Electric Propulsion - Our First 2,500 Miles

Every decision starts somewhere: You hear about a new system idea, read an article, talk with others about options, do research - but it is often hard to say where the specific start of the process begins.

For us, the idea for implementing electric propulsion started when we read an article in Sail Magazine by Nigel Calder.   The idea was intriguing but we did not realize how deep it would take us when we first thought about it.   We talked with friends about a conversion to electric propulsion from diesel on a bluewater cruising sailboat. Many thought it was crazy. Others, like us, were intrigued and even urged us to proceed.

The problem was that we did not have a boat when we first began to think about an electric conversion.   We had sold our CSY 37 in Gibraltar after crossing the Atlantic and cruising for a year in the Mediterranean. Converting to electric remained an idea until 2007 when we bought our current boat, a Hylas 44.

We had been without a boat for five years and our ideas for where to cruise, sail, and enjoy the water had changed quite a bit.   Even more critical, one month after buying our boat we found out that we would be having a child.   Our new expanded family changed everything for us but we still wanted to be near the water.   It took us three more years to finally make the plunge into electric propulsion.

In some ways it is easy to put facts on paper and say “this is how much it costs”; “this is how the motor works”; “this is much quieter than diesel.”   To provide the most useful information we wanted to wait until we had really used the system in a variety of conditions over a longer period of time. With this in mind, we have been cruising for 9 months - 2,500 nm of off-shore and coastal cruising along the East Coast of the US, the Bahamas, and in the Gulf of Mexico.

This is an account of how and why we did it, the choices we made, the costs, and our opinions on the positive and negatives of cruising in an electric-hybrid sailboat.

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Electric Propulsion - The Conversion

In order to provide a concise discussion, we have simplified the process of converting from diesel to electric propulsion into three steps:

1. Remove existing propulsion diesel engine
2. Clean and prepare boat for the new system
3. Install new electric propulsion system

We have included photos to illustrate the steps and narrative to give some detail to the process.

Remove Existing Propulsion Diesel Engine

Our sailboat had an existing Yanmar 4JHTE diesel engine that is rated for 55 H.P. and it had approximately 5,500 hours of runtime. This number is approximate because the hour gauge was replaced by a previous owner of the boat. The engine ran well enough when supplied with clean fuel. It could push the boat at over 6 knots while burning an average of 1.25 gallons of diesel an hour (based on personally collected data).

Engine Compartment - Prior to Removal

The removal took two days of work that included dismantling the engine (mostly transmission, alternators, hoses, and wires) as the boat was built around the engine and it could not be removed intact. The actual lifting process was accomplished with three people, straps, several 2x4 supports, and the main halyard.


Engine Compartment - During Removal

Clean and Prepare the Compartment for the New Electric Motor

Once the engine was removed, the cleaning process began.   The first phase of the clean-up was the removal of old wiring and hoses (fuel, exhaust, and air venting) but the real work was getting rid of 20 years of oil, grease, and rust buildup.   The sound proofing material was saturated with diesel and oil odors that could be smelled throughout the boat but most prominently in the aft cabin.

After removing the bulk of the material and scraping the bilge and bulkheads with paint scrapers and drill-driven wire brushes, we cleaned the compartment with degreasers and a high-pressure washdown.   There was a considerable amount of over-spray but it provided a clean surface for the installation.

Finally, we applied several coats of Interlux Bilgekote paint to a provide a “like-new” environment that makes maintenance inspections easier and helps to protect the bulkheads and bilge.


Engine Compartment - The Clean-up Process

Motor Compartment - After a few Coats of Paint

Installing New Electric Propulsion System

An installation process will vary based on the motor selected but it is a fair assumption that the motor will weigh less than the diesel that it replaces. However, adding in the weight of the batteries the overall weight will be similar the diesel but in smaller, more manageable parts. Our Thoosa motor was light enough to carry it up a ladder onto the boat while in the boatyard.

