# Composites for Renewable Energy

Eric Greene
www.EricGreeneAssociates.com

**Abstract**
In today's global economy, the United States can boast about our high productivity rates (needed to offset high labor costs) and world-leading innovation. However, we are somewhat disadvantaged in the short-term when competing against countries with state-controlled industries that benefit from price controls, low labor costs, and direct subsidies. Although it is the antithesis of our free market system for the Government to pick "winners or losers" from our industrial pool, the current challenges with the economy, global warming and energy security necessitate some long-range planning and Government involvement. Indeed, we can proudly look at national achievements from nuclear power to the Internet as examples where Government research and development (R&D) funding has yielded benefits that are orders of magnitude greater than the initial investment. In the current environment of increasing partnerships between industry and Government, we should expect to see an accelerated transformation from the laboratory to market of new technology.

Composite construction refers to any structure with two or more distinct materials that are combined to create an engineered product with properties "greater that the sum of its parts." Most people recognize fiberglass - fiber reinforced plastic (FRP) with E-glass as the reinforcing fiber - as the most common form of composite construction. Higher strength composites utilize carbon fiber as a reinforcement. Composite construction has developed primarily to support recreational boats, although construction and aerospace applications are now ubiquitous. The engineering expertise, experienced labor force and established material supply chains for construction of large composite structures in the U.S. is adroitly suited for development of renewable energy structures. This paper will explore current and future opportunities to diversify our recreational and industrial composites industry for renewable energy applications.

**Background**
The global composite products market reached $56 billion in 2007 according to Sean Lofgren of Lucintel. Data from the American Composites Manufacturing Association (ACMA) suggests that the U.S. has about a 30% market share. U.S. composite manufacturers employ 125,000 people and impacted suppliers and manufacturers employ another 338,000. In 2006, the U.S. manufactured over 4 billion pounds of composite structures. By weight, the breakdown of composite construction by industry is as follows: construction (45%), marine (20%), corrosion (12%), transportation (12%), sporting goods (5%) and aircraft (2%) [1]. Note that segments of the marine, sporting goods and especially aircraft industries represent a significantly higher percentage on a dollar basis as the product complexity and materials utilized are more high-tech. Although different market segments have gone up and down over the years, composites recently have seen more growth than aluminum or milled steel products. However, the current economic downturn has hurt the construction and marine industries severely.

The U.S. is responsible for building some of the largest composite structures in the world. Goodrich reports that they build surface sonar domes that weigh over 20,000 lbs (submarine domes can weigh over 40,000 pounds) and their facility in Jacksonville, FL has built composite structures weighing more than 100,000 lbs. [2]. For comparison purposes, DIAB reports that a 50 meter wind turbine blade weighs about 40,000 lbs. As an example of U.S. composites manufacturing capability, Christensen Yachts has plans to build a 186-foot motor yacht in a new facility in Tennessee (see Figure 1). The size, structural demands and complexity of composite structures built in the U.S. has positioned us well to undertake the construction of large structures envisioned for renewable energy devices.

Wind turbine blades are ideally suited for composite construction, as lightweight, complex airfoil shapes can be produced from molds with minimal labor input. Indeed, engineering and manufacturing processes for producing composite wind turbine blades is quite mature. However, the challenges of producing larger blades (and mass producing smaller ones) leaves room for development of improved design and manufacturing as we learn from systems that have already been fielded.

The greater opportunity for established U.S. composites fabricators may rest with newer renewable energy concepts that are now on the drawing board or in the prototype stage. The economic viability of composite construction increases with the number of units produced, where the cost of design development and tooling can be amortized. For large renewable energy devices, the reduced weight of composite components when compared to metallic construction can greatly reduce transportation and erection costs. Perhaps the biggest advantage of composites for large energy projects is reduced maintenance costs over an expected 20-30 year service life. For large, unmanned engineered structures, corrosion resistance will be paramount for long-term economic viability.

So the stars are aligned for us. We have an emerging market that will need large, engineered structures that can withstand environmental degradation. The U.S. has a leading-edge composites fabrication capability with a diminishing demand for the products they produce. However, composites fabricators operate in a very competitive environment that leaves little room for internal R&D that would facilitate a smooth transition to the energy industry.

