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MARINE GROUP

The Next Giant Leap Beyond Diesel-Electric

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DRAMATIC ENERGY COST SAVINGS TO THE MARINE INDUSTRY NOT YET AVAILABLE TO AUTOMOTIVE. *(Note: Fuel prices may vary from US to Europe since publication date.)*

Arc Lite™ Power is now offering its ***Pulse Buffering Power Core***™. It is a brand new hybrid-ion power system for a wide range of applications that consume power. It comes in various sizes with applications for small things such as motor homes or houses to large things like 200' marine vessels. It is especially applicable to luxury yachts and workboats. The Power Core replaces all of the standard marine propulsion diesels, generator sets, and lead acid battery banks. It converts a vessel to hybrid electric and provides the power to perform all work aboard the vessel.

This system is the next giant leap beyond diesel-electric. It performs many functions that diesel-electric does not. In principle, it operates very differently. Some common missions can be performed at staggering efficiency increases. Cost efficiencies of hundreds of percent of are offered. The Power Core can save larger work vessels millions on fuel over its product lifetime. In almost any vessel, its net cost is free. It saves more in fuel costs than its initial price.

The Arc Lite Power Core system is being offered in the new EnergyTech Marine 83 foot HD-X super yacht. The vessel has been in extended testing and development and is nearing completion. It was designed from the ground up to be a hybrid energy system electric yacht. It was originally planned to be diesel-electric but EnergyTech Marine Group and Arc Lite Power co-developed the much more advanced Power Core hybrid-ion system which offers dramatically improved performance.

The new vessel is far enough into sea trials to be able to report some of the efficiency gains over and above standard direct-coupled diesel installations, as well as diesel-electric. Compared to either of those systems, the efficiency improvement of the Power Core is substantially higher. Sea trials were conducted to discover the exact kilowatt power absorption at every 100-rpm increment for direct diesel drive so it could be compared to the precise kilowatt output required of the Power Core at the same rpm at the identical power absorption.

Specific fuel consumption required to make the respective power represents the efficiency of each mode. The abbreviated goal for this paper is to account for the liters of fuel required to deliver the identical kilowatts of power for each mode. Although specific fuel consumption is usually quoted in grams per kilowatt-hour, we have taken the liberty to convert it to terms of a measured volume such as liters or gallons. For the sake of what we are attempting to display, it will certainly be close enough and may be easier for the reader to picture.

WHAT IT IS IN SIMPLEST TERMS

For the EnergyTech Marine 83' yacht, the *Pulse Buffering Power Core* is much more compact and lighter than the standard twin-diesel propulsion engines and transmissions, twin diesel generators and lead acid battery banks that it replaces. It saves so much space that, among other things, it allows for a sixth full beam cabin.

In the simplest literal terms, the Power Core can be set to seek out any energy source available to the vessel and convert it into a more efficiently usable fuel – charged ions – which it stores until they are released to produce electricity to run everything requiring power on the vessel.

The Power Core has two systems for storing and releasing charged ions that are converted into electricity. Different kinds of ions are stored away depending on their eventual task. For simplicity you can just think of the ions as stored electricity. Some are packed into the Arc Lite proprietary 400-kilowatt hour lithium-ion battery storage system, while other kinds of ions are stored in large super capacitors (also called ultra capacitors). The losses for this conversion are almost zero. The coulombic efficiency is greater than 99%. Simply, this is the ratio of amps out divided by the amps put back in to replace the charge.

It is this remarkable efficiency that makes the Power Core possible. Compare this to the approximate efficiency of lead acid batteries of around 70%. You often see lead acid battery efficiencies touted as high as 90% or more. This is due to the misleading nature of the coulombic efficiency equation when applied to lead acid chemistry. For lead acid batteries, amps out divided by amps in to replace them, does not accurately describe their energy efficiency. It would be more accurate to measure their efficiency as a ratio of kilowatt-hours out vs. kilowatt-hours in because lead acid batteries charge at a higher voltage than they discharge. This means that the replacement amps are going in at significantly higher kilowatt consumption. Also don't forget all of the wasted energy to maintain the float charge, which is not needed for the Power Core.

