BT2 Operating Principles of Battery Management Systems

BY THE FARADAY INSTITUTION AS A DELIVERY PARTNER OF THE FARADAY BATTERY CHALLENGE BY INNOVATE UK

THE FARADAY INSTITUTION

BT2 Operating Principles of Battery Management Systems

What is a Module and a Pack?

- A cell is an individual energy source
- A battery consists of 1 or more cells
- A module is a collection of 1 or more batteries assembled in a frame
- A pack is the complete enclosure that delivers power

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Cell

A cell is a basic unit of a lithium-ion battery that exerts electric energy by charging and discharging. Made by inserting cathode, anode, separator and electrolyte into an aluminium case.

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Image source: UKBIC

Module

A module is a battery assembly put into a frame by combining a fixed number of cells to protect the cells from external shocks, heat or vibration.

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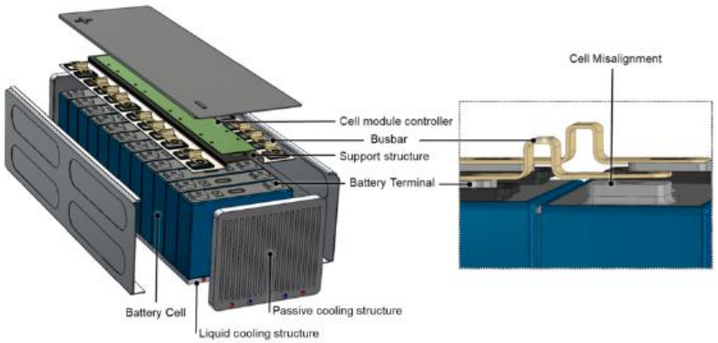

Source: mdpl.com

Module cont.

A battery module is a combination of components of a battery system that includes at least the following components:

- cells
- battery management electronics for Battery Cell balancing
- voltage and temperature measurement
- connectors

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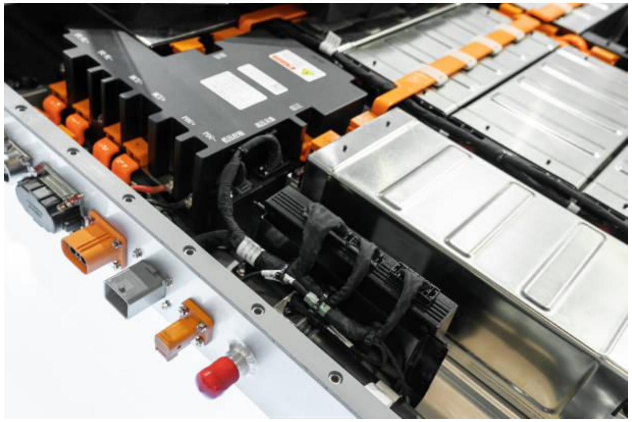

Image source: UKBIC

Pack

This is the final shape of the battery system installed. Composed of modules and various control/protection systems including a BMS (Battery Management System), potentially a cooling system, etc.

Notes:

Pack cont.

A battery pack is a series of individual modules and protection systems organised in a shape that will be installed into a unit – e.g. an electric vehicle or static storage.

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The Battery Manufacturing Process

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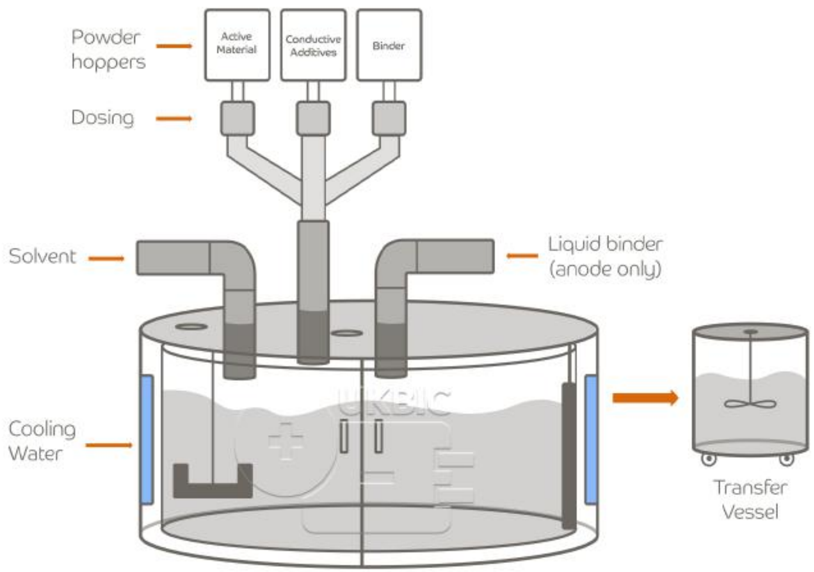

Image source: UKBIC

Notes:

Electrode – Mixing

- Powder hoppers – hold the ingredients in hoppers
- Dosing – weights out the required amount of ingredients as outline in the recipe
- Solvent in – solvent is pumped into the mixer - Anode slurries use de-ionised water as the solvent.
  Cathode slurries use N-Methyl-pyrrolidone (NMP) as the solvent
- Liquid Binder (Anode) – Modified SBR (Styrene Butadiene Rubber) or PVDF (Polyvinylidene Fluoride) are most common
- Cooling jacket – cool water is pumped around the mixer to keep the temperature constant
- Paddles – agitate the mixture to ensure complete mixing of ingredients – no “hot spots” and distributed slurry
- The slurries are degassed in the transfer vessel to remove bubbles and improve the quality of the coating

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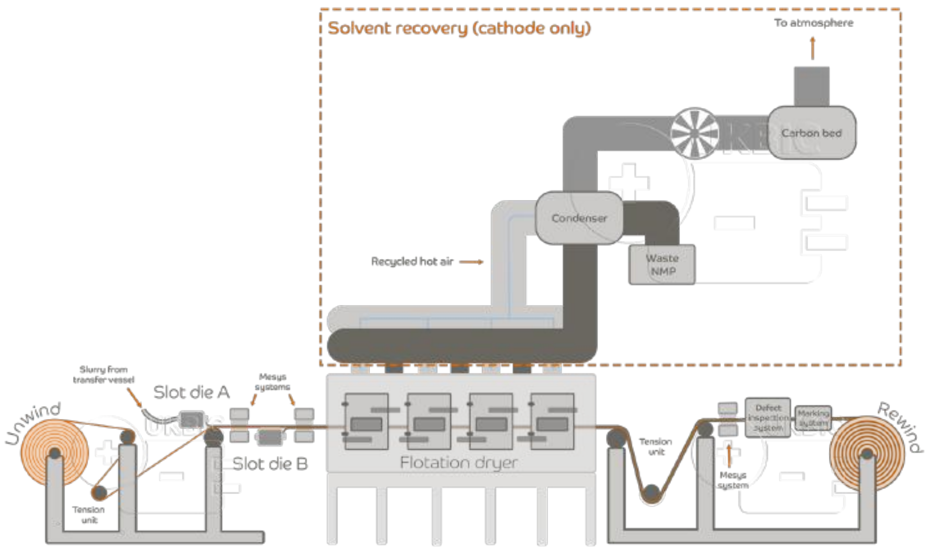


Image source: UKBIC

Notes:

Electrode – Coating & Drying

- The anode slurry is coated on copper foil, whilst the cathode is coated on aluminium foil. Any material that we coat onto is known generally as substrate
- Unwind – uncoated mother roll is unwound under tension to prevent wrinkles
- Slot Die A and B coats both sides of the roll simultaneously
- Floatation dryer – the roll is floated through a high temperature dryer to dry the slurry and remove the solvent
- Solvent recovery (Cathode only) – the solvent is recovered through a condenser for re-use)
- Defect inspection system – locates and marks any defects on the slurry to ensure removal at cell assembly
- Rewind – coated mother roll is rewound under tension ready for the next stage

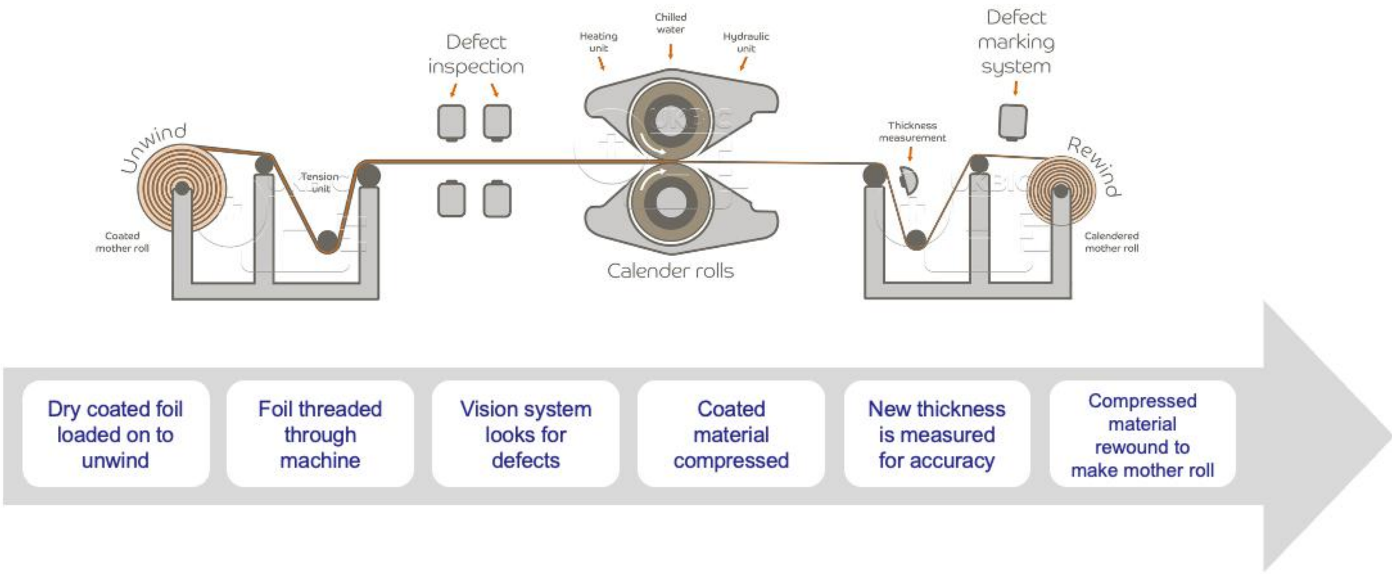


Image source: UKBIC

Notes:

Electrode – Calendering

- The coated mother roll is unwound.
- The rolls can apply up to 36 tonnes of pressure to the coating and the tension can be controlled at different points in the process.
- There is a defect inspection system before the calender rolls.
- If a large defect is detected, the calender rolls will open to prevent the defect damaging the calender rolls.
- The calender rolls are controlled by a hydraulic unit and can be heated to a reference temperature.
- Active gap control is used for intermittent coating to prevent damage to calendar rolls.
- The defect marking system marks the defected area using ink.
- The marked areas are then easily identified and discarded at cell assembly.

