Composites for Marine Energy Systems

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Clark Little photo

Eric Greene

410.263.1348 EGAssoc@aol.com
www.EricGreeneAssociates.com

eric greene associates

What Are Composite Materials?

- A composite is the combination of materials that results in a greatly improved structure.
- Resin matrices transform from liquid to solid during fabrication to “tie” the structure together.
- Fiberglass, Aramid, and carbon laminates with resins are examples of composites, as is plywood and other “engineered” wood products.
- Resin matrices are either “thermosets” that cure to solids through a non-reversible chemical process called “crosslinking” or “thermoplastics” that can be reformed when heated.

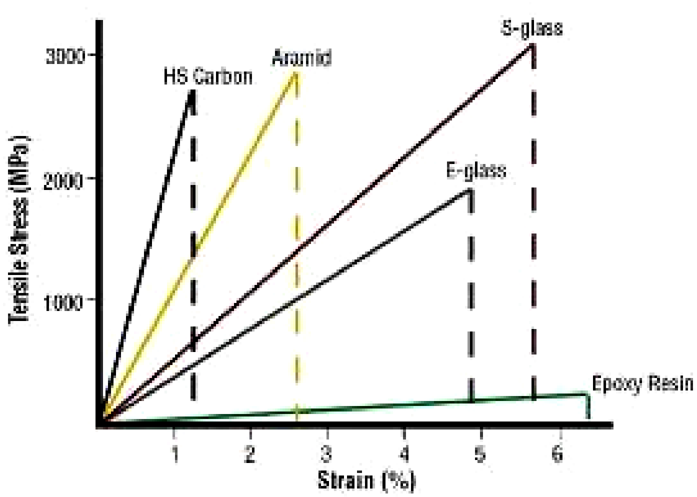
Why Use Composites for Marine Energy Systems?

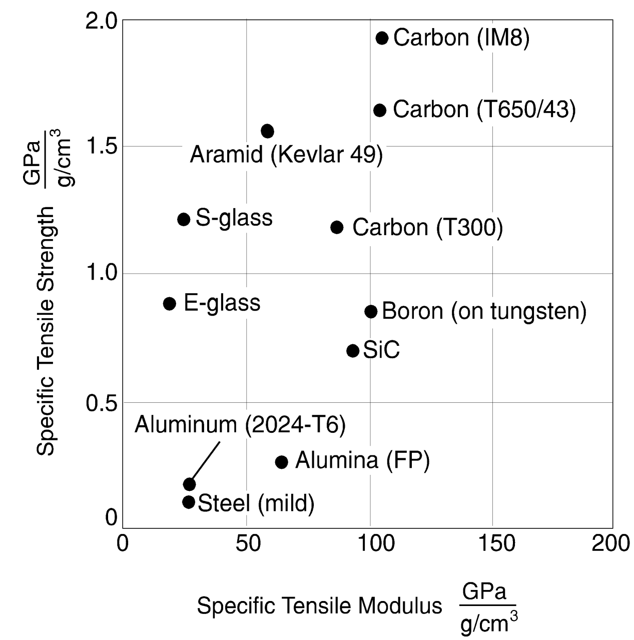
- Composite materials are not subject to corrosion degradation.
- Complex shapes are easily formed with composites.
- Lightweight composite structures are easy to handle and require smaller control machinery.
- Sandwich laminates are ideal for resisting hydrostatic loads.
- Composite laminates have excellent fatigue characteristics.

Fibers

	Density gm/cm^3	Strength MPa	Modulus GPa	Specific Strength MPa*	Specific Modulus GPa*
E-glass	2.60	3450	72	1327	28
S-glass	2.49	4589	87	1843	35
Aramid	1.44	3623	124	2516	86
Carbon (commercial)	1.76	2415	227	1372	129
Carbon (high performance)	1.76	4830	393	2744	223
Polyethylene	0.97	3000	170	3093	175
Basalt	2.66	2950	90	1109	34
HT steel	7.86	750	210	95	27
Aluminum	2.66	310	75	117	28

* Strength or stiffness divided by density





Resins

	Tensile Strength	Tensile Modulus	Tensile Elongation	Heat Distortion Temperature	Shrinkage
	MPa	MPa	%	ºC	%
Ortho Polyester	41	3480	1.2	65	9.00
Iso Polyester	61	3380	1.6	97*	8.20
Vinylester	79	3380	5.0	105-120*	7.80
Laminating Epoxy	83	3680	9.0	110*	0.75
Multi-Purpose Epoxy	50	3170	10.0	54	0.80

* Post-cured data

from ATL Composites Pty Ltd

Polyester

- *Polyester* resins are the simplest, most economical resin systems that are easiest to use and show good chemical resistance.
- *Isophthalic (iso)* resins generally have better mechanical properties and show better chemical resistance.

Vinyl Ester

- Superior corrosion resistance
- Hydrolytic stability (blister resistance)
- Better secondary bonding properties
- Excellent physical properties, such as impact and fatigue resistance.

Epoxy

- Epoxy resins show the best performance characteristics of all the resins used in the marine industry.
- The high cost of epoxies and handling difficulties have limited their use for large marine structures to date.

