WE CAN HAVE HYBRID

COURTESY WHISPERPOWER

Though the hype around marine hybrids died down after early failures, the development of these systems has persisted. The results include some viable and almost-viable power choices for the recreational marine market.

Above—*Hybrid propulsion systems are being consistently refined by multiple equipment manufacturers looking to deliver cleaner, more efficient onboard powering options. This superyacht-scale hybrid system is being tested at the WhisperPower factory in The Netherlands.*

It has been almost a decade since Groupe Bénéteau (www.beneteau-group.com) launched the Lagoon 420 catamaran with a hybrid propulsion and energy system. The concept was an instant hit with buyers, and dozens were sold before it was discovered that the boats had insufficient power to make headway against wind and seas in rough conditions. Bénéteau subsequently retrofitted almost all the boats with conventional diesel drives. Bénéteau has experimented with several hybrids since then but has not brought another system to market.

Back in those days, hybrid propulsion systems were a hot topic. I received far more e-mails from people interested in putting a system into their boats than on any other subject I have ever written about ” My response was always the same: “Don’t do it now. Wait for the technology to mature. Ask me again next year.”

Over the next few years, we had a series of high-profile failures of hybrid or electrical propulsion systems on recreational boats, including from such giants of industry as Siemens, which thought its well-tested hybrid bus technology could be readily adapted to marine applications. Unfortunately, although hybrid systems are conceptually simple, the duty cycle in boats is much tougher than in most other applications; the control systems are more complex, and the environment is particularly harsh. Even Siemens did not get it right. (Note that this is not the case in the commercial world, where we are seeing an increasing number of successful hybrid applications, notably among ferries and offshore workboats for oil fields and wind farms; unfortunately the scale of these systems is such that the technology does not readily transfer into the recreational marketplace.)

Successive inventors and boatbuilders, most with severely limited resources but some with million dollar budgets, have wrecked on the technical rocks. There have been hundreds of underperforming and failed hybrid boats. The boat-buying public gradually got the message, and the hybrid e-mails dried up. Today I get very few inquiries.

Below the Radar

In the interim, the effort to create viable marine hybrids has never ceased. Although most of the early developers were enthusiasts with little funding and without the resources to solve the problems that emerged during the development process, one or two hardy companies are still around. These now have more recent competitors with deeper pockets and greater technical resources.

There are two possible architectures for the resulting hybrid-propulsion systems: serial and parallel. In a *serial system*, the boat is driven by an electric motor that in turn is powered by a diesel generator and/or batteries, with no mechanical connection between the diesel engine and the propeller. In a *parallel system*, the boat has a conventional diesel installation directly connected to the propeller with an auxiliary electric "machine" operating as an electric motor and also as a generator connected to the propeller shaft. A series of clutches enables the propeller to be driven by either the diesel engine or the electric machine, or both; the electric machine in turn can be driven by the engine as a generator. In serial and parallel applications, a freewheeling propeller on a boat under sail can drive the electric machine as a generator.

Serial Woes

Most early attempts at marine hybrids were serial systems. The Lagoon 420 was one. The core problem here is that because the only thing connected to the propeller is the electric motor, it must be powerful enough to keep the boat moving in the worst possible conditions. In those days of serial development, a lot of nonsense was spoken and written about 1 electric horsepower being the effective equivalent of up to 4 diesel horsepower. This was partly responsible for the underpowering of the Lagoons and other vessels. Unfortunately, it simply doesn't work like this. Although an electric motor offers some potentially significant gains (the discussion of which is beyond the scope of this article), if a serial hybrid is to have the equivalent performance under power of a conventional installation, it still needs a powerful electric motor, with a powerful generator, both of which are expensive.