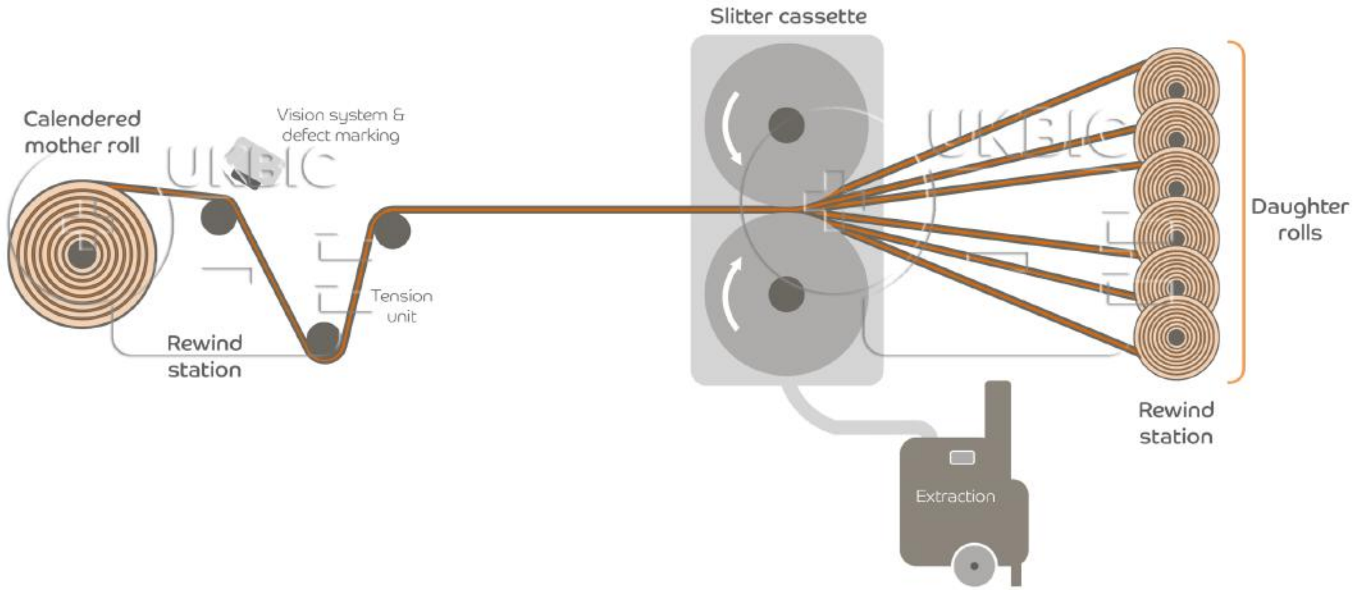


Image source: UKBIC

Notes:

Cell Assembly - Slitting

- Calendered mother rolls are unwound and are fed through several tensioning units to prevent creasing and improve cut quality.
- The slitter cassette consists of a series of blades. The distance between each blade determines the width of the daughter roll.
- An extraction system is used to removes any particles produced during slitting.
- The daughter rolls are then rewound ready for vacuum drying

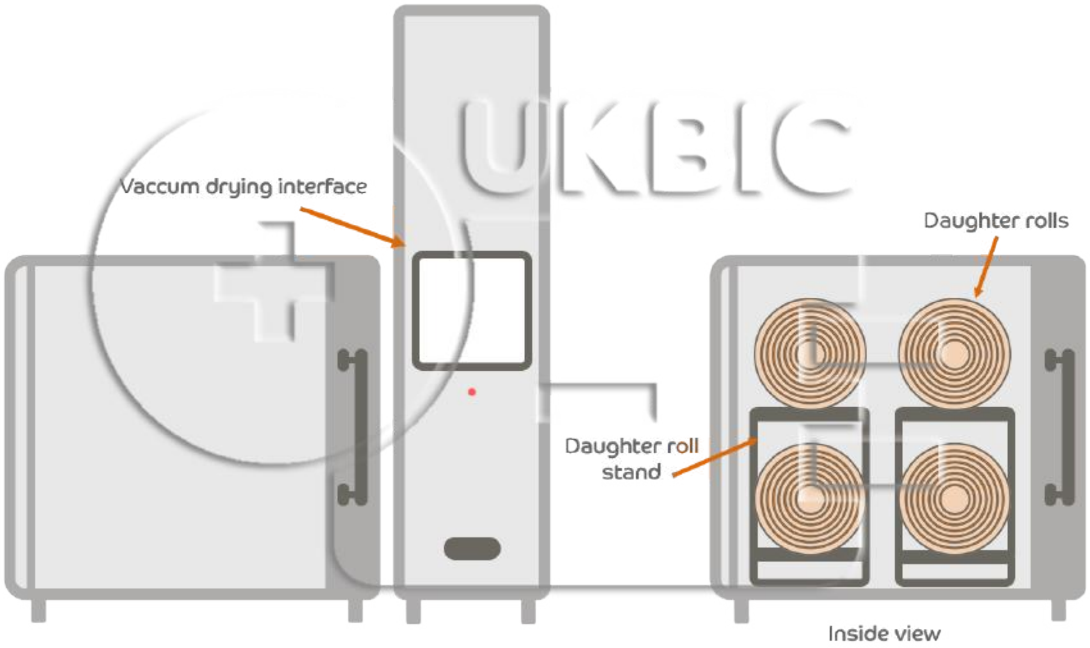


Image source: UKBIC

Notes:

Cell Assembly – Vacuum Drying

- Daughter rolls are loaded into the vacuum dryer via a special goods carrier.
- Any remaining solvents or moisture are evaporated out from the coated foil at this stage.
- Evaporation is achieved at high temperature under a nitrogen vacuum.

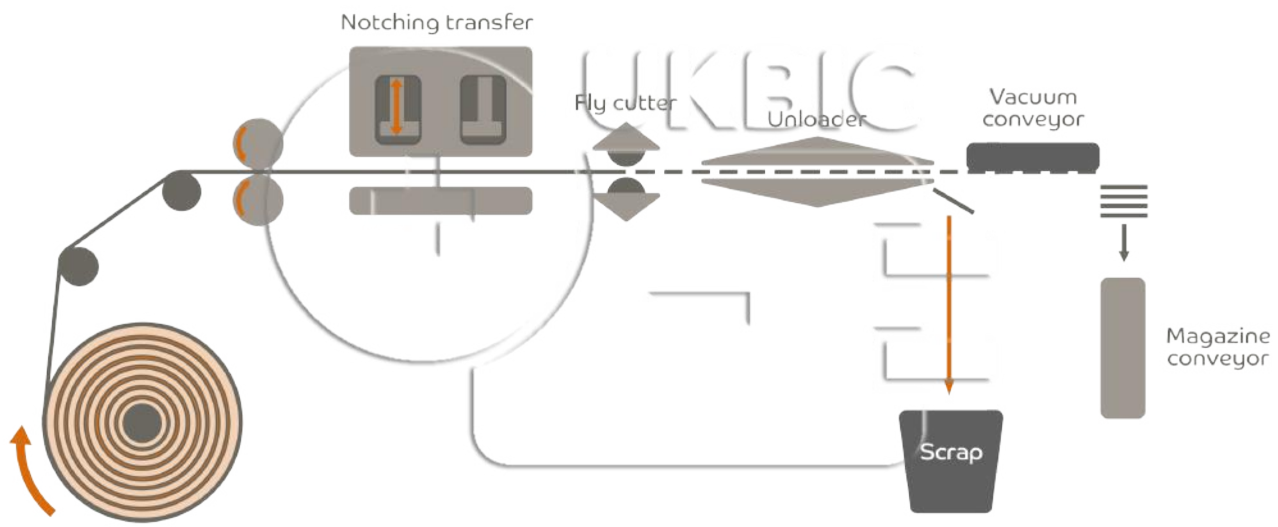


Image source: UKBIC

Notes:

Cell Assembly (Pouch) – Notching

- The daughter rolls are unwound and passed through a notching unit where they are cut to size ready for insertion into the pouch cell.
- A vision system is present at the end of the line to confirm dimensions.
- Two machines are used one for anode and one for cathode to prevent cross contamination.

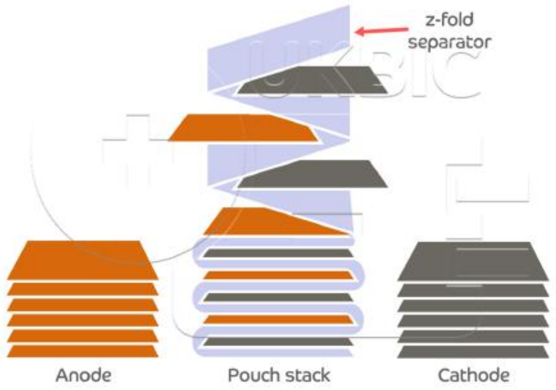


Image source: UKBIC

Cell Assembly (Pouch) - Stacking

- Pouch stacking is where the cathode and anode electrode sheets are stacked using a technique known as Z-folding.
- The anode and cathode sheets are stacked and separated by a continuous roll of separator to form the pouch stack.

Notes:

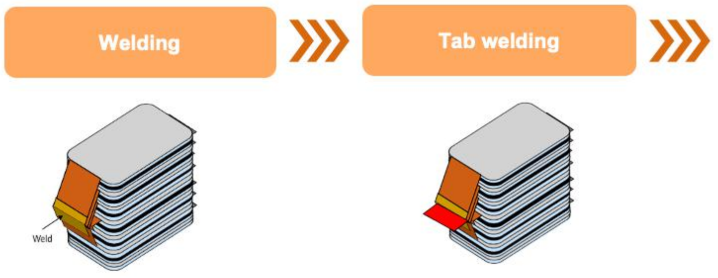


Image source: UKBIC

Cell Assembly (Pouch) – Packing & Filling

- Ultrasonic welding is the technique applied to pre-weld the unwrapped electrodes together.
- Next the electrode sheets are trimmed.
- A tab is then laser welded onto the uncoated electrodes.

Notes:

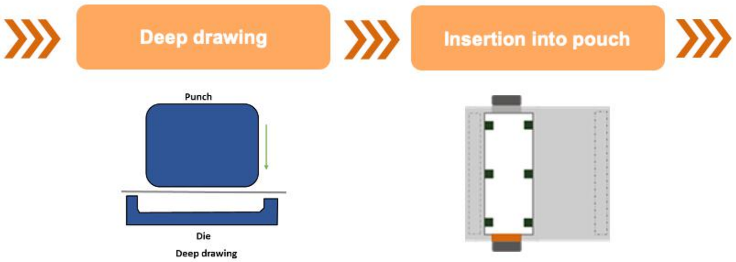
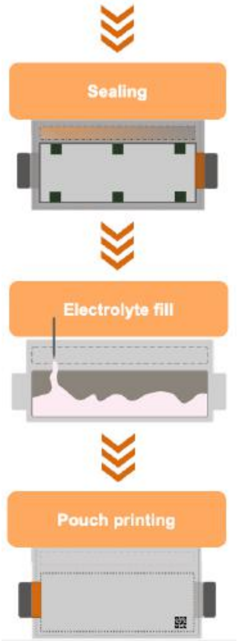


Image source: UKBIC

Cell Assembly (Pouch) – Packing & Filling cont.

