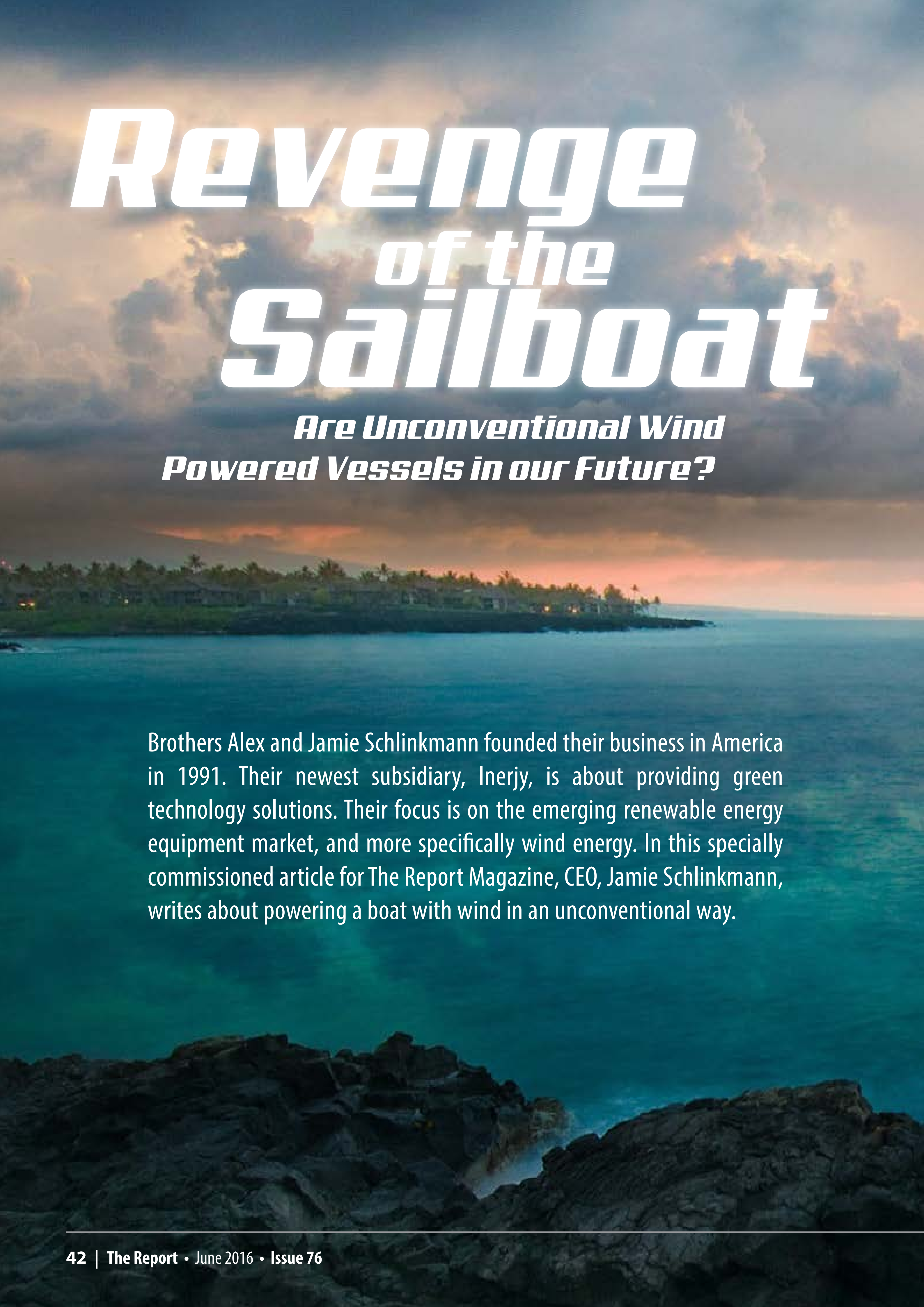


Revenge of the Sailboat