PROBLEMS THE POWER CORE ELIMINATES

Lead acid batteries could never duplicate this mission. They are heavier. They take up more volume. They can waste a huge portion of their energy due to Peurkert's law when trying to run fast discharge loads like inverters. Their self-discharge rates are enormous compared to the Power Core, which is almost zero. You can't discharge them past 50% without shortening their lives. They take many hours to recharge instead of minutes. Because internal resistance rises so abruptly once they reach 80% state of charge, you cannot practically charge them above that point at sea. Their life is measured in hundreds of cycles instead of tens of thousands. They take 20 hours to deliver their rated capacity. They are environmentally hazardous compared to the benign Power Core system.

The list is lengthy. In the interest of brevity, we simply point out two overwhelming facts in favor of the Arc Lite Power Core system and skip the rest. First, it would require more than 32 tons of lead acid batteries to perform the same mission as the Power Core. Second, because Arc Lite Power manufactures its own proprietary lithium-ion battery systems it can deliver performance superior to that of lead acid batteries at one fifth the cost per kilowatt hour delivered. It does more and costs less. Add to this that in most large vessel installations; the Power Core is virtually free because of the fuel savings over the life of the system.

The Arc Lite Power Core is a closed system that accepts and converts energy of various types and stores it away for future use, acting as a buffer. It includes equipment to harvest diesel energy. It includes twin encapsulated hydroelectric reaction turbines to harvest flowing water kinetic energy. It can fill up at the dock if it can find 240V AC power from the utility company. It can also be configured to harvest and convert solar energy.

For example, if there is diesel fuel available, it utilizes its enclosed diesel powered 400,000 watt industrial alternator to burn it off and convert it to stored ions. It buffers the energy from the diesel fuel in a large, brief pulse. Greater than 99% of the net energy output of the generating system makes it into the storage buffer for future use. The lithium-ions can be stored for years without degrading or needing polishing like diesel fuel. The stored ions also weigh less than a millionth as much as the diesel fuel that was burned off.

HOW DOES IT WORK?

The Pulse Buffering Power Core is a charged energy system. It converts all available energy aboard the vessel into charged ions, which are stored in either the super capacitors or the lithium-ion storage system. The Power Core then releases its charge to distribute electricity to anything on the vessel that requests power. As an example, if propulsion power is needed, it can choose to use the energy stored either in the super capacitors or the lithium-ion storage system. The energy is converted to electricity at an extremely high rate of speed (unlike a lead acid battery which requires 20 hours to release its total rated energy).

If the vessel is on a long passage, it will power its electric motors using the Power Core's super capacitors as the energy source. The super capacitors can convert their charge into electricity almost instantly. In this scenario, the diesel fuel aboard the vessel is converted by the Power Core diesel engines into a fast pulse charge of the super capacitors and then shut off. The super capacitors power the vessel until they are nearly depleted, and then the process is repeated. The diesel engines may cycle on four times per hour for a couple of minutes to charge the super capacitors, and then shut down. The encapsulated diesels are so quiet that you may not be aware they are running.

The super capacitors are used to relieve the lithium-ion batteries of the expenditure of valuable life cycles. We could simply use the lithium-ion storage system for this propulsion mode and enjoy tens of thousands of such pulse cycles, but a small amount of battery life is expended with each cycle. Lead acid batteries have a finite life of hundreds of cycles of being discharged to a 50% state of charge. The Arc Lite lithium-ion batteries have a finite life of thousands of cycles of being discharged to 30% state of charge. Super capacitors have, for all practical purposes, no life cycle limitations. Their life cycles to a 0% state of charge are rated in the millions.
If we had, on the other hand, picked up an initial charge from the utility power grid at our slip, we would employ the energy stored in the lithium-ion batteries for most of a short cruise of 200 miles. We would then use the super capacitors for propulsion after we used up the cheaper kilowatt-hours we purchased from the electric company.