- The pouch foil is formed using a process called deep drawing where pressure is applied to the foil against the slot die.
- The pouch foil is closed on three sides using a heat-sealing process.
- Two highly accurate dosing needles are used to fill the pouch cells with electrolyte under vacuum conditions.
- Electrolyte solution is outsourced and is highly hazardous.
- Final edges are heat sealed

Notes:



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Cell Assembly (Pouch) – Packing & Filling cont.

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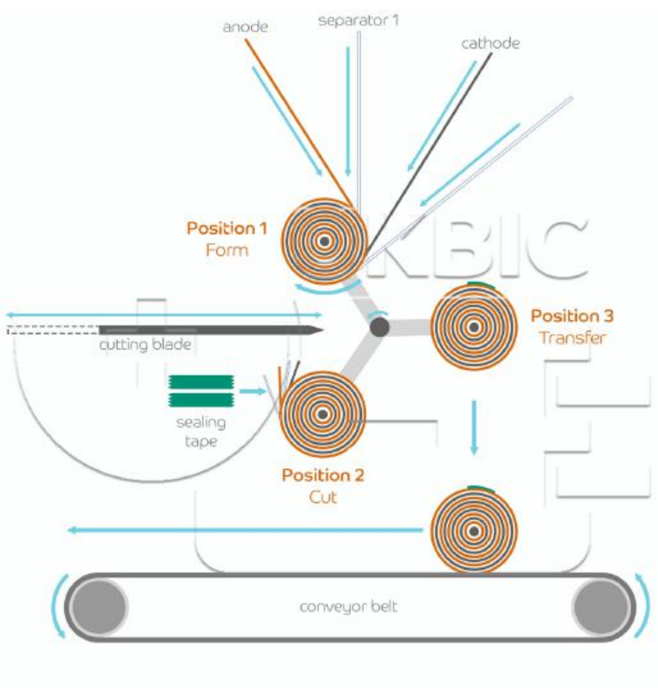

Image source: UKBIC

Notes:

Cell Assembly (Cylindrical) - Winding

- The anode and cathode tabs are welded to the electrode foil.
- Separator layers are placed in between the cathode and anode electrodes and are wound together.
- The completed product is known as a coil pack.
- To prevent the coil pack from opening it is secured with adhesive tape.

Image source: UKBIC

Notes:

Cell Assembly (Cylindrical) – Packing & Filling

- An insulator is placed at the bottom of the coil pack to prevent a short circuit between the two electrodes.
- Next the coil pack is inserted into the can and the anode tabs are welded to the base of the can.
- An insulator is also inserted on the top of the coil pack.
- The top of the open can is crimped before electrolyte filling to allow the top to be attached once filled.
- This is achieved by a hydraulic press indenting the top of the can to improve purchase when sealing.
- The cell is next filled with electrolyte under vacuum conditions using a fine dosing needle.
- The tab is laser welded to the cap.
- The top of the cell is then sealed using a crimping method.
- Crimping is achieved when the mouth of the can undergoes a certain level of pressure causing it to deform, forming a seal around the cap.

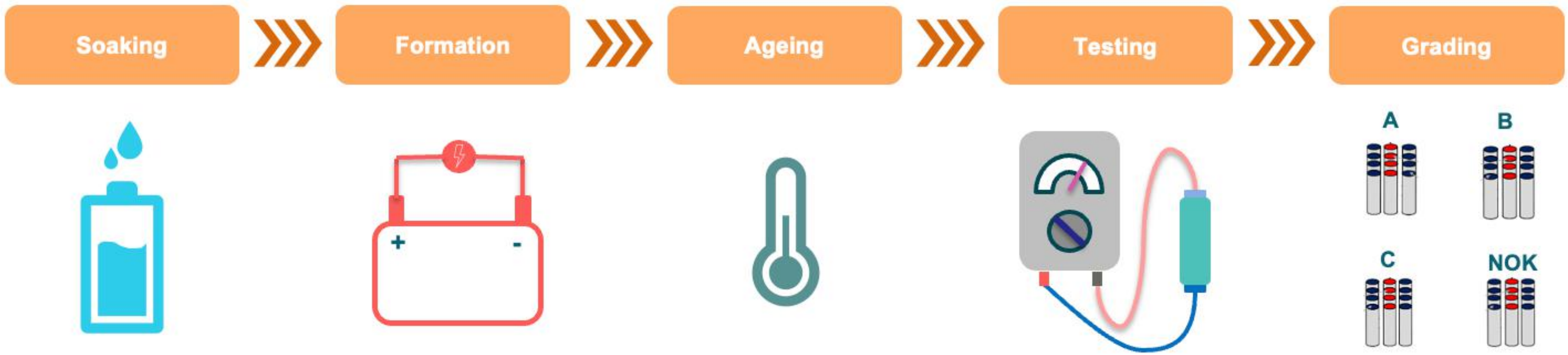

Image source: UKBIC

Cell Assembly (FA&T) - Packing

- Soaking – cells are left to allow electrolyte to be fully absorbed into the electrodes
- Formation – Cells are charged and discharged for a pre-determined period of time to form the Solid Electrolyte Interphase (SEI)
- Ageing – cells are heated to dissolve and crystalise and contaminants (2 different temps – normal-temp and high-temp)
- Testing – cells are testing against customer demand (Open-Circuit Voltage and Direct Current Internal Resistance)
- Grading – cells are graded according to customer specifications and grouped.

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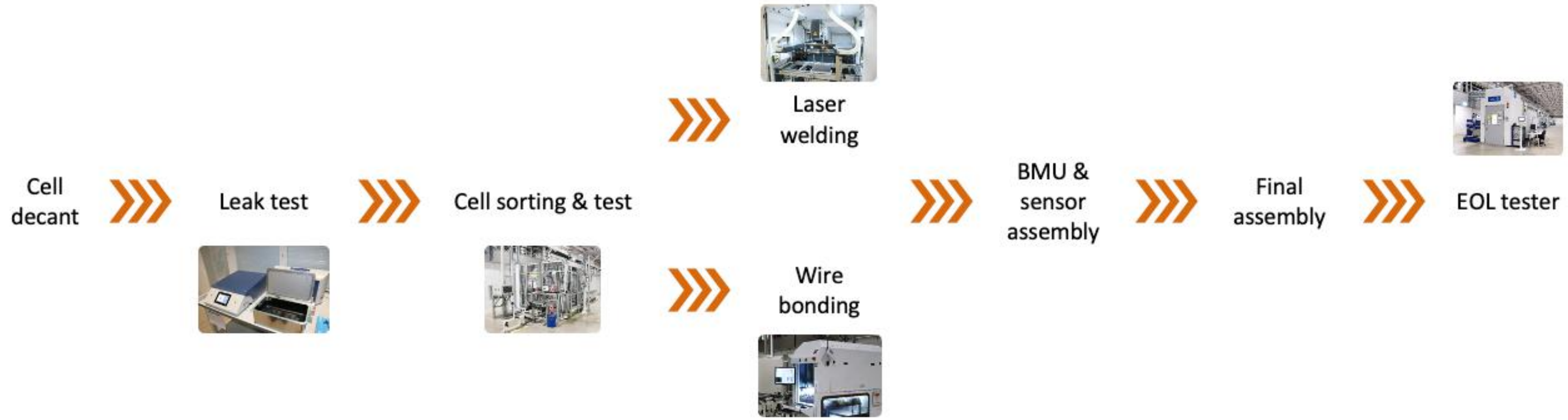
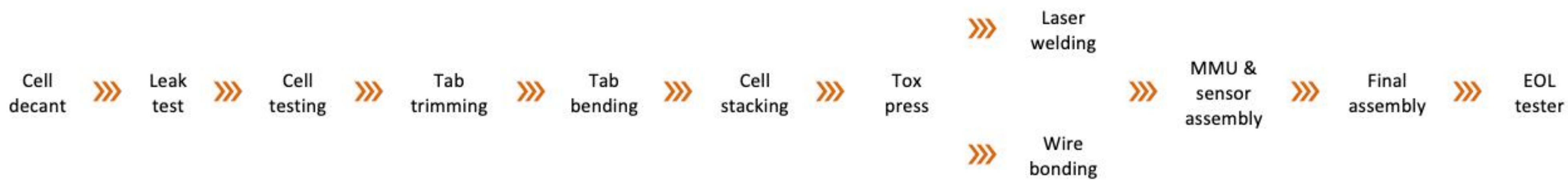


Module Assembly – Module Line (cylindrical)

- Cell Decant - Cylindrical cells are removed from packaging and visually inspected for defects
- Leak test - Cylindrical cells are loaded into a magazine which is then inserted into the leak tester. Cells are now analysed for any potential electrolyte leaks.
- Cell Sorting and Testing - The magazine full of cells is now loaded into the robot. As the cells are drawn into the machine an OCV and resistance measurement is taken to assess the cells health. A vision system is also used to detect defects which could have been missed in previous processes. If passed the robot will automatically orientate the cell and place it into the correct position within the module casing. During this process the bar codes of each cell will be recorded into the HMI system for traceability.
- Laser Welding - Bus bars are now cleaned and added onto the cells into the specified locations. Module is then feed into the welder where bus bars are welded onto the individual cells connecting them together.
- Wire Bonding - Bus bars are now cleaned and added onto the cells into the specified locations. The module is then placed into the wire bonding machine where bus bars are connected to individual cells using aluminium wire.
- BMU & Sensor Assembly - Welded modules will now have any additional sensors / cooling or LV harnesses added along with BMU (Battery monitoring unit).
- Final Assembly - Final parts will now be added onto module and casing fitted
- EOL Tester - Fully assembled modules will be placed into the test chamber and connected to the test rig. Various tests can be performed to assess the module is fit for purpose depending on customer requirements



Module Assembly – Module Line (pouch)

- Cell Decant - Pouch cells are removed from packaging and visually inspected for defects
- Leak test - Pouch cells are loaded into the leak tester. Cells are now analysed for any potential electrolyte leaks
- Cell testing - Pouch cells are loaded into a testing jig where an OCV and resistance test is taken to assess the cells health.
- Tab Trimming - Pouch cells are loaded into a jig where tabs are trimmed to a predetermined length specified by the customer
- Tab bending - Pouch cells are loaded into a jig where tabs are bent to the correct angle predetermined by the customer
- Cell stacking - Pouch cells have a thermal adhesive pad applied and are stacked up inside of the module casing
- Tox press - Module is now loaded into Tox press with pouch cells stacked inside. Press will apply a predetermined pressure onto the pouch cells compressing them to a set thickness and height. Cage will be secured to keep level set before being moved to next process
- Laser welding - Bus bars are now cleaned and added onto the cells into the specified locations. Module is then feed into the robot where buss bars are welded onto the individual cells connecting them together
- Wire bonding - Bus bars are now cleaned and added onto the cells into the specified locations. The module is then placed into the wire bonding machine where bus bars are connected to individual cells using aluminium wire
- MMU & Sensor Assembly - Welded modules will now have any additional sensors / cooling or LV harnesses added along with MMU (Module monitoring unit). Once assembled a final OCV and resistance test is taken.
- Final Assembly - Final parts will now be added onto module and casing fitted.
- EOL Tester - Fully assembled modules will be placed into the test chamber and connected to the test rig. Various tests can be performed to assess the module is fit for purpose depending on customer requirements

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Pack sub assembly ❯❯❯ Module & cooling system fit ❯❯❯ BMS & cover install ❯❯❯ Leak test ❯❯❯ Pack EOL tester

Pack Assembly – Pack Line

- Pack Sub Assembly – Sub assemblies for the pack build are built up. Various sub-assemblies could be made depending on pack design and specification.
- Module and cooling System fit – Modules are now placed into the pack casing along with any cooling system components. Bus bars are added ready for connecting.
- BMS and Cover Install - BMS is now installed into pack and all HV and LV connections are made before outer cover is installed to pack. Once cover is fully installed a Resistance and voltage test will be conducted to ensure pack is safe.
- Leak Test – Sub assemblies for the pack build are built up. Various sub-assemblies could be made depending on pack design and specification.
- Pack EOL Tester - Fully assembled Battery Packs will be placed into the test chamber and connected to the test rig. Various tests can be performed to assess the module is fit for purpose depending on customer requirements.

