Marine Composites

Webb Institute
Senior Elective

Ocean Renewable Energy Applications

Eric Greene, Naval Architect
EGAssoc@aol.com
410.703.3025 (cell)
http://ericgreeneassociates.com/webbinstitute.html

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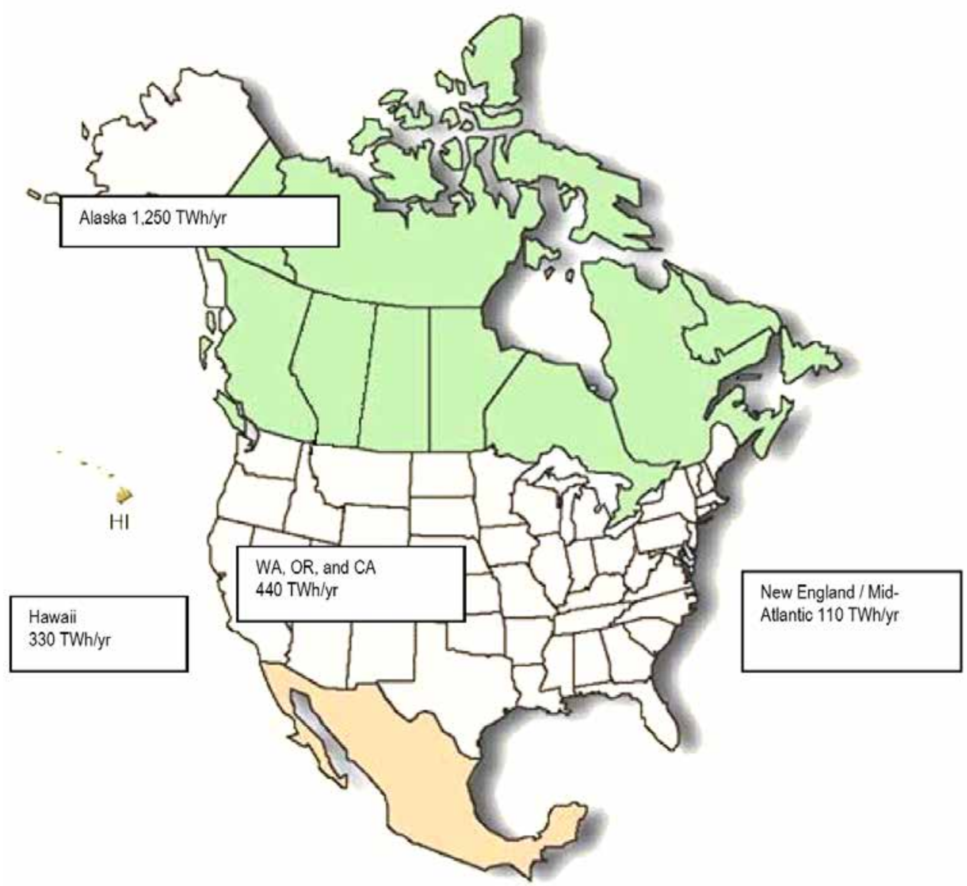
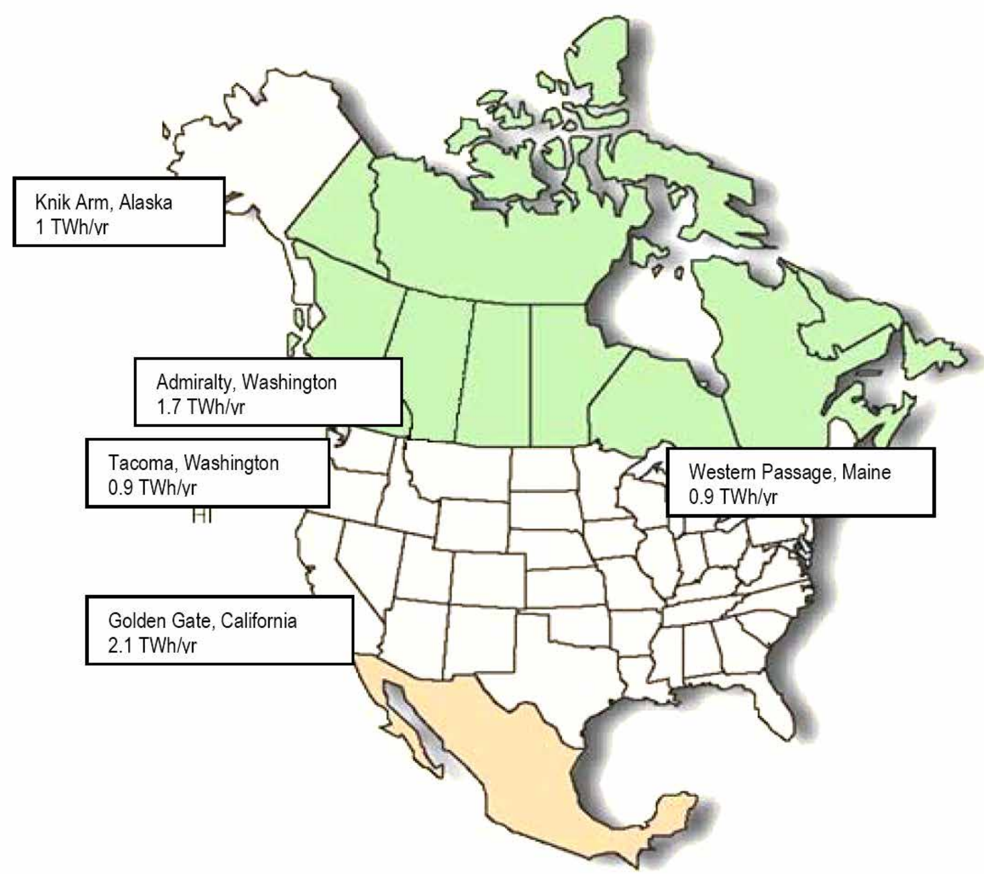
U.S. Hydrokinetic Energy Resource Estimate

Preliminary Estimate of U.S. Coastal Wave Energy Resources (60-meter Depth and Greater than 10 kW/m)



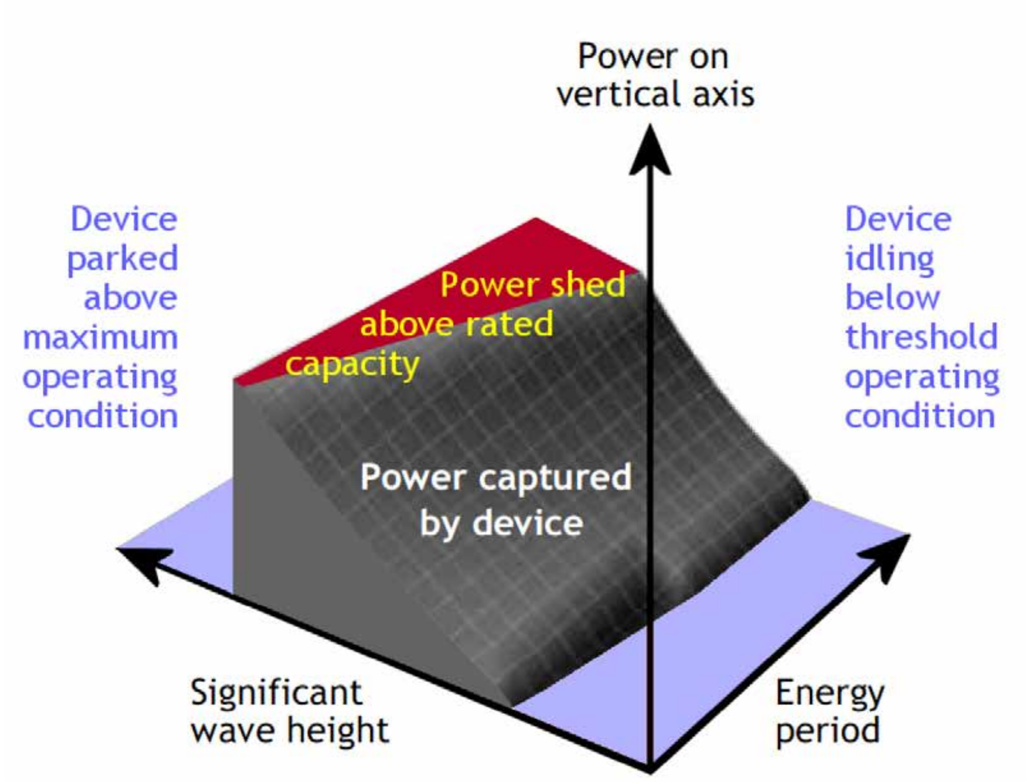
Estimated Tidal Energy Resources in the U. S. for Selected Tidal Passages