Cores

End-Grain
Balsa

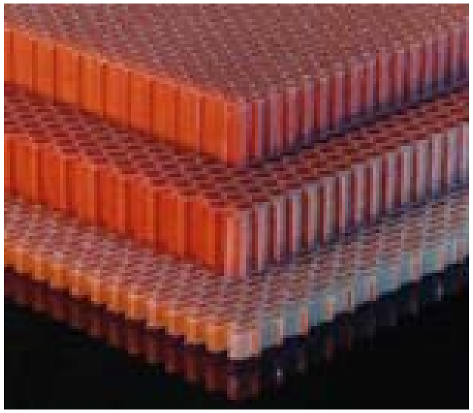
SAN Foam

Linear
PVC Foam

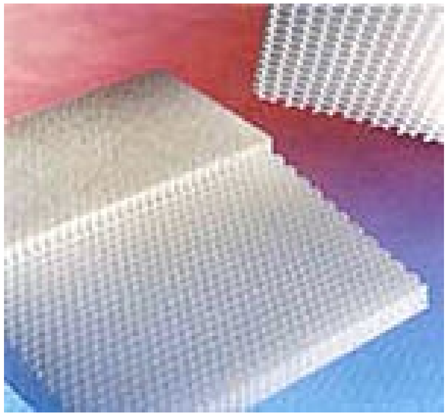
Aromatic
Polyester Foam

Cross-Linked
PVC Foam

PET Foam



Aramid
Honeycomb

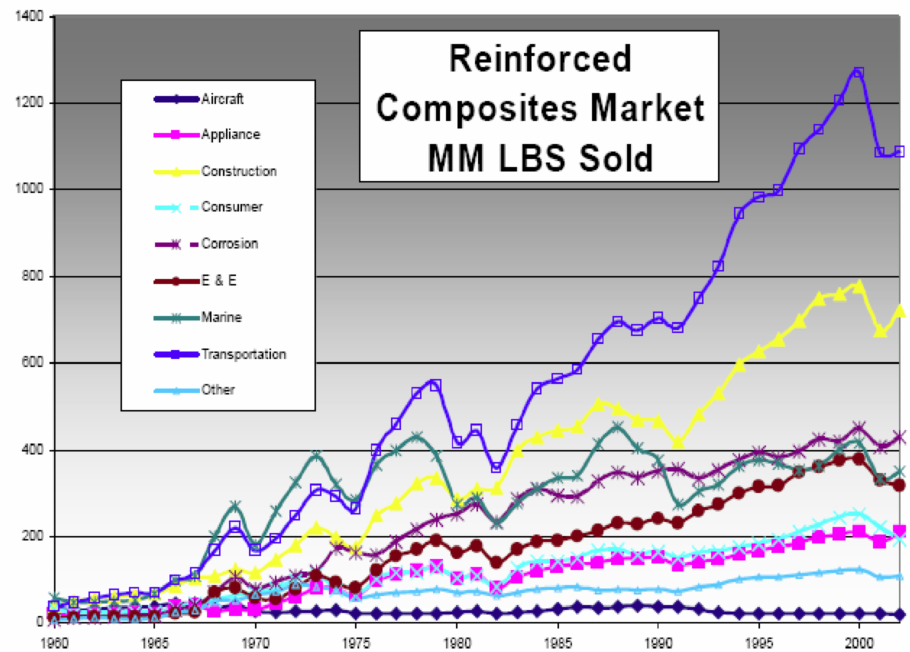


Polypropylene
Honeycomb

Worldwide Use of Engineering Materials

Shipments, M-tonnes						
	1999		2004		2009 (est.)	
	Steel	Composites	Steel	Composites	Steel	Composites
North America	142.4	2.2	152.5	2.3	155.5	2.8
Europe	330.7	1.4	379.2	1.5	398.2	1.7
Asia	300.5	1.3	473.9	2.2	548	3.2
Rest of World	63.5	0.2	80	0.3	92.5	0.4
Total:	837.1	5.1	1085.6	6.3	1194.2	8.1
% Change:			29.7%	23.5%	10.0%	28.6%

Composites Use Breakdown by Industry in the U.S. Market



Manufacturing Processes

Hand
Layup

Resin Infusion

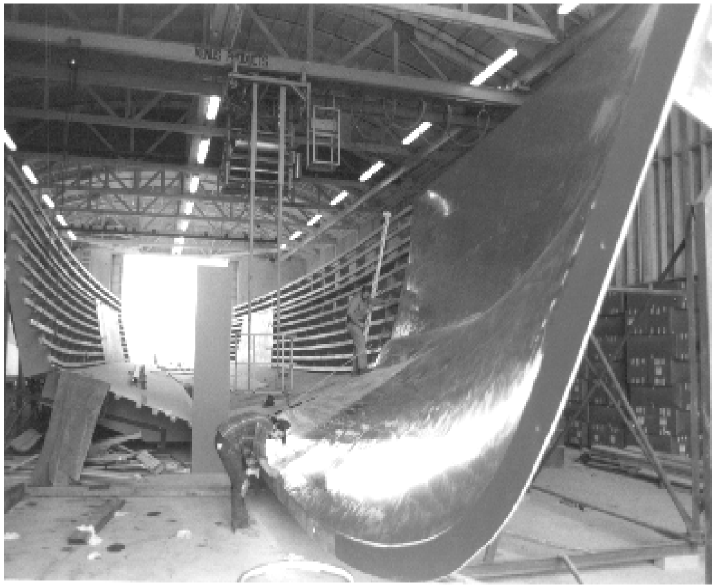
Filament
Winding

Pultrusion

Prepreg

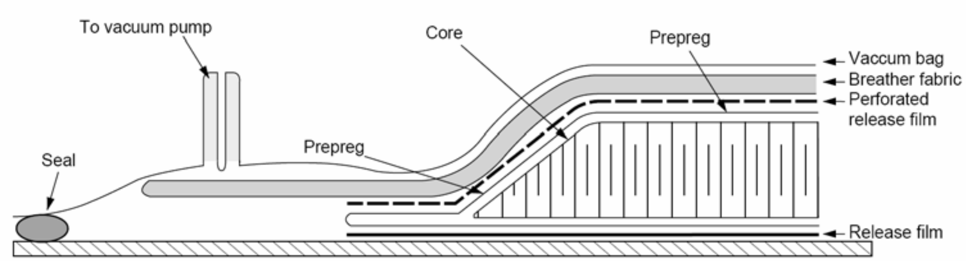
Key Processes Parameters

- Mold Production
- Material Handling
- Fiber Wet-Out
- Laminate Consolidation
- Curing Profile
- Inspection



Two Part Female Hull Mold

Impregnator on Overhead Gantry



Vacuum Bag Arrangement

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 in height.