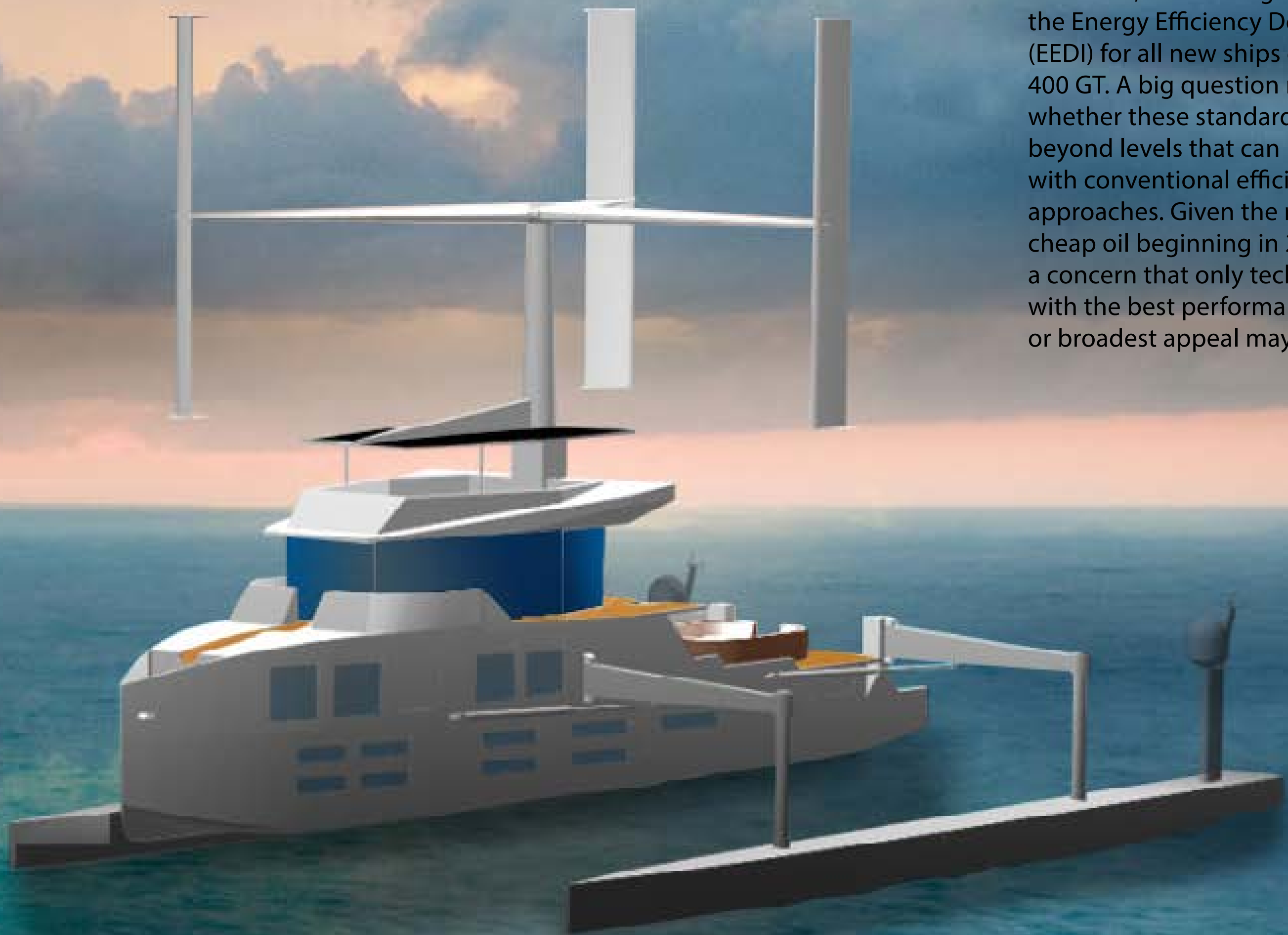
Are Unconventional Wind Powered Vessels in our Future?

