

Going Electric Handbook

A Resource on Electric Outboard Motors

This document was produced by Rowing British Columbia as part of the RowElectric Pilot Project.

RowElectric 
Go Clean Go Quiet

The aim of the Row Electric pilot project is to accelerate the transition from gas to electric outboards by providing users with firsthand experience and reliable, relevant information on costs and performance.

Electric outboards reduce CO2 emissions and air, water and noise pollution, benefitting athletes and coaches, the community, the climate and the environment.

For more information, please visit

rowingbc.ca/rowelectric



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For more information on the *RowElectric* project, please visit
rowingbc.ca/rowelectric

The *RowElectric* Pilot Project

The purpose of the RowElectric project is to assess the feasibility of using electric outboards at rowing clubs, to collect data on performance and costs under “real world” conditions and to provide people with a chance to see and use electric outboards in real situations.

Rowing clubs use small tin runabouts, rigid hull inflatables (RHIBs) or catamarans, powered by 9.9-25 hp gas outboards, for coaching, officiating and safety. Coach boats are used year-round, for 1 to 3 sessions per day. Sessions are typically 1.5 to 2 hours long, with coach boats travelling 10 to 20 km per session, at average speeds of 10 to 15 km/h (5-8 knots). Top speed to keep up with the fastest rowing shell is about 24 km/h (13 knots). Coaching is notoriously hard on gas outboards, with lots of gear changes, stopping and starting, idling, multiple users and outside storage.

Rowing clubs want to know:

1. Will it go fast enough?
2. Will it last for a full session or a full day?
3. How long will it take to charge?
4. Is it reliable?

Five electric outboards (two 6 kW and three 12 kW) were mounted on 16’ catamarans at four rowing clubs in British Columbia. The outboards were installed in the Spring of 2024; preliminary data were collected from Spring 2024 to Fall 2025; detailed data collection began in Fall 2025 and will continue until the end of 2026.

For more information, please visit rowingbc.ca/rowelectric.



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Introduction

Electric outboards have been around for over 100 years, but until recently their use was limited by the capacity and weight of lead-acid batteries. Technological advances in lithium-ion batteries and innovations in motors and control systems are dramatically improving the performance and range of electric outboards, making them practical for a widening range of uses. Commercially available electric outboards now range from portable motors of less than 1 kW all the way up to 225 kW motors that deliver similar performance to a 250 hp gas outboard.

Electric outboards are being used on a wide range of boats, including rigid hull inflatables (RHIBs), pontoon boats, runabouts, workboats, cruisers and sailboats, and for a wide range of uses, including pleasure cruising, coaching, wildlife viewing, water taxis, and recreational fishing. The industry is in a phase of rapid innovation, with a growing number of manufacturers and a growing number of products commercially available or in development.

Interest in electric outboards is growing as range and performance improve, more models become available, and as boaters become familiar with the operation and advantages of electric vehicles of all types. Like their EV counterparts, electric outboards are clean, quiet, low maintenance and have low operating (fuel) costs.

This handbook is for anyone curious about electric outboards or exploring the idea of replacing a gas outboard with an electric outboard. It focuses specifically on outboards greater than 5 kW (rather than portable and trolling motors, inboards or stern drives) and shares information learned to date through the RowElectric Project.



Why Go Electric?

Quiet

Electric outboards are quiet — with less noise and vibration. The quiet, smooth ride gives a more relaxing, peaceful experience, allows for easier communication amongst passengers, reduces the impact on wildlife, reduces the risk of hearing damage, and reduces the overall physical fatigue that results from noise and vibration.

Clean

Electric outboards are cleaner than gas alternatives in several ways:

GHG Emissions

Electric outboards have no exhaust — meaning zero emissions of CO₂e. And in BC, where 98% of energy comes from renewable sources, emissions from charging batteries are negligible. In contrast, a 25 hp gas outboard running at full throttle for 1 hour will emit about the same amount of CO₂e as an SUV car travelling 100 km.

Air Pollution

As well as being smelly, the exhaust from gas outboards contains harmful air pollutants like carbon monoxide (CO), nitrogen oxides (NO_x), particulates (PM), ozone and volatile organic compounds (VOC) that contribute to smog and respiratory disease. And because gas outboards do not have catalytic converters, compared to cars, they emit significantly higher amounts of these pollutants per liter of fuel burned.

Water Pollution

Switching to an electric outboard eliminates the small gas leaks that inevitably occur during refueling, disconnecting fuel lines or from damaged fuel lines or fuel tanks.

Low Maintenance

Electric outboards are simpler than gas outboards with fewer moving parts and no combustion process. Unlike gas outboards which need regular service and winterizing, routine maintenance on most electric outboards is limited to inspecting connections for corrosion and lubricating cables and connections.

Low Operating (Fuel) Costs

Electric outboards are cheap to operate. It costs about \$14 to run a 25 hp gas outboard at full throttle for one hour¹ compared to about \$1.40 to run a 12-kW electric outboard.²

Long Lifespan

Electric outboards can have a lifespan of 10,000-30,000 hours or more. The batteries can last 8-10 years and 1000-3000 charging cycles before their capacity drops below 80%. In contrast, the average gas outboard will last around 1500-4000 hours before needing a major repair.

Responsive and Smooth

Electric outboards accelerate (and decelerate) quickly, feel more responsive, run smoothly even at low speeds and idle without difficulty. The smooth, precise controls and instant response make it easier to maintain a constant speed and to maneuver in tight quarters.

