
# MARITIME BATTERIES 101

Singapore – 8 MAY 2023

# ABOUT THE FORUM

A PLATFORM FOR SHARING KNOWLEDGE, BEST PRACTICES, EXPERIENCE AND BUILDING A GLOBAL NETWORK

REDUCE FINANCIAL, REGULATORY AND KNOWLEDGE BARRIERS

DRIVING SAFETY IN OPERATIONS

ARENA FOR COLLABORATION ON TECHNOLOGY DEVELOPMENT AND STANDARDIZATION



# ABOUT ME

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***BATTERY EXPERT - R&D DEPARTMENT***

ROTTERDAM

***NETHERLANDS***


# BATTERY BASICS

- LITHIUM-ION BATTERIES – THE **BASICS**
- WHAT MAKES A BATTERY SYSTEM A **MARITIME** BATTERY SYSTEM?
- **SAFE** INTEGRATION ON BOARD SHIPS
- **SIZING** AND **SELECTING** THE RIGHT BATTERY FOR YOUR SHIP

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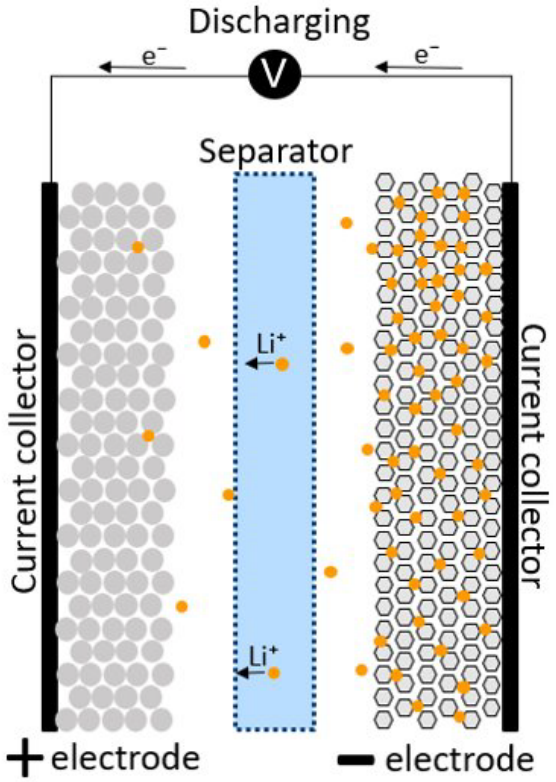
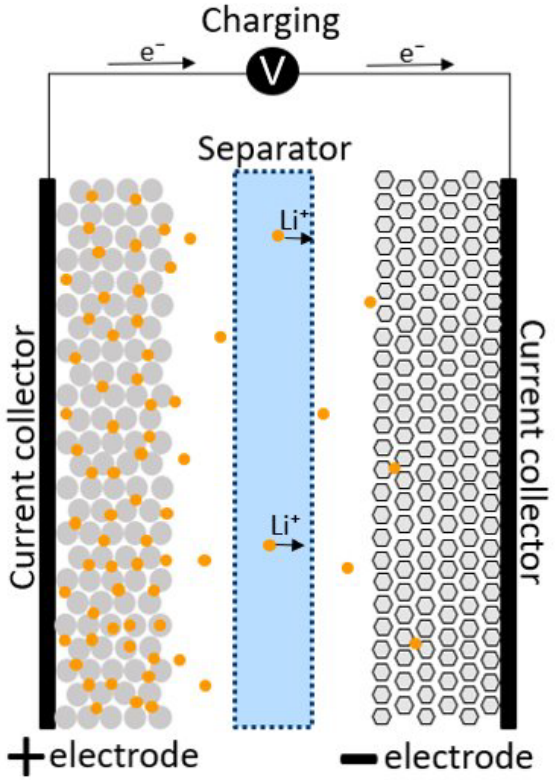
# MARITIME BATTERIES 101

## BATTERY BASICS

# LITHIUM-ION BATTERIES

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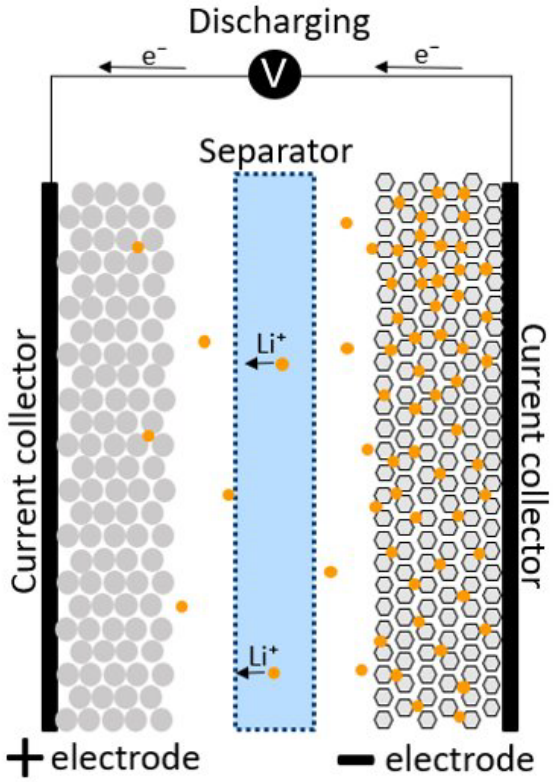
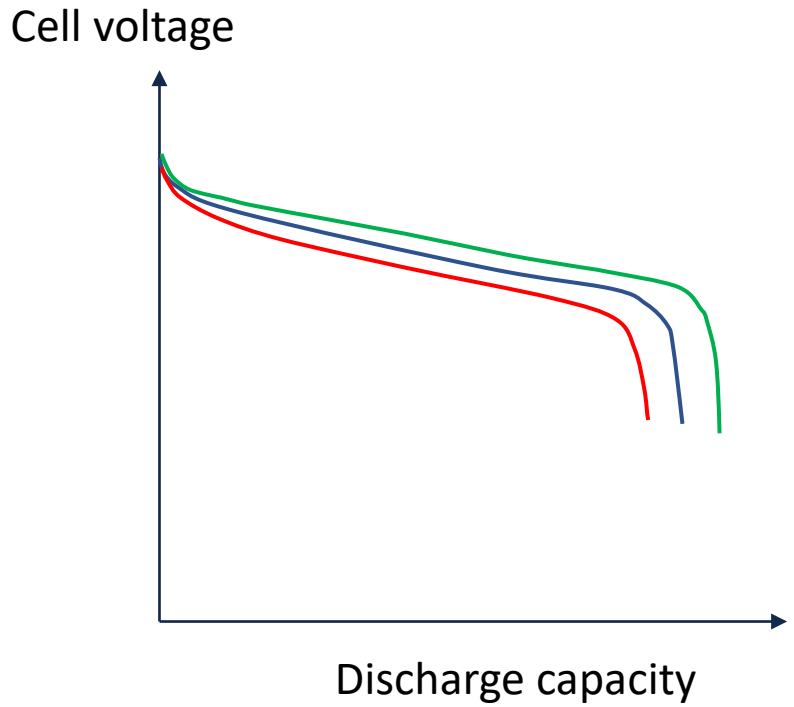
# LITHIUM-ION BATTERIES

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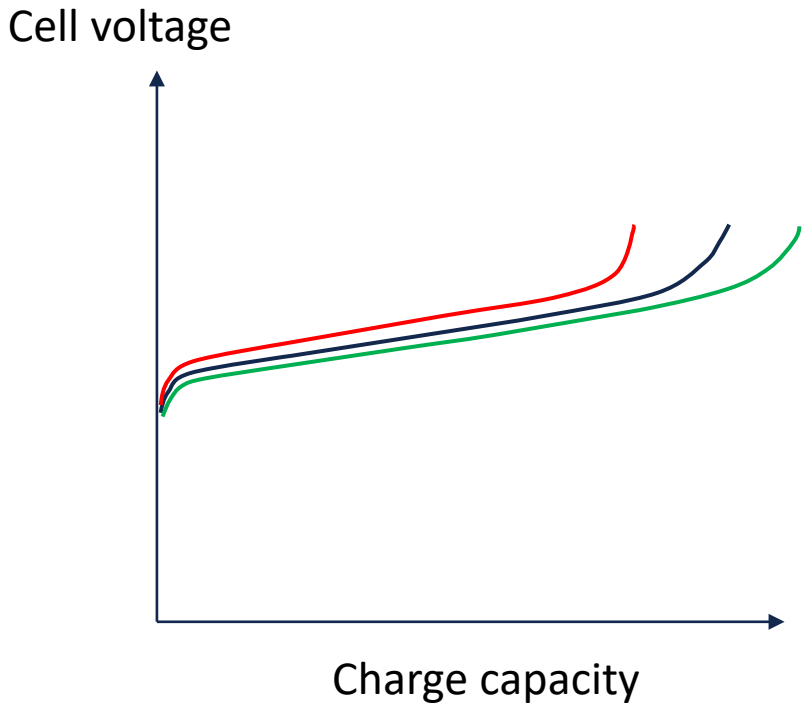
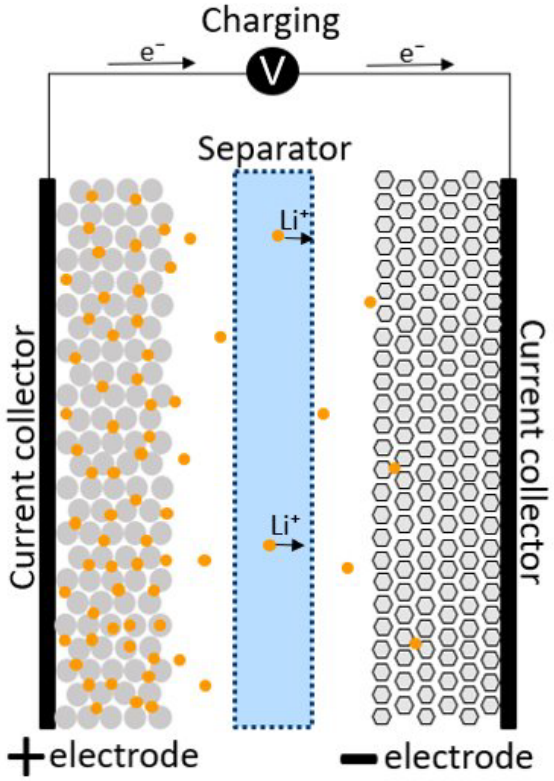
# LITHIUM-ION BATTERIES

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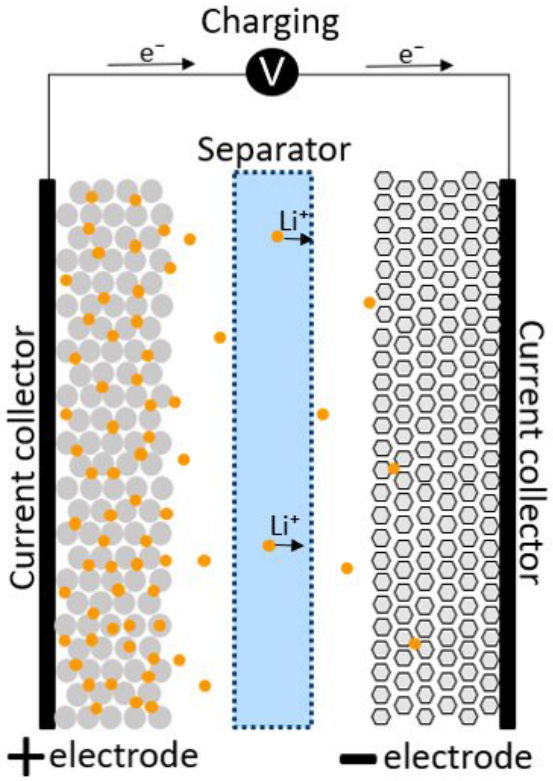
# LITHIUM-ION BATTERIES

Nickel Manganese Cobalt

Iron Phosphate




Graphite

Titanate

NMC = Nickel Manganese Cobalt

LFP = Lithium Iron Phosphate

LTO = Lithium Titanate

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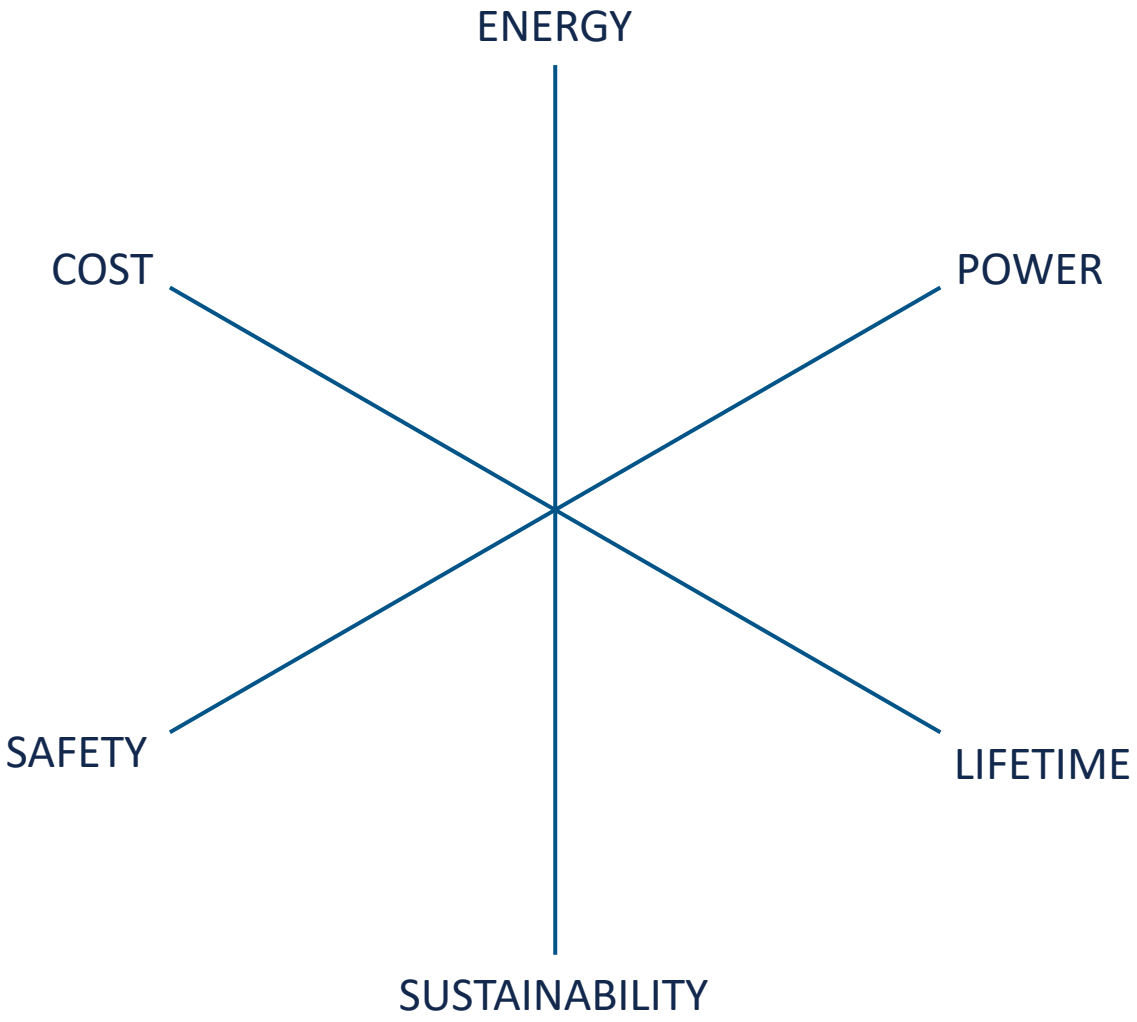
# LITHIUM-ION BATTERIES