Super capacitors have a high internal discharge rate. If you leave them charged overnight they will be nearly flat by the next morning. The lithium-ion storage system can hold its charge for years. We only charge the super capacitors when we know that we are going to use that energy immediately. If at the end of the day we have not used all of the energy stored in the super capacitors we discharge it into the lithium-ion storage system for long-term storage.

Energy collected and used for other demands is almost entirely stored and distributed from the lithium-ion battery system. The super capacitors are used for high speed buffering for pulse propulsion cycles.

EFFICIENCY COMPARISONS

When the vessel issues power demands for propulsion, air conditioning or other needs, it requests only the amount of net kilowatts of power required, after efficiency losses, to get the job done. Of course there are all sorts of losses in the process of rectifying and inverting and running electric motors and such, but they are miniscule compared to the efficiency gains. We will not neglect the 15% losses. They are calculated into all of our numbers.

PROPULSION EFFICIENCY

First let's compare propelling the vessel with straight diesel engines attached to transmissions and shafts and props, to the Power Core which supplies electricity to propel the vessel with its powerful electric motors. As with most displacement hull pleasure craft, the prop (or in the case of the EnergyTech vessel, the impellers, since it has UltraJet® jet-drives) comes pitched to achieve maximum hull speed at the maximum power available from the propulsion system.

When the traditional direct-coupled diesel is operating in this peak-power mode it is fully loaded, generating the peak amount of horsepower that it is capable of. The prop is pitched to absorb its peak horsepower or kilowatts of power at exactly this rpm. At this moment the traditional direct-coupled diesel cannot be beaten for efficiency.

The only problem is that the waste inherent at that speed is astronomical. Most vessels will only opt to operate in this mode for a few minutes or hours in their service lifetime. Owners want this option in order to get out of the way of a tanker or to deliver important charter clients to their flight on time. The rest of 99.9% of the time, you operate at lesser rpm and lesser speeds.

The brainteaser is that even though you can achieve this high horsepower per liter of fuel efficiency with the direct-coupled diesel engine, it is producing the worst possible fuel mileage at that moment because this horsepower being delivered to the water is going almost entirely to waste. Hull speed limitations are beyond the scope of this paper. We can, however, demonstrate the results of these limitations for displacement hull vessels by pointing out that at maximum hull speed you can reduce your velocity by a little more than 10% and save 50% of the fuel burned.

It is important to point out that a diesel engine will have a "sweet spot" in its power curve, usually around 75% of its rated peak rpm. This so-called sweet spot, when fully loaded, will produce a kW of power while burning the least amount of fuel. This is its point of greatest efficiency.

At all points on the diesel power curve that are *less* than that perfect match of loading and rpm, you are operating at reduced efficiency. The lower the rpm, the worse it gets. As you slow to more normal operating speeds, you begin to burn more liters of fuel to produce a kilowatt of power. This is due to the fact that the engine is progressively more under-loaded the further it gets below the rpm for which the prop is pitched. The more under-loaded an engine is, the less efficiently it operates.

The efficiency increases can be large when you replace the diesel propulsion engines with the Arc Lite Power Core system that includes electric motors to deliver the same or more power to the water. The reasons are numerous and some are quite complex. We will only discuss a few simple and obvious ones.

THE SHORT AND SIMPLE VERSION

The Power Core contains enclosed high horsepower diesel engines for turning diesel fuel into electricity, which is used to charge the ions in the storage banks. It does not operate like a typical genset or a hybrid car. Once the engines are warmed up for the day, they are always operated at near 100% loaded condition right at their sweet spot, producing the maximum constant kilowatts of electricity possible per liter of diesel fuel. Nearly 100% of the electricity they produce, at this maximum efficiency, is converted and stored for future use in the super capacitors and lithium-ion storage systems. Operating the engines *only* in their sweet spot may prolong engine life by more than double. This operating range also greatly reduces emissions. Add to this that you are also only operating the Power Core engines in quick powerful pulses and then they shut off. They only operate for a fraction of the time that they would in direct propulsion mode.