The other critical problem with serial systems is the nature of duty cycles on a boat. When a car reaches cruising speeds on the highway, the relatively light propulsion loads make it feasible to provide a range under battery power of 100 miles (161 km) or more. When a boat gets up to cruising speeds, the loads are continuously high, especially with displacement-type hulls. In most applications it is not practicable to put enough batteries

Seaweed*, a fast cruising yacht fitted with a parallel hybrid system from Hybrid Marine, has just completed a six-year circumnavigation of the North Atlantic, from the Hebrides to Madeira and Nova Scotia to the West Indies; the owner was very pleased with the system.*

in the boat to maintain this speed for even an hour, let alone several hours; and as such, at traditional cruising speeds the range under batteries is typically only a few miles. Of course, you can always choose to go slower, which dramatically reduces the load with a displacement hull and concomitantly increases the range under electric power, but then you are not comparing apples to apples. Once the batteries are discharged, the generator must be cranked, but now instead of the diesel engine directly driving the propeller, it is driving a generator that is sending power through cables and a motor controller to an electric motor driving the propeller. The additional hybrid system components cause efficiency losses into the system along with a significant level of complexity and, in many systems to date, a greater number of potential failure points.

Although at low speeds there can be significant improvements in system efficiency over a conventional installation, if the normal duty cycle includes sustained powering at cruising speeds, it is next to impossible to make a serial system in propulsion mode even as efficient as a conventional drive. That's not to say a serial hybrid makes no sense; other good reasons for this approach are mostly related to lifestyle issues. Timo Jaakkola of serial hybrid manufacturer OceanVolt notes: "Efficiency is not the first criteria for selecting an electric motor system. More important are silent propulsion, less maintenance, no vibration, no exhaust fumes, the ability to regenerate power under sail, and sleeping silently overnight without a generator running."

The higher the house loads relative to the propulsion loads, the better a serial system looks, as it can almost always dramatically improve the efficiency with which the house energy is created. An ideal application for a serial system is a fast cruising catamaran with high air-conditioning loads: the propulsion loads are relatively light; the house loads are relatively high, and the vessel can regenerate significant amounts of energy under sail.

From Electric Boats to Serial Hybrids

For years, the issues of cost, efficiency, and complexity nearly ended attempts to create viable serial systems. In the meantime, a considerable development around pure electric boats (no generator) has resulted in thousands of installations, which are very effective for short-distance operation if shore power is available to recharge the batteries. If you want more range on occasion, you can put a small generator in the boat to charge the batteries, but operation is considerably less efficient than with a conventional installation. So, if the generator must be run on a regular basis, it makes little sense.

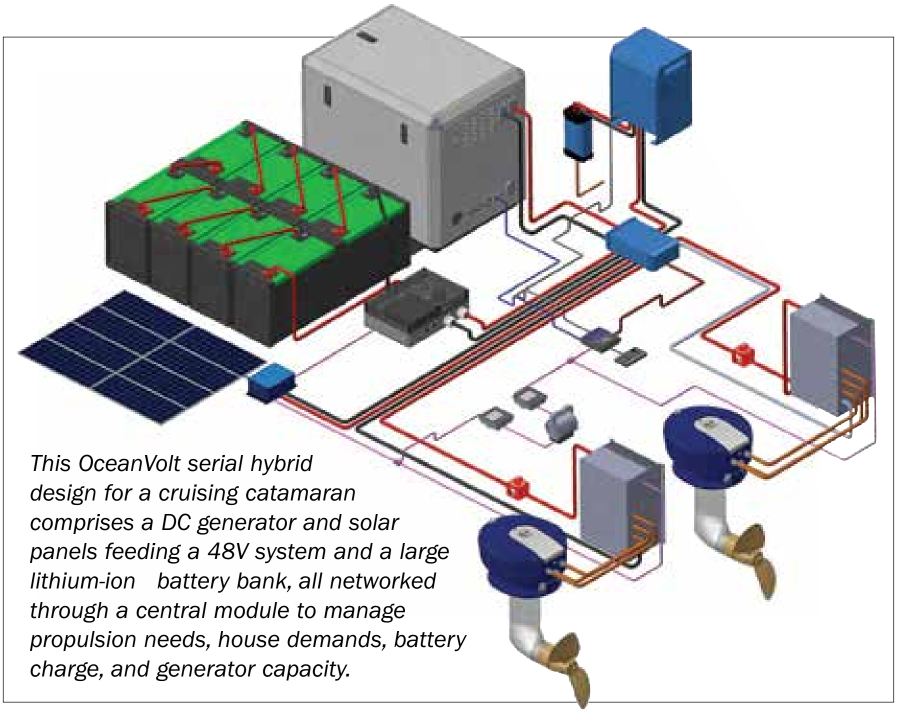
An electric motor with a range-extending generator is not a hybrid system. The hybrid system comes in when you add complex control systems that manage the generator and batteries to optimize system operation and efficiencies. It is a significant technical leap to go from a range-extending generator to an integrated serial hybrid system. In the field today, one company in particular, Fischer-Panda (www.fischer-panda.de), has been developing these systems for more than a decade. Two other companies that I believe have the staying power to make this step are Torqeedo (www.torqeedo.com) at the high-powered end of the marketplace and OceanVolt (www.oceanvolt.com) at the relatively low-powered end. Torqeedo is still in the development phase, while OceanVolt is delivering systems.

