ENERGYTECH®
MARINE GROUP

The Power Core Hybrid-ion Energy System Version 1.6.1 – 04/26/2009
The Operational Advantages of Using Regeneration Energy

"Quit wasting the wind energy on your sailboat by trying to sail with it"

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INCREASE SPEED AND DISTANCE BY HUNDREDS OF PERCENT, USING THE SAME WIND ENERGY

For a sailing yacht, wind is wonderful. In most vessels, it is potentially able to contribute more thrust to your forward motion than the most powerful diesels you would ever put onboard. The horsepower available, free for the taking, from the kinetic energy contained in the wind that strikes your sails can be amazing. The only problem is that it is intermittent. That problem can now be almost completely eliminated as EnergyTech Marine introduces a hybrid energy system that uses wind power captured by sails to do much more than just sail.

As you will see, it is much more efficient to capture the wind energy in your sails and convert it to electric power for motoring than it is to simply waste it by just trying to sail with it. By converting the energy to electricity before you use it, you can go much farther, much faster, than only sailing with it. The EnergyTech Power Core™ Hybrid-ion Energy System turns a vessel into a giant hydroelectric generator. This process can simultaneously completely eliminate the carbon footprint for your voyages.

Let us give a simple example of what can happen if you are on a passage and you have decided that you are only going to use free wind energy to propel your vessel. On a vessel the size of the EnergyTech Marine 83 HD-X, a good wind can propel you at 12 knots. Since wind is intermittent, it might blow briskly from three until five in the afternoon and then cease until 11AM the next day. That would be two hours of brisk wind followed by an 18-hour lull. This can happen on any passage. It is a common example picked to show the difference in the performance of the Power Core Hybrid-ion Energy System compared to plain sailing without it. This one example is not the sole advantage of the system.

The Power Core Hybrid-ion Energy System in the EnergyTech 83 foot sailing yacht utilizes a pulse buffering strategy for energy smoothing. The implementation of this system dramatically increases range, MPG, and average speed while greatly reducing emissions. At the same time, the accompanying cost efficiencies can be almost unbelievable.

In our example, many people would find it inconvenient to have to drop anchor and wait 18 hours until the wind returns. Of course in reality you might simply fire up the diesel power and plow forward through the night and the next morning while burning X dollars worth of fuel. But for this example let's just say that you were conserving fuel, and for whatever reason you had chosen to do this passage with *wind energy only*, like many people do.

In this case, without the Power Core you would have sailed at 12 knots for two hours and zero knots for the next 18 hours. This means that for 20 hours of your passage you covered 24 miles at an average of 1.2 knots.

The Power Core Hybrid-ion Energy System integrally contains an extreme regeneration option that can be deployed at the push of a button to convert huge amounts of wind power into stored electrical energy. This system is unique to the 83 HD-X. It is the only regeneration system that throttles sail-power into variable kinetic energy in the flowing water beneath the vessel.

The amazing attribute of the EnergyTech Marine horizontal-axis hydroelectric reaction turbine system is that is can selectively convert the wind energy that drives the boat speed beyond a chosen velocity, without affecting the required energy to achieve a lesser-chosen target speed.

This means that the Power Core can skim off the extra energy from the sails that drives the vessel beyond, for instance, ten knots to reach the12 knots in our example. It can do this without taxing any of the power being absorbed by the rig to propel the vessel to ten knots.

So, for our above example, how much extra power is being absorbed from the sails to achieve 12 knots instead of ten knots? The answer is that for each of the two hours it requires an extra constant 324 kW (435 HP) to achieve the extra two knots. That is 648-kilowatt hours (over half a megawatt) of extra energy dedicated to the extra two knots for two hours for a gain of only four miles.

What happens to the averages in our cruising example if we were to convert the energy from that extra half megawatt source of energy into something that could be used later to propel the vessel during the subsequent18 hours when the wind is becalmed?

