

Dr. Alix Valenti

The Power Problem – The Less Sexy Side of Autonomy

Unmanned surface and underwater vehicles are rapidly becoming central to missions from CUI protection to ISR and hybrid fleets – but their most critical constraint is how to power them.

OPT has tested a wave-powered PB3 PowerBuoy as a standalone UUV charging and communications hub
(© OPT)

Despite all the hype around UxVs (unmanned surface and underwater vehicles), a critical, though admittedly less glamorous, conversation is still largely missing: how to power them. From Critical Underwater Infrastructure (CUI) monitoring to Intelligence Surveillance and Reconnaissance (ISR), all the way to the concept of the “hybrid fleet”, these systems are set to become critical nodes in maritime security strategies worldwide.

Yet in the absence of viable boundless sources of energy, how do we keep them running as we continue to demand more of them – payloads, communications, demanding operating environments?

“It’s really dependent on the concept of operations (CONOPS),” Simon Adams, Founder and Director of the USV Group, told MS&D: “What are we trying to achieve, and how does that impact our endurance?” Powering UxVs may be one of the least publicly discussed technology stacks, but it is key to making autonomous operations at sea work – and navies and industry are quietly working to untangle it.

Endurance starts with the mission

For navies across the world, UxVs are set to fill one critical gap that has been growing over the past decade: recruitment difficulties compounded with financial constraints – even as budgets increase – are at odds with increasing challenges and threats to maritime security. Navies are

investing heavily in UxVs to build fleet architectures that support more efficient deployments across the maritime security spectrum.

As a result, the scope of these systems’ missions is expanding quickly. “We want them to be out at sea for longer, potentially going further, and with greater energy demand for the sensors onboard,” Dr Thomas Beard, Clean Shipping Service Lead at BMT, told MS&D.

It starts with the operating environment. “Before you even meet the enemy or the threat, half the battle for energy endurance is the operating environment,” Peter Karlström, Product Manager for Autonomous & AI Systems at Saab Naval, told MS&D. Currents, winds, wave heights, temperatures and salinity can all increase the power needed to move efficiently – and successfully – from point A to point B. Then come the sensors and effectors. “Back to the old chestnut of CONOPS and what navies need that system for,” Adams explained. Depending on mission requirements, UxVs may carry more or less power-hungry systems – from communications, acoustic sensors, electro-optical and infrared (EO/IR) sensors and radar to electromagnetic warfare systems and, in some cases, weapons. Many will also require edge computing for mission planning, sensor interpretation and decision-making.

Together, the operating environment, payload and mission profile determine the real endurance requirement. Power is not a fixed technical specification; it is a CONOPS problem.



Unplugged uses inductive wireless power transfer: a receiver inside the UUV communicates with a charging pad on a fixed or towed station (© Unplugged)

Persistence Below the Surface

One of the key challenges navies are seeking to address through UxV acquisition and fleet integration is CUI monitoring. Europe alone gives the scale: the North Sea has more than 45,000 km of subsea assets – pipelines, umbilicals and cables – installed since 1966, per ScienceDirect/UK HSE and Norwegian Petroleum Directorate data; Western Europe hosts 35% of all submarine cable landings, with another 30 cables expected before 2027 (Analysys Mason, 2024); and enclosed and semi-enclosed seas bordering Europe total approximately 4.4 million km³.

By comparison, European NATO nations count approximately 70 submarines and a little over 100 frigates/destroyers – not all always operational, and many already stretched across a wide range of maritime security missions. The math is simple: there are not enough assets, nor the money to buy enough assets, to ensure persistent CUI monitoring.

“The endurance challenge is a cost challenge,” Dr Thomas J.J. Meyer, CGO of Unplugged, told MS&D. Most of these platforms are battery-operated UUVs with battery lives ranging from a few hours to four or five days – except for XL UUVs, which can operate autonomously for roughly 45 days. “And as soon as you have to plug something to recharge it, you need a human,” Dr Meyer added, “and as soon as you need a human, you break the loop of autonomous operations.”