The U.S. military/industrial partnership was very efficient during the Cold War, although today it is viewed as an inefficient, bloated enterprise. However, for focused technological challenges, the evolved system of partnerships between academia, industry, Government laboratories and end-users continues to serve the country well. The composites industry has no "big players" comparable to today's defense giants and has for the most part been left out of the renewable energy revolution. With a minimal amount of guidance from Washington and directed R&D funding we can provide the "green jobs" promised by this year's politicians by exploiting an industry where the U.S. is already a world leader. We also have the advantage of participating early on in the process as a new administration in Washington is developing both renewable energy and economic stimulus policies.

## Opportunities

Renewable energy collection devices fall into two broad categories. First, are the large municipal projects that we commonly considered our primary source for energy. Because renewable energy doesn't require a centralized generation plant, energy collection devices can also be distributed at the household level. Composite construction looks attractive at both scales. For the largest structures, composites allow us to build lighter weight, maintenance-free components. With ocean renewable projects, corrosion resistance will be paramount. For "consumer" level devices, the ability to cost-effectively mass produce complex shapes from molds is attractive. Indeed, industrial designers have embraced the notion that complex geometric forms are easily reproduced using composite materials. This attribute has allowed engineers to literally think outside (or beyond) the box to create non-planar forms with a fewer number of assembled parts. As we consider existing or proposed renewable energy solutions, this design flexibility will become apparent.

## Wind Turbine Blades

Over 15,000 new wind turbines were installed worldwide last year, up 26% from the previous year. Over 440 million pounds of composite material was used to build the blades, valued at over $4 billion [3]. The U.S. Department of Energy's office of Energy Efficiency and Renewable Energy reports that the U.S. share of that market for 2007 was 27% [4]. Table 1 shows data for some recently-started manufacturing facilities in the U.S., which generated almost $1 billion in international investment to help overseas companies tap into the underdeveloped U.S. wind energy market. To minimize transportation costs, manufacturers like to produce blades as close to wind farm sites as possible.

A study from the National Renewable Energy Laboratory (NREL) indicates that we will need between 50,000 and 500,000 new wind turbines in the U.S to achieve wind power penetration targets of 10%-40% in the 2020 to 2030 timeframe [5]. At the time of the report, it was estimated that about 20% of the fiberglass manufactured in the U.S. would be required to meet this goal, prompting a need to increase domestic production. However, the recent downturn in other industries that use fiberglass (construction and marine) may provide an opportunity to meet these goals at current production levels.

We have the fasted growing wind energy market here in the U.S. but are mostly relying on the expertise and investment of foreign companies to build turbine blades. An indigenous capability exists to manufacture large composite blades and it has some historical precedence. Builders of large, custom yachts have been able to successfully transition to wind turbine blade manufacturing. Abeking & Rasmussen is one of Germany's most renowned builders of luxury yachts and has built more than 6,000 ships and boats since 1907. In the 1980s, A/R Rotec began constructing composite wind turbine blades and is now at the forefront of manufacturing technology in Germany.

In the U.S., TPI Composites started as a builder of quality production sailing yachts in Warren, RI. They were among the first to use resin infusion manufacturing, which is now commonly used to mold wind turbine blades. Based on the manufacturing capability developed to build high-quality yachts, TPI transformed its business focus to serve the military and wind energy markets. They currently have manufacturing facilities in Iowa, Rhode Island, Ohio, Mexico and China. Knight & Carver is a San Diego-based custom yacht builder who stumbled into the wind industry quite accidentally. As a result of their experience with large composite structures, they were approached to repair a wind turbine blade. According to the company's web site, since that time, Knight & Carver's Wind Blade Division has repaired and rebuilt thousands of blades and has fabricated hundreds with facilities in California and South Dakota.

All three of the builders cited had stellar reputations for building quality yachts before they ventured into the wind power industry. A familiarity with composites design, materials, manufacturing processes, testing and quality assurance made the transition a logical one. There are a number of other quality yacht builders in this country who could help to meet the anticipated increased demand for domestic wind turbine blades. As is apparent from Table 1, turbine blade manufacturing must be near installation sites to be competitive. Yacht builders typically are located near our nation's coasts and therefore may need to establish satellite facilities in the heartland. The good news is that aside from floor space, wind turbine blade production is not all that capital intensive.

**Wind Turbine Housings**

The generators that convert the mechanical energy of wind turbine blades to electricity sit on top of massive support towers and are encased in wind turbine housings. These housings need to be lightweight, low maintenance, and preferably aerodynamically streamlined. Composite construction has been the obvious choose for these components and has served the industry well. There have been some very isolated incidents where accidental fires have destroyed composite housings. This presents an opportunity to leverage composites technology recently developed for the mass transportation and marine industry with regards to passive structural fire protection [6].