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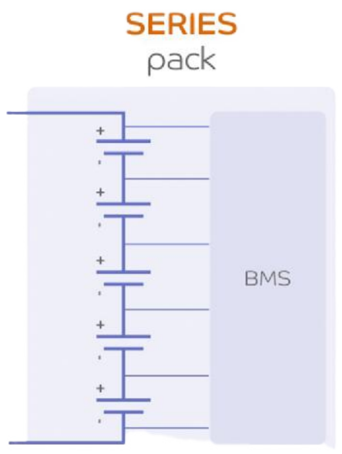

Image source: UKBIC

Module Arrangement - Series

Series connections involve connecting 2 or more batteries together to increase the voltage of the battery system but keeps the same amp-hour rating.

In series connections each battery needs to have the same voltage and capacity rating, or you can end up damaging the battery.

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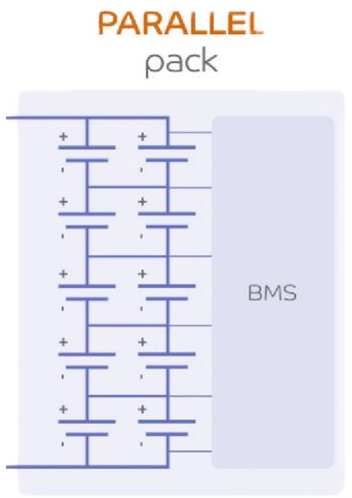

Image source: UKBIC

Module Arrangement - Parallel

Connecting a battery in parallel is when you connect two or more batteries together to increase the amp-hour capacity.

With a parallel battery connection, the capacity will increase, however the battery voltage will remain the same.

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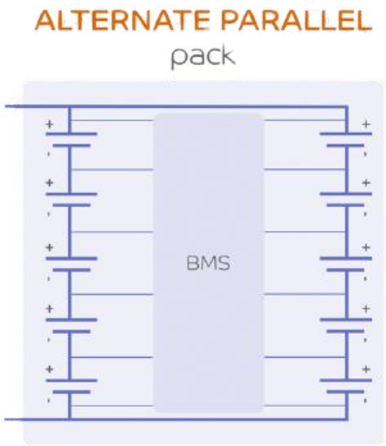

Image source: UKBIC

Module Arrangement – Alternate Parallel

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Power Outputs

Nissan Leaf - 110kW

Hyundai Kona Electric – 150kW

Mercedes-Benz EQC - 300kW

Porsche Taycan Turbo S – 560kW

Tesla Model S Performance – 595kW

Notes:

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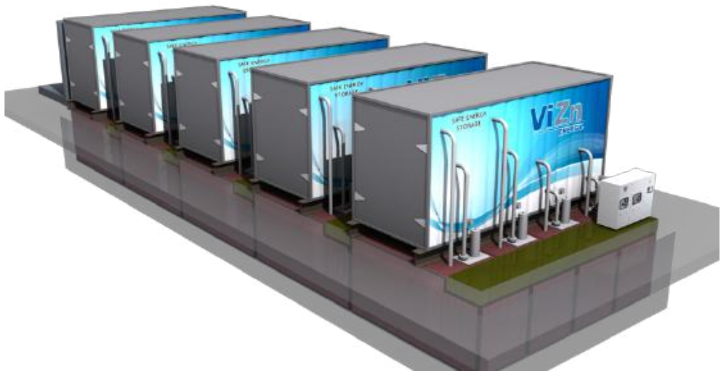
Main Considerations of Design - Rail

- Power output – high, consistent
- Weight – no real push – but heavier means more power required
- Longevity - Long life
- Capacity – Dependant on journey

Notes:



Source: imgbin.com

Main Considerations of Design – Static Storage

- Power output - Various
- Weight – Doesn’t matter
- Longevity - Long life
- Capacity – High (for higher loads)

Notes:

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Main Considerations of Design - Marine

- Power output – Huge power output, consistent but potential ebbs and flows
- Weight – Relatively important – however less than aerospace
- Longevity - Long life
- Capacity - High

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Main Considerations of Design – Aerospace

- Power output - High consistent power
- Weight - Lightweight
- Longevity - Long life
- Capacity - High

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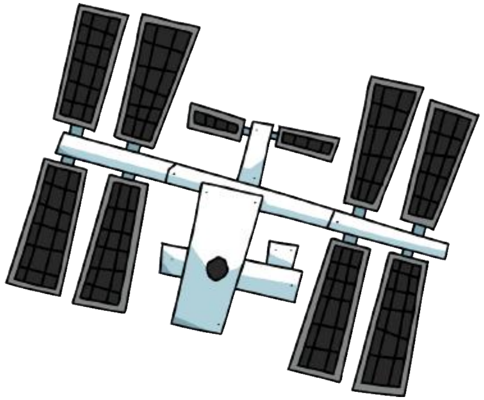

Source: imgbin.com

Main Considerations of Design - Space

- Power output – huge, consistent
- Weight – Super lightweight
- Longevity - Long life
- Capacity – Super high

Notes:

BATTERY CONTROL

Main Considerations of Design – Commerce

- Power output – low to medium
- Weight – no real push – but heavier means more power required
- Longevity – various
- Capacity – dependant

Notes:

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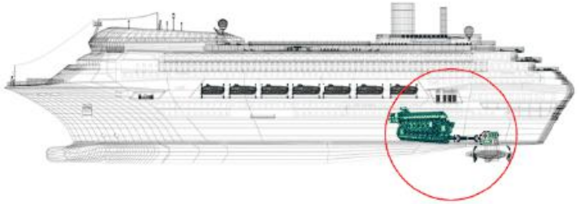

How Does Location Impact Design?

- Parameters
- Size
- Weight

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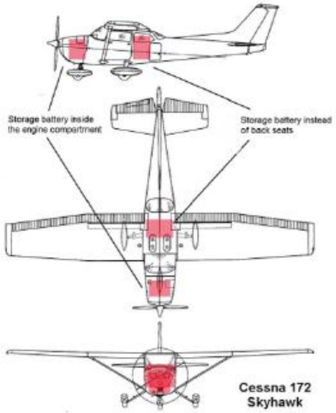

Point to Consider in Relation to Location

- Close to where the power is needed
- In areas that are "spare" or less used?
- Weight distribution
- Power transfer
- Application
- Balancing
- Design issues

Notes:

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Other Points to Consider

- Cold temperatures
- Hot temperatures
- Dry
- Wet
- Corrosive atmosphere
- Vacuum

Notes:

Source: researchgate.net

Components and Organisation – Module and Pack

Each manufacturer will have their own designs and layouts, based on their individual requirements. The example shown is one layout used by Nissan on the Leaf.

Notes:

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Image source: UKBIC

Components – Module – Clamping

A clamping frame is used to secure the cells in the modules to the casing.


Image source: UKBIC

Notes:


Image source: UKBIC

Components – Module – Sensors

A range of sensors (temperature, voltage etc.) are monitored to ensure it is working within the set safety parameters.

Notes:


Image source: UKBIC

Components – Module – Cells

A set number of cells are contained within the module (company specific) the number depends on the requirements and application of the end use.


Image source: UKBIC

Notes:


Image source: UKBIC

Components – Module – Terminals

There are 2 terminals present on the module to allow connection to the central bus bar.

Notes:

Image source: UKBIC

Components – Module – Cell Interconnects

Each cell has a +ve and a –ve tab which are welded to connect to the terminals.

Notes:

Components – Module – Cooling

Modules may need to be cooled in various ways to remove/redirect heat and avoid potential issues such as Thermal Runaway.

Working temperature of an electric vehicle engine is much higher than the optimum battery operating temperature range (due to the exothermic reaction occurring within the cell) therefore some sort of cooling is needed.

Notes:

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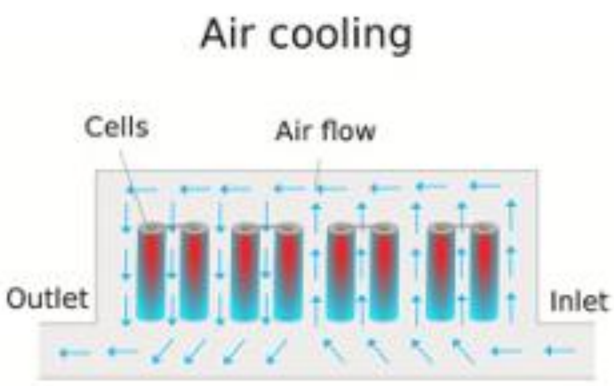


Image source: UKBIC

Components – Module – Air Cooling

Air can be fed through while driving as with some conventional ICE Vehicles – but can also include a fan to force air through.

- Not for use for high performing modules – not efficient enough
- Works by the air passing by and due to the constant flow the air is always colder than the modules/cells therefore transfer of heat will always be in the correct direction (Possible use of drawing onto the presentation)

Notes:

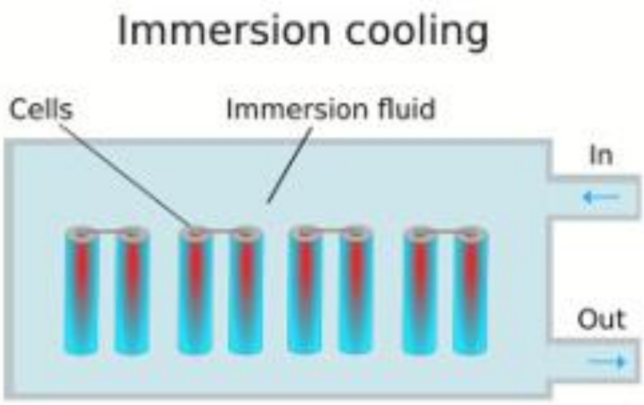


Image source: UKBIC

Components – Module – Immersion Cooling

With immersion cooling the cells are immersed into a heat conductive fluid (mineral Oil is the best example as is sometimes used in PCs) however more efficient "cold" liquids exist.

