gempacs

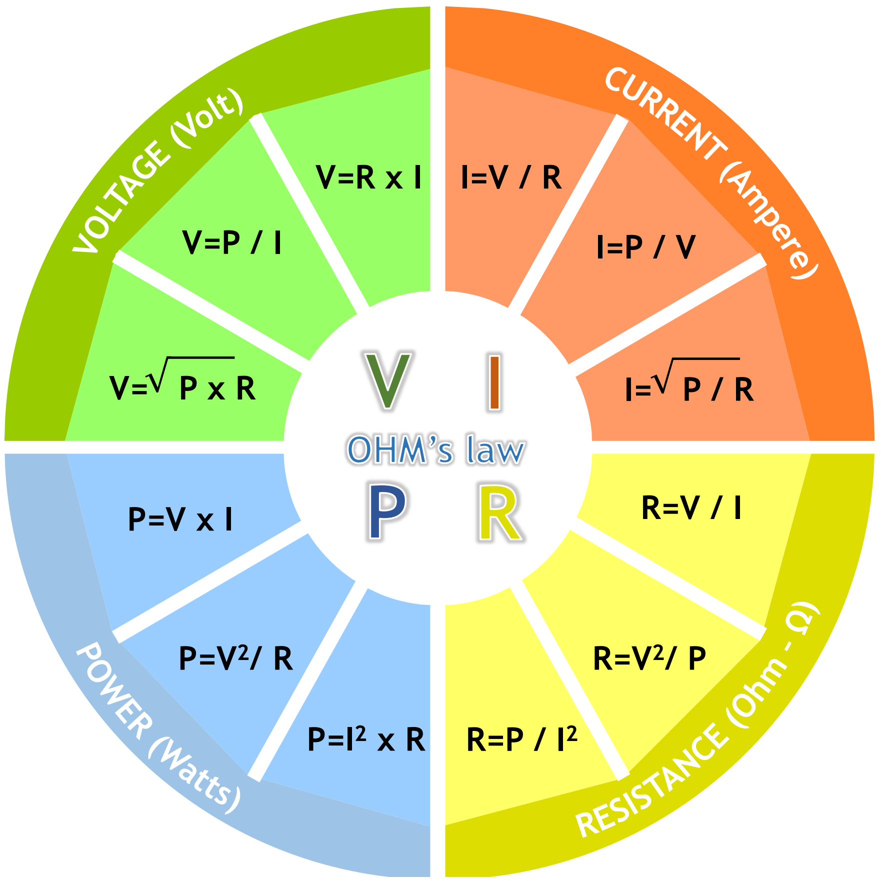
Electric Propulsion & Electric Boats

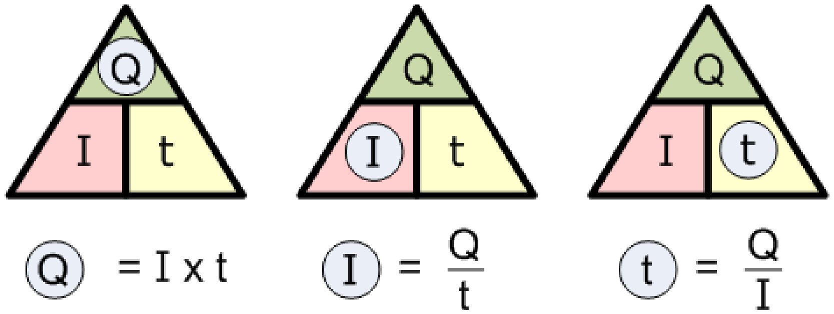
Version 2.5

The Basics…

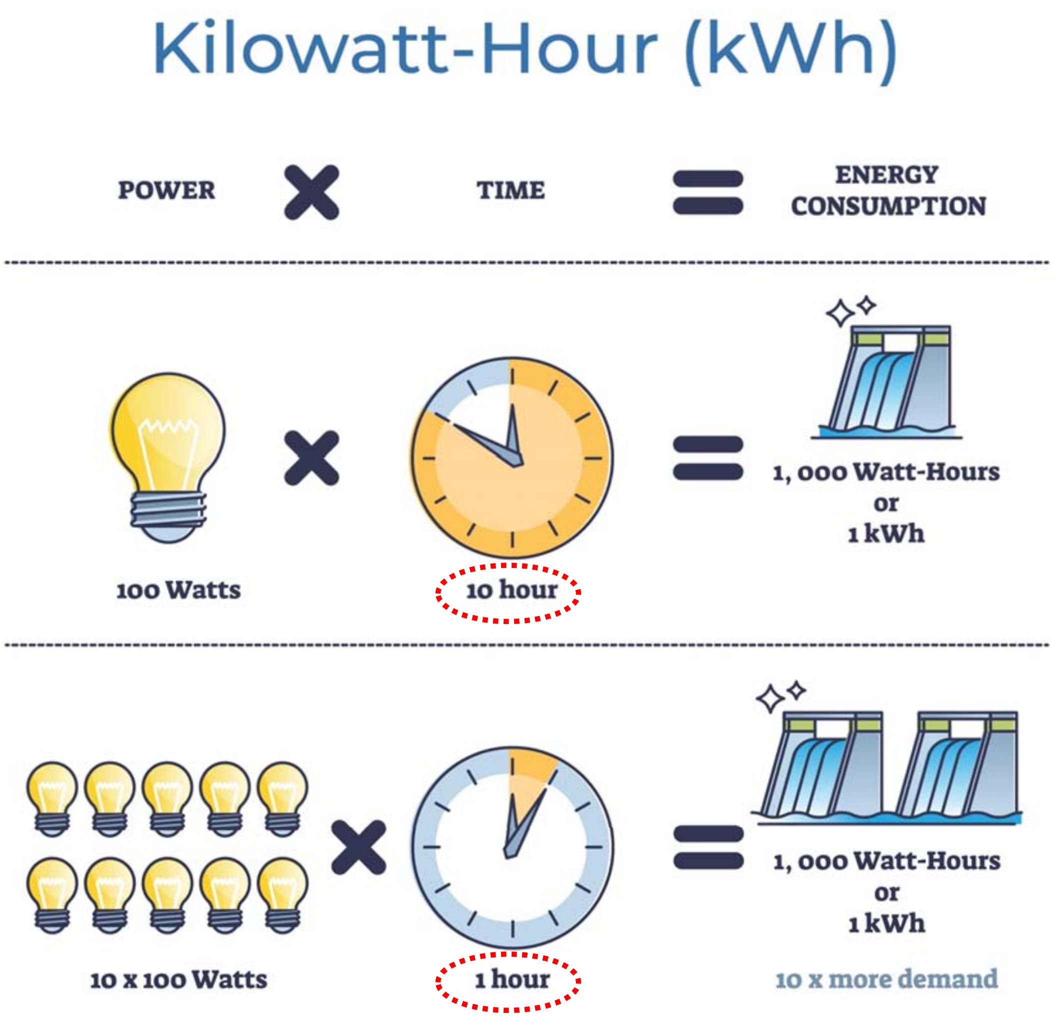
Measurement units:

• Quantity of Charge	Q	- Coulomb	C
• Voltage	V	- Volt	V
• Current	I	- Ampere	A
• Resistance	R	- Ohm	Ω
• Inductance	L	- Henry	H
• Capacitance	C	- Farad	F
• Power	P	- Watt	W
• Energy	E	- Watt Hours	Wh
• Volt	=	Joule / Coulomb	
• Ampere	=	Coulomb / second	
• Watt	=	Joule / second	
• Watt second	=	Joule	
• Watt hour	=	3600 Joules	





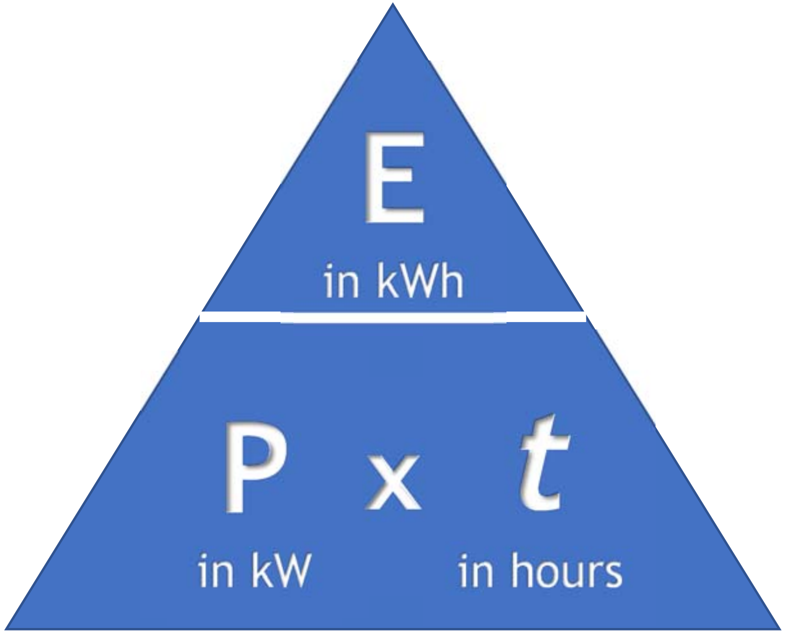
Electrical Power and Energy



Speed = How many km **in** 1 hour

Speed = 18 km/h
Time = 4 hours
Distance = ? km

distance = speed × time



Energy = How many Watts **per** hour

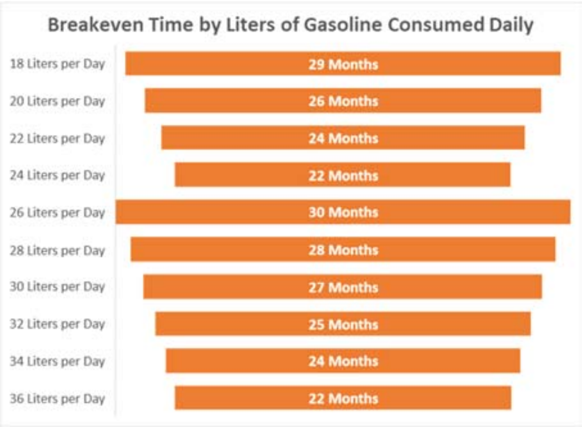
Liters of Gasoline versus kWh of Electric Energy

1 Liter of Gasoline ≈ 1.2 kWh
of Propulsion Energy

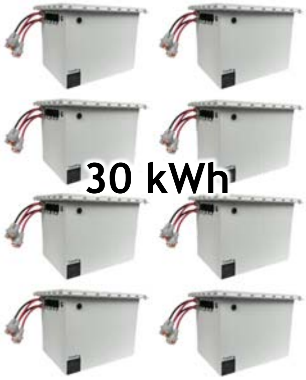
25 Liters of Gasoline ≈ 30 kWh of Propulsion Energy

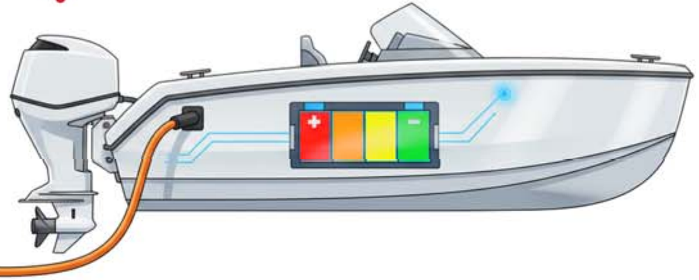
25 Liters of Gasoline cost is between 15 and 19 USD in Indonesia

30 kWh of Electric Energy cost is between 2.5 and 4 USD in Indonesia



Equivalent to 8 Battery Packs of 4 kWh each

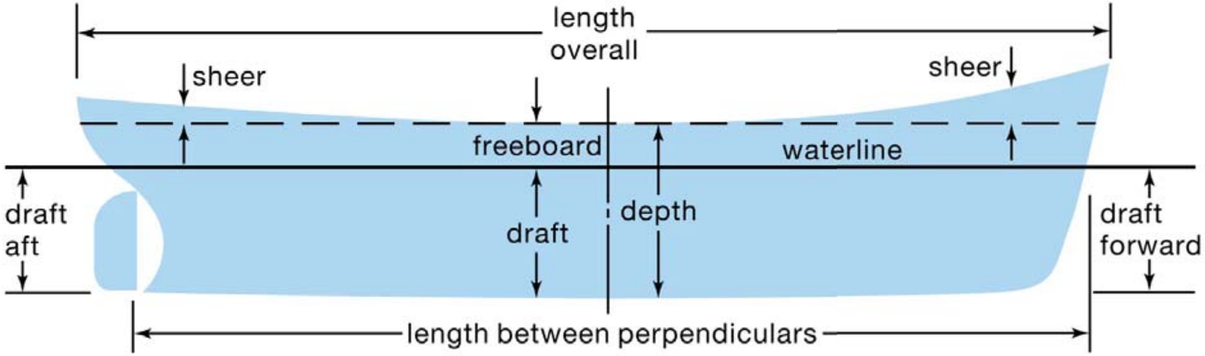


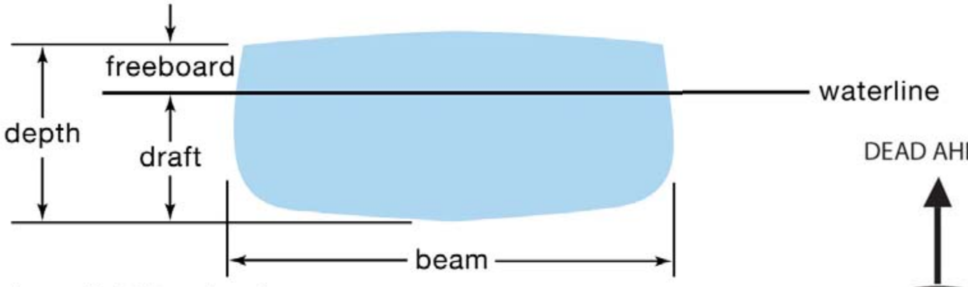


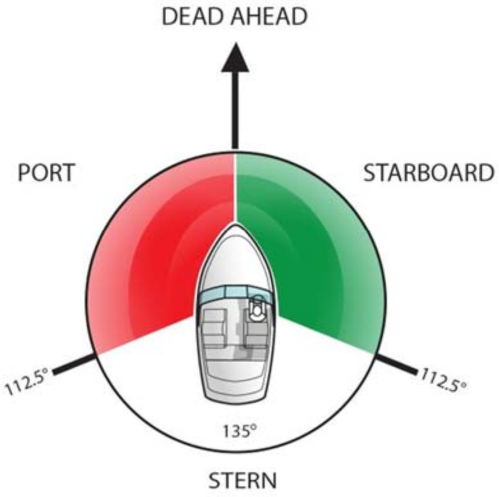
Switching to Electric Energy is 5 times cheaper than running on Gasoline
and it pays back the Battery cost in less than 3 Years