¹ Assuming 8.7l/hr, \$1.61/L

https://ycharts.com/indicators/vancouver_bc_average_retail_price_for_regular_unleaded_gas_oline_at_self_service_filling_stations

² 12kWh @\$0.1172/kWh

What are Electric Outboards Suited for?

Use is mostly determined by range and access to charging. Electric outboards are best suited for:

- Operating at low to moderate speeds.
- Shorter trips (say, less than 4-6 hours, depending on speed).
- Uses that involve lots of idling, slower speeds and changes between forward and reverse (e.g., coaching, near shore recreational fishing).
- Where quiet and clean operation are critical (e.g., on waterways where gas motors are prohibited, wildlife viewing).
- Where there are both access and time to charge between uses or to “top up” the battery (e.g., travelling between marinas or to a “mothership”, day use, coaching).

In general, electric outboards are less practical for going at full speed for extended periods or where access to charging is limited. This will likely evolve as battery and motor technology advances.

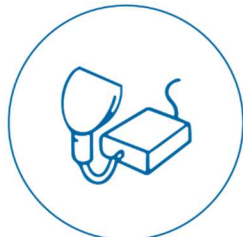
In determining if an electric outboard is right for you, understand and carefully consider your needs and how they fit with electric outboard technology.



Overview of Electric Outboard Motors

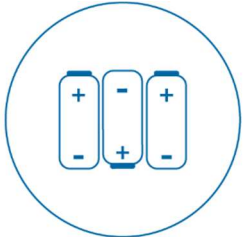
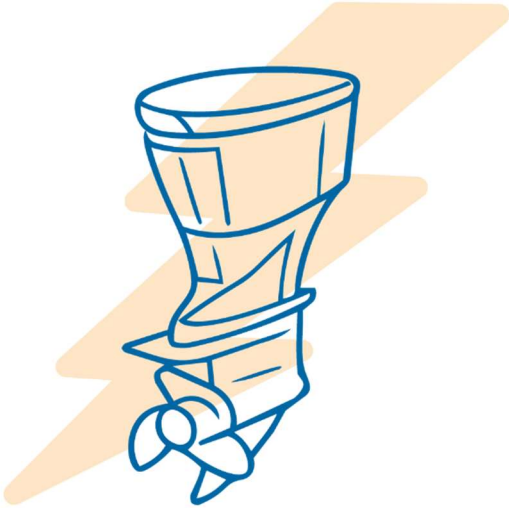
Components of an electric outboard system

An electric outboard *system* includes:



Charger

Electric Motor & Propellor



Battery Bank



Throttle (either tiller or remote), Display Unit, Cables, Accessories



Battery Management System

Some manufacturers sell all the components as an integrated system, whereas others sell only the motor, with users sourcing the other components separately.

How Do Electric Outboards Work?

Both electric and gas outboard motors convert stored energy into mechanical energy that rotates a shaft and turns the propeller. Gas outboards use the chemical energy stored in gas; electric outboards use electrical energy stored in batteries. In both systems, the throttle controls the amount of “fuel” (either gas or electricity) going to the motor.

Gas outboards generate force through internal combustion: repeated controlled explosions of a fuel-air mixture drives pistons, creating the force to rotate the shaft and propeller. The combustion process, as well as the movement of pistons and other parts, creates noise, vibration, heat, and exhaust. Electric motors work by electromagnetic forces that spin a rotor that is directly attached to a shaft. This way of generating force is inherently quieter, smoother and more efficient than gas outboards, with fewer parts, no exhaust, and less energy lost as heat.

Electric Outboard Configuration

Direct drive: the motor is housed in a waterproof casing at the bottom of the engine leg. It spins a horizontal shaft that is directly attached to the propeller. The vertical leg houses the wires that connect the motor to the battery. Direct drive systems are gearless and passively cooled. Most direct drive systems are 12 kW or smaller, as motors bigger than 12 kW create too much drag and turbulence to be mounted underwater.

L-drive: L drives are the familiar configuration of gas outboards where the motor is housed at the top of the leg. It drives a vertical shaft that then spins the horizontal shaft that is connected to the propeller. L-drives are more common with larger motors, and they have both cooling and gear systems.

Rim Motors: The propeller blades are attached directly to the motor, rather than to a central shaft. One of the advantages of rim motors is that the propeller blades are protected by the rim, minimizing the risk of entanglement in ropes or weeds. They also provide better, more precise maneuvering.

Smaller electric motors are available as both tiller and remote steered; larger motors are available at remote steered. Most electric outboards are available in several shaft lengths.

Understanding Power

Outboards are normally described in terms of their power. Boaters are familiar with how their boat performs with a gas outboard of specific horsepower (hp) and will be looking for an electric outboard that provides similar performance. The power produced by an electric outboard is usually defined in kilowatts (kW). Although both hp and kW are measures of power (where $1 \text{ hp} = 0.75 \text{ kW}$), comparing performance is a bit more complicated than simply converting hp to kW. Factors like torque, RPMs, motor efficiency, and prop design all affect performance. And gas outboards and electric outboards generate force differently. Gas outboards only deliver full power once they are operating at maximum engine RPMs, which takes a short time to achieve. In contrast, electric outboards have “instant torque” meaning they deliver full power right away.

An electric outboard will accelerate faster and more smoothly and operate better at low speeds but will have a lower top end speed than might be indicated by simply converting kW to hp.

To account for these differences, some manufacturers describe their electric outboards in terms of “horsepower equivalence”. This is an *estimate* of how the performance of the electric outboard compares to the performance of a gas outboard, considering differences in torque and efficiency. It is not a direct measure of power, and there is no standardization or consistency in how the term is used. It is best to use “horsepower equivalence” as a guideline only. As a rule-of-thumb, 6 kW is similar to 9.9 hp, 10 kW is similar to 20 hp, and 90 kW is similar to 120 hp.