Torqeedo. Best known for its electric outboards, Torqeedo is building a serial hybrid around a common control system that provides whole-boat energy management, delivering electric power at any desired standard voltage, AC or DC, to all electrical loads on the boat. This control system can be applied to a series of standardized electric machine, generator, and other modules. The idea is to have a system scalable from 27 kW up to 55 kW (35 hp up to 74 hp) continuous, including twin-propulsion systems for catamarans, using the same controllers, software, and building blocks. These systems run at hundreds of volts; the high power levels require high voltages to keep cable sizes within bounds.

Todd Sims, Torqeedo's global sales manager, states, "The standardization of components allows for consistent performance, a high level of safety, and easier service and support." Torqeedo is investing heavily in this system, including massive lithium-ion battery packs from top-tier manufacturers. If the 60,000 electric outboards it has sold to date are anything to go by, the finished product will be beautifully engineered.

COURTESY TORQEEDO

Electric outboard manufacturer Torqeedo is developing a serial hybrid system built around an energy-control module that can be applied to standardized inputs from electric machines, generators, solar, and other sources. This schematic is for a serial hybrid catamaran.



This OceanVolt serial hybrid design for a cruising catamaran comprises a DC generator and solar panels feeding a 48V system and a large lithium-ion battery bank, all networked through a central module to manage propulsion needs, house demands, battery charge, and generator capacity.

OceanVolt. This Finnish company also has well-engineered electric machines up to 15 kW and operating at a nominal 48 volts. To date, these have been used almost exclusively in electric boats, with more than 200 systems delivered, powered by lithium-ion battery packs. OceanVolt has been investigating serial options, initially in a range-extending fashion but evolving into a full-fledged serial hybrid system: the OceanVolt SEA (Silent Electric Autonomy). The system runs at a nominal 48 volts using DC generators from Fischer-Panda and Polar Power.

Timo Jaakkola: "Generator operation is controlled with a central unit that communicates on the same CAN-bus as the propulsion and battery system. The batteries send their state of charge (SoC) information and other

OceanVolt Calculator

Project: **Voyage 45 DC**

Hull data:

Length wl **12.3**m

Width wl **7.65**m

Displacement:

Weight **9,200** kg

Lwl/Vol$^{1/3}$) **7.396**

Environmental properties:

Gravity **9,807**m/s^2

Kinem. visc. **1,2E+06**m^2/s

Coefficient of drag **0.0029**

Density **1,025** kg/m^3

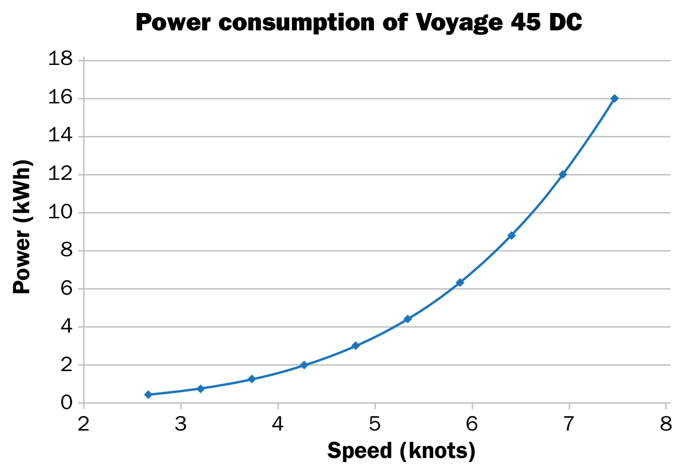
Customer factors: Battery capacity **21** kW