U.S. Large Composite Hull Fabrication

This 160 foot composite motoryacht is typical of infused hulls produced by Christensen. The company has plans to produce a 186 foot, 500+ GT yacht will be constructed in a purpose-designed facility in Tennessee.

Examples of Large Composite Vessels

The ***Mirabella V***, the largest composite vessel and largest single-masted sailing yacht yet built, was launched in 2004 by VT Shipbuilding. The 75m long super-yacht displaces 740 tonnes

The ***VISBY*** displaces 600 tons (fully equipped), is 73 m overall length with a 10.4 m beam. Material of construction for the hull is sandwich construction carbon fiber reinforced plastic giving a quoted speed of >35 knots.

U.S. Large Composite Hull Fabrication

Atlas Hovercraft of Florida is introducing commercial hovercraft technology to the US. Bonded pultruded structural profiles are used to develop the large, flat surfaces.

Examples of Large Composite Marine Structures

Composite Submarine Bow Dome Infused with Epoxy by Goodrich Composites

Advanced Composite Sail Envisioned for Virginia Class Submarines

Composite Drilling Riser Developed by Aker Kvaerner Subsea

Large Naval Composite Marine Structures

Structural Composites infused a composite rudder with complex shape for the US Navy's DDG 51 class destroyer.

The ***Skjold*** is Fast Patrol/Missile torpedo boats Built by Umoe Mandal. ***Skjold*** ('Shield') has an air-cushioned catamaran hull (surface effect) which, with waterjet propulsion, provides high speed and maneuverability.

Future High Performance Marine Vehicles

Umoe Mandal (Norway) worked on this 75 meter advanced composite ship for the US Office of naval Research. This forth-generation Umoe composite ship converts from an SES to a hovercraft to transport equipment from a “Sea Base” to a beach.

Marine Aviation Vehicles

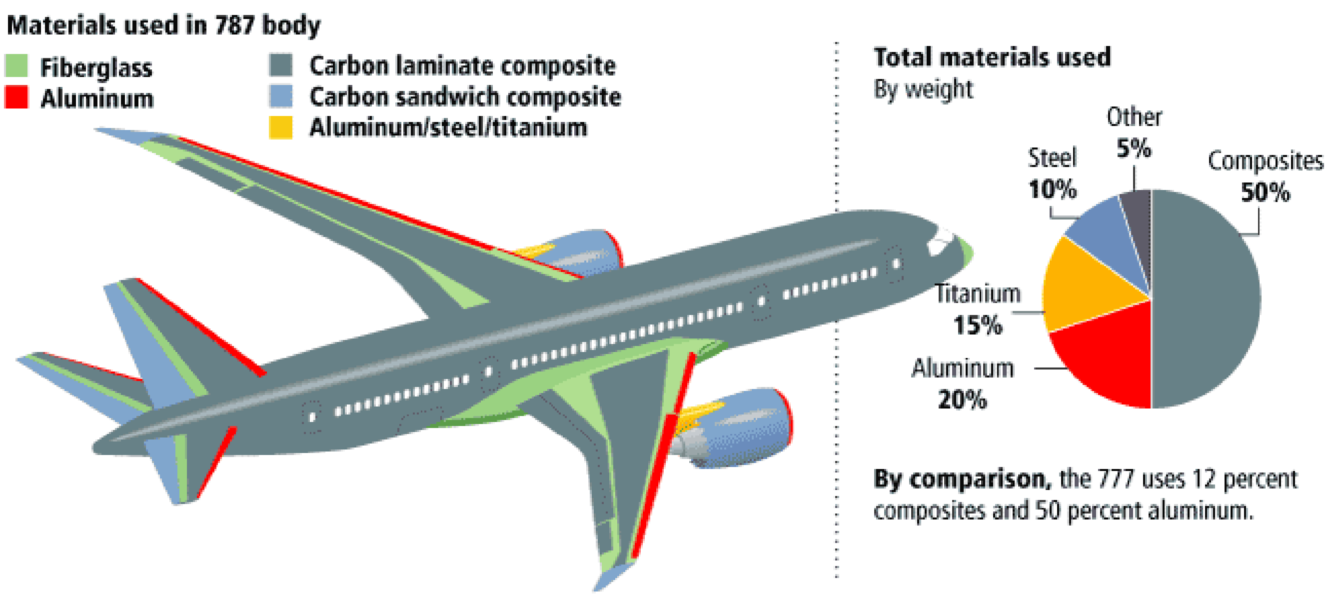
Howard Hughes' ***Spruce Goose*** was 218 feet long with a 320 foot wingspan and designed to carry 700 soldiers. At 181 tons at takeoff, the flying boat flew only about one mile in 1947.

In 1984, the Dornier company introduced an all-composite, 12 passenger amphibian transport.

Composite Aircraft Structures

The Beechcraft Starship achieved FAA Type Certification in 1987.