Unplugged, a NATO DIANA cohort company currently finishing its programme, is building what Dr Meyer describes as the underwater equivalent of a Tesla charging station. “The charger is the product,” he told MS&D. “Persistent underwater presence is the outcome, and interoperability is how we deliver it.” The technology uses inductive wireless power transfer: a receiver inside the UUV communicates with a charging pad on a fixed or towed station. No connectors, no crew, no physical intervention – the vehicle hovers with



Getting a UUV to within five to ten metres of a subsea charging station is a solved problem; guiding it to docking precision without GPS remains a challenge (© Unplugged)

roughly one centimetre of the pad, and power and data transfer begin autonomously.

That last centimetre is where most of the engineering challenge lives. Getting a UUV to within five to ten metres of a subsea charging station is a solved problem; guiding it to docking precision without GPS – which does not penetrate water – requires acoustic transponders, camera-based fiducial recognition and Unplugged’s magnetic homing technology. “The ability of a UUV to find its position and come back into the vehicle is a hot topic which is proprietary for most UUV makers,” Meyer said.

The system supports three deployment configurations. The first, the “garage”, draws power from nearby fixed infrastructure such as an oil and gas platform, port installation or lighthouse, with the UUV returning to recharge much like a Roomba returning to its dock. The second pairs a subsea docking pad with a wave-powered surface buoy, enabling persistent operations where there is no offshore footprint. The third is a towed charging station beneath a mothership: the vessel transits, the UUV departs on mission, then returns to recharge before deploying again.

A Saipem vehicle with a 12-hour battery lifetime, once requiring recovery and recharge every half-day, has been operating on eight-month residency missions since Unplugged’s technology was integrated. Unplugged’s charging stations have logged more than 800 dockings in real-world deployments.

The same principle – keeping vehicles in the water continuously rather than cycling them through surface recovery – is also driving development at Ocean Power Technologies (OPT), whose wave-powered PB3 PowerBuoy has been tested as a standalone UUV charging and communications hub. The solutions differ in architecture but converge on the same operational imperative: if persistent autonomous presence at sea is the ambition, the energy problem must be solved at the vehicle level rather than by bringing the vehicle home.

ISR at the Surface

Beyond CUI protection, navies are also increasingly turning to UxVs for ISR. In this context, the power question begins to shift. Endurance still matters, of course, but the operational value of the system is increasingly measured by what it can see, how quickly it can communicate, and how reliably it can keep feeding information back into the command chain.

That is why navies – including the US Navy, the Royal Navy, the Royal Australian Navy and France – are predominantly turning to USVs, rather than UUVs, for these missions. But powering USVs for persistent ISR comes with its own trade-offs. Today, the vast majority of these platforms run on diesel or, increasingly, diesel-electric engines. According to Adams, there are two key reasons for this.

First, diesel remains the most energy-dense power source. As USVs grow in size to accommodate more missions and, with them, more power-hungry payloads and C2 systems, navies continue to rely on proven technology that allows these platforms to go faster, further and with a degree of redundancy.

Second, as Adams points out, “the infrastructure for other sources of energy – e.g., hydrogen, methanol, ammonia – simply isn’t there yet.” Additionally, many of these alternatives still require too much onboard real estate, which navies can ill afford. Trials are underway in the commercial domain, with ACUA Ocean testing hydrogen, for instance, but several challenges, including safe bunkering, remain unresolved.

Until new solutions emerge, and the infrastructure follows – something likely to be driven by the commercial sector – diesel-electric systems remain the technology of choice, conveniently combining diesel’s range and speed with electric’s stealth where and when needed.

Diesel, however, comes with its own problems. On long missions, where the usual challenge is finding space onboard for sufficient fuel, that calculus shifts to weight once refuelling at sea is off the table. “The weight margins aren’t there when you can’t rely on refuelling at sea,” Dr Beard told MS&D. Replacing diesel engines with batteries, even lithium-ion batteries, would potentially make matters worse. Diesel contains roughly 12,600 Wh per kilogram, while a lithium-ion battery contains roughly 150–250 Wh per kilogram. That is a gravimetric energy-density gap of approximately 50:1 in favour of diesel.

Autonomous diesel bunkering at sea is equally complex. Since December 2024, as part of its No Manning Required Ship (NOMARS) programme, the US Navy has been running autonomous bunkering trials. The latest, in September



*UxVs CONOPS, power sources and trade-offs
(ChatGPT-generated, based on article research)*

2025, were successful, but they used water rather than fuel. “We are simply not there yet with trusting an autonomous system to put a nozzle on another boat,” Karlström concluded. Sea state would also be a severe limiting factor.