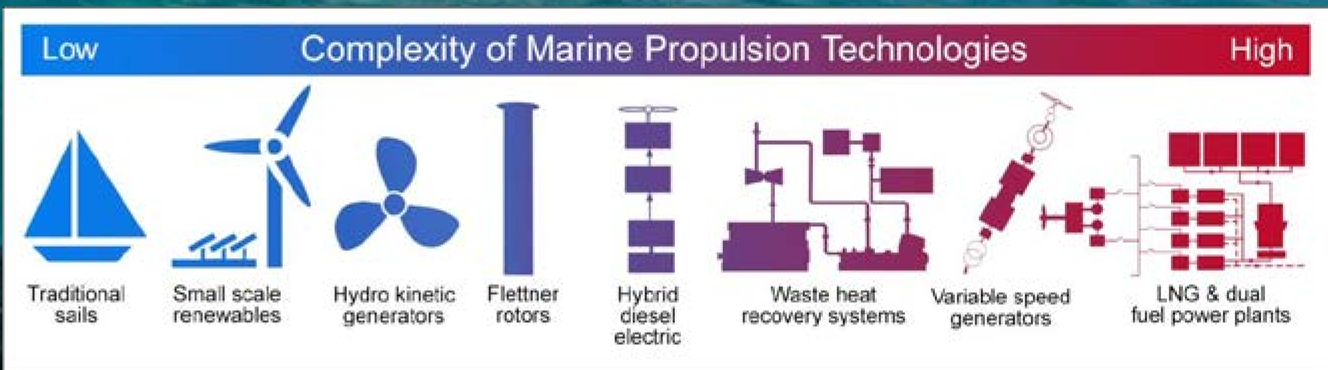
Brothers Alex and Jamie Schlinkmann founded their business in America in 1991. Their newest subsidiary, Inerjy, is about providing green technology solutions. Their focus is on the emerging renewable energy equipment market, and more specifically wind energy. In this specially commissioned article for The Report Magazine, CEO, Jamie Schlinkmann, writes about powering a boat with wind in an unconventional way.

There's a new idea getting a lot of attention: powering a boat with wind—in an unconventional way. Aside from pleasure boats built by and for purists, fossil fuels took over the high seas already over a century ago. Since then ship propulsion technology has been refined over and over again, culminating in complex multi-fuelled hybrid electric drivetrains with many pieces of technology added to enhance performance. Although efficiencies and emissions levels have certainly improved, this common theme remains: the prime mover is fossil-fired. Today a variety of factors are calling conventional wisdom into question. In an energy-rich environment such as the open ocean, why carry all of the energy used on a voyage aboard?

MOTIVES FOR CHANGE

Rising fuel prices combined with a desire to curb carbon emissions have spawned interest in technologies beyond traditional efficiency measures. The global commercial marine sector accounts for nearly one billion tonnes of carbon emissions annually, more than the entire nations of the UK, Canada, or Brazil. This sobering fact has prompted the International Maritime Organization, a division of the UN, to issue regulations like the Energy Efficiency Design Index (EEDI) for all new ships exceeding 400 GT. A big question remains whether these standards will reach beyond levels that can be achieved with conventional efficiency approaches. Given the return of cheap oil beginning in 2015, it is a concern that only technologies with the best performance, benefit, or broadest appeal may survive.