Bombardier Aerospace new mid-size business jet is an all-composite design



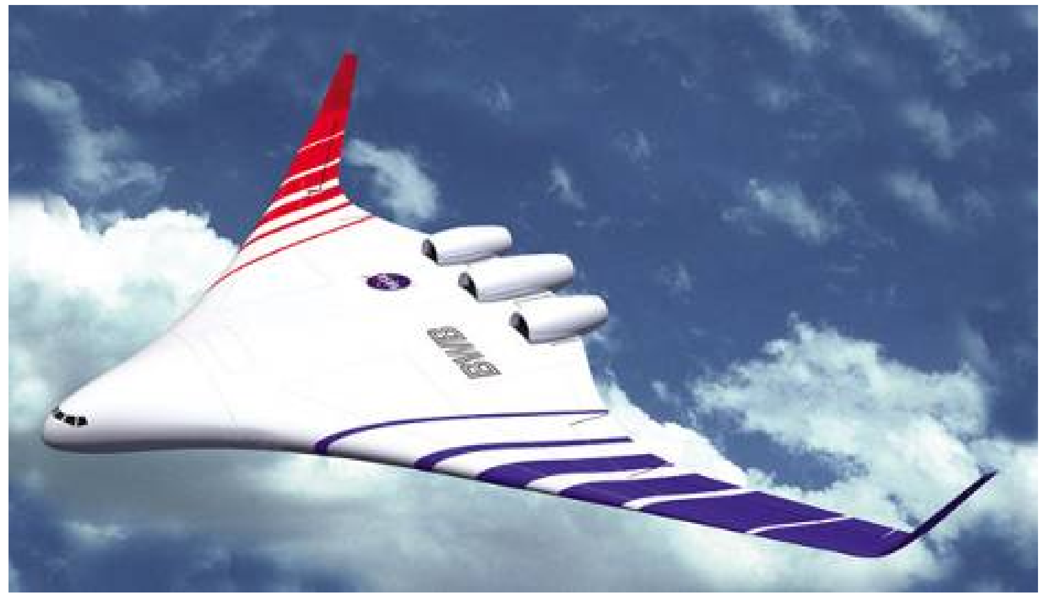
Composite Cars

The Toyota 1/X concept car uses a carbon composite body to produce a car that weighs 1/3 of the Prius. The structure of the 1/X is designed to absorb shock and impact loads. The car is claimed to travel more than 600 miles on four gallons of fuel.

The Aptera achieves high mileage in part from its composite aerodynamic body.

Future Transportation Platforms?