The difference is enormous. All of the resulting energy ends up having been converted and stored at the most advantageous efficiency possible from the diesel fuel. Now when the vessel calls for propulsion power at, for instance, five knots, it is using energy that was manufactured at the lowest possible fuel consumption. To propel the 83' test yacht at five knots, using the Power Core buffer, it is burning kilowatt-hours of energy produced at a rate of 4.18 kWh/liter of diesel vs. 2.18 kWh/liter using direct-coupled diesels. At this speed the direct-coupled diesel is delivering the requested power while operating only 21% loaded. The resulting inefficiency at this low loading level is terrible.

Even after system losses, the Power Core delivers 63% more miles per gallon. The test vessel in a typical charter application will spend a preponderance of its motor operation time at a thousand rpm. At three dollars per gallon, at that rpm, the Power Core would save $2,495 US per fill up.

The standard direct-coupled diesel propulsion system is being operated at less than maximum efficiency almost 100% of the time. When it is operating at its maximum efficiency its energy is not converting into more miles per gallon because it is nearing the end of its hull speed envelope with the water. On the test vessel, slowing down one knot from peak hull speed cuts the fuel consumption, per mile in half.

The point is one seldom uses the maximum peak on the power curve on a direct-coupled installation. You only occasionally pass through this point on the curve. The power core uses the sweet spot absolutely all of the time. It then uses the resulting efficiently stored energy for all cruising velocities. This gets the maximum amount of power out of the available energy.

COMPARING THE POWER CORE SYSTEM TO DIESEL-ELECTRIC

The initial cost of diesel-electric is a bit less than the Power Core. The extra efficiency from Pulse-Buffering the energy vs. diesel-electric can save hundreds of thousands of dollars in larger vessels.

For propulsion on the 83' HD-X test vessel, diesel-electric is less efficient than the hybrid-ion system for two very basic reasons.

First, diesel-electric uncouples the diesel from the shaft just like the Power Core. It then depends on slowing the engine to lesser rpm than it would use to provide the desired velocity if it were coupled. This is called a *load following* system. The lesser rpm is selected based on the point at which the engine, when fully loaded, can produce the required power for the electric motor. This means that the diesel can save fuel because it is operating at higher loading efficiencies and at lower rpm than it can when directly coupled.

Unfortunately for the test vessel, this would require the diesel's rpm to be reduced to below engine idle speed before loading in order to achieve some of the desired speeds. Since this is impossible, we would lose much of the potential gains from the system.

Second, even after fully loading a diesel at low rpm, it is still much less efficient than fully loading it at the peak efficiency point of its power curve. Fuel mapping the test diesels in the 83' HD-X showed that the fully loaded engine could produce only 2.08 kilowatt hours per liter of fuel at 600 rpm. It produced 4.18 kilowatt hours per liter at 2,600 rpm. That is twice the efficiency at full loading at peak power vs. full loading at low power.

The Power Core produces greater efficiencies by pulsing at full-load for shorter amounts of time at higher rpm than normal. The diesel-electric system depends on loading up at lower rpm than normal all of the time. The difference is that the Power Core is always inherently more efficient. At some rpm it has double the efficiency.

Some diesel-electric manufacturers recommend installing four or five diesel engines, which can be shut down one at a time to more fully load the remaining running engines. This, by the way, is how cruise ships do it with even more engines. They are all diesel electric.

This was not an option for the 83' test vessel because much of the motivation to go electric was to take up less propulsion footprint, not more.

The savings in diesel fuel will, in most cases, offset the investment in the Power Core to the point that its net cost is free. Owners with a diesel-electric installation can add elements of the Power Core to enjoy enhanced savings. The Power Core, however, offers many cost-savings way beyond the scope of diesel-electric propulsion.