The first thing you would do is to deploy the ram intake scoops into the water flow beneath the vessel and divert an adjustable current into the enclosed reaction turbines. This diverts the dynamic pressure from the drag into kinetic energy from the water flow being forced into the turbine blades. The wider we open the adjustable scoops up to an area equal to that of the turbine blades, the greater the flow.

Large reaction turbines are greater than 90% efficient. Micro-hydro turbines are typically around 50% efficient. The EnergyTech marine reaction turbines would technically be defined as mini-hydroelectric turbines, which are generally assumed to be 65% efficient. Although that is our target number, we are going to be conservative and project about half that for 33.3% efficiency. To further enhance efficiency where possible, the EnergyTech system employs large industrial permanent magnet alternators, which charge lithium-ion battery banks and optional supercapacitors.

When we introduce enough drag to absorb the extra constant 324 kW (435 HP) being expended to take the velocity of the vessel beyond ten knot to twelve knots the vessel will slow to ten knots. The extra power is now being absorbed to convert some of the energy in the diverted water into torque as it is forced through the turbine blades. The torque is then used to generate electricity. The potential electrical energy increases dramatically with the increase of the velocity of the water flow against the turbine blades. The available energy increases by the cube of the velocity. A little more speed means a lot more energy.

The EnergyTech Marine vessel employs twin horizontal-axis reaction turbines, each with 200,000-Watt industrial alternators capable of converting a sustained 400,000-Watts of water flow into electricity to store in the 400,000 Watt-hour lithium-ion battery-bank. The hydroelectric capabilities of the system could hypothetically capture more than nine million Watt-hours of energy per day. Therefore, in our example of tasking the system to capture one third of 324kW (108kW) per hour (after efficiency losses) we are barely scratching its potential.

Let's look at what happens in the above 20-hour passage example if we store the large two-hour pulse of energy we regenerated from the excess wind and used it instead to propel the vessel with the electric motors after the wind dies.

In the regeneration mode we only travel at ten knots for the two hours when the wind is blowing and cover 20 miles instead of the 24 miles we cover if we forgo the drag produced by the energy regeneration. In the regeneration example we have stored (after 66.6% losses) 108,000 Wh for each of the two hours of sailing for a total of 216,000 Wh of energy. We then use that energy to power the vessel for the next 18 hours when there is no wind, at five knots. Five knots requires 12 kW of power and will deplete the 216,000 Wh we stored away, in 18 hours.

There would be some other minor losses in this process but for the sake of round numbers and simplicity for the following energy-smoothing™ estimates we are using flat energy assumptions. We have already been more than generous in favor of losses by assuming only 33% efficiency for the turbines. You may recall from earlier Power Core papers on the subject that the charge-discharge efficiency of the lithium-ion energy storage system is more than 99%.

In the first example without regeneration, we cover 24 miles in the 20 hours at an average of 1.2 knots. In the second example with regeneration we cover 20 miles in the first two hours from sailing and then an additional 90 miles from electric propulsion with the free energy we buffered in the batteries. That is 110 miles at an average of 5.5 knots for regeneration mode versus only 24 miles at an average of 1.2 knots for straight sailing.

We have increased our average speed by hundreds of percent. We have also increased our distance covered by hundreds of percent. We did all of this without ever starting an engine and burning expensive fuel; therefore compared to diesel motoring, we increased our cost efficiency by hundreds of percent. Emissions at the same time are reduced by orders of magnitude.

JUST FOCUS ON THE TRADEOFF

So what is the combined tradeoff of going *both* farther *and* faster using regeneration? What did we give up, and what did we get? For the two hours under sail, we could have gone 24 miles at 12 knots instead of 20 miles at ten knots. So we gave up four miles covered at an average of two extra knots. What we received in exchange was 90 miles at five extra knots on the same energy. This means we went **22.5 times farther** at **more than double the speed**. That is literally the ratio of what we got for the trade.

The obvious advantage is that you can use wind energy for propulsion even when the wind isn't blowing, thus removing much of the "intermittent" aspect of sailing. It performs farther, faster, cheaper, and cleaner. We greatly increased the efficiency of our use of the wind. Using the wind energy in our hybrid electric generator system instead of just trying to blow ourselves around with it greatly increased the practical work harvested from it. By using our energy-smoothing™ system we are also affording ourselves the advantage of using the stored electricity to create a thrust vector that moves us straight forward. There is no need to tack when powering with the electric motors.