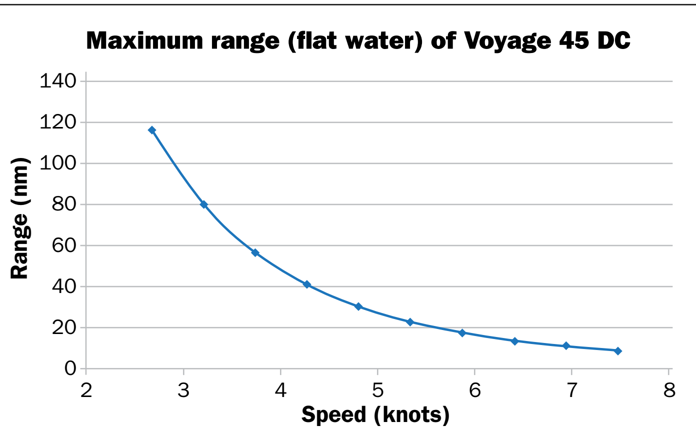
Speed		Resistance	Power	Range	
m/s	kts	N	Total	Flat sea	Sea margin
1.37	**2.67**	**137**	**0.43**	**116.5**	**87.3**
1.92	**3.74**	**282**	**1.25**	**56.5**	**42.4**
2.47	**4.80**	**528**	**3.01**	**30.2**	**22.6**
3.02	**5.87**	**908**	**6.33**	**17.5**	**13.2**
3.57	**6.94**	**1457**	**12.00**	**10.9**	**8.2**

Legend:

Flat sea = range in flat water, [nm] capacity * Battery margin/Pbat
Sea marg = range with sea margin, [nm] Rflt * Sea margin (25%)

The calculations give an estimate of resistance and power consumption for conventional catamarans (30–60′/9.1m–18.2m) with a length–weight–ratio of 6.5–9.3 at displacement speeds. Results are not contractual.





COURTESY OCEANVOLT (ALL)

OceanVolt's generic calculation of speed and range in flat water for a serial hybrid system in a cruising catamaran illustrates the significant increases in range efficiency to be gained by moderating speeds. Note that results in the real world will vary significantly, especially in headwinds or adverse seas.

COURTESY OCEANVOLT

This electric propulsion installation from OceanVolt includes the electric motor (center), white motor controller box (lower left), lithium-ion battery pack strapped down (mid-left), and a bank of Victron inverters and chargers (top left to right).

important data to the central module, which automatically starts and stops the generator at low and high SoC." There are additional settings for starting the generator if, for example, a predetermined motor power is to be used for a predetermined time. The central module can be connected to the Internet for remote diagnostics, updates, control, and communication.

To date, OceanVolt has delivered 30 of these systems.

Fischer-Panda. Fischer-Panda has been at this longer than anyone else still in the business (I tested one of its serial hybrid boats a decade or more ago). The company is now on its fourth generation of submersible, pod-type, electric machines together with the controllers and software that integrate these with Fischer-Panda generators. Packages are designed for easy installation, with the cables for the electric machine, the battery cables, the joystick, and the helm display all plugging into a central control box, operating at a nominal 48 volts. Power levels are 10 kW and 20 kW. Given that boats rarely operate at wide-open throttle for any length of time, and the fact that once you throttle back, the load reduces dramatically, Fischer-Panda recommends sizing generators at half the kW rating of the electric motor.