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# LITHIUM-ION BATTERIES

## BATTERY CELLS

Cylindrical


Prismatic

Pouch

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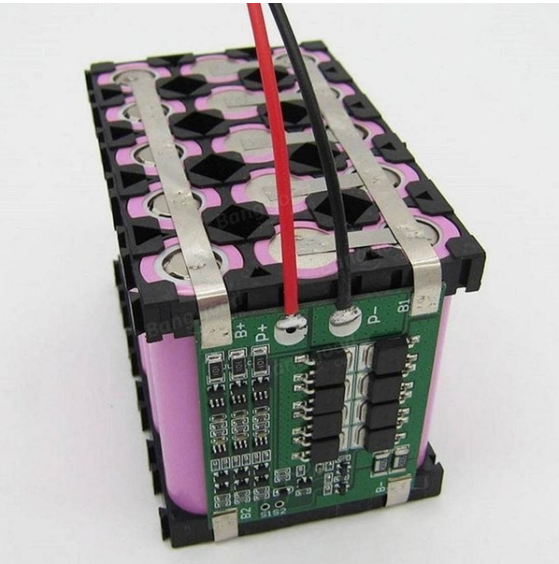
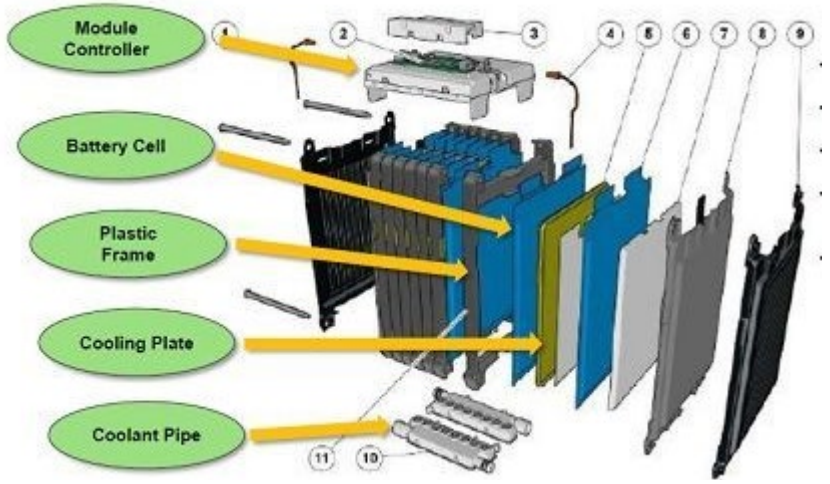
# LITHIUM-ION BATTERIES

## BATTERY MODULE



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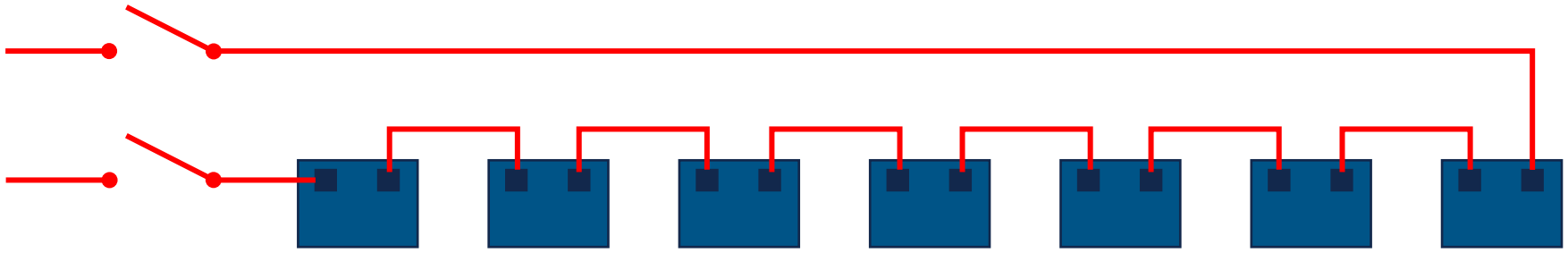
# LITHIUM-ION BATTERIES

## BATTERY STRING



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# LITHIUM-ION BATTERIES

## BATTERY MANAGEMENT SYSTEM (BMS)

### Monitoring

- Voltage
- Temperature
- Current
- Gas detection
- Humidity

### Computation

- System voltage
- State of charge (SOC)
- State of health (SOH)
- Current limits
- Voltage balance

### Communication

- With PMS/EMS
- Warnings
- Alarms
- Charging/discharging

### Protection

- Over-current
- Over-voltage
- Under-voltage
- Over-temperature
- Under-temperature
- Ground faults
- Current leakage detection
- Voltage balancing
- Cooling liquid leakage detection

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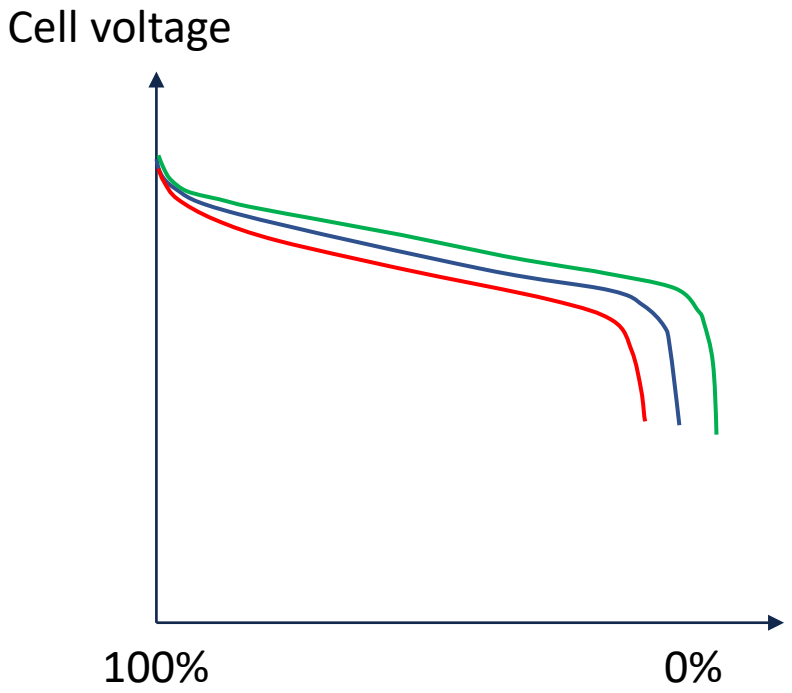
# LITHIUM-ION BATTERIES

## STATE OF CHARGE (SOC)

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# LITHIUM-ION BATTERIES

## C-rates

Charge C-rate = Charge power [kW] / Capacity [kWh]

Discharge C-rate = Discharge power [kW] / Capacity [kWh]

2000 kW / 1000 kWh = 2C
500 kW / 1000 kWh = 0.5C

Typical maximum continuous C-rates of maritime batteries between 0.5C – 6C

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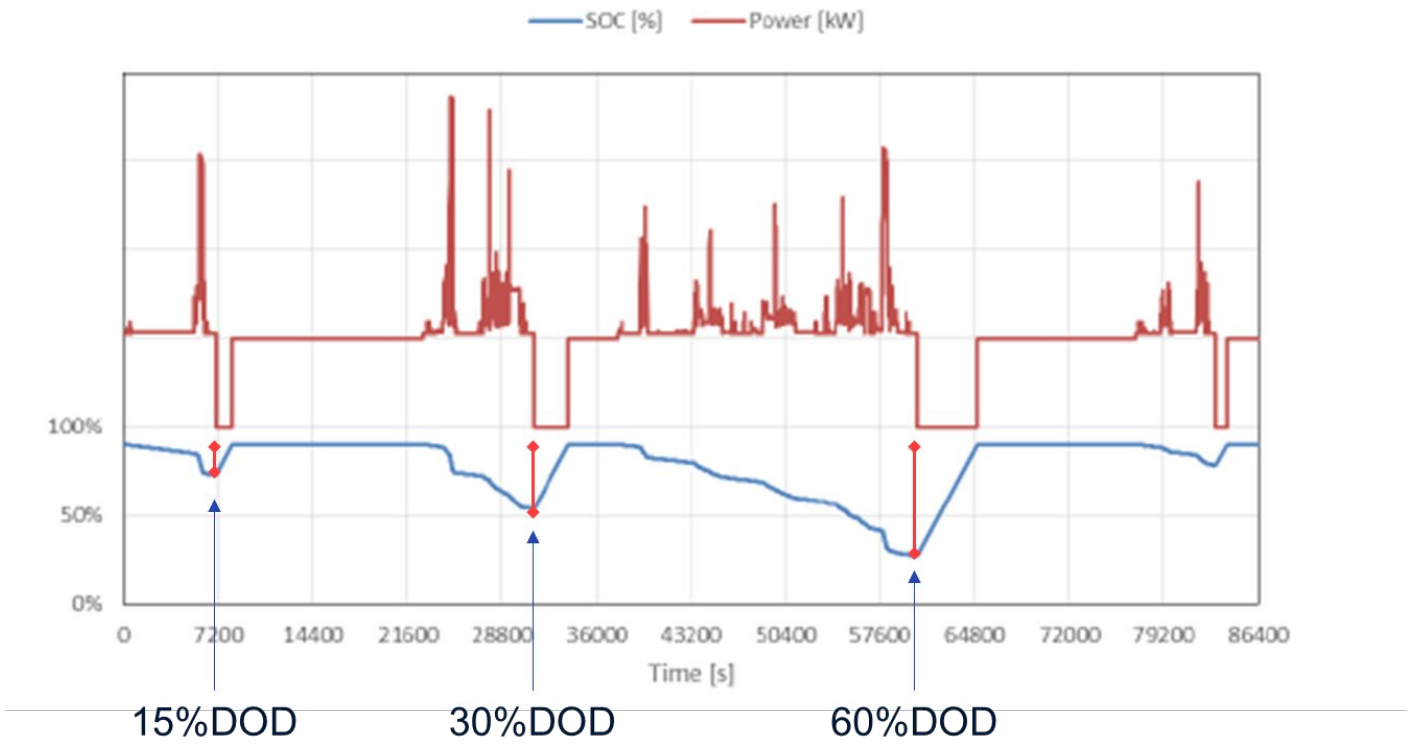
# LITHIUM-ION BATTERIES

## Cycles & Depth of discharge (DOD)

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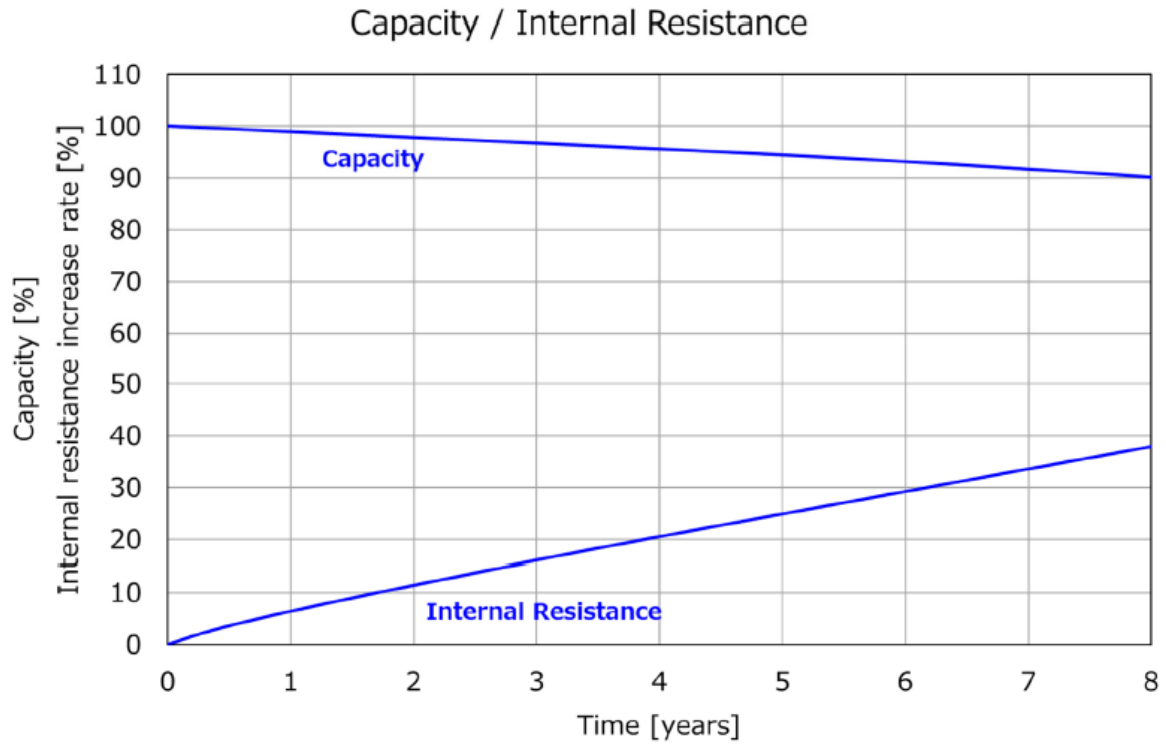
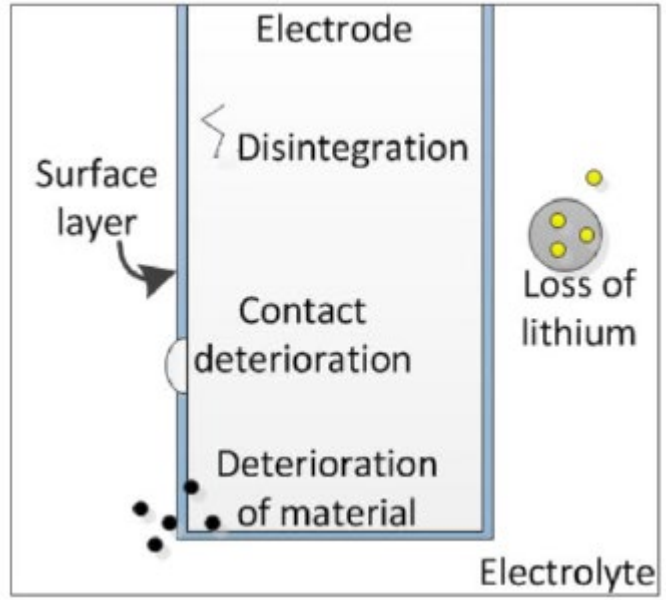
# LITHIUM-ION BATTERIES

