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Foghorn Focus:

# Environmental Issues

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**EPA Marine  
Emissions  
for 2009-2018**

# Hybrid Propulsion

By Chris McKesson, Alion-JJMA Maritime Sector

**H**ybrid vehicles are all the buzz these days. We see hybrid cars and buses, and even hybrid SUVs. But when will we see hybrid ships? It's coming – recent delivery of the Riverquest Hybrid Vessel Explorer, orders by the National Park Service, and announcements by companies like Foss are moving the hybrid drive forward in our industry.

Alion Science & Technology's JJMA Engineering Group has worked on several hybrid projects, and would like to help our PVA friends understand the pros and cons of this technology choice.

## What do we mean by "Hybrid?"

As we use the term, a hybrid drive means there is more than one type of power source which can turn the shaft, via an electrical interconnection. Thus there might be a combination of batteries and diesel generators all of whom can feed their power into an electric propulsion motor. Further we might add additional power sources such as solar panels or even windmills. The contributions from these sources may be small, but every drop of propulsion power collected from the sun and wind means one less drop of fuel purchased.

At Alion we have worked on several hybrid projects, including power from batteries, diesel generators, fuel cells, and solar panels. One project that may be known at PVA is the Riverquest, née Pittsburgh Voyager (<http://www.riverquest.org/>).

For Riverquest, Alion designed a comprehensive hybrid plant including solar as well as diesel-generator power sources. The owner eventually went with a different core design, and used the Alion components only for the solar and ancillary functions.

Riverquest is a bit unique, in having a very 'green'

*raison d'être*, and thus being willing to be out in the forefront of a technology like this. But other than this appeal, what other advantages does a hybrid offer?

## What are the advantages of a hybrid?

### Fuel Efficiency

In an ideal hybrid drive system, choices are automatically made by the system to determine the most efficient source of power for a given load demand. In the case of a vessel the demands of the hotel load and propulsion load can be coupled together electrically and powered by a combination of power sources including generators, batteries, and alternative power sources. This will permit an operator to "tune" his operation into an extremely fuel efficient mode as opposed to traditional mechanically

geared propulsion systems. In hybrid operation the engine in the system (e.g. a diesel generator) would run at a constant load. When this load suits the vessel's propulsion needs then this power would be sent to the propellers (as electricity sent to a motor) and consumed in propulsion. But during those times when this power was not needed (e.g. during low-speed maneuvers) the engine would still produce the power, it would simply be banked in an accumulator array (probably batteries.)

Then, when power surges are required, the accumulator array is drawn upon and its power is added to the still-continuous output of the engine. Thus the engine runs at steady load whenever it runs at all, while the motor is throttled up and down as usual.

Because of this steady load on the diesel, it is possible to optimize the engine for best fuel consumption.

Traditional marine vessel propulsion plants require the use of engines that are sized for the maximum output and speed cases. While there is an attempt to optimize fuel



Engine room.

consumption across a wide range of power and RPM, even modern diesel designs with electronic injection systems have a reduced efficiency while operating at varying loads from its design point.. This necessarily involves compromises. Optimizing for a single power-point permits a tight optimization and the best fuel economy the engine is capable of.

**MythBuster:** Note that in this example the engine is sized for an “average” power, and does not have the horsepower reserve required for peak power – peak power is accomplished by drawing on the accumulator or battery system. This means that the diesel engine which is coupled to a generator is smaller than would be specified in a normal marine propulsion direct drive system. But this reduction in engine size is not the sole key to reduced fuel consumption. The smaller engine will indeed have a smaller fuel consumption *rate*, but the total gallons per day needed may not be reduced. This is because the smaller engine must run longer hours than was required of its larger sister, because the ‘work’ – the energy required to move the ship across X miles at Y knots – is the same in both cases. If there is a reduction in fuel consumption it will not be because the engine is smaller, but rather because it operates at a more efficient point on its performance curves.

In some applications people speak of “plug hybrid” vehicles. These are vehicles wherein the “power accumulator” can be charged by plugging the vehicle into the electrical grid.

Plugging in may be thought of as a way of getting a “free tank of gas” by storing a full charge of stored energy without using the ship’s engine. Of course, this ‘tank of energy’ is not free, but it is probably more attractively priced than producing the energy on board. It is also possible, depending on details of the route, that the morning charge could be



*Battery bank.*

big enough to permit a substantial reduction in the size of the on-board engine, with attendant weight and cost savings. In the limit one arrives at a no-engine plug-in vessel, completely battery driven. (At present such a limiting case is only suitable for very small vessels on very short runs – just the same problem as plug-in electric cars. It is worth noting that Duffy electric boats have been very successful in just this niche.)