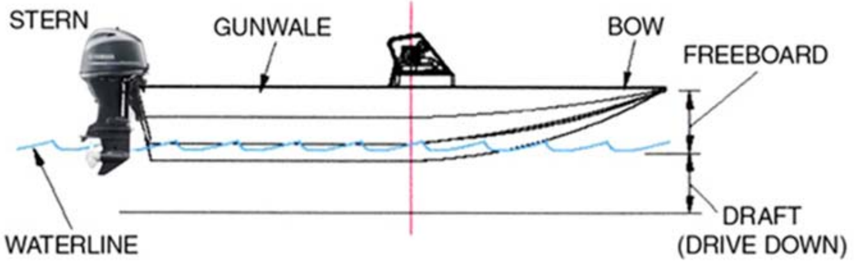
Hulls & Propellers

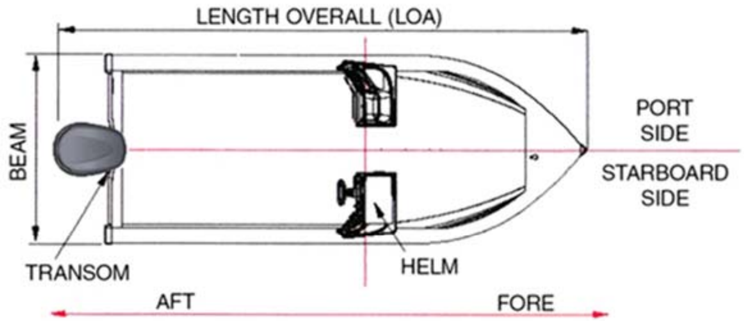
Boat Hull Terminology

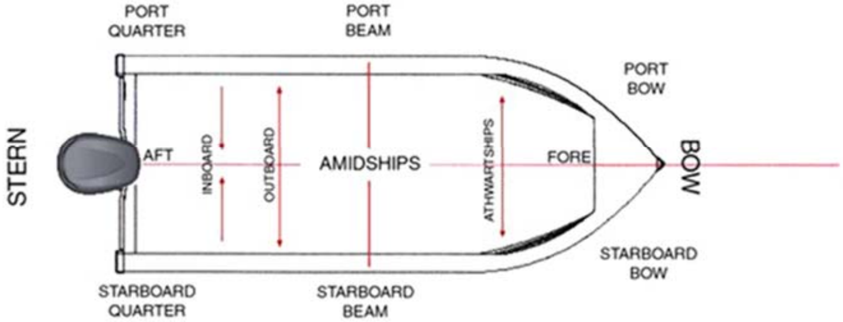




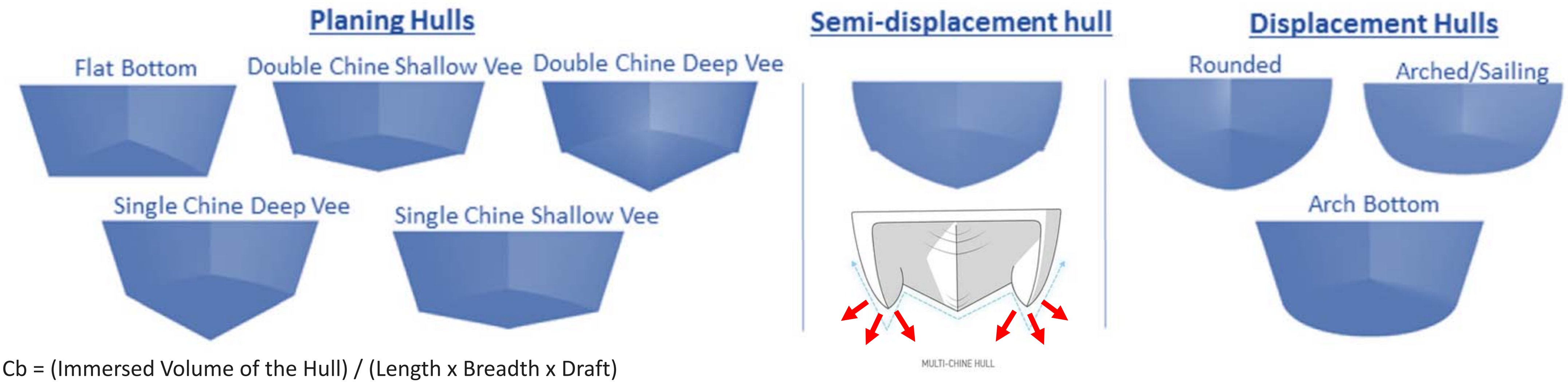




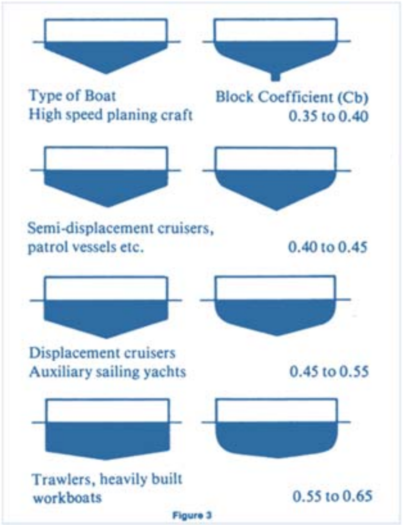


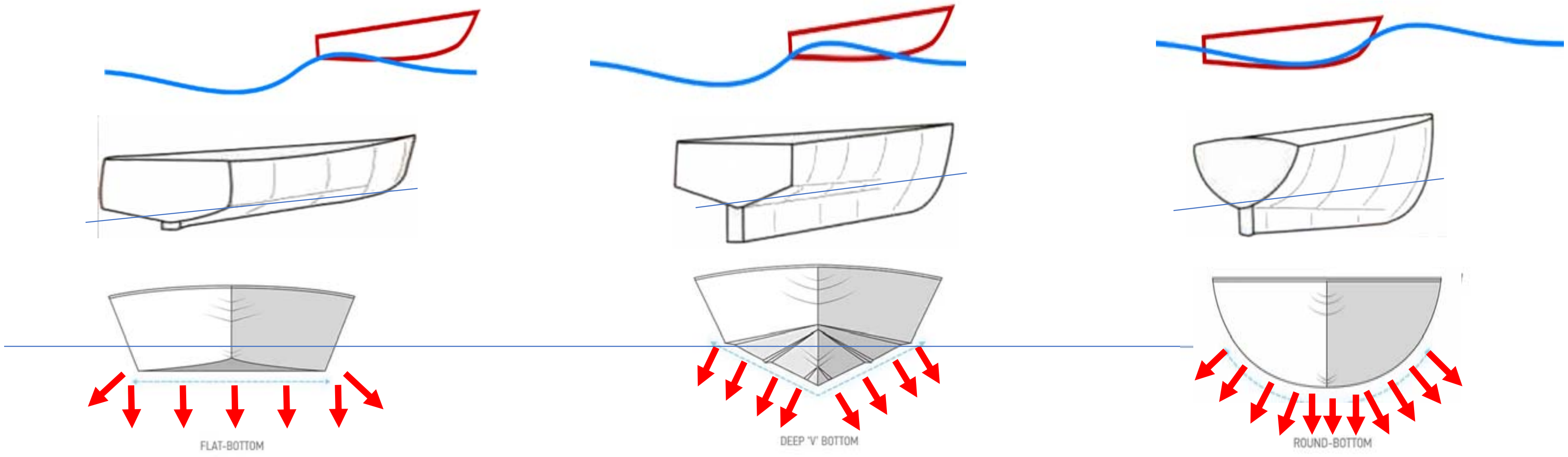


Hull Types

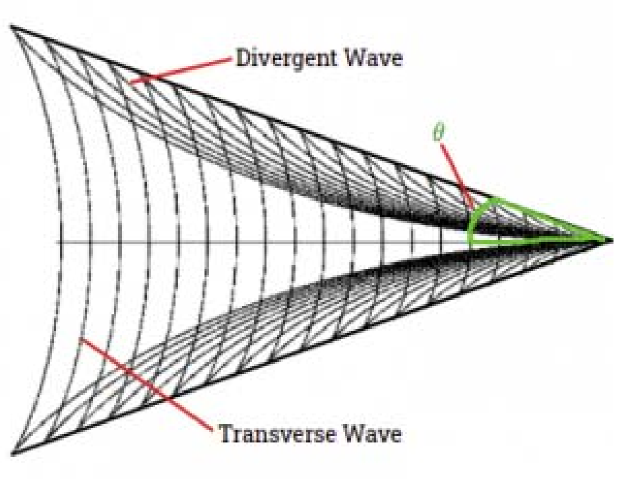


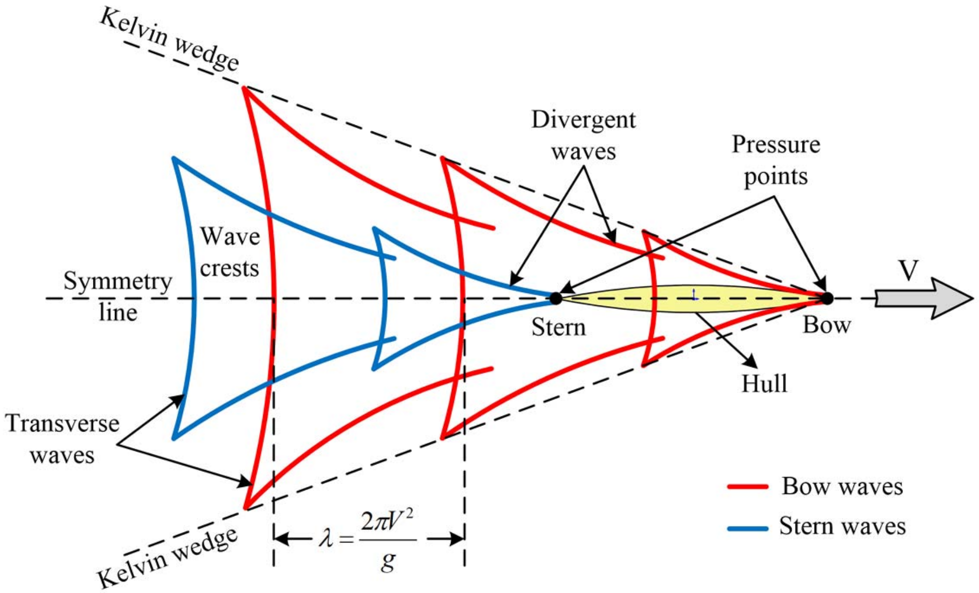
Cb = (Immersed Volume of the Hull) / (Length x Breadth x Draft)

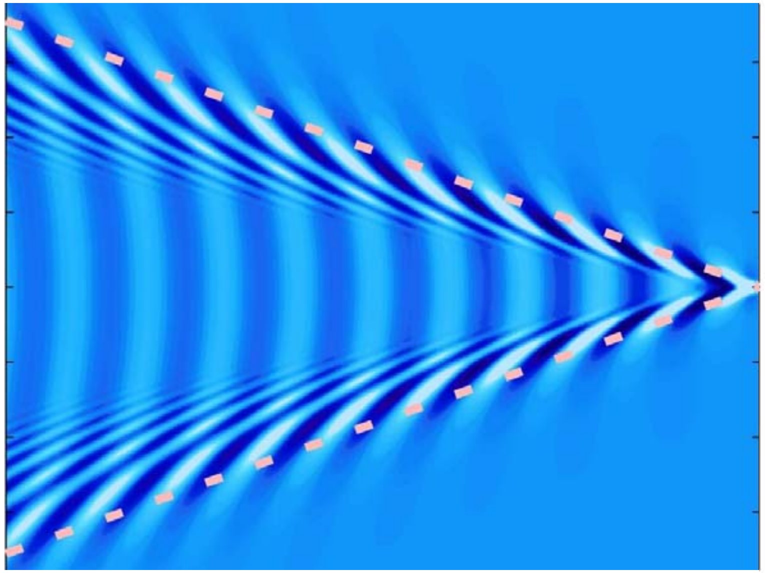


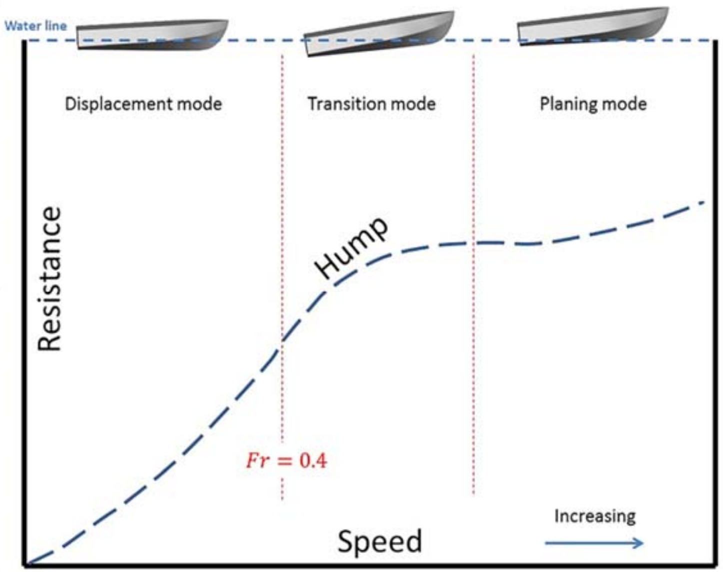


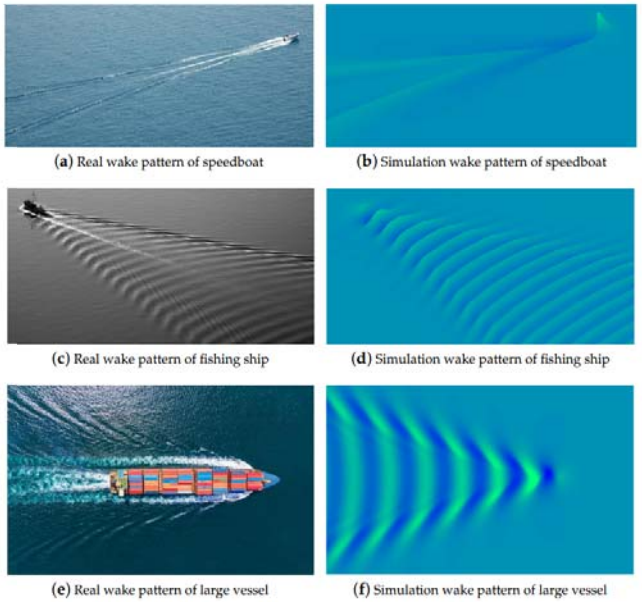
Hull’s Waves and Wake











(a) Real wake pattern of speedboat
(b) Simulation wake pattern of speedboat
(c) Real wake pattern of fishing ship
(d) Simulation wake pattern of fishing ship
(e) Real wake pattern of large vessel
(f) Simulation wake pattern of large vessel

Theoretical Boat Speed (Rule of Thumb)

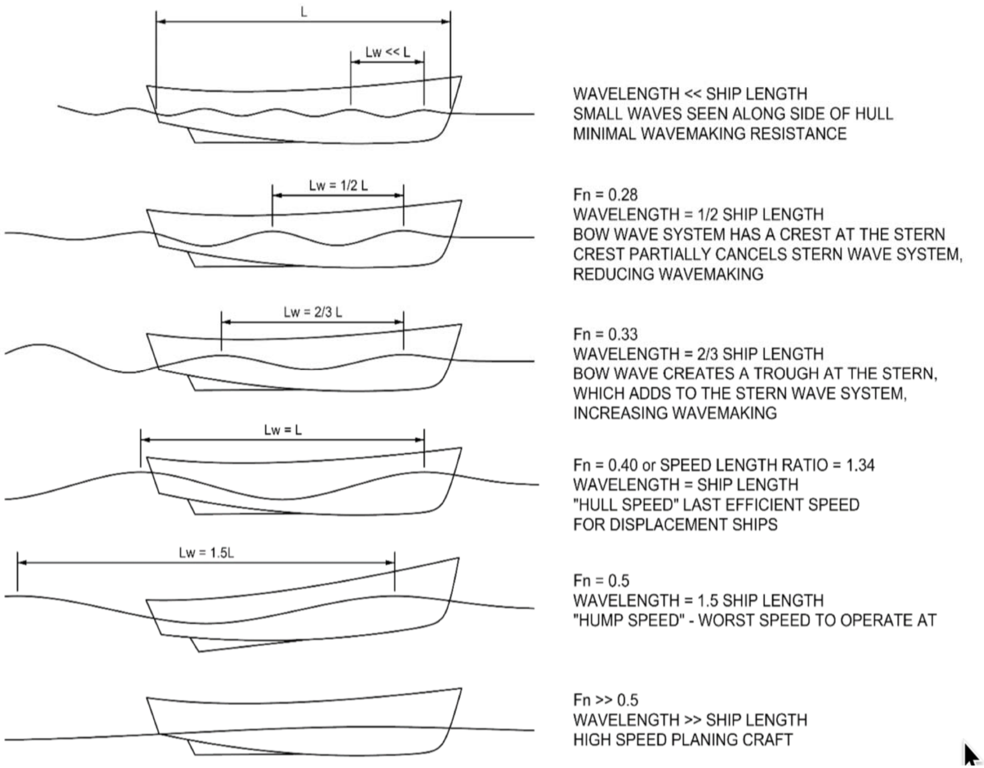
$$BOAT\ Speedkmh = 3.6 * Froude_{number} * \sqrt{G_{force} * Length^{Pl}_{meters}}$$

Pl is the Planing exponent for planing hulls, it ranges between: 1 (no planing) and 2 (full planing)

Froude number (Fn)	Typical Interpretation
Fn < 0.1	Very slow flow, negligible influence of gravity on wave formation
0.1 < Fn < 0.3	Subcritical flow, wave patterns influenced by ship and gravity
0.3 < Fn < 0.4	Transition region, complex wave interactions
0.4 < Fn < 1.0	Semi-displacement region, hull can exceed traditional hull speed limits
Fn > 1.0	Supercritical flow, planing hulls often operate in this regime

The Froude number (Fr, after William Froude) is a dimensionless number defined as the ratio of the flow inertia to the external field (the latter in many applications simply due to gravity).

Froude Number	0.4	
Length in Meters	Speed in kmh	Speed in knots
2	6.4	3.4
4	9.0	4.9
6	11.0	6.0
8	12.8	6.9
10	14.3	7.7
12	15.6	8.4
14	16.9	9.1
16	18.0	9.7
18	19.1	10.3
20	20.2	10.9



Power Requirement Estimations (Rules of Thumb)

The primary function of engine power is to overcome various forms of drag:

Hull Shape: The single biggest influence. Slender hulls vs. wider ones have vastly different drag profiles.
Speed: Drag changes non-linearly with speed, especially due to wave-making resistance.
Wave-making drag: Energy spent creating waves as the boat moves. Significant at Froude numbers above ~0.3.
Frictional drag: Resistance from the water flowing along the hull's surface.
Displacement Drag: According to Archimedes' Principle, a floating object displaces a volume of water equal to its own weight. Therefore, the hull displacement of a boat is directly equal to the boat's total weight, including everything onboard. Increased weight makes the boat sit lower in the water, increasing the wetted surface area, which further increases drag.
Admiralty Coefficient: It is used in the preliminary estimations of the power required in a new design to attain the desired speed.

Admiralty Coefficient

$$C_{Ad} = \frac{D^{2/3}\ V^3}{P}$$

D in Metric Tons
V in Knots
P in HP

$$Power_{kW} = \frac{Displacement_{tons} * Speed^3{}_{kmh}}{DLR * \mu * C_{Ad}}$$

$$DLR = \left(Displacement_{Tons} / Lenght_{meters}\right)$$

$$\mu = (Viscosity\ or\ Friction\ Coefficient)$$

$$C_{Ad} = (Admiralty\ Coefficient)$$

Submerged/Wet Friction Coefficient (μ)

Material	Min.	Max.
Coated Steel	0.14	0.24
Aluminum	0.2	0.3
Fiberglass (GRP)	0.21	0.33
Plastic (UHMW)	0.05	0.1
Wood	0.2	0.6

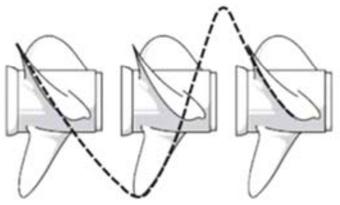
$$Displacement_{kg} = LWL_m * BWL_m * Draft_m * C_b * Density\ H_2O_{kg/m^3}$$

Block Coefficient C_b for Small Hulls

Small Hull Type	Min.	Max.
Flat-Bottom Skiff / Punt	0.85	0.95
Traditional Hull (Displacement)	0.50	0.60
Modern Cruising Sailboat	0.35	0.45
Planing Motorboat (Deep-V)	0.25	0.35
Racing Dinghy / Skiff	0.20	0.30
Olympic Sprint Kayak	0.15	0.25
Multihull (Catamaran hulls)	0.30	0.40

Propellers

Pitch

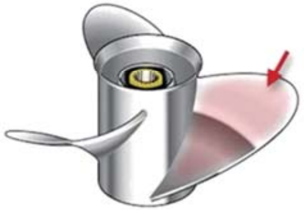


The distance (in inches) a propeller would theoretically move after one revolution if traveling through a solid.

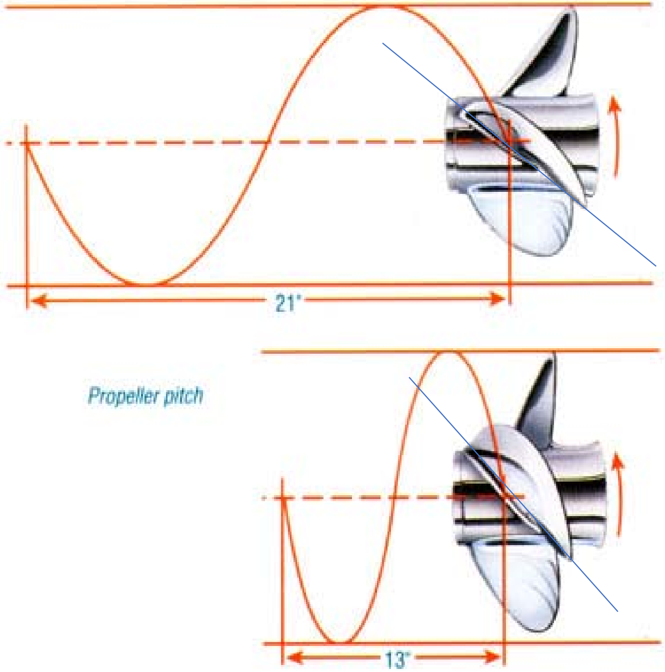
Diameter

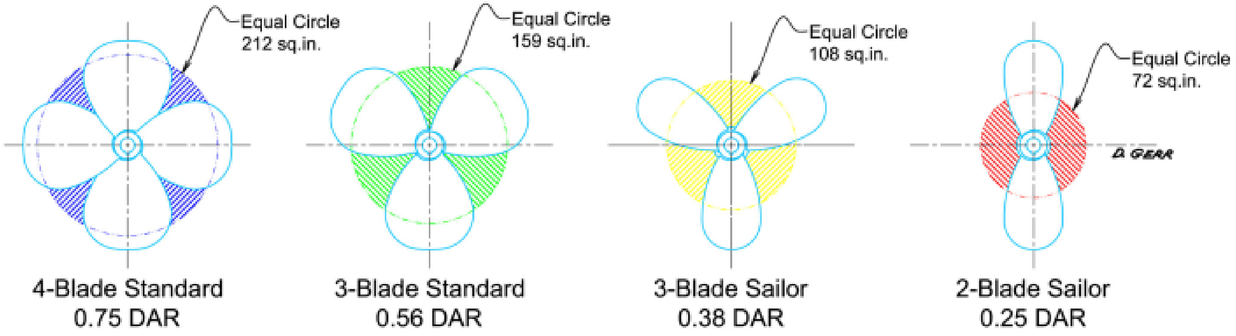
The total width of the circle created by the blade tips as they spin.

Blade Surface Area



The total surface area of the propeller blade.