The example of ten knots versus 12 knots is only one instance. We will list other possible speed/energy tradeoffs in a moment. A more likely scenario for the above example is to use the stored 216,000 Wh to motor-assist or motor sail for 18 hours using the electric motors to provide 12 of the kW and a light wind in the sails to achieve the rest of the power for a combined motor sailing speed of ten knots. The difference is still 200 miles for hybrid regeneration mode versus 114 miles for straight sailing. That still comes to an average speed of ten knots over the 20 hours in the example for regeneration.

Even in the electric/motor sailing example we gave-up only four miles while covering an extra 90 miles gained from regeneration mode. It is still an extraordinary net gain. We actually went farther, faster than just using the wind to sail.

WHY IS THE 83 HD-X ABLE TO REGENERATE AT THESE LEVELS?

In order to take advantage of the total possible water pressure acting on the blades, you need a reaction turbine, which must fully contain the water during the energy transfer. For a boat, you specifically need a horizontal-axis reaction turbine, which is entirely encased so that the captured water pressure cannot escape. Just dragging your propulsion props while sailing cannot achieve these high-energy capture levels.

As it happens, the closer to hull-speed a displacement hull vessel travels, the less relative effect a measured amount of drag has on the speed of the vessel. With the full Power Core Hybrid-ion Energy System, the operator can choose the amount of maximum sailing speed they are willing to trade at any given moment, for the amount of energy captured that can be used later for a greater distance and speed. With the Power Core you can choose to give up a little for a net gain of a lot.

We know how much extra power is required to be absorbed by the additional measured amount of drag which must be overcome to cause a vessel to achieve a particular velocity increase. We know that if we add the same measured amount of drag and still apply the above-mentioned extra power, we will only be able to achieve the velocity at which the vessel was cruising before the extra power was applied.

Remember, the act of reducing the required speed from 12 knots to 10 knots reduces the amount of power required to overcome the drag being absorbed from the vessel by 435 HP. If one is willing to sail at 10 knots when there is enough wind to drive you to 12 knots, you have an extra 435 HP left over which can be used to make a large amount (after losses) of electricity.

WHAT ARE THE PRACTICAL USES?

Of course trading 12 knots for ten is at the upper end of the best-case scenario for regeneration. It is chosen as an example to display a near-maximum, yet very real potential for an 83' vessel. As mentioned above, this specific example yields a 22.5 times distance increase at more than twice the average speed, using the same amount of wind energy. The yield in increased distance and speed in the 10 versus 12-knot example are so enormous that it almost causes one to glaze over from disbelief. So let us weigh the advantages from more common speed-shaving™ scenarios.

We do not need to deploy the regeneration system only at the upper extreme to enjoy a sizable advantage. Even mid-range sailing speeds can yield very worthwhile increases in speed and distance by energy-smoothing™ the power from the wind.

The obvious ultimate application of the principles is to take that first giant leap toward eliminating the need for diesel propulsion except for occasional convenience. Of course none of this is possible without the huge lithium-ion battery and supercapacitor system in the Power Core. Read *Pulse Buffering Power Core* on the **energytechmarine.com** home page. There is no point to regenerating the energy if there is no place to store it, or if you are going to lose much of it through battery inefficiencies.

The 83 HD-X may be the defining vessel that changes the emphasis from engines-only to a hybrid with sails. The regeneration system is powerful enough to allow propulsion from wind energy even when the wind is not blowing. Energy-smoothing™ redistributes the wind power to actually get you to a farther destination faster than just sailing by itself.