## STATE OF HEALTH (SOH)




## AGING

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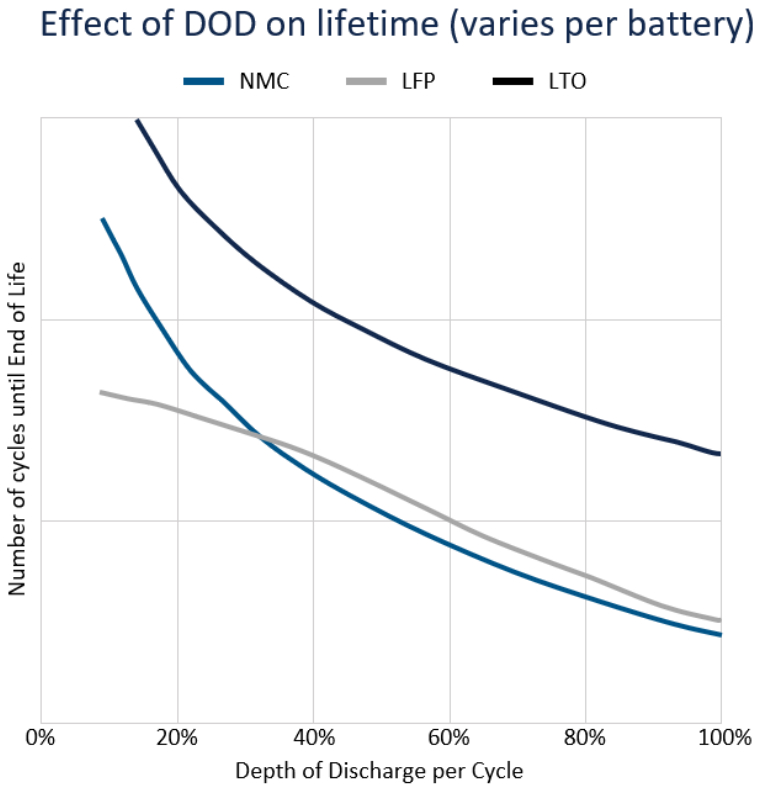
# LITHIUM-ION BATTERIES

## Aging

Calendar aging → Temperature
Calendar aging → State-of-Charge

Cycle aging → Depth of discharge
Cycle aging → C-rates

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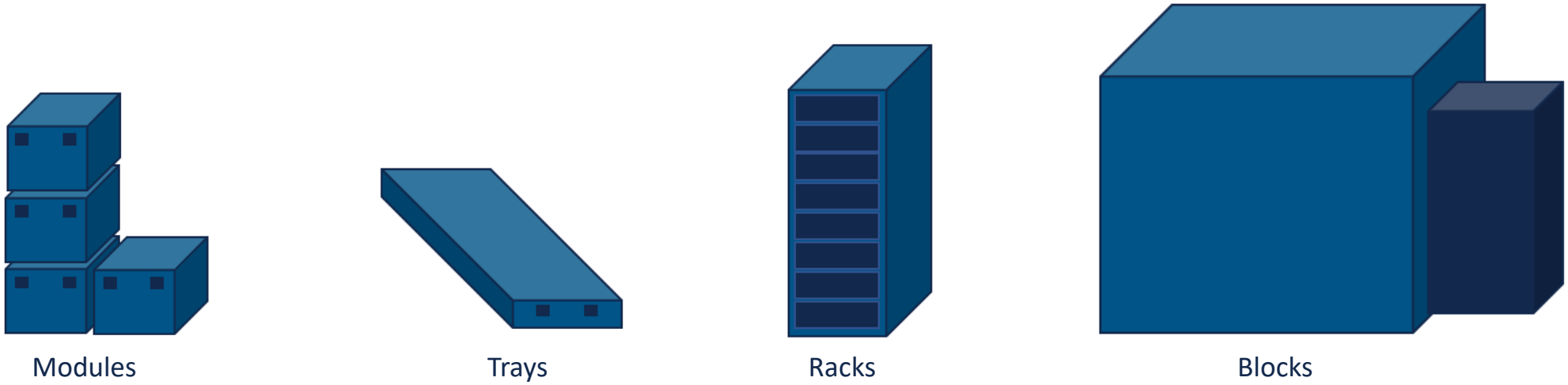
# MARITIME BATTERIES 101

MARITIME BATTERY SYSTEMS

# MARITIME BATTERY SYSTEMS




Flexibility ⟷ Easy integration

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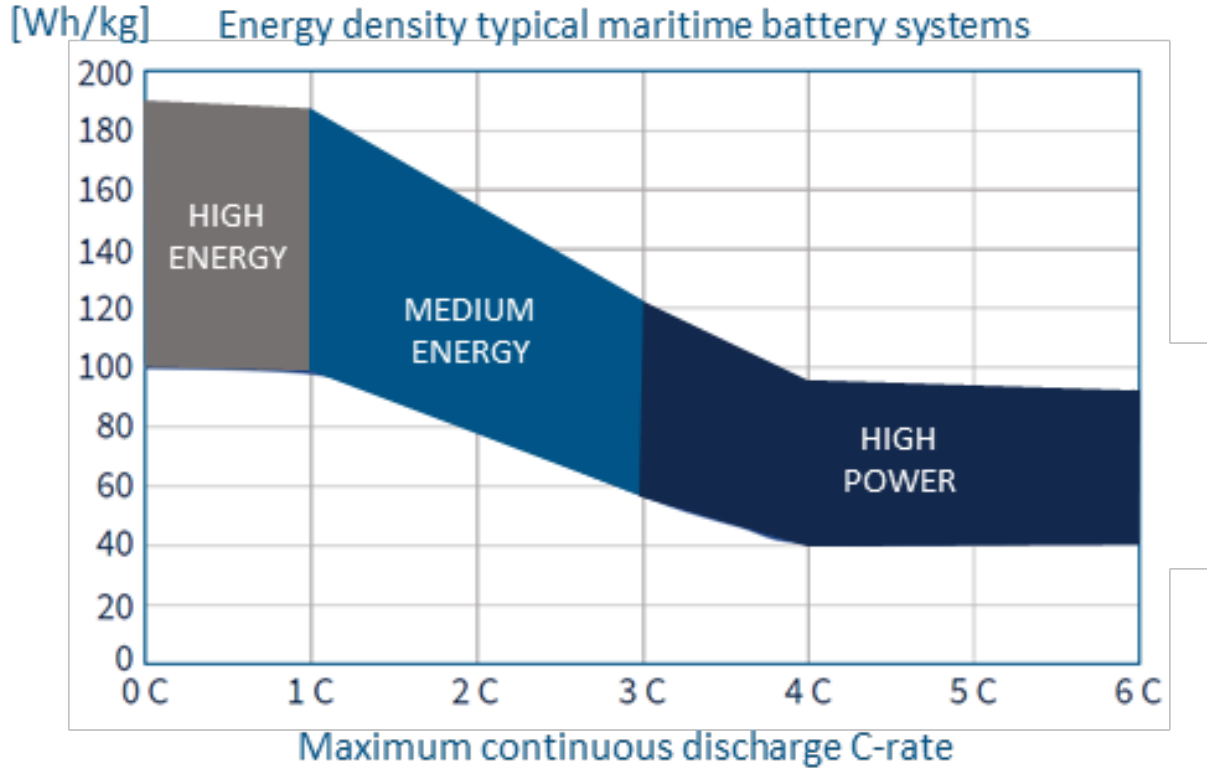
ENERGY DENSITY - POWER

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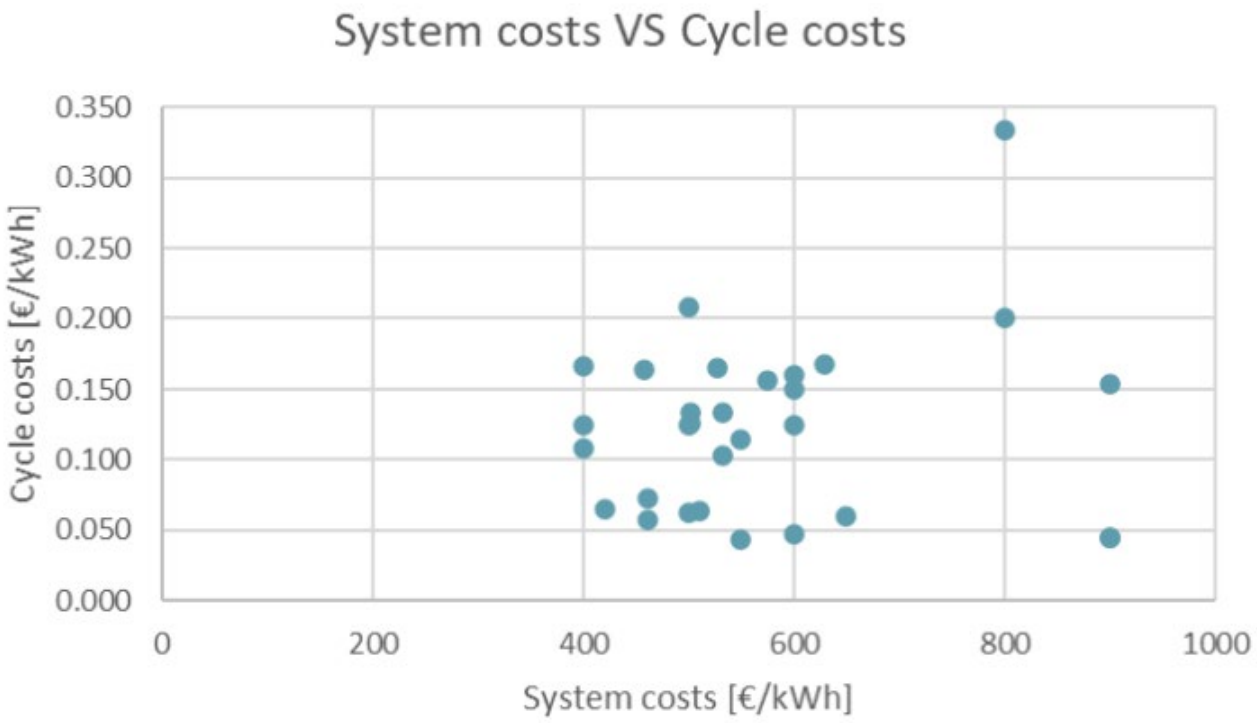
# MARITIME BATTERY SYSTEMS

## COSTS




Source: SEABAT D2.2 Key Performance Indicators List [2021]