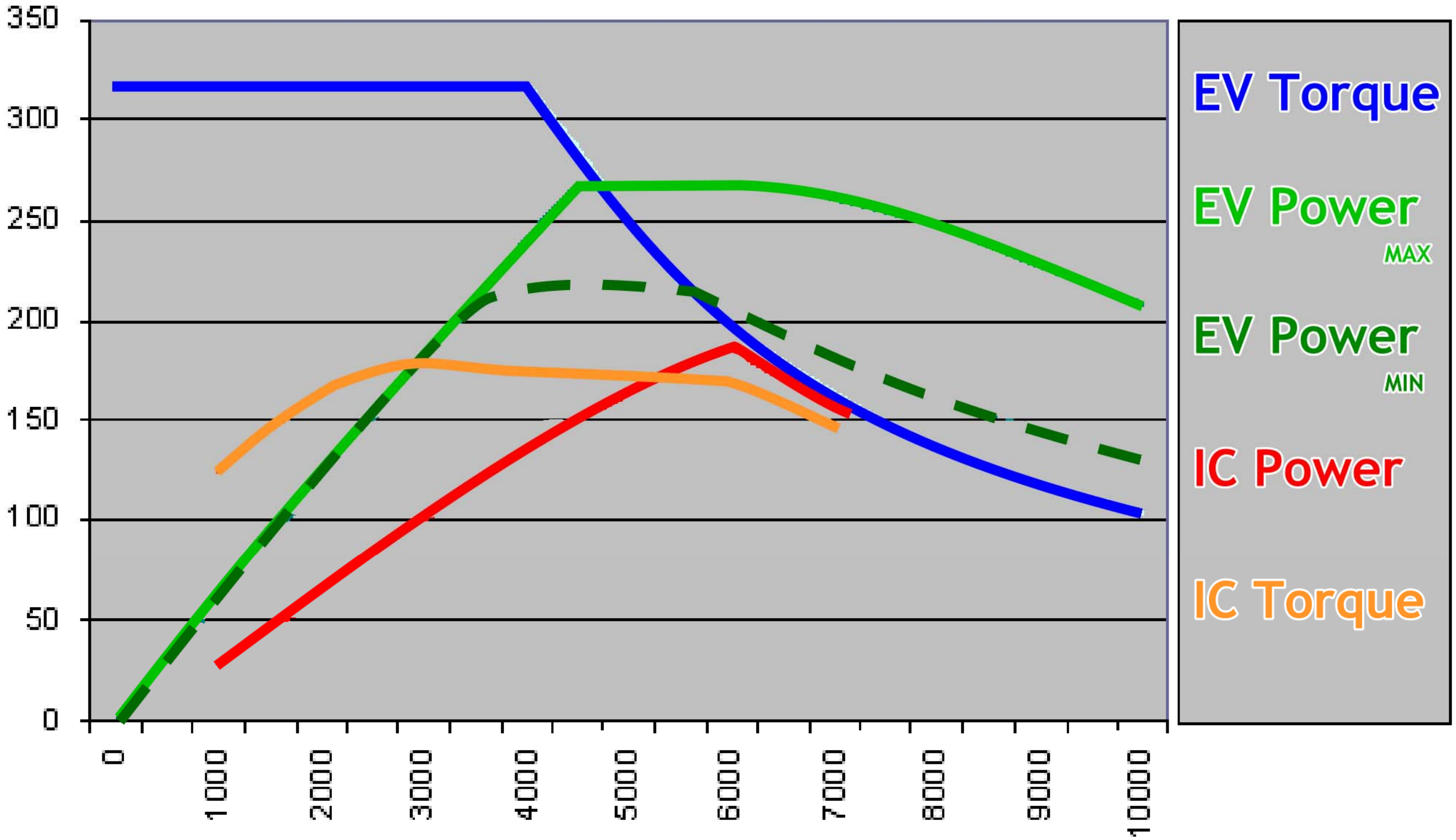




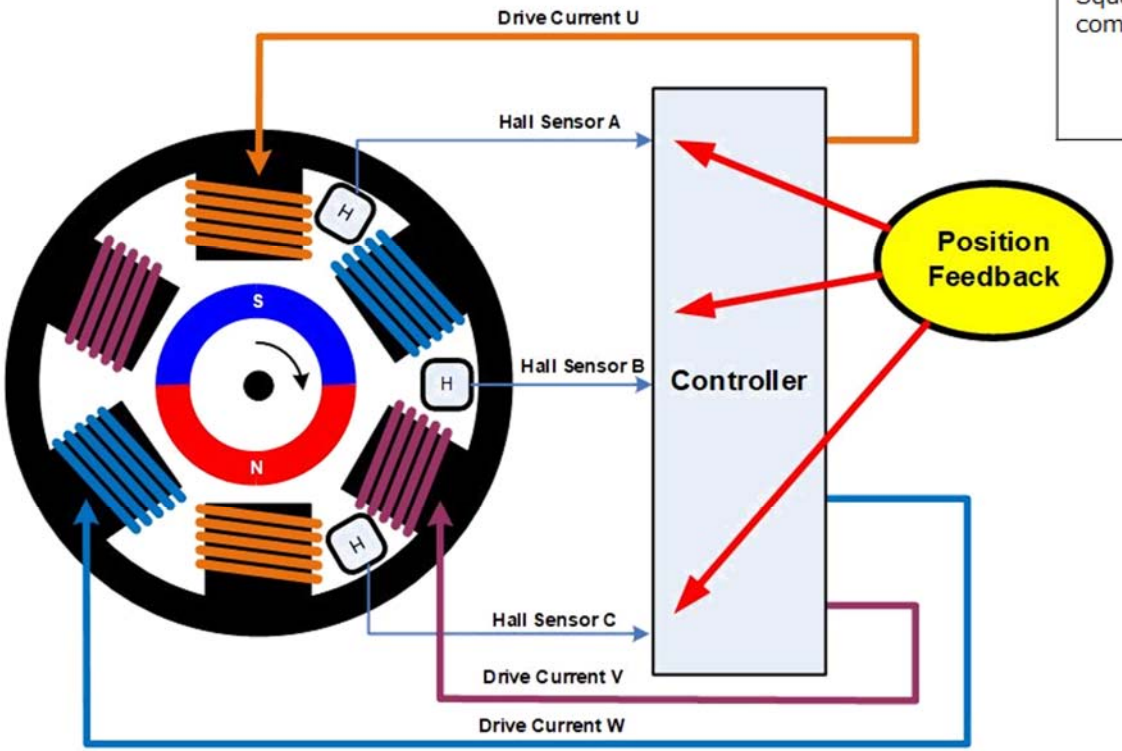
Propeller Blade Areas Compared - All 19-in. Diameter

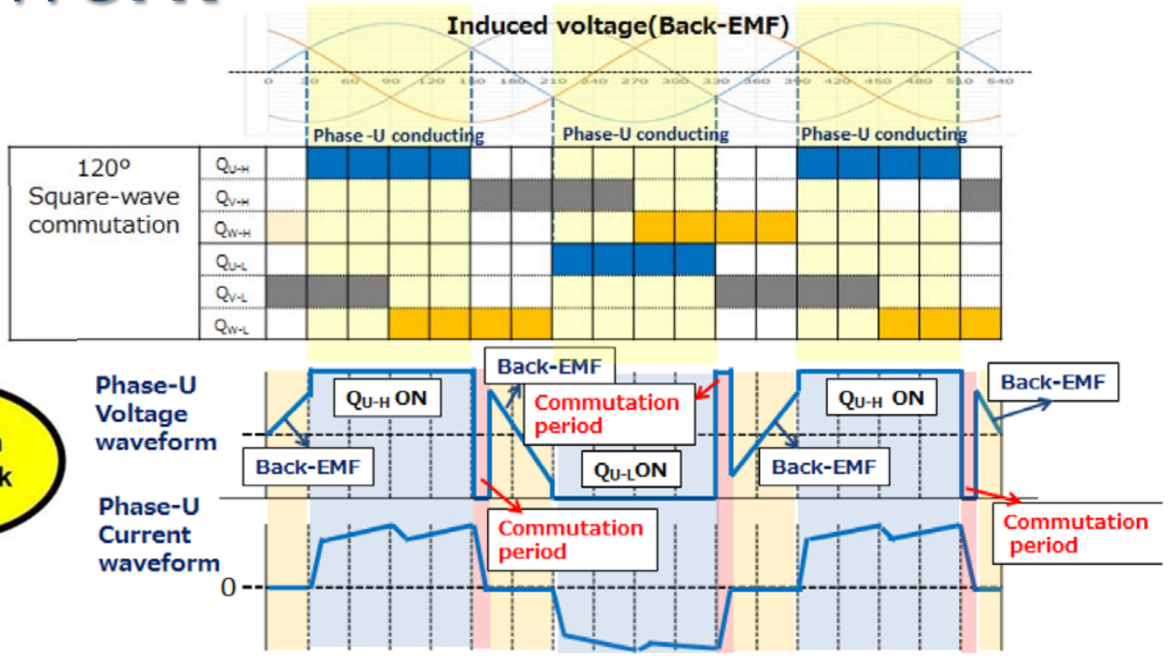
BLDC Motors

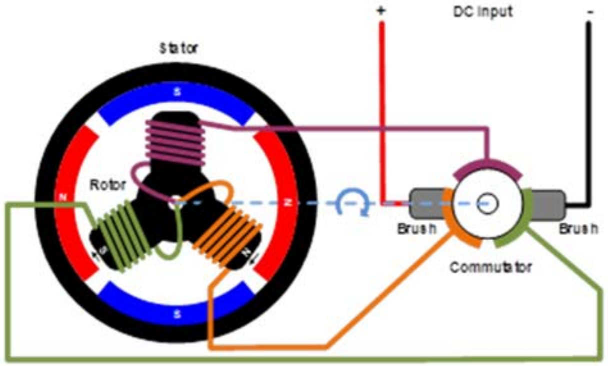
Electric Motor vs Combustion Engine



BLDC - Principles of Work

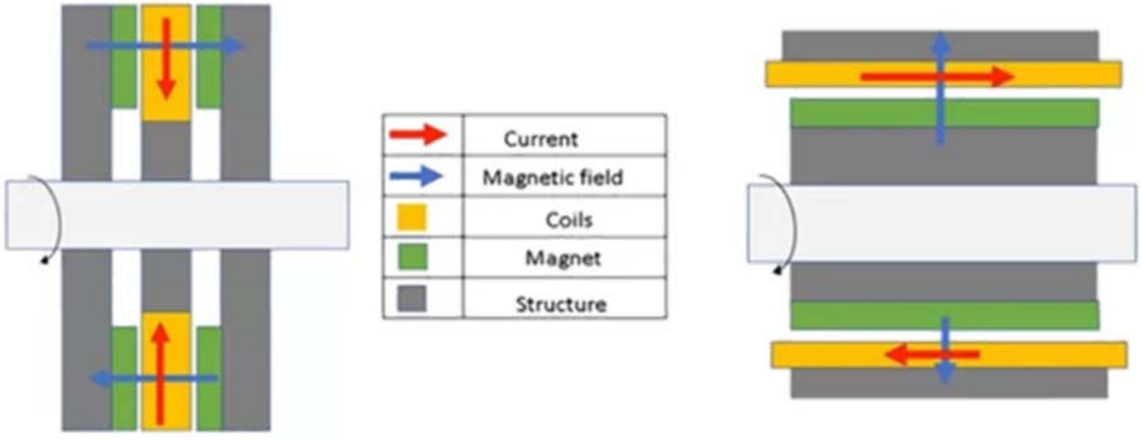




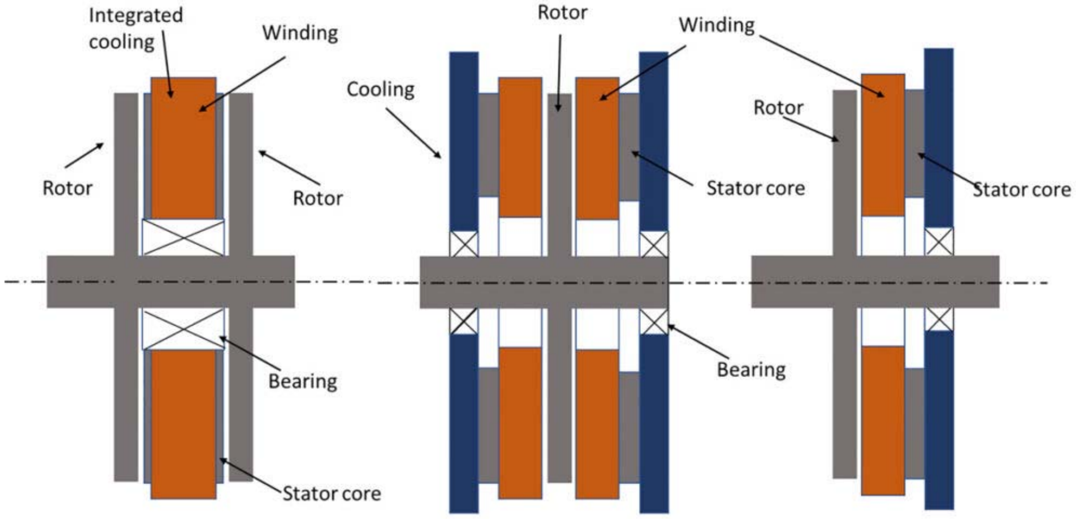


Axial Flux vs Radial Flux

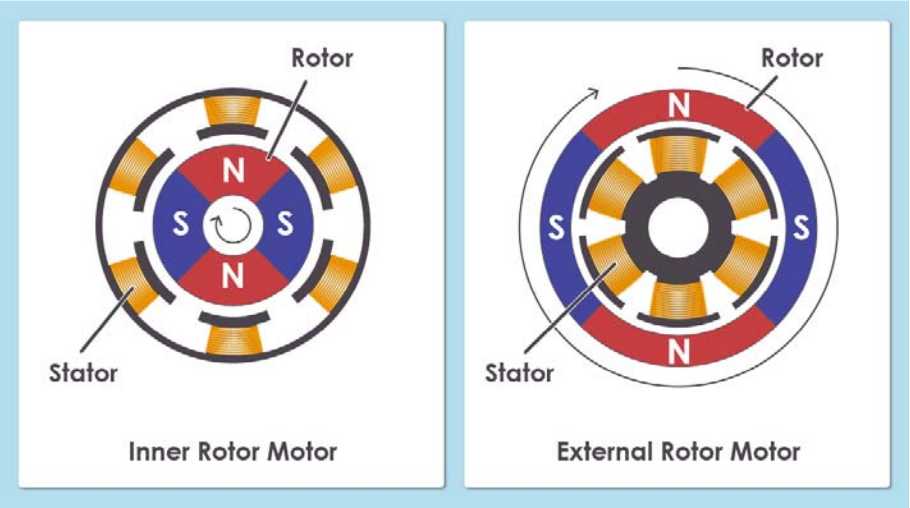
Axial Flux



Radial Flux

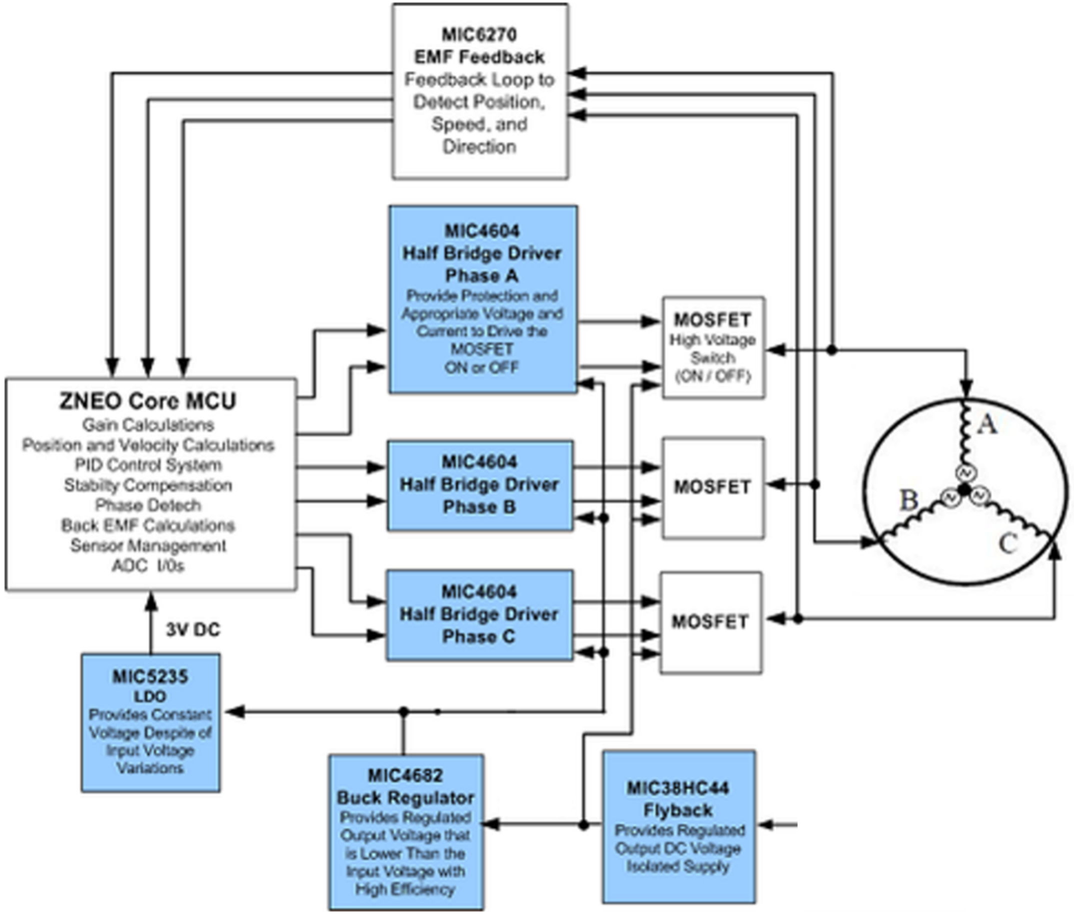


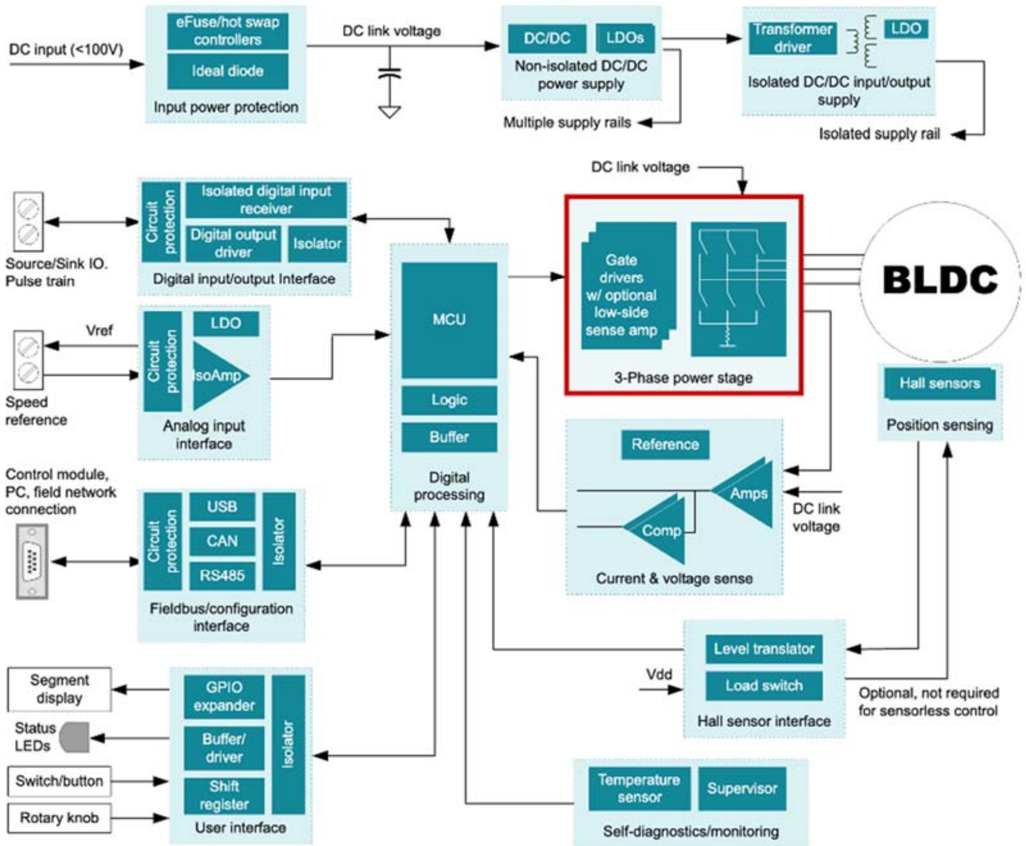
Central Stator **Central Rotor** **Single sided**