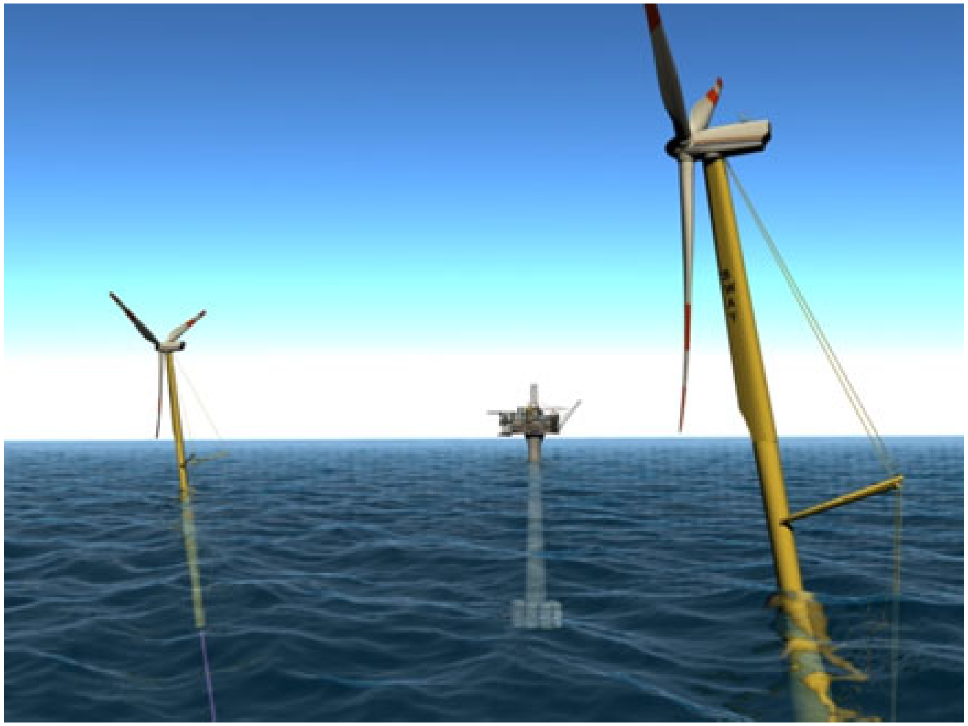
Very High Speed Sealift
Trimaran -VHSST



Blended Wing Body Aircraft

SeaBridge – A Pentamaran
Bridge over the Sea

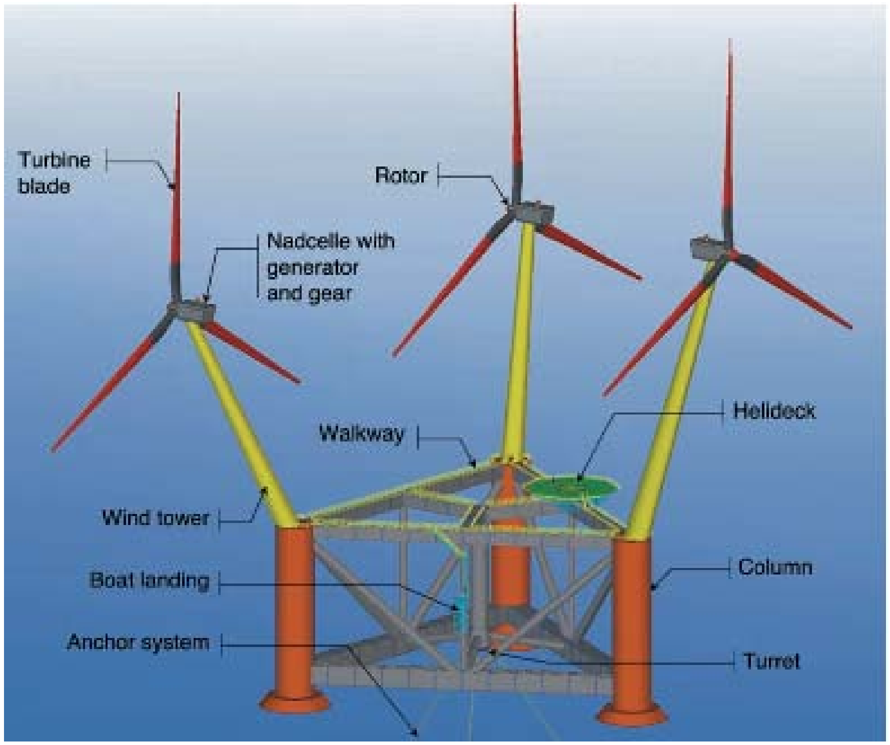
Offshore Wind Energy



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 Foundations

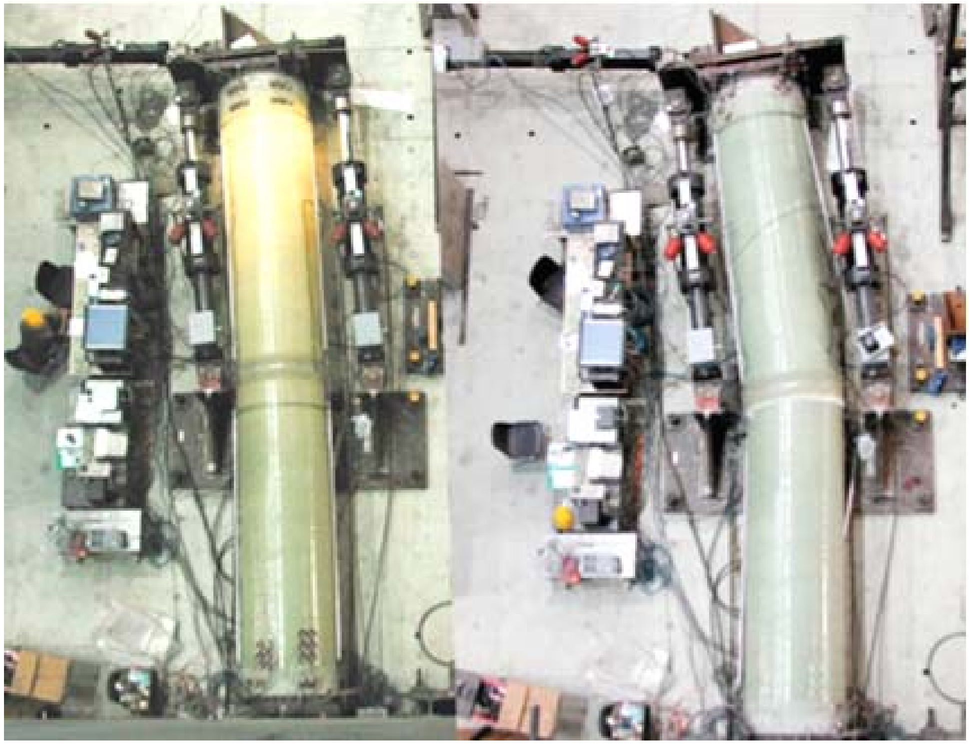


WindSea is a three-sided semi-submersible vessel with corner columns, each supporting one wind turbine.

- 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

Offshore Wind Foundations

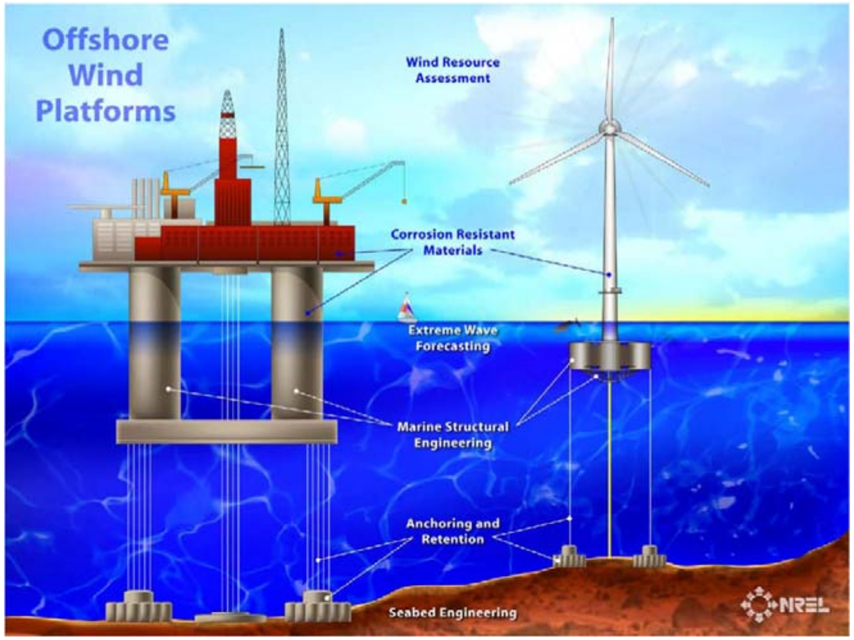
Floating Power Plant has a 37 meter model for a full off-shore test off the coast of Lolland in Denmark.

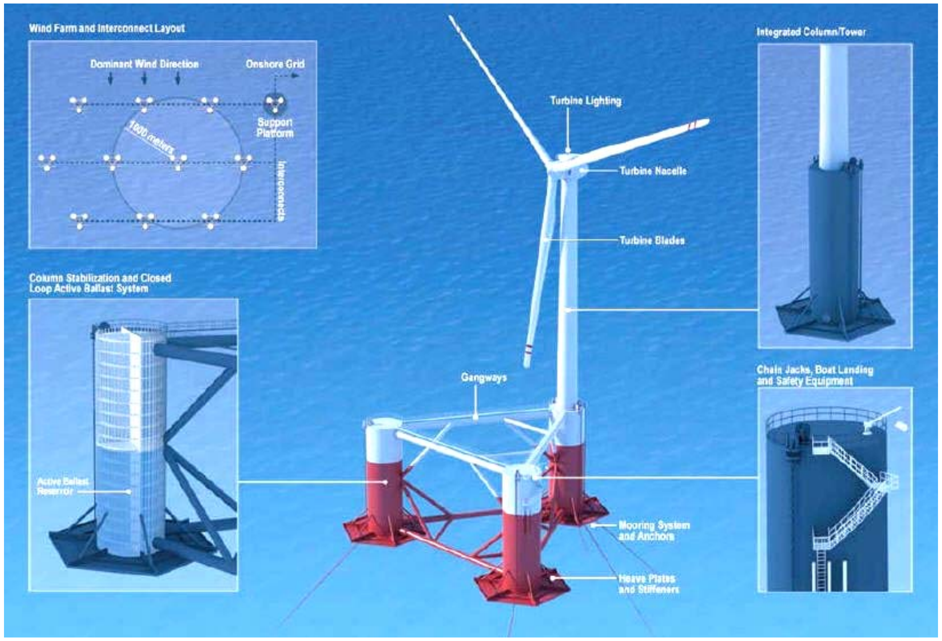


During the MEGAWIND project, testing of this one-third-scale, filament-wound, monolithic-shell tower was conducted at the ELSA laboratory of the JRC, European Commission, Ispra, Italy.