In some narrow circumstances you cannot beat the efficiency of a direct-coupled diesel propulsion system. You can always do as some cruisers in smaller boats do and pitch your prop for the sweet spot in your engine's power curve based on your target cruising speed only. This sacrifices top speed performance, which most large yacht owners don't opt for. It also only helps when you are at your *top* cruising speed. Smaller boats, which can't power at double digit velocities anyway, may never find a need to slow down and are happy to always travel at top cruising speed. Larger yachts find themselves in many circumstances where they should not be going 13 knots and must slow down. This is where the savings kick in.

We submit that life is too short for variable pitched props. They can fully load your engine but they need constant adjustment as sea conditions change. We have had experienced captains ruin expensive diesels by over-loading them. There are better ways.

WHY IS THE POWER CORE SO MUCH MORE EFFICIENT FOR PROPULSION?

Increased fuel efficiencies can be achieved in electrically propelled marine vessel by more fully loading the diesel engines while they are running. All cruise ships are propelled electrically for that reason. The Power Core simply loads the engines more efficiently. But this still doesn't explain why the electric motor propels the vessel better than the diesel.

It is because electric motors operate so differently than internal combustion engines. They are more efficient. Their power is rated on a different scale. Electric motors are constant power and internal combustion engines are rated at peak power. They are smaller and lighter for the same amount of power. They require no exhaust systems or oil changes. They last tens of thousands of hours longer. The comparison really is apples to oranges. But with that said, why does wasting all of the energy to convert from mechanical power to electrical power and back to mechanical power result in a savings?

You started out with a few hundred horsepower diesel and replaced it with a few hundred horsepower electric motor. The prop is still not pitched for efficiency at, for instance, five knots. Isn't the electric motor dramatically under loaded also at 1,000 rpm or five knots?

The answer is yes. But here lies the key that no one ever seems to mention. An electric motor (once you get into larger motors above 100 HP) can operate at above 95% efficiency at only 20% loading and a diesel cannot come close.

The impeller on our test vessel absorbs or uses 12 kW (16 HP) of power at five knots. The required 12 kW could be supplied by either a diesel engine or an electric motor. The electric motor is going to request 12 kW from the Power Core plus the 15% loss inherent in the process, or 13.8 kW. These kilowatts of power used by the electric motor were cooked up, in effect, burning only 3.3 liters of diesel per hour.

The diesel can also supply the 12kW of power needed for the impeller at 1,000 rpm, but it is capable of producing 52 kW (70 HP) if it were fully loaded at that rpm. Instead, it is operating at a very inefficient fraction of its loading capacity. It is wasting nearly half of its fuel to supply the 12kW being used by the impeller. The diesel's kilowatts of power were produced by burning 5.5 liters of diesel fuel per hour vs. 3.3 liters per hour for the electric motor. The net savings for the electric motor are much greater than the 15% losses. This is why the Power Core only uses its electric motors for propulsion. It saves fuel and increases range.

The electric motor is so much more efficient at lower speeds than the direct-coupled diesel that it ends up saving a lot of fuel on the average voyage. This is before you take into account that you can fill-up at the power outlet at your dock with an energy source that your electric motor can burn instead of generating it with diesel fuel. And this is before you scoop up all of the free energy you want from the hydroelectric reaction turbines.

In short, the electric motor is able to deliver kilowatts of power to the water that were produced at a much lower cost than the straight direct-coupled diesel.

EVEN GREATER COST SAVINGS

Miles per gallon for propulsion is only a small part of the cost savings. Hotel loads or house loads, as they are sometimes called, on a modern luxury yacht can be enormous. The test vessel comes standard with eight 16,000 BTU air conditioners, washer, 240V AC clothes dryer, dish washer, freezers, refrigerators, ice makers, toasters, coffee-makers, microwaves and so on. Above all you must also be prepared for all six cabins to fire up their 1500-Watt hair dryers at once. Someone paying $40,000 for a one-week charter doesn't understand when he or she turns on their hair dryer after a swim and it kills the whole system.