We selected the ASMO Marine Thoosa 12000 and six Northstar AGM batteries to provide the 72v DC needed to drive the motor.   The Thoosa motor and the Northstar batteries have the following characteristics and was close to a 1:1 match of weight compared to our old diesel.

Thoosa 12000
- 12 kW motor
- Total system weight (per ASMO) is 44 kg / approx. 96 lbs

Northstar AGM batteries
- NSB 170 batteries
- Weight per battery 128 lbs - total for six batteries - 768 lbs

By our estimate, we replaced the weight of the old engine with the new motor and batteries to within 50 lbs - a trivial amount on a 30,000 lbs cruising sailboat.

One of the biggest challenges during the installation was that the new motor dimensions were so much smaller than the old diesel.   The old engine struts were too far apart to hold the new motor.   The struts are u-shaped steel that is through-bolted through fiberglassed stringers. To adjust for the width, we had additional steel (2 inches per side, total of 4 inches) welded onto the old struts to narrow the separation between them.

New Wider Struts with Motor Suspended Above for Initial Measurements

In addition to the narrower motor supports, the vertical length of the new motor was smaller.   To adjust for height and allowing for motor shaft and propeller shaft alignment, we used motor mounts rated for much more weight than was required but allowed for greater flexibility in the height adjustment of the motor. The motor mounts we selected were R&D mounts - model 800-021 - and provided over 5 inches of vertical adjustment.

In addition to supporting the new motor, the old engine struts became the base to support the batteries. We built a battery platform out of 3/4” marine grade plywood that was also laid up with several layers of fiberglass to support the weight of the batteries. The platform is attached to the forward bulkhead of the motor compartment and securely fixed to the steel struts. The batteries are also strapped to the platform and spaced between the port and starboard bulkheads so as to prevent any movement of the batteries.

We built a plywood panel on top of the batteries as a mounting surface for the contactors and wiring used to connect the six batteries into a single 72v DC battery bank needed for the motor.

New Motor Mounts, Battery Platform, and Unfinished Wire Platform

After mounting the motor and batteries, the next steps were to attach the batteries and the different motor components: motor controller, key, throttle, and battery monitor.

At the helm, we installed the on/off key, the throttle, and battery monitor. In the electric propulsion world, the battery monitor is now the “fuel gauge” and the power output guide. The AMPS OUT view provides an indication of the effort from the motor which is similar to the RPM gauge for the old diesel.   The AMP HOUR view indicates the “fuel” remaining in the batteries.

During close-quarters maneuvering and docking, we have found that AMPS OUT and the GPS are the best indications of effort and speed as there is little change in sound produced by the motor.   With our old diesel we would look at Engine RPM and listen to the engine noise to estimate speed and effort.

At the Helm - Key and Throttle (left) and Battery Monitor and Auto-pilot Controls (right)

In the motor compartment, the remaining components are readily accessible despite the batteries occupying much of the space.   In addition to the motor, motor controller, and batteries; we also located the two battery chargers in the motor compartment.

We chose to introduce some additional complexity to the battery configuration.   The motor requires 72v DC. Six batteries in series would have been the easiest configuration but we have a 4 year-old child onboard and want to reduce the potential shock voltage when the motor is not in use.   Therefore, our design allows for three banks of 24v DC each.   These three banks are then combined or separated as necessary with the use of heavy-duty solid state contactors. An additional set of contactors are used to isolate the battery chargers thus providing greater flexibility in battery and charger management.

The Motor Compartment
(clockwise) Batteries & Wire Platform, Battery Chargers, Motor Controller, and Motor

Why Electric Propulsion

There are several options to choose from when switching to electric propulsion for a sailboat. There are groups of people following the DIY route, there are companies installing systems, and others are selling turnkey solutions that are complete enough to be installed on your own.

Even more diverse than the choices available for full systems and components are the reasons why people decide to switch to electric propulsion. As the saying goes, “10 sailors, 10 opinions” but to name a few:

- Quiet motoring
- Fewer odors than a diesel
- Lower maintenance time and costs
- Reduced fuel costs
- Better boat handling at docking speeds
- No need to warm up the engine before leaving the dock/mooring
- New and cheaper battery technology on the market
- New and proven companies offering the technology

For us, the main reasons were fewer odors and less noise while motoring, reduced fuel consumption, and the chance to introduce our son to more “green” technologies as he grows up.