Parallel Hybrids

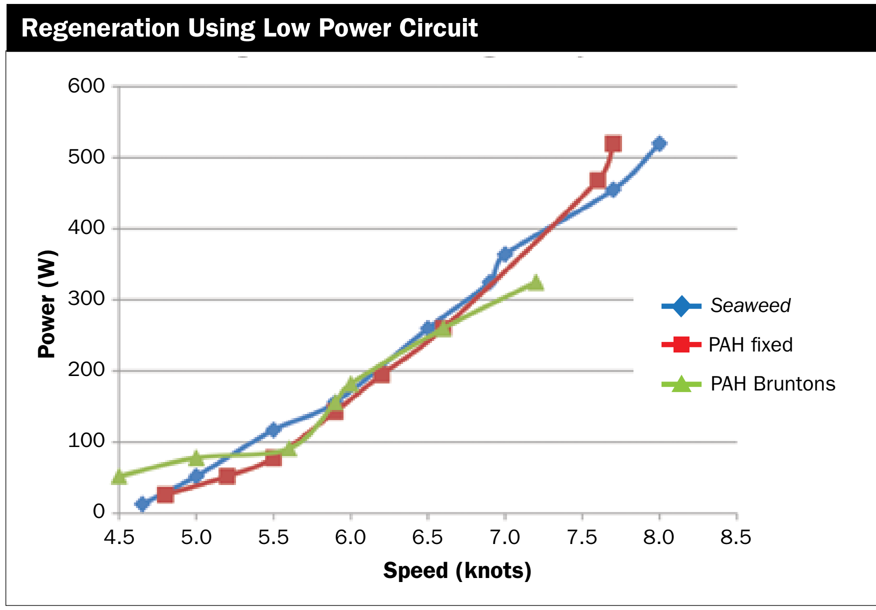
Recently, Fischer-Panda has begun adapting its electric machine technology to parallel hybrid applications. The electric machine is connected via a belt drive to the propeller shaft in a conventional installation, providing low-speed maneuvering. The systems have been added to boats up to superyacht size. In calm conditions, the 20-kW electric motor is adequate to move these large boats at slow speeds in harbor.

This low-power, low-speed capability is a defining feature of parallel systems; no attempt is made to provide sustained electric propulsion at anywhere near cruising speeds. The goal is to have sufficient electric power from, and electric storage capacity of, batteries to handle low-power situations, notably maneuvering in harbor or motorsailing in a sailboat. When operating as a generator (i.e., driven by the propulsion engine), the electric machine will be powerful enough to recharge the batteries rapidly, resulting in a house electrical system that will support the comforts of home without running a generator for long hours.

Greenline. By far the most successful implementation of the parallel approach is to be found in the Greenline series of powerboats, built in Slovenia (www.greenlinehybrid.si); more than 600 have now been built, with approximately 70% of these as parallel hybrids, in sizes from 33′ to

COURTESY J&J MARINE

The Greenline 36 (10.9m), the latest in the Greenline family of parallel hybrid cruisers, relies on an integrated flywheel electric machine built into a Volvo Penta D3, and a simple manual selector for electric or diesel propulsion.



Above—*One great benefit of a parallel system to a cruising sailboat is the ability to generate power through a freewheeling prop while under sail. Data for the Hybrid Marine system were collected aboard Seaweed using three different propellers—folding, fixed, and the Bruntons Autoprop.*

Left—*A tidy installation of Hybrid Marine's parallel hybrid on Seaweed, with the motor and clutches center right, the batteries to the left, and various control devices in the background.*

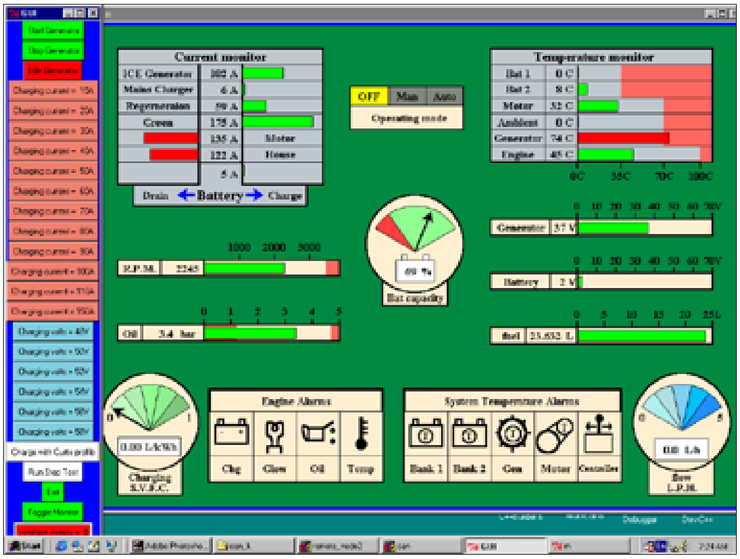
48′/10m to 14.6m (for more on the Greenline 33 Hybrid, see Rovings, PBB No. 147, page 10). A 65′ (19.8m) version is on its way. The electric machine provides 15 kW of propulsive power and 10 kW of generating capability (in earlier models it was 10 kW and 7 kW, respectively), operating at a nominal 48 volts. The Greenlines include sizable lithium-ion battery packs, soon to be provided by Torqeedo, enabling the use of overnight air-conditioning without running a generator—an important consideration in the Mediterranean, where many of these boats operate.