To further complicate comparisons, there is no standardization of where power on an electric outboard is measured or how it is reported (unlike gas outboards, where regulations require that power is measured at the propeller). Some manufacturers report input power (the amount of power delivered to the motor) while others report output power (the amount of power delivered to the propeller). Manufacturers may report continuous power, peak power, or both.



Batteries

Advances in battery technology and chemistry have been a gamechanger for electric outboards. Lighter, more powerful lithium-ion batteries have dramatically improved runtime and performance, making electric outboards practical for a wider range of marine uses.

Batteries are defined by voltage, power, capacity, and chemistry, as well as weight and portability. Depending on the electric outboard maker, batteries may be bought as part of an integrated system or sourced separately.

Using a third-party battery gives you flexibility in battery choice; however, communications systems between a third-party battery and the motor may not be fully compatible, limiting the battery information that will be displayed.

Battery Specifications

Voltage (V)

Batteries are described in terms of their nominal voltage, e.g., 24 V, 48V, 96V. Low voltage batteries (48V or 24V) are preferred for smaller outboards (12 kW or less) because they are safer and less expensive, while still providing adequate power and runtime. High voltage batteries are used for more powerful electric outboards because they can deliver power more efficiently with a more compact design and can charge more quickly. The downside is that the higher risk of electric shock requires a more complex battery design, specialized materials and professional installation, making them more expensive.

Battery Power (W or kW)

Battery power is the rate at which the battery can deliver energy to the motor, measured in watts or kilowatts (W or kW). To get the maximum performance from your outboard motor, the battery must be able to deliver power about equal to the power that the motor draws. If the battery supplies less power than the motor draws, the motor will still work, but its performance (speed) will be limited. For example, to achieve its peak power, a 12-kW motor needs a battery that can *deliver* about 12 kW of power.

Battery Capacity (Wh or kWh)

Battery capacity is commonly given in watt-hours or kilowatt-hours (Wh or kWh). It is the total amount of energy a battery can store — analogous to the size of the fuel tank — and is a key determinant of runtime. For example, running a 12-kW motor at full throttle for one hour will require a battery capacity of at least 12 kWh.

Some systems allow multiple batteries to be connected *in parallel*, increasing the overall battery capacity. For example, two 5000Wh batteries connected in parallel will provide about 10,000 Wh (10 kWh) of energy. Modular systems provide flexibility in tailoring battery capacity to your needs (for example, allowing you to add a battery to extend your range) and allowing individual batteries to be lighter.

Battery Chemistry

Batteries store energy in chemical bonds and convert it into electrical energy. Battery chemistry refers to the combination of chemicals that make up the battery. Battery chemistry determines performance characteristics, including power, capacity, lifespan, safety, and cost.

Rechargeable lithium-ion batteries are the battery of choice for electric outboards because they can store higher amounts of energy. There are many varieties of lithium-ion batteries, but the two most used with electric boats are Lithium Nickel Manganese Cobalt Oxide (NMC) and Lithium-Iron-Phosphate (LFP). NMC batteries provide more energy per kilogram, allowing for more runtime and higher speed. LFP batteries, while providing less energy per kilogram than NMC batteries, are safer, have a longer lifespan, and are less expensive. LFP batteries are becoming the preferred choice for many boaters.

Battery chemistry and technology are continuing to advance rapidly and are expected to lead to even more improvements in battery performance and cost. Salt (sodium) batteries, solid state batteries, and aluminum air batteries are all under development although not yet commercially available. The cost of batteries is expected to come down as a result of both technological advances and increased production.

Weight

Weight depends on battery chemistry, voltage, and capacity. NMC batteries are more energy-dense than LFP batteries, meaning a 5000 Wh NMC battery will be lighter than a 5000 Wh LFP battery. A high voltage battery will be lighter than a low voltage battery with the same capacity. The table below gives some battery weights (as provided by manufacturers).

| | Battery Voltage | Battery Capacity | Kg per battery |
|-----------------------------|-----------------|------------------|----------------|
| Torqueedo 48-5000 (NMC) | 48V | 5000 Wh | 36 kg |
| E Propulsion E163 (LFP) | 48V | 8345 Wh | 76 kg |
| Mercury Avator (LFP) | 48V | 5376 Wh | 42 kg |
| E Propulsion G102-100 (LFP) | 96V | 10,240 Wh | 100 kg |
| Evoy Taiga | 350V | 28,000 Wh | 150 kg |
| Acel (LFP) | 400V | 43,000 Wh | 103 kg |

Determining Battery Size

It is now common for the motor, batteries, and charger to be sold as an integrated system where the components are designed to work together. Some systems give you the choice of different battery sizes and allow you to connect two or more batteries (of the same model) in parallel to increase total capacity. The optimal battery capacity depends on your desired runtime, how fast you want to go, and charging time. Dealers can help you determine the optimal battery capacity for your needs.

Battery Placement

Lithium-ion batteries should be placed in a cool, dry, well-ventilated location to protect them from overheating and water damage. Avoid a location where the batteries may end up sitting in water. If you anticipate using your boat in cold weather (below 5°C) you may want to consider a location that provides some insulation or that can be kept warm. The batteries should be firmly secured, so they don't move around, and protected from physical damage (such as someone stepping on them). Place the batteries so that the monitoring lights are visible and so that the batteries are accessible in case they need to be serviced or removed.