### *Easy to Upgrade*

Another advantage of hybrid drive is that it is inherently modular. Consider a stereotype hybrid, having one or more diesel generators, a battery bank, and a propulsion motor. In a case like this you can change out a major component of the system without disturbing the rest of the system. For example, a Carl Moyer repower may be as simple as removing one 200kW gen set and replacing it with another. Or

if battery technology changes – let’s imagine that NiMH batteries become affordable – you can change the battery bank without touching the motor or generator. For that matter, when other more effective forms of energy storage are commercialized, the batteries can be replaced by them.

Let me illustrate this with an example from my own boat. I “repowered” from one generator to another in one day by doing nothing more than lifting the old one off and placing the new one on and plugging it in. Certainly had I performed a similar upgrade with a diesel it would have meant hours of fiddling with motor mounts, alignments, auxiliaries, and other matters.



*Propulsion motor.*

A related advantage is that the individual components are generally smaller and lighter than their traditional counterparts. Thus the manipulation of any one component is likely to be physically easier than in a traditional set up.

This modularity can have an “administrative” element to it too, as well as the physical one I have described. By this I mean that the components of the system need not come from a single vendor. My preference, for example, is to use a common power

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standard such as 120 Volt AC, or 240V 3-Phase power. Using such a common standard is about equivalent to using USB devices on your computer: Everything is plug and play. The motor doesn't need to know what type of generator you have, the generator doesn't care what RPM the motor works at, etc. The system is, in some "administrative" sense of the word, decoupled.

### *Arrangeability*

This modular or "component architecture" nature of a hybrid drive also brings some potentially-important design flexibility and it is possible to put the components nearly anywhere on the boat. Thus, the generators can be placed in the bow or the stern, freeing the midships portion for revenue-generating passengers.

### *Operational Flexibility*

Finally, we come to a question of operational flexibility. In a hybrid drive there is no need for all the generators to be the same size. Thus we might imagine a twin screw boat with two 400 hp electric propulsion motors and a 60 kW ship service electric load, and equipped with one 400 kW generator, one 200 kW unit, and one 50 kW unit.

With all generators on line full power can be delivered to the props (600kW is about equal to 800 hp.) With only the bigger generator running an economical cruise is attained at about 80% of max speed while still providing the full ship-service electrical capacity. Note that the propulsion power can still be evenly distributed to the two props, even though only one diesel is running. With just the 200kW generator running the boat goes into a quiet mode at about 50% speed, say for tourism. In fact, if there are batteries on board too, then both generators can be shut down for a super-quiet "stealth" mode ideal for, say, whale-watching.

But during all of these modes both props are turning. It's a much more flexible mode than shutting down one conventional engine and limping along on one shaft only.

Further, all of these generators could be based on the same engine, just having different cylinder configurations – parts commonality galore. This system architecture give the operator the opportunity to decide which power source to have online depending upon the operation vice having a 400 hp engine putting out 100 hp for cruising.

### **What are the disadvantages of a Hybrid?**

TANSTAAFL: "There Ain't No Such Thing As A Free Lunch." In the paragraphs above I indicated that a hybrid drive can be more flexible, lower fuel consumption, more arrangeable, and have other advantages over a conventional mechanical drive. Unfortunately, but unsurprisingly, those advantages come at a cost. In some cases this cost is financial, but some of the 'costs' are measured in other units, such as complexity or weight. In the following paragraphs I will discuss these costs.

### *Weight, Due to Multiplication of Components*

In a conventional drive, the driveline is fairly simple: Propeller, Shaft, Clutch, Gearbox, Engine. In a hybrid drive there are more pieces: Propeller, Shaft, Motor (maybe no Gearbox), Cables, Switchgear, Batteries, Generator. Further, let's look at the weight of some of these pieces: Imagine a 500 horsepower installation; The Generator includes a diesel engine that may be slightly less than 500 hp – let's say 400 hp. (Actual size will depend on duty cycle questions mentioned above.) Now we add the electrical part of that generator, which is a pretty big piece of copper that might weigh half as

much as the diesel. Then we add a 500 hp electric motor, which is another very big piece of copper. The switchgear at this power level includes some pretty large cabinets of electronics, and finally we add batteries which are made of lead. The result of all this is that, for equal total power, the hybrid drive system will be heavier than a mechanical drive system.

### *Cost, Same Reason*

Of course, each of those weighty components mentioned above had to be purchased. Further, there is a substantial cost involved in the installation, with wiring and so forth. The complexity of the system may also limit your choice of shipbuilders – not all boat yards are up to the challenge of installing a hybrid drive. So the cost of the hybrid drive is again likely to be higher than the cost of a mechanical drive. Of course, for this cost you get flexibility, efficiency, reduced environmental impact, and other benefits. But still: TANSTAAFL.