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

Offshore Wind Foundations





Small Wind Energy

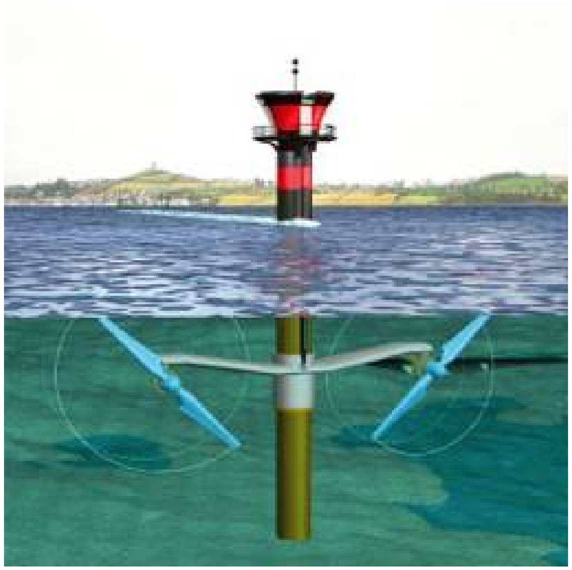
Greentenco has developed a combination wind/solar power generator for remote, rural applications.

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

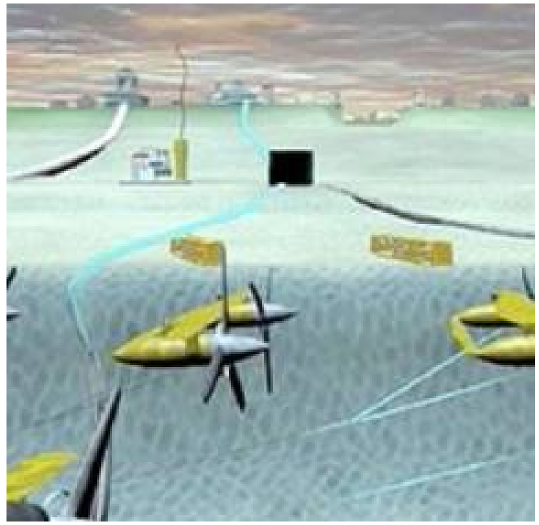
Quiet Revolution in the UK has manufactured this aesthetically-pleasing vertical axis wind turbine with carbon composites.

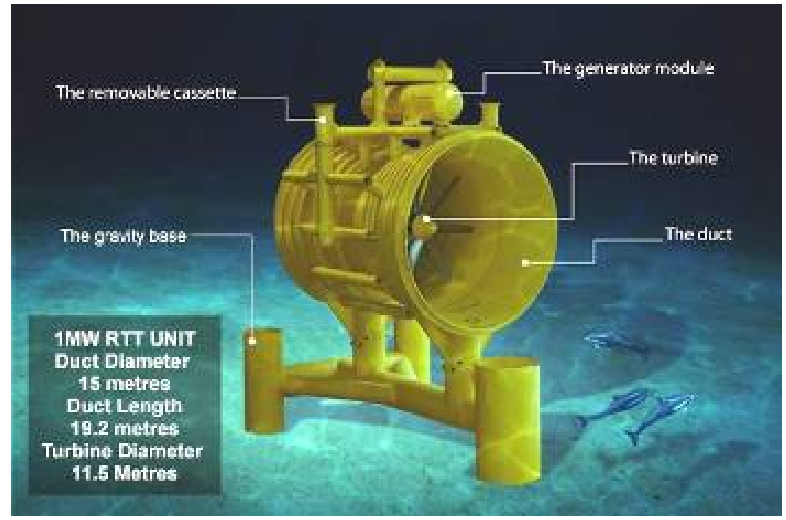
Skystream (left) and Zephyr (right) manufacture small wind turbines for individual residences.

Ocean Tidal Energy



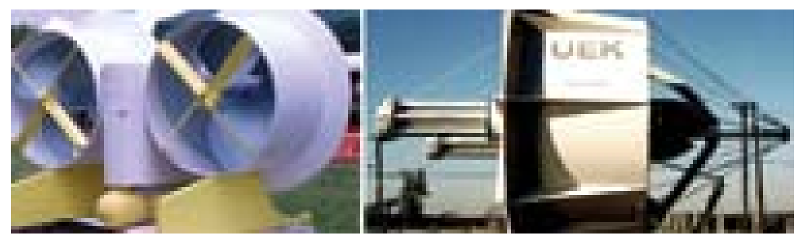
Marine Current Turbines Ltd has installed a 1.2MW SeaGen tidal energy system in Ireland.





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.