Trim and stability are important to consider when installing the batteries. Distributing the battery weight to achieve proper trim minimizes drag and boat wake and optimizes speed, fuel efficiency and handling. Situating the battery to achieve proper trim may require some trial and error as the total weight of the electric outboard system will likely be more than the total weight of a comparable gas

outboard and fuel, and the weight will be distributed differently. With gas outboards, most of the weight is right in the stern, in the motor itself whereas with electric outboards, the motor is lighter, but the batteries are heavy.

Battery Care and Lifespan

Lithium-ion batteries have a functional lifespan of 8-10 years and anywhere from 1000-3000 cycles before the battery capacity drops below 80%. This degradation is normal and unavoidable but can be slowed by proper battery care and use. The two most important things you can do are:

1. Avoid extreme temperatures during use, charging, and storage. Avoid charging at temperatures below 5°C or above 30°C (in order to protect the battery, most chargers will not work at temperatures below 0°C).
2. Avoid deep (full) discharge. Ideally, charge the battery before it gets to 20%. If you do fully deplete the battery, recharge it promptly.

Additional considerations:

Partial charge: generally, Li-ion batteries are happiest when they are less than fully charged. It's ok not to fully charge the battery after every use, particularly if you don't need the full capacity or if it is going to be unused for a little while.

Storage: If the battery is not going to be used for several months, it should be stored in a cool, ventilated space, at less than full charge. Check the battery periodically and charge it if the state of charge drops too low (check the battery manual).



Battery Safety

Manufacturers use a number of measures to mitigate the risk of battery fires.

Marine batteries are encased in a protective, “watertight” casing with an IP67 rating—meaning that they exclude all dust and particles and are watertight to depths of 1m for up to 30 minutes. The casing also protects the battery from physical damage. Sophisticated battery management systems are designed to protect the battery, shutting it down before it can overheat. Most systems now use Lithium-Iron-Phosphate (LFP) batteries, which are more thermally stable and safer than other lithium-ion batteries.

As a boater, it is important to choose high quality batteries designed for marine use and follow recommended installation, use and care instructions to protect the battery and minimize the risk of fires.

Battery Management System

The Battery Management System (BMS) is a critical component of the system: it monitors and manages the battery during charging and discharging, balancing the voltage and current of the individual cells that make up the battery, and monitoring temperature and other variables. The BMS is important for optimizing battery performance and lifespan and ensuring safe operation. The BMS is typically linked to a display that shows the state of charge, power consumption, speed, and other variables in real-time. The BMS may be a separate unit, or it may be built into the battery (called “smart batteries”).



RowElectric¹ Battery Placement

On three boats, the batteries and charger were installed in existing under seat storage, in the center of the boat. On two boats (where the under-seat storage was located too far forward), the batteries and charger were mounted in a resin deck box purchased for the purpose.

On one boat, it took a bit of trial and error to find the best spot for the batteries. This was probably due to the battery box being aligned crosswise (rather than fore and aft on the centerline), and the poor buoyancy of that boat design compared to the others (making it very sensitive to changes in weight distribution).

Charging

The charger is a separate unit that converts alternating current (AC) power from the electrical grid (either 110V or 220V) to direct current (DC) power that it delivers to the battery. It plugs into the battery at one end and a regular power outlet at the other end. The charger and battery are usually purchased together from the same manufacturer to ensure that they are compatible.

Where and How to Charge

The charger for larger outboards (more than 5 kW) is typically mounted on the boat, as the batteries are too heavy to remove easily for regular charging. Most marinas have shore power outlets mounted on pedestals on the dock — charging is simply a matter of plugging a power cord from the charger into the outlet on the dock. With boats that are stored on trailers, the charger can be plugged into any nearby GFCI outlet that provides the correct voltage and current. In situations where there is no easy access to charging near where the boat is stored, some 48V batteries are light enough (20-35 kg) to be lifted out and are designed with “plug and play” connections and handles, making it possible to remove them for charging.

Small electric outboards (e.g., less than 5 kW) have batteries that are light enough to remove from the boat for charging or in some models, the battery is integrated with the motor into one portable unit and charging can be done anywhere.

For safety, the charger must be plugged into a circuit that provides more current (amps) than the charger draws. So, a charger that draws 15 amps must be plugged into a circuit of 20 amps or more. Chargers are designed to plug into circuits of a particular voltage, with some chargers designed to work with both 110V and 220V circuits. Plugging a charger into a 110V outlet is analogous to Level 1 charging with an EV; plugging it into a 220V outlet is analogous to Level 2 charging.

Some batteries are designed to be compatible with DC fast charging, where the DC shore charger plugs straight into the battery, bypassing the AC charger (analogous to Level 3 fast chargers with EVs). DC “fast chargers” are still relatively uncommon in Canada.

Some batteries can be charged using solar panels. Because solar charging is slower than charging through the electricity grid, it is most practical for small capacity batteries, for “topping up” the battery charge while underway, or where there is space for a large array of solar panels.