Let us look at some typical passage scenarios and compare cruising using hybrid/wind regeneration versus diesel engine propulsion. It is pointless to compare straight sailing to diesel propulsion. When we look at cost comparisons between the two, we know you can go anywhere in the world for free under wind power if you are patient enough. The point of the regeneration system is to dramatically increase both the average speed and distance traveled by wind power to see if the intermittent aspects can be reduced sufficiently to compete with the convenience of straight diesel powering. Are the tradeoffs between the two worth the switch from a motor yacht to a sailing yacht? Maybe the tradeoffs can be zero.

MOTORING VERSUS HYBRID/WIND REGENERATION

Let us first look at a typical average day from a passage of, say, 500 miles. For comparison, our target cruising speed for either diesel power or hybrid/sailing is ten knots by day and eight knots at night. The wind might be light from seven in the morning until 11 AM. In hybrid/sailing mode we would reach our desired ten knots by electric motor/sailing, consuming 12 kW (16 HP) from the battery to attain part of the speed and then the rest of the ten knots from the sails. That would take us 40 miles in four hours and consume 48 kWh from the batteries.

Let's say from 11AM until five PM the wind velocity increases to a moderate level with a force capable of moving the vessel at ten knots for three of the hours and 11 knots for three of the hours. It takes very little power to move the 83 HD-X at ten knots and therefore there is not much regenerative energy to be gained. Let us say that for those three hours the regeneration system is engaged, slowing the vessel to eight knots while converting 26.3 kW of power per hour for the extra two knots (after 66% losses) into stored electrical energy. That would total 78.9 kWh of recharged energy.

During the three hours when the wind is capable of propelling the vessel at 11 knots the turbines are once again engaged to slow the vessel this time to nine knots while converting the remaining 51 kW per hour to stored electricity for a total of 153 kWh of energy recharge. So from 11 AM until five PM we traveled 51 miles and recharged the batteries a total of 231.9 kWh.

From five PM until eight PM the wind might become moderate and only move the vessel under sail-only at nine knots. If the turbines are not engaged, the vessel covers 27 miles with no drag/speed penalty and zero battery charge or discharge.

From eight PM until seven AM the wind might become very light and electric motor/sailing might possibly only reach a total of eight knots with the combination of 12 kW of power from the batteries/electric motors plus the sails. This would consume a total of 132 kWh of electric energy and take us 88 miles at an average of eight knots.

This 24 hour segment of the passage using only sails and regenerated energy would have taken the vessel 206 miles at an average of 8.6 knots. It would have regenerated an extra 51.9 kWh of charge into the batteries. 25kWh could be used for the hotel loads like air conditioning and dishwashers (more energy than an average American house uses in a day). In this typical example, the net energy usage is a positive 51.9 kWh of battery charge, which means an AC generator is not needed because even after hotel loads you still added a 26.1 kWh charge to the batteries. All energy is free.

Let us explore the tradeoff against the same 500-mile passage with an identical size and weight 83' motor yacht powered only by direct coupled diesel engines, cruising at ten knots by day and eight knots at night (eight PM till seven AM). The motor yacht would have covered more distance. It would have traveled 218 miles/day instead of 206 for an extra 12 miles per day. It would also have gone faster for an average of 9.1 knots instead of 8.6 knots. This means the motor yacht would have completed the 500-mile passage in 54.9 hours instead of 58.1 hours for the hybrid regeneration example.

The story lies in the difference in fuel costs. The motoryacht would have consumed 31.6 liters (8.35 gallons) per hour at ten knots and 14.9 liters (3.94 gallons) per hour at eight knots for a total of 1351 liters (357 gallons) for the entire 500 mile trip at the stated speeds at the stated times. At $3.00/gallon US, the motoring cost would equal $1,071.00. An 83' vessel will also typically have a 30 kW diesel generator running 24 hours a day on such a passage. The additional fuel cost at $3.00/gallon US will run $4.89/hour. That would add $269.17 for a total fuel cost for the 500 mi. passage of $1,340.17. The fuel cost for the identical size and weight vessel using energy-smoothing with regeneration from sails would be zero.