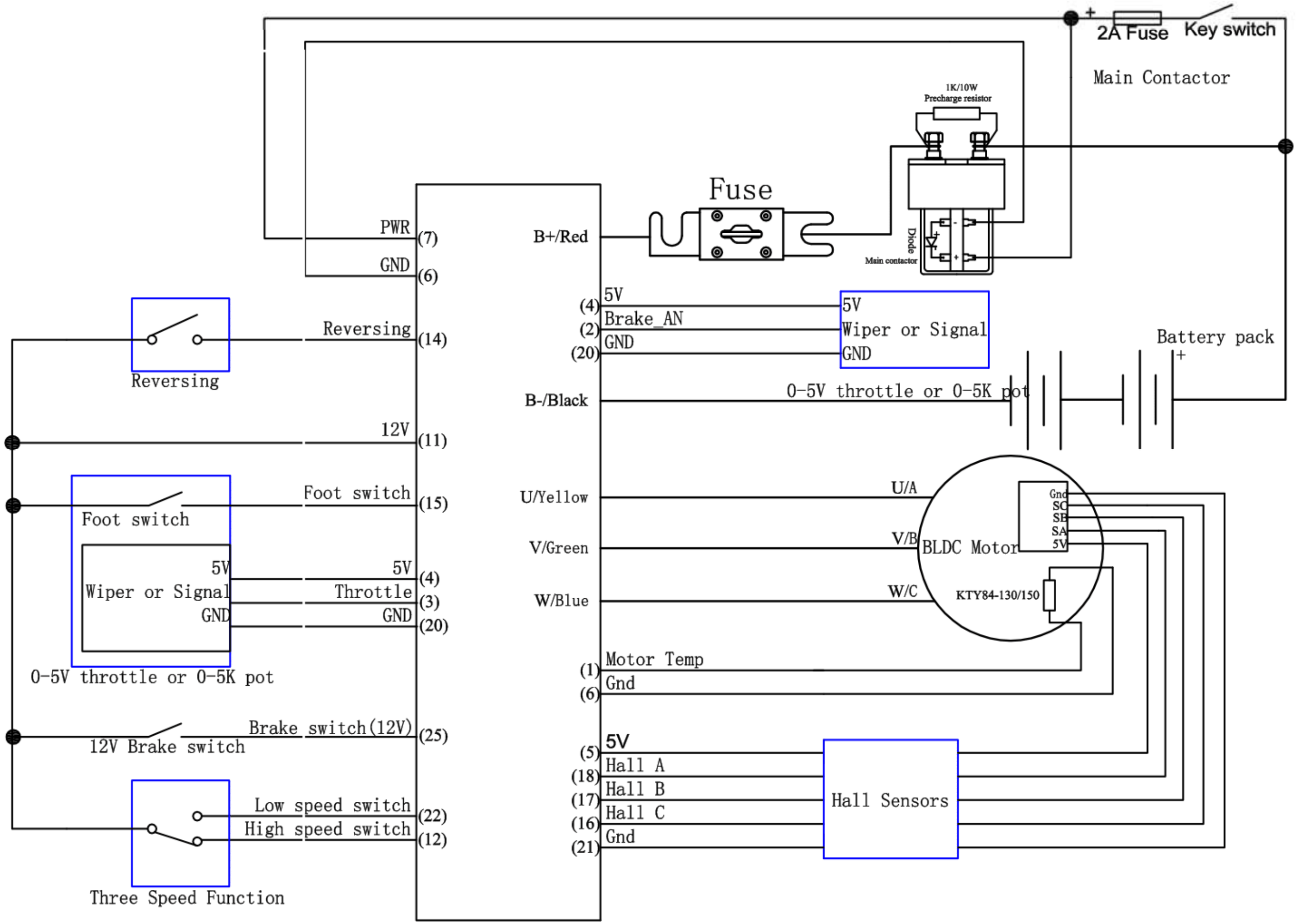
BLDC Motor Controllers

BLDC Motor Controllers Functional Diagrams

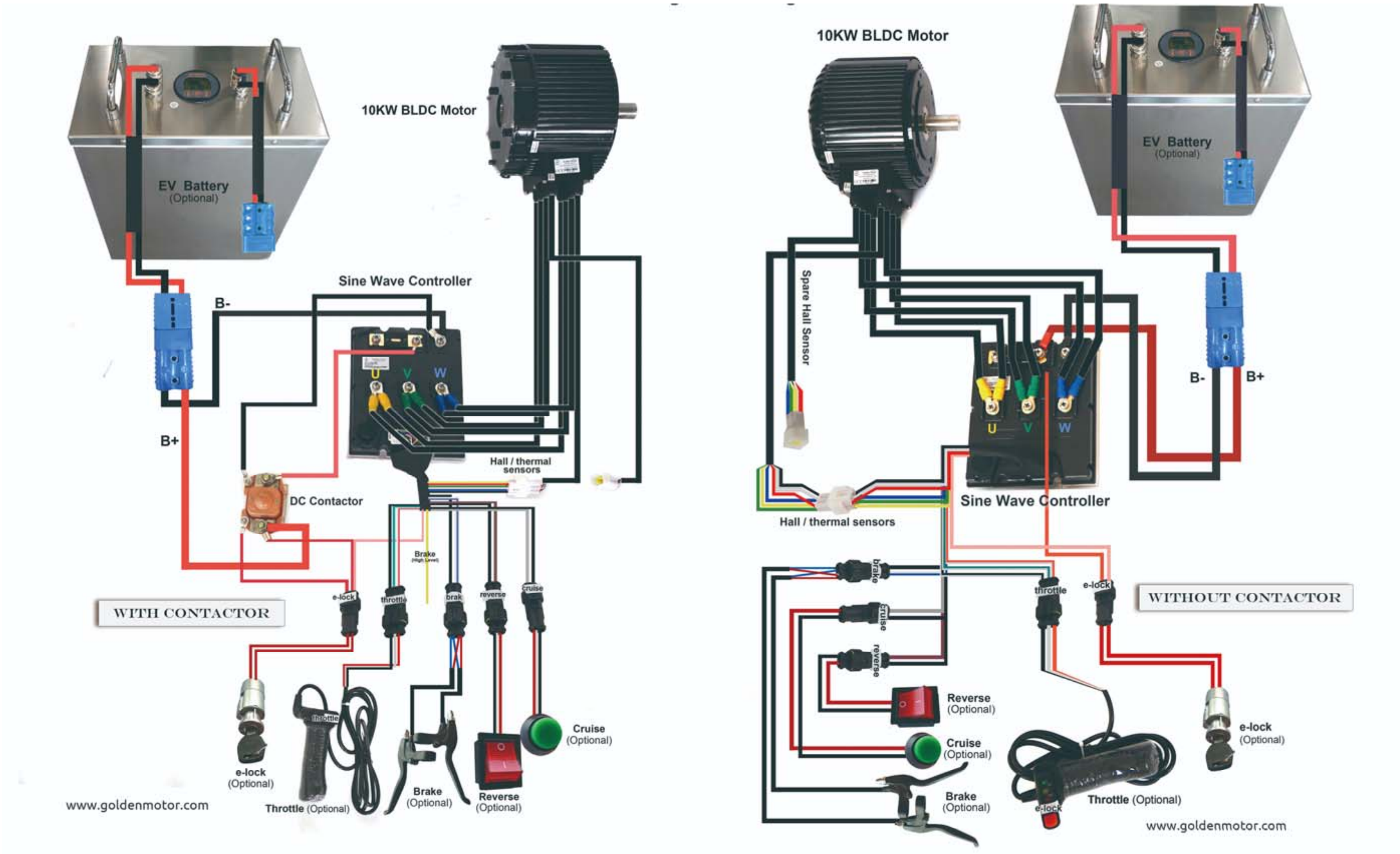




Controller Wiring Schematics Example

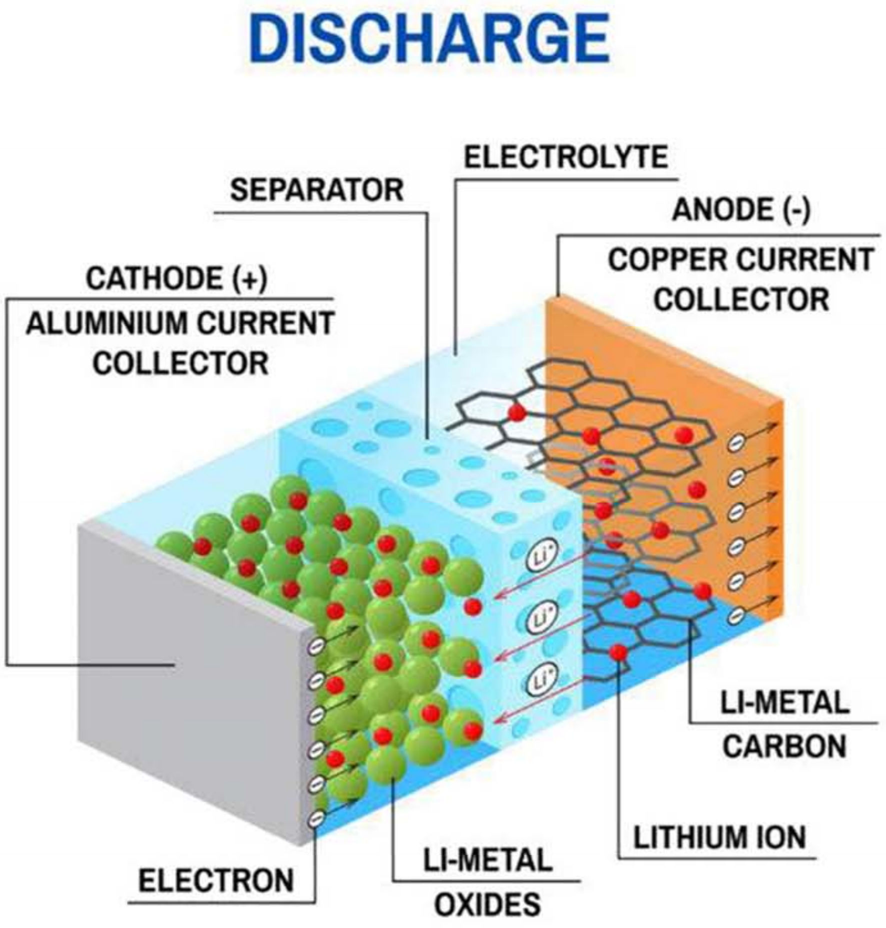


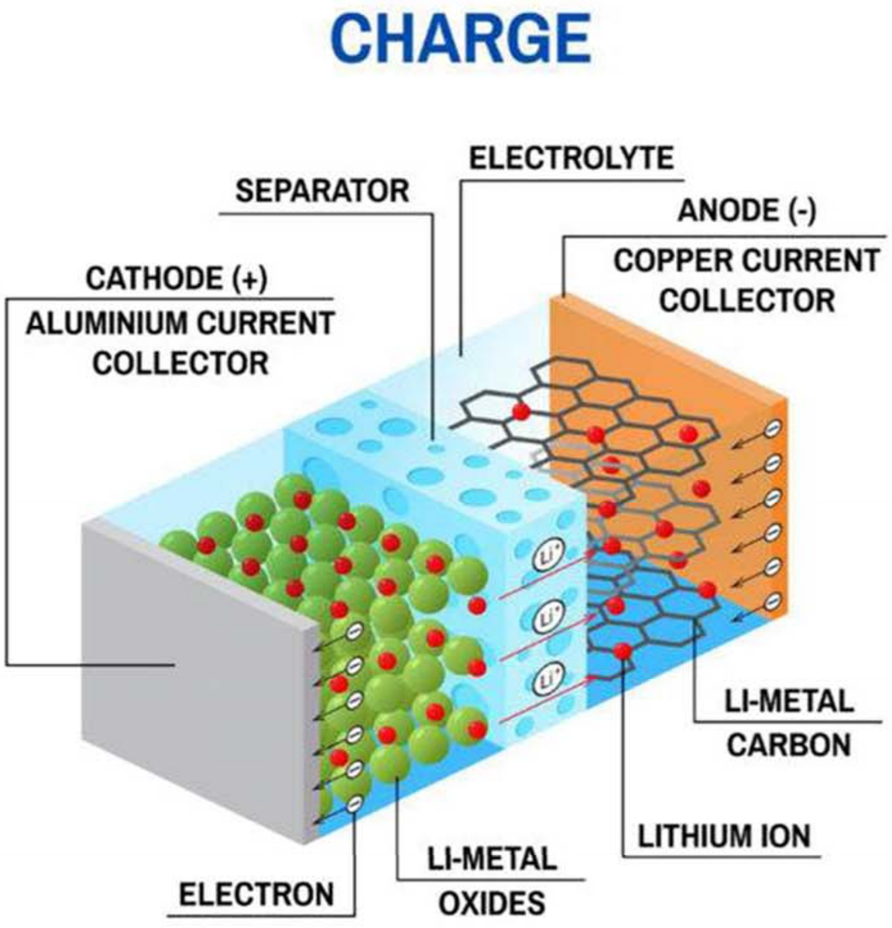
Wiring Diagram Example



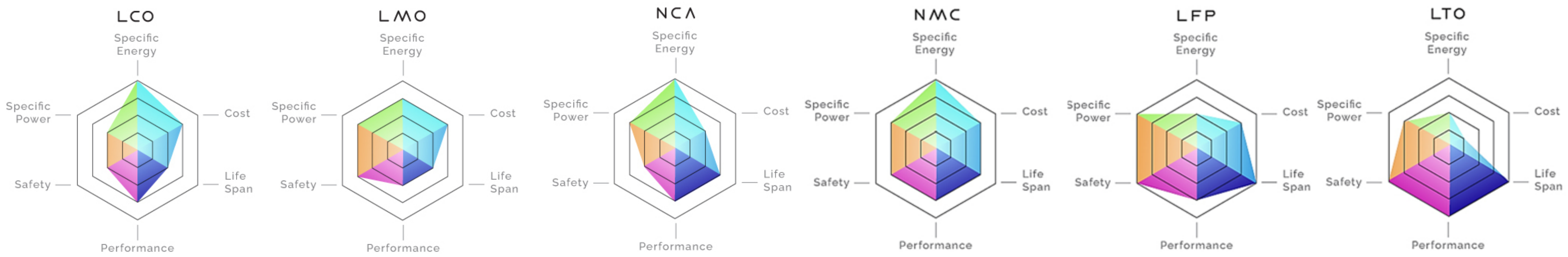
Lithium Batteries

BATTERIES - Lithium-Ion





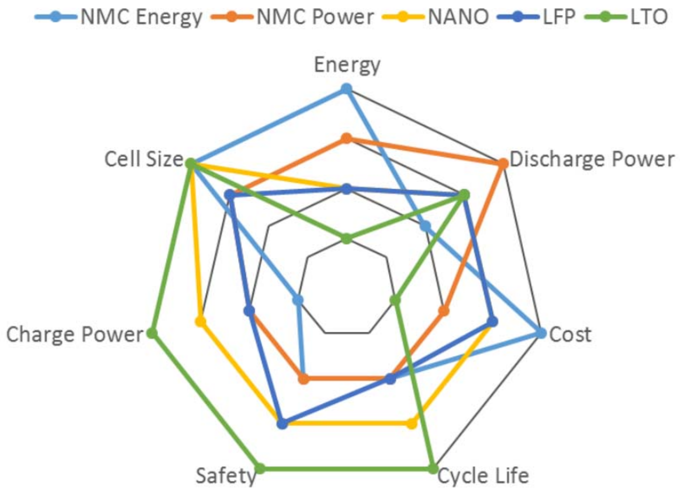
Comparison of Lithium Ion Battery Chemistries



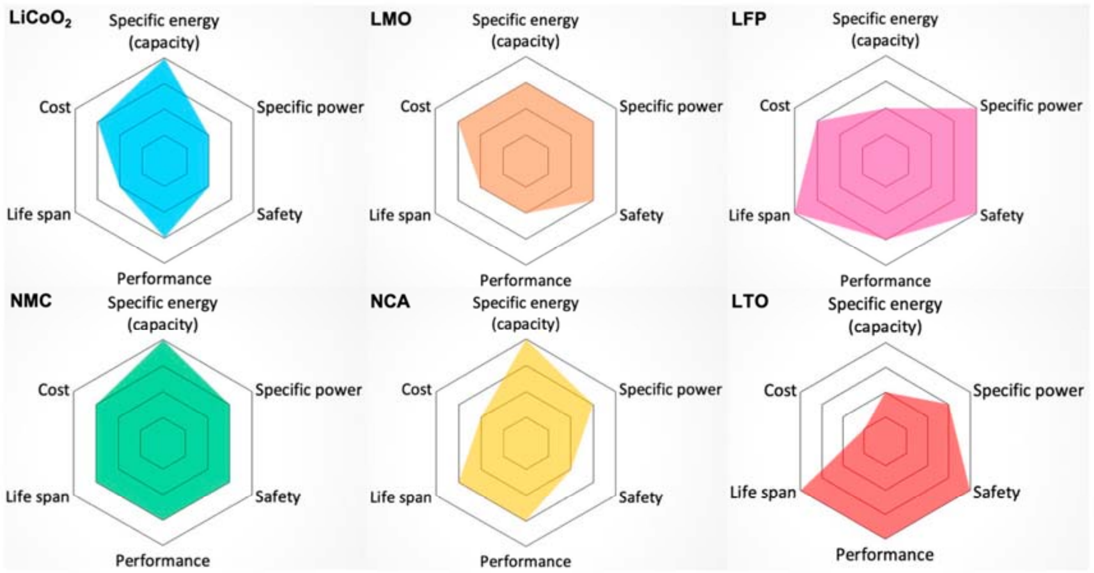
Chemistry	Energy Density (Wh/kg)	Power Density (W/kg)	Cycle Life	Cost	C-Rate	Safety	Marine Suitability
Li + Cobalt Oxide (LCO)	150-200	High	500-1000	High	1C - 5C	Lower stability, thermal runaway risks	Very Limited
Li + Manganese Oxide (LMO)	100-150	High	300-700	Moderate	5C - 10C	Good safety profile	Limited - primarily as hybrid systems for power boosts
Li+Nickel Cobalt Aluminum Oxide (NCA)	200-260	Very High	>3000	Moderate	1C - 3C	Risky, Requires careful management	Limited - specialized applications needing extreme energy density
Li+Nickel Manganese Cobalt Oxide (NMC)	150-220	High	1000-2000	Moderate	1C-3C	Good safety with proper management	Good - common in larger vessels, offers energy and power balance
Li+Iron Phosphate (LiFePO4 or LFP)	90-160	Moderate	2000-3000	Lower	1C - 10C+	Excellent safety & thermal stability	Excellent - robust, well-suited for marine environments
Li + Titanate Oxide (LTO)	50-80	Very High	20,000+	High	10C - 30C+	Exceptionally safe, very high C rates, wide temp range	Mandatory for ships fast charging, extreme safety, very long life
Lithium Polymer (LiPo)	130-250	Moderate to High	300-700	Moderate	1C - 10C+	Swelling & fire risks with damage	Moderate - safety depends on casing, BMS, and handling

Battery Electrochemistry Types

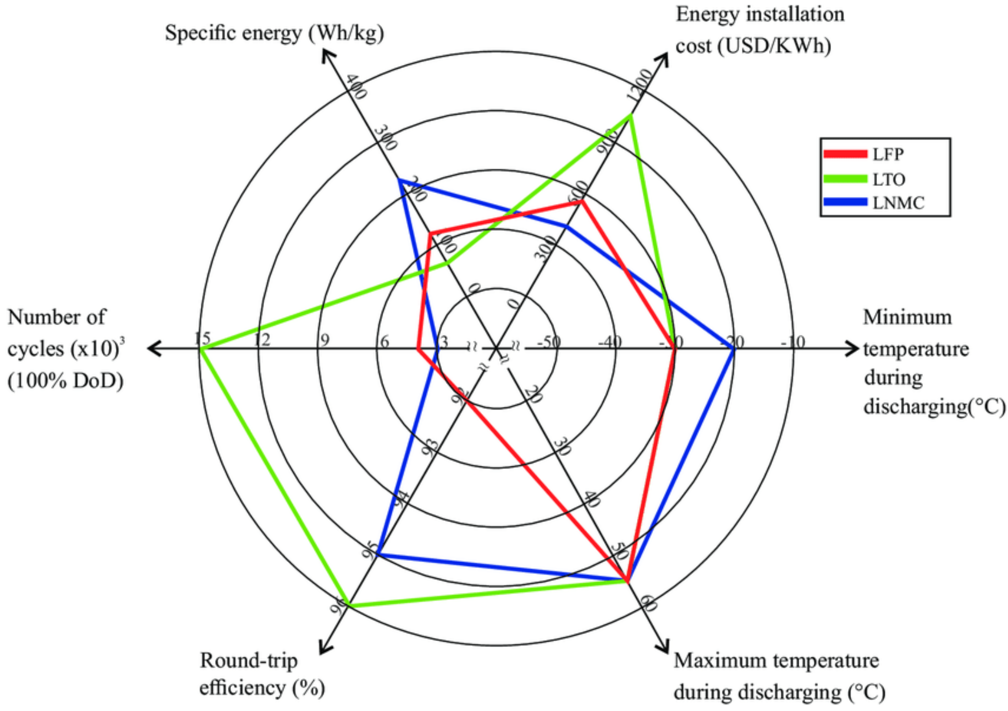
Lithium-Ion Chemistry	Chemical Composition	Cathode (+)	Anode (-)	Nominal Voltage
Nickel Manganese Cobalt (NMC)	$Li(NiMnCo)O_2$	Nickel Manganese Cobalt	Graphite	3.6/3.7 V
Lithium Iron Phosphate (LFP)	$LiFePO_4$	Lithium Iron Phosphate	Graphite	3.2/3.3 V
Lithium Titanate Oxide (LTO)	$Li_4Ti_5O_{12}$	NMC, NCA, LMO	LTO	2.2/2.3 V