Charging Speed and Time

Charging speed is affected by:

1. The size (capacity) of the battery. Larger capacity batteries store more energy and so will take longer to charge.
2. Initial state of charge. The lower the state of charge, the longer it will take to charge up to 100%. Also, charging slows down as the state of charge approaches 100%. So, a battery will take longer to charge from 90% to 100% than from 50% to 60%.
3. The power delivered by the charger (W or kW). A higher-powered charger delivers energy faster than a lower-powered charger.
4. Number of chargers per battery. Connecting two chargers *in parallel* will increase the total current (amps) and reduce charging time.
5. The voltage of the circuit (outlet) the charger is plugged into. A 220V circuit will allow faster charging than a 110V circuit, *provided the charger is compatible with 220V*.
6. Voltage drop. As a result of resistance, voltage drops as current travels along the cable from the outlet to the charger. Voltage drop can be reduced by minimizing the length of the cable or by using thicker gauge, better insulated cable.
7. DC (fast) chargers. DC chargers are significantly faster than AC chargers because they deliver current directly to the battery, bypassing the inverter, and generally have a much higher power output.
8. Temperature. Batteries will not charge when the temperature is below 0°C. Chargers are designed to shut off at temperatures below 0°C to avoid damaging the battery.

Charging time can be roughly estimated by dividing the battery capacity (in Wh) by the power of the charger (in W). Keep in mind that the *actual* charging time will be a bit longer because the charging rate slows down as the battery gets full, and is affected by battery health and temperature.

charging time (hrs) = battery capacity (Wh)/ charger power (W)

The table below gives some examples of charging times (published on manufacturers' websites).

| Charger | Circuit Voltage | Battery Capacity | Estimated Charging Time |
|---------------------------------------|-----------------|------------------|-------------------------|
| Torqeedo 2900 W fast charger | 220V | 5000 Wh | < 2hrs |
| Torqeedo 650 W charger | 220V | 5000 Wh | 14 hrs |
| EPropulsion 25A charger | 220V | 8345 Wh | 7.2 hrs |
| EPropulsion 25A charger | 110V | 8345 Wh | 11 hrs |
| Mercury Avator 520 W portable charger | ? | 10,800 Wh | 20 hrs |
| Acel Smart Charger | DC | 43kWh | < 1 hr |

Charging Safety

Water and electricity can be a dangerous combination, leading to short circuits, fires, and electric shock. The risk can be mitigated by following common safety procedures.

- Chargers should only be plugged into GFCI outlets. A GFCI (Ground Fault Circuit Interrupter) outlet shuts off power to the circuit when it detects a ground fault, protecting against short circuits, fire and electric shock. GFCI outlets are commonly used in wet or damp areas.
- Use marine-grade shore power cords that are designed for wet conditions. Shore power cords use waterproof twist-lock connectors that ensure a secure connection and keep water out.
- Regularly inspect the plug and receptacle for discoloration that may indicate corrosion or short circuiting. Replace damaged plugs or receptacles.
- Don't let the cord fall in the water (or sit in puddles). If it falls into salt water, rinse it thoroughly with fresh water and dry it well.
- Make sure there is some slack in the cord (to avoid undue tension on the connectors) and that the cord can't get pinched (e.g. between the dock and the boat).

- Always disconnect the shoreside of a power cord first. Do not leave the cord plugged into the shore power outlet when it is not being used.
- Make sure the voltage supplied by the outlet matches the voltage used by the charger. And make sure the combined current (amps) drawn by all devices plugged into an outlet does not exceed the current (amps) of the outlet. For example, two chargers that each have a peak draw of 16 amps should not be plugged into a 30-amp circuit.

RowElectric Charging

With all four pilot clubs, the charger is mounted in the boat and plugged into a shore power outlet on the dock for charging. At two locations, it was necessary to run electricity to the dock and install shore power outlets; the other two clubs had shore power at the top of the dock that was extended and upgraded. Two clubs use 220V power and two clubs use 110V power.

The chargers are mounted in the box with the batteries or in the box that forms the aft passenger seat.

At all four clubs, the batteries are normally charged every two or three sessions, overnight. This fits well with the routine at all four clubs. If there has been heavy use during a session and another session is planned for later in the day, the charge may be topped during the day. Charging time has not constrained use.

One location experienced problems with the circuit tripping and interrupting charging. The suspected problem was corrosion and water damage to the extension cord. Users had been leaving the extension cord plugged into the outlet and laying on the dock exposed to the weather when they unplugged it from the charger. The problem was resolved by buying a shore power cable with waterproof twist lock connectors, installing a post to hang the cable and plugging it into a “dummy outlet” when not in use.

There have been a few instances where the air temperature dropped below freezing, causing the charger to switch off (to protect the charger and the batteries). Charging resumed with no issue when the temperature warmed up.

A word about shore power outlets

Boaters are accustomed to hooking up to shore power to run electrical systems and charge their batteries when they are at the dock. Shore power outlets may supply 110V or 220V, and most marinas provide both 30 A and 50 A service. Plugs and receptacles can have different configurations, depending on the maximum amperage they are rated to carry (e.g., 15 A, 30 A, 50 A) and whether they are designed to supply 110V or 220V. You can buy pigtail adaptors that allow you to plug a 15 A charger into a 30 A receptacle.

Operation

Operating an electric outboard is much simpler than a gas outboard. Turn the system on, allow a short time for the system to initialize, and then turn the motor on. Unlike a gas outboard, there is no choke and the engine does not need to be warmed up. Engage the throttle to go forward or reverse. There is no shifting lever, and no need to throttle down before going into reverse. Charging simply requires turning the motor off (but leaving the system on) and plugging the charger into the shore power outlet.

Performance

Performance (particularly speed and range) is strongly affected by hull design, weight, wind and water conditions and other factors that affect drag. The weight and shape of the boat matter — a lot. Keep this in mind when comparing reported range and speed. (Manufacturers will sometimes include the type of boat and testing conditions when they report range and speed.

Acceleration: Electric outboards are sometimes described as having “instant torque”— they can deliver maximum force immediately. In contrast, gas outboards need time to “rev up” (increase the RPMs) before they can deliver maximum force. Instant torque means that electric outboards accelerate (and decelerate) more quickly and smoothly than gas outboards. For a planing hull, faster acceleration means the boat will get up on plane faster.