For luxury charter, you must have a system that is prepared to let all of these appliances be operated at the same time, anytime of the day or night. Traditional installations require two 30kW generators to supply this sort of power extravagance. One is always running, 24 hours a day, seven days a week. The other is a spare in case of failure, without which a charter could end abruptly.

In comparison, the Power Core uses no AC generators. The fuel efficiency increase is almost unbelievable. The space and weight savings are also substantial. On a high-energy consumption charter with eight to ten guests plus four crewmembers you can consume 42-kilowatt hours of energy per day just from appliances. This is far more than most homes.

To meet this demand with gensets, a 30 kW generator slogs away 24 hours a day, seven days a week. Meanwhile, the Power Core creates and buffers the same amount of energy in one very large pulse lasting about seven minutes per day. It then releases it on demand through its large internal inverter system. Run everything at once. It doesn't care. It delivers the same identical performance as the 30kW generator in 7.2 minutes of diesel engine run time vs. 24 hours of diesel engine (genset) run time. The Power Core supplies the same power using 4.2 gallons of diesel vs. 38.4 gallons for the traditional 30kW genset. It is nine times as fuel-efficient.

This extreme difference in fuel cost is due to the inherent difference in the system design. A traditional generator has to accommodate what is called “peak power” demand. Peak power is the maximum amount of electricity that will be needed at any given instant: How many things do you want to turn on at the same moment? A generator must operate constantly prepared for peak power capability or everything will go dark when you reach that limit. Large luxury yachts start their diesel generators the day they leave the factory and some never shut them off until re-fit.

The Power Core is a completely different design philosophy. It is a “total energy consumption” design or a “stored energy” design. One advantage is that a stored-energy design with appropriate inverters can provide peak power that is many times greater than a generator system. For standard generator systems the appliance load cannot exceed the power generated, as this will result in a system collapse.

The other huge advantage is that it does not need to consume any fuel to be on standby. The standard diesel generator is always gulping fuel just to remain on standby even though peak power is not being requested of it. Significant fuel burn continues even when no power is being requested.

The Power Core operates as a charged system. But how can it charge in only 7.2 minutes per day? This is not a misprint. To understand this, you must consider the scale. The lithium-ion storage system alone is 400,000 Watt-hours. It can comfortably charge at 400,000 Watts without heating up at all. This is the same power as if you had 13, 30kW generators.

The Power Core always charges at 400,000 Watts when it is charging. So, think about it. If you were charging at 400,000 Watts, how long would it take to stash away 42,000 Watt-hours of energy? If it makes 400,000 Watt-hours each hour, then it makes 42,000 Watt-hours every tenth of an hour. What is a tenth of 60 minutes? After energy losses, that would be about 7.2 minutes a day.

42,000 Watt-hours to the Power Core is nothing. It can produce over nine megawatt-hours per day. It can produce enough power to propel the vessel wide open while running all of the appliances on high while simultaneously recharging its super capacitors and its lithium-ion storage system. Of course 400kW of industrial alternators costs a lot more than 30kW marine generators. But it saves so much fuel the cost nets out to be less than zero.

In a charter environment, the test vessel’s Power Core could save $3,000 per month in fuel costs just for hotel loads, not to mention the tens of thousands each time you destroy a traditional generator by running it in an under-loaded condition most of the time. The Power Core, of course, operates fully loaded any time it runs.

Because you can go days without ever starting engines in the Power Core, it also reduces emissions by an order of magnitude.

This is far beyond the scope of diesel-electric.

STILL EVEN GREATER COST SAVINGS (FILL-UP FOR NEXT TO NOTHING AT YOUR SLIP)

The Power Core acts as an energy-clearing house by converting and then buffering any kind of energy it can get hold of. 240V AC shore power is no exception. It automatically senses if it is available and if it is, it gulps it into its storage system for later use. One of the keys to the Power Core's effectiveness is how rapidly it can absorb a pulse of high energy. At sea, the internal system is so powerful that it can completely recharge in less than an hour. The Power Core can recharge itself at 400,000 watts.