- Useful for high performance cars as the immersion fluid can be very efficient at heat conduction meaning the cells are kept at their optimal temperature

Notes:

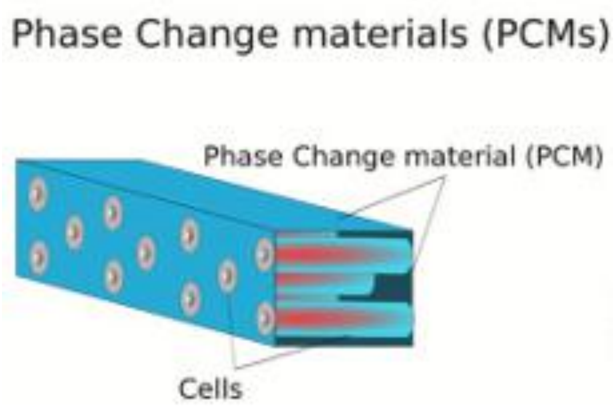


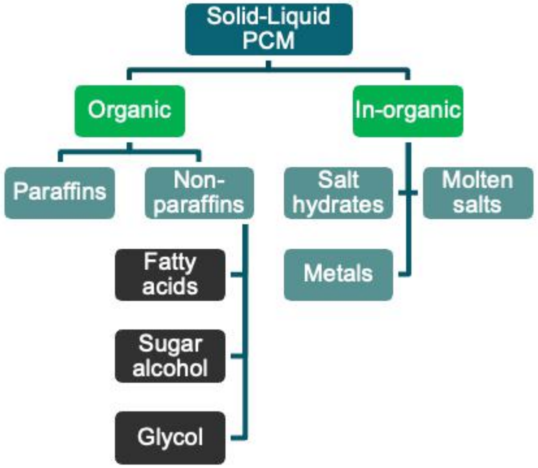
Image source: UKBIC

Components – Module – Phase Change Materials (PCMs)

The most well know PCM are the hand warming pads used to warm your hands up in the winter (exothermic reaction) or the cooling packs used in First Aid that undergo an endothermic reaction (absorbing heat).

PCMs work by absorbing and storing the thermal energy in both latent and sensible forms then discharging it in the opposite direction.

Notes:



Components – Module – Phase Change Materials (PCMs) cont.

As the temperature rises the PCM initially captures and stores the energy in the form of heat (heats up) then as latent heat after it reaches the PCM temperature. The reaction with the PCM takes place (Endothermic) and wicks away the heat from the cells.

Potential uses are for use in High performance vehicles that require large amounts of energy for a period of time as the PCM can become saturated with heat and become ineffective for cooling.

Notes:

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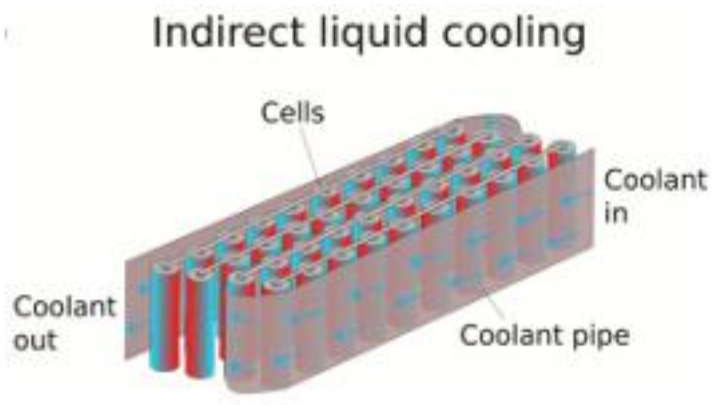

Image source: UKBIC

Components – Module – Indirect Cooling

Indirect cooling – Cell are surrounded by a cooling liquid – very similar to ICE vehicles or anything with water cooling.

A rough counterflow current system is at work with the coolant absorbing and wicking away the heat from the Cells.

Good use for normal EVs etc. but not for those with high temperature and power outputs.

Notes:

Source: warwick.ac.uk

Notes:

Components – Pack – Upper Case

The case on top of the pack has several functions:

- preventing ingress of moisture and dirt
- fire protection
- piecing protection
- a safety device for any personnel servicing the pack

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Image source: UKBIC

Components – Pack – Battery Modules

Many battery modules are connected together in a structural frame to meet the requirements of the application/manufacturer.

Notes:

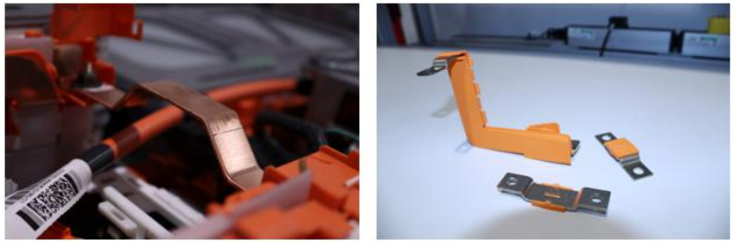


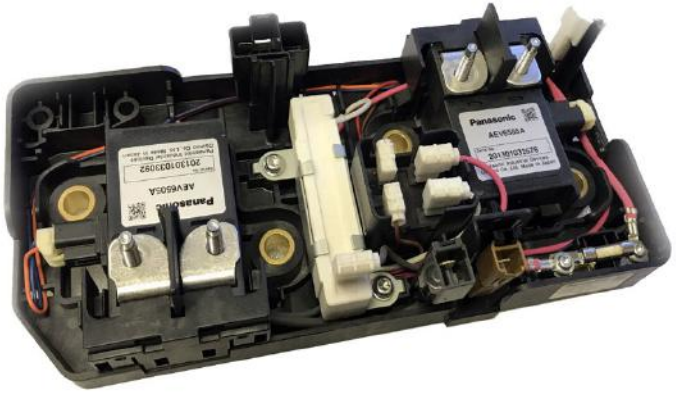
Image source: UKBIC

Components – Pack – Bus Bars

Bus bars are used to connect between the modules and the contactors. These come in various shapes and sizes, based on the application.

Notes:

BT2 Operating Principles of Battery Management Systems



Components – Pack – Contactors

Contactors are used within packs to provide electrical isolation and safety.

Notes:

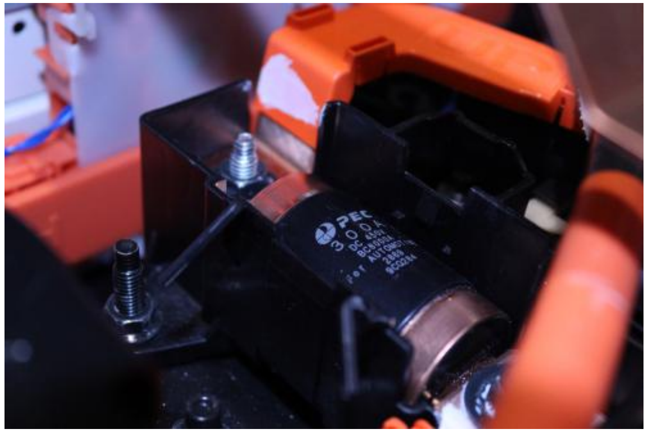


Image source: UKBIC

Components – Pack – Fusing

Fuses are used to provide protection to the system and components from faults and power surges. These operate in a similar way to those found within household appliances.

Notes:


Image source: UKBIC

Components – Pack – Disconnect

Service disconnects are installed to provide a means of isolation during servicing, maintenance and fault finding.

Notes:

Components – Pack – Cooling

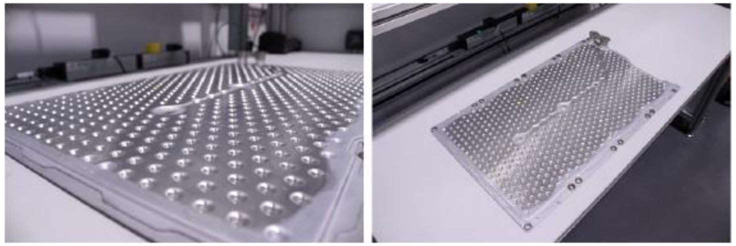


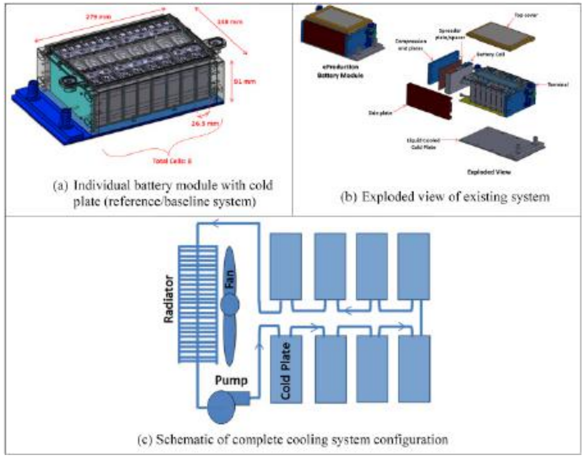
Image source: UKBIC

Dependant on the application and the location, the pack may require cooling. This could be:

- Air cooling: Air running through the battery pack can cool the batteries
- Liquid cooling: This is the most popular way of cooling a battery pack
- Cooling with heat conductive materials
- Submersion cooling

Notes:

BT2 Operating Principles of Battery Management Systems



(a) Individual battery module with cold plate (reference/baseline system)

(b) Exploded view of existing system

(c) Schematic of complete cooling system configuration

Image source: UKBIC

Components – Pack – BMS

The Battery Management System (BMS) is the "brain" of the pack and ensures safe operation of the pack within pre-determined safe set parameters.

Notes:

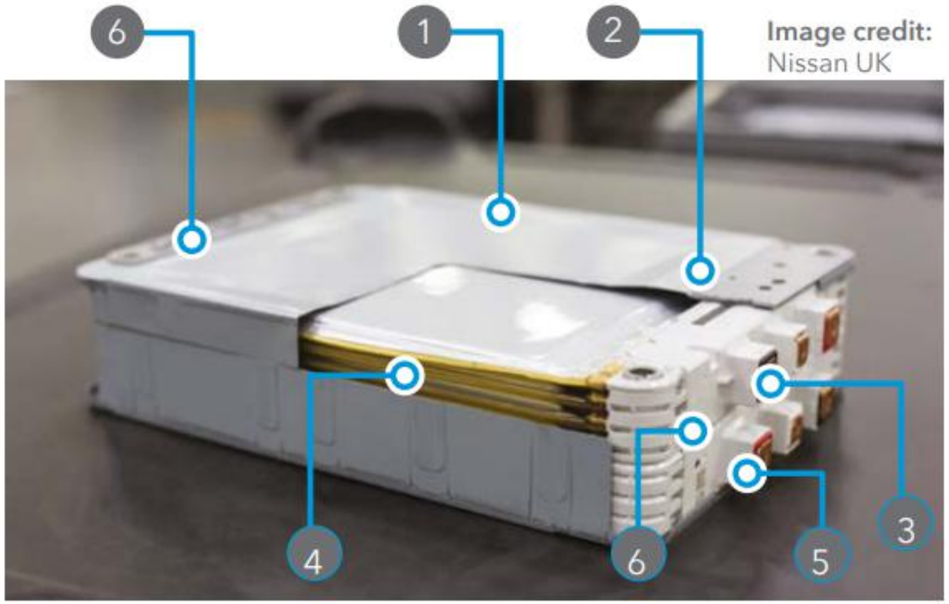
Source: warwick.ac.uk

Components – Pack – Lower Case

The lower case supports the battery as well as preventing ingress of moisture and dirt. It also provides a level of fire protection and piecing protection.