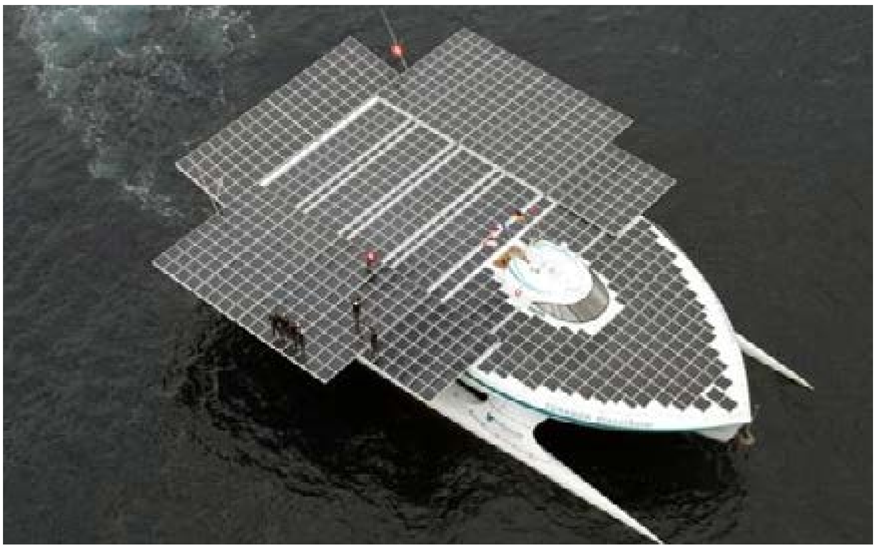


Perhaps above all Northern European emissions restrictions have been the principal drivers for efficiency improvements and the renewed study of wind and non-traditional propulsion technologies. The Netherlands for instance has recently announced plans to eliminate the allowance of any emissions whatsoever on inland waterways. Of course this kind of regulation will mostly promote hybrid drivetrains and battery technologies.

RENEWABLE ENERGY RESOURCES

Wind, wave, and solar PV are the favoured non-fossil energy sources being tested on oceangoing vessels. Wind obviously has the greatest history, and not by accident. Average wind power densities on the open ocean are considerably higher than on land, and except for a narrow equatorial region, exceed 400W/m^2 (measured perpendicular to the wind direction). Wave energies are tremendously dense and most often measured in kW per horizontal meter of wave front (as with wind, perpendicular to direction of travel). Bear in mind wave power only scales linearly and not in two dimensions like solar or wind. Densities of 30kW/m and higher are common, but tapping that energy has proven challenging on fixed or moored devices so even more so on a moving vessel. Solar has the disadvantage of night hours containing no usable energy and in contrast to the wind densities it ranges from about 300W/m^2 in the equatorial region to half of that in Northern Europe.

Note that all these resources have limitations to their extractable energies. For wind, the theoretical limit, known as the Betz limit, is 59.3%. As a device removes power from a free stream of wind, the wind begins to blow around the device. Thus the device's own disruption of airflow limits its usefulness. The most efficient turbines today convert about 50% of the kinetic energy in wind after conversion losses. Monocrystalline solar, currently the most efficient technology available, has about a 32% theoretical conversion limitation and in practice the best cells are working at about a 21% efficiency after conversion losses. This limit is known as the Shockley-Queisser limit and exists because of physical limitations of moving electrons in a semiconductor. Finally, wave energy also has theoretical limitations but they correspond to given wave periods and amplitudes. Every mariner knows that these factors are widely varied and that's one of the key reasons converting wave energy into electricity is so difficult. Some devices claim to achieve 80% efficiencies in lab testing but real-world tested machines have fallen very short of that number. In a shipboard application the absolute power converted for use (resource x efficiency) will take second place to the device's impact on propulsion efficiency and other practical aspects of integration into the vessel.