Responsiveness and Handling: Instant torque also means that electric outboards feel more responsive than gas outboards and run smoothly even at low speeds or when idling. The smoother throttle control makes it easier to maintain a constant speed and to maneuver in tight quarters. Instant torque and no transmission also mean that you don't need to "throttle down" to reduce the RPMs before shifting from forward to reverse.

Speed: Power is a combination of torque (rotational force) and RPMs. Higher RPMs translate to higher speed. Generally, electric outboards operate at higher torque and lower RPMs, while gas outboards operate at lower torque and higher RPMs. This means that electric outboards perform well at lower speeds while gas outboards perform better at high speeds, and an electric outboard will not deliver the same top end speed as a gas outboard of similar power but it will achieve its top speed faster. On the other hand, advances in motor and battery technology mean that electric outboards are now capable of high speeds. For example, a 5.4 m RHIB powered by a 90-kW electric outboard can hit a top speed of 35 knots and cruise at 20 knots.

Runtime: Runtime is determined by battery size and charge, throttle (e.g., full throttle, half throttle) and engine size. A boat with a 10-kW electric outboard and a fully charged battery of 10 kWh can run for about one hour at full throttle. At half throttle, it would use about 5 kW and could run for 2 hours. Most systems are designed with the goal of providing about one hour of runtime at full throttle.

Range: Range describes how *far* a boat can go and is determined by battery capacity (how much "fuel" there is) and fuel efficiency. Fuel efficiency is determined by hull design, speed, weight, wind and water conditions, and other factors that increase drag. Range will be reduced in headwinds or rough conditions and when travelling against the current, at high speed, or with extra weight. Even things like algae growth on the hull create drag and decrease range. Driving behaviour also affects fuel efficiency and range just as it does with EVs and gas vehicles. High speeds, fast and frequent acceleration, and operating at speeds that are suboptimal for the hull shape will all reduce range. Because of all the variables that affect range, it is more useful to compare runtimes rather than range.



RowElectric Performance

Speed

Will I be able to keep up with crews? This was one of the key questions coaches had about using the electric outboards. The simple answer is yes. The fastest men's eight crew has a top speed of around 22-24 kmh. With one person on board the catamaran powered by a 12-kW motor had a top speed of 28 kmh. Speed was affected by load, with top speed dropping to 25 kmh with 2 people and 22 kmh with 3 people – still fast enough to keep up with crews.

The boat powered by a 6-kWh motor had a top speed of about 24 kmh with one person onboard and about 22 kmh with 2 people. These speeds are suitable for coaching club level crews although they may not be fast enough for varsity or elite crews.

Coaches sometimes want to go faster than 24 kmh, for example to catch up to a crew or to quickly reach a crew in trouble. Coaches noticed that the electric boat was not quite as fast as a gas-powered boat in these situations but was still adequate.

Acceleration

The quick response and fast acceleration were especially helpful when coaching crews practicing short “starts”. The electric outboard was able to keep up with the crew immediately, allowing the coach to see the entire start sequence from close range. With gas outboards, there is a lag before the engine hits maximum power, resulting in coaches getting “left behind” as crews accelerate away.

Range (Runtime)

What is the range- will I get through a full training session? Will I get through a full day (sometimes 2-4 sessions)? This was the second key question coaches had. Again, the answer was yes for all four clubs. Coaches soon stopped worrying about range. Training sessions used 10%-40% of the battery capacity, with 15-20% being typical. Coaches plugged the charger in after the last session of the day, and the batteries were fully charged and ready to go for the first session the next morning. Sometimes the battery would be “topped up” during the day after a longer than normal training session.

Range was enough for even the most demanding training session to date. For example, during one session the boat was out for an elapsed time of two

hours (about 1 hour and 45 minutes of moving time), covered 20 km, and used 62% of the battery capacity (6.6 kWh).

Other Performance factors

Coaches noted that the heavier total weight of the electric system limited the number (or total weight) of passengers they could carry, as well as reducing top speed and range.

The electric outboard seemed to struggle more in the thick weed patches found at one of the lakes in the summer. Mats of weeds get caught around the propellor on both gas and electric outboards, but the problem seemed worse with the electric outboard. This was likely due to weed getting caught on the “pod” housing the motor, although differences in prop size and shaft length may have also contributed.

Umpire Boats

Probably the most demanding use of the electric outboard was as an umpire boat during regattas. During club level regattas, the umpire boat, with a driver and one or two umpires, follows a 2000m race at a speed of about 10-16 kmh, then drives back up to the start at about 20-24 kmh for the umpire’s next scheduled race. The umpire boat is usually stationary at the start for about 5 minutes as the rowing shells are lined up, before starting off again.

The 12-kW electric outboard with 10,000 Wh battery capacity and carrying two people used 83% of its battery capacity (8300 Wh) to complete a 4 ½ hour shift. The boat travelled a total distance of 29 km, moving for a total of 3 hours at an average speed of about 10 kmh.

The electric outboard offered several benefits as an umpire boat:

- The smooth, precise throttle made it easier for the driver to establish and maintain a consistent speed and stay in position when following crews.
- It was easier for the driver to hear the umpire’s directions and for the umpire to hear radio communications.
- The umpire boat was able to get close behind the crews quickly off the start — something gas outboards often struggled to do — allowing the umpire a better view and control of the start of the race (when collisions are most likely to occur).
- Idling and holding the boat in position waiting for the next race was much easier.
- Overall, the quiet, smoother and easier control of the electric outboard reduced the level of mental and physical fatigue felt by the umpires and volunteer drivers.