Composite turbine housings are not as structurally demanding as the blade assemblies are. Therefore, these components can be manufactured by fabricators that have expertise with low-cost, volume production. This will ensure that opportunities in the renewable energy field are available to the entire industry and not just the elite, high-end specialty fabricators. Indeed, a mix of manufacturing processes will be required to produce wind turbine assemblies that are cost-competitive on the global market.

**Towers**

Wind speeds increase the further away from the ground we get. Therefore, taller towers lead to more efficient wind farms. These towers have been traditionally constructed of steel, although Enercon's new monster 7 MW wind turbine has a 131 meter tower made from 36 pre-cast concrete segments [7].

Composite construction is currently not cost-competitive with steel for tower structures, but innovative designs and manufacturing processes may level the playing field. Composites are making inroads with infrastructure applications, such as utility poles and large storage tanks that can be manufactured on site. This has led to the development and testing of new composite material systems and manufacturing of massive composite structures that in the past were built with steel and concrete. In addition to seeing existing infrastructure elements repaired or reinforced with composite material, entire bridge spans can now be more easily assembled on site with composite components (see Figure 2). Although the industry will have its hand full tackling the country's crumbling infrastructure, we can be assured that spin-off technology and developed supply chains will benefit the renewable energy industry as well.

Offshore wind farms, where the environment is extremely corrosive and access for maintenance will be costly, also would benefit from a composite tower (see Figure 3). Indeed, floating wind turbines being considered for deeper offshore locations will benefit tremendously from lighter weight support structure to lower the overall center of gravity. Composite towers may also play a significant role in the "small wind" market, where residential users will appreciate easier installation (lighter weight) and a maintenance-free structure. This is also true for installations in remote, rural locations (see Figure 4).

**Water Turbines**

Harnessing the power of tidal currents and ocean currents such as the Gulf Stream has been an age-old dream of marine engineers. Because the density of water is almost 1000 times the density of air, there is an enormous potential to extract power from moving water, although velocities are at least an order of magnitude less than found at efficient wind farms. The engineering challenge has always been to build a device that could survive in such a harsh environment and operate efficiently. Figure 5 shows some existing prototype water turbines and conceptual ideas. It is interesting to note that the Verdant Power installation in the East River off of New York City experienced a structural failure in its first attempt to operate in the fast moving currents.

Tidal power is very attractive because unlike wind and solar, water currents are predictable for a given location, whether they are cyclic for tidal areas or constant for ocean currents. If we examine the concepts presented in Figure 5 it is apparent that underwater structure and fairings must be streamlined, which is best accomplished with composite construction. Maintenance on underwater turbines will be even more problematic than for offshore wind installations.

Just as multiple turbines at wind farms can justify the installation of transmission lines to the site, harnessing ocean currents will only be economically viable if multiple energy capture units are deployed. With just a handful of prototype installations, the industry is at its infancy, still trying to figure out what works and what doesn't. Nevertheless, this is the point in time when equipment needs to be developed that takes advantage of the engineering flexibility of composite construction and promises cost saving when units are mass produced.

**Ocean Wave Energy**

Anybody who has ventured offshore in a small boat or even watched the surf crash at an ocean beach can attest to the amount of energy available from wave action. The engineering challenge is to convert this kinetic energy into some type of mechanical motion that can then be converted to electrical power. According to the NREL, "Harnessing 20% of offshore wave energy resource at 50% efficiency would be comparable to all U.S. conventional hydro generation in 2003." If all the energy could be captured, it would equal 20% of the total U.S. electrical capacity [8]. Figure 6 shows some examples of "point capture" devices. If you want to know how costly it is to maintain buoys, especially offshore, just ask the U.S. Coast Guard. With internal moving parts, wave buoys will be even more susceptible to degradation from corrosion than conventional buoys and would benefit greatly from composite construction. While we are still at the prototype stage, a consideration of composite construction will open the drawing board to unconventional structural shapes.