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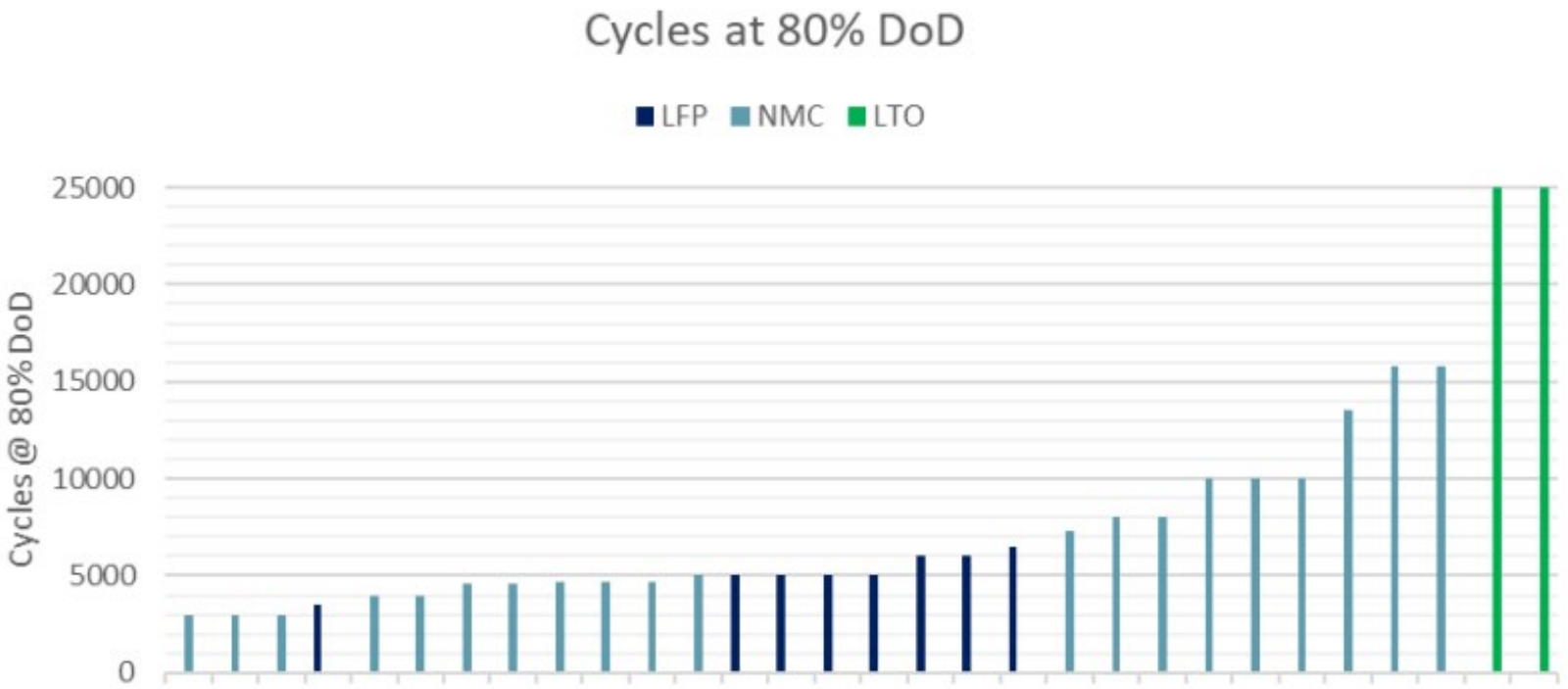
# MARITIME BATTERY SYSTEMS

## CYCLE LIFE




Source: SEABAT D2.2 Key Performance Indicators List [2021]

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# MARITIME BATTERY SYSTEMS

## THERMAL MANAGEMENT

Passive cooling

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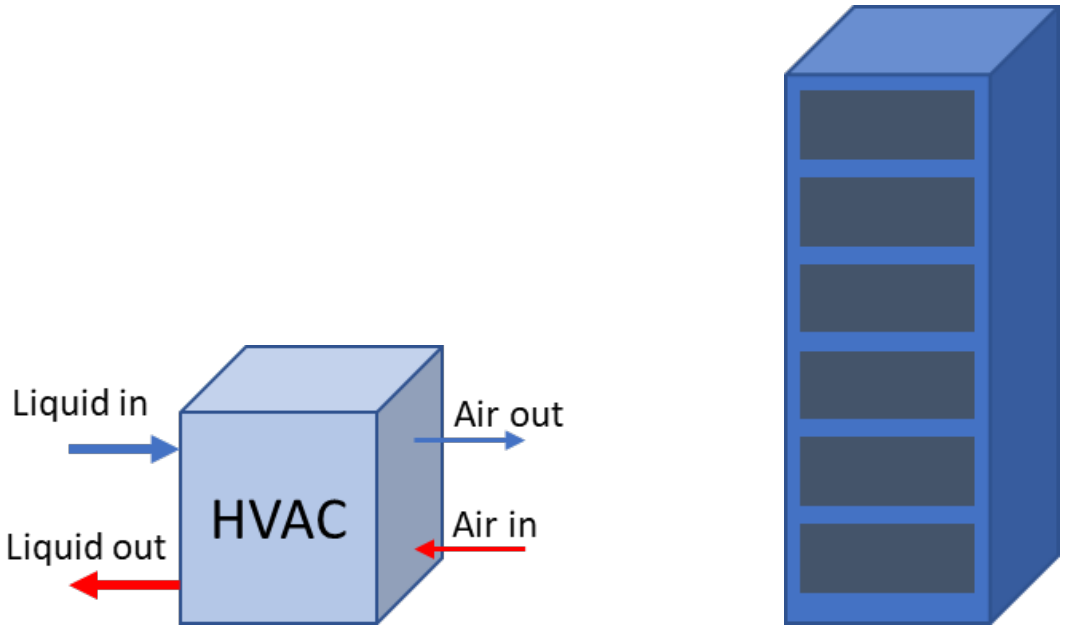
# MARITIME BATTERY SYSTEMS

## THERMAL MANAGEMENT

Passive cooling with HVAC in battery space

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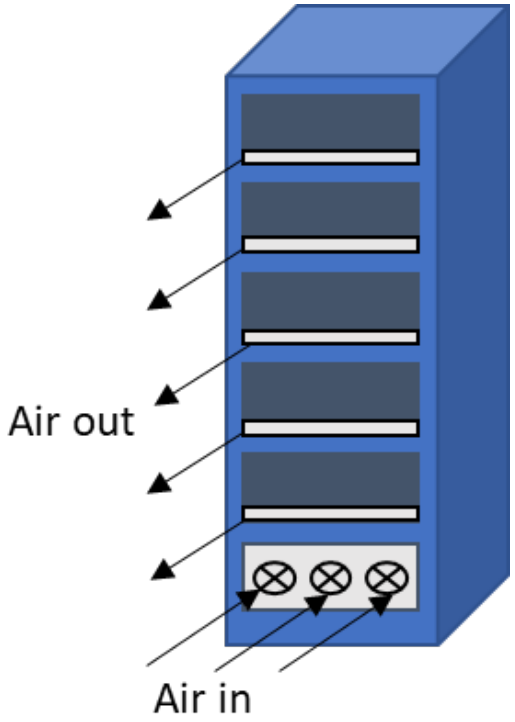
# MARITIME BATTERY SYSTEMS

## THERMAL MANAGEMENT

Forced air cooling

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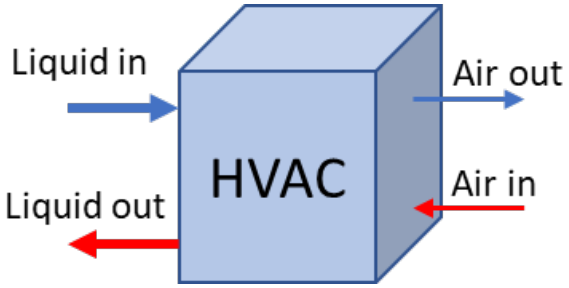
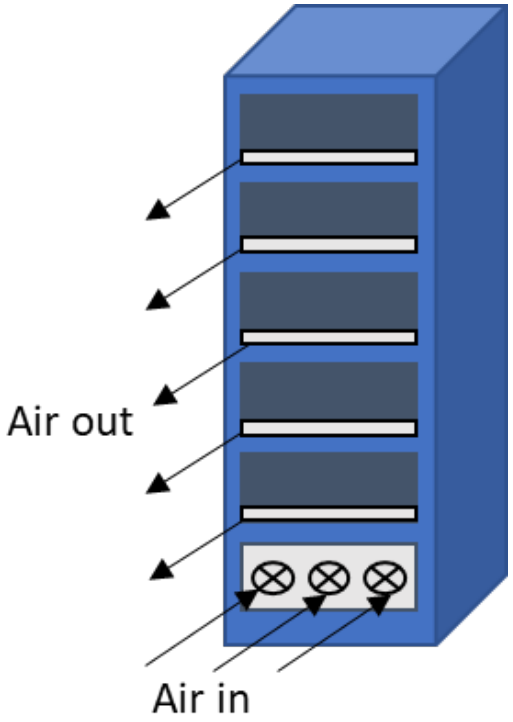
# MARITIME BATTERY SYSTEMS

## THERMAL MANAGEMENT

Forced air cooling with HVAC in battery space

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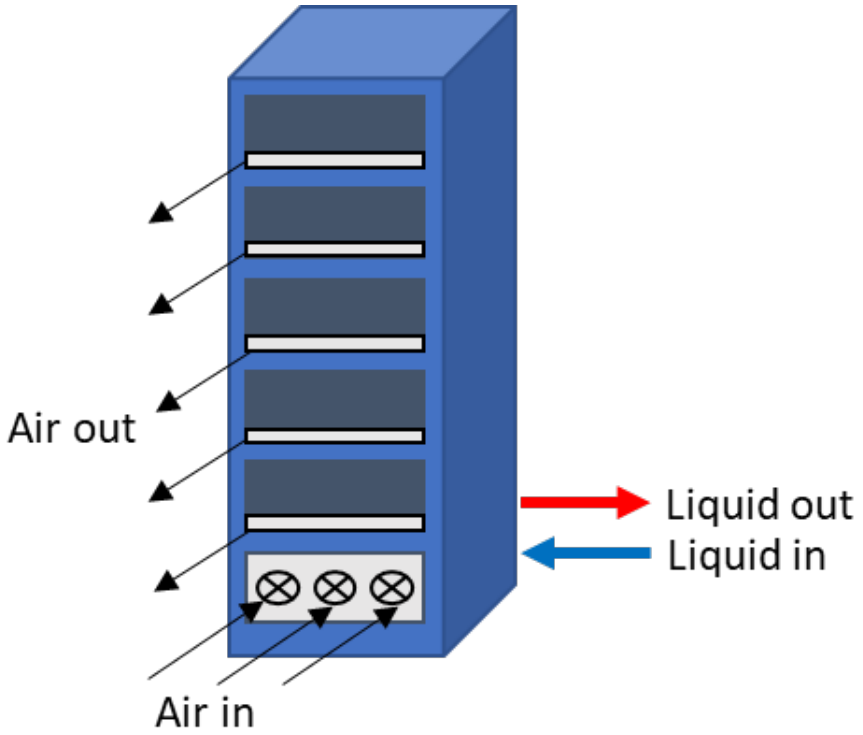
# MARITIME BATTERY SYSTEMS

## THERMAL MANAGEMENT

Forced air cooling with liquid cooling in battery system

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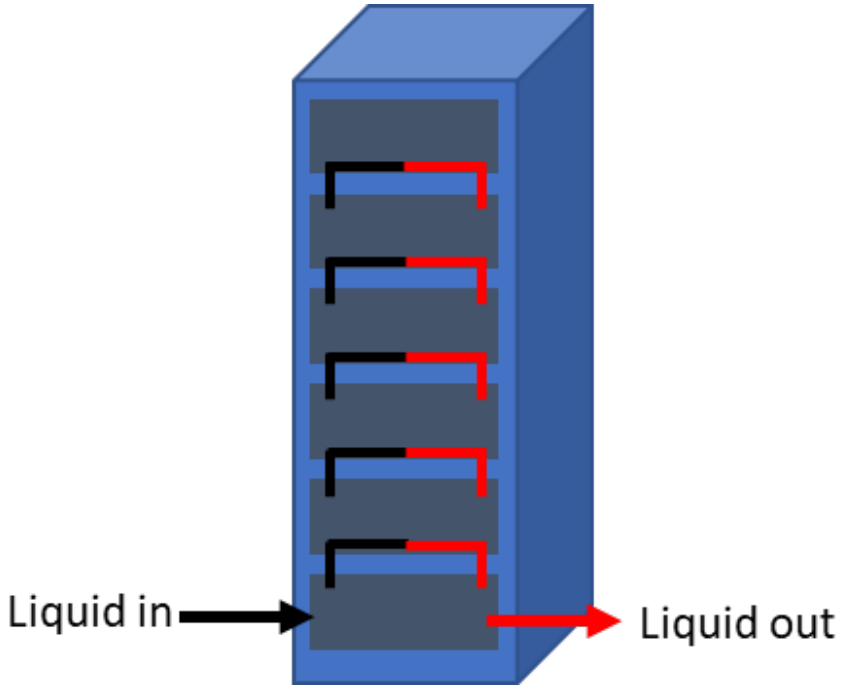
# MARITIME BATTERY SYSTEMS

## THERMAL MANAGEMENT

Liquid cooled battery rack

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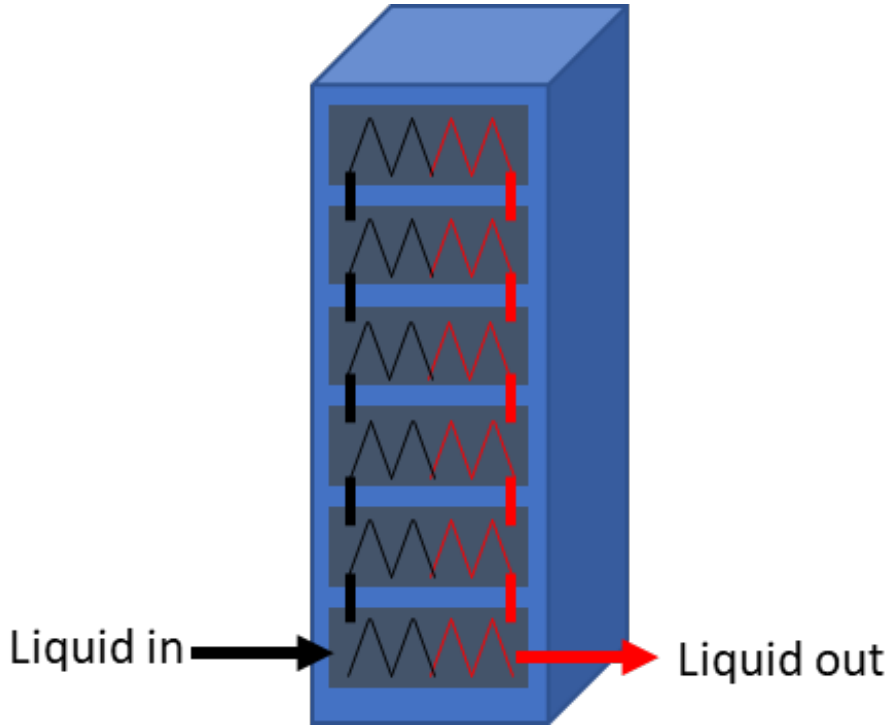
# MARITIME BATTERY SYSTEMS

## THERMAL MANAGEMENT

Liquid cooling inside the battery modules

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# MARITIME BATTERY SYSTEMS

## THERMAL MANAGEMENT

Things to take into account when selecting a battery system and designing the thermal management system

- Use the Root Mean Square charge and discharge power, not the maximum
- Required inlet temperature/pressure cooling medium
- Environmental conditions
- Not only cooling, sometimes heating is required
- Humidity requirements – no condensation
- Air quality – no conductive dust or swarf

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# MARITIME BATTERIES 101

SAFETY

# SAFETY

What have we learned from incidents?

