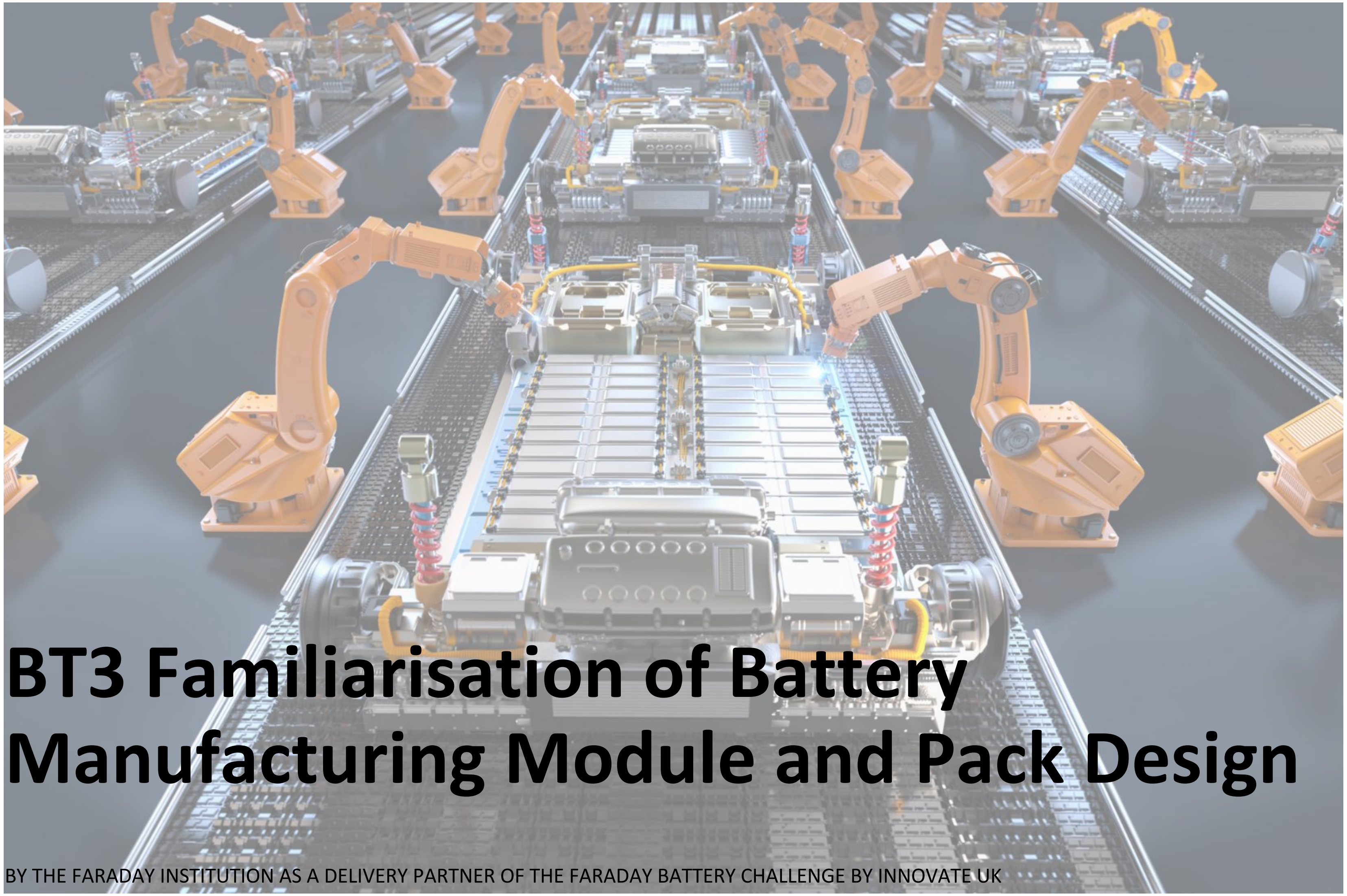

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

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

THE FARADAY INSTITUTION

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

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

Notes:

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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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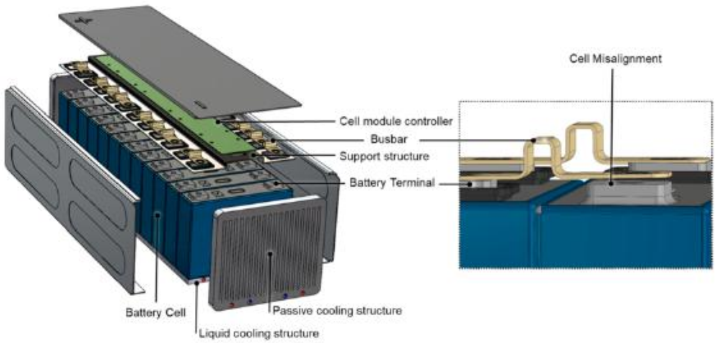

Source: mdpl.com

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

Notes:

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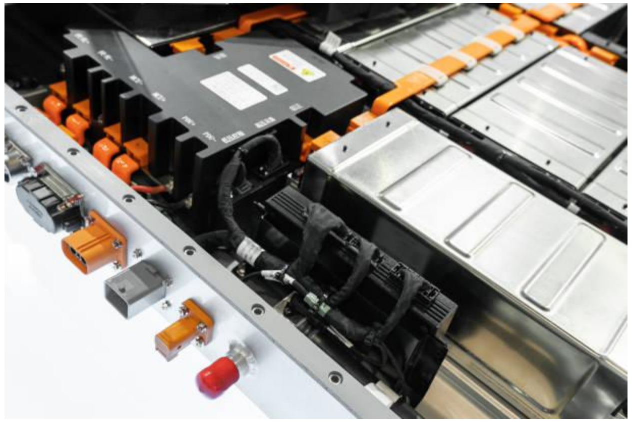

Image source: UKBIC

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.

Notes:

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The Battery Manufacturing Process

Notes:

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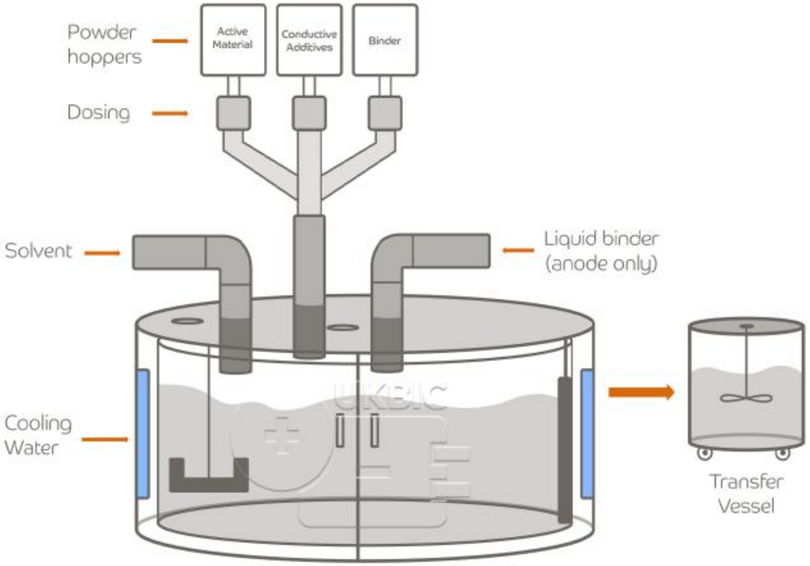

Image source: UKBIC

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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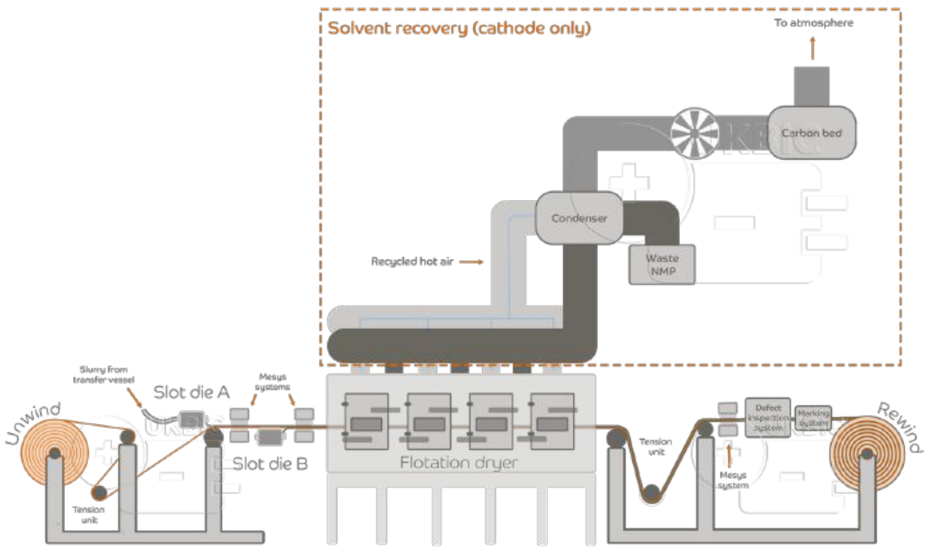