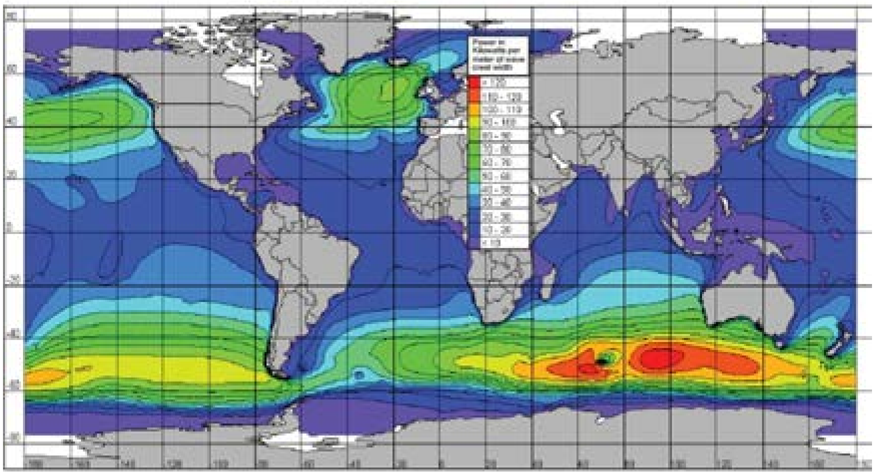
TECHNOLOGIES

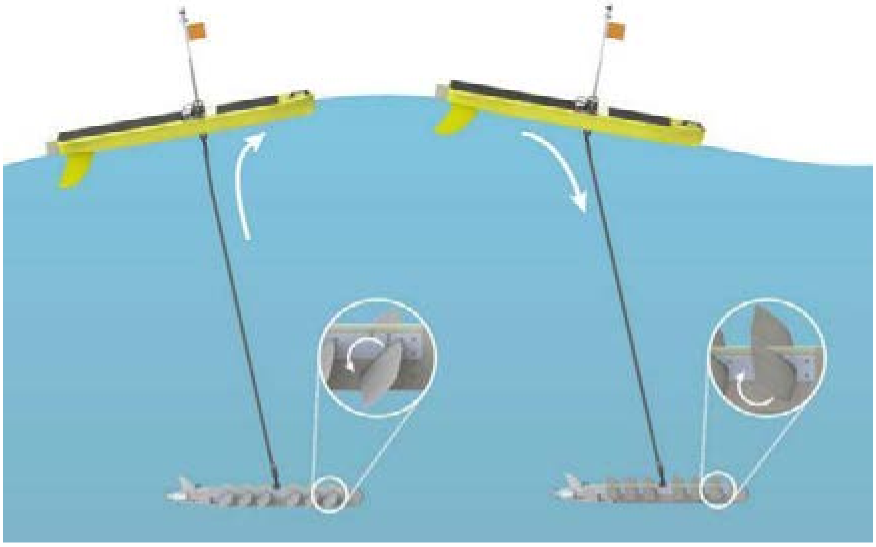
Solar PV

Silicon based PV is great technology. It is simple, reliable, predictable, and cost-effective. PV modules belong on nearly every vessel that has an electrical system developed enough to take advantage of their power output. Many commercial vessels like tankers and bulk carriers could supply entire hotel loads if properly rigged with PV systems. The catch is that it's only enough power for propulsion in dedicated, special purpose vessels. Planet Solar's MS Turanor is a great example. This vessel proved solar's place at sea by circumnavigating the globe on PV power alone. A look at the vessel however reveals some obvious practical limitations to the scale of the energy capture integrated. Other vessels such as Nissan's Nichioh Maru demonstrate successful and practical use of solar on a car carrier. On the yacht side, Italian yard Arcadia builds an 85' vessel with a unique integration of 3.5kW of solar PV. This is a well-engineered example, but just one of many builders now integrating the tech into their builds. Greenline of Slovenia has delivered more than 400 boats worldwide with PV systems and hybrid electric drivetrains. With these boats it is possible to sail on PV power alone, albeit at very slow speeds.

Wave

The most successful wave powered vessel so far, and perhaps the only one in serial production, is Liquid Robotics' Wave Glider®. Its clever design is like a surfboard with an underwater kite tethered beneath it. As waves lift and drop the main hull, the 'kite' has foils that pivot to different angles of attack to pull

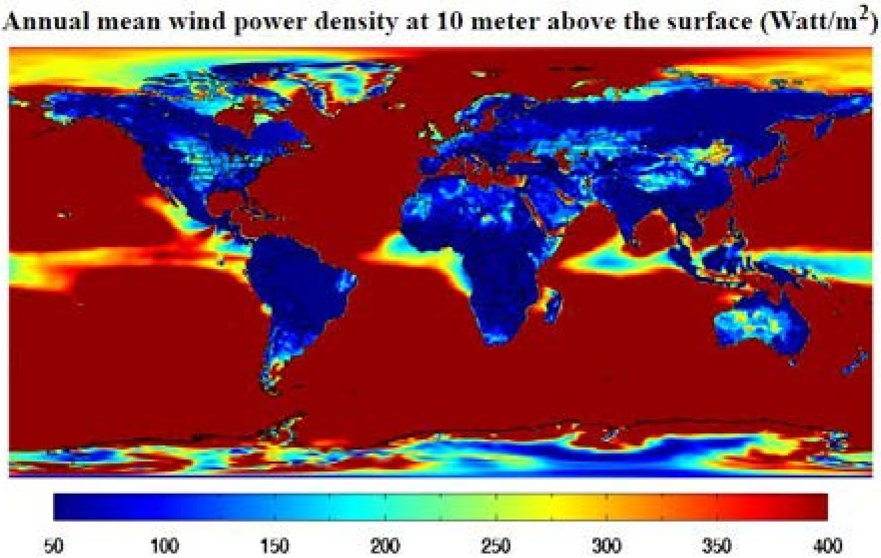




without negatively impacting propulsion dynamics. It remains a contest whether someone can crack the code that unleashes the immense power of waves for vessel propulsion. So far this contest doesn't have many competitors.