Let us examine the tradeoffs for a motoryacht versus Power Core Hybrid Regeneration System. The motoryacht could have departed on the 500 mile passage three hours and twelve minutes later and arrived at the same time as the 83 HD-X wind generated vessel with energy-smoothing. In other words it would cost an extra $419.00/hour for each of the three hours and twelve minutes sooner that the motor yacht arrived. There is an insignificant difference in the performance. There is a large difference in the cost.

The ultimate application of the EnergyTech Marine 83 HD-X might be the ability to present a fully hybrid vessel offering virtually identical performance to a motor yacht at a fraction of the operating cost. Energy-smoothing via its extreme hybrid regeneration system allows it a performance relatively the same as a motoryacht while outperforming a normal sailing yacht using the identical wind power by a large margin.

EVEN IF THE WIND IS A FRACTION OF THAT IN OUR EXAMPLE

Let us look at a comparison of the performance of the 83 HD-X versus the above identically sized motor yacht even if the wind energy is less. Remember; the Power Core also has access to diesel fuel and can cook it up into charged ions (think of it as electrical charge) anytime the operator elects.

We examine a series of voyages (examples A-E) in which we begin with the stated contribution that the wind adds to the overall speed. We then reduce the wind's contribution by a knot and then another knot and then another and so on. We will then supplement the shortfall of electricity from wind regeneration with electricity made by the Power Core burning diesel fuel. Then we will compare the cost differences. This is motoryacht vs. hybrid/regeneration.

For the sake of comparison, both the motoryacht and the hybrid in all of the examples cruise from seven AM until eight PM at ten knots and then at eight knots for 11 hours from eight PM until seven AM. Let us first consider an example, which displays how we would probably employ the hybrid system when supplementing with diesel fuel. In the following example (A) we can see what it would cost for the hybrid to run the trip in *exactly the same elapsed time* by supplementing the propulsion with some electricity made from diesel fuel.

The table (below) shows that for example (A) the sails provided part of the stated speeds and also some regeneration when those stated speeds were exceeded. There was not enough net power from the sails to perform the mission in the exact identical time as the motoryacht so the Power Core had to contribute some diesel fuel to the mission. It required an extra 236.4 kWh of energy to match the motoring requirements and the hotel loads delivered by the motoryacht. The Power Core can put that charge (plus enough extra to cover the losses) in the battery by running the diesels sometime during the voyage for 42 minutes. At $3.00/gallon US, that would have increased the cost of the hybrid voyage by $56.00.

Now the passage times would be identical in every way but the cost difference would still be huge. The motor yacht voyage would still have cost $1,340.17. That is 24 times more cost for the motor yacht with no gain in any way for example (A).

Now let us reduce the wind contribution to each leg of the voyage for example (B-E) by one-knot increments and then supplement the cruise speed with electricity made from the Power Core's diesel generators until the voyage elapsed time is exactly identical to the motor yacht. This will give us the cost comparison of the two vessels when the wind is producing incrementally one-knot lesser cruise speeds.

The comparisons for examples (B-E), like example (A) will have both vessels traveling for 13 hours per day at 10 knots and 11 hours per day at 8 knots. In example (A) above the wind contributed most of the power for the voyage of the hybrid by providing five of the ten knots between seven AM and Eleven AM. The other five knots came from the batteries. The wind provided all of the propulsion from 11AM until 5PM and during half of that time the wind also contributed regenerated electricity to be stored and used later. From five until eight PM the wind provided all but one knot of the cruise-speed and the batteries contributed the rest. From eight PM until seven AM the wind provided three of the eight-knots cruise-speed and the batteries provided the rest.

The chart on the following page displays the sailing speeds required to be contributed by the wind to be able to maintain the stated speeds of the mission and to also, when possible, regenerate hydroelectric energy stored away for later use. The chart does not display the cruising speeds of the vessel. It displays the speed that wind-only is able to add to the vessel's velocity on top of the speed provided by electric power, or diminished by drag when regeneration is deployed. The actual cruise speeds of the hybrid vessel will be identical, for these comparisons, to the motoryacht. This chart is to display the costs incurred from supplementing the electric charge by burning diesel fuel as in each subsequent example the wind contribution diminishes.