Image source: UKBIC

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

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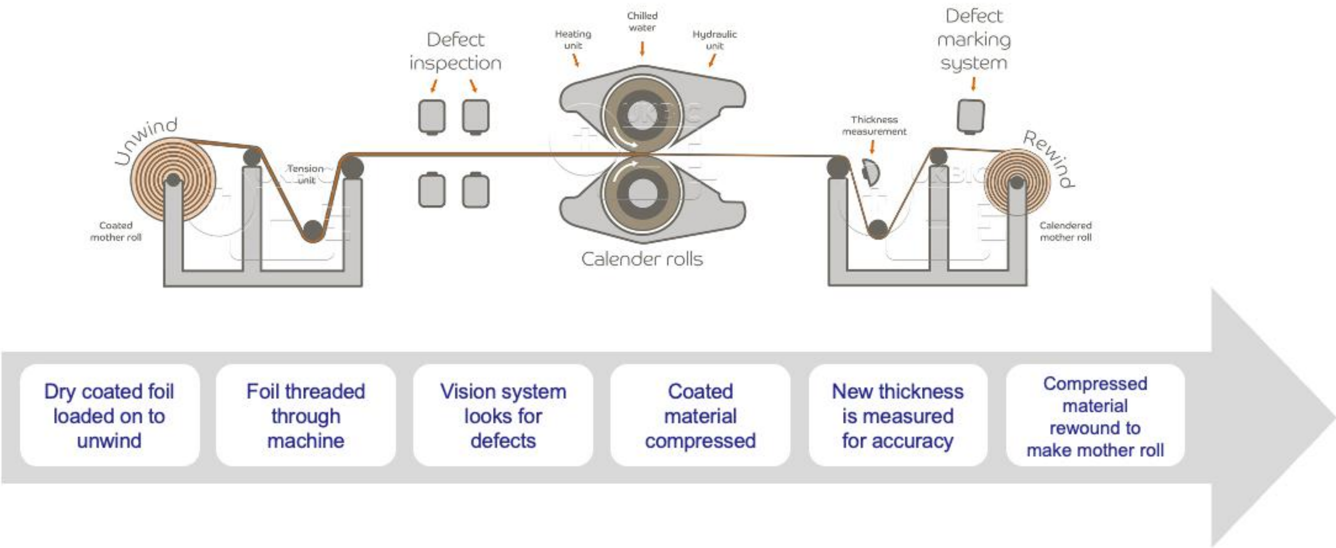

Image source: UKBIC

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.

Notes:

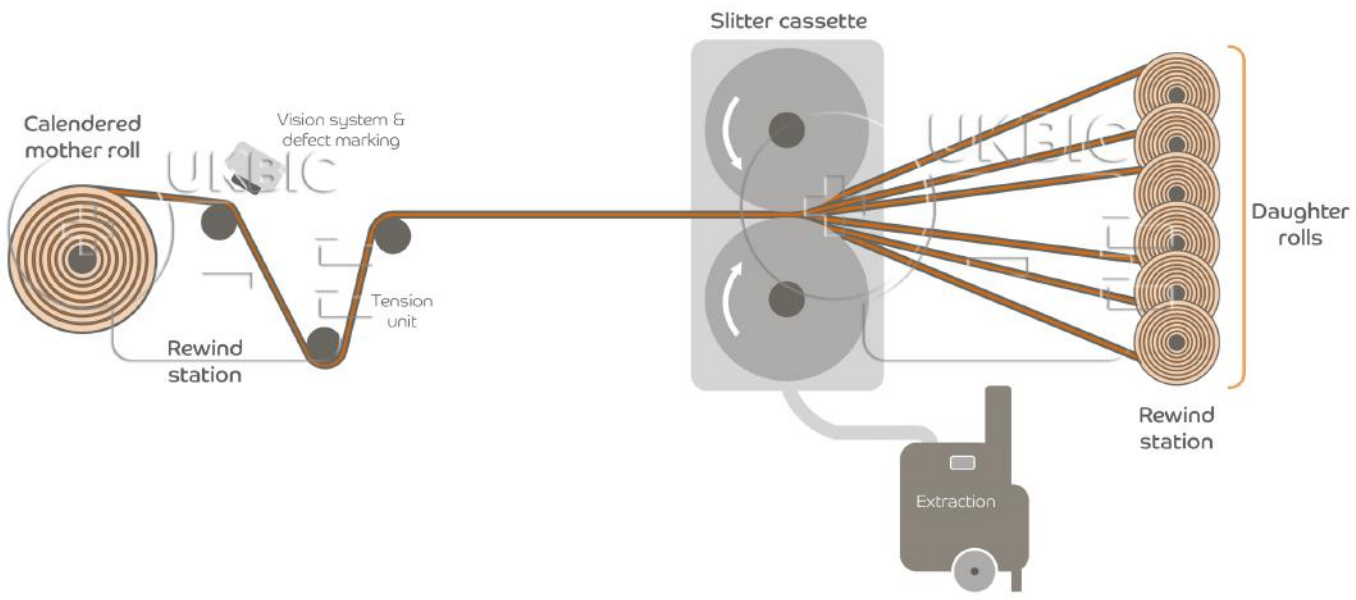

Image source: UKBIC

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

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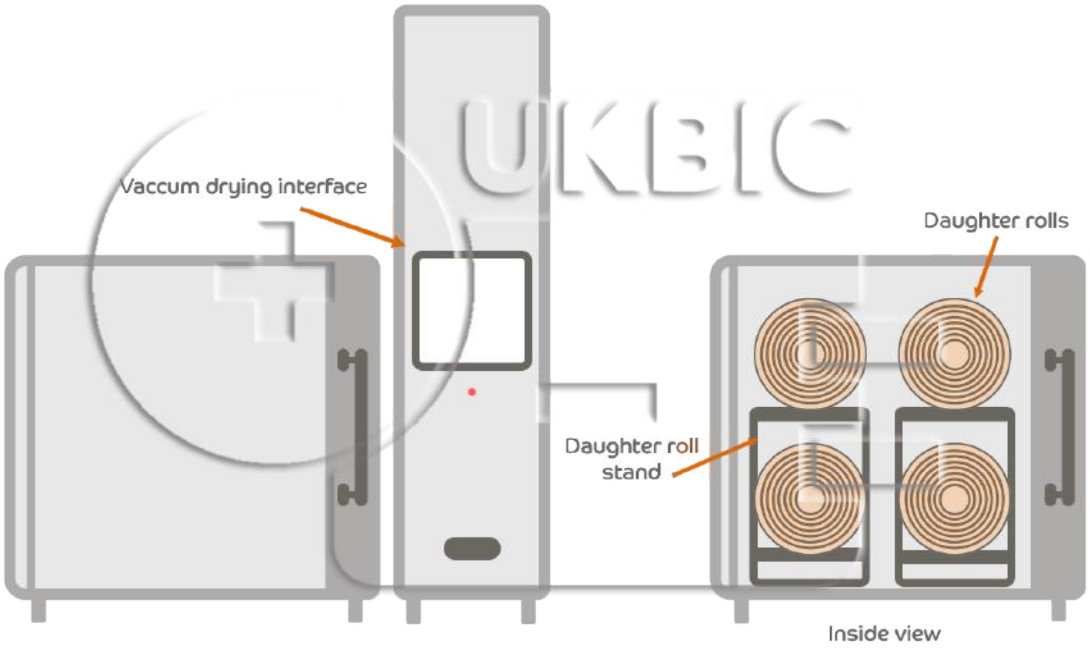

Image source: UKBIC

Notes:

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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.