Notes:

BT2 Operating Principles of Battery Management Systems



Pouch cell module (Nissan Leaf)

Source: warwick.ac.uk

Notes:

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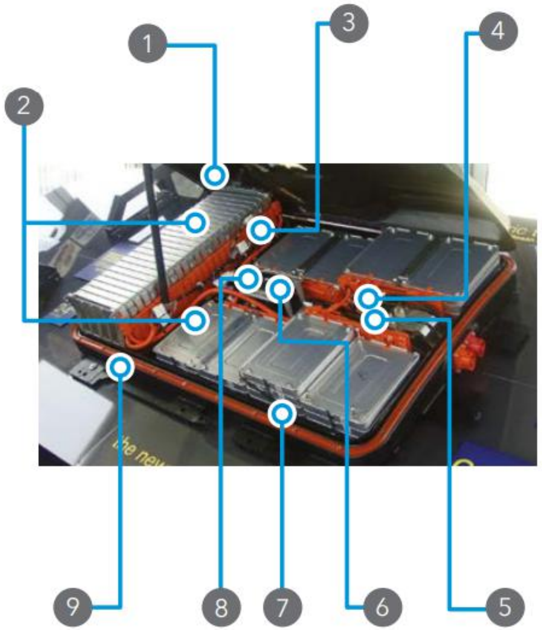
Module Components

1. Casing: casing protects and compresses (pouch) cells for support and ensure best performance
2. Clamping frame: cells are secured in the modules to the casing
3. Temperature sensors: temperature is monitored to ensure it is working within the set safety parameters
4. Cells: a set number of cells are contained within the module (company specific) the number depends on the requirements and application of the end use
5. Terminals: there are 2 terminals present on the module to allow connection to the central bus bar
6. Cell interconnects: Each cell has a +ve and a –ve tab which are welded to connect to the terminals

BT2 Operating Principles of Battery Management Systems



Source: warwick.ac.uk

Notes:

Pack Components

1. Upper case: the case on top of the pack has several functions – preventing ingress of moisture and dirt, fire protection, piecing protection, also a safety device for any personnel servicing the pack
2. Battery modules: many modules are connected together in a structural frame as mentioned in the previous slide.
3. Bus bars: connection between the modules and the contactors
4. Contactors: Electrical isolation and safety.
5. Fusing: protection from faults and power surges – like fuses in home appliances
6. Disconnect: used for isolation during serving, maintenance or fault finding
7. Cooling: most modules require cooling – this could be liquid, chemical, air etc.
8. Battery management system (BMS): the BMS is the “brain” of the pack ensures safe operation of the pack within safe set parameters – more info to follow
9. Lower case: Supports the battery as well as preventing ingress of moisture and dirt, fire protection, piecing protection etc.

BT2 Operating Principles of Battery Management Systems

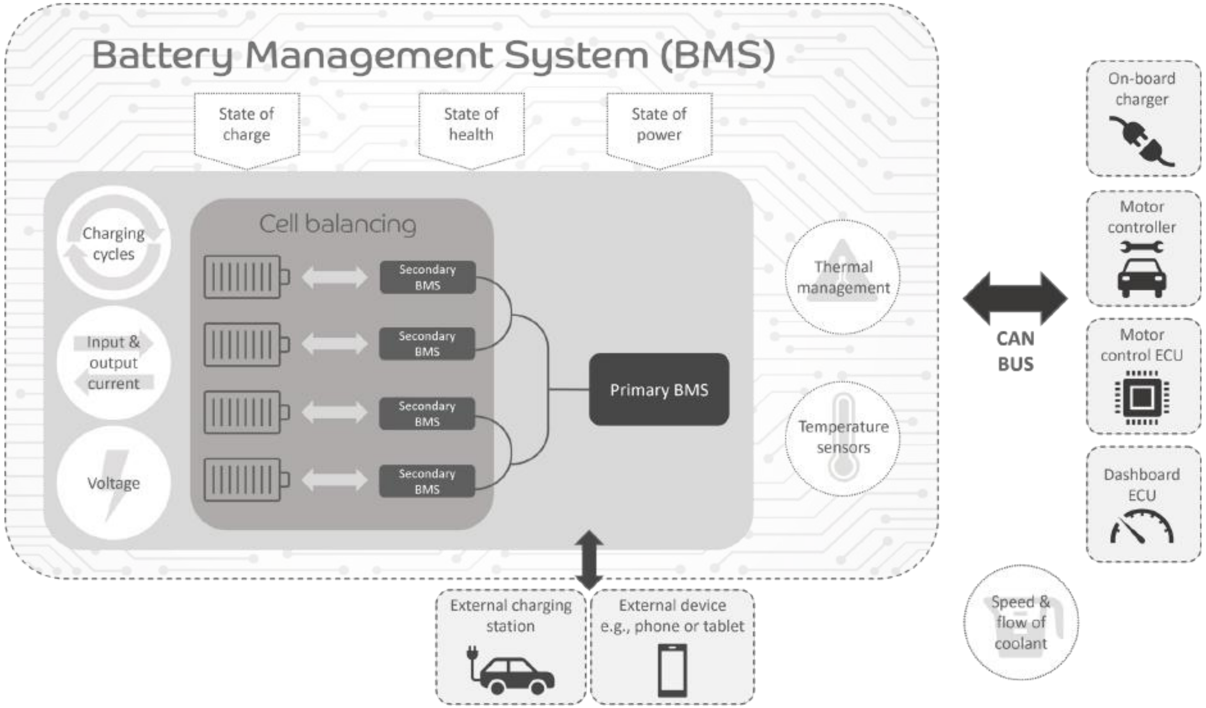


Image source: UKBIC

Notes:

What is a BMS?

A battery management system (BMS) is technology dedicated to the oversight of a battery pack. This is an assembly of battery cells, electrically organised in a row x column matrix configuration to enable delivery of targeted range of voltage and current for a duration of time against expected load scenarios.

https://www.synopsys.com/glossary/what-is-a-battery-management-system.html

BMS Safety and Security

A battery management system should be covered by the following standards -

- Cyber secure ISO 21434
- Functional Safety ISO 26262

Cyber security ISO 21434 - to protect the vehicle's electrical system from being attacked.

Imagine what could happen if the Battery Management System was attacked by malicious software?

Notes:

BMS Safety and Security cont.

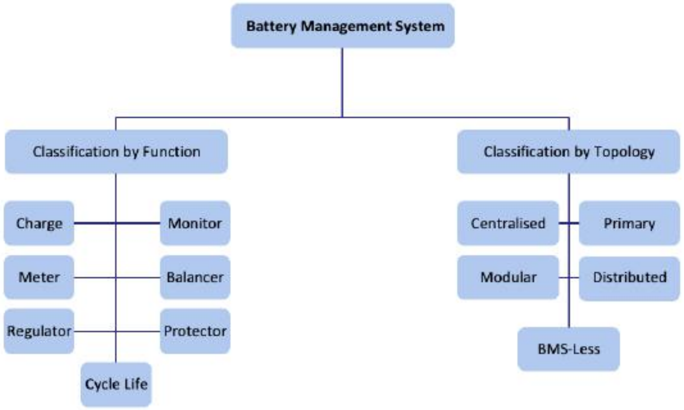
Functional Safety ISO 26262 - This standard relates to the design and implementation of safety-related systems in vehicles.

Designers need to use fail safe systems when designing a vehicle.

If an electrical/electronic system were to fail what would the potential outcome be?

Notes:

BT2 Operating Principles of Battery Management Systems



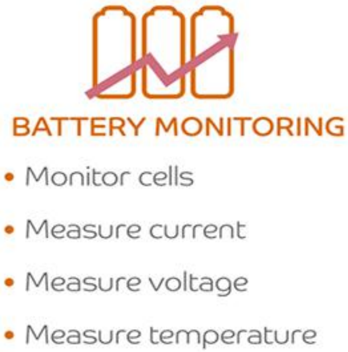
BMS Purpose

A BMS is an electronic system that manages a secondary battery. It protects the battery from operating outside of its safety parameters and can constantly monitor its:

- State of charge
- Voltage
- Temperature
- Coolant flow
- Current (in or out)
- Health of individual cells
- State of balance

It also controls the charge and discharge of the pack.

Notes:



BMS – Battery Monitoring

A BMS both monitors and measures values within the battery pack, which includes:

- Monitoring the cells
- Measuring the current
- Measuring the voltage
- Measuring the temperature

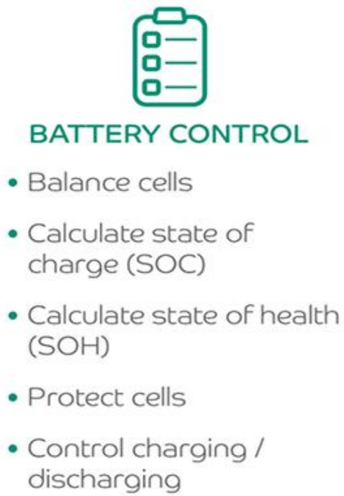
Notes:

BT2 Operating Principles of Battery Management Systems

BMS - Communication

The BMS facilitates the communication between the charger and related devices and is also responsible for displaying battery data to the end user.