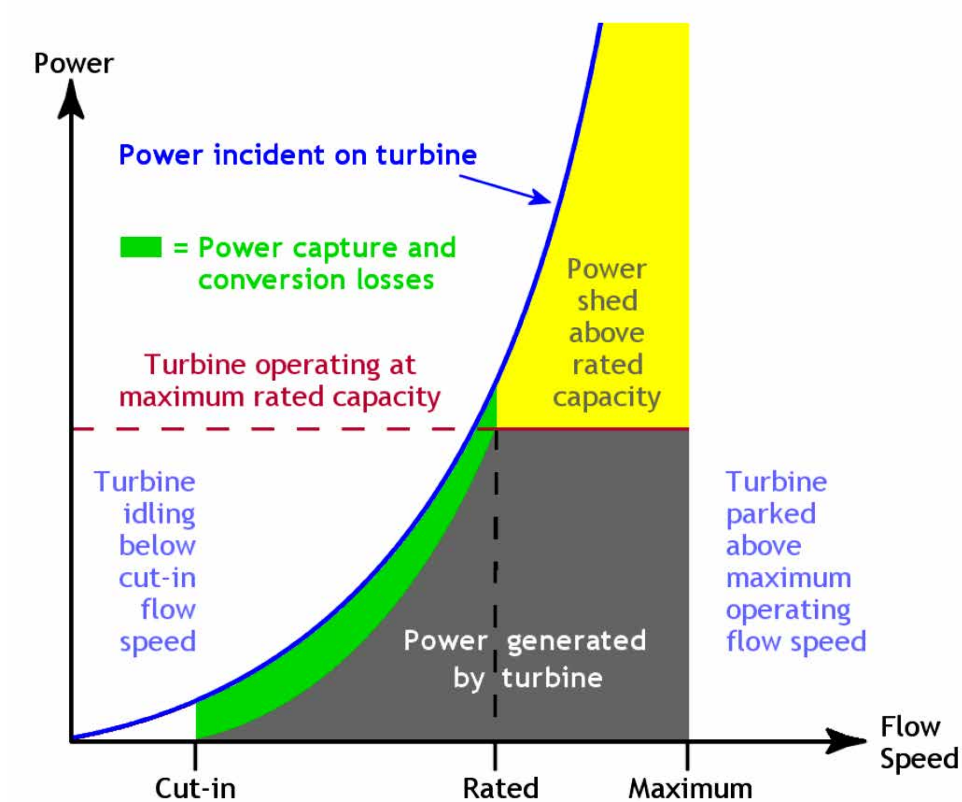
Electric Power Research Institute

Hydrokinetic Energy Extraction

Wave Energy Devices



Tidal Current Devices



Carbon Trust, “Future Marine Energy,” January 2006.

Ocean Environment

Corrosion

Recent studies estimate the direct cost of corrosion in the United States to be nearly $300 billion dollars per year.

Extreme Waves

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

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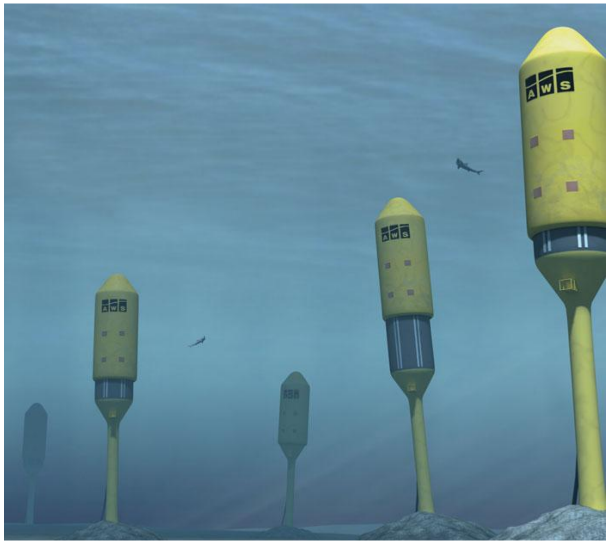
Foundations

AquaBuoy

SEADOG Pump

OWEC Ocean Wave Energy Converter

Energetech



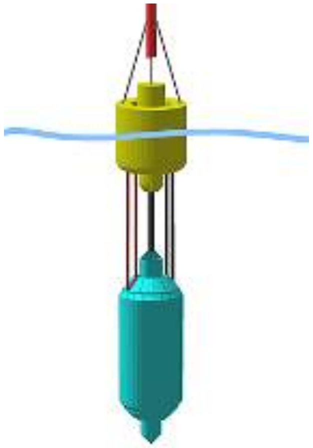
AWS Ocean Energy

Moving Parts

Aquamarine Power

Wavegen

Ocean Power Technology



Wavebob

Pelamis Wave Power

Wavestar

Sea Snail

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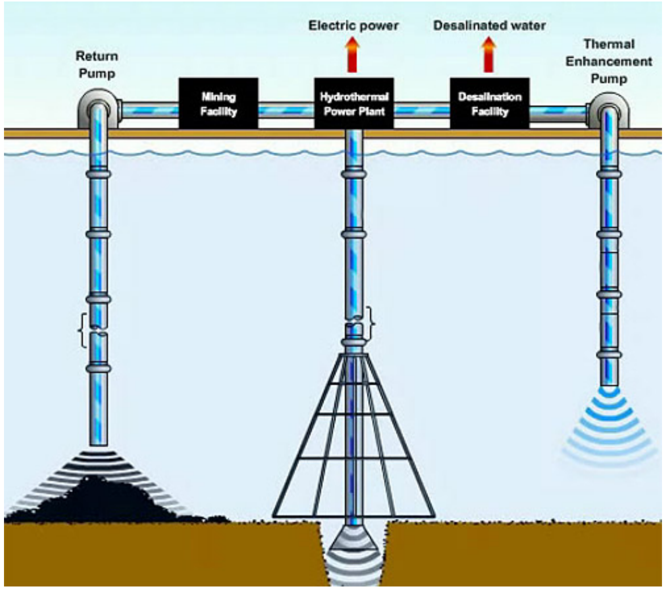
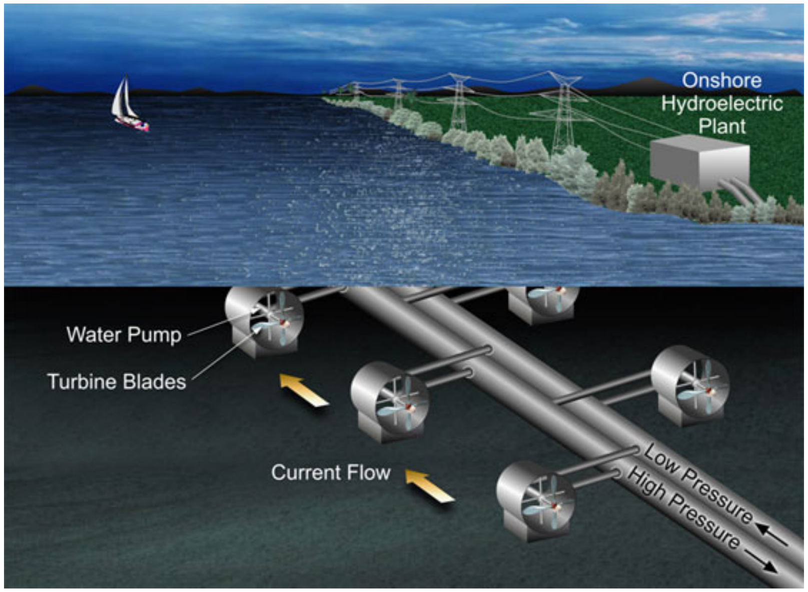
Piping Systems