At the dock you can't get that kind of power, but you can still get enough to completely charge overnight. The energy from the grid is so cheap that it can greatly alter your cost efficiencies for operating a large luxury yacht. See the detailed write-ups of two typical outings entitled "10 hour cruise" and "typical weekend outing" at **EnergyTechMarine.com**. Both write-ups show how charging at the dock can alter costs.

TEN HOUR OUTING

The website describes a boat ride around the harbor with 8-10 guests for a ten-hour outing. It is a typical day-cruise for a private 83' twin-engine luxury yacht. The report shows the cost incurred by the Power Core compared to a standard diesel connected to a shaft and prop along with an accompanying 30KW generator running constantly.

The report details all costs based on the current diesel price of three dollars per gallon. The traditional installation cost $137.60 for the outing compared to $59.24 for the Power Core. This is partly because you can buy kilowatt-hours from the power company at the dock for 13 cents. The cost of fuel for the traditional installation is 2.3 times as much as the hybrid-ion system. For this outing, just think of the Power Core as offering $1.30 per gallon diesel.

TYPICAL WEEKEND OUTING

The same website also details an extended weekend cruise to a 70 mile distant island and back. The standard diesel installation cost is $541.50 for fuel compared to $243.38 for the Power Core. That is 2.23 times as much for the cost of the standard installation vs. the Power Core.

Diesel electric does not offer this savings.

HYDROELECTRIC REACTION TURBINES AND SOLAR ENERGY

The Power Core offers twin integrated hydroelectric reaction turbines. They are capable of more than 100 kW output. If your vessel is a sailboat or if you can anchor in a heavy current, you can harvest a significant amount of free energy.

For the purposes of this paper, we are comparing the efficiency of purchased energy. We do not take into account any sailing or free energy like hydroelectric regeneration. Even a small amount of free energy throws the averages way off.

The free energy from the optional solar system would also greatly skew the numbers. With the use of these options you could literally cut your fuel costs to zero if you were willing to be patient. Therefore, sail, hydro, and solar energy are not included in this comparison. See regeneration labeled documents for the renewable energy efficiency stories.

THE FINAL ANALYSIS

The application for large luxury yachts and other marine vessels can be beneficial. A workboat used in harvesting crabs or fish, depending on the season, can burn 1,200 gallons of diesel per day. At a fuel rate of $3.00 per gallon, that is more than $3,600 per day in fuel costs. Between the different seasons that vessel can operate 300 days per year. That is $1,080,000 per year in fuel costs. The Pulse Buffering Power Core can potentially save that vessel half of its fuel costs. That would amount to $5,400,000 in fuel savings over the life of the Arc Lite product. It would be free after the first 18 months and the rest goes to the bottom line.

Smaller cruising vessels can benefit from the entry level Power Core systems sized more for motor homes. They can store cruising energy at a fraction of the cost of lead acid batteries (per kilowatt-hour delivered). In other words, when you buy a battery you are doing so to have kilowatt-hours of energy to use as you see fit. So after X amount of discharge cycles, an energy storage system runs out of satisfactory storage capability and won't deliver the kilowatt-hours you require. At this point you have spent its life and must replace it. Our Power Core comparison cost is calculated on price per kilowatt-hour delivered up until the point at which it will no longer deliver half of its rated capacity (the generally accepted end of life formula for deep-cycle marine batteries).

Small Power Cores are offered as replacements for AC generators of 5kW, 10kW, 15kW, and 20kW. These small systems have no engines and are rapidly pulse charged by large main-engine alternators. They cost less than gensets and battery banks and provide superior performance

SO WHAT DOES IT COST?

The lithium-ion storage system in the Power Core delivers many times more discharge cycles and delivers a much greater depth of discharge per cycle than any marine deep cycle lead acid battery (AGM, Gel, and flooded are all lead acid batteries). To fairly take all of the performance variables out of it, let's just compare the cost to deliver the same kilowatt-hours of energy as the

Arc Lite Power Core does, to the cost of using the most efficient and exotic lead acid batteries in the world. The cost would be more than five times as much for the lead acid batteries.