The Greenline approach is based on an integrated flywheel electric machine, initially built into a Volkswagen marine engine but now into the Volvo Penta D3. Note that a very similar approach has been adopted at one time or another by Steyr and Nanni (two European marine-diesel-engine manufacturers), but neither appears to be making much effort at the moment to improve or promote this technology. Part of the secret to success for the Greenlines has been eliminating many of the complex software and control issues associated with fully integrated parallel hybrids. Instead, the operator uses a switch to select electric propulsion or diesel propulsion.

Hybrid Marine. So far as fully integrated parallel hybrids for recreational boats are concerned, the only well-tested system of which I am aware comes from Hybrid Marine in the U.K. (www.hybrid-marine.co.uk). This system has been continuously developed and tested for 12 years. It uses a 10-kW electric machine (or multiples of 10 kW) operating at a nominal 48 volts.

I was recently aboard *Seaweed*, a 40′ (12.2m) offshore cruising boat with a Hybrid Marine system, immediately after the owner returned from six years of cruising on both sides of the Atlantic. *Seaweed* had been sailed from the Hebrides to the Madeira Islands and from Nova Scotia to the West Indies. The owner was delighted with the hybrid performance, especially his ability to maneuver in harbor under electric power, to regenerate from a freewheeling propeller when under sail ("I often used the electric kettle on passage when sailing at 6 knots or over and reckoned to recover the energy for my large mug of tea in about 40 minutes"), and the ability to add a kilowatt or two of electric power to the propeller shaft when sailing in light winds, substantially boosting the boat's speed with only a limited impact on the batteries.

Hybrid Marine has also installed systems in a number of recreational canal boats in the U.K. The canals have a speed limit of 4 mph (6.4 kmh), but occasional river sections may have considerable currents. These boats have relatively large engines to handle the river sections but are then effectively overpowered for most of the time they are under way. This is a chronically inefficient duty cycle for a



Left—Graeme Hawksley, the founder and owner of Hybrid Marine, testing one of his systems in the Beta Marine factory in the U.K. ***Above—***This detailed system data display and diagnostic tool from Hybrid Marine is representative of those being created by all the hybrid developers. It monitors a lot more than the rpm, temperature, oil pressure, and voltage of a conventional system.

conventional installation but ideally suited to a parallel hybrid. Enough battery power can be provided to run all day in the canals under electric power. If it is not possible to plug in and recharge overnight, a relatively short run under conventional power will recharge the batteries. The battery-charging adds sufficient load to the engine to create a reasonably efficient duty cycle even at low cruising speeds.

COURTESY WHISPERPOWER

Hybrid propulsion systems and the associated electrical installations on large yachts are far more complex than anything on smaller recreational boats. Superyacht applications are individually designed and engineered, cleanly installed, and closely monitored.

Superyachts

Superyachts have seen a lot of sophisticated and expensive experimentation with serial and parallel systems, and some that incorporate both approaches. As early as 2008, *Ethereal*, built by Royal Huisman (www.royalhuisman.com/en/yacht 936.html) with a hybrid system from HYPS (www.hyps.nl) garnered considerable attention. WhisperPower (www.whisperpower.com) has several large yachts in its portfolio, two of them being part of the J-class fleet (www.hollandjachtbouw.nl/). A recent launching is *Savannah*, a 274′ (83.5m) yacht completed by Feadship in 2015 (www.feadship.nl/en/fleet/yacht/savannah). All these companies are based in Holland, which seems to be the epicenter for large recreational vessel hybrid development. In Italy, Ferretti has also done one or two boats. Every one of these systems is individually engineered. Given the complexity of these large boats, I believe we are still some way from "generic" systems that can be dropped into practically any boat with little customization.