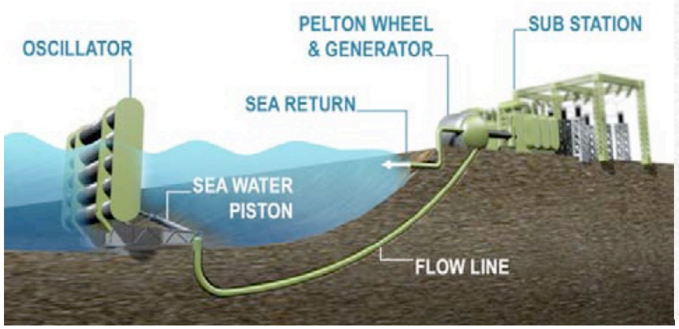
SEADOG Pump



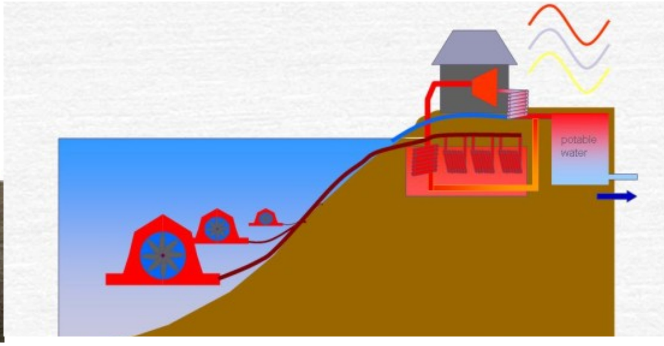
Marshall Hydrothermal Recovery System



JPL/Caltech Hydrokinetic Energy System



Aquamarine Power



Gentec Venturi

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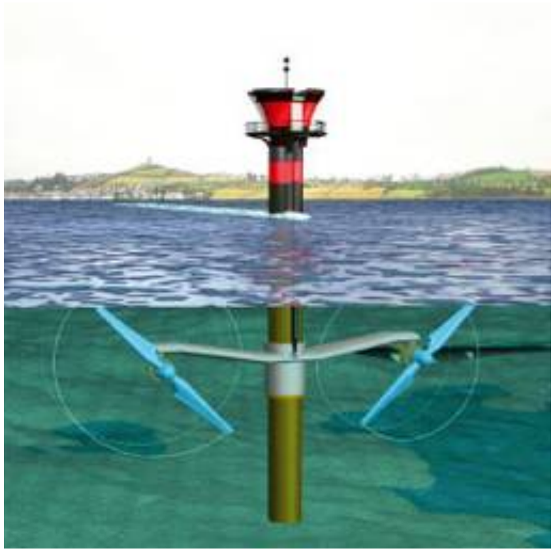
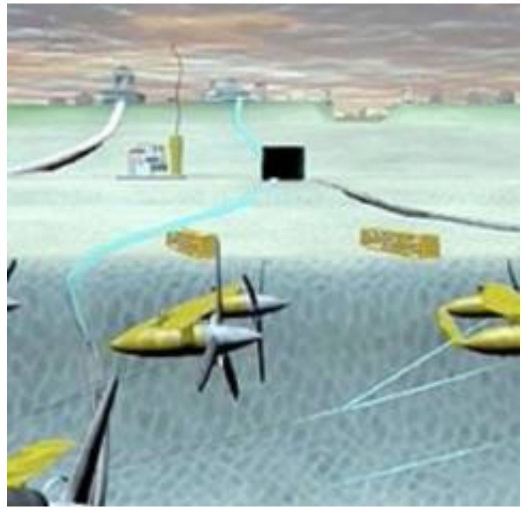
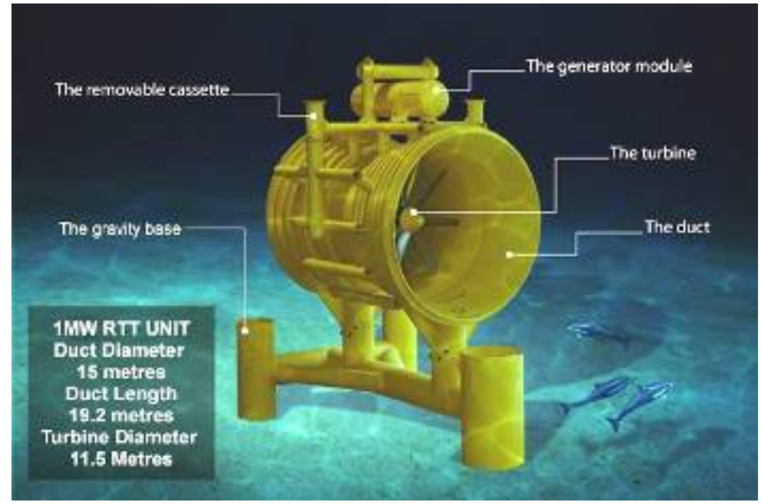
Ocean Tidal Energy



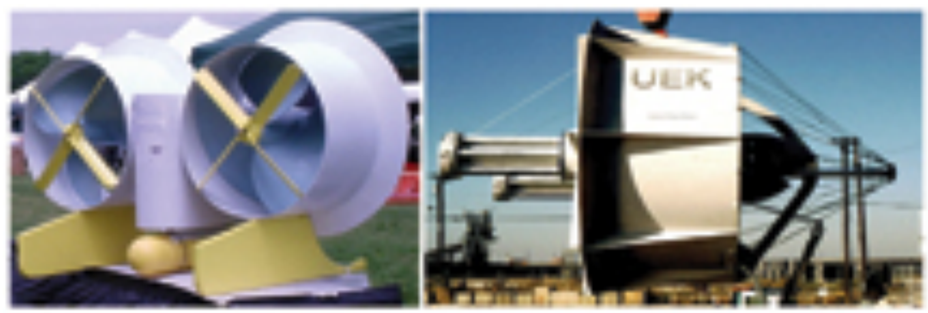
Marine Current Turbines Ltd has installed a 1.2MW SeaGen tidal energy system in Ireland.





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

Verdant Power

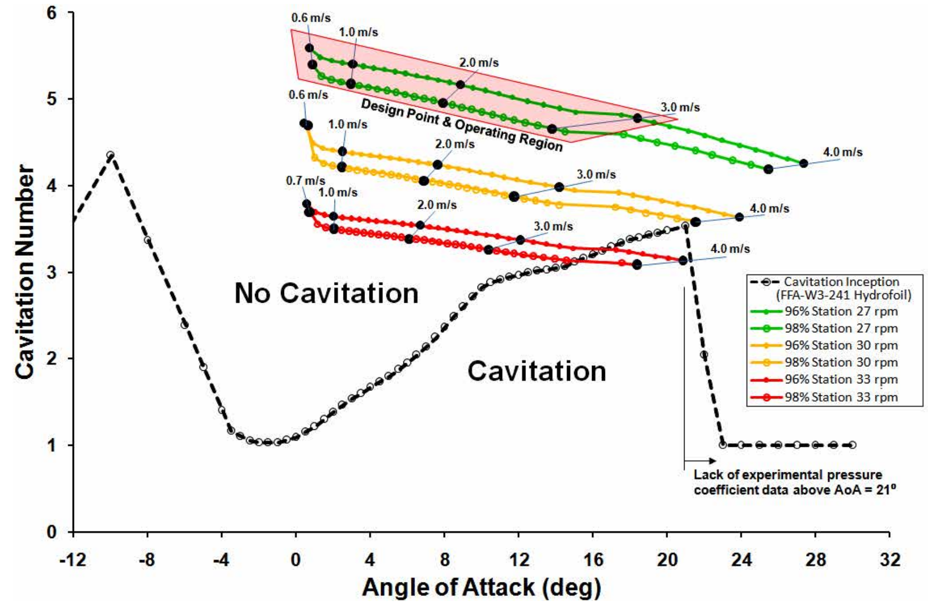
Power in kW

Rotor Diameter, meters	Current Velocity, meter/sec				
	2	**2.5**	**3**	**3.5**	**4**
7	55	110	190	300	450
8	72	144	245	395	590
9	92	182	315	500	745
10	115	225	385	615	920
11	138	272	470	745	1110

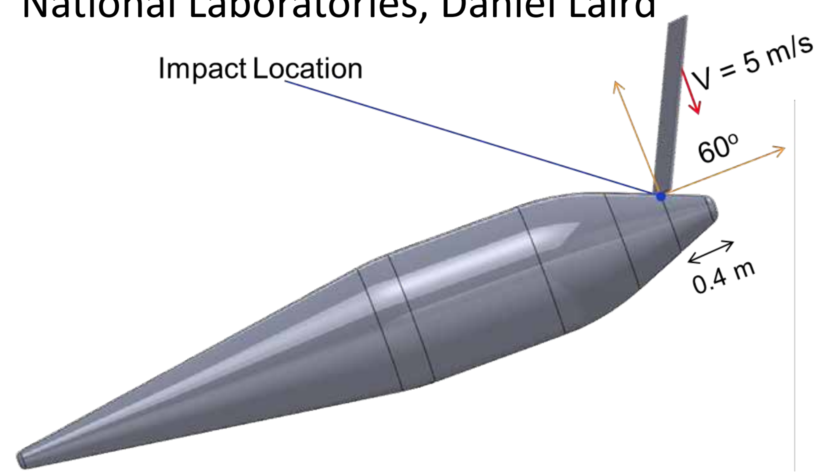
Jonathan Colby, "Hydro R&D Rising: DOE's New Program - Verdant Power's Path to Commercialization," National Hydropower Association 2009 Annual Conference, May 2009

Metal Prototype to Composite Turbine Blade

Water turbine blade being tested at the DoE National Renewable Energy Lab in Boulder, CO



Cavitation Bucket Diagram (top) and Impact Analysis (bottom) developed by Sandia National Laboratories, Daniel Laird



Andritz Water Turbine Blades

Andritz Hydro Hammerfest is producing blades for the HS 1000 1MW equipment, one of which has been installed at EMEC for over a year now. These blades have been made using epoxy resins for the ultimate in long-term performance in a subsea environment. Glass fiber has been widely used in the blades, with carbon employed in more structurally demanding areas.