**The Path Forward**

The U.S. has an established composites manufacturing capability that leads the world in terms of innovation and productivity. However, the demand for composite (marine and construction) has recently been on the decline, leaving us with excess manufacturing capacity. The renewable energy industry is relatively new in this country, with many novel concepts still at their design or prototype stage. Wind turbine blade technology has been developed in Europe so for the most part, these two industries have not come together in the U.S., which is required if we are to become a world leader in renewable energy technology. Some modest investment in R&D and market development now can reap huge returns in the immediate future. Unfortunately, the uncertainty surrounding renewable energy profitability and lack of a long-term, national energy strategy has hamstrung private equity investment. The following initiatives are proposed to put us on the path to energy independence and create green jobs from an ailing industry:

1. The composites industry needs to develop an accurate assessment of current U.S. composites manufacturing capabilities that can support the renewable energy market.
2. Engineers and managers with knowledge of the composites industry should meet with renewable energy companies and present technical and business data to support the use of composite structures.
3. The U.S. is a world leader in transitioning technology from universities and Government labs to the marketplace. However, a Government entity is required to coordinate regional consortia to ensure funded efforts are aligned with national energy and economic goals.
4. Big companies with internal R&D funds gravitate to large projects with guaranteed payback though economies of scale. The Defense Advanced Research Projects Agency (DARPA) has provided a successful model of how to fund innovative companies and "long-shot" technology concepts with huge payback potential. Seed money should be provided to small, innovative renewable energy companies based on the DARPA model. Government support should not have a "matching funds" requirement, as this tends to rule out high risk concepts and small businesses.

By focusing a small amount of Government funding capital (and more importantly, our world-leading innovative "human capital") to the composites and renewable energy industries, we can create a win-win situation for the American consumer and the American worker.

## References


1. American Composites Manufacturers Association, The 2006 Composites Industry Report, www.acmanet.org/professionals/2006_composites_industry_report.pdf

2. Goodrich, Large Composite Structures, http://www.epp.goodrich.com/prodapps/largecompositestructure.shtml

3. Red, Chris, "Wind Turbine Blades: Big and Getting Bigger," *Composites Technology*, June 1, 2008

4. Wiser, Ryan and Bolinger, Mark, "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007," Lawrence Berkeley National Laboratory, Report Summary, May 2008

5. Laxson, A., Hand, M.M., and Blair, N., "High Wind Penetration Impact on U.S. Wind Manufacturing Capacity and Critical Resources," Technical Report NREL/TP-500-40482, October 2006

6. Greene, E., Ship Structure Committee report 442, "Labor-Saving Passive Fire Protection Systems for Aluminum and Composite Construction," PB2005-108998, May, 2005

7. Enercon, "Construction of world's most powerful wind turbines in progress in Emden," news 28/09/07, http://www.enercon.de/en/_home.htm

8. Robinson, M., "Renewable Energy Technologies for Use on the Outer Continental Shelf," National Renewable Energy Laboratory, June 6, 2006, http://ocsenergy.anl.gov/documents/docs/NREL_Scoping_6_06_2006_web.pdf