Our Component Choices

The three major components to an electric propulsion system are: 1) Motor and controller, 2) Batteries, and 3) Charging Sources. Again, there are more choices than can be easily listed but we wanted to share our thought-process and decisions on each of these components.

Motor and Controller

“turn the prop as fast as the diesel - go as fast as the diesel”

After researching on and off for several years, watching some systems come and go, and then some serendipity at the Annapolis Boat Show, we chose the ASMO Marine Thoosa motor and controller. We wanted a reliable motor with a proven quality history and a complete system that we could install ourselves. We knew we did not have the patience or technical background to follow the DIY path but we felt comfortable installing a new system with consultations from experts as necessary.

Our primary criteria for motor size was quite simple - if we could turn the propeller shaft as fast as we did with the diesel then the boat would move as fast as it did before.

We knew, from our research, that we should expect a shorter duration at the top-end speeds than we got from our diesel. The style of sailing we try to do - day sails or long-range cruising (but with no real time constraints) - works with the trade-off for continuous top end boat speeds. We chose to implement a "hybrid-electric" approach that is discussed later in the Charging Sources section.

The Thoosa 12000 is ASMO's largest DC motor offering. We were the third purchaser of the motor in the world and the first in the US. This motor is rated by ASMO for boats 35-45 feet in length which, at 44', puts us just within the range. Another metric that we considered was "1 Kw per ton of boat weight" which, at nearly 15 tons, the new 12 kW motor is less than the target of 15 kW. However, after talking with the ASMO dealer for the USA - Annapolis Hybrid Marine - we believed we could achieve top-end speeds acceptable to us and maneuvering performance to be safe and seaworthy.

Prior to the conversion to electric propulsion, we performed sea trials to record boat speed, propeller shaft RPM, and diesel engine RPM. After the conversion, using the same propeller and shaft, we recorded boat speed, propeller shaft RPM, and watts (AMPS Out x actual voltage DC). We performed the tests twice, except reverse, to obtain an average to minimize for any current, wave, or wind impacts. The full test documentation is included in the Appendix.

	GPS Speed	Shaft RPM	Engine RPM
Forward - Idle	2.4	471.5	1,100
Forward - Low	3.5	634.5	1,400
Forward - Med	4.7	777.5	1,700
Forward - Med	5.6	924.5	2,000
Forward - Cruise	6.4	1,190.5	2,487

Speed Test Data - Propeller RPM with Old Diesel Engine

	GPS Speed	Shaft RPM	Battery AMPs Out	Watts (72v DC Nominal)
Forward - Low	2.2	277.5	6.6	487.5
Forward - Med	3.7	534.5	31.1	2238.5
Forward - Full	5.3	776	85.5	6011
Med Reverse	1.3	559	19.2	1392

Speed Test Data - Propeller Shaft RPM With Thoosa 12000 Electric Motor

The new motor did not achieve the same top speed of the old diesel since we did not achieve the shaft RPM but it did give us a top speed of over 5 knots. This speed fell within a range we were comfortable with for safe maneuvering and our lifestyle of sailing.

Batteries
"Cost versus New Technology"

Our choice for batteries was influenced most by cost and dimensions of the batteries. We knew we wanted to fit batteries into the old diesel compartment to keep the weight distribution similar to the old layout. We also new that we could not afford the newer Lithium technology.

We chose the Northstar AGM batteries with a 200 amp-hour capacity. These batteries are long and skinny which fit well into the space we had available. The cost of the batteries was more reasonable than Lithium (1/3 the cost) for the same amp-hour capacity.

We expect the Northstar batteries to last 3-5 years. During this time, we expect the price of the Lithium batteries to fall. This price drop will allow us to upgrade to a larger amp-hour capacity in dimensions similar to our existing battery bank.