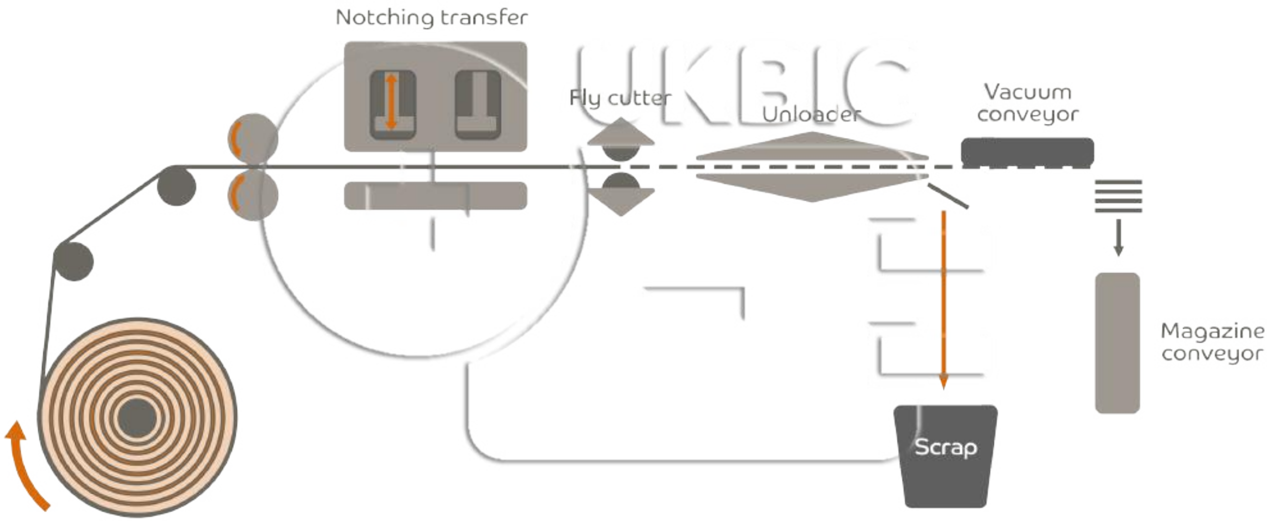

Image source: UKBIC

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.

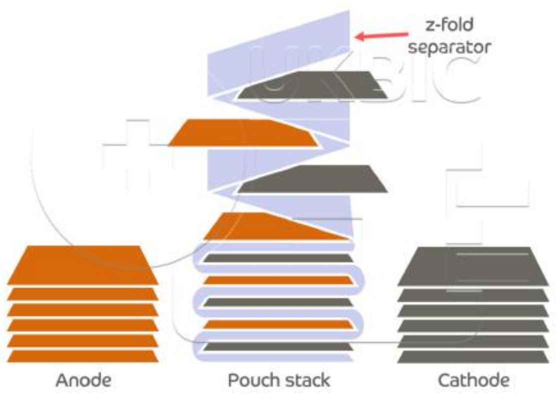

Image source: UKBIC

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:

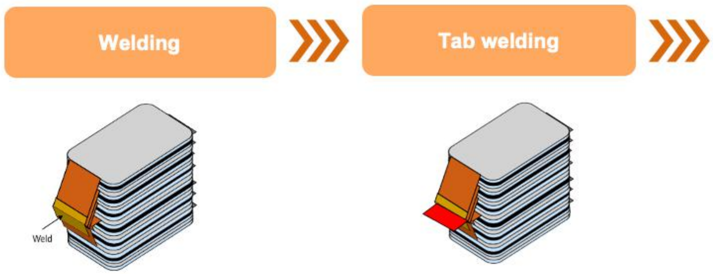

Image source: UKBIC

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:

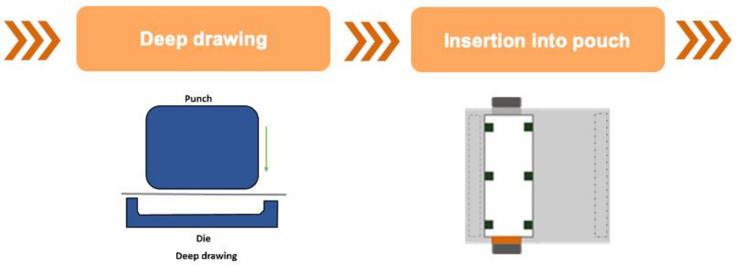

Image source: UKBIC

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:

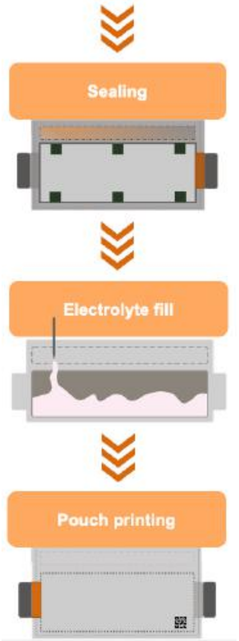

Image source: UKBIC

Cell Assembly (Pouch) – Packing & Filling cont.

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Notes:

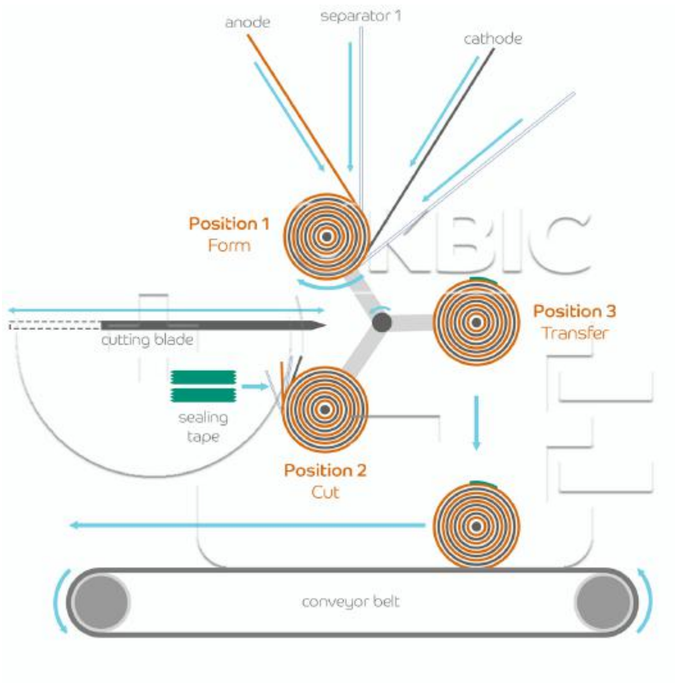


Image source: UKBIC

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

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.

Notes:

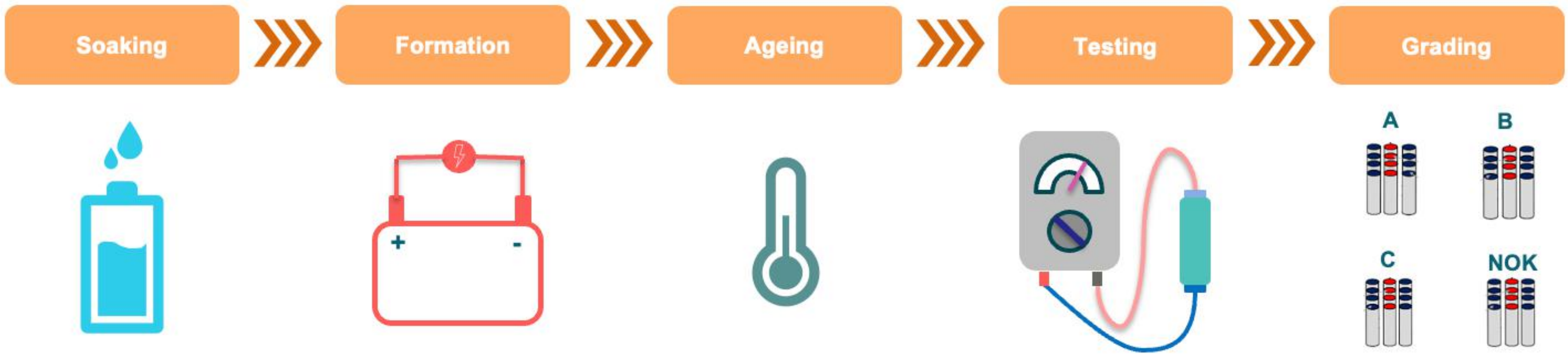
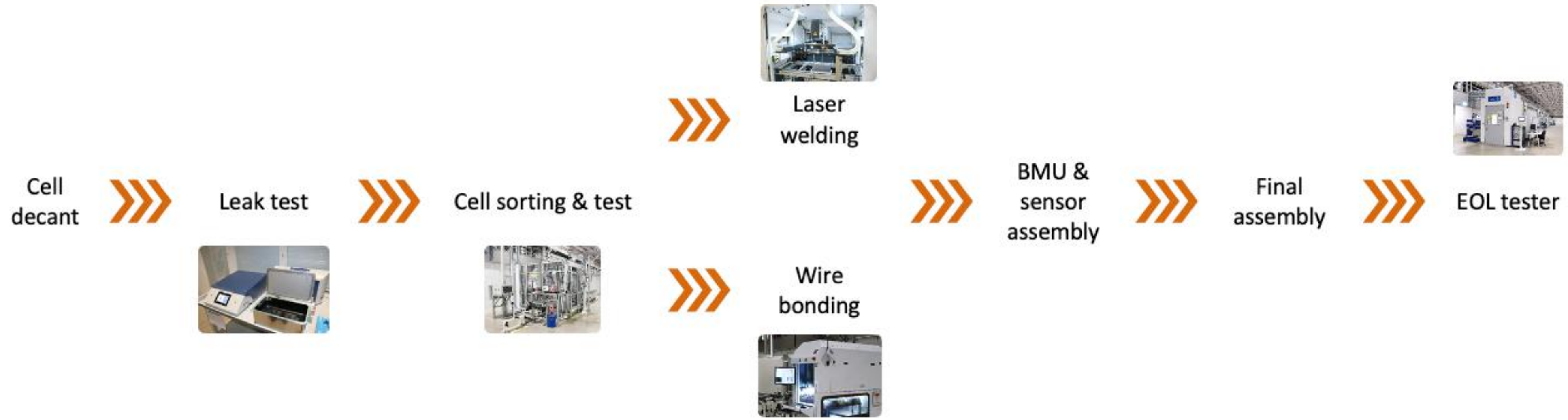