Neil Calder, “Composites blades turn the tide,” Composites in Manufacturing, February 2013

Marine Current Turbines
SeaGen Rotor Assembly

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Ocean Renewable Power Company Helical Turbine Blades

Helical turbine assembly built by Hall Spars for Ocean Renewable Power Company

ORPC installed the country's first grid-connected, Commercial TidGen™ Power System at a 60-acre site in Cobscook Bay, Maine

OpenHydro Rotor

The Open-Center Turbine is designed to be deployed directly on the seabed. Installations will be silent and invisible from the surface. They will be located at depth and present no navigational hazard. [openhydro.com]

All-Composite SeaUrchin

Michael Urch (left), and Darren Burrowes, inspecting a pre-production prototype of the 2 kW SeaUrchin.

The design is based on a clever assembly of thin shells made of glass fiber/vinyl ester laminate. The lay-up schedule of the SeaUrchin uses chopped strand mat (CSM), woven roving (WR) and unidirectional (UD) glass reinforcement. The components were then foam-filled in situ using a cellular epoxy foam system to obtain the global rigidity required for the application.

Pierre Gouhier and Darren Burrowes , "SeaUrchin: the future is tidal," *Reinforced Plastics*, March/April 2013

Rotor Fabrication

Ocean Renewable Power prototype

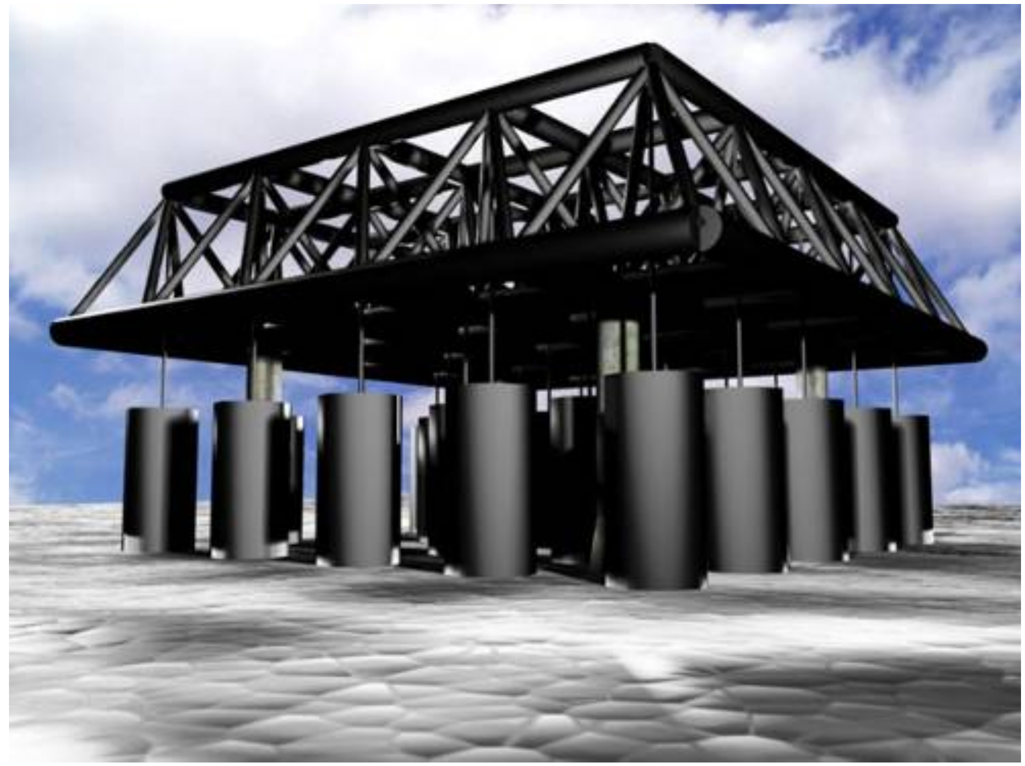
Airborne Marine in the Netherlands uses Resin Transfer Molding (RTM) injection technology in combination with preforming technology for turbine blades that will be installed at the EMEC test center in Orkney / Scotland.

Hydra Tidal is receiving funding to study Morild's wood components at the Norwegian University of Science and Technology (NTNU) laboratories in Trondheim and will verify the company's findings.

Ocean Wave Energy

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

Wavebob plans a wave-farm for the West of Ireland



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.

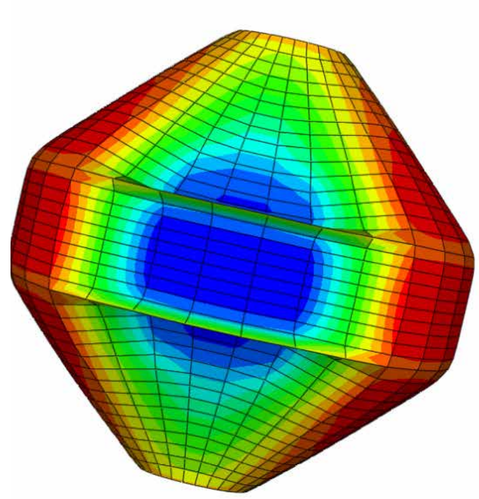
Columbia Power Technologies Wave Buoy

Energy is captured from both heave and surge motion

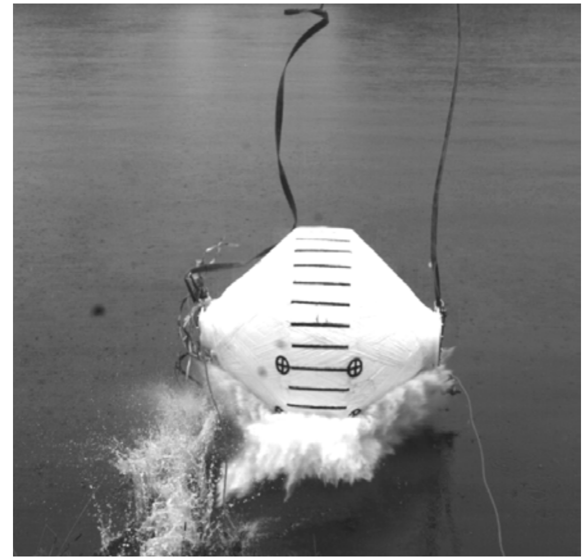
The device's two fiberglass wings, which are attached to a cylindrical nacelle, are directly connected to a magnetic generator. As the wings rise and fall in the waves, magnets move up and down a generator coil to create a magnetic field that produces voltage.

"Bobber" Survivability

1:3 scale platform off the coast of Norway



Simulated radial displacements under breaking-wave slamming



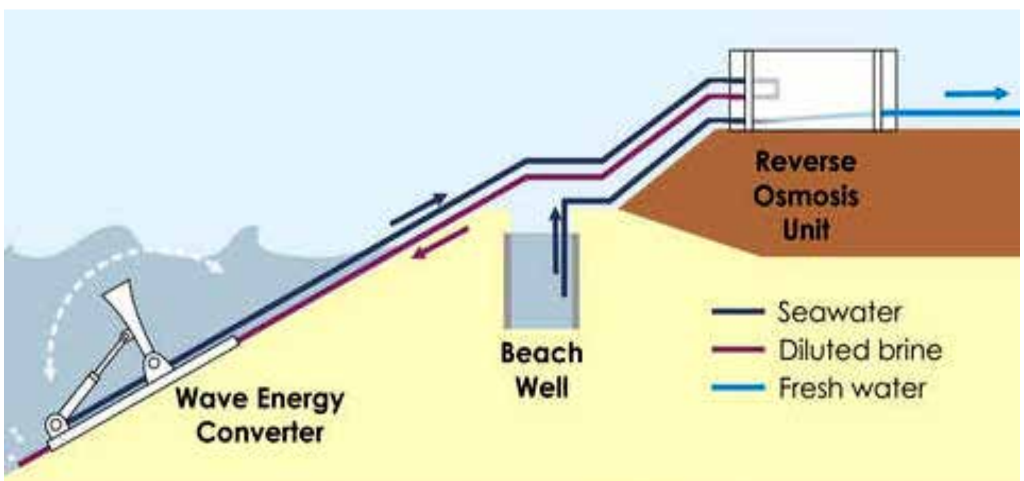
High-speed recording of vertical drop test from a height of 7.20m

To simulate breaking-wave slamming, the buoys were rotated by 90° and accelerated toward the calm water surface. The flexible buoy survived the slamming tests as well as the stiff buoy, but weighed 150kg less and was much cheaper to fabricate because it lacks a sandwich foam core, which had to be manually draped onto the filament-wound inner skin.