## Table 1. Recently Established Wind turbine Blade Manufacturing Facilities in the U.S.

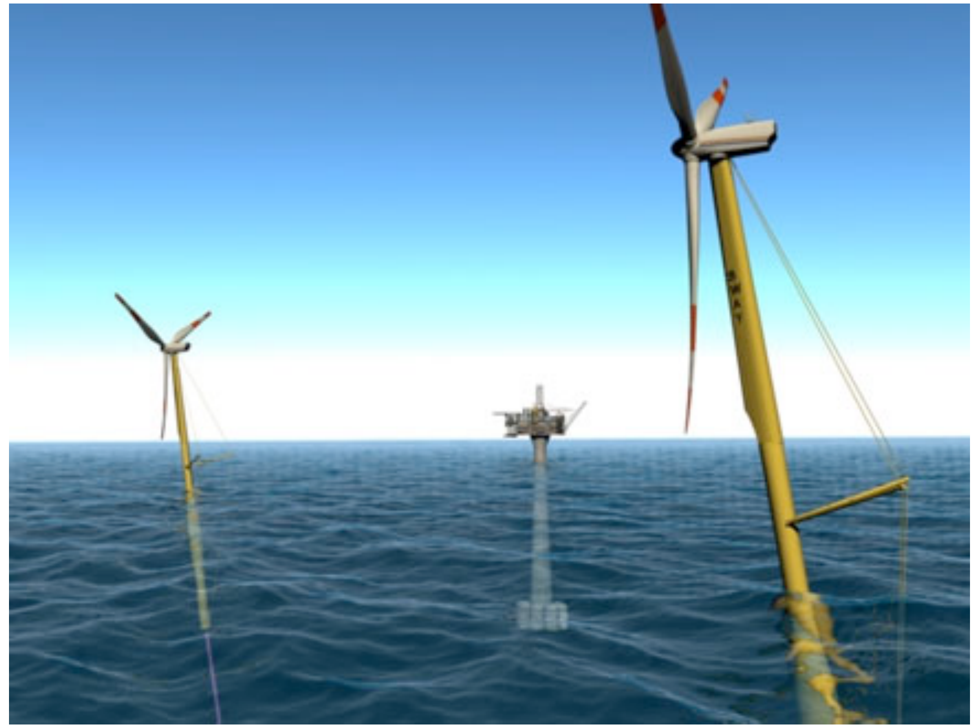
| Manufacturer | Plant Location | # of Employees | Investment | Internet Reference Source |
|---|---|---|---|---|
| Acciona Windpower | West Branch, Iowa | 100 | $23,000,000 | http://www.westbranchtimes.com/article.php?id=1689 |
| Fuhrländer AG | Butte, Montana | 150 (housings) | $25,000,000 | http://www.fuhrlaender.de/index.php?option=com_content&task=view&id=94&Itemid=104&lang=en |
| | | 600 (blades) | | |
| Gamesa SA (Fiberblade LLC) | Ebensburg, Pennsylvania | 235 | $50,000,000 | http://www.gamesa.es/en/press/press-releases/gamesa-opens-its-first-high-tech-manufacturing-plant-with-an-investment-of-50-million-dollars |
| Knight & Carver | Howard, South Dakota | 50 | | http://www.kcwind.com/09.07.07.aspx |
| LM Glasfiber | Little Rock, Arkansas | 1100 | $150,000,000 | http://www.littlerock.org/citymanager/divisions/publicrelations/MediaReleases.aspx?ID=184 |
| Molded Fiber Glass Companies | Aberdeen, South Dakota | 750 | $40,000,000 | http://www.adcsd.com/press/MoldedFiberGlass.pdf |
| Nordex AG | Jonesboro, Arkansas | 700 | $100,000,000 | http://www.lucintel.com/newspage.aspx?sno=5400 |
| Nordic Windpower | Pocatello, Idaho | 160 | | http://www.reuters.com/article/pressRelease/idUS145972+10-Mar-2008+PRN20080310 |
| Polymarin Composites USA, | Little Rock, Arkansas | 830 | $20,000,000 | http://climate.weather.com/articles/turbines100801.html?page=1 |
| PPG Industries | Shelby, North Carolina | E-glass production with existing labor | $20,000,000 | http://www.manufacturing.net/wind-power-generates-n-c-jobs.aspx?menuid= |
| Siemens AG | Fort Madison, Iowa | 400 | $25,000,000 | http://w1.siemens.com/press/en/pr_cc/2007/09_sep/pg200709076_1463246.htm |
| Suzlon Rotor Corporation | Pipestone, Minnesota | 270 | $14,000,000 | http://minnesota.publicradio.org/display/web/2007/10/18/indiablades/ |
| TPI Composites | Newton, Iowa | 800 | $27,200,000 | http://www.renewableenergyworld.com/rea/news/story?id=53594 http://www.desmoinesregister.com/article/20081014/BUSINESS/8101402 |
| Vestas Wind Systems A/S | Brighton, Colorado | 1350 | $290,000,000 | http://www.colorado.gov/cs/Satellite/GovRitter/GOVR/1218795720308 |
| | Windsor, Colorado | 650 | $65,000,000 | http://www.rockymountainnews.com/news/2008/mar/05/wind-plant-officially-opens-doors/ |
| | **Totals:** | **8145** | **$849,200,000** | |

**Figure 1. U.S. Large Composite Hull Fabrication**
This 160 foot composite motor yacht is typical of infused hulls produced by Christensen. The company has plans to produce a 186 foot, 500+ GT yacht that will be constructed in a purpose-designed facility in Tennessee.

Installation of ZellComp composite bridge decking in Bradford VT (top) and Tangier, VA (bottom)

Composite footbridge built in Scotland in 1990 (top) and large carbon fiber beams from Strongwell (bottom)

**Figure 2. Composite Bridges**



The SWAY technology utilizes a “downstream” turbine design with aerodynamic turbine housing and support spar.

StatoiHydro is investing $79M to develop a 2.3 MW offshore wind turbine. The floating wind turbine can be anchored in water depths from 120 to 700 meters.