Safety

It is normal to have questions about the safety of electric outboard systems, given the hazard posed by the combination of electricity, water and lithium-ion batteries and news reports of battery fires. Keep in mind that both gas and electric outboards come with safety risks. Gas is highly flammable and explosive. Fuel leaks from overfilling fuel tanks, damaged or improperly closed fuel tanks, damaged fuel lines, and when disconnecting fuel lines are all common occurrences. Boaters are familiar with and accept the risks of transporting, storing, and using gas. The key question is not “*are electric outboards safe*” but rather “*how does safety compare to gas outboards, and can the risks be mitigated*”?

With electric outboards, the main risk is battery damage from water or overheating, leading to a battery fire. Electric outboard systems and batteries incorporate sophisticated safety measures to reduce the risk of damage. Marine batteries are encased in a protective, “watertight” casing with an IP67 rating. The casing also protects the battery from physical damage. Sophisticated battery management systems are designed to protect the battery, shutting it down before it can overheat. And Lithium-Iron-Phosphate (LFP) batteries, which are more thermally stable and safer than other lithium-ion batteries, are becoming the battery of choice for marine use.

Shore power outlets, plugs and cables also carry a risk of fire and electrical shocks if not handled and maintained properly. This is true for any electrical system, particularly in the damp marine environment — it is not unique to the electric outboard system.

As a boat owner, you can minimize risk by:

- Choosing high quality batteries with a good Battery Management System.
- Choosing LFP batteries.
- Mounting batteries in a ventilated location, protected from physical damage and from sitting in water.
- Following operating, safety and maintenance instructions provided by the owner’s manual.
- Following normal safety precautions for use of electrical cables in marine environments:
 - use outlets with Ground Fault Circuit Interrupters (GFCI),
 - ensure secure, weatherproof connections (e.g., twist lock connections and outlet covers),
 - disconnect power at the shore side first, route the cable so it doesn’t fall into the water regularly inspect cables, plugs and outlets for signs of corrosion.

Maintenance and Repairs

Servicing

Gas outboards have ignition, combustion, transmission and cooling systems, all of which require regular maintenance and winterizing. In contrast, electric outboards have few moving parts and no combustion process to create heat and vibration. Regular maintenance is typically limited to inspecting connections for wear or corrosion, lubricating moving parts, and replacing the galvanic anode as needed. Larger motors (more than 12 kW) may have cooling or gear systems that require periodic servicing, such as changing the gear oil or replacing the water impeller. To maintain optimal efficiency and performance, the prop should be checked for damage and cleaned to remove algae growth or weeds wrapped around it. As with any electrical system in a marine environment, plugs and shore power outlets should be checked regularly for signs of corrosion or damage.

Extending Battery Life

To extend battery life: 1) avoid extreme temperatures during use, charging and storage and 2) avoid deep discharges. If the battery is not going to be used for several months, it should be stored in a cool, ventilated space, at less than full charge. Check the battery periodically and charge it if the state of charge drops too low (check the battery manual).

Error messages and Troubleshooting

The Battery Management System (BMS) is designed to detect problems and in some cases will protect the system by shutting it down. When issues or abnormal conditions are detected, the control system will display an error code or warning message. User manuals or displays generally provide a list of error codes, what they mean, and what action to take. Sometimes the solution is as simple as rebooting the system, checking and cleaning connections, or allowing the battery or charger to warm up or cool down to the correct operating temperature. In other cases, the batteries may need to be reset or rebalanced, or with more serious issues you may need to contact customer support or an authorized service center. Marine electricians can provide valuable support in troubleshooting and resolving electrical and communications issues.

RowElectric¹ - The Rowing Experience

Coaching is hard on motors with a lot of stopping, starting, idling, frequent gear changes and changes in speed. Boats are used year-round, often in cold, rainy conditions and by multiple users. They are stored outside, exposed to rain and sun. With gas outboards, problems starting and idling, water in the fuel line, failing seals, dirty carburetors and worn transmissions are all common problems. In the RowElectric pilot, the two biggest issues with the electric outboards have been broken propellers and the batteries getting too cold during a three-week period where temperatures dropped to -5°C .

Broken propellers: Altogether pilot clubs have broken nine propellers in two years by hitting submerged logs or rocks. Whereas metal propellers get dented and banged when they hit things, the Torqeedo propellers are made of resin that chips or shatters. Although the props are easy to replace, they are expensive and must be ordered from the distributor rather than purchased locally, resulting in more downtime for the boat. To minimize downtime, some clubs are now stocking spare propellers to have on hand. We are also investigating options including using third party metal propellers or 3D printing a propeller locally (at lower cost).

Cold Weather: Lithium-ion batteries do not work well at low temperatures and according to documentation will not work at all if they drop below -10°C . If the batteries get too cold, the BMS will shut them down to avoid damage. If that happens, the batteries need to be warmed up to $+5^{\circ}\text{C}$ before they will work again. During a three-week cold snap when air temperatures reached lows of -5°C , four of the boats displayed error codes indicating the batteries were too cold, although the motors continued to work. Suggestions for keeping the batteries warm to avoid this problem include mounting them in an insulated location, using a heat lamp or heating pad (when they are not running) or bringing the boat or batteries inside. If you do use an external heat source, it is important that the batteries don't get too hot (e.g., use a heating pad that doesn't get too hot and do not place the batteries directly on it). Some lithium-ion batteries come with an internal heater.