Wim Van Paepegem, "Survivability design of composite wave-energy Converters," Society of Plastics Engineers, 2011

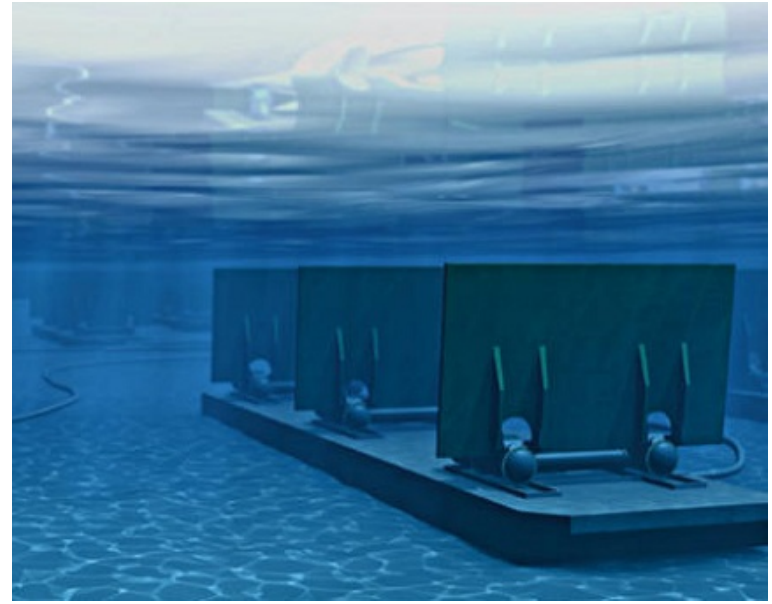
Resolute Marine Energy

Prototype construction elements

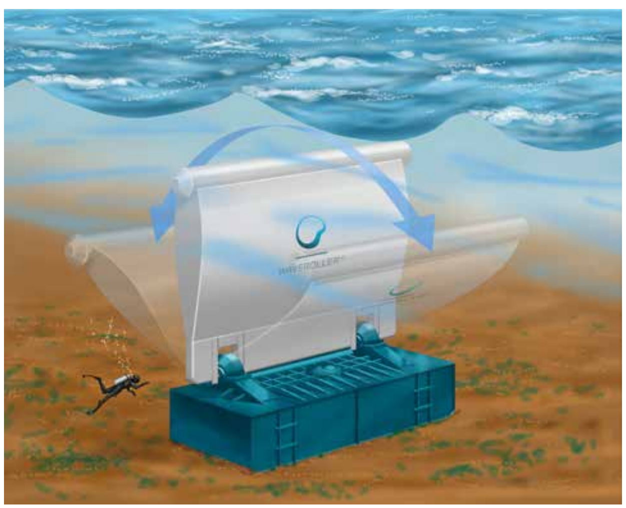


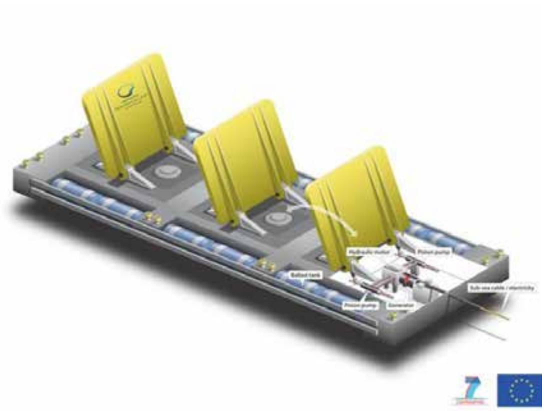
AW-Energy, Finland

WaveRoller wave energy panel built with E-glass reinforcement



Each of the three "doors" of the units weighs twenty tons





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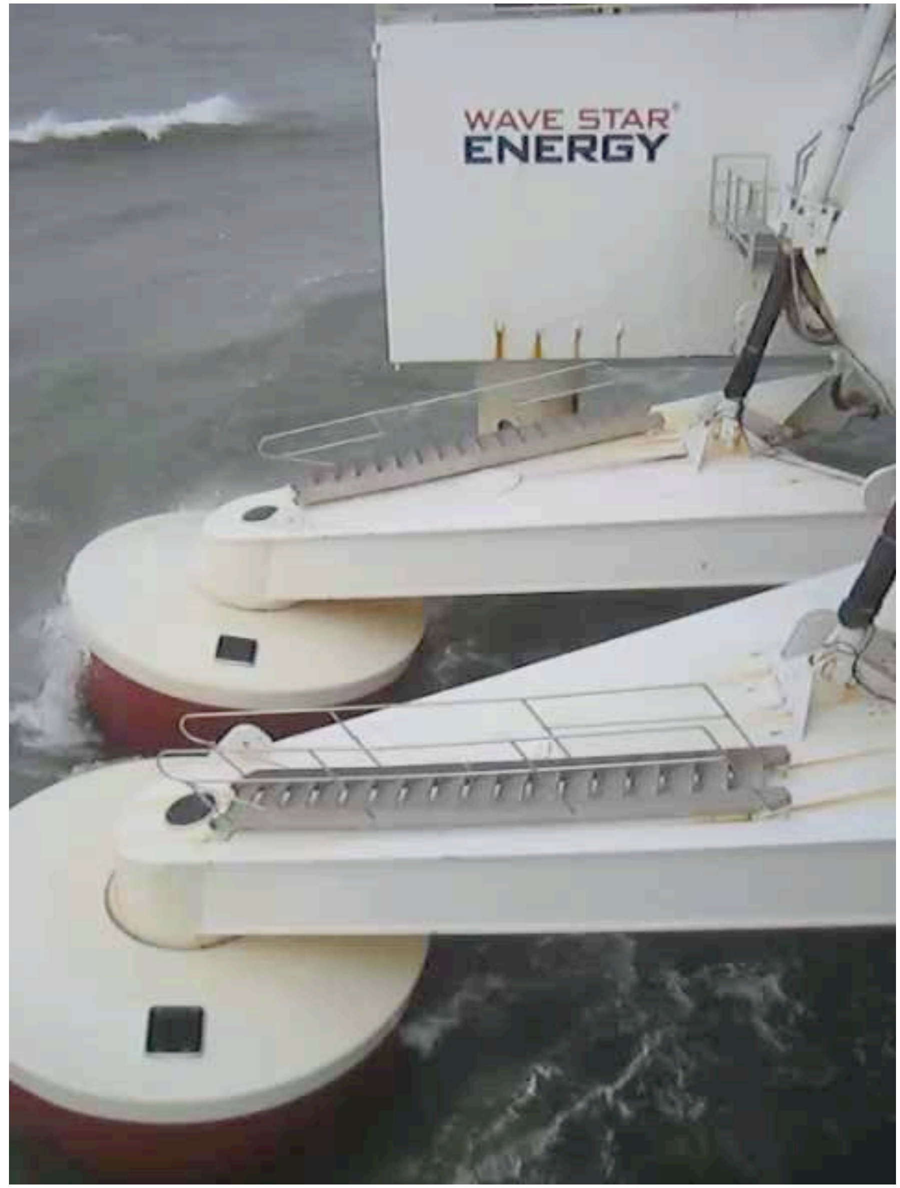
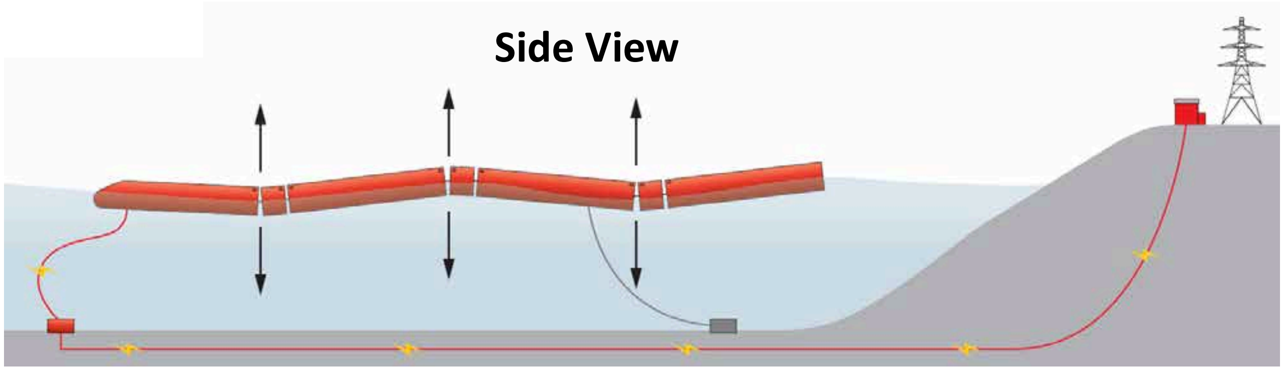
WaveStar Energy

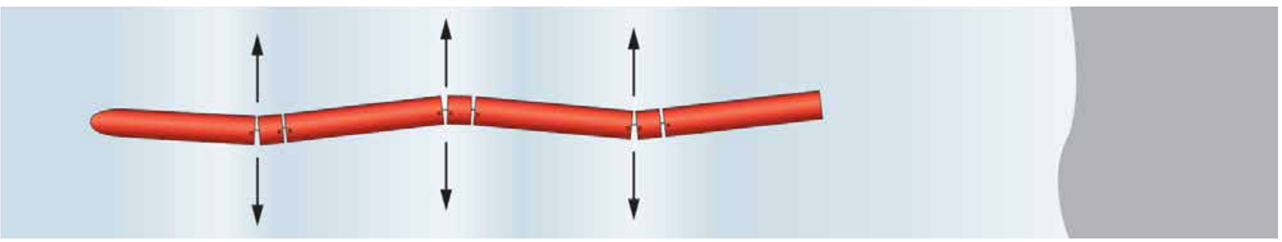
The Wave Star® Energy marine hydrokinetic energy concept was invented by sailing enthusiasts Niels and Keld Hansen in 2000. The half-submerged buoys rise and fall, allowing energy to be continually produced despite waves being periodic. The buoyancy of the float is 20-40 times its dry weight, made possible by composite construction.