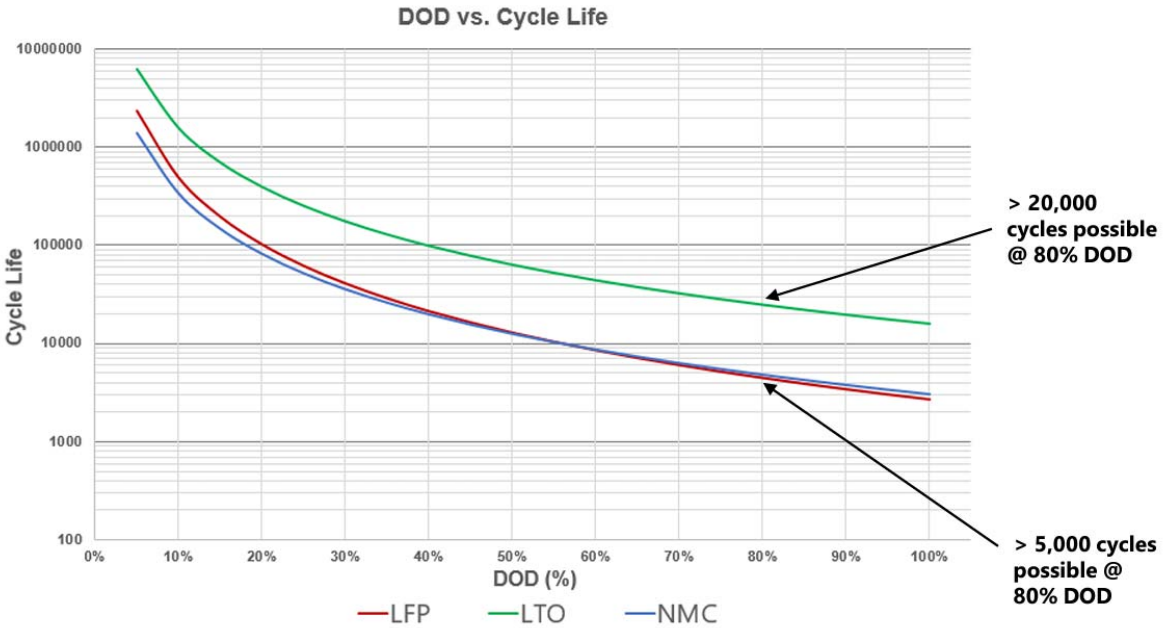
Lithium-Ion Chemistry	Cell-Level Energy Density	Cycle Life (at 80% DOD)	Recharge Time (0-80% SOC)	Advantages
Nickel Manganese Cobalt (NMC)	**300-410 Wh/L**	> 6,000 cycles	≥ 20 mins	• Highest energy density • Power/energy balance
Lithium Iron Phosphate (LFP)	200-250 Wh/L	> 6,000 cycles	≥ 20 mins	• Flat voltage response • Balanced chemistry
Lithium Titanate Oxide (LTO)	145-180 Wh/L	**> 20,000 cycles**	**≥ 6 mins**	• Highest cycle life • Highest continuous charge rates

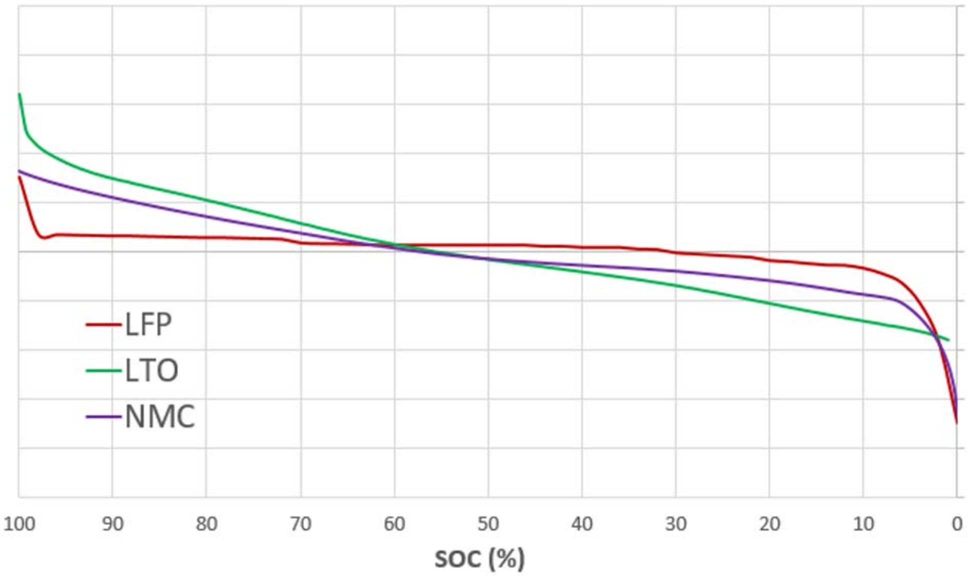


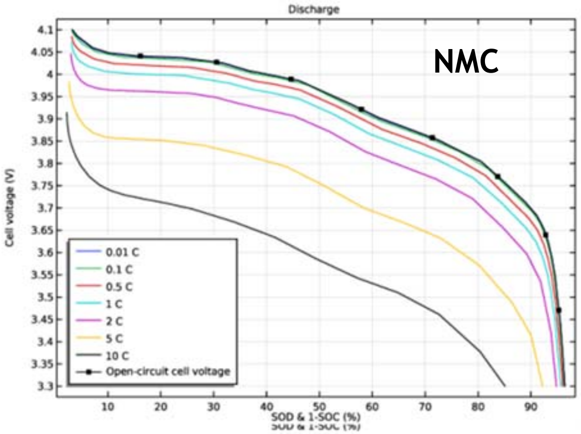
NMC vs LFP vs LTO

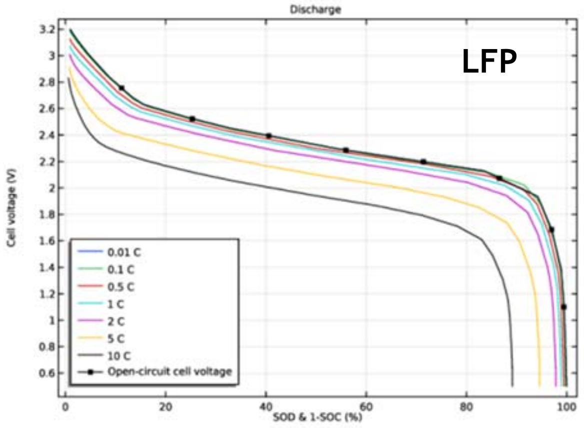


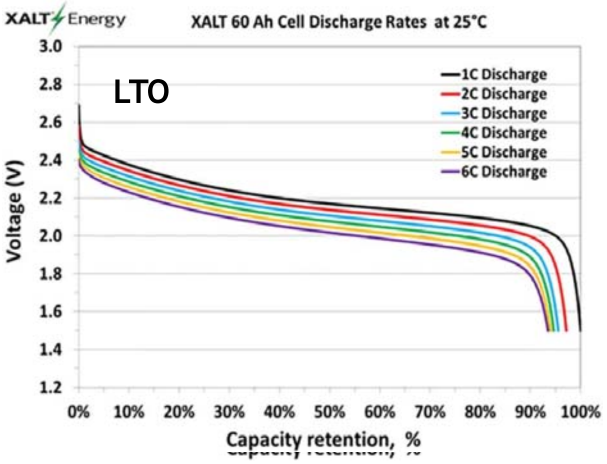
NMC vs LFP vs LTO









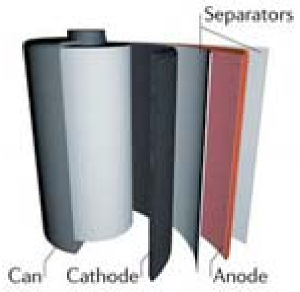
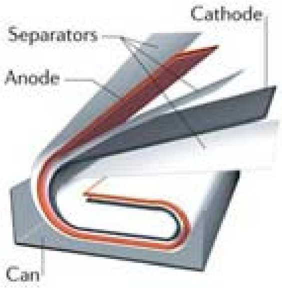
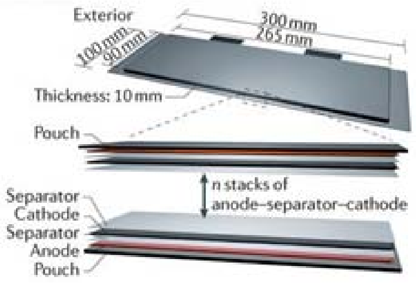


LiFePo$_4$ - LFP - Lithium Iron Phosphate Battery

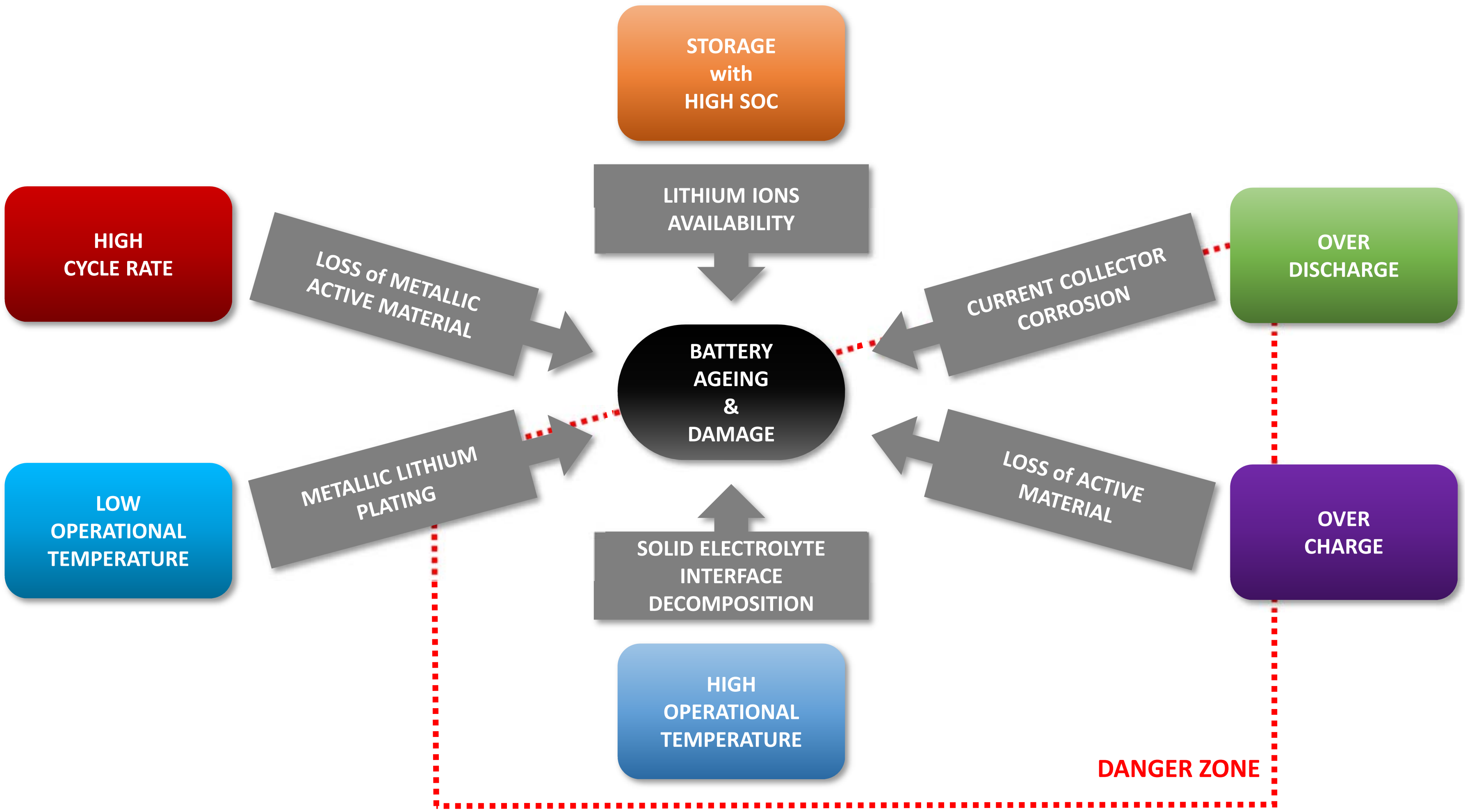
- The lithium iron phosphate battery or LFP battery (lithium ferro-phosphate) is a type of lithium-ion battery using lithium iron phosphate ($LiFePO_4$) as the cathode material, and a graphitic carbon electrode with a metallic backing as the anode. Because of their low cost, high safety, low toxicity, long cycle life and other factors, LFP batteries are becoming the chemistry of choice for EV Propulsion.
- Cell voltage
  - Minimum discharge voltage = 2.0-2.8 V
  - Working voltage = 3.0 ~ 3.3 V
  - Max viable voltage = 2.5 ~ 3.47 V
  - Maximum charge voltage = 3.60-3.65 V

- Volumetric energy density = 220 Wh/L (790 kJ/L)
- Gravimetric energy density > 90 Wh/kg (> 320 J/g). Up to 160 Wh/kg (580 J/g).
- Cycle life from 2,500 to more than 9,000 cycles depending on usage conditions.
- One important advantage over other lithium-ion chemistries is thermal and chemical stability, which improves battery safety. $LiFePO_4$ cells are more structurally stable than cells with other chemistries, such as NMC. When abused (short-circuited, overheated, etc.), the oxygen atoms are released more slowly, thus, they are highly resilient during oxygen loss, which typically results in an exothermic reaction in other lithium cells and they do not not decompose at high temperatures.

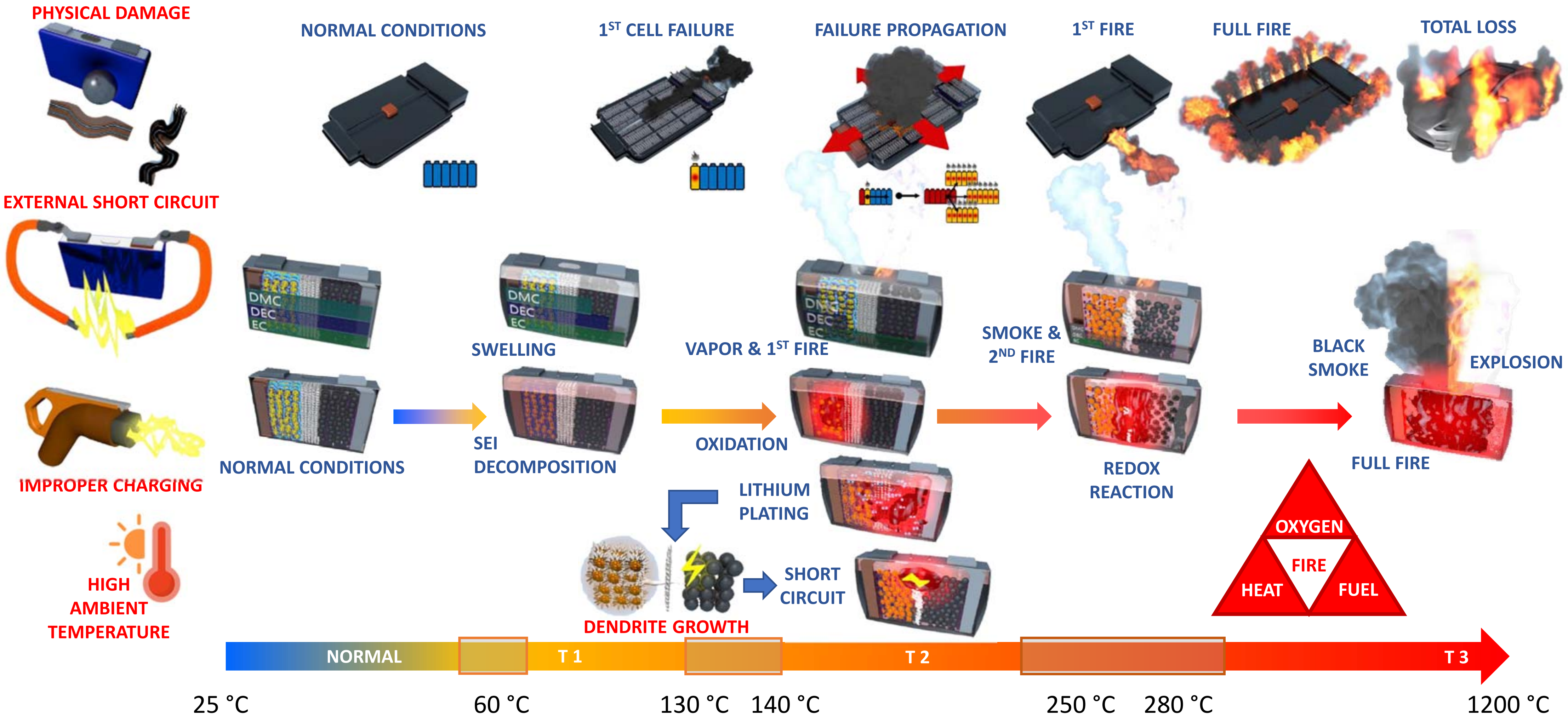
Physical Arrangements of Battery Cells

Shape	Cylindrical	Prismatic	Pouch
Physical			
Electrode Arrangement	Wound	Wound	Stacked
Mechanical Strength	++	+	–
Heat Management	–	+	+
Specific Energy	+	+	++
Energy Density	+	++	+