Image source: UKBIC

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.

Notes:



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

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

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

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

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.

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

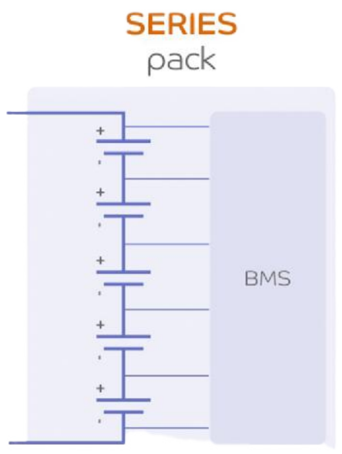


Image source: UKBIC

Notes:

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.

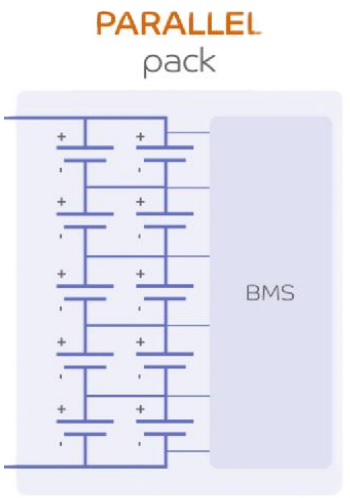


Image source: UKBIC

Notes:

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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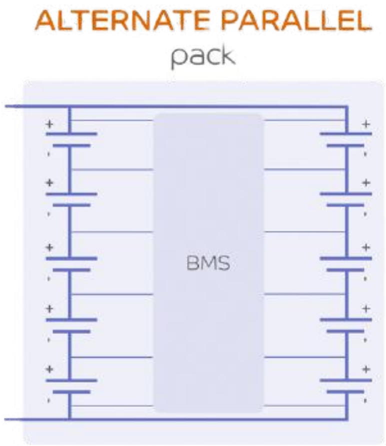


Image source: UKBIC

Module Arrangement – Alternate Parallel

Notes:

Notes:

Power Outputs

Nissan Leaf - 110kW

Hyundai Kona Electric – 150kW

Mercedes-Benz EQC - 300kW

Porsche Taycan Turbo S – 560kW

Tesla Model S Performance – 595kW

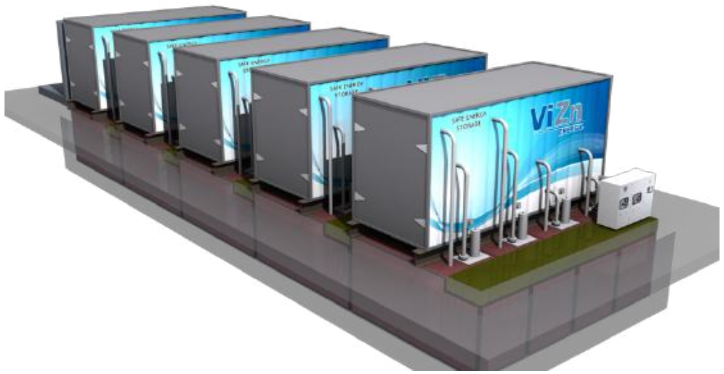
Notes:

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

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:

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

Main Considerations of Design - Marine

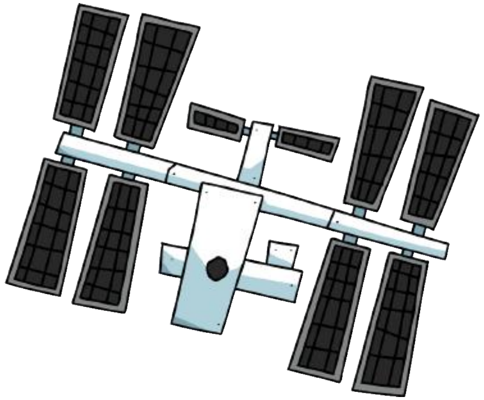
- Power output – Huge power output, consistent but potential ebbs and flows
- Weight – Relatively important – however less than aerospace
- Longevity - Long life
- Capacity - High

Notes:

Main Considerations of Design – Aerospace

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

Notes:



Source: imgbin.com

Main Considerations of Design - Space

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

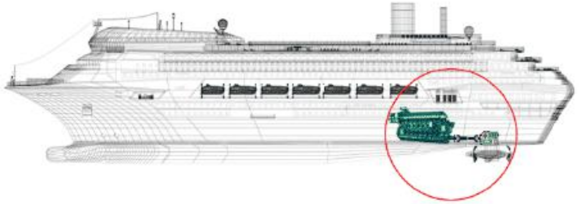
Notes:

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:

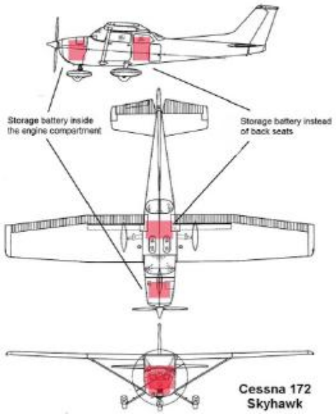
BT3 Familiarisation of Battery Manufacturing Module and Pack Design



How Does Location Impact Design?

- Parameters
- Size
- Weight

Notes:



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:

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:

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

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:

BT3 Familiarisation of Battery Manufacturing Module and Pack Design


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:

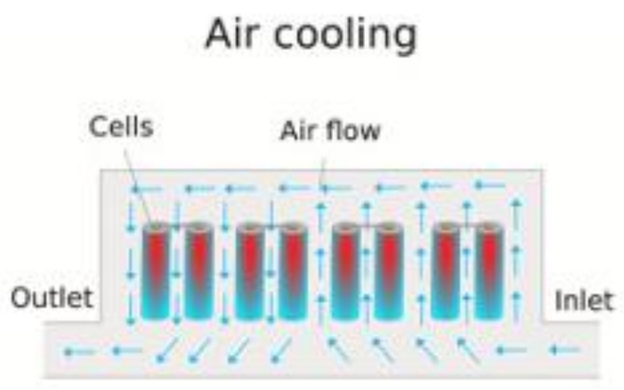


Image source: UKBIC

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:

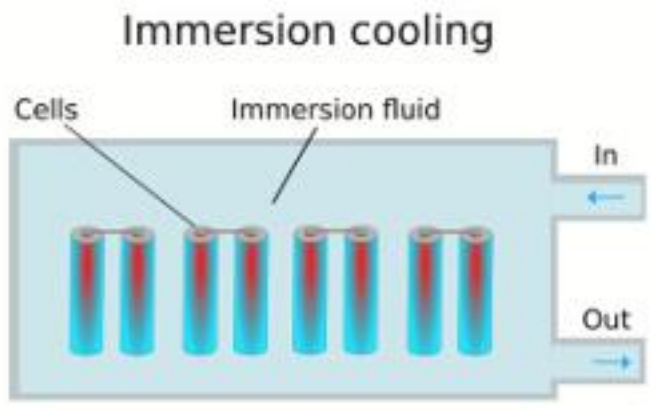


Image source: UKBIC

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:

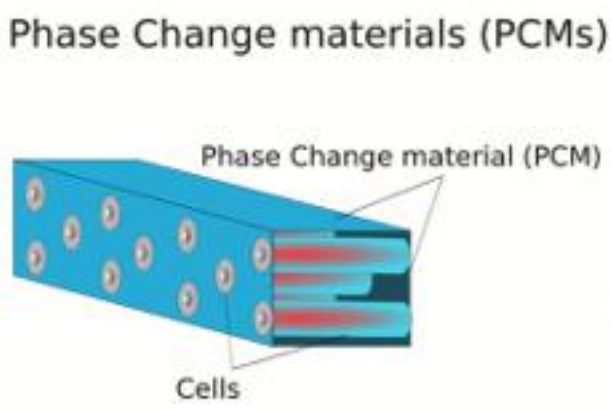


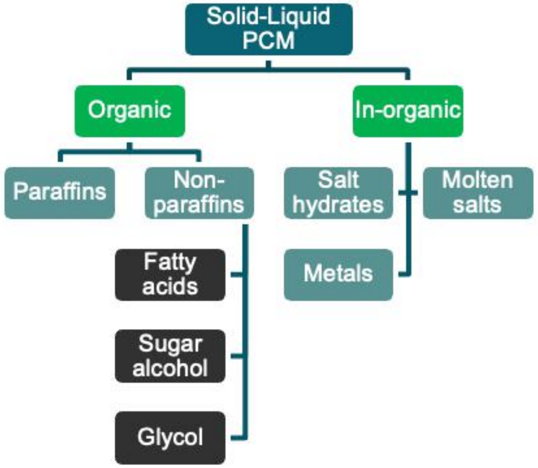
Image source: UKBIC

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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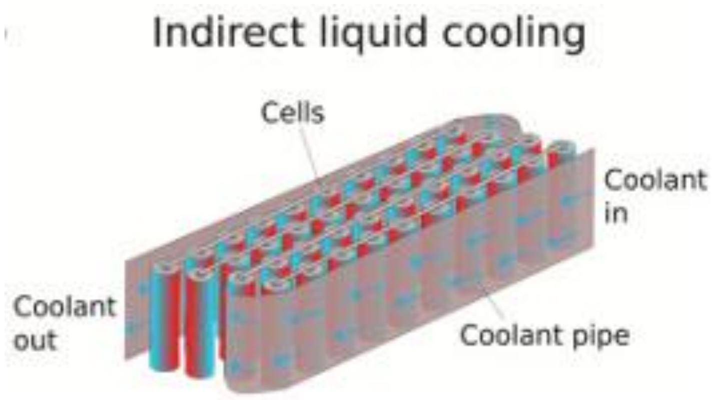


Image source: UKBIC

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

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

Notes:

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

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:

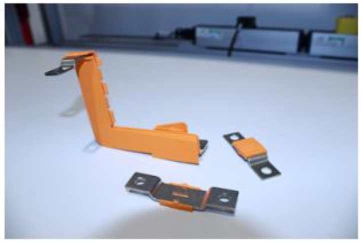


Image source: UKBIC

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:


Image source: UKBIC

Components – Pack – Contactors

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

Notes:

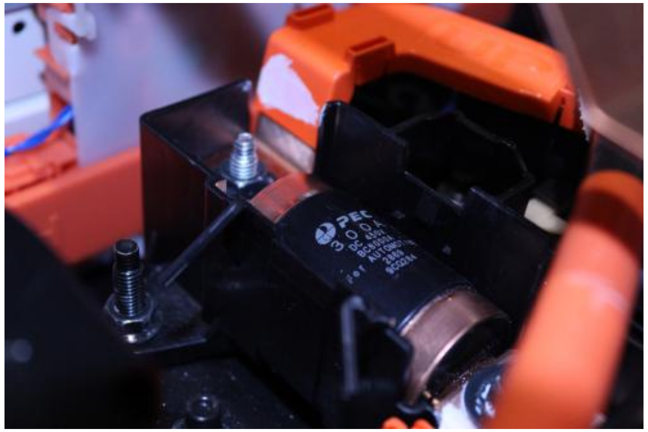


Image source: UKBIC

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:

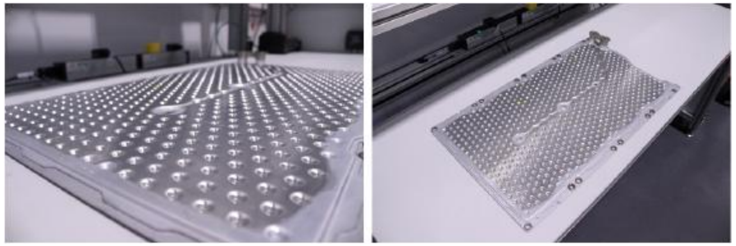


Image source: UKBIC

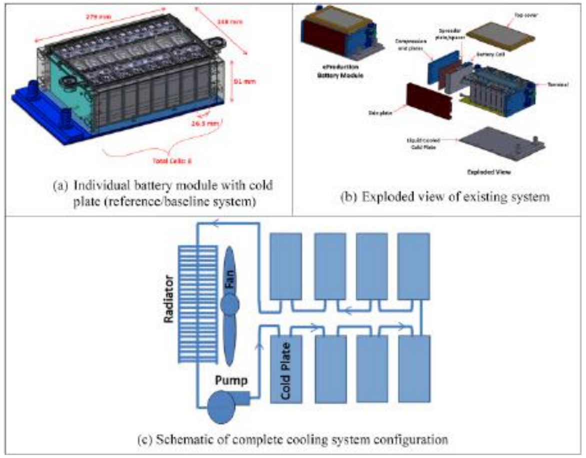
Components – Pack – Cooling

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:

BT3 Familiarisation of Battery Manufacturing Module and Pack Design



(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:

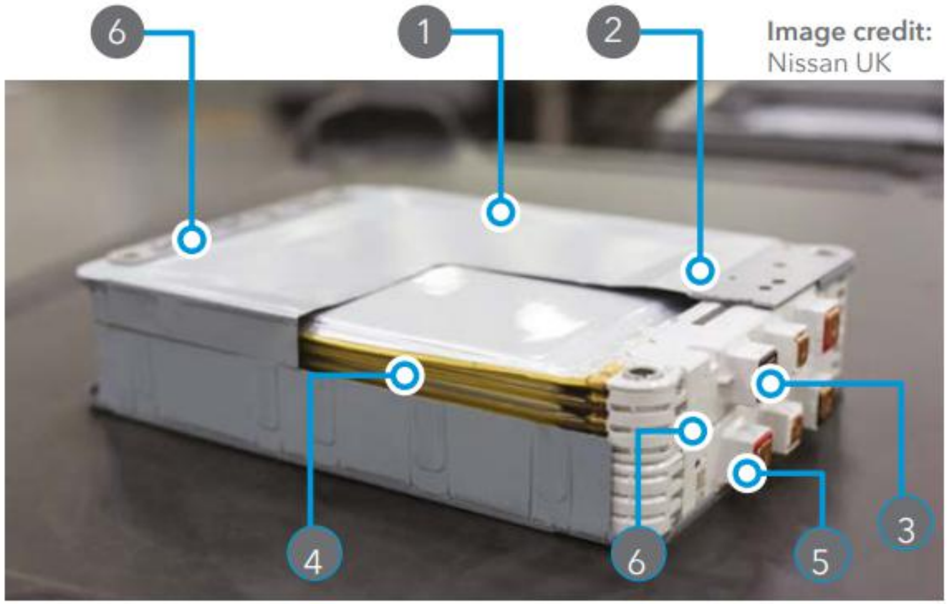
Source: warwick.ac.uk

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:

BT3 Familiarisation of Battery Manufacturing Module and Pack Design



Pouch cell module (Nissan Leaf)

Source: warwick.ac.uk

Notes:

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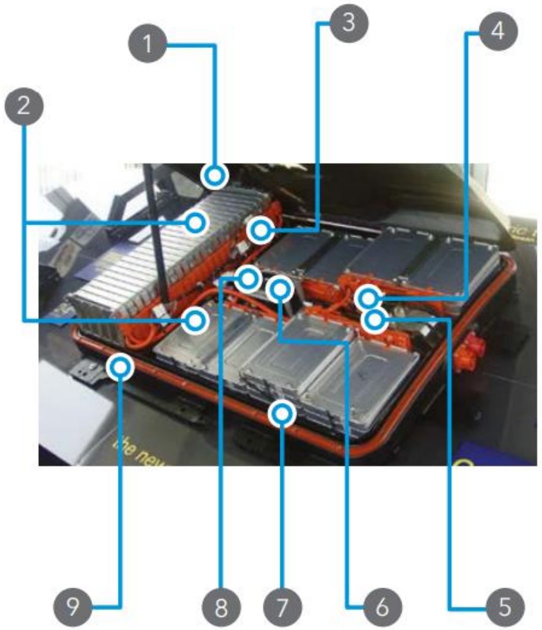
Module Components

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

BT3 Familiarisation of Battery Manufacturing Module and Pack Design



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.