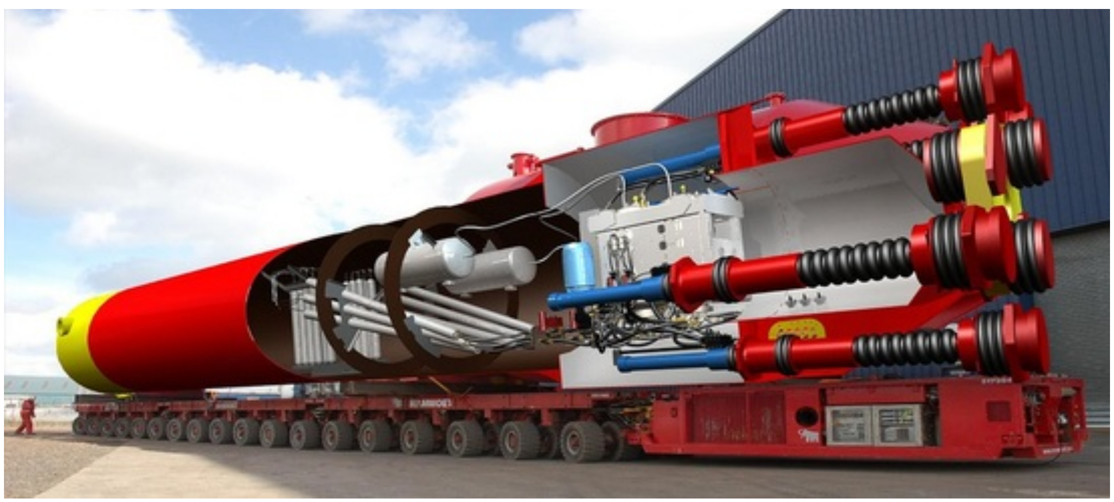


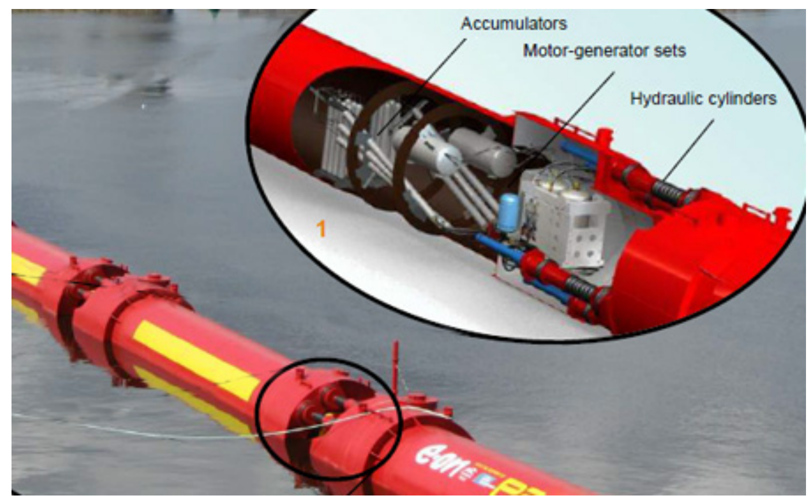
Pelamis Wave Energy Converter



Top View

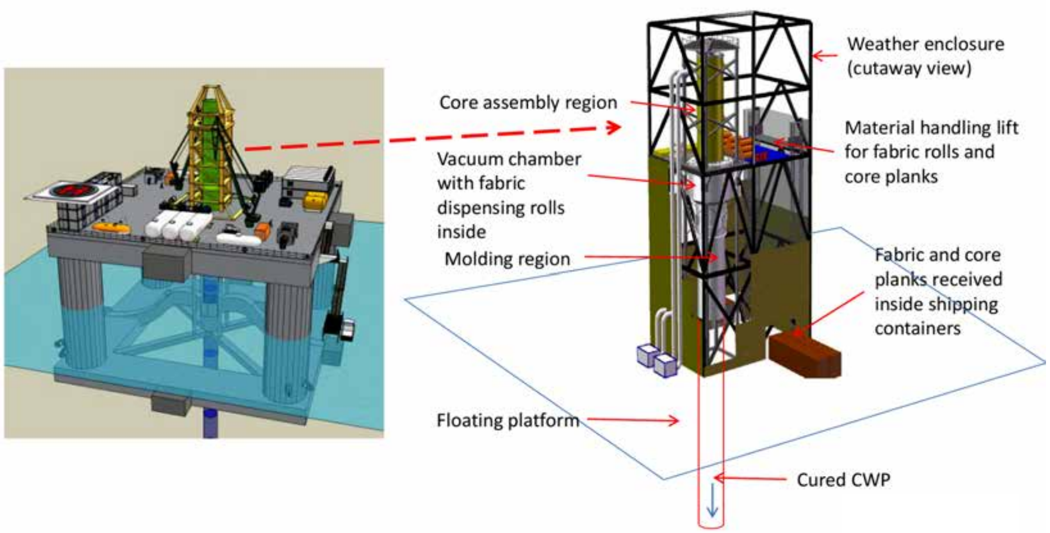






OTEC Pipe

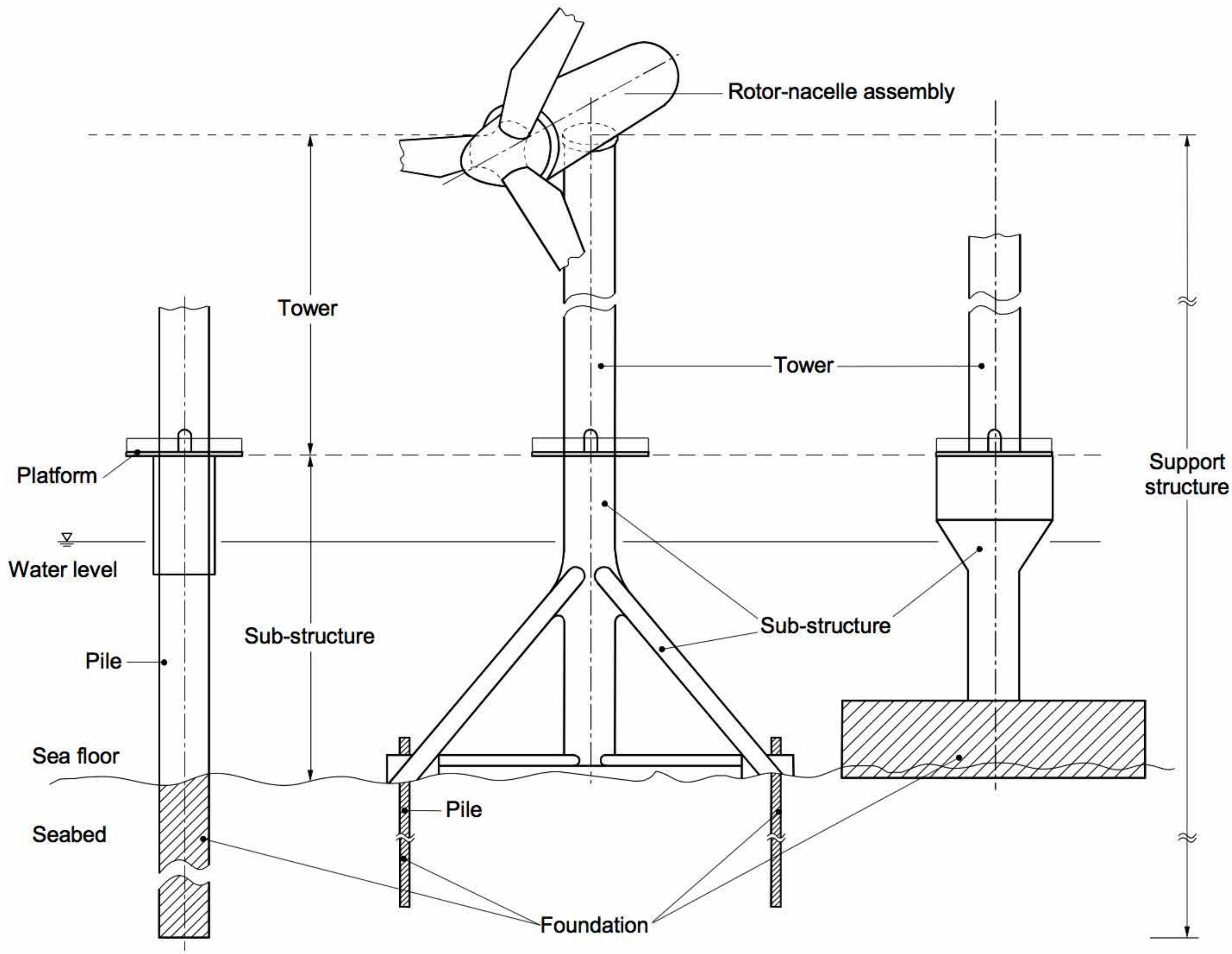
Cold water pipe fabricated on-site



Sandwich core built from pultruded sections

Alan K. Miller, Lockheed Martin, "OTEC Advanced Composite Cold Water Pipe," Rev. L, Sept. 4, 2011