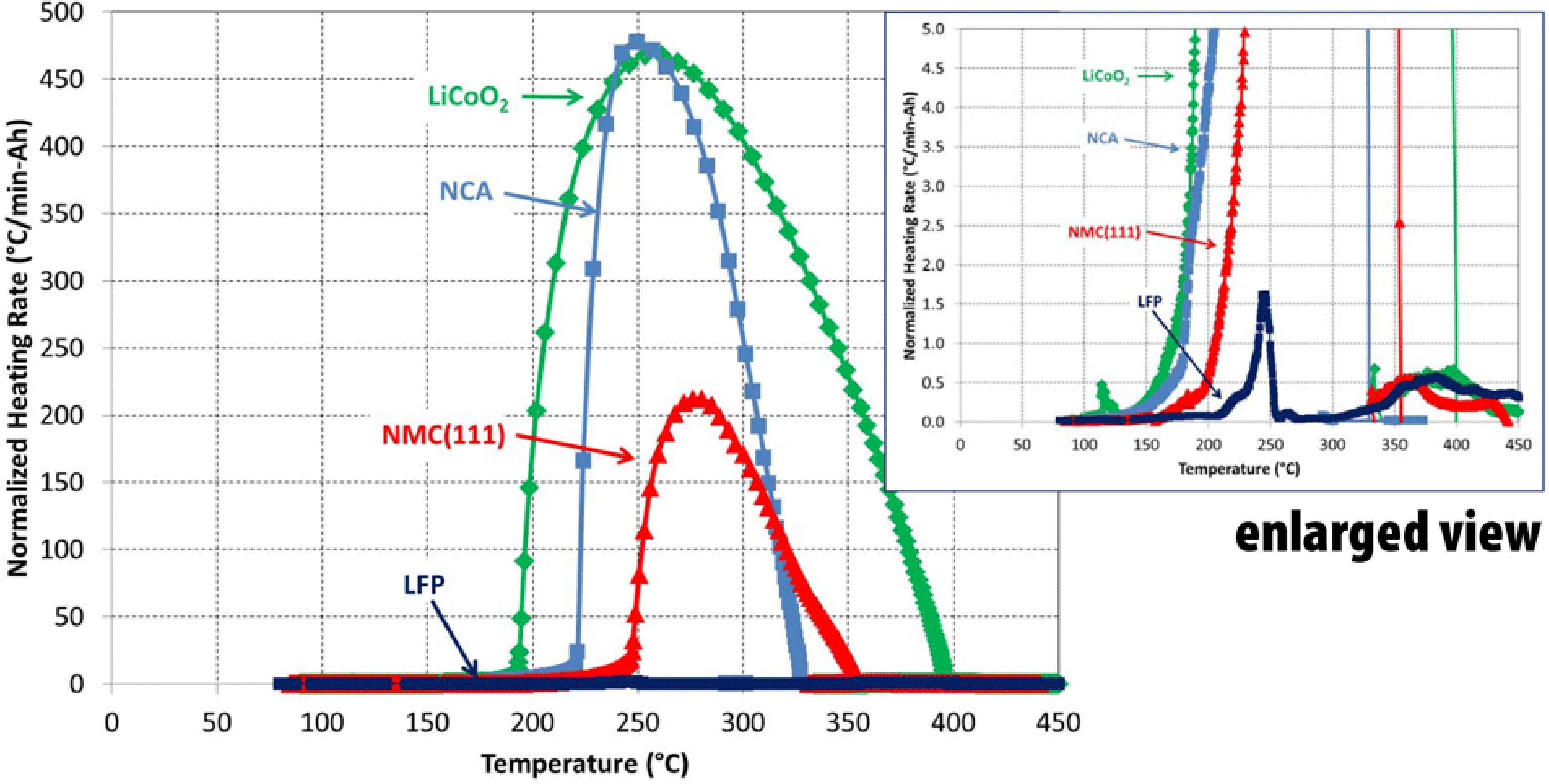
Li-Ion Damages Causes & Effects



Li-Ion Thermal Runaway & Catastrophic Failure

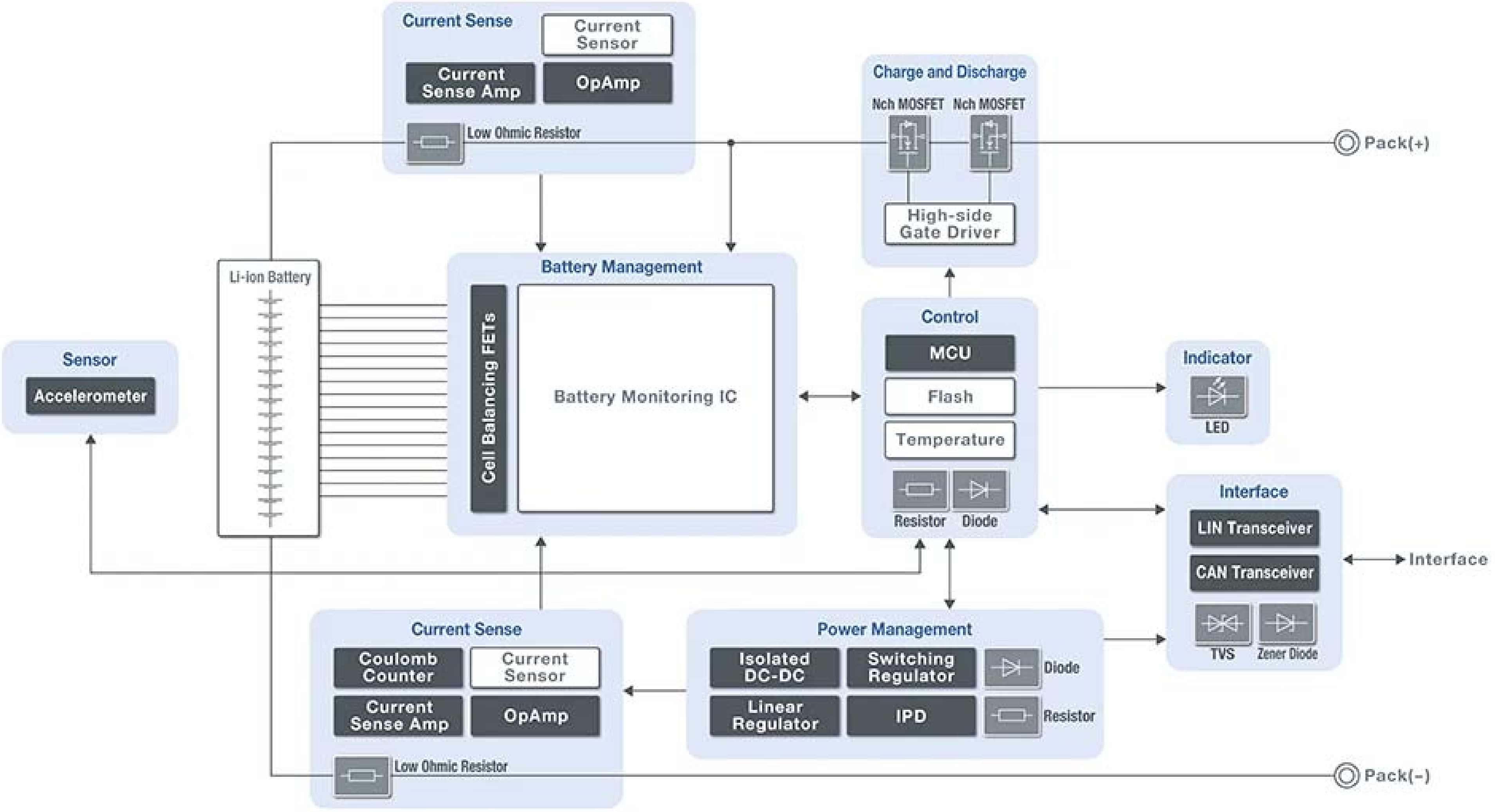


Thermal Run-Down in Lithium Electrochemistries



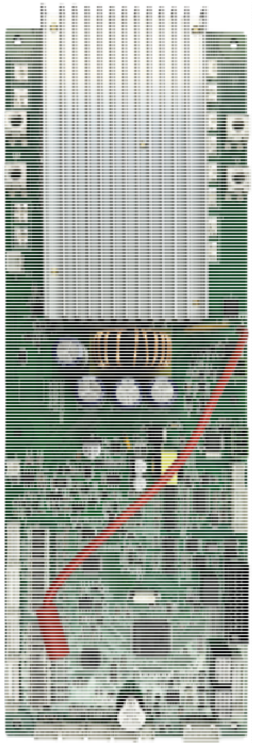
Battery Management System

BMS – Battery Management System Block Diagram

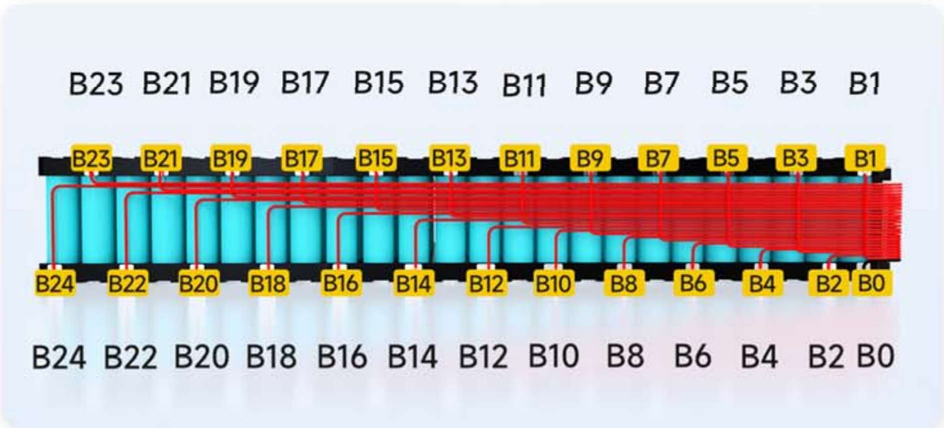


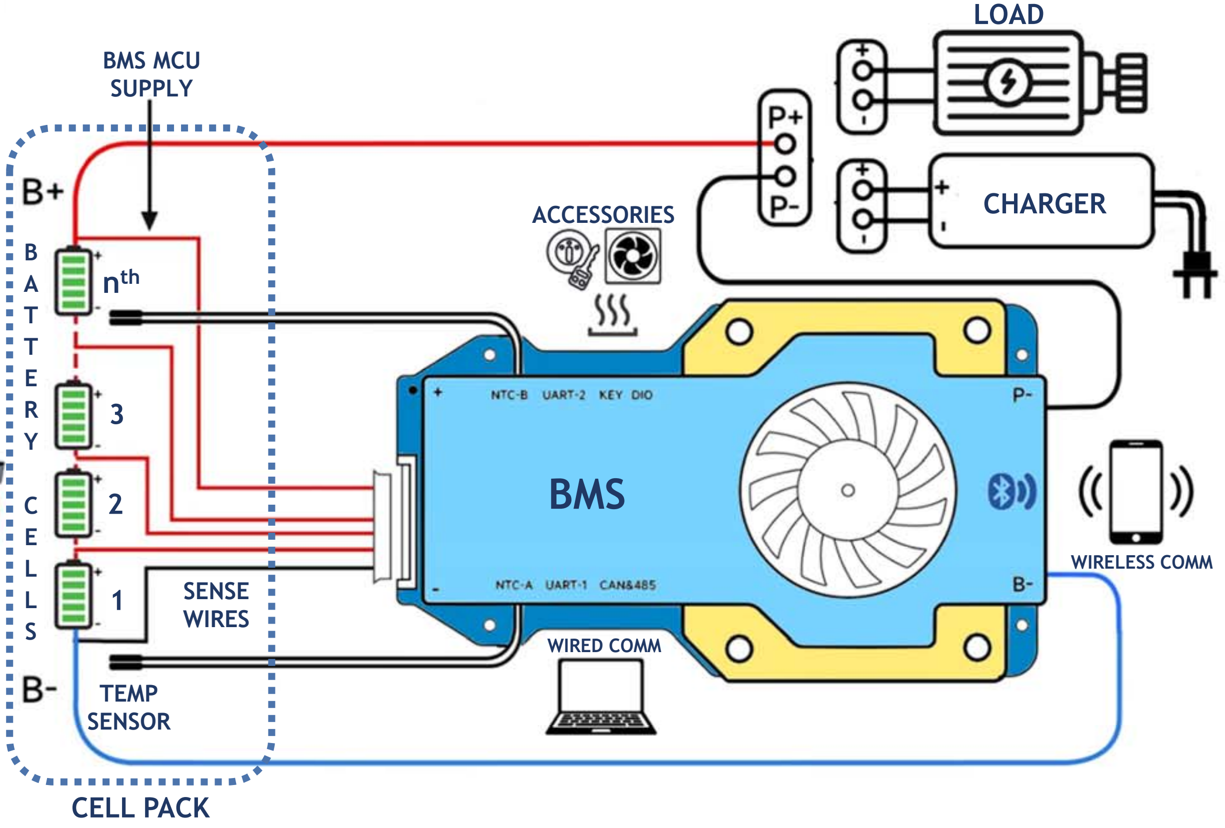
Key Functions of a Battery Management System

- Monitoring:
  - Continuously tracks battery cell voltage, current, temperature, and overall pack health (State of Health - SoH) and charge level (State of Charge - SoC).
- Protection:
  - Prevents unsafe operating conditions like overcharging, over-discharging (under-voltage), overcurrent, and overheating by shutting down or limiting operations.
- Cell Balancing:
  - Ensures all battery cells have similar charge levels, preventing some cells from degrading faster than others, which improves capacity and longevity.
- State Estimation:
  - Calculates critical metrics like SoC (how much charge is left) and SoH (overall battery health/degradation) for accurate reporting.
- Thermal Management:
  - Controls the battery's temperature, often through fans or cooling systems, to keep it within optimal operating ranges.
- Charge/Discharge Control:
  - Manages the flow of energy during charging and discharging cycles for optimal efficiency and safety.
- Communication:
  - Reports battery status and alerts to the host device (like an electric vehicle or energy system) for system integration.



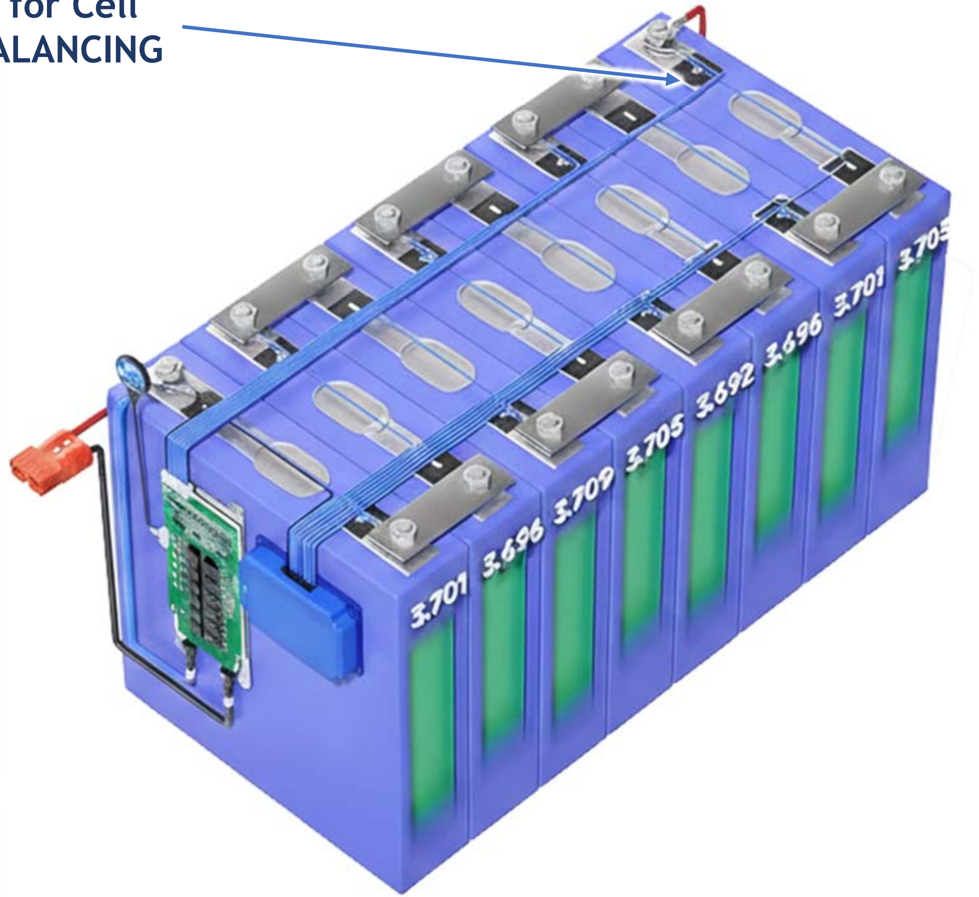
BMS Wiring Example – 24 Cells in Series (24S)



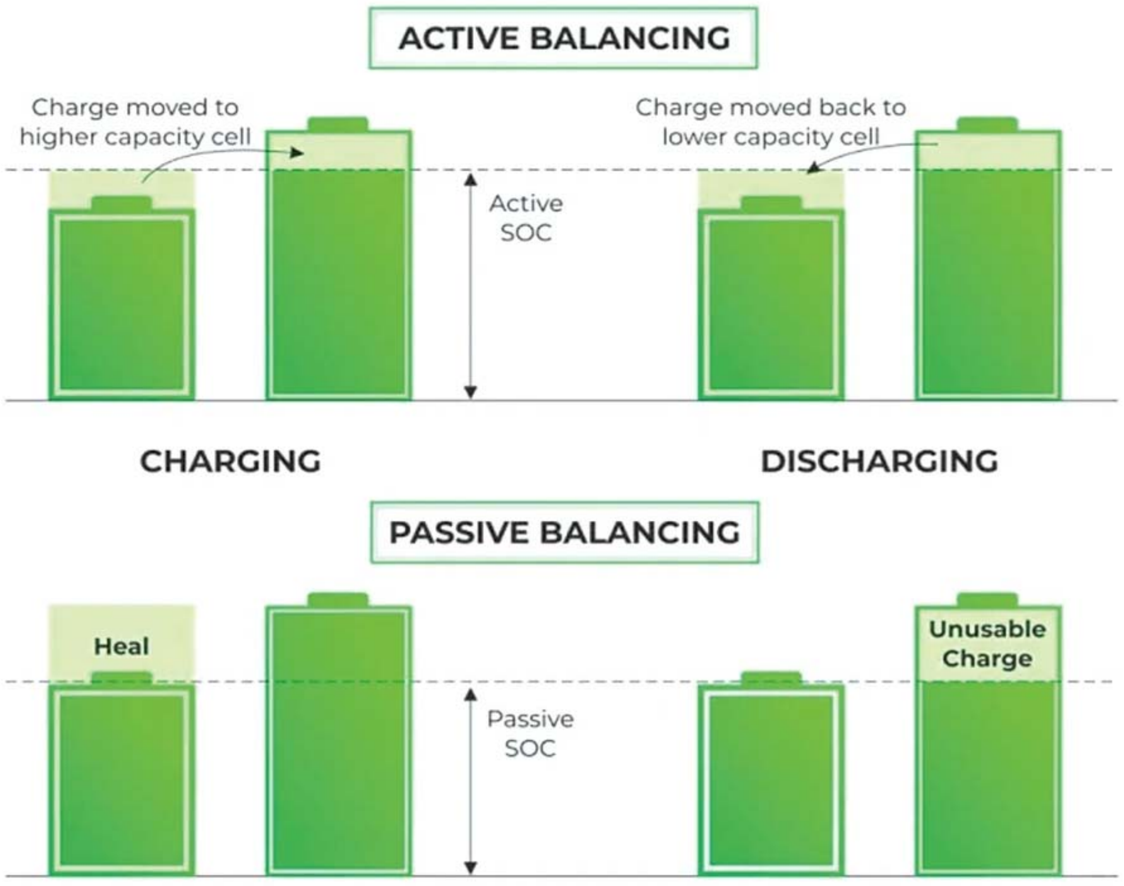


BMS Cell Balancing

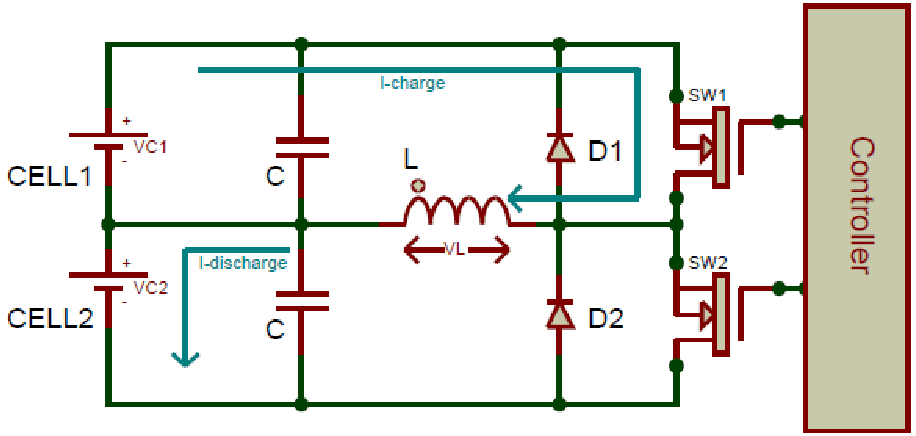
Same Wires for Cell
SENSING & BALANCING

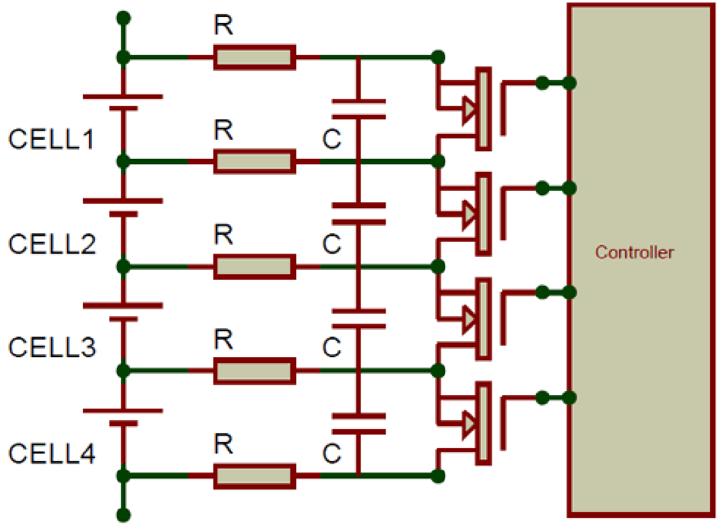


BMS - Active vs. Passive Cell Balancing



Comparison of active and passive balancing





Passive Cell Balancing using bypass resistors - charge shunting

Charging Methods

Charging Methods

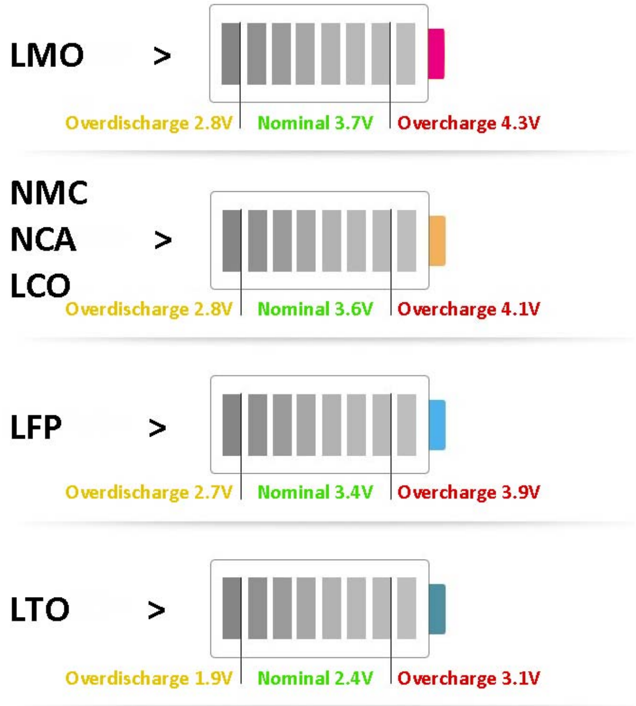
- Each Battery Pack is supplied with its own 1.5kW AC Battery Charger.
- The 1.5kW Battery Charger takes care of the Charging Method (Constant Current, Constant Voltage, Trickle Charge) according to the State of Charge (SOC).
- The Battery Management System of the Battery Pack, takes care of the State of Health (SOH) of the battery cells inside the Battery Pack.
- On board of each Boat, the Battery Packs are always divided in two separate groups.
  During navigation, one group of Battery Packs supplies the energy to the electric motor(Active Group), while the other is being charged by the Solar Panels (Stand-By Group).
  When the Active Group is discharged it is switched in stand-by mode and gets recharged, while the Stand-By Group becomes active and supplies the energy to the Electric Motor.
- All battery Packs can be removed from the Boats and charged separately, or simultaneously, inside a Swap Station.
- The Swap Station must be designed specifically for the model of the Battery Packs.
- Battery Packs can be charged simultaneously from a single AC Source, as long as it can supply enough power (i.e. 1.5 kW multiplied by the number of Battery Packs to be charged simultaneously).