Wind

Numerous wind propulsion technologies are coming onto the market. On the commercial shipping side, this topic has such attention that an organization was established to promote and 'sectorize' the effort: the International Windship Association, or IWSA (wind-ship.org). Some are new ideas, many are not, but there is a substantial effort by corporations to market these products and a corresponding audience to consume and test them.



Traditional Sails

Sails could be the most successful invention ever created. We know by ancient drawings that man has been sailing for at least seven thousand years. Imagine having just a 1% royalty from every sail ever sold. Sure there are more wheels used today, but how about a thousand years ago? Sails are simple, reliable, and flexible, but they have some downsides: They are only moderately efficient. Their airfoil shape and limited speed don't capture energy as well as a modern wind turbine. One exception would be a high speed foiling catamaran racer. Since this vessel can sail faster than the wind, its airfoil can do a more efficient job of extracting energy. Also the area of wind acting on a fixed sail is limited to barely over its actual sail area, and its efficiency on that can only be optimized for a narrow range of operating conditions (vessel course, wind direction, etc.). It is cumbersome to adjust sails to suit a given condition, especially when sail area must be added or removed. Sometimes condition or course adjustments are even risky—to equipment and to person.

Kites

Kitesurfing is a mainstream watersport. Kite surfers can be found in waters near virtually every coastal town across the globe. A logical use for the technology that brings such excitement to tens of thousands of people is propelling ships. Some benefits: higher-altitude winds contain more energy; vessel retrofits are more feasible than other technologies. Drawbacks? Hard to automate; limited range of heading/wind direction benefit; hard to maximize the useful area/propulsion benefit. Assuming oil prices rise again, this one should be a no-brainer for existing operators.

Rigid Sails

Promising simpler rigging and higher aerodynamic efficiencies, rigid sails, also known as wing sails, have emerged. Many projects are under construction or test of different rigid sail configurations. These span the range from dinghies to cruise ships. While they can deliver on higher efficiencies, one principal drawback limits the extent of their benefit: they are fixed-area and therefore difficult to reduce their exposure in high winds. Note that most ships and oceangoing vessel concepts depicting rigid sails have a significantly lower sail area than their traditional sail counterparts. It is however a simple and effective way to propel on the high seas.

Hydro Kinetic Generators

These devices are used on sailboats to provide electrical power for hotel loads or charging batteries. Although not a propulsion technology, they allow an otherwise powerless sailing vessel the ability to produce electricity for refrigeration, electronics, or other minor loads, using the motion of the boat through the water. Propeller driven devices can either be mounted below the waterline or even towed. While it's a simple and compact solution, it slows down the vessel by more than its proportional electrical output.

In circumstances where desired electrical power output is a small fraction of propulsion energy, and the loss of speed is acceptable, it is a good renewable solution.

Flettner Rotors

These tall spinning cylinders can now be seen on several vessels. They work like a sail to provide aerodynamic force that pulls the ship along; only instead of an airfoil they use something called the Magnus Effect to create their lift. This effect is what curves the motion of a spinning ball. Multiple organizations have refined versions of the technology, including Thiiink, Norsepower, and Magnuss. Since the rotors themselves require an external energy source to rotate them, the technology is presently most useful to provide supplemental propulsion to conventional drivetrains. Also, as with a traditional sailboat, the thrust provided is greatest when the wind is at a right angle to the vessel's heading. Since the thrust amount can be controlled by rotational speed, and the cylinders themselves are relatively unobtrusive, it has some mainstream curb appeal. It has also successfully been tested as a retrofit on the Ro-Ro carrier MS Estraden. The ship's operator, Bore Ltd, working with the VTT Technical Research Center of Finland proved a fuel savings based ROI with a single rotor and proceeded to install a second rotor onto the ship.