Vessel speeds added by sails as wind diminishes in each example (by time of day)
and
Hybrid's cost of diesel for total 500-mile passage at the different wind levels

Examples A-E	*7A-11A*	*11A-2P*	*2P-5P*	*5P-8P*	*8P-7A*	*Diesel (US $)*
A) Knots added from sailing-only	5	10	11	9	3	$ 56.00
B) Knots added from sailing-only	4	9	10	8	2	$ 408.00
C) Knots added from sailing-only	3	8	9	7	1	$ 502.00
D) Knots added from sailing-only	2	7	8	6	0	$ 614.00
E) Knots added from sailing-only	1	6	7	5	0	$ 672.00

The above supplemental diesel fuel costs in column seven are required for the hybrid vessel to perform at the same speeds as the motor yacht as the wind diminishes in the examples. The diesel costs also include the burden of generating 25 kWh of energy per day to run hotel loads for normal household AC needs.

How to Read The Preceding Table

In example (E) there is almost no wind for the 54.9 hours of the 500-mile voyage. There is only enough wind to add one extra knot to the boat speed for the four hours from seven AM until 11 AM each day. The rest of the ten knots for those time periods had to come from electricity made from diesel fuel. There is only enough wind to contribute an extra six knots to the boat speed from 11 AM until two PM and the rest of the ten knots once again had to come from the diesel fuel, and so on. The cost for the diesel required to supply the rest of the energy required beyond hybrid sail-power for example E is $672.00. That is compared to the $1,340.00 cost for the identical trip at the identical speed for the motor yacht. The motor yacht trip is still double the cost for a passage on which there were consecutive days with almost no wind.

Cost differences for same performance of the EnegyTech Hybrid versus The Motor Yacht.

Examples:

A. The motor yacht cost is 24.0 times as expensive.
B. The motor yacht cost is 3.2 times as expensive.
C. The motor yacht cost is 2.7 times as expensive.
D. The motor yacht cost is 2.2 times as expensive.
E. The motor yacht cost is 2.0 times as expensive.

The cost savings are a combination of two things. First, energy-smoothing by The Power Core is a result of speed-shaving^{TM} from the wind. You skim off huge amounts of energy when it isn't producing much velocity or distance gain anyway. The energy can be used later to get you much farther and faster for free by using that same energy in the form of electricity when the wind is light. When the wind power is at its maximum, its speed and distance contribution/kW is at its minimum. The hybrid energy-smoothing system reverses this wasteful process. Also, using that energy for electric propulsion delivers the thrust in a completely forward vector with no wasteful tacking.

Second, The hybrid-ion electric propulsion system, as described in the *Pulse Buffering Power Core* paper on the **energytechmarine.com** home page, dramatically increases the fuel efficiency of using diesel fuel for propulsion by converting it to electrical energy first.

NOW – IDENTICAL PERFORMANCE TO A DISPLACEMENT MOTOR YACHT AT A FRACTION OF THE OPERATING COSTS AND EMISSIONS

Upon close examination of the EnergyTech Marine 83 HD-X, you will find little, if any, difference in speed and distance performance from that of a displacement motor yacht. Range and comfort will be much greater for the HD-X because it needs little or no combustible fuels and the keel and sails have a significant stabilizing effect. Cabin accommodations will be superior for the HD-X due to the smaller footprint of the hybrid-ion electric propulsion system.

In this modern age, all sail control is push button and is single-handed. Of course with the high motoring speeds of the HD-X, you always have the option of operating it as a motoryacht if you want to skip the sails. It's still nice to know that the sail regeneration turbines give you the option of going anywhere in the world with zero emissions and zero need to stop for fuel. In this time of international instability, there might be some countries you would prefer to bypass without the need for a fuel stop. Less fuel stops also contribute to greater average cruising speeds.

When considering operating costs, you might project that oil will not always be thirty-something per barrel, which it is as of this writing. Even at the current low fuel prices the operating savings can be extremely large.

Power Core Hybrid-ion Energy Systems are also currently separately available for custom installations and re-powering projects.

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