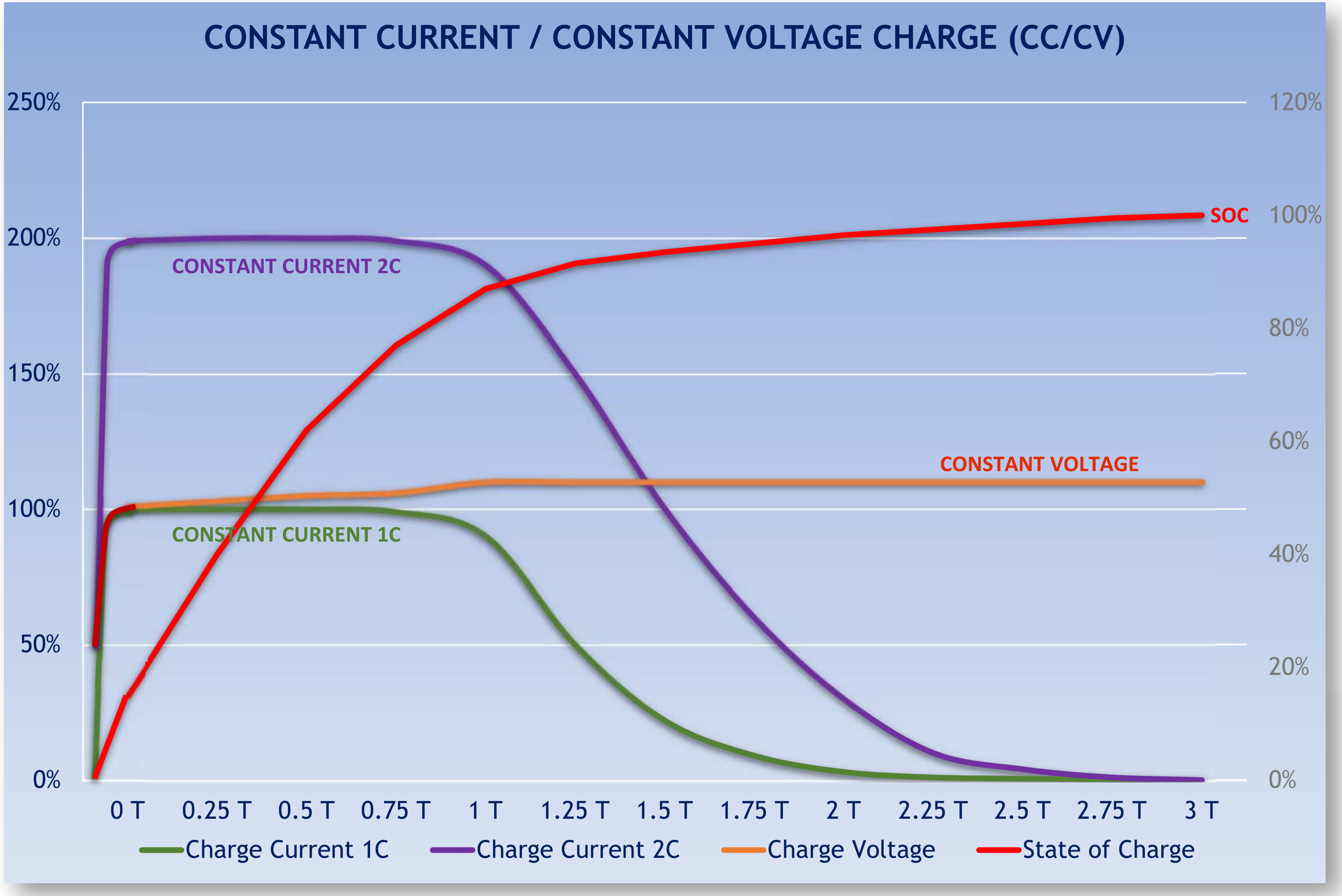
Charging Method & Limits

CHARGE RATE (C_{Rate} or C) :

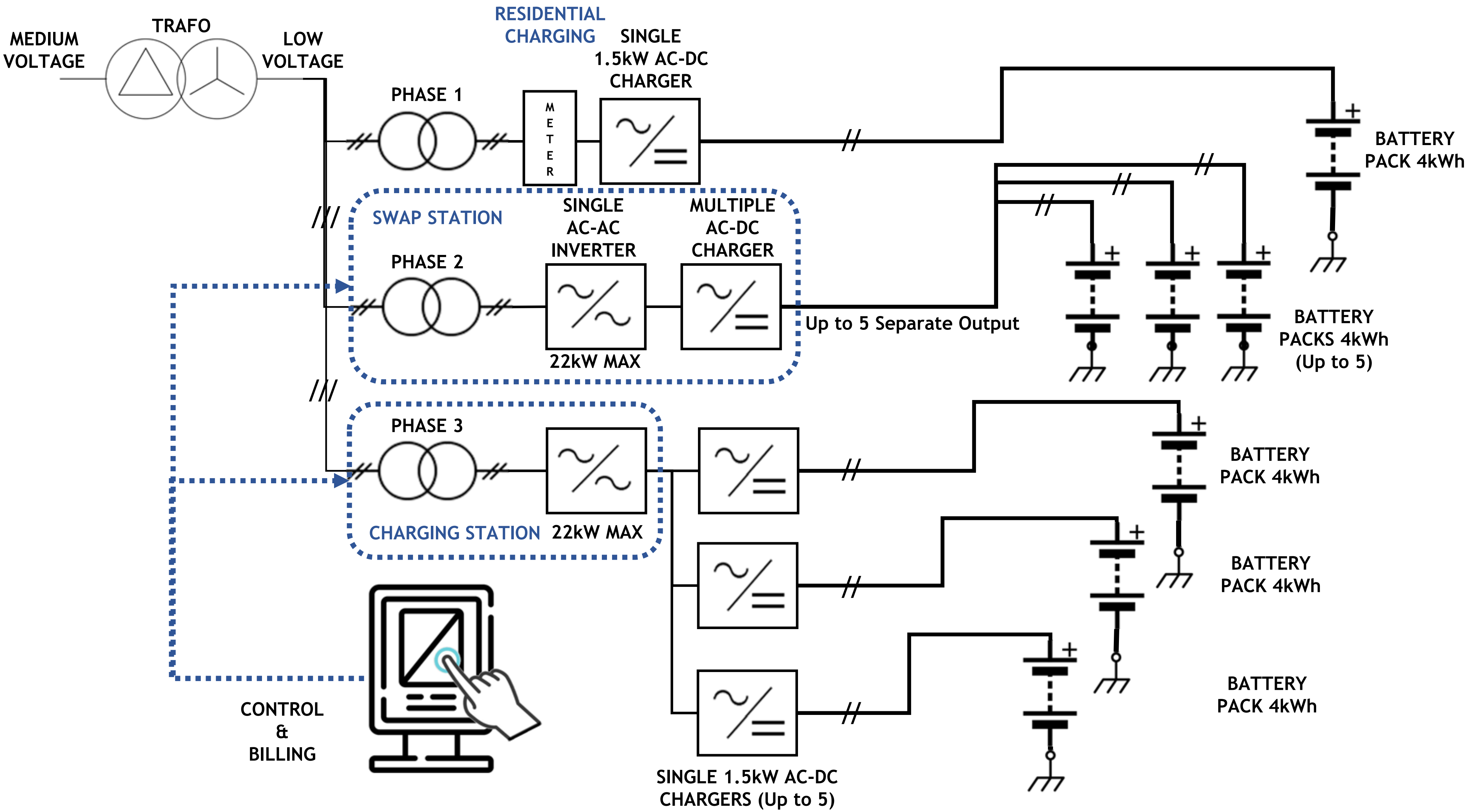
$$C_{Rate} = \frac{P_{Charge\,(W)}}{E_{Capacity\,(Wh)}}$$