- Improved BMS design
- Thermal runaway propagation insulation
- Firefighting instructions
- Increase ingress protection ratings

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# SAFETY

- THERMAL RUNAWAY PROPAGATION INSULATION
- VENTILATION & GAS DETECTION
- FIREFIGHTING
- LEAKAGES AND (SEA)WATER INTRUSION

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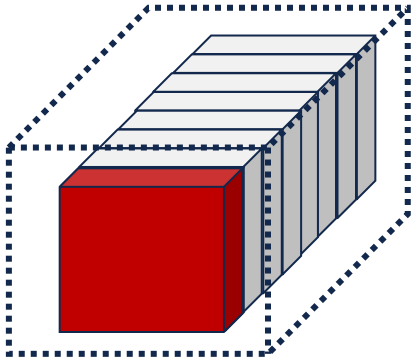
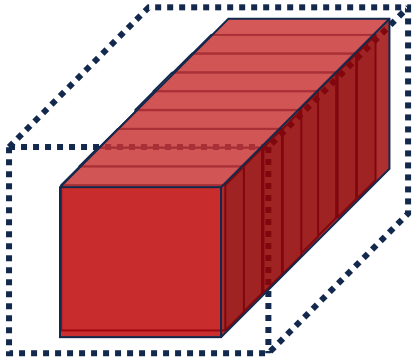
# SAFETY

## THERMAL RUNAWAY PROPAGATION INSULATION



Cell level



Module level

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# SAFETY

VENTILATION & GAS DETECTION

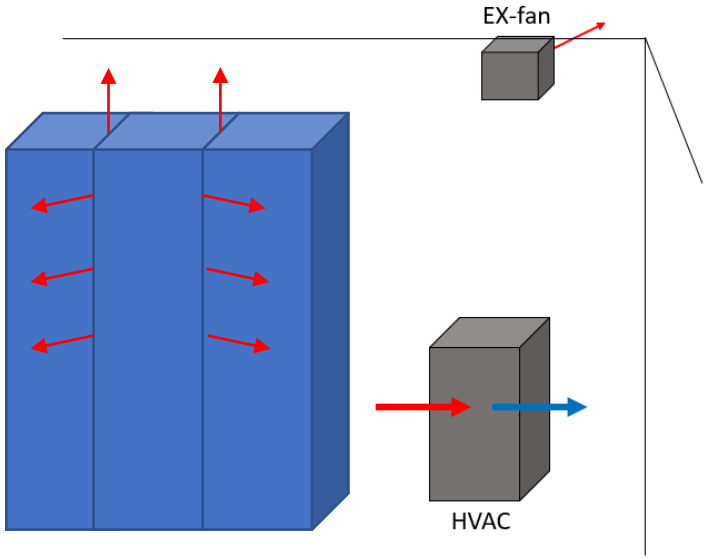
## Why ventilation?

- In case of a thermal runaway, or damaged battery cell, it can exhaust toxic and explosive gases
- Remove these hot gases from the battery system, to protect the surrounding cells
- Prevent these gases from building up in the battery space

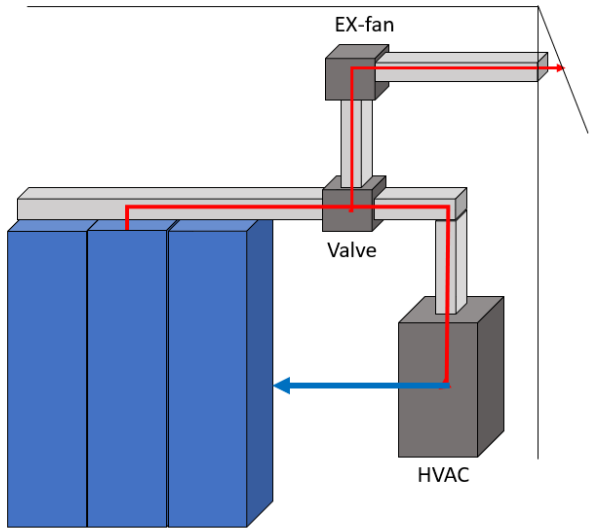
# SAFETY

## VENTILATION & GAS DETECTION

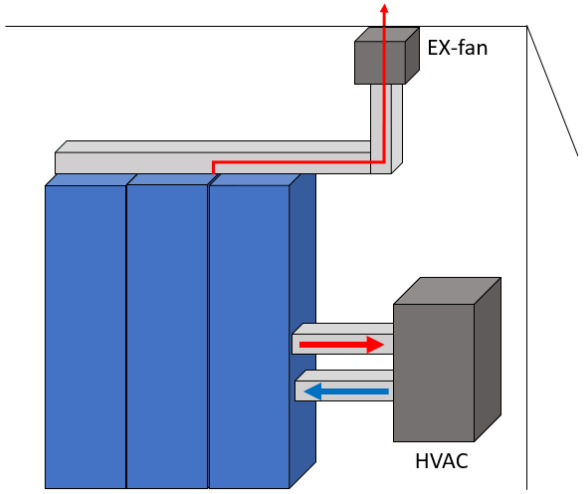
### OPEN




### HALF-OPEN




### CLOSED

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# SAFETY

VENTILATION & GAS DETECTION

## Why gas detection?

- If there is something wrong with the batteries, you will most likely see it on the temperature and/or voltage measurements
- Off-gas can be detected before a thermal runaway starts
- What if temperature and voltage sensors are damaged?
- To monitor the battery space after an incident

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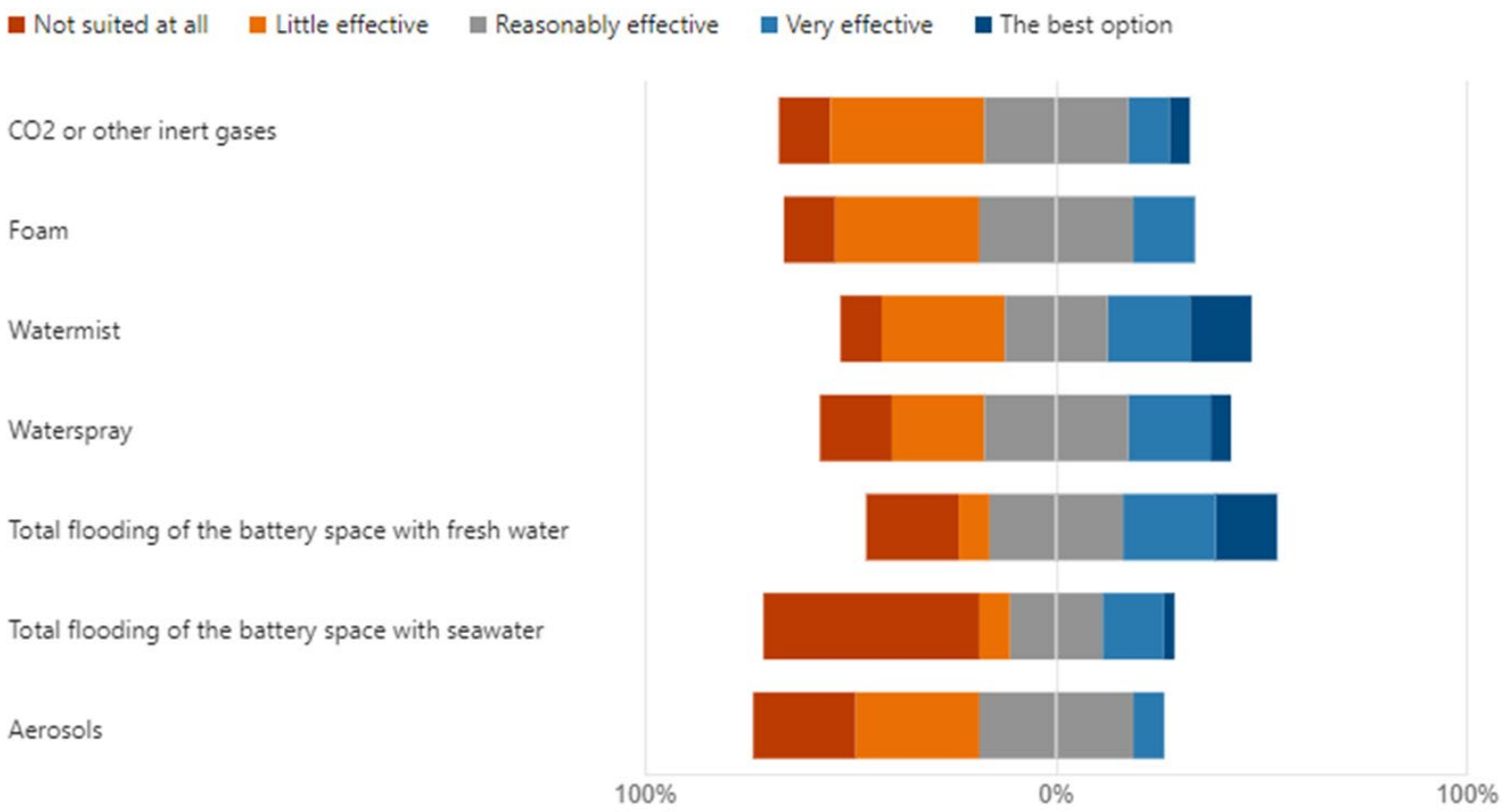
# SAFETY

## FIREFIGHTING

## What do you want to achieve?

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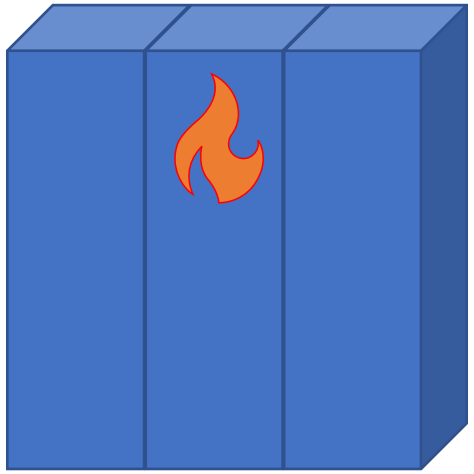
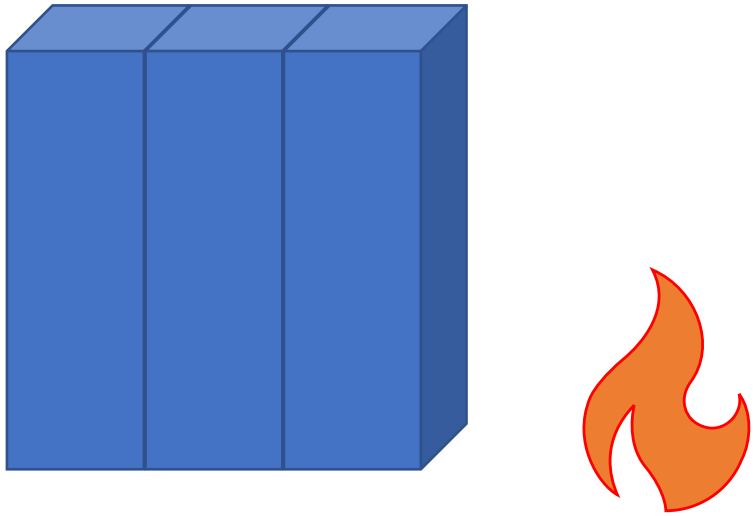
# SAFETY

## FIREFIGHTING

INTERNAL



EXTERNAL



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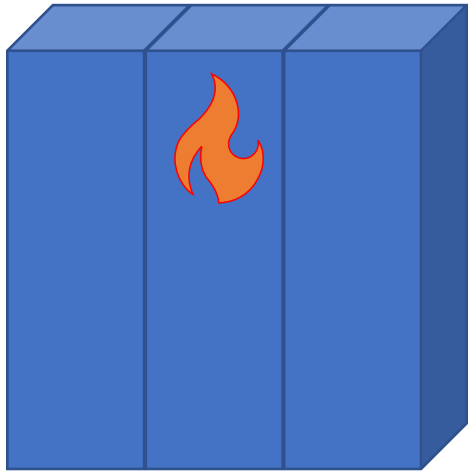
# SAFETY

## FIREFIGHTING

INTERNAL



- Prevent the fire from spreading to other batteries
- Direct cooling at the battery cells/modules
- Extinguish flames that are heating up surrounding batteries

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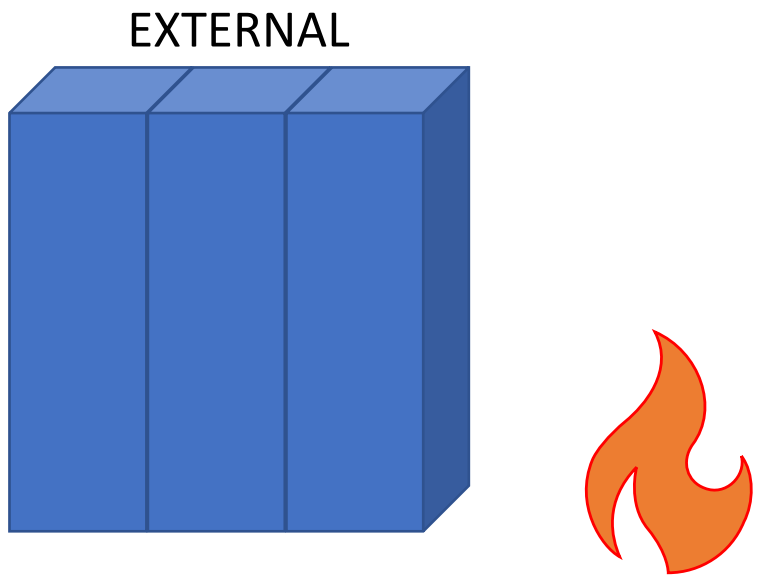
# SAFETY

## FIREFIGHTING

- Prevent the fire from heating up the batteries
- Extinguish the flames in the battery space withouth damaging the battery system
- Cool the batteries so they don’t go in thermal runaway

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# SAFETY

## FIREFIGHTING GUIDELINE

| | | | Method | Type of release | Ventilation | IP rating | Secondary firefighting system | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Fire suppression | | | | | | | | | Fire extinguishing | | | | | | | | | | | | Total flooding | | | |
| | | Fire fighting systems | | | | | None | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| | | 0 None | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Primary firefighting system | Fire suppression | 1 CO2 | I | M | ⊗ | xx | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 2 CO2 | F | M | ⊗ | xx | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 3 NOVEC | I | M | ⊗ | xx | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 4 NOVEC | F | M | ⊗ | xx | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 5 Aerosols | I | A | ⊗ | xx | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 6 Aerosols | F | A | ⊗ | xx | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 7 Inert gases | I | M | ⊗ | xx | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 8 Inert gases | F | M | ⊗ | xx | | | | | | | | | | | | | | | | | | | | | | | | |
| | Fire extinguishing | 9 Watermist | I | A | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 10 Watermist | F | A | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 11 Water spray | I | A | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 12 Water spray | F | A | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 13 Compressed air foam | I | A | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 14 Compressed air foam | F | A | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 15 Aspirated low expansion foam | I | A | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 16 Aspirated low expansion foam | F | A | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 17 Aspirated medium expansion foam | I | A | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 18 Aspirated medium expansion foam | F | A | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 19 Aspirated high expansion foam | I | A | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 20 Aspirated high expansion foam | F | A | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Total flooding | 21 Total flooding with fresh water | I | M | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 22 Total flooding with fresh water | F | M | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 23 Total flooding with seawater | I | M | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 24 Total flooding with seawater | F | M | ⊗ | | | | | | | | | | | | | | | | | | | | | | | | | |

Firefighting method — Direct injection or external flooding (I or F)

Automatic or manual release — Automatic release is preferable to shorten activation time, but is not allowed for all systems. A= automatic release is possible, M= manual release is required

Detection inside battery system or in battery space — How do we add the location of fire detection in the guideline?