Charging Sources
"Use Existing Genset to Create a Hybrid Electric System"

We chose to configure our battery bank into three 24v DC banks that can be combined into a single 72v DC battery bank using contactors. In addition to the safety reasons already mentioned, this configuration allows us to charge the batteries in smaller banks which gives them better "care and feeding" than if we had permanently combined a bank of six batteries: avoiding over - or under - changing the first and last batteries in the series.

The chargers we installed are as follows:

- Sterling ProCharge 24v30
  - Universal Power Input from 90v AC to 270v AC / 40-70 hertz
  - Three (3) charging outputs channels - 24v DC up to 10 amps per output channel
  - Battery type is user selectable

- Zivan NG3 72v
  - 240v AC Power Input / 50-60 hertz
  - Single 35 amp, 72v DC charging output - configured at factory for AGM batteries

Our boat already had a diesel AC generator - NextGen 5.5 kW - that is located below the galley sink and the companionway steps and we chose to use this genset for cost purposes.

Existing Genset - 5.5 Kw NextGen Generator with 240v AC Output

Prior to converting to electric propulsion, our boat had a single 30 amp shore power inlet and the genset was wired for 120v AC output.   During the conversion, we added a second 30 amp shore power inlet and rewired the genset to 240v AC output. This shore power configuration allows us to use one shore power line to supply our house bank charger, water heater, and AC outlets and the second shore power line to supply our Sterling 24v30 charger and our other AC loads.

Shore Power Inlets - Two 30 Amp Lines

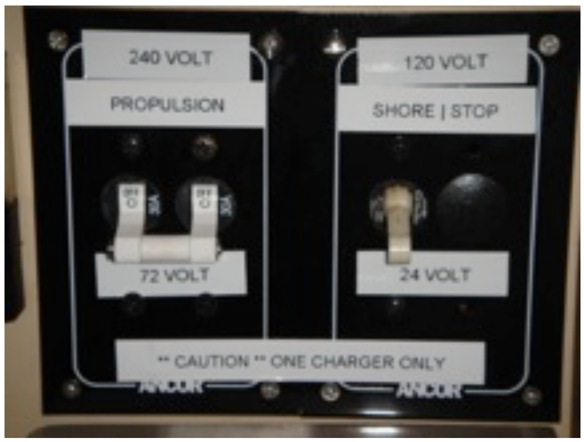
The 240v AC genset configuration allows us to utilize the two line configuration we use when on shore power but more importantly the configuration supplies 240v AC to the Zivan charger, which in-turn passes-through 72v DC through the batteries to the electric motor.

The Zivan charger never runs off shore power to avoid the potential for out of phase issues between the two 30 amp shore power lines, which would damage the charger.

In summary, there are three battery chargers on our boat:

1. Hybrid-Electric Charger - 72v DC for extended propulsion (only runs via the genset)
2. Primary Propulsion Charger - 24v DC (can be run via shore power or genset)
3. House Bank Charger - 12 v DC (not detailed in this case study)

The two propulsion bank chargers are isolated via contactors and have clearly labeled, separate circuit breakers.   As an additional control point, we intend to install a new panel for these circuit breakers that contains a slide lock to physically ensure only one of the chargers is selected at a time.



Charger Circuit Breakers - New Panel will Physically Ensure Single Selection

Genset and Utility Subpanel - (right enlargement) Control Switch for Battery Contactors

Conversion Cost Summary

Due to differing budgets, available time, and mechanical training/abilities every conversion to electric propulsion will be unique. We budgeted funds for both a boat purchase and a conversion to electric propulsion and we were willing to perform most of the conversion/installation projects ourselves. As mentioned before, we were not inclined to follow the DIY approach to find and configure individual components of the electric propulsion systems and we did not have the funding to hire others to do the bulk of the conversion for us.