**Figure 3. Offshore Wind Energy**

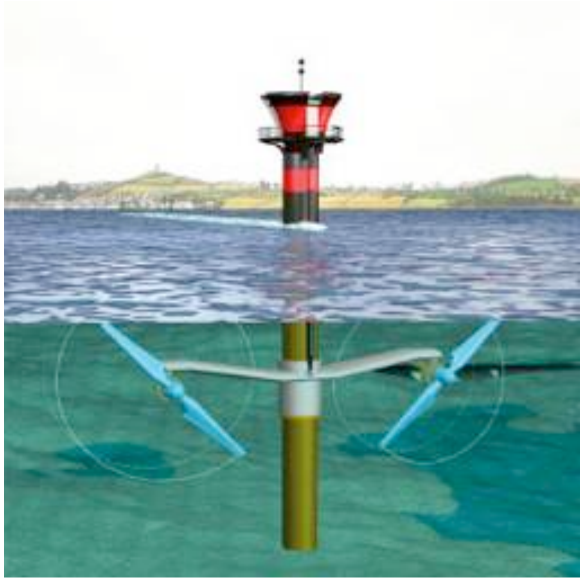
Greentenco has developed a combination wind/solar power generator for remote, rural applications.

Aeroturbine has developed a wind turbine for installation on urban rooftops.

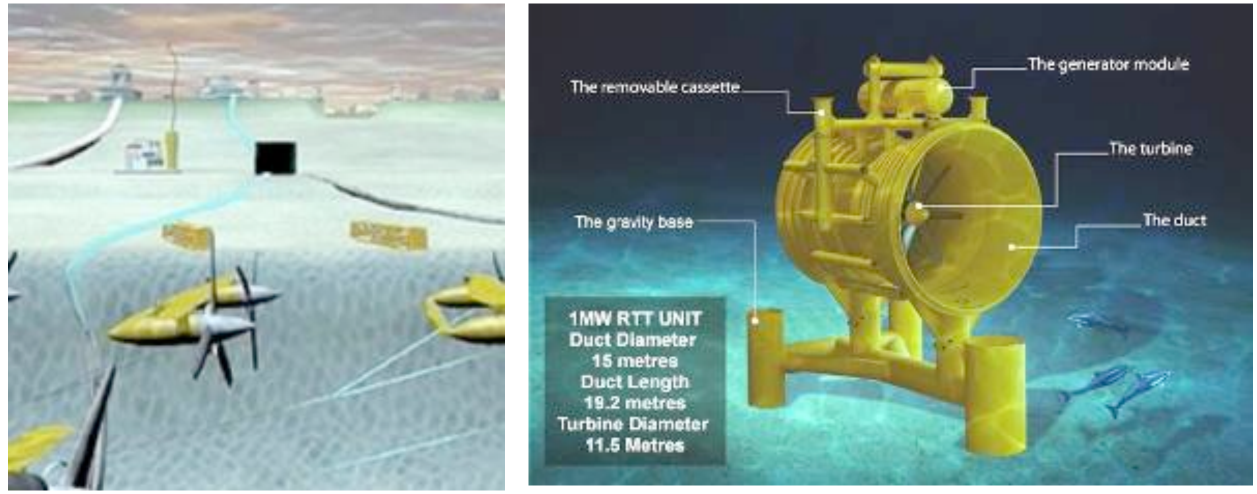
Quiet Revolution in the UK has manufactured this aesthetically-pleasing vertical axis wind turbine with carbon composites.

Skystream (left) and Zephyr (right) manufacture small wind turbines for individual residences.