Combination with ventilation systems — Ventilation is important in case of a TR, some systems can't be used in combination with ventilation. **not** possible with ventilation = ⊗ possible with ventilation = ⊗

Required IP rating — Some fire fighting systems require a specific IP rating for the battery system

# SAFETY

LEAKAGES & (SEA)WATER INTRUSION

## MULTIPLE INCIDENTS WITH BATTERIES ON BOARD SHIPS STARTED WITH A LEAKAGE OR WATER INTRUSION

IP-RATING OF BATTERIES
DESIGN OF THE BATTERY SPACE

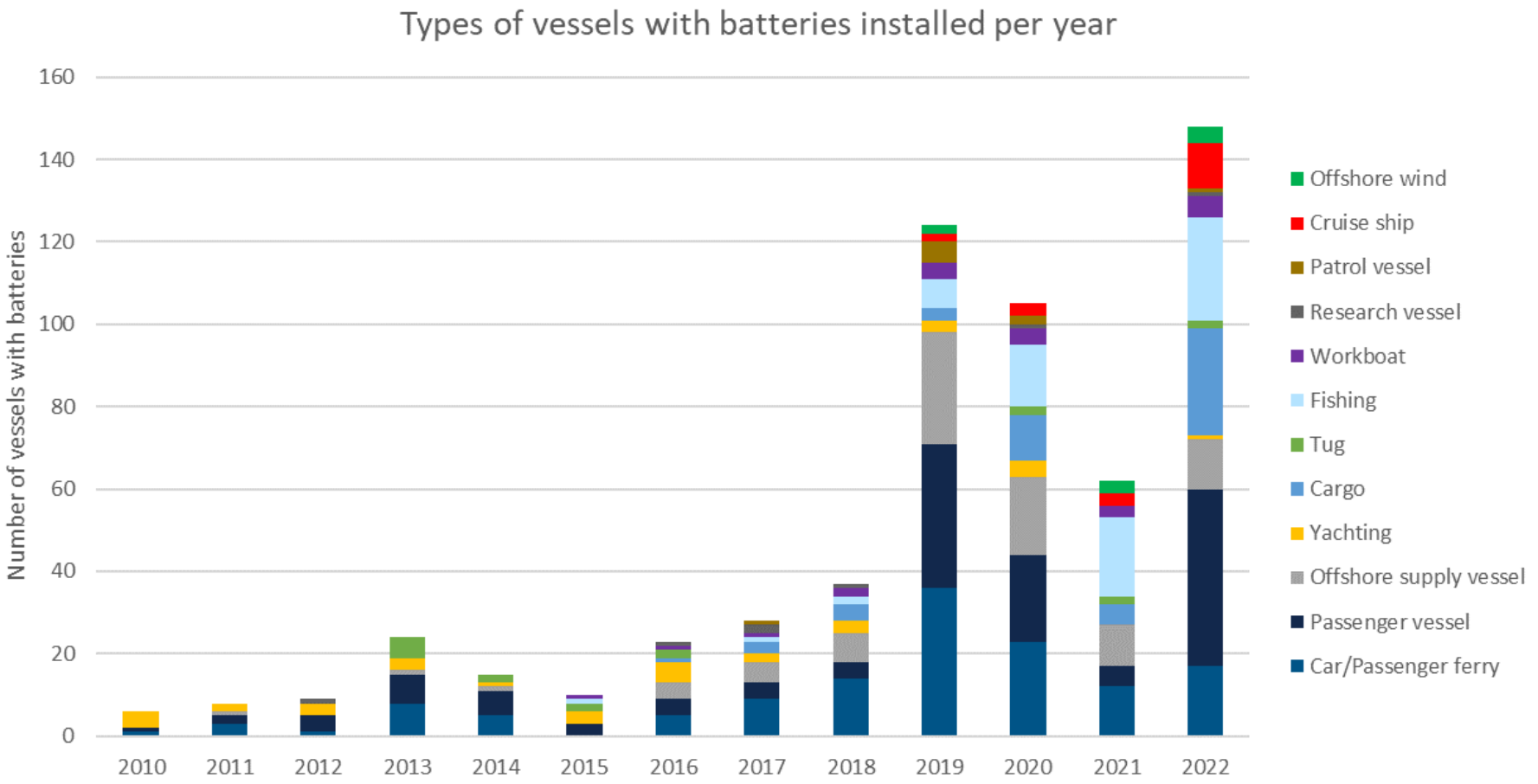
Maritime Battery Forum


# MARITIME BATTERIES 101

## SIZING & SELECTING


AIDAprima

# SIZING & SELECTING

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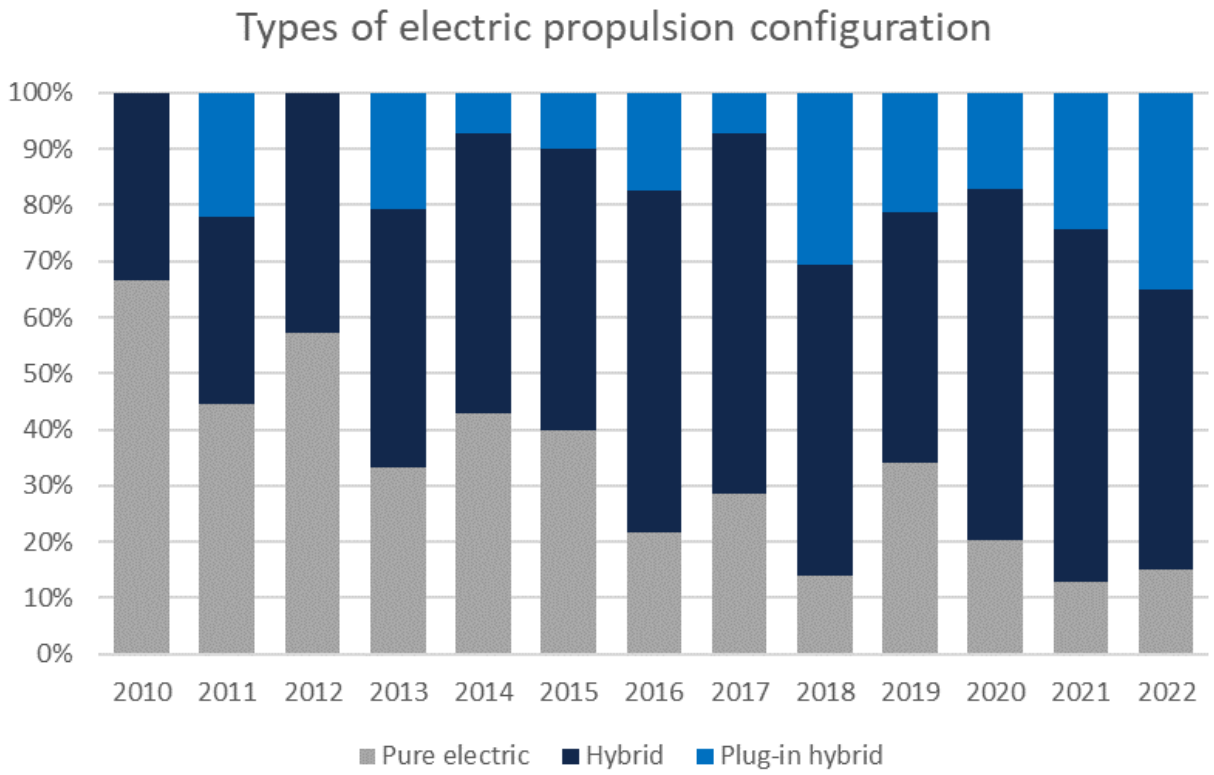
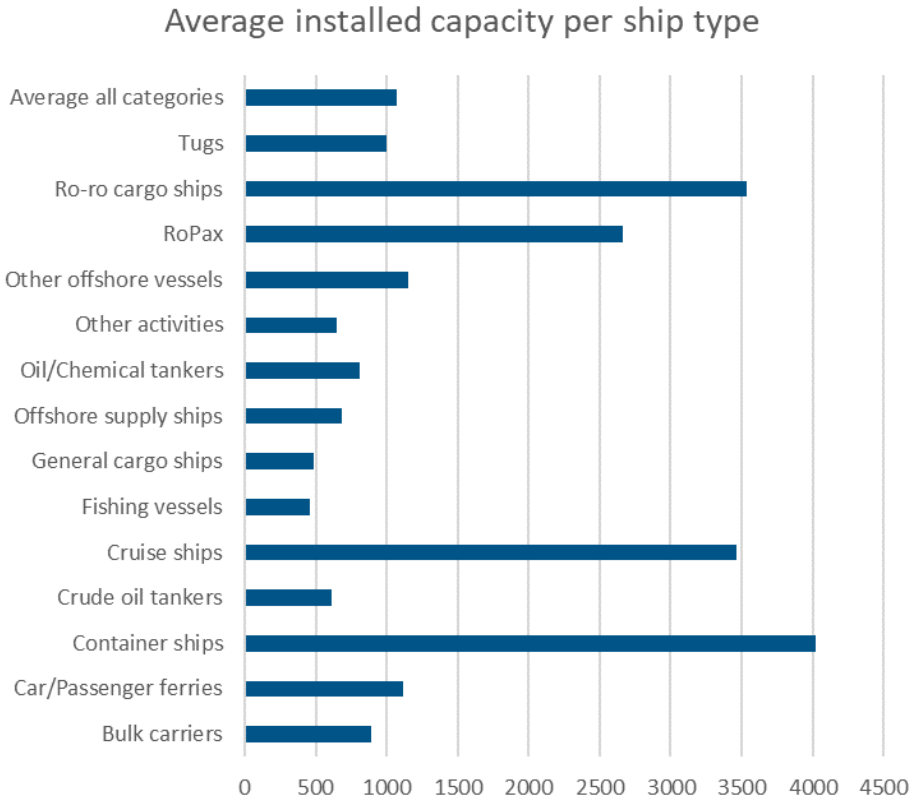
# SIZING & SELECTING

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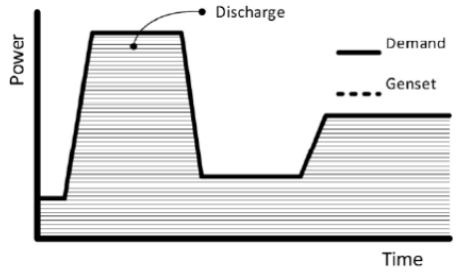
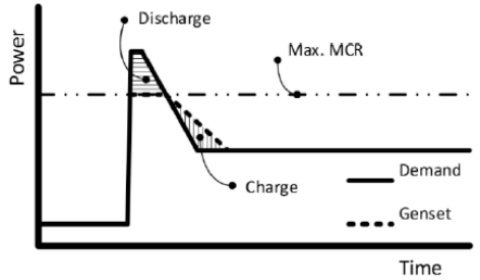
# SIZING & SELECTING