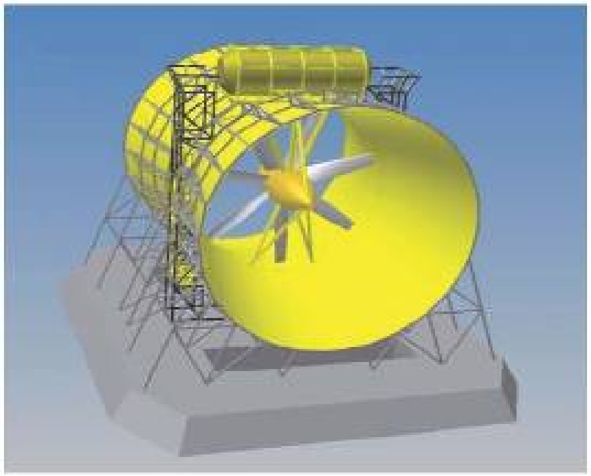


UEK Corporation has been developing a practical way to harness river, tidal and ocean currents with hydro kinetic turbines since 1981

Rotors and Shrouds


Verdant Power


Ocean Renewable Power

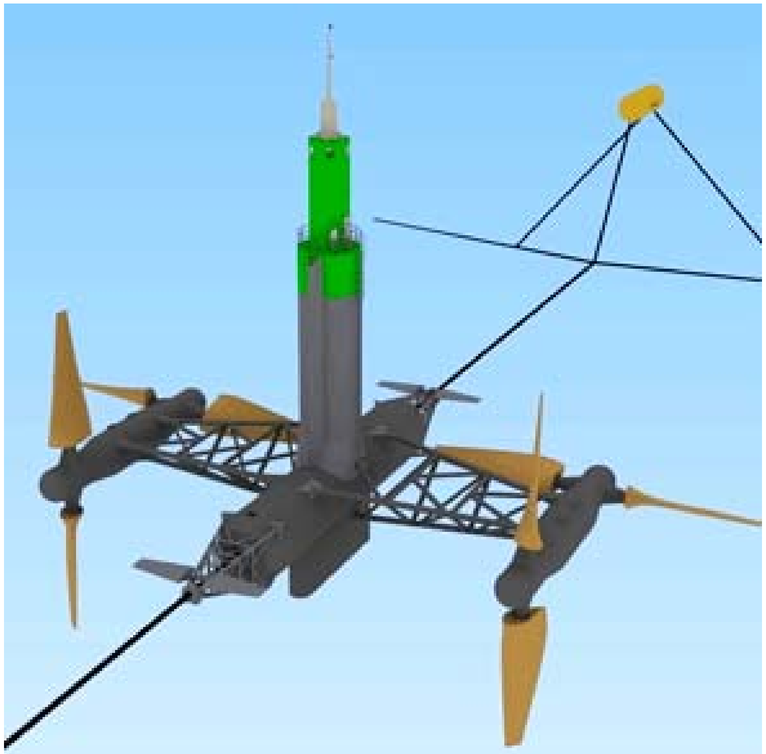

Lunar Energy


OpenHydro


Marine Current Turbines


Hydro Green
Energy

Ocean Tidal Energy Wood Blades



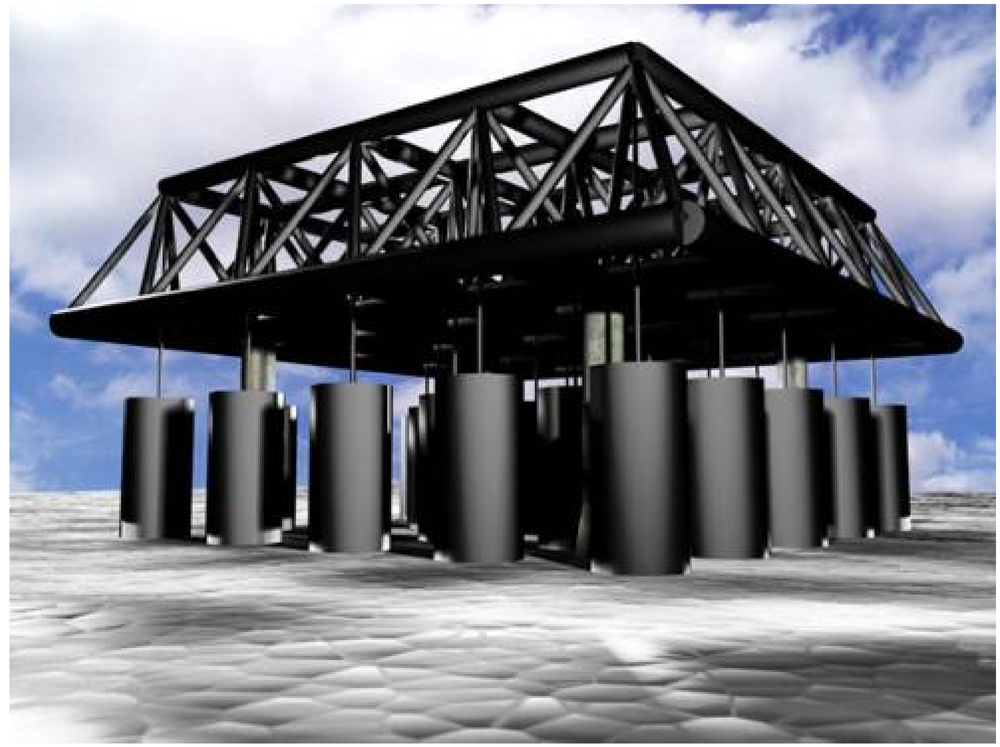
Hydra Tidal will install a full-scale (1.5-MW) prototype of its tidal energy plant that will be moored to the seabed and mostly submerged, with turbine wings spanning a diameter of 23 meters.

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 and has opened a North American office

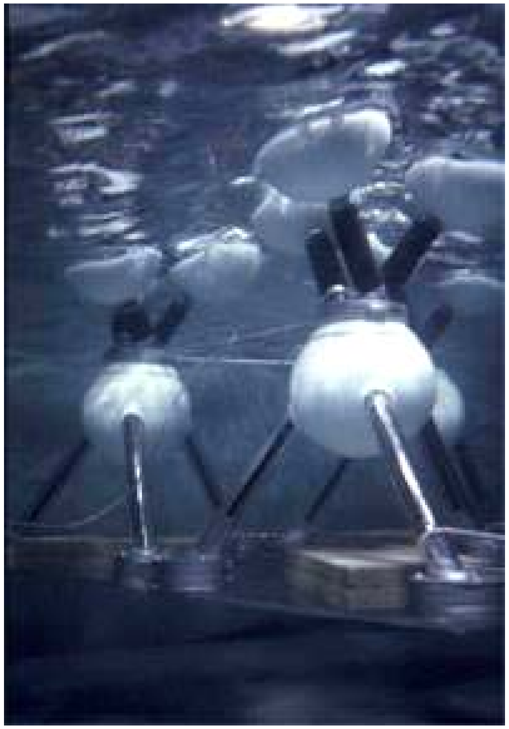


The Manchester Bobber is an innovative wave energy device. With the Bobber, a floating mass rises and falls under the action of waves in the water and this causes a pulley and its shaft to oscillate.