Finally, for smaller USVs, and potentially even medium-sized ones, diesel-electric generators have limits of their own. A DC variable-speed generator runs at very high RPMs, creating heat and, consequently, wear. That not only decreases reliability but also increases noise signature. “You would have to be careful about how you install and configure your system and power sources onboard, so as not to impact your stealth, reliability or even sensors,” Adams explained. This is why many smaller USVs remain battery-powered when they need to move fast and/or carry multiple payloads or use alternative energy sources – such as solar or wind – when they are passively collecting information without critical communications requirements.

Hybrid Fleets, Hybrid Burdens

Several navies are also working on developing ‘hybrid fleet’. The drivers differ, but the destination is the same: a fleet ar-



In a test as part of the NOMARS programme, the USV Mariner (right) deploys a refueling probe towards the USV Ranger (left) in the first test of fueling at sea (FAS) without any human interaction required on the part of the receiving vessel. The personnel aboard the Ranger are observers only (© DARPA)

chitecture in which unmanned systems, launched from motherships, deliver the reach, mass and persistence that conventional means alone cannot.

The US Navy, which coined the term, is building toward a fleet of 350 crewed ships alongside 150 large USVs. Its Modular Attack Surface Craft (MASC) requirement also gives a glimpse of the power burden, with containerised payloads expected to consume up to 75 kW each. “The Defence Investment Plan explicitly embeds both USVs and UUVs in the Royal Navy’s force architecture, with the First Sea Lord framing the shift around mass and lethality that neither budgets nor recruitment can deliver conventionally.” South Korea’s Navy Sea GHOST programme is driven by demographic pressure as much as technology ambition. Portugal launched Europe’s first purpose-built drone carrier, NRP D. João II, in 2025. And several navies, including the French, Belgian and Dutch navies, are preparing for advanced combined-domain MCM mothership capability, with each vessel designed to deploy USVs, AUVs, ROVs and UAVs as a single integrated mine warfare system.

The Royal Navy example shows how quickly this becomes a force-architecture problem. As Dr Beard explained, the hybrid navy concept is built around a mix of functions: sense platforms for air and subsurface threats, an effects platform and a command-and-control vessel tying the group together. That architecture promises more hulls in the water and greater mass, but it also multiplies demand. If the original ambition was to keep these systems at sea for 30 days, larger sensors, effectors and communications payloads mean more fuel, less range, or a harder design loop. For diesel or diesel-electric USVs, this raises an immediate logistics question. Larger platforms may deploy from shore

or with the task group, but if there are no friendly ports to refuel in, the fuel has to come with them. The issue then scales up to the mothership. If it is expected to support multiple unmanned systems, it must also absorb their energy demand without compromising its own propulsion, HVAC, weapons and sensors. At some point, this becomes less about buying UxVs than designing the group’s energy budget, as Dr Beard pointed out.

Battery-powered UUVs and smaller USVs do not make the problem disappear; they simply change its shape. Bringing them back onboard to recharge or hot-swap batteries sounds simple until the battery pack weighs tonnes, requires cranes, dedicated charging capacity and shipboard infrastructure that many vessels were never designed to host. Launch and recovery then becomes part of the endurance equation: if the vehicle can operate in a higher sea state than the ship can safely recover it in, it cannot reliably come back to refuel or recharge. And, as Adams warned, if an entire unmanned fleet depends on one host ship for charging, refuelling and recovery, that ship becomes “one massive single point failure” for the fleet.

From Energy Architecture to Operational Advantage

None of this means the challenge is intractable. Unplugged, OPT, NOMARS trials and ACUA Ocean’s hydrogen work all show that the energy problem is being attacked from multiple angles.

But the pace and shape of that movement will be driven as much by commercial operators as by defence requirements, and navies will still have to do the hard work of integration. “The main challenge is to see all of this as one coherent software stack, from the lowest node of the USV all the way up to the point where a human has to decide whether to employ deadly force,” Karlström concluded. It will also require standardization across many of the charging systems – think the equivalent of the one standard charging cable across Europe. The navies that crack that architecture first – energy, autonomy, logistics and command – will gain more than endurance. They will gain operational advantage.

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