When we started our conversion to electric propulsion, specifically when we pulled the old diesel engine out, we quickly found ourselves making changes, repairing newly found problems, and adding in new systems not related to electric propulsion. For example, we had 13 below-the-waterline through-holes but we filled in 10 of them over the timeframe of our conversion, while combining gray water drains, converting to composting heads, etc. We also replaced 100% of the fresh water plumbing and fuel lines; removed one fuel tank, two heads and holding tanks, one shower; installed a new propane stove and hoses; refurbished several overhead hatches; and replaced and labelled nearly all the existing wiring on the boat.

With the above in mind, below is a summary of our costs to convert - restricted only to the costs for conversion to electric propulsion.

Category	Cost	Totals
Motor Components		
ASMO Thoosa 12000 Motor, Controller, Throttle, Key, and Mounting Hardware	12,685	
Shaft Coupling, Mount Mounts, Misc. Hardware and Supplies	934	13,619
Battery Components		
Batteries, Contactors, and Related Wiring	3,981	
Battery Chargers	1,550	5,531
Labor		
Electrical Design, Welding, Mill Work, Related Yard Labor	2,057	2,057
Total		$21,207

Note on labor costs: we did not include the cost for our labor but we did spend most weekends and an occasional day during the week working on the conversion over the course of a year. We hired out a few items to ensure we leveraged experts as necessary. For example, our battery wiring design, with the contactors, shore power, and generator feeds was designed for us by JTB Marine Corp. in St. Petersburg, FL and we had the boatyard mechanics align the propeller shaft and the motor. These costs are included in summary under Labor.

<u>Savings During Our First Year</u>

Our first year of electric propulsion has been full-time cruising, both coastal and bluewater. During the first, colder part of the trip we stayed in a lot of marinas for heat but then anchored out as much as possible as the weather warmed.

We sailed when we could but also motor-sailed quite a bit. We ran the generator many days to charge the house battery bank, as we did with the old diesel. Since we started this cruise we have tallied 512 hours on the genset. We did oil changes and fuel filter changes every 100 hours - 5 this year. We would have done the same with the old Yanmar diesel.

The main cost difference between diesel propulsion and hybrid-electric propulsion for us has been fuel consumption and reduced costs for oil changes, as follows:

	Old Diesel	**Hybrid-Electric**	**Savings**
Fuel			
512 engine hours Diesel Average - 1.20 gallons/hour Genset Average - 0.2 gallons/hour Average Gallon of Diesel - $4	2,458	410	2,048
Oil			
5 oil and filter changes Diesel - 6 quarts Genset - 2 quarts Quart of oil - $5 per quart	150	50	100
Total	2,608	460	2,148

Summary

In short, we are happy that we made the switch to electric propulsion.

We have had a great break-in period, using the boat in almost all conditions:

- Cold weather, Chesapeake Bay sailing and motoring
- Motoring, sailing, and motor-sailing in the Atlantic ICW
- A placid, almost silent, trip through the Dismal Swamp
- More ICW motoring, mixed with offshore days with light and heavy weather
- Anchoring in Georgia (ICW) to recharge the propulsion bank in order to press on through opposing currents - seamingly always against us
- Days motoring on the ICW using only electric - recharging overnight at marinas
- Frustrating days trying to sail into the wind but making slow progress in a sea with slower electric propulsion
- Successfully electro-powering through a channel, into 25 knot winds, and a building sea
- A very wet, but safe, two-day sail across the Gulf Stream around the North end of Abaco
- Almost three months of Bahamas cruising with only one stop to get some "just in case" fuel even though we did not need it
- An electric only trip up the Miami River
- A near perfect slow motor-sail from Dry Tortugas to Tampa Bay

Our Cons

For us, there are two primary drawbacks when using the electric propulsion system while cruising:

- On a longer motor-sailing day where we use the genset for our hybrid-electric propulsion, we still hear a diesel albeit much quieter than the old diesel engine.

  In addition, depending on the speed we are trying to make, we might use the power from the 72v DC charger AND some additional power from the batteries. This requires that we run the genset AFTER we arrive to recharge the propulsion battery bank. Compared to the old diesel propulsion, where we were all charged up at the end of a long motoring day, we now have to continue to run the genset. Of course, when pulling into a marina this is not an issue.