$$P_{Charge\,(V)} = V_{Chrg\,(V)} * I_{Chrg\,(A)}$$



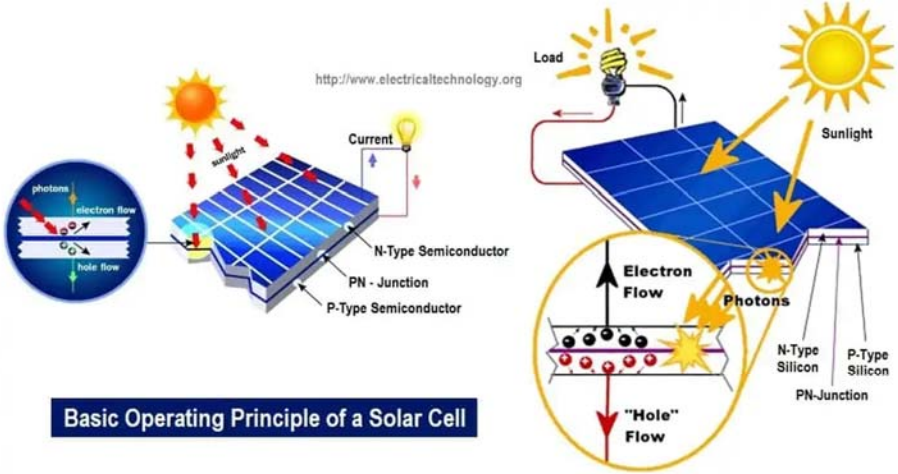


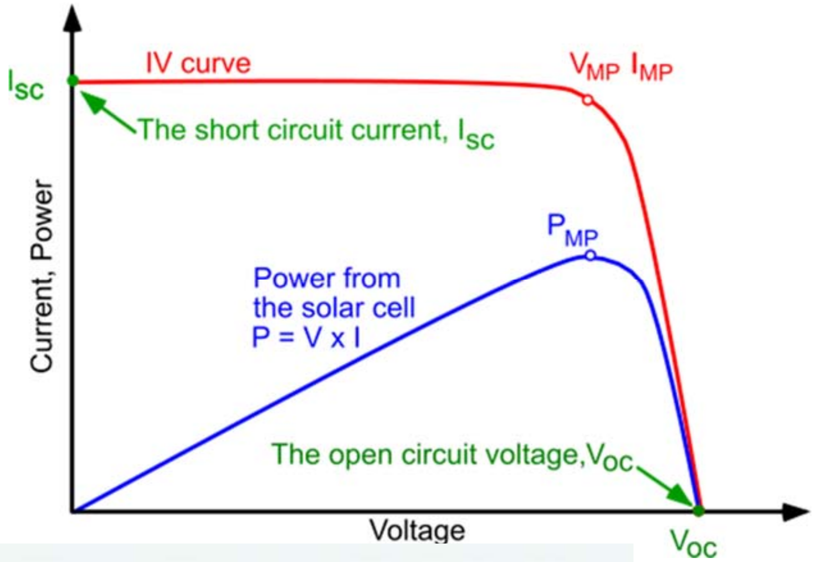
Charging Methods Diagrams

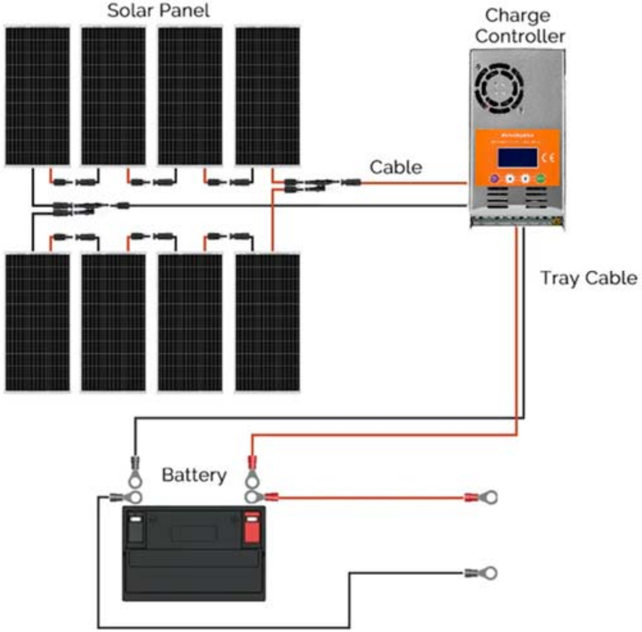


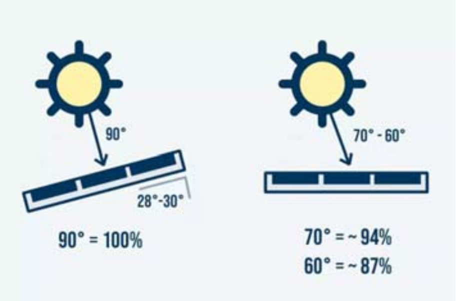
Photovoltaics

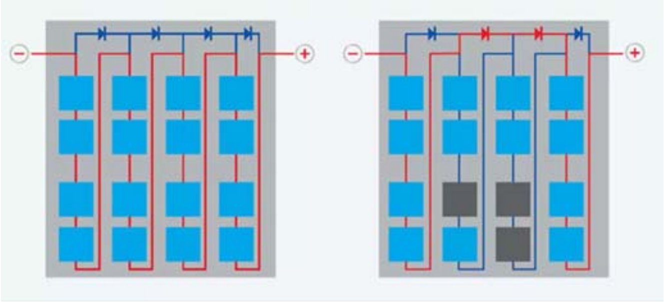
On Board Photovoltaics

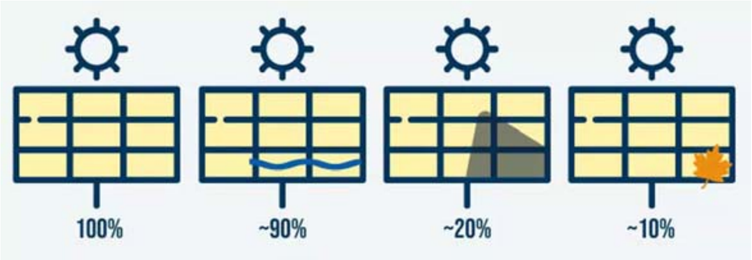




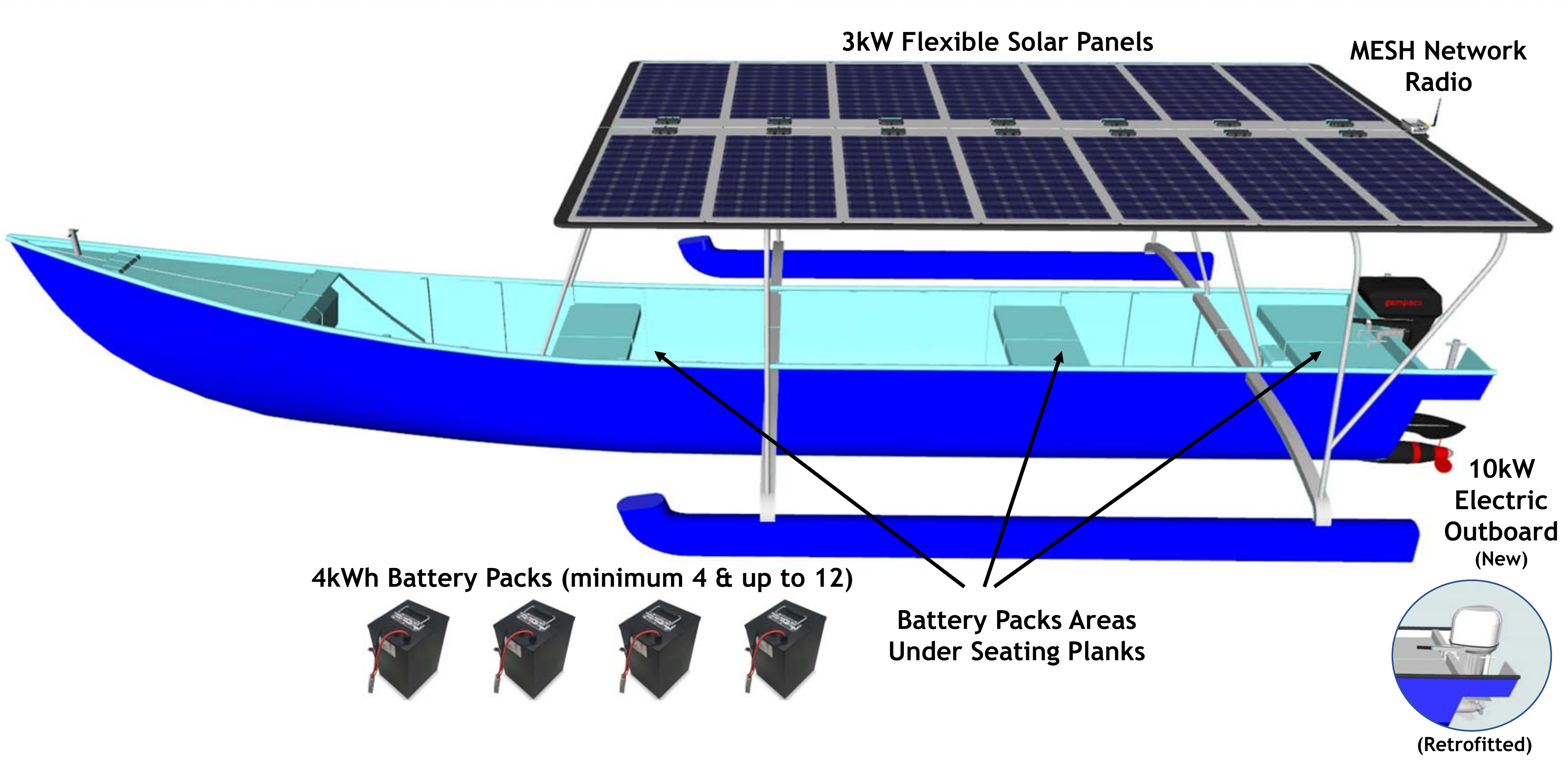








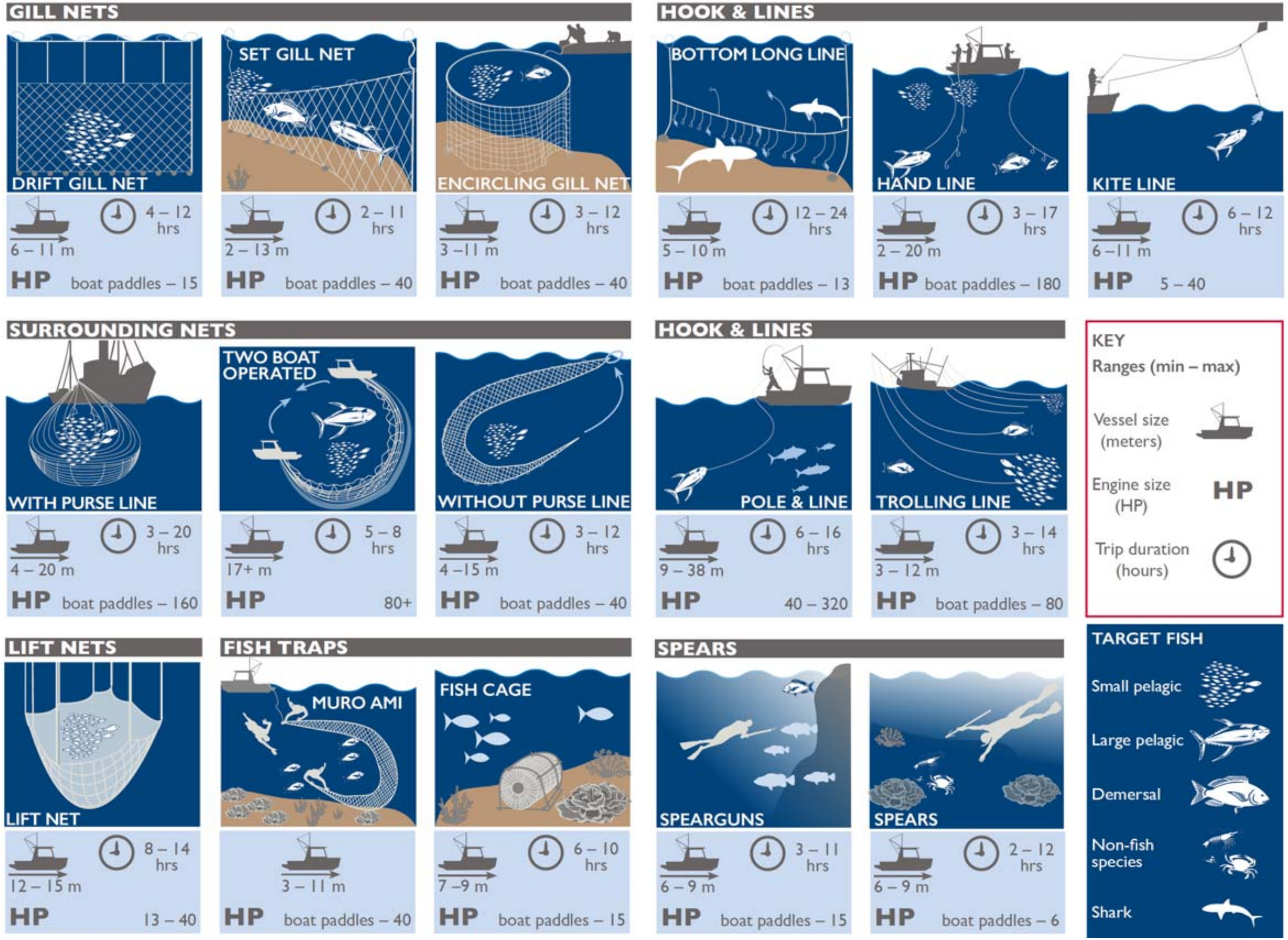
gempacs Standard Boat Model



Fishing Gears & Profiles

To understand different Boat Usage Profiles

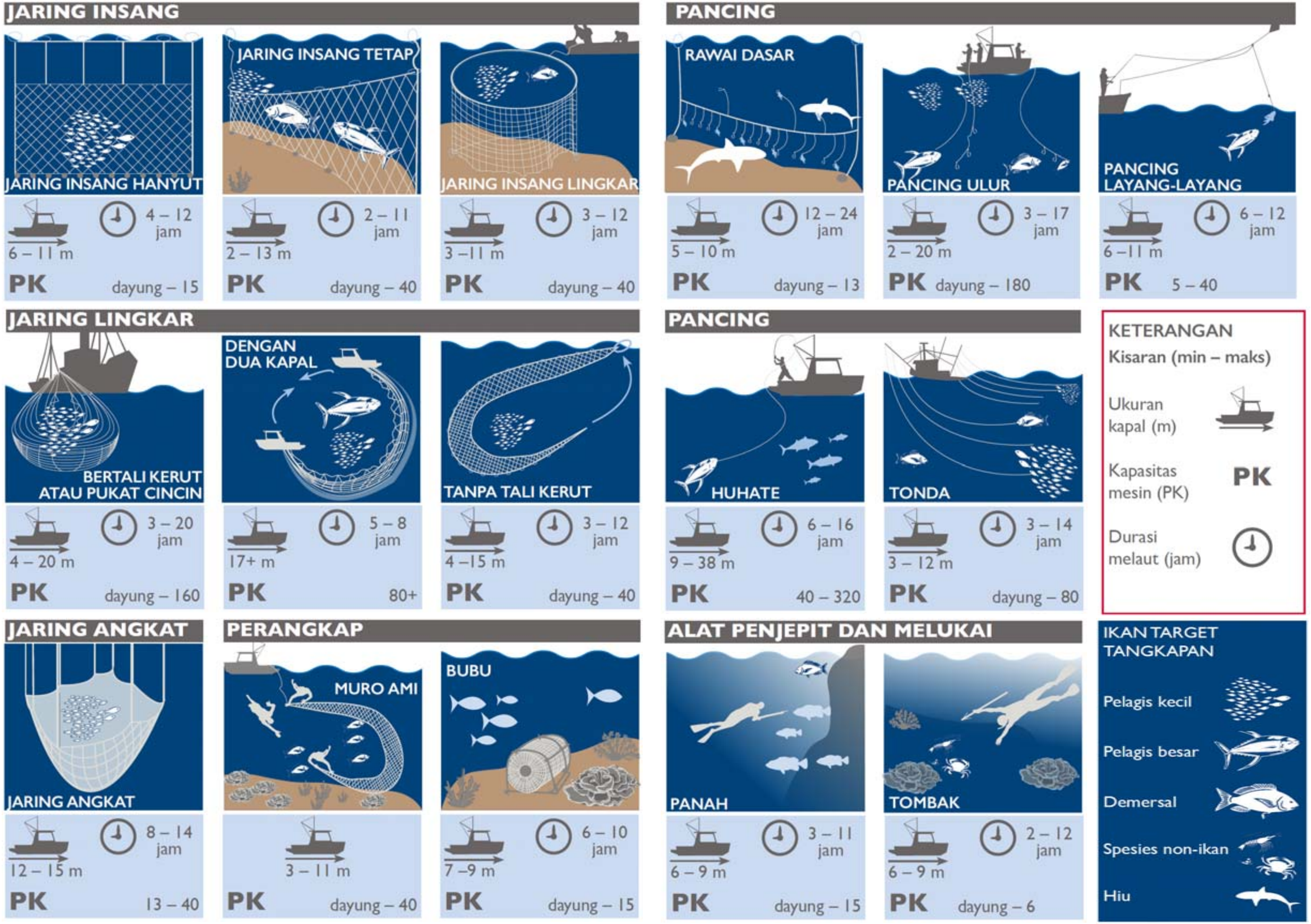
Fishing Profiles & Common Gear Types in Small-Scale Coastal Fisheries



Gear specifications.

- **Gill nets:**
  encircling (100 - 300m long x 5 - 15m wide.
  Mesh 1 - 3.5 inches);
  drift (50 - 200m long x 3 - 5m wide.
  Mesh 1.5 - 3.5 inches);
  set (50 - 300m long x 3 - 5m wide.
  Mesh 1 - 3.5 inches).
- **Lift nets:**
  15 x 15m nets, 9 - 30m depth.
- **Surrounding nets:**
  with purse line (200 - 300m long x 9 - 40m wide.
  Mesh 1.5 to 2 inches); two boat operated (200 -300m long x 60m wide);
  without purse line (100 - 200m long x 5 - 10m wide).
- **Fish cage:**
  100 cm long x 50 cm wide.

Jenis Alat Tangkap Yang Umum Digunakan Dalam



Spesifikasi alat

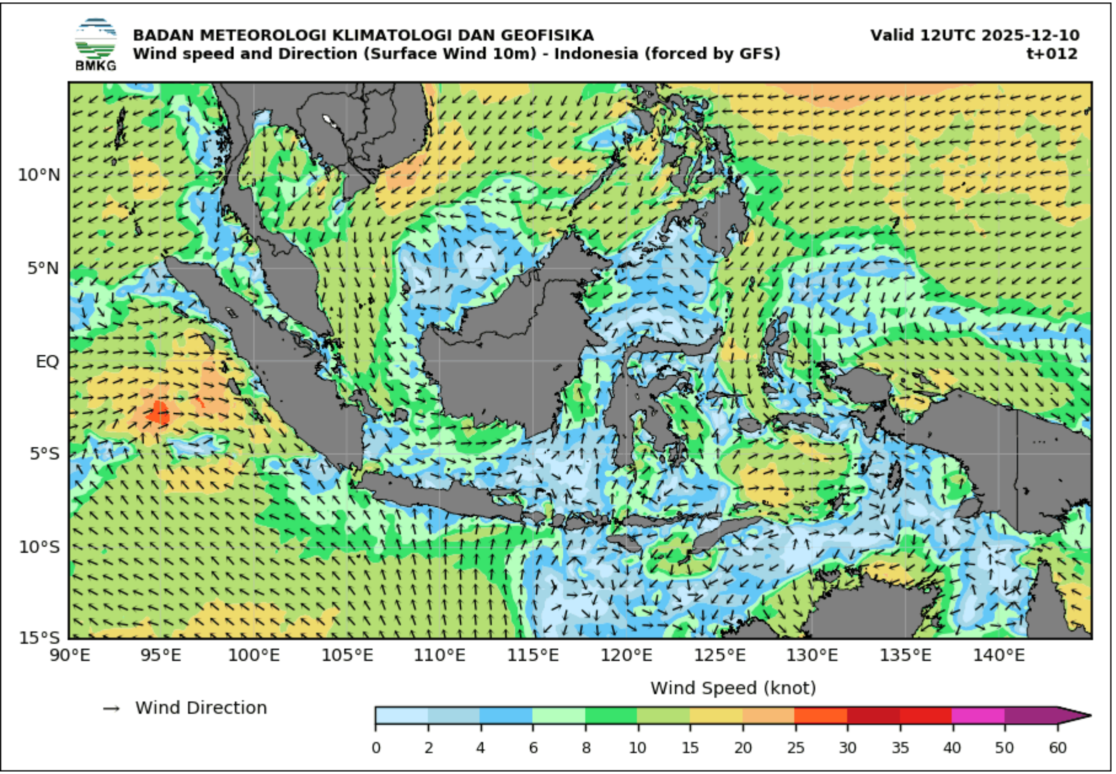
- tangkap: Jaring insang: lingkar (panjang 100 - 300m x lebar 5 - 15m. Mesh 1 – 3,5 inchi); hanyut (panjang 50 - 200m x 3- 5m lebar. Mesh 1,5 – 3,5 inchi); tetap (panjang 50 - 300m x lebar 3 - 5m. Mesh 1 – 3,5 inchi)
- Jaring angkat: jarring 15 x 15m, kedalaman 9 - 30m.
- Jaring lingkar: bertali kerut/pukat cincin (panjang 200 - 300m x lebar 9 - 40m. Mesh 1,5 – 2 inchi); dengan dua kapal(panjang 200 - 300m x lebar 60m); tanpa tali kerut (panjang 100 - 200m x lebar 5 - 10m).
- Bubu:Panjang 100 cm x lebar 50 cm.

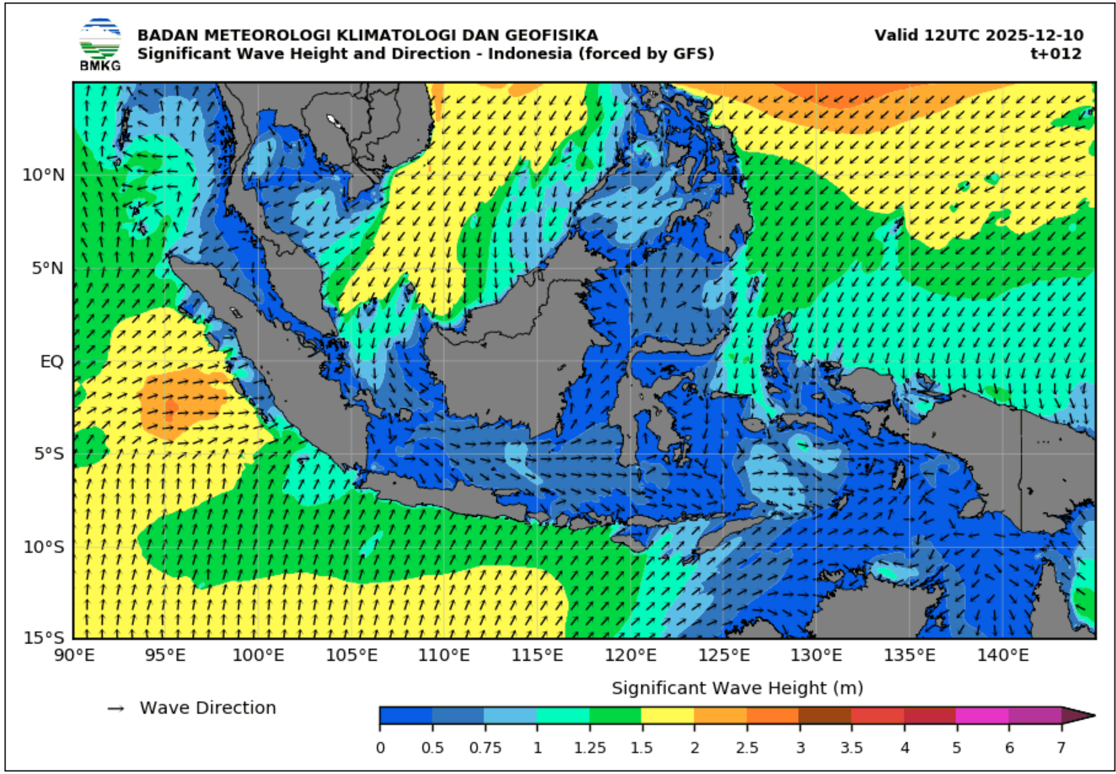
Sea Conditions

Possible Sea Conditions to Withstand

- It is expected that the Electric Outboard can be completely submerged for few seconds by the sea waves, in bad weather conditions, especially when performing beach landing.
- Therefore a minimum IP67 level of Ingress Protection must be enforced on all equipment

Winds & Waves Maps





https://maritim.bmkg.go.id/ofs-static

Boat Types

What are the Suitable Boats for Conversion

Suitable Fishing Boat Types - Gross Ton Classification

3GT (Gross Ton) Boat

- Length: up to 10 meters
- Width: up to 1.5 meters
- Height up to 0.8 meters
- Weight: about 1 Tons (metric)
- Power: 15 - 25 hp
- Range: 6-8 hours at 7-9 knots
- Operation: Daily Return
- Outriggers: Yes

1.5GT (Gross Ton) Boat

- Length: up to 7 meters
- Width: up to 1 meters
- Height up to 0.6 meters
- Weight: about 0.6 Tons (metric)
- Power: 5 - 15 hp
- Range: 6-8 hours at 7-9 knots
- Operation: Daily Return
- Outriggers: Yes

Mesh Networking

To allow communication and geo-localization of the boats

What is MESHTASTIC

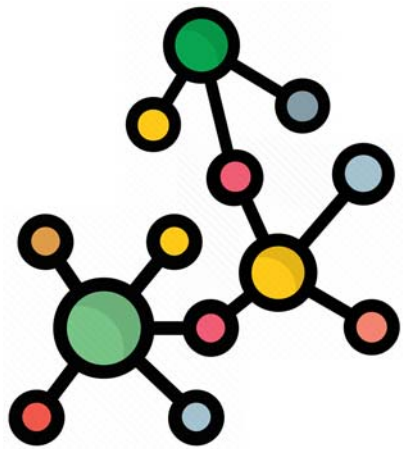
- **MESHTASTIC** is an **OPEN-SOURCE**, **PEER-TO-PEER MESH** networking platform that allows low cost radio devices to communicate with each other without the need for a central server or infrastructure. This makes it ideal for use in remote or challenging environments where traditional CELLULAR or Wi-Fi networks are unavailable or unreliable.
- The underlying protocol is **LoRa-P2P**, which is a low-power, long-range wireless technology that is well-suited for outdoor use.
- **MESHTASTIC** also uses encryption to protect data from unauthorized access and ensure reliable and secure communication between devices with a typical range of about 10 kilometers between devices.
- **MESHTASTIC** can be used for:

☑ **Communication**: to send text messages, voice messages, and location data between devices. This can be useful for communicating in remote areas, or for coordinating search and rescue & disaster relief operations.

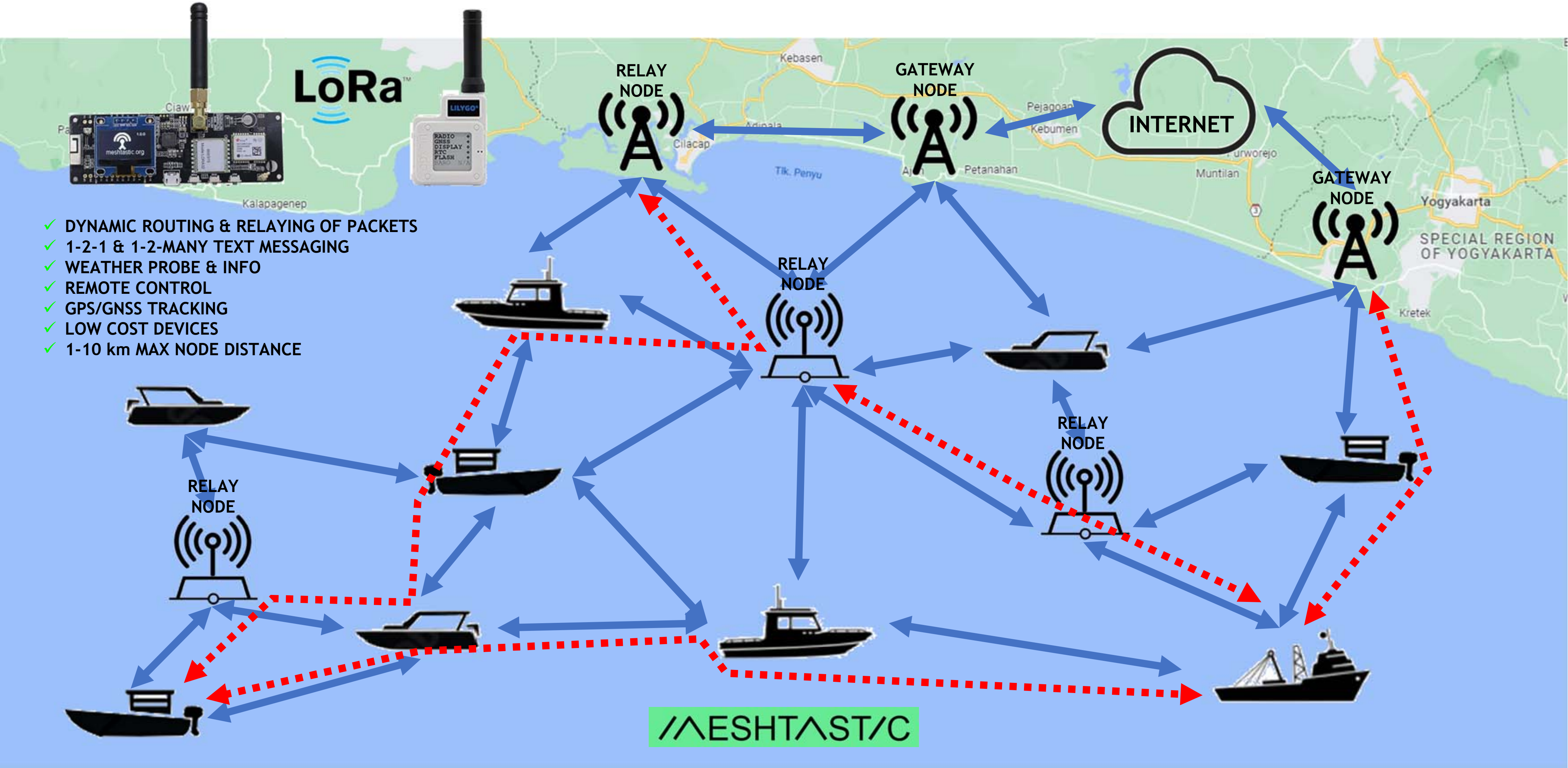
☑ **Tracking**: to track the location of devices. This can be useful for keeping tabs on children or pets, or for monitoring the movement of assets.

☑ **Alerting**: to send alerts to devices. This can be useful for warning of danger, or for notifying people of important events.

☑ **Networking**: to create a network of devices. This can be useful for sharing data or resources, or for creating a resilient communication network.



MESHTASTIC Network Communication System



COASTAL ECOSYSTEM