Offshore Wind Turbine Components



IEC 61400-3, INTERNATIONAL STANDARD, Wind turbines – Part 3: Design requirements for offshore wind turbines, International Electrotechnical Commission, 2009

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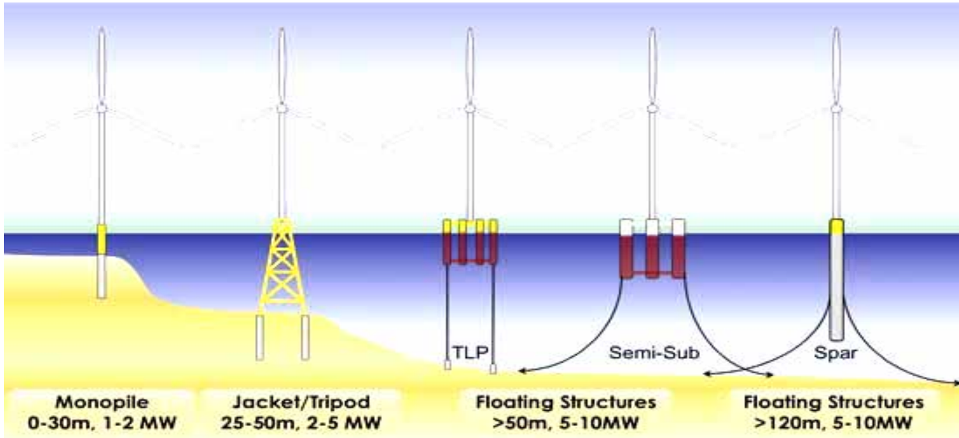
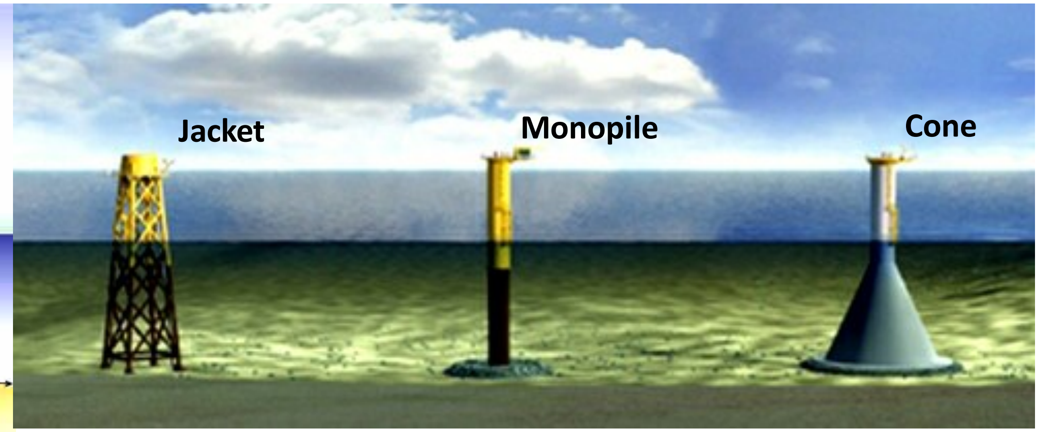
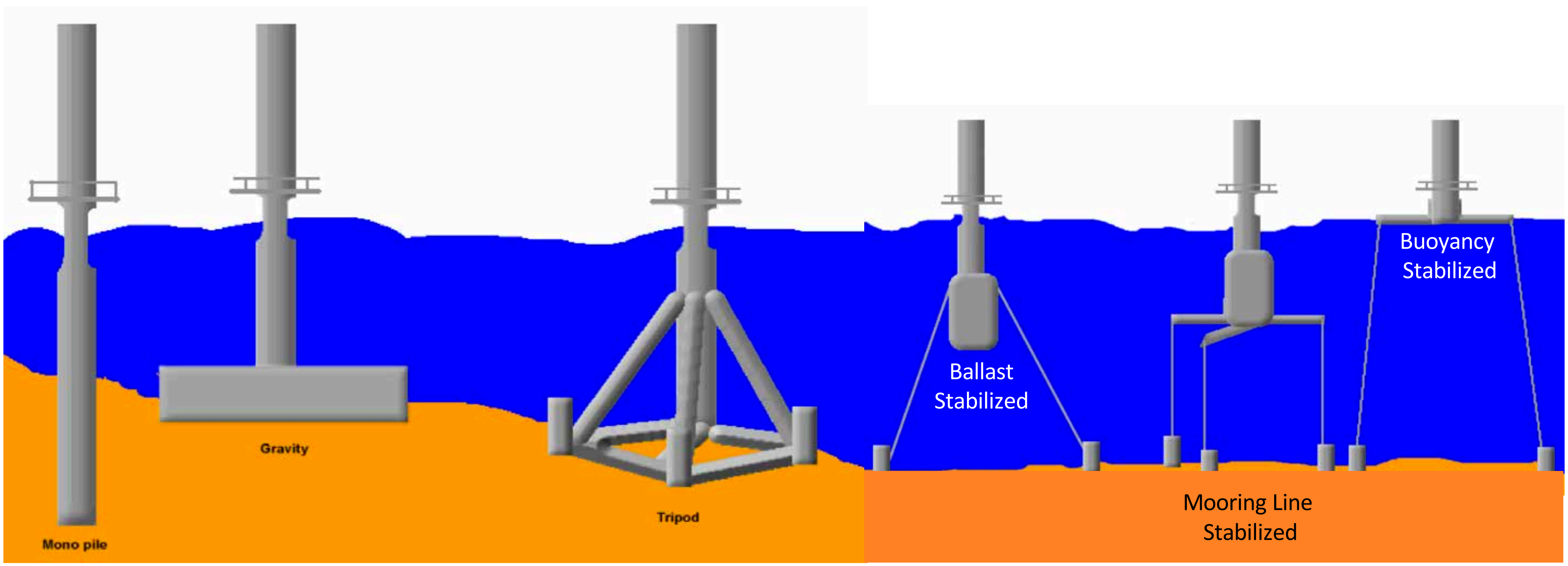
Offshore Wind Foundations