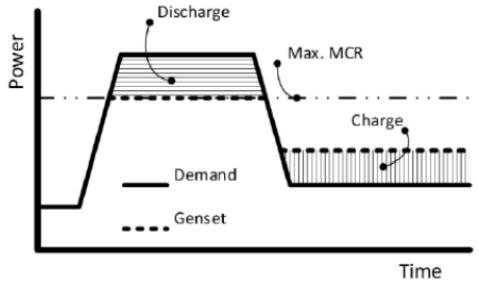
## APPLICATIONS



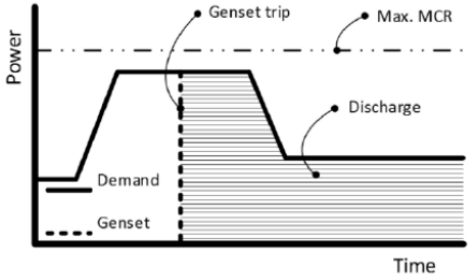

FULL ELECTRIC



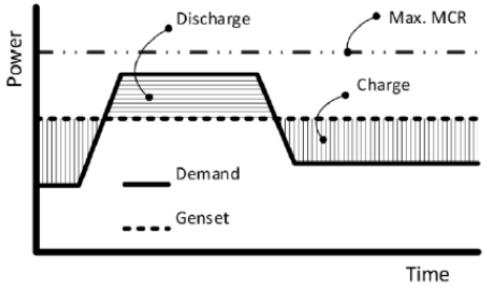

PEAK SHAVING



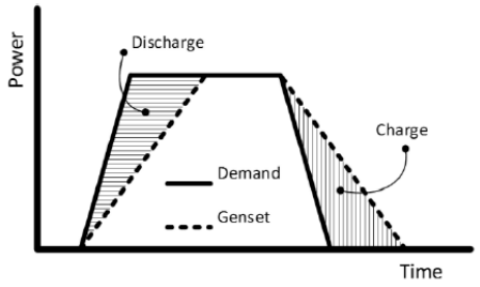

BOOST FUNCTION




SPINNING RESERVE




LOAD LEVELING




RAMP SUPPORT

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# SIZING & SELECTING

OPERATIONAL PROFILE

| Description | Total time (min) | Time step (min) | Power (kW) | Energy step (kWh) | Accumulated energy (kWh) |
|---|---|---|---|---|---|
| Manoeuvring | 0 | 2 | 100 | 3.33 | 3.33 |
| Sailing 7kts | 2 | 5 | 500 | 41.67 | 45 |
| Sailing 11 kts | 7 | 10 | 1500 | 250 | 295 |
| Idle | 17 | 5 | 60 | 5 | 300 |
| Charging | 22 | 20 | -900 | -300 | 0 |
| End | 42 | 0 | - | - | - |

Different operational scenarios:

- Normal operations
- Light operations
- Heavy operations
- Emergency operations
- Secondary operations

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# SIZING & SELECTING

OPERATIONAL PROFILE

MINIMUM REQUIRED ENERGY

DISCHARGE POWER

CHARGE POWER

NUMBER OF CYCLES

| Description | Total time (min) | Time step (min) | Power (kW) | Energy step (kWh) | Accumulated energy (kWh) |
|---|---|---|---|---|---|
| Manoeuvring | 0 | 2 | 100 | 3.33 | 3.33 |
| Sailing 7kts | 2 | 5 | 500 | 41.67 | 45 |
| Sailing 11 kts | 7 | 10 | 1500 | 250 | 295 |
| Idle | 17 | 5 | 60 | 5 | 300 |
| Charging | 22 | 20 | -900 | -300 | 0 |
| End | 42 | 0 | - | - | - |

Determine the maximum required (dis)charge power
And the RMS value

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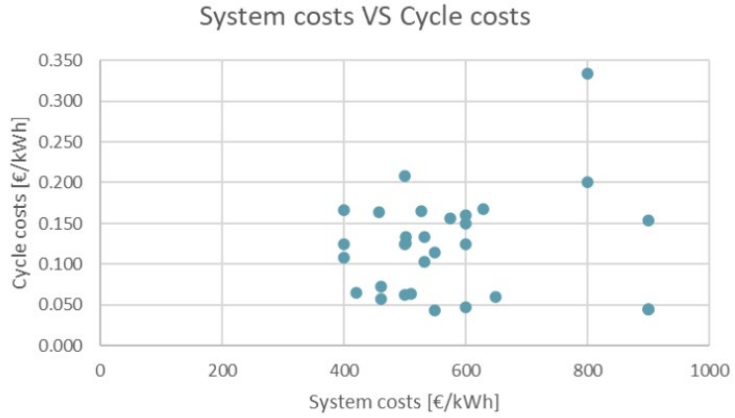
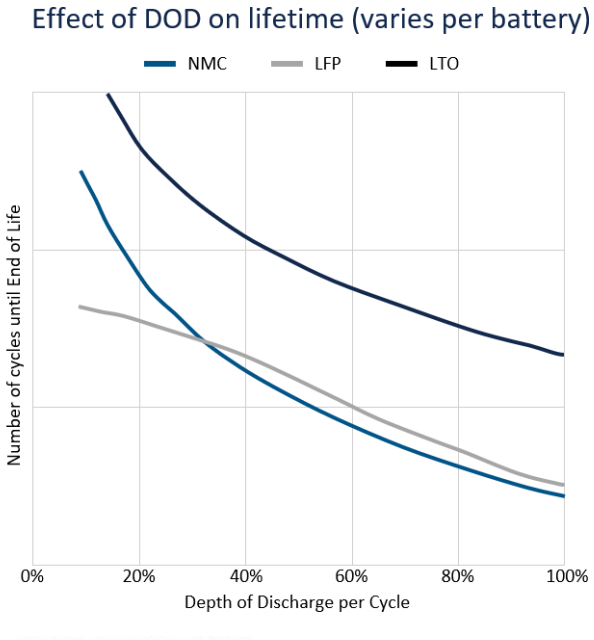
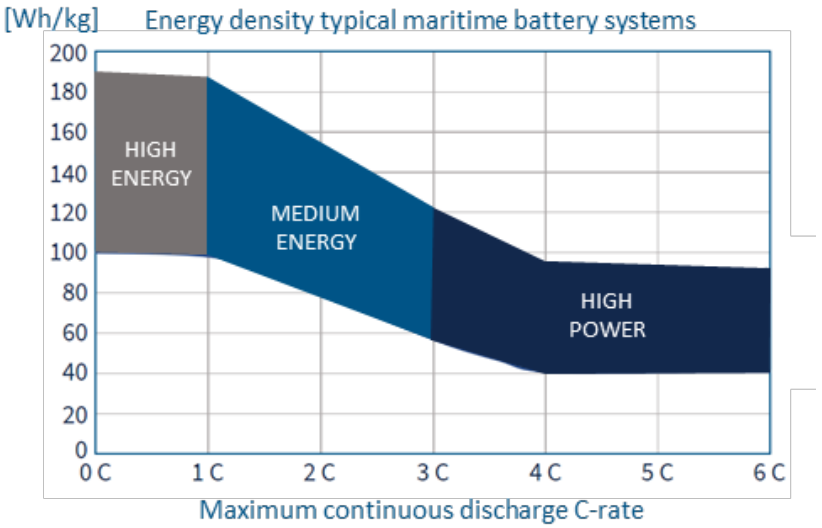
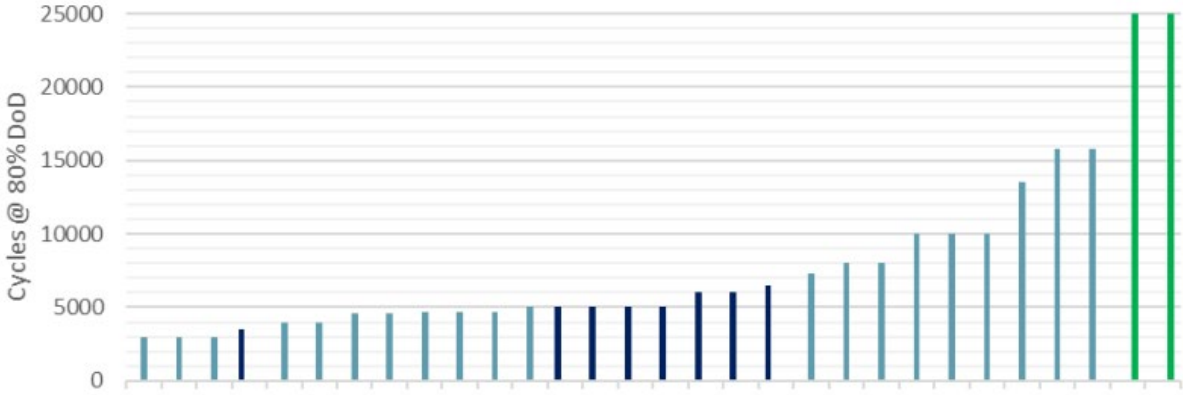
# SIZING & SELECTING

## SIZING STRATEGIES FOR DIFFERENT TYPES OF BATTERIES

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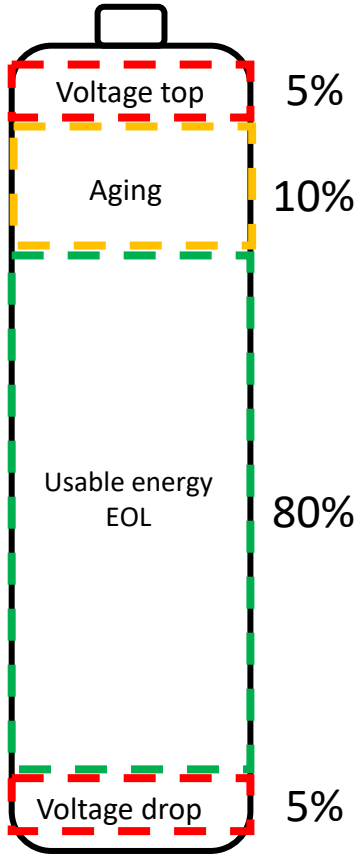
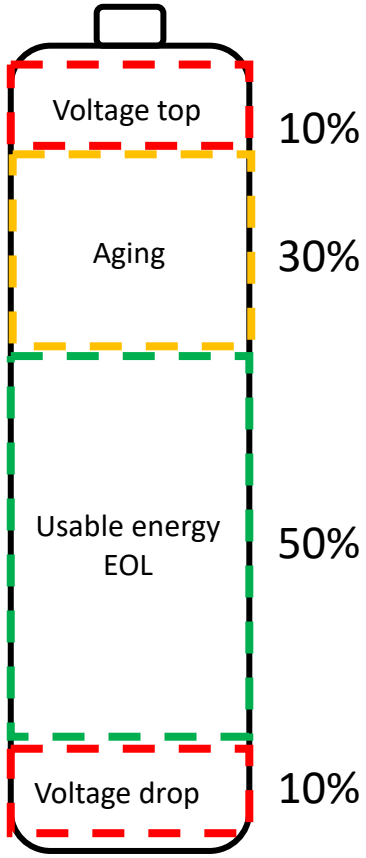
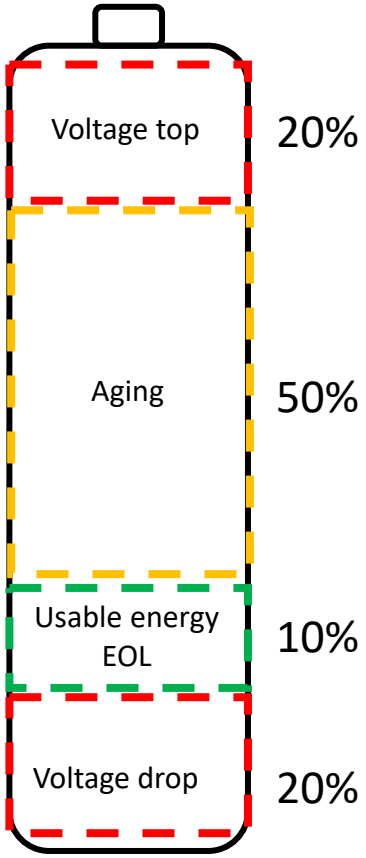
# SIZING & SELECTING

## SIZING STRATEGIES FOR DIFFERENT TYPES OF BATTERIES

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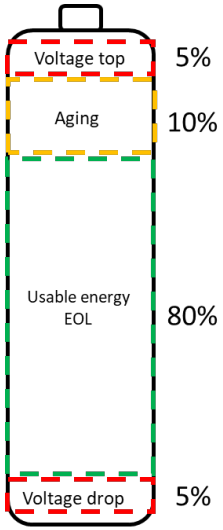
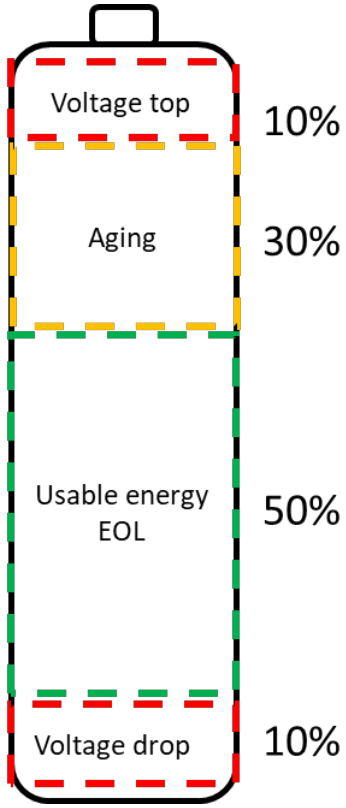
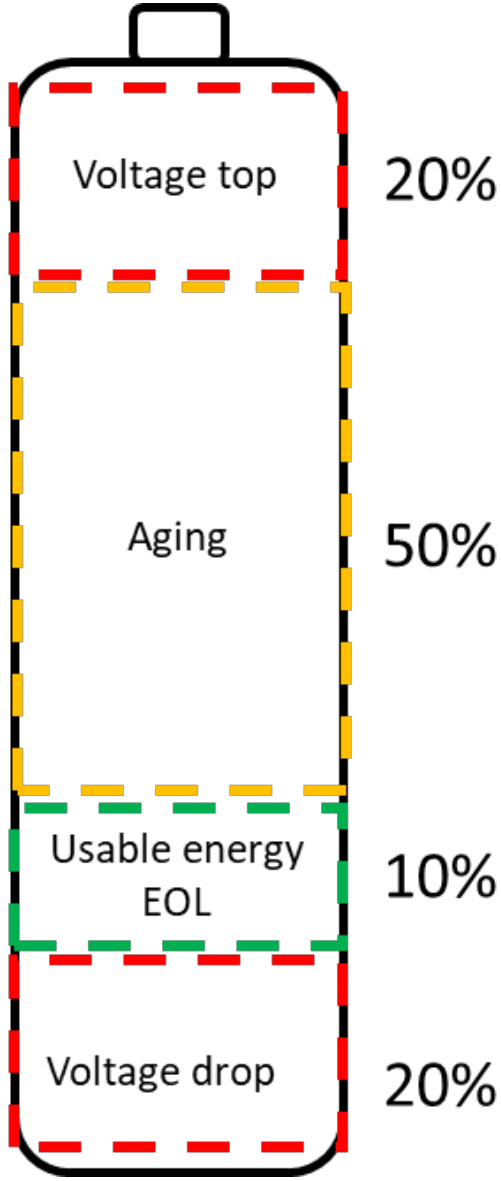
# SIZING & SELECTING