### *Be Advised, Batteries are Consumables*

Finally I wish to note that batteries do not last forever. There are plenty of batteries we are familiar with in our everyday life. Battery choices include lead-acid, advanced glass mat, gel, nickel metal hydride, and Lithium Ion. For most operators the lead acid or advanced glass mat battery is still a very competitive battery candidate for a hybrid ship, but a lead-acid battery can only survive approximately 1000 charge/discharge cycles. Eventually it reaches a point where it no longer holds a useful amount of energy. We have all experienced this with car batteries at times. In my life it seems to be whenever the weather is least pleasant!

As a result, while a hybrid drive may reduce fuel consumption, and this can benefit your bottom line, it will also lead to increased battery consumption and you should make the appropriate financial provisions

for this in your operating budgets. Here again it is important to realize that a careful system design with property sizing of the battery bank and the correct battery management system will maximize the life of the batteries, but it can't extend them indefinitely.

### **When does a Hybrid make sense? (or cents...)**

So what's the bottom line? Is the hybrid a good idea? Are all PVA vessels going to be hybrids in the next decade, or none of them? Well, as always, the answer is "it depends."

#### **Not Always**

First, we hasten to state that hybrid drives are not suitable for all applications. A hybrid drive is a specialized means of optimizing a propulsion system, and like any propulsion optimization effort it depends upon specifics of the vessel, the operation, the regional availability of resources (fuels), and myriad other concerns. An individual cost/benefit analysis is a must.

#### **Varied Load Cycle**

The key to utility of a hybrid drive is in an application with a varied duty cycle: A vehicle that has many different levels of power demand during its day. Consider the following examples:

#### **Commuter Traffic**

By commuter traffic, I mean the ferry services in Puget Sound or San Francisco Bay. In these cases the ferry runs are between 30 and 60 minutes long, and turn-around times are fairly short. There is not a lot of stop-and-go content to the service, as they operate only between two ports.

This type of operation is probably not suited to hybrid drive. We studied hybrid drive for the San Francisco Water Transit Authority and found that, for their nominal 45-minute runs, a hybrid drive would actually result in *increased* emissions

compared to a clean diesel installation. This is because the weight increases associated with hybrid drive resulted in reduced passenger capacity on the ferry, so that the fuel burned was moving fewer people, and the increases in fuel efficiency were not sufficient to compensate for this.

#### **Water Taxi**

A water taxi might be in some ways the opposite of the commuter case. When I speak of the water taxi I envision a small-capacity boat making short hops between many closely-spaced locales, with passengers hopping on and off frequently. Such services exist in New York, Fort Lauderdale, and Victoria BC among other places.

The water taxi may – depending on details of the route – spend as much time idling at the dock as it does underway. In fact, the National Park Service's Arizona Memorial taxis in Pearl Harbor spend *more* time at idle than underway. These services are ideal for hybrid drive. A quite small generator can be used, which might have a power output as little as one-fourth of the propulsion motor power. (As explained above, this little generator runs at full output the whole time, and the power is stored in batteries for use when the taxi sprints to its next destination.)

#### **Substantial Shore Power – Plug-Hybrid**

The third major situation where a hybrid makes sense is that case where there is a substantial amount of shore power available. This could be the situation for a vessel that makes only one or two harbor cruises a day, or a vessel whose turn-around time is so long that it makes sense to plug in and charge up at each dock call.

In the most extreme case of this the vessel could have no onboard engines, and be entirely battery powered. Alternatively we might

want some onboard generating capacity, but this would be used primarily for ship-service purposes or to power an electric galley, and the ability to cross-connect to feed the power into the propulsion plant would be only a 'backup' or casualty mode, with the boat running on batteries 99% of the time.

This case has the attraction of drastically reducing fuel use. I have a set-up like this on my personal boat, and one of the more humorous results of this is that I don't know where the fuel docks are in my area. When a transient boater asks me where to find fuel, I have to shrug and say something like "I don't know – I don't use it, myself." A nice problem to have.

### **Final Caveat: It still has to be a well-designed marine propulsion plant**

Hopefully I have painted the picture that a hybrid drive can have some substantial attractions, but that it is also a complex system that needs to be well tailored to the particular application of the vessel. As a final point on this line please allow me to state that, given the number of variables and areas for optimization presented by the hybrid concept, it is very important to approach it as an integrated comprehensively-engineered solution. It is too easy to collect a few good parts, but assemble them in a non-optimized, or non-marinated system, and end up with a disappointment.

Of course, this is true of any of a ship's engineering systems, but the complexities and opportunities of hybrid drive make it all the more important in that case. ■

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