> It takes years of experimentation and research, with a great deal of practical on-the-water experience, to evolve market-ready systems.

An emerging concept in the superyacht world known as the "hour of power" may change this situation. The idea is to provide these boats with sufficient battery-powered electric propulsion to enable operating at up to 10 knots for one hour to get in and out of harbors and anchorages, resulting in zero emissions. A battery pack large enough to do this will also support overnight air-conditioning without running a generator. There may also be a significant market for hybrid superyacht tenders that eliminate emissions when under way and when alongside the mother ship.

If the hour of power concept gains traction, we can expect to see considerable investment in hybrid systems for larger recreational boats. This may also be driven by legislation as more harbors look at the feasibility of implementing zero emissions rules. Amsterdam, for example, has set a deadline of 2025.

Software and Battery Challenges

To be successful, any hybrid system, whether serial or parallel, needs a control system that is, in effect, a whole-boat energy-management system. On all but the simplest systems, this involves balancing and optimizing a mind-boggling number of possible permutations of, and interactions between, the components in the energy system: electric machines and their controllers, batteries, generators, other energy sources (shore power, solar, wind, regeneration, maybe fuel cells), various voltage converters (DC-to-DC, DC-to-AC, AC-to-DC), and all the loads on the boat. At all times, the system must ensure a safe mode of operation, often when moving extremely high-current levels around the boat.

It takes years of experimentation and research, with a great deal of practical

COURTESY OCEANVOLT

This neat OceanVolt serial hybrid installation includes a large bank of lithium-ion batteries at right and a Fischer-Panda generator in a box at center rear.

on-the-water experience, to evolve market-ready systems. We are now seeing some of these developed as part of a finished system from a single supplier and also as embryonic control systems that can be applied to other companies' systems (e.g., www.triskelmarine.co.uk).

The other principal challenge is an old one: battery technology. Effective hybrid systems on boats require the ability to store considerable amounts of electrical energy, with the only practical way of doing this still being batteries. Lithium-ion is currently by far the most capable technology, but it is prohibitively expensive in many applications. It also requires highly sophisticated battery management systems (BMS) to ensure its safe operation, especially where high discharge and recharge rates are concerned, as is the norm with hybrid systems.

A great deal of research to improve the performance of lead-acid batteries has mostly focused on variants of absorbed glass mat (AGM) chemistries, with some promising results. Notable are the combination of the thin plate technology introduced by EnerSys and Northstar some years ago with various permutations of adding carbon to the negative plates (Northstar www.northstarbattery.com/batteries/nsbblue/index.php), or making the plate grids from a carbon foam (Firefly www.fireflyenergy.com). The effect is to substantially increase:

- the rate at which these batteries can be charged and discharged
- the depth of discharge the batteries can routinely handle
- cycle life
- the ability of the battery to operate in a partial state of charge (pSoC) for extended periods of time, eliminating the need for the extended charging periods at low charge rates traditionally required to prevent sulfation.

The performance is still nowhere near that of lithium-ion but is considerably better than anything we have seen in the past. What's not to like about this?

Ready for Prime Time

One way or another, the combination of technological advances (especially in lithium-ion and lead-acid batteries), dogged perseverance, and an increasing body of real-world experience is finally delivering reasonably well-tested and proven parallel and serial hybrid systems. If market interest once again begins to pick up, we can expect this to boost further development.

I have experimented with various hybrid technologies in the past but ultimately have taken them off my boat and reinstalled the diesel engine. We have finally reached a point where there are one or two systems I would be willing to put in my boat and take offshore. The choices are likely to improve significantly in the near term. For some systems, the "next year" I warned readers to wait for has finally arrived, and for others, it really will be next year.