Notes:



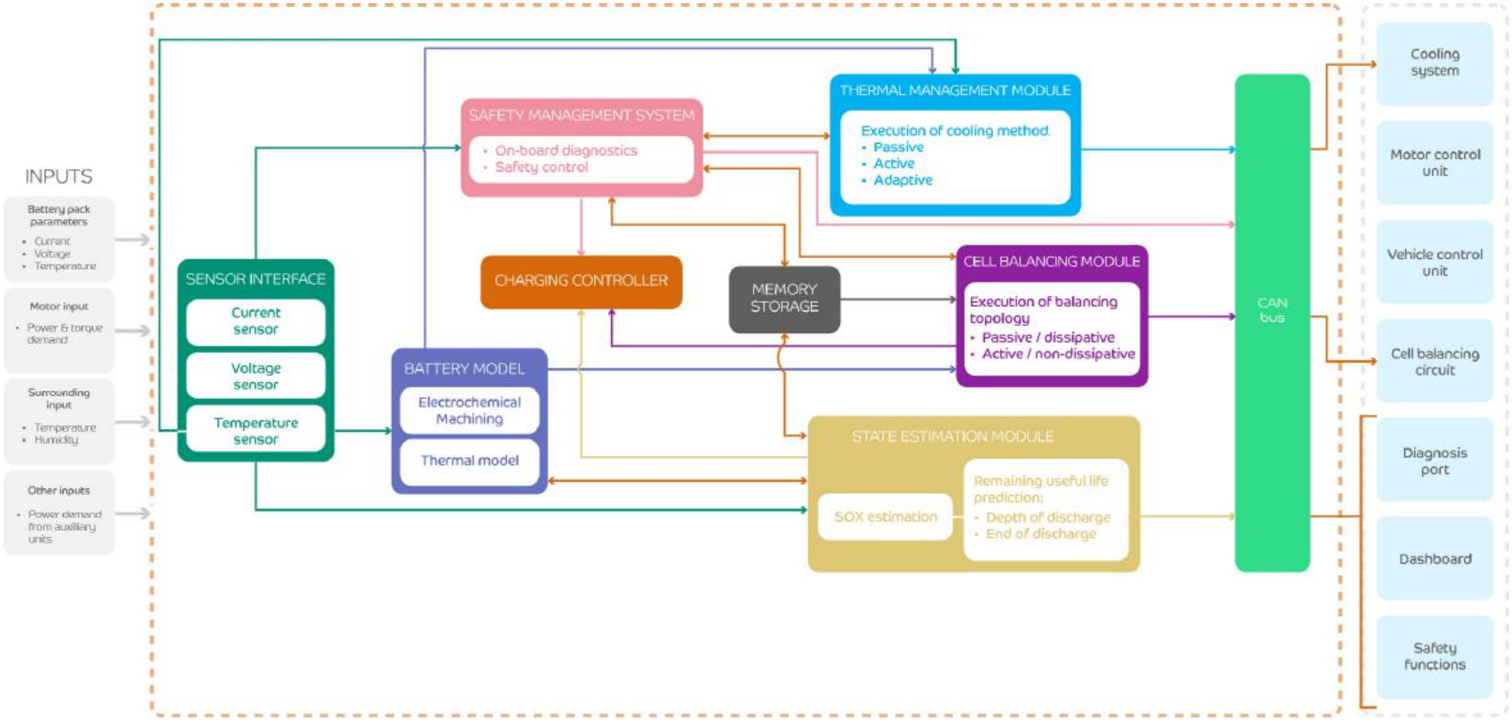
BMS – Battery Control

The BMS is responsible for:

- Controlling the balance of the cells
- Calculating the state of charge (SOC)
- Calculating the state of health (SOH)
- Protecting the cells
- Controlling charging and discharging

Notes:

BT2 Operating Principles of Battery Management Systems

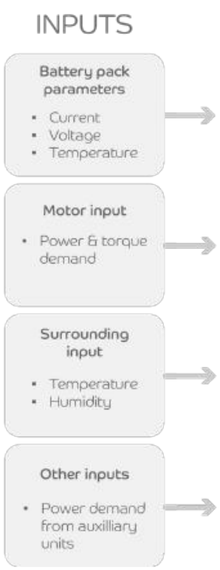


Notes:

How Does the BMS Work?

The BMS works by monitoring all the values already mentioned and undertaking real-time calculations to ensure the battery is safely working within its pre-set limits.

BT2 Operating Principles of Battery Management Systems

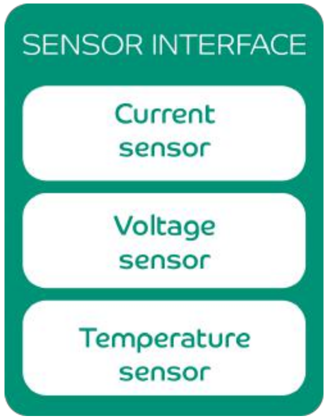


BMS - Inputs

General (potential) inputs of a BMS include:

1. Battery pack parameters
   1.1. Current
   1.2. Voltage
   1.3. Temperature
2. Motor Input
   2.1. Power demanded
   2.2. Torque demanded
3. Surrounding Input
   3.1. Temperature
   3.2. Humidity
4. Other Inputs
   4.1. Power demand from Auxiliary units

Notes:



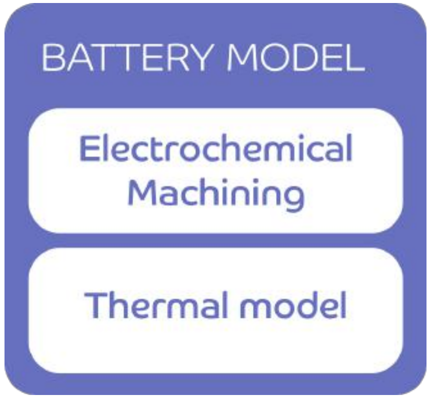
BMS – Sensor Interface

The sensor interphase measures all of the inputs using various sensors – these will depend on the application and usage of the Pack.

These sensors feed real-time data to the rest of the BMS and are just sensors – they undertake no processes except the gathering of information to be passed on to the various "modules" in a pack.

Notes:

BT2 Operating Principles of Battery Management Systems



Notes:

BMS – Battery Model

The battery model collates and performs Algorithms to create a complete picture of what is occurring in the pack. This data is then passed onto the other modules to act as appropriate.

Notes:

BMS – Safety Management System

The Safety Management system is quite self-explanatory. It uses on-board diagnostics to ensure that the pack is operating within the set safety limits. If not, it works in partnership with the Battery Model to put in place actions using the various different models to ensure the pack is brought back into safe limits as part of usual operations.

BT2 Operating Principles of Battery Management Systems

CHARGING CONTROLLER

BMS – Charging Controller

The charging controller is responsible for ensuring safe, effective charging.

It will work with the other systems to ensure the State of Charge and State of Health are in consideration while charging. Receiving information from the Safety Management System (from the sensor interface) and the State Estimation module.

Notes:

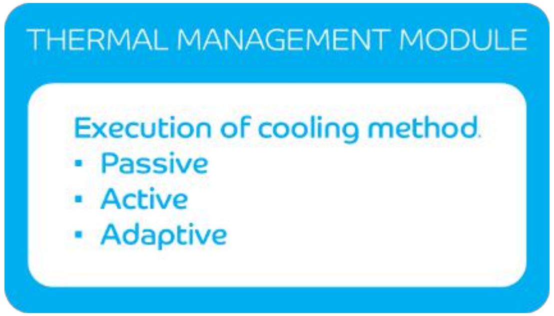
MEMORY STORAGE

BMS – Memory Storage

Memory Storage stores information from the BMS that may need to be called upon at a later date, including pertinent charging data, SOC/SOH Data etc.

Notes:

BT2 Operating Principles of Battery Management Systems

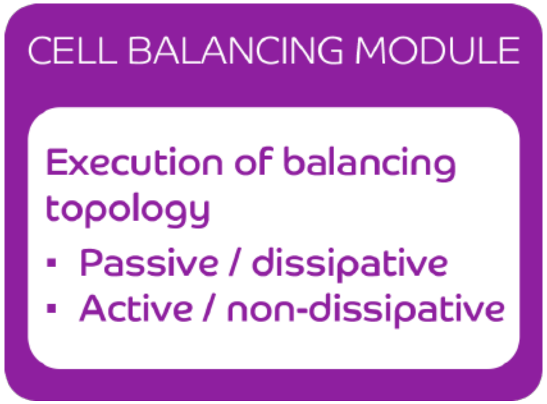


Notes:

BMS – Thermal Management Module

The Thermal Management Module ensures that the temperature of the cells stays within the optimum operating range.

This is achieved by using various methods of cooling (passive, active, adaptive), as already covered previously.



Notes:

BMS – Cell Balancing Module (Passive)

In passive balancing, energy is drawn from the most charged cell and dissipated as heat, usually through resistors.

Passive balancing equalises the state of charge at some fixed point – either "top balanced", with all cells reaching 100% SOC at the same time; or "bottom balanced", with all cells reaching minimum SOC at the same time.

BMS – Cell Balancing Module (Passive) cont.

This can be accomplished by bleeding energy from the cells with higher state of charge (e.g. a controlled short through a resistor or transistor), or shunting energy through a path in parallel with a cell during the charge cycle so that less of the (typically regulated constant) current is consumed by the cell. Passive balancing is inherently wasteful, with some of the pack's energy spent as heat for the sake of equalizing the state of charge between cells. The build-up of waste heat may also limit the rate at which balancing can occur.

Notes:

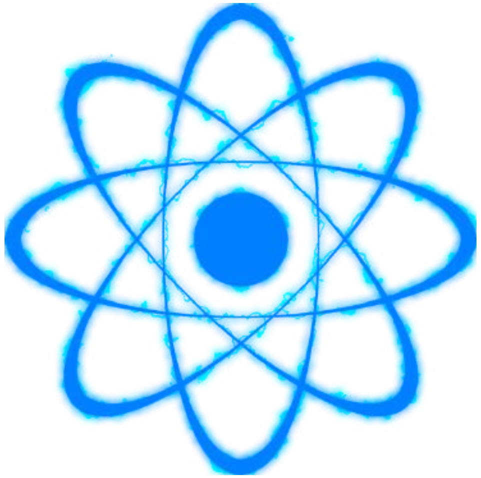
BMS – Cell Balancing Module (Active)

In active balancing, energy is drawn from the most charged cell and transferred to the least charged cells, usually through capacitor-based, inductor-based or DC–DC convertors.

Active balancing attempts to redistribute energy from cells at full charge to those with a lower state of charge.

Notes:

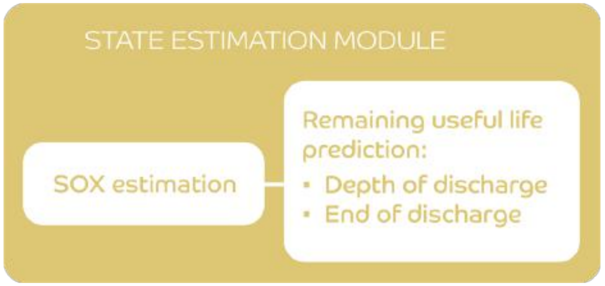
BT2 Operating Principles of Battery Management Systems



BMS – Cell Balancing Module (Active) cont.

Energy can be bled from a cell at higher SOC by switching a reservoir capacitor in-circuit with the cell, then disconnecting the capacitor and reconnecting it to a cell with lower SOC, or through a DC-to-DC converter connected across the entire pack. Due to inefficiencies, some energy is still wasted as heat, but not to the same degree. Despite the obvious advantages, the additional cost and complexity of an active balancing topology can be substantial and doesn't always make sense depending on the application.