Thermal Issues - Cooling

Cooling can be a potential issue with the cell itself as well as the module and pack.

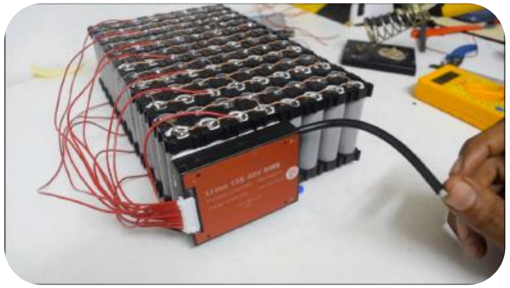
Issues with cooling can lead to thermal events or even fires.

Notes:

Thermal Issues – Thermal Management

Modules and packs need to be kept at a pre-defined temperature range to work effectively. Outside of these temperature ranges the cell performance starts to suffer. Getting too hot can lead to a thermal events. Too cold and the cell chemistry/reaction can be retarded and ineffective.

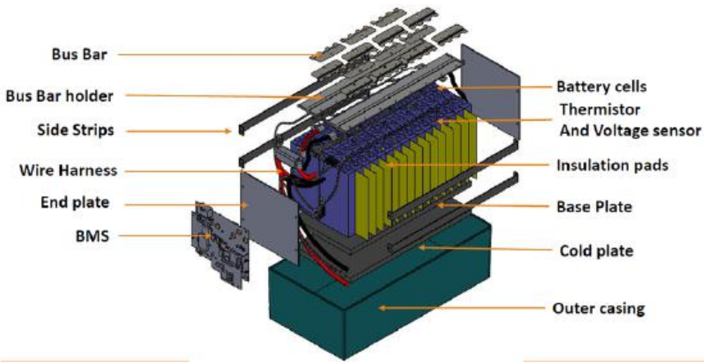
Notes:



Thermal Issues – Battery Management

The Battery Management System (BMS) needs to deal with all of these issues but design can reduce the requirements.

Notes:



Mechanical Issues

Mechanical issues can include:

- Battery management
- Connectors
- Busbars and Hazardous Voltage Infrastructure (HVI)

Notes:

Form and Function Impacts

Form and function impacts include:

- Cooling
- Maintenance
- Reliability
- Performance

Notes:

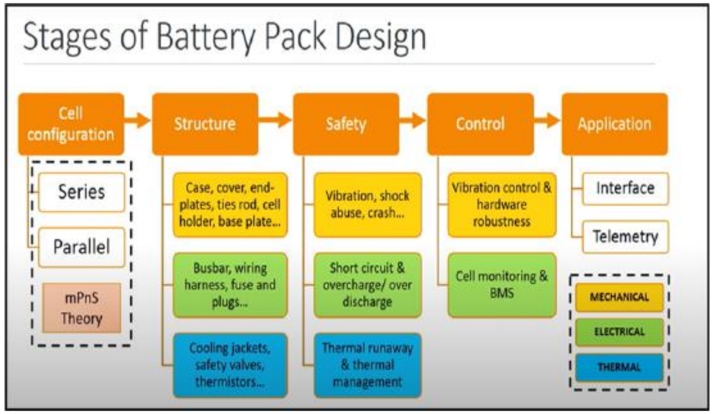
Main Considerations of Design

Information relating to the main considerations whilst designing a battery module and pack for different industries can be seen on pages 22 to 24 of this workbook.

Don't forget to consider IP Rating and environmental factors (cold, hot, dry, corrosive, vacuum etc.)

Notes:

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

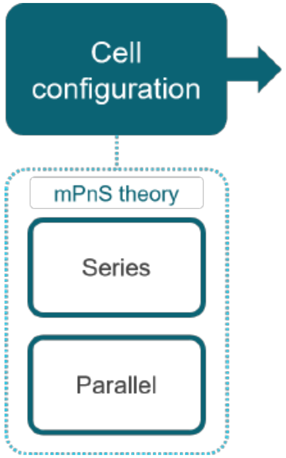


Stages of Battery Pack Design

There are four stages of battery pack design, which are:

- Electrical design
- Thermal design
- Mechanical design
- BMS design

Notes:

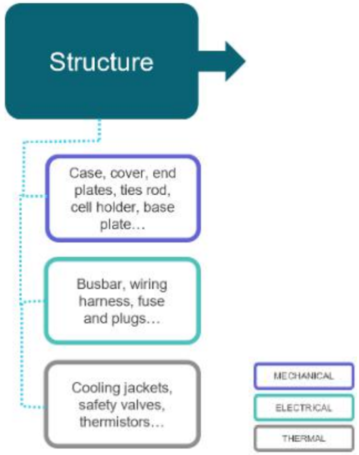


Cell configuration

A decision needs to be made, based on the application and available space, whether the cell configuration should be series or parallel.

Notes:

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

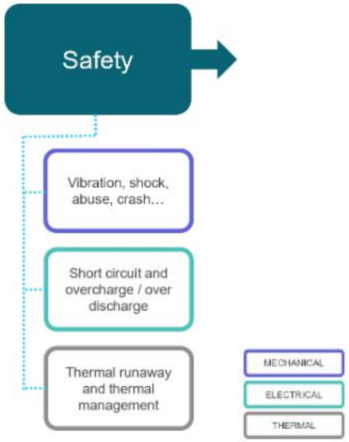


Structure

The structure of the battery pack needs to consider the required contents and the space/shape available.

- Case, cover and securing devices
- Busbars, wiring, fuses and plugs
- Cooling and safety features

Notes:

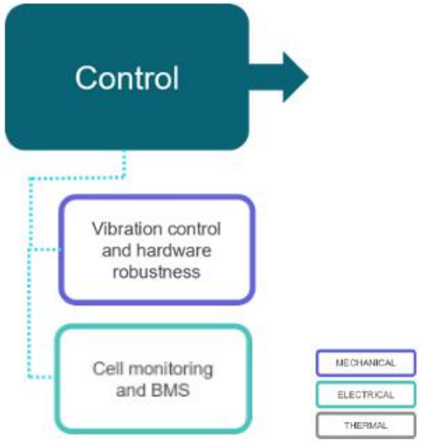


Safety

Safety needs to be a high consideration when designing a battery pack. The design needs to consider vibration, shock and abuse, in addition to the impact following an accident/crash. Thermal management is also significant as the design and location of the battery pack could impact this.

Notes:

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

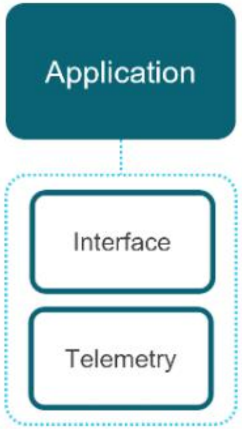


Control

The battery pack design needs to control, as much as possible, any vibrations on the hardware. Although the hardware can be robust, continuous vibrations over a long period of time will cause damage.

Other controls required include cell monitoring and a battery management system (BMS).

Notes:



Application

During the design process thought needs to be given to the final application requirements. What does the battery pack need to interface with and is there a requirement for telemetry?

Notes:

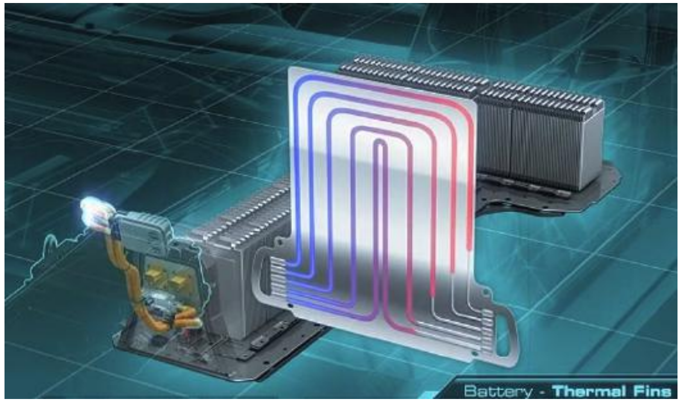
BT3 Familiarisation of Battery Manufacturing Module and Pack Design

Electrical Design

The electrical design needs to ensure it meets the required capacity, voltage and current for the application. Safeguards also need to exist for high voltage isolation and short circuit prevention.

Another key aspect is to ensure the battery pack can provide efficient power delivery.