The cost comparison to normal marine deep-cycle batteries that you would find at a marine supply store (the kind you probably have in your vessel now) could be *more* than five times as expensive as the Power Core lithium ion storage system.

THE QUICK-CHECK COST FORMULA

Simply figure the number of kilowatt-hours you want your battery bank to deliver over, say, the next ten years. Calculate the cost of all the lead acid batteries you will use-up over that period, including replacements, and then divide by five.

That's about what the Power Core energy storage system will cost.

Cost per kilowatt-hour delivered until it expires is the only true way to compare the cost of an energy storage system. This is called *lifetime energy throughput*. That is how the Arc Lite systems are quoted. But be careful. This system delivers a lot of kilowatt-hours over its life, and you have to pay for them all on the first day. Even the smallest Power Core may deliver more energy than you can use in your lifetime and you could end up passing it on to your grand children. The first day cost is more, but the overall cost is a fraction. The good news is that its cost is less than zero if you use a normal amount of energy. If you are happy living like Robinson Crusoe with kerosene lanterns and no generator, no microwave or air conditioner on board it is probably not for you.

For a small vessel owner who wants the benefits of a generator and just doesn't have the room for it, a small Power Core could be a Godsend. It certainly solves the problem of being able to carry enough energy with you and being able to replace it quickly if you are trying to exist in some degree of shore-side comfort away from the dock. It is incredibly tiny.

WHY DOESN'T EVERYBODY DO THIS?

Arc Lite Power and EnergyTech Marine Group co-developed the proprietary large-scale lithium-ion battery system used in the Power Core. The main barrier is that the complexity is very severe. It is far beyond the scope of the do-it-yourselfer. Even if we gave you one of our large-scale batteries, you could not buy a battery charger for it anywhere – no one sells one. If you think a four stage smart charger for your lead acid battery bank is tricky, you would be taken aback by what is needed in order to correctly (and without damaging it) charge a large lithium-ion system.

In addition, for a marine vessel, you would need to use an inherently safe chemistry that won't blow up if damaged or overcharged. The Power Core uses a safe chemistry, unlike some of the automotive lithium-ion applications. DO NOT try to build a system yourself using conventional lithium-ion chemistry. Thermal run-away at sea at this scale would be catastrophic. The Power Core includes a very special proprietary lithium-ion system, specifically designed to be safe for the marine environment.

Lithium-ion batteries have to be cell balanced. This requires a separate computer board to manage each cell. Circuits that can handle the 650 volts of the Power Core are in and of themselves sophisticated. A proper charging system requires hundreds of these intelligent circuits.

Of course no one offers such a system on the market so you would have to invent and build the charging system as well. Without cell balancing you would destroy your battery. Lithium-ion is dramatically more complex to deal with than other battery chemistries such as NiMH, NiCad or lead acid. Super capacitors have similar issues concerning cell balancing.

Arc Lite has offered semi large-scale lithium-ion batteries with cell-balancing since August, 2006. Some of them are being used for weight savings in factory motor racing vehicles. Arc Lite Power and EnergyTech Marine Group share some of the same investors so co-development was a natural fit.

Having succeeded in developing an energy storage system that can deliver electricity at less than the cost of the lead acid battery at a fraction of the weight and size makes for a proud moment for the two companies. Add to this that the system can save more than it costs. It is believed that this could transform the marine energy scene for vessels up to 200'. It will certainly over time mean the end of the lead acid battery. The lead acid battery has had an amazing run since its introduction in 1859. Technology passed it by long ago, but price-point has just now sped past it. Lead acid batteries are now the high price spread.

When these technology and price-point breakthroughs can be developed for the automotive industry it could change the whole energy dynamic of the world. For the automotive world this level of breakthrough is years away. Autos and marine vessels operate on such different principles that sadly none of this has an application for the auto industry.

However, for marine vessels we can start enjoying the energy efficiencies delivered by this technology now. It slashes energy costs just when we may need it the most.

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