## SIZING STRATEGIES FOR DIFFERENT TYPES OF BATTERIES

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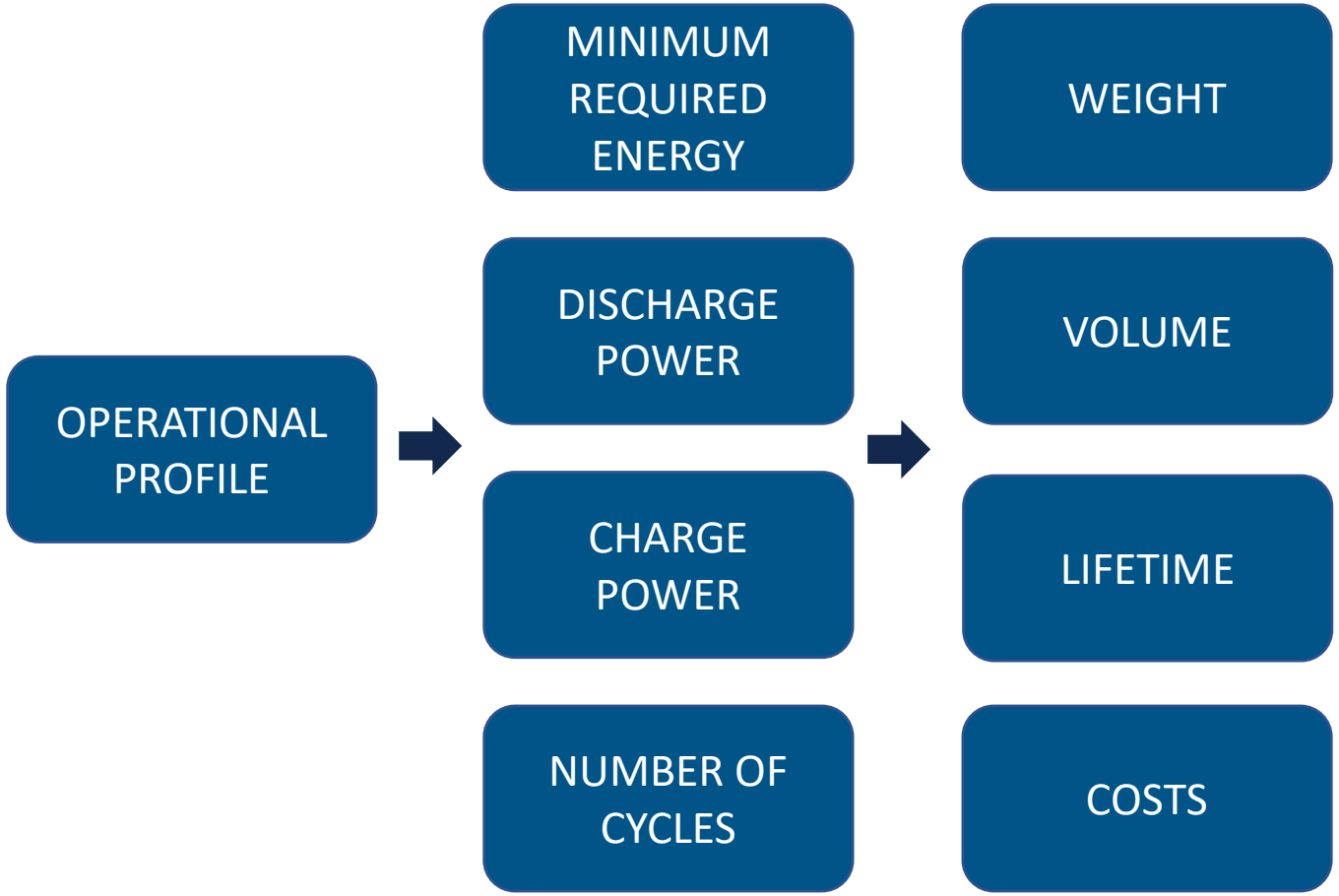


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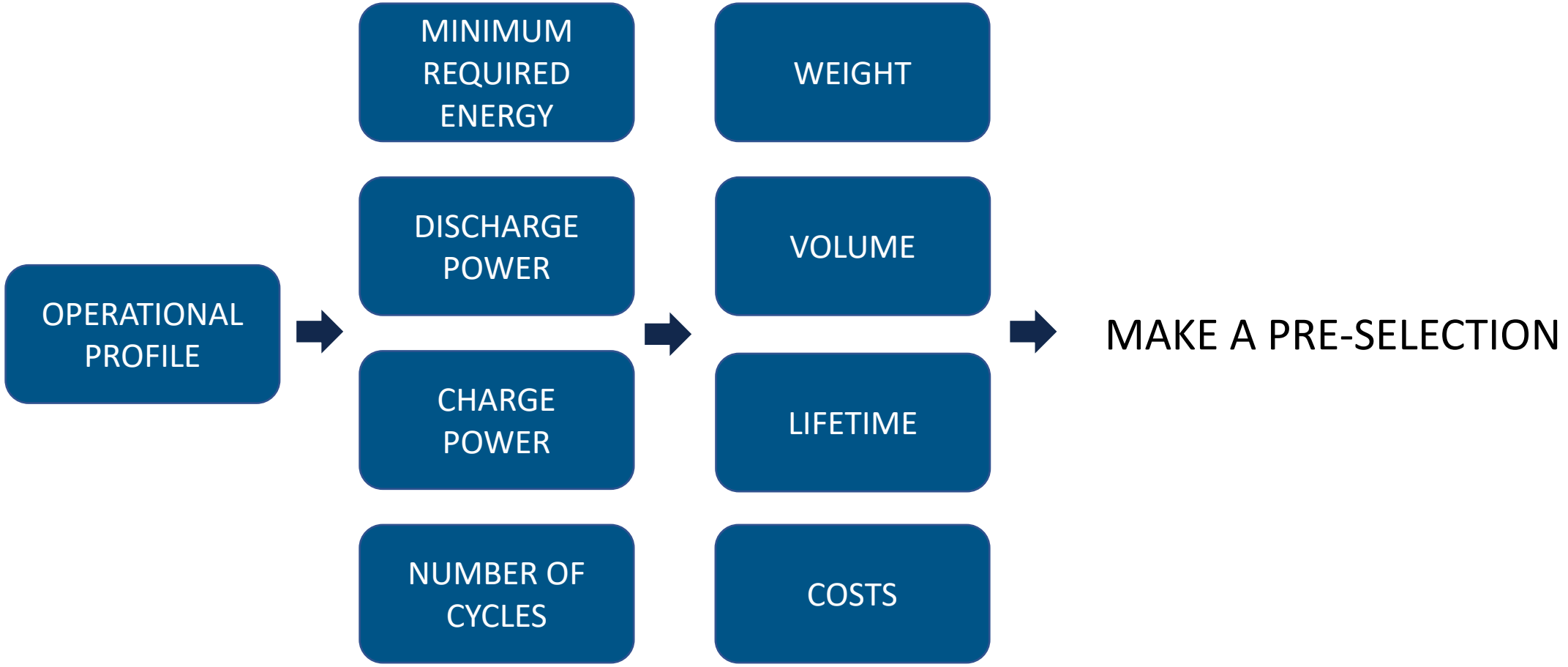


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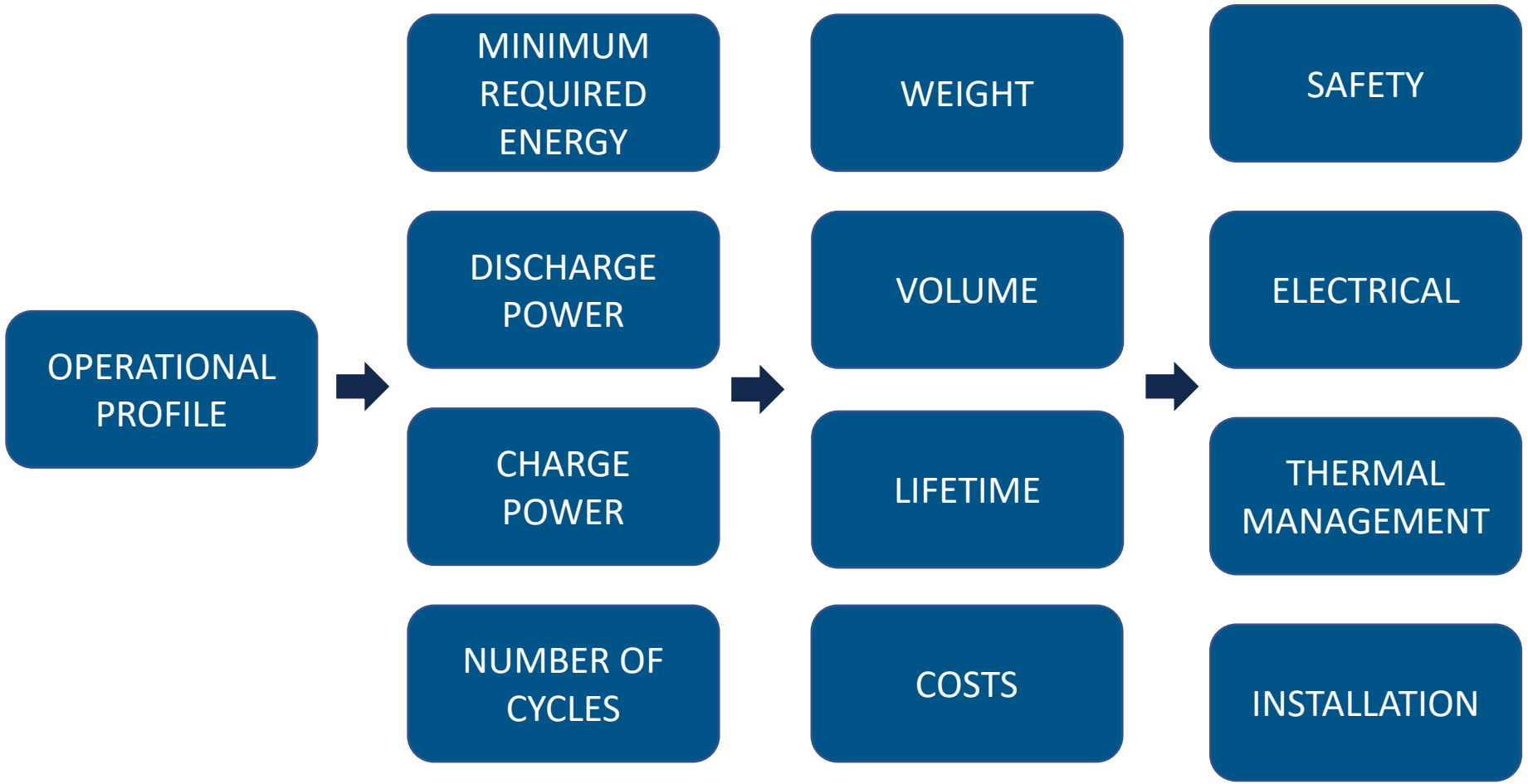


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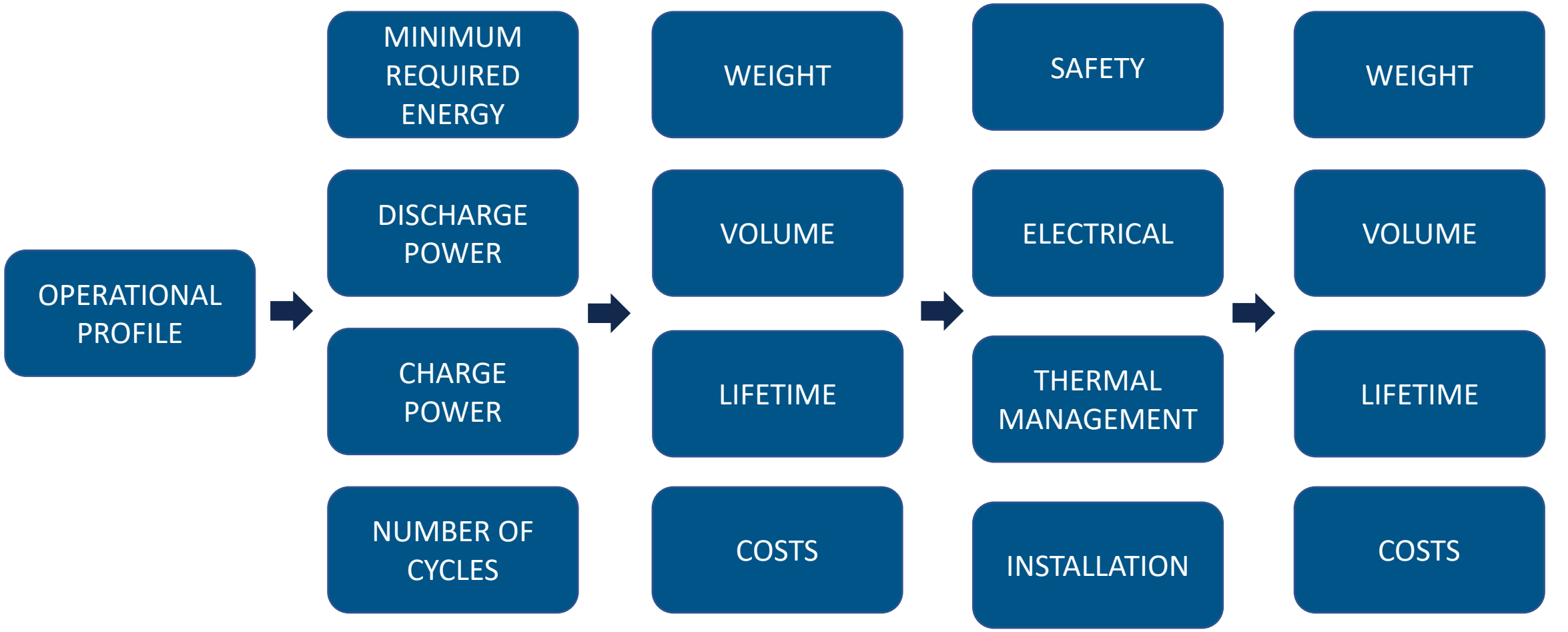


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