- Slower motoring in a sea.

  Although a known drawback when we finished our initial sea trials, this still can be frustrating when we remember how the diesel continuously pushed better through a sea. It is important to note that the electric propulsion pushes well through a sea but not for a long duration of time a diesel provides.

Our Pros

There are many advantages to electric propulsion.   For us:

- Quiet Motoring

  By far the best part of electric propulsion is the quiet motoring. It feels like sailing because you can still hear the water, have a soft spoken conversation, and your bones don’t feel shaky from the rattle of diesel engine.

- Reduced fuel costs

  We go less and less often to the fuel dock and we are considering taking out a second fuel tank to get some more storage below decks.

- Improved Boat Control

  The slow speeds that you can apply to the propeller with electric propulsion allow for much more control in docking. You can immediately go between forward and reverse without the telltale “clunk” of the transmission from the diesel.   We enjoyed ever time a dock master would come to help move us into a new slip or help us away from the marina and they would say “ok go ahead and warm up your engine” - it was nice to say “no need - we have an electric motor.”

Authors' Biography

Bill and Amy McManus are currently cruising on their Hylas 44 in the Gulf of Mexico. They, along with their son, Finn, and cat, Quincy, have spent 2012 cruising the US Atlantic East Coast, Bahamas and the Gulf of Mexico.

They are members of the Ocean Cruising Club (OCC) having crossed the North Atlantic in 2001 aboard their CSY 37. They cruised the Mediterranean as far East as Italy and then sailed back across the Atlantic aboard a Catana 43 catamaran in 2003.

Counting their current cruise, they have cruised or lived aboard for over six years on three different boats.

Appendix

Test Data 1 - Old Diesel Engine

Propeller Shaft RPM Matrix

Vessel:	Marama	**Testing Date:**	10/31/2010
Make/Model:	Hylas 44 CC	**Location:**	Severn River / Chesapeake Bay
Displacement:	22,000	**Overall Conditions:**	Winds 10-15 Gusts Higher
Engine Make/Model:	Yanmar 4JHTE		1-2 Foot Waves
Engine HP Rating	55 HP		

Specific Conditions	GPS Speed	Shaft RPM	Engine RPM
Wind 9 knots	6.7	1219	2525
on the Stern, Port	5.7	879	2000
Quarter	4.9	746	1700
	4.2	603	1400
	3.4	539	1150
	3.1	470	IDLE (1,100)
Wind 15 knots	6.2	1162	2450
on the Bow	5.6	970	2000
	4.5	809	1700
	2.8	666	1400
	1.7	473	1100

Test Data 2 - New Electric Motor with Same Propeller

s/v Marama October 22, 2011
Test data for new motor
Same Prop - Diameter 17” Pitch Variable - Auto Prop
Severn River - Annapolis MD
Conditions - Less than 5 knots of wind, calm water
Gearing 22/72

	GPS Speed	**Shaft RPM**	**Watts** (72v DC Nominal)
Slow Forward	1.7	276	481
Slow Forward	2.7	279	494
Average	2.2	277.5	487.5
Med Forward	3.8	528	2,275
Med Forward	3.6	541	2,202
Average	3.7	534.5	2,238.5
Full Forward	5.3	776	5,763
Full Forward	5.3	776	6,259
Average	5.3	776	6,011
Med Reverse	1.3	559	1,392

Test Data 3 - New Electric Motor with New Prop and Gearing

s/v Marama July 1, 2012
Test data for new prop - Diameter 18” (Fixed 3 Blade) with 13 pitch and cup
Prop should be considered 18/14
Biscayne Bay Florida
Conditions - SE Winds 5-10, light chop
Gearing 22/90

	GPS Speed	**Shaft RPM**	**Watts** (72v DC Nominal)
Slow Forward	0.9	239.6	491
Med Forward	3.0	445.1	2,179
Full Forward	5.5	765	9,847