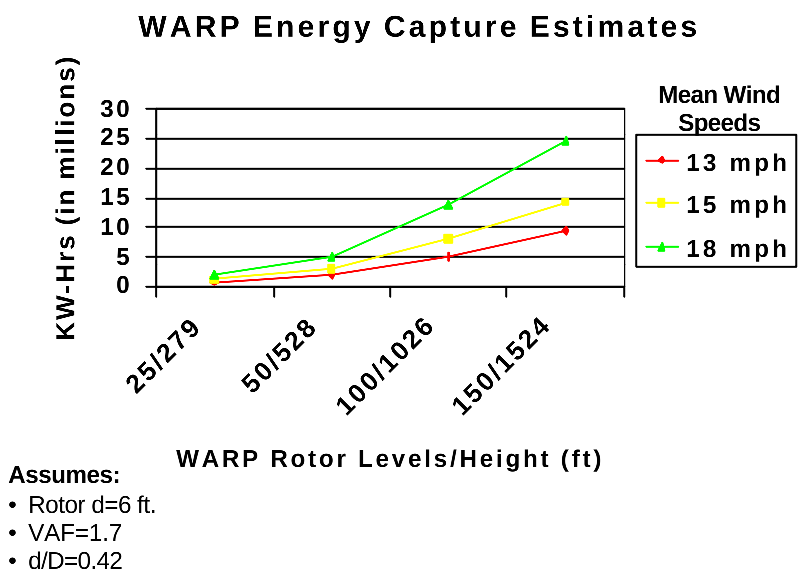


Fig. 7 WARP Energy Capture is Enhanced by Access to Greater Heights

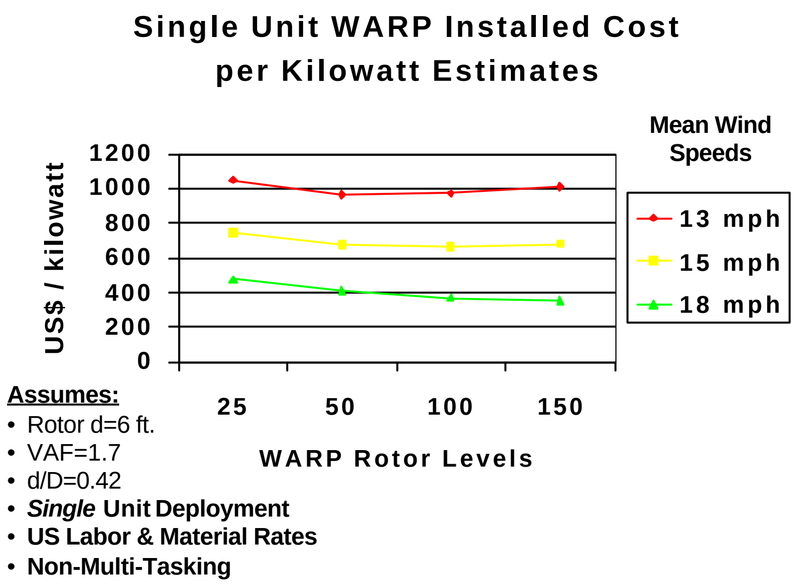


Fig. 8 WARP Costs can be Further Reduced by Local Labor Rates

Roughly 80% of WARP cost resides in general construction and common structural components versus complex, costly and sophisticated large rotor heads as on conventional windmills. When accounting for much lower labor cost in other countries where at least 50% to over 80% of WARP sub-systems can be readily fabricated and assembled for local deployment, system cost can be significantly lower yet. This can aid also the local economy and local market access.

SUMMARY

Based on WARP systems' propensity for mass customization and lower sub-system complexity, it provides economic benefits in power plant design and construction not readily found in traditional power plants and large bladed windmills. WARPs are also environmentally attractive and manage to resolve many critical issues facing electric power plants today, including those of big bladed conventional windmills. Key features of WARPs, especially in comparison to today's conventional wind turbines, are:

- Low cost mass production with minimal tooling investment;
- No turbine redesign required to change system capacities;
- Better performance capability;
- Reduced risk and liability;
- More user-friendly servicing and reliability;
- Free warehousing space for spares equipment, etc in base housing;
- Greater environmental benefits such as:
  - No pollutants;
  - Greatly reduced land needs;
  - Readily deployable offshore with integrate fuel cells &/or optional PV at reduced cost;
  - Essential absence of EMI/TV interference;
  - Lower risk and far-field noise;
  - Attractive appearance (no disco effect);
  - Virtually no bird kill potential;
  - Improved safety;

The synergistic impact of these WARP system benefits can generate attractively low cost energy and excellent return on investment for system manufacturers and end users.