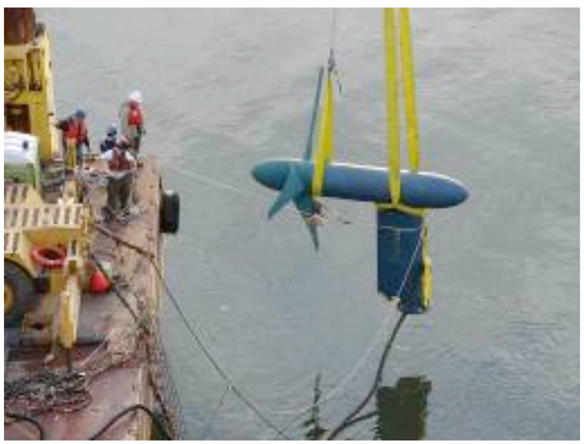
**Figure 4. Small Wind Energy**



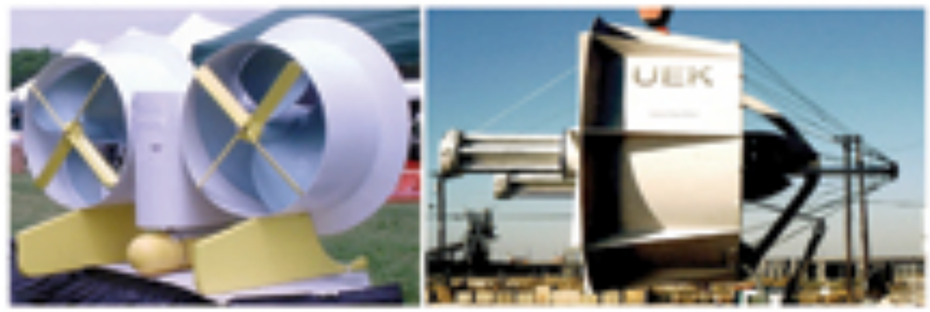
Marine Current Turbines Ltd has installed a 1.2MW SeaGen tidal energy system in Ireland.




Underwater turbine farms have been proposed by Florida Atlantic University (left) and Lunar Energy (right)



Verdant Power has tidal turbine installations in New York and Canada.

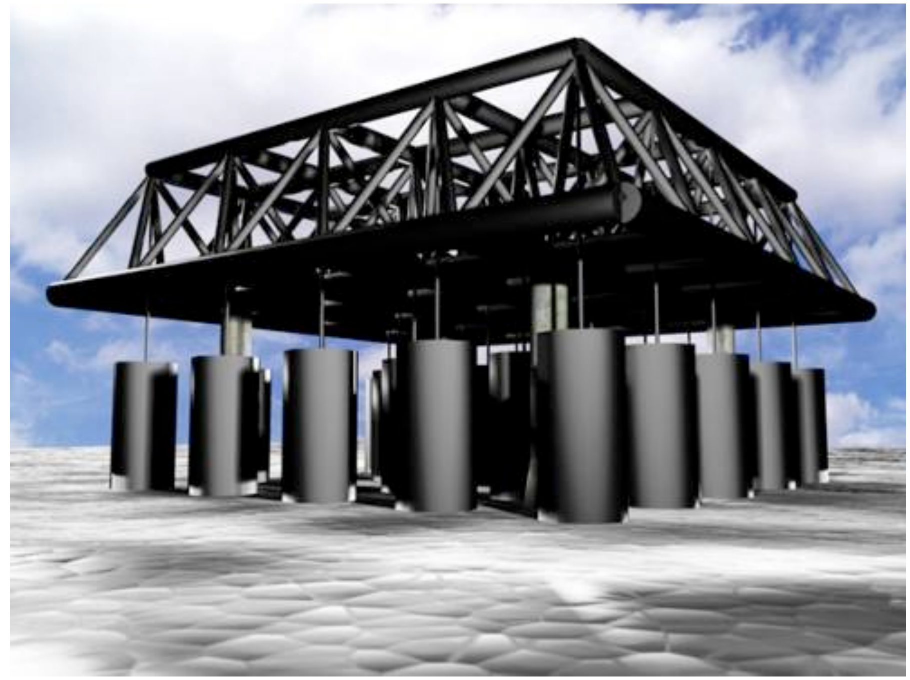



UEK Corporation has been developing a practical way to harness river, tidal and ocean currents with hydro kinetic turbines since 1981

**Figure 5. Ocean Tidal Energy**

Ocean Power Technologies has installed the first PowerBuoy® system near Reedsport, Oregon.


Wavebob plans a wave-farm for the West of Ireland and has opened a North American office



The Manchester Bobber is an innovative wave energy device. With the Bobber, a floating mass rises and falls under the action of waves in the water and this causes a pulley and its shaft to oscillate.

**Figure 6. Ocean Wave Energy**

A shipyard worker is shown grinding rust on a U.S. Navy ship. Recent studies estimate the direct cost of corrosion in the United States to be nearly $300 billion dollars per year.

On the open sea, waves can commonly reach seven meters in height or even up to fifteen in extreme weather. Indeed, some reported rogue waves have exceeded thirty meters in height.

**Figure 7. The Ocean Environment**