Wave Energy Foundations

AquaBuoy

SEADOG Pump



OWEC Ocean Wave Energy Converter

Energetech

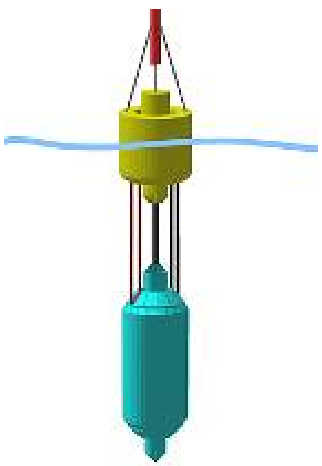
AWS Ocean Energy

Wave Energy Moving Parts

Aquamarine Power

Wavegen

Ocean Power Technology



Wavebob

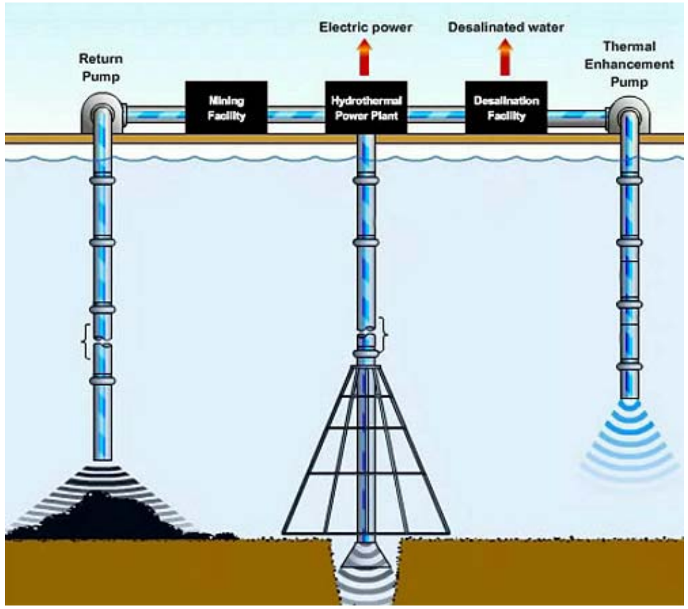
Pelamis Wave Power

Wavestar

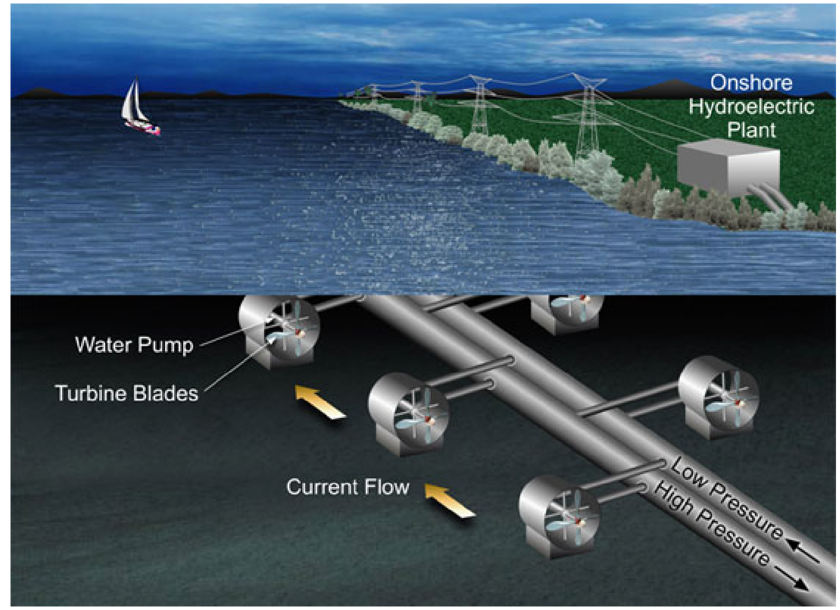
Sea Snail

Hydraulic Piping Systems

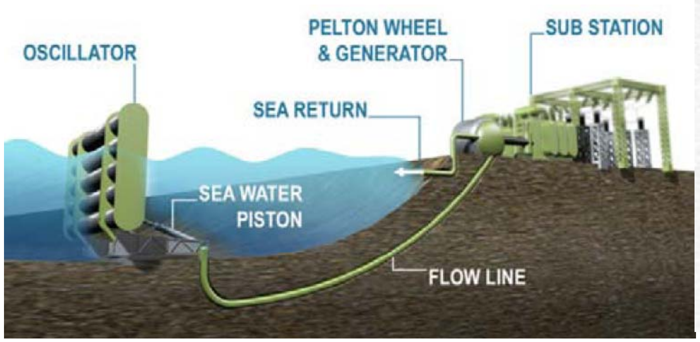
SEADOG Pump



Marshall Hydrothermal Recovery System



JPL/Caltech Hydrokinetic Energy System



Aquamarine Power

Gentec Venturi

Summary

- Composite materials are well suited for marine energy devices because they are non-corrosive and have good fatigue life.
- Directional properties of composites permit design optimization but loads, material properties and failure modes need to be defined.
- The physical properties of composite structures are defined during fabrication, so quality assurance procedures are paramount.
- Composites are especially attractive to build complex shapes, when weight is critical, and when manufacturing production quantities.