Wind Turbines
Wind turbines are a logical technology for maritime propulsion. They are extremely efficient at converting wind into electricity, and since the blades move they act on an area of a wind stream much larger than their blade area. This is known as the turbine's swept area, and this helps a control system mitigate loading in winds stronger than desired. Also a turbine can maintain optimal angle of attack and blade speeds regardless of vessel course relative to wind direction. This provides a tremendous advantage over most other wind propulsion technologies. Still, the efficient blades can provide too much load high above the deck of a boat in some conditions; and traditional turbines operate at speeds over 200 mph which makes them uncomfortable to be around.

New Turbine, New Possibilities
The EcoVert75™ wind turbine was designed for distributed generation applications, like powering schools, retail stores, etc. The key requirements focused on people living and interacting near the machine. It is technically called a pitch-controlled H-VAWT, a design originally modelled, prototyped, and tested by McDonnell Aircraft Corporation (now Boeing) in the early 80's. It produces a healthy 70kW in a 21 knot wind at 32 rpm. With a few modifications from the terrestrial version it is an excellent machine for use aboard a vessel. Here are a few reasons why:

- Less than ¼ the head mass and a third the storm wind loads compared to other similarly sized turbines
- Less than ½ the operational blade speeds of conventional turbines at similar power outputs
- Very low noise & safe blade path for vessel occupants
- High power efficiency, Cp > 0.5 at some wind speeds
- The ability to produce propulsion thrust directly with the turbine instead of converting all the wind power into electricity, saving conversion losses

Gemma One
Propulsion scale wind turbine power is the heart of Gemma One. A common metric used to describe a sailing vessel is the sail area displacement ratio (SA/D). This basically allows vessels to be compared to each other in terms of a power to weight ratio. The highest SA/D ratio tested with a turbine thus far has been less than five. Gemma One's target SA/D is eleven. Given that ocean going sailing vessels are commonly around 15, and racing vessels above 20, there is opportunity for future advancement in power to weight ratio metrics. Battery density and desired capacity play a role in this ratio.

The 2,500 kWh energy storage system will be divided into the two outrigger hulls, along with the DC-DC converters, the propulsion motors and drives, and HVAC equipment. Cooling requirements are suppressed by the highly paralleled architecture. Unlike an automobile or even a ferry, the battery system is sized for a very low duty cycle. This approach limits the interfaces with the main hull, eliminates raw water systems entirely, and allows building and testing of these hulls at a subsystem level—completely decoupled from the requirements of the main hull.

Gemma One's main hull is dedicated to little more than guest and crew spaces. In transit conditions the hull is jacked up clear of the water so it has no main running surfaces. Given the absence of diesels or related systems, all spaces within the main hull can be environmentally controlled, and relatively little mechanical space is necessary. A large enclosed garage is provided for storage of multiple tenders and recreational equipment. Performance numbers are decent for a boat that gets all its energy from the environment. She boasts a top speed of 16 knots and in average Caribbean conditions an unlimited range at 5 knots. Five days at anchor (or adrift) will fill fully depleted batteries.

IC engine propulsion has served ships well and will continue to for many years, especially on high speed vessels. It has drawbacks however that seem ubiquitous today in the absence of alternatives. One such drawback is the physical I/O that contributes to virtually all internal shipboard maintenance:

- Introduction of copious amounts of humid air into mechanical spaces
- Introduction of fuel having conditioning and contamination mitigation requirements
- Introduction of cooling water that fouls complex cooling systems
- Output and exhausting of high temperature gases
- Output of high frequency mechanical vibrations

These negatives are eliminated along with the engines. Moving electrons around is not immune to failure but generally does not require a lot of maintenance, and while the wind turbine has moving parts they are few in number compared to an IC engine. Gemma One is a lot closer in complexity to a sailboat than a modern diesel vessel.

Not all purposes are suitable for wind powered battery electric ship technology. As of now the batteries will hold far less energy than large fuel tanks. But with most regions of the world's oceans having abundant wind energy available on a regular basis, is there a need to carry weeks or months of energy on board?