Notes:



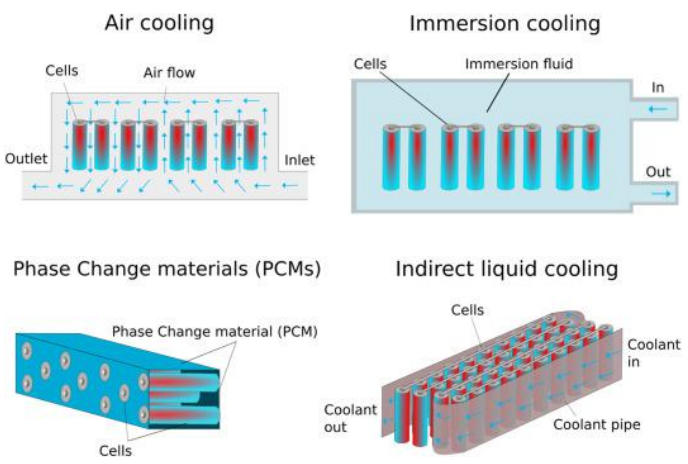
Thermal Design

Things to consider relating to the thermal design include:

- Improve battery pack efficiency
- Mitigate thermal accidents
- Increase the battery pack life

For example, the most common thermal management challenges for EV batteries are the climate and overheating/underheating.

Notes:

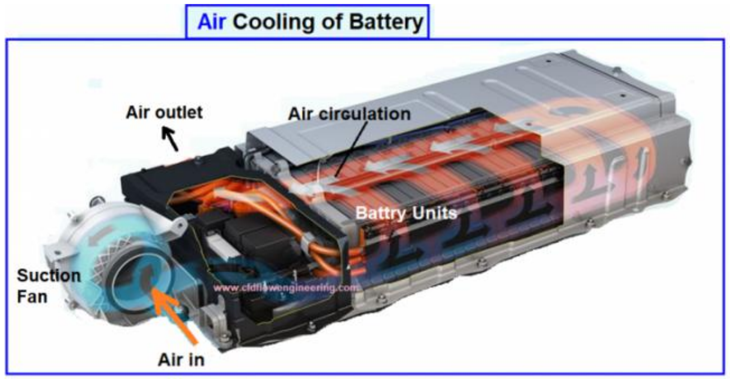


Cooling

There are four different ways of cooling (covered on pages 29 and 30) which are:

- Air cooling
- Liquid cooling
- Cooling with heat conducting materials
- Submersion cooling

Notes:

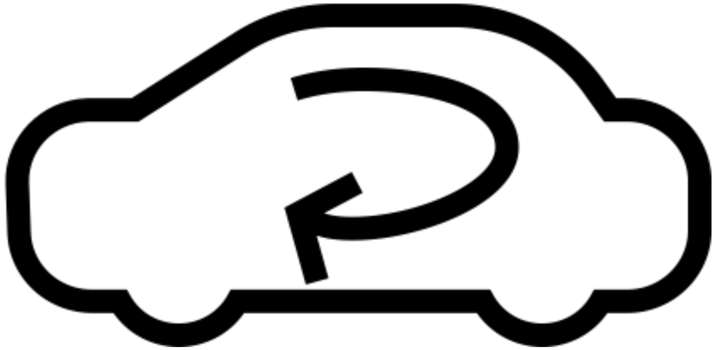


Air Cooling

Air cooling is the simplest form of cooling. In this design air is passed through the battery pack in two major ways:

- Internal circulation
- External circulation

Notes:

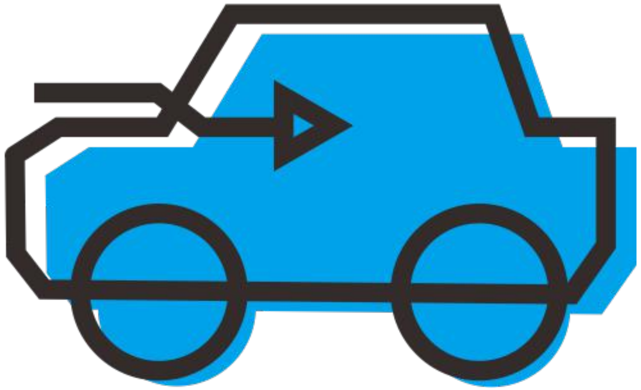


Internal Circulation

When applied to an electric vehicle, internal circulation is where air is circulated from inside the vehicle through to the battery pack. This allows for both cooling of the battery pack and heating of the battery pack, during cold winter days.

One downside to this system is that the temperature of the air inside the vehicle is also the temperature at which the batteries get cooled. Turning up the heat inside the vehicle means the cooling air circulated is already warm.

Notes:

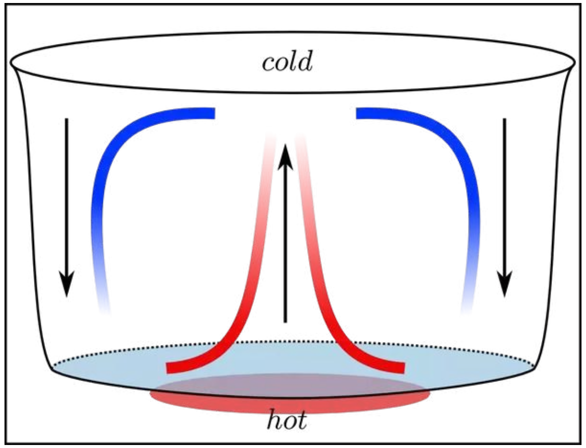


External Circulation

External circulation is where the outside air is circulated through air ducts to the battery pack. This causes the temperature of the batteries to fluctuate with the change of outside temperature.

The downside to this is that during hot summer days, or hot climates, the batteries will rise in temperature.

Notes:

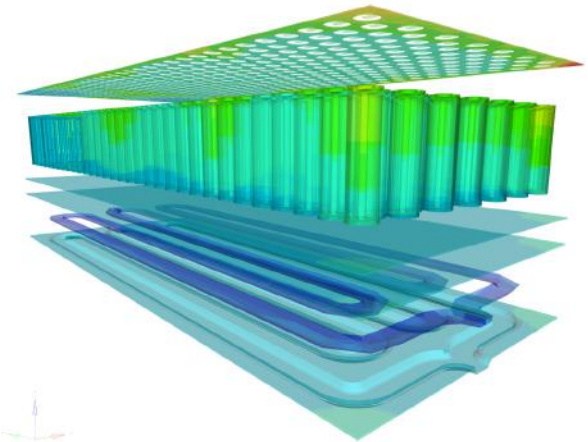


Air Cooling Applications

In most low to medium power applications, air cooling is sufficient. The power demanded from the drivetrain is not too high, meaning the battery temperature will be maintained just by the airflow.

Even when high power is occasionally demanded, air cooling will still be enough because the batteries will have enough time to cool down after a short high-power demand.

Notes:



Liquid Cooling

Liquid cooling is usually water and ethylene glycol and is the most popular way of cooling a battery pack.

A liquid cooling system consists of a lot more complex components than an air-cooled system to improve the cooling performance.

In an electric vehicle the cooling system is only used to cool the battery pack, to ensure it stays below the pre-determined temperature.

Notes:

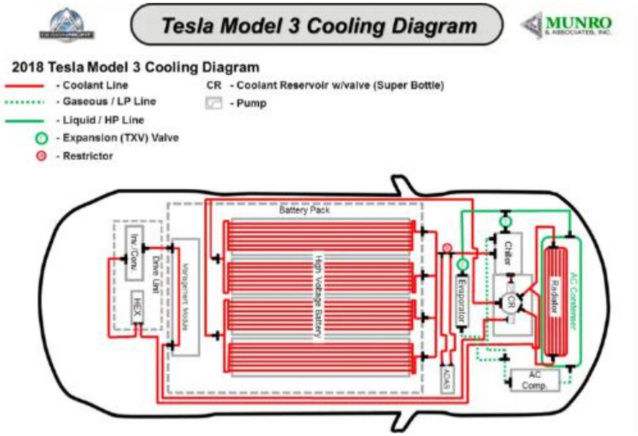


Image credit: Munro

Liquid Cooling Cont.

The motor(s) and controller are cooled with a second liquid cooling system, due to the temperature difference between the components.

The temperature of the motor(s) and controller can reach 140 degrees Celsius.