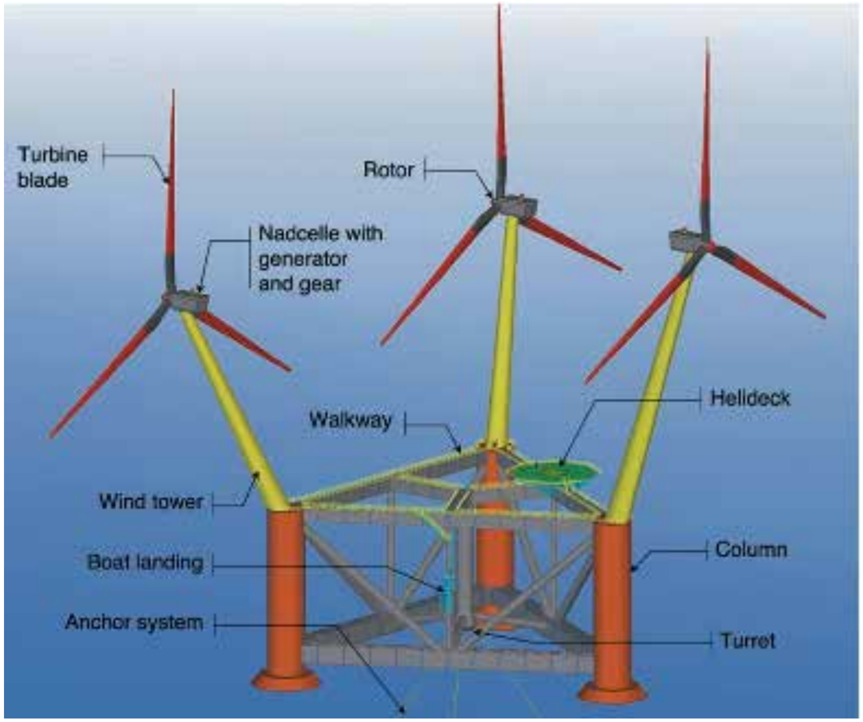




Types of offshore wind turbine foundations



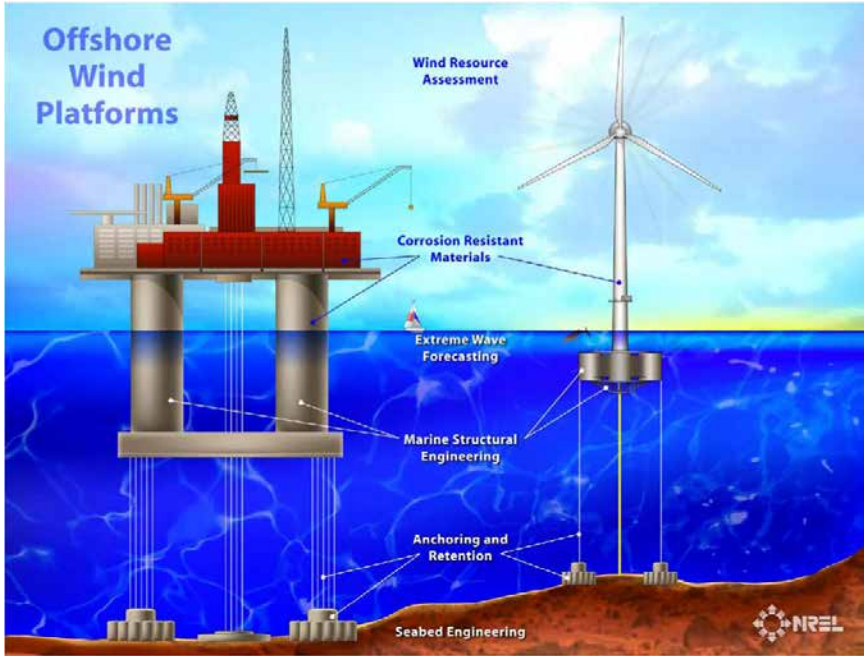
Offshore Wind Foundations

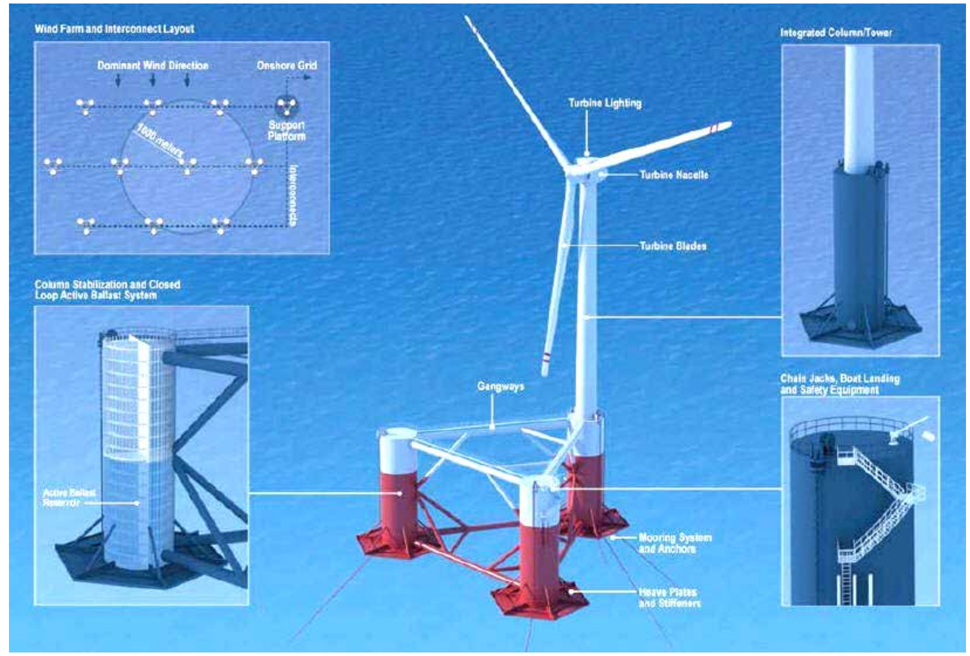


WindSea is a three-sided semi-submersible vessel with corner columns, each supporting one wind turbine.

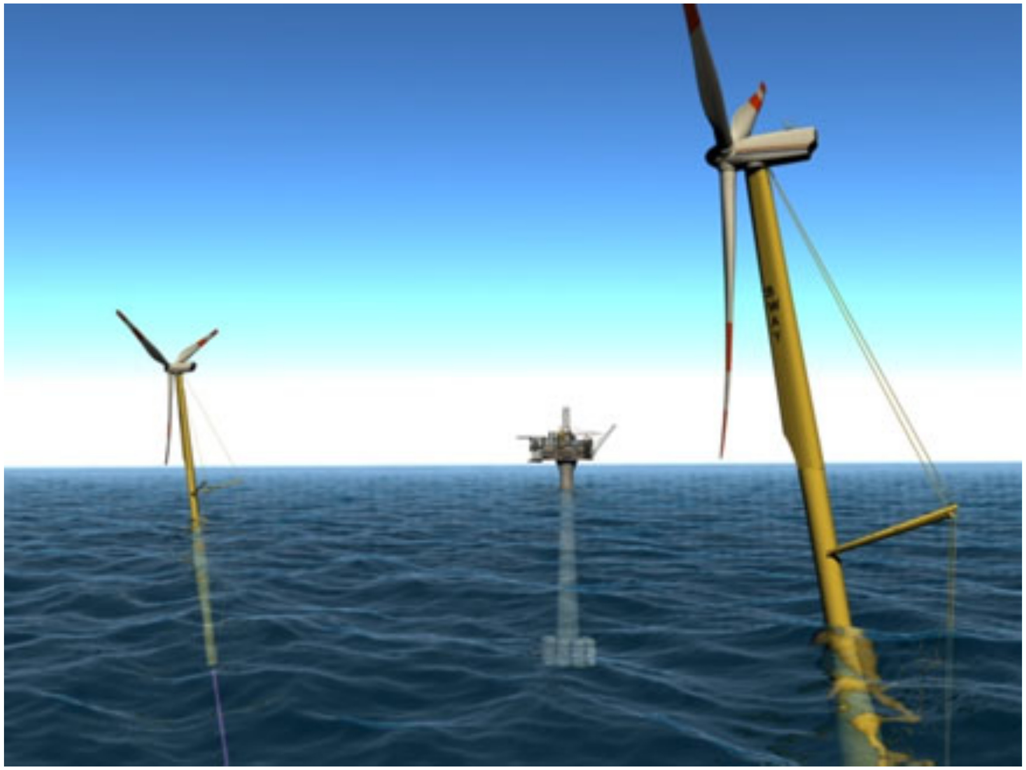
- All construction is performed at yard, including turbine installation
- The floater is tugged to the mooring lines offshore
- Self orientating towards the wind
- Easy access for inspection and maintenance
- Easily disconnected from the turret and tugged to the yard for modification or more extensive maintenance

Floating Platform Concepts





Offshore Wind Spar Concepts



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

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

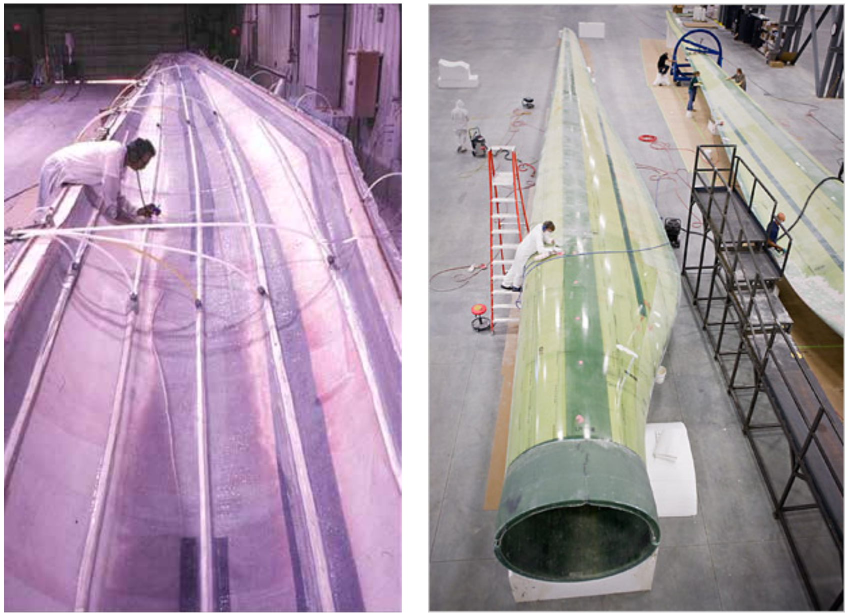
Offshore Wind Foundation Prototype Testing

Floating Power Plant has a 37 meter model for a full off-shore test off the coast of Lolland in Denmark.

The Flat Faced Tripod needs three large 96-inch (243 cm) diameter piles but no cast components

During the MEGAWIND project, testing of this one-third-scale, filament-wound, monolithic-shell tower was conducted at the ELSA laboratory of the JRC, European Commission, Ispra, Italy.

Wind Turbine Blade Manufacturing



Early TPI Blade Infusion, Warrick, RI

Laying up E-glass for vacuum resin infusion at LM Glasfiber

Resin infusion manufacturing at Siemens