Notes:



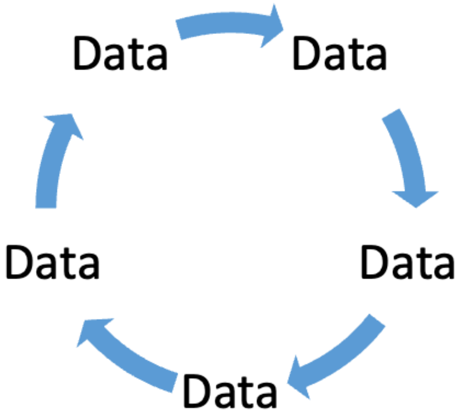
BMS – State Estimation Module

The State estimation Module looks after the State of X (SOX):

- Charge
- Health

Notes:

BT2 Operating Principles of Battery Management Systems

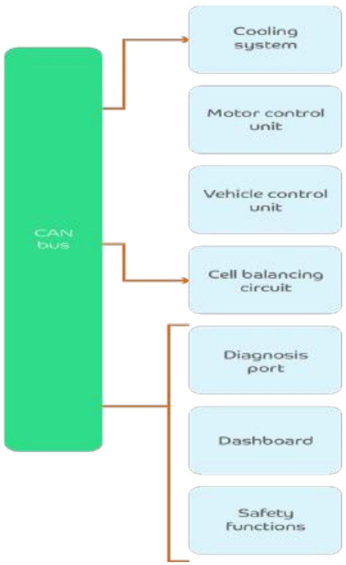


BMS – State Estimation Module cont.

It uses data from the sensors, memory storage and the Battery Model to work out:

- SOC – which is the difference between a fully charged battery and the same battery in use – in essence it estimates the remaining quantity of electricity available in the cell (Defined as the ratio of the remaining charge in the battery or can be called Depth of Discharge)
- SOH – describes the difference between a New/fresh battery and the "aging" Battery.

Notes:



BMS – CAN Bus

Controlled Area Network (CAN) Bus is essentially the nervous system of the BMS, allowing communication from the modules within the BMS to the external displays and units that control certain systems.

Notes:

BT2 Operating Principles of Battery Management Systems

How it is Calculated

$$\mathrm{SoC}/\% = 100\frac{(Q_0 + Q)}{Q_{\max}} = \mathrm{SoC}_0/\% + 100\frac{Q}{Q_{\max}} \quad (1)$$

Q_0/mAh = Initial charge of the battery.

Q/mAh = The quantity of electricity delivered by or supplied to, the battery. It follows the convention of the current: it is negative during the discharge and positive during the charge.

$Q_{\max}/\mathrm{mAh}$ = The maximum charge that can be stored in the battery.

$\mathrm{SoC}_0/\%$ = The initial state-of-charge $(\mathrm{SoC}/\%)$ of the battery.

- If the battery is new: $Q_{\max} = C_r$ and $Q_0 = 0.5\,Q_{\max}$ generally. C_r is the rated capacity of the battery as given by the manufacturer.
- If the battery is fully charged: $Q_0 = Q_{\max}$ and $\mathrm{SoC}_0 = 100\%$.

$$\mathrm{SoH}/\% = 100\frac{Q_{\max}}{C_r}$$

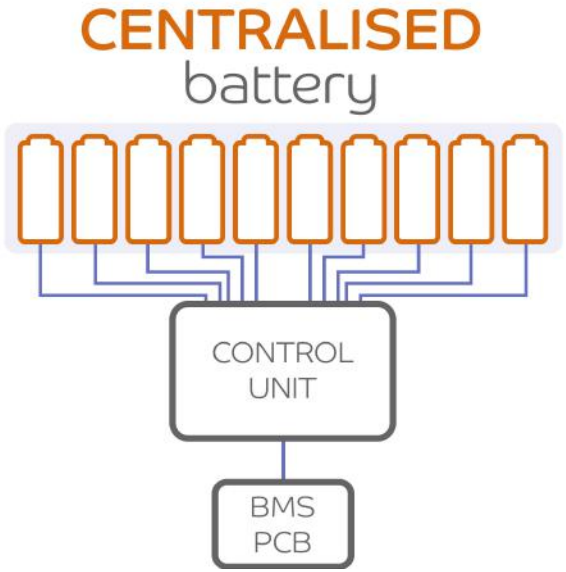
$Q_{\max}/\mathrm{mAh}$ = The maximum charge available of the battery

C_r = The rated capacity

Notes:

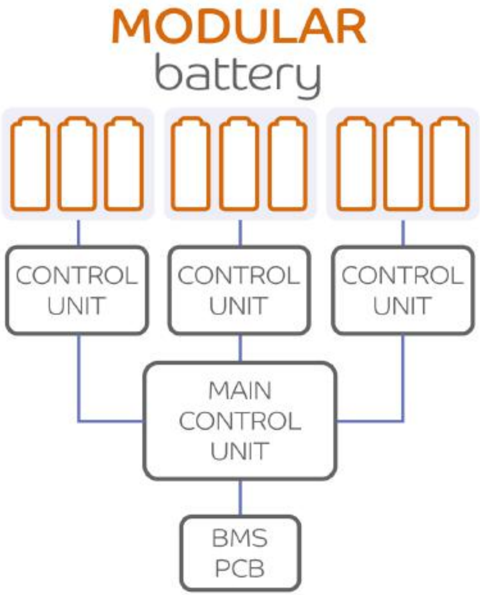
BT2 Operating Principles of Battery Management Systems

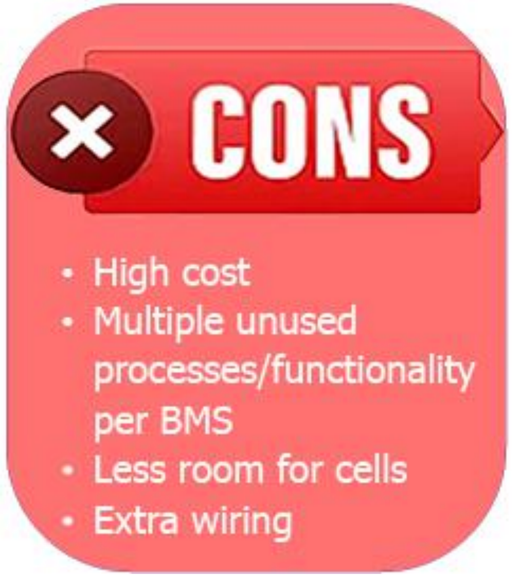
Centralised Battery Management System



In a Centralised Battery Management System, a single BMS is the hub for all of the cells. All of the cells link to one control unit.

Notes:

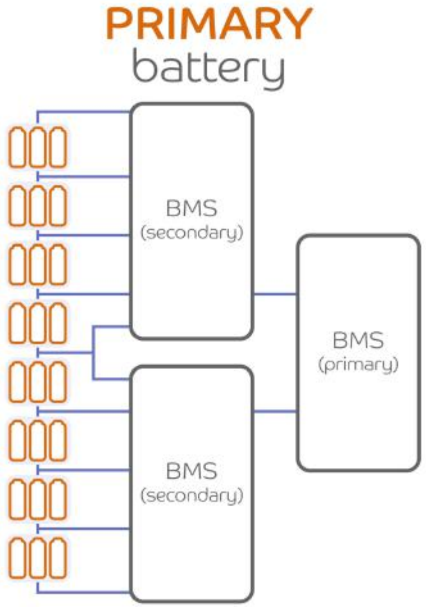




In a Modular Battery Management System, groups of duplicate modules are connected to the control units, joined with separate wires and buddle connected to a main control unit (MCU), then finally to a BMS. Control units gather the data from the sensors and pass it on to the MCU. The MCU gathers all the data and can do some processing/algorithms before passing it onto the BMS. The BMS will undertake further processing and then action them as required.

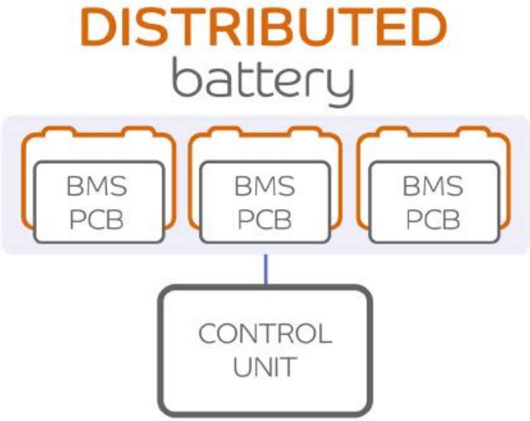
Notes:

BT2 Operating Principles of Battery Management Systems



The Primary Battery Management System is similar to the modular topology. There is one primary BMS in charge of a secondary BMS. The secondary units could also be LMU's (Lithium Monitoring Units). LMU's/Secondary BMS's have less functionality than 'Primary BMS'. LMU's/Secondary BMS's are primarily focused on the collection and transfer of measurement information. 'Primary BMS' undertakes control, calculations and communication.

Notes:



In a Distributed Battery Management System each module/group of modules has its own BMS which undertakes some or all of the processes expected of the BMS. Each BMS controls its own Module or group of modules and can act as an independent BMS or pass on its information to the control unit. The control unit can also be its own BMS and this can collate the information and action it as required.

Notes:

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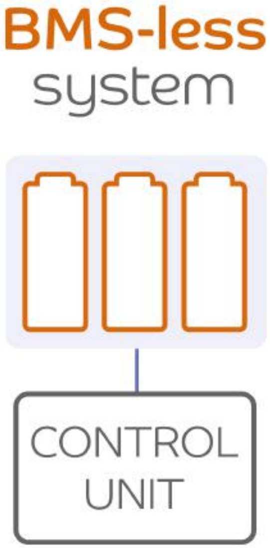

In a BMS-Less system there is no battery management system. Everything is controlled by Lithium Monitoring Units (LMU) or control units. The control unit undertakes a simpler application as a BMS but on a smaller level.

Notes:

BT2 Operating Principles of Battery Management Systems

Glossary of Terms

Term/phrase/abbreviation	Explanation
BMS	Battery Management System
BPS / BPU	Battery Protection System / Battery Protection Unit
CAT ratings	Multi-meter category https://www.digikey.co.uk/en/blog/what-are-multimeter-cat-safety-ratings
Cell	An individual power source - cylindrical, pouch, prismatic or blade.
CMR	Convention on the Contract for the International Carriage of Goods by Road
DGSA	Dangerous Goods Safety Advisor
EDU	Electric Drive Unit
FA & T	Formation, Ageing & Testing
ICE	Internal combustion engine
KIB	Potassium Ion Battery
LAB	Lead Acid Battery
LBC	Lithium Battery Controller (same as BMS - different term)
LFP	Lithium, Iron Phosphate (Cells)
LIB	Lithium Ion Battery
MCU	Motor Control Unit

Glossary of Terms Cont.

Module	An arrangement of cells makes up a module
MRP - ERP	Manufacturing Requisition Planning / Enterprise Resource Planning
MVIB	Multi Valiant Ion Battery
NMC	Nickel, Manganese & Cobalt (Cells)
NMP	N-methyl-2-pyrrolidone (NMP) is the most common solvent for manufacturing cathode electrodes in the battery industry; however, it is becoming restricted in several countries due to its negative environmental impact.
Pack	An arrangement of stacked cells or modules joined in series and/or parallel, makes up a pack.
PVDF	Polyvinylidene fluoride more commonly known as (PVDF) polymers, are widely used as binders in lithium-ion batteries. It can be injected, moulded or welded and is commonly used in the chemical, semiconductor, medical and defence industries, as well as in lithium-ion batteries.
SAP	Systems Application and Products (Planning)
SEI	Solid Electrolyte Interphase
SIB	Sodium Ion Battery
TMS / TMU	Thermal Management System / Unit