Battery Imbalance: Two of the systems experienced "battery imbalances". This required disconnecting the batteries, charging each on separately and then reconnecting them. The cause of the battery imbalance was not identified.

Water Egress: one motor experienced a catastrophic failure when an O ring failed, and water got into the motor. It was sent back to the service centre and replaced under warranty. The O ring may have been damaged when the prop became entangled in a high-tension steel cable.

Cost

Electric outboards have higher upfront costs but lower operating costs than gas outboards. The upfront cost is largely determined by the size and sophistication of the motor and by the battery capacity, with the battery bank making up about one-third to one-half the total price. In comparing costs, be aware of what components are included, and the battery capacity, to make sure you are comparing apples-to-apples.

The payback time for an electric outboard will depend on how much it is used: because of the substantially lower operating costs, more use will mean it takes less time for the savings in operating costs to offset the higher purchase cost. The upfront cost of an electric outboard is also spread out over a longer lifespan, further reducing its lifecycle cost.

| | | | |
|--|-------------------------------|---------------------------------|---------------------------------|
| Electric Outboard (including motor, batteries, charger, throttle etc.) | ~ 6 kW motor 8 kWh battery | ~ 12 kW motor 10 kWh battery | ~ 40 kW motor 32 kWh battery |
| Purchase Cost | ~ \$15,000 - \$18,000 | ~ \$30,000-\$35,000 | ~ \$50,000 |
| Fuel Cost (\$0.1172/kWh) | ~ \$0.94 | ~ \$1.17 | ~ \$3.75 |
| Gas Outboard (motor only) | 9.9 hp | 25 hp | 50hp |
| Purchase Cost | ~ \$4,000 | ~ \$5,900 | ~ \$10,500 |
| Fuel Cost (\$1.61/l) | ~ \$6.44 | ~ \$14.00 | ~ \$30.00 |

Fuel cost for one hour of runtime at full throttle.

The RowElectric project will explore the relative costs of electric and gas outboards in more detail later, using data collected on fuel consumption and maintenance and repair costs.

Electric Outboards: Glossary

Amp hours (Ah): a measure of how much current flows in one hour (or how much current a battery can deliver in one hour). Some batteries specify Ah but not kWh. To determine the total amount of energy a battery can provide: $kWh = (Ah \times V)/1000$

Amps: a measure of current - the flow of electrons (electrical charge).

Axial flux: a type of electric motor where the flux is parallel to the shaft, sometimes called “pancake” motors because of their shape.

Charge amps: the amount of current that a charger can deliver to the battery. Higher amps mean faster charging.

Charge voltage: the voltage that is applied to the battery during charging. Overcharging (where the voltage supplied to the battery exceeds the battery’s capacity) can damage the battery; undercharging (where the voltage is too low) can lead to incomplete charging and reduced battery life.

Continuous power: the amount of power the motor can generate for a sustained period, without overheating or sustaining damage.

Current (AC and DC): Direct Current (DC) is when the electrons (current) flow in one direction; Alternating Current (AC) is when the direction of the flow of electrons (current) changes periodically. Batteries provide DC; most power outlets provide AC. To charge the battery, the AC from the outlet is converted to DC (through an inverter) before it gets to the battery.

DC Brushless: a type of DC electric motor that uses an electronic controller rather than brushes to switch the current.

Horsepower (hp): a measure of the power produced by an engine. Horsepower describes the amount of work that is done in a unit of time or how *quickly* the force is applied.

Input power: the amount of (electrical) power going into or used by the motor.

Kilowatt (kW): a measure of power, in this case the power produced by an electric motor.

Kilowatt hours (kWh): a measure of energy, commonly used to measure energy consumption. kWh expresses the total amount of energy stored in a battery or the total amount of energy used by an electric motor.

Nominal voltage: the “standard” or “named” voltage (e.g., for a battery). The nominal voltage is used to match different components of the system (e.g. the battery and the charger).

Output power: the amount of (mechanical) power generated by the motor to spin the propellor.

Peak power: the maximum amount of power the motor can generate for a short burst. High peak power allows for quick acceleration.

Permanent Magnet Synchronous Motor (PMSM): a type of electric motor that uses AC current and permanent magnets. PMSM motors are more efficient, lighter and more compact but more expensive than induction motors.

Power: how much work is done or energy is transferred in a unit of time. Power is measured in Watts (or kW). Electrical power is commonly expressed in W or kW; mechanical power is commonly expressed in horsepower (hp). $1 \text{ hp} = 0.75 \text{ kW}$

Radial flux: a type of electric motor where the flux is perpendicular to the shaft. Radial flux motors are the older, more established technology.

Specific energy (Wh/kg): the amount of energy stored per kg. Batteries with higher specific energy will be lighter (for a given amount of energy that they store).

Torque: the twisting force that causes something (e.g., like the shaft of a motor) to rotate.

Transverse flux: a type of electric motor where the flux follows a complex 3D path. Transverse flux motors are the newest, most complex and expensive of the three types but they provide the most power per kg.

Voltage: the difference in electrical potential between two points in a circuit. It is the “pressure” or force that pushes electrons through an electrical circuit, like water pressure. Household circuits in North America are either 110V or 220V.

Watts (W or kW): a measure of electrical power- or the *rate* at which electrical energy is transferred or used. When comparing motors $1 \text{ hp} = 0.75 \text{ kW}$ and $1 \text{ kW} = 1.34 \text{ hp}$.

Work: the transfer of energy (by a force) that causes an object to move. So work is done when the electrical energy from the battery is used to make the rotor in a motor turn.