Notes:

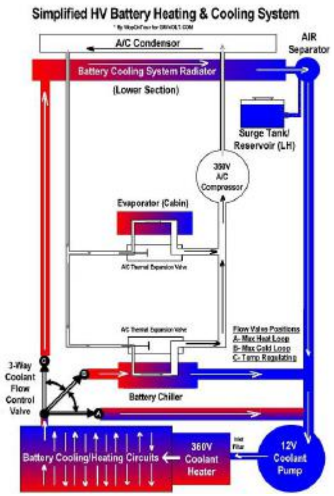


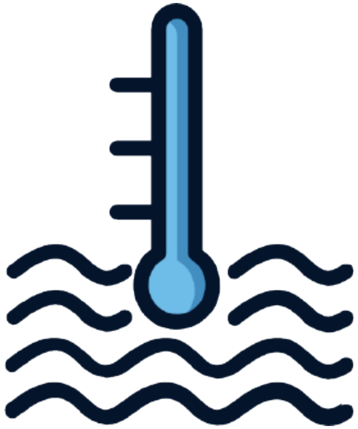
Image credit: WopOnTour

Liquid Cooling Advantages

Whether it is a low power or high-power application, liquid cooling has the most advantages.

With low power applications, the battery pack can be nursed so it will always operate at the right temperature.

Notes:

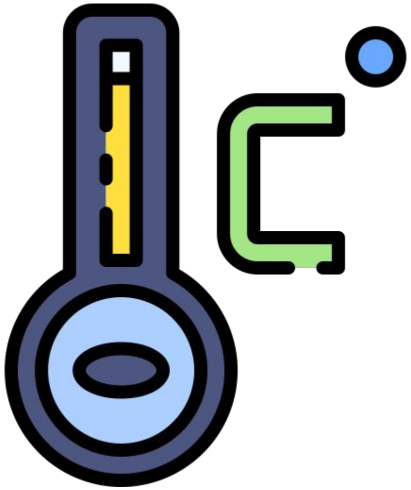

Source: Flaticon.com

Liquid Cooling Applications

With high power applications the battery pack can be cooled to the maximum.

The temperature of the cooling system must be kept as low as possible to enable maximum power for the longest time possible.

Notes:


Source: Flaticon.com

Liquid Cooling Advantages

Depending on operating environment, the pack can be heated as well by adding a heating element in the system.

The cooling system of the battery pack and the cooling system of the motor and controller need to be separated.

These two cooling systems can occasionally be combined to heat the battery pack when needed by the motor and controller. This is very useful during cold winter days.

Notes:

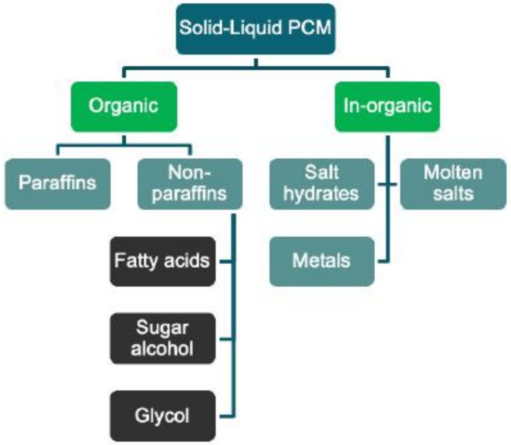
Source: epectec.com

Liquid Cooling - Challenges

The most common thermal management challenges for EV batteries are leaks, corrosion, clogging, the climate, and aging.

Liquid cooling systems present challenges that are absent for air cooling systems.

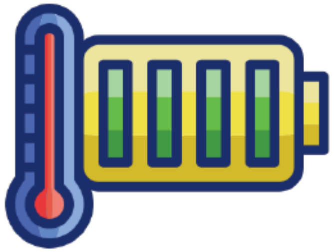
Notes:



Cooling with Phase Change Materials (PCM)

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).

Notes:



Source: Flaticon.com

Cooling with Phase Change Materials (PCM) Cont.

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

Notes:

Source: Flaticon.com

Cooling with Phase Change Materials (PCM) Cont.

Potential uses are 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:

Source: Flaticon.com

Cooling with Phase Change Materials (PCM) – Indirect Cooling

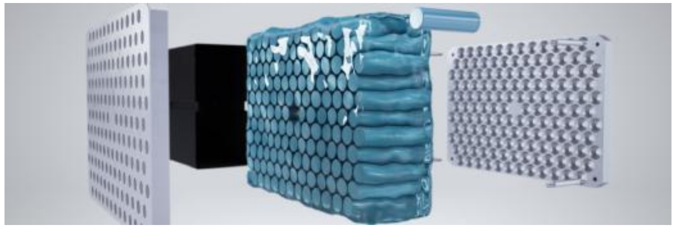
Cells are surrounded by a cooling liquid, very similar to ICE (internal combustion engine) vehicles or anything with water cooling.

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:

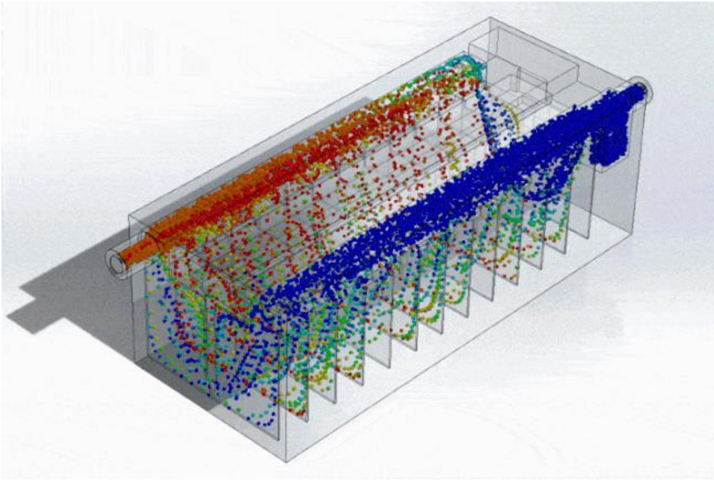
Notes:



Immersion Cooling

Another way of cooling a battery pack with liquid is to submerge the complete battery pack in the cooling fluid.

This technology is already used in the world of supercomputers. However, this method is very expensive.



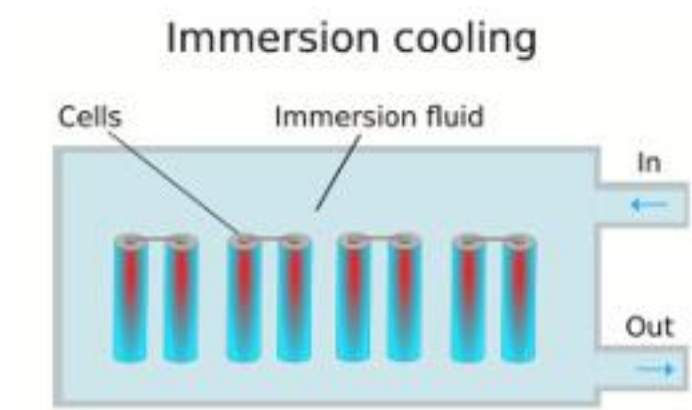
Immersion Cooling Cont.

One downside is that the fluid used has a certain heat capacity (dependent on chemistry). This is the amount of heat that a material can absorb.

By submerging the entire battery pack in a fluid, the fluid can only cool as much as the heat capacity allows it to. In other words, the fluid heats up together with the battery pack. The fluid just slows this process down.

High surface area surrounding the cells with the cooling fluid means maximum cooling potential.

Notes:

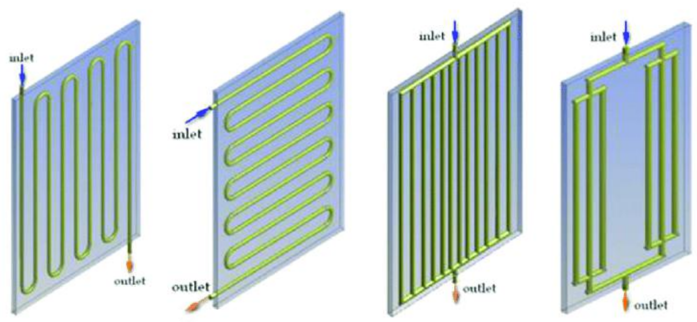


Source: UKBIC

Immersion Cooling Cont.

In high-power applications this method of cooling will need to be combined with other types of cooling systems. For example, the housing can be made of aluminium, which conducts heat very well. When air passes alongside this housing, the battery pack and the fluid inside can be cooled.

Notes:



Immersion Cooling Cont.

Immersion cooling is a safer and better alternative to air cooling. Liquid cooling or immersion cooling for EV battery uses a water-glycol mix. This liquid is pumped and circulated through the battery pack. It uses several tubes and cold plates for the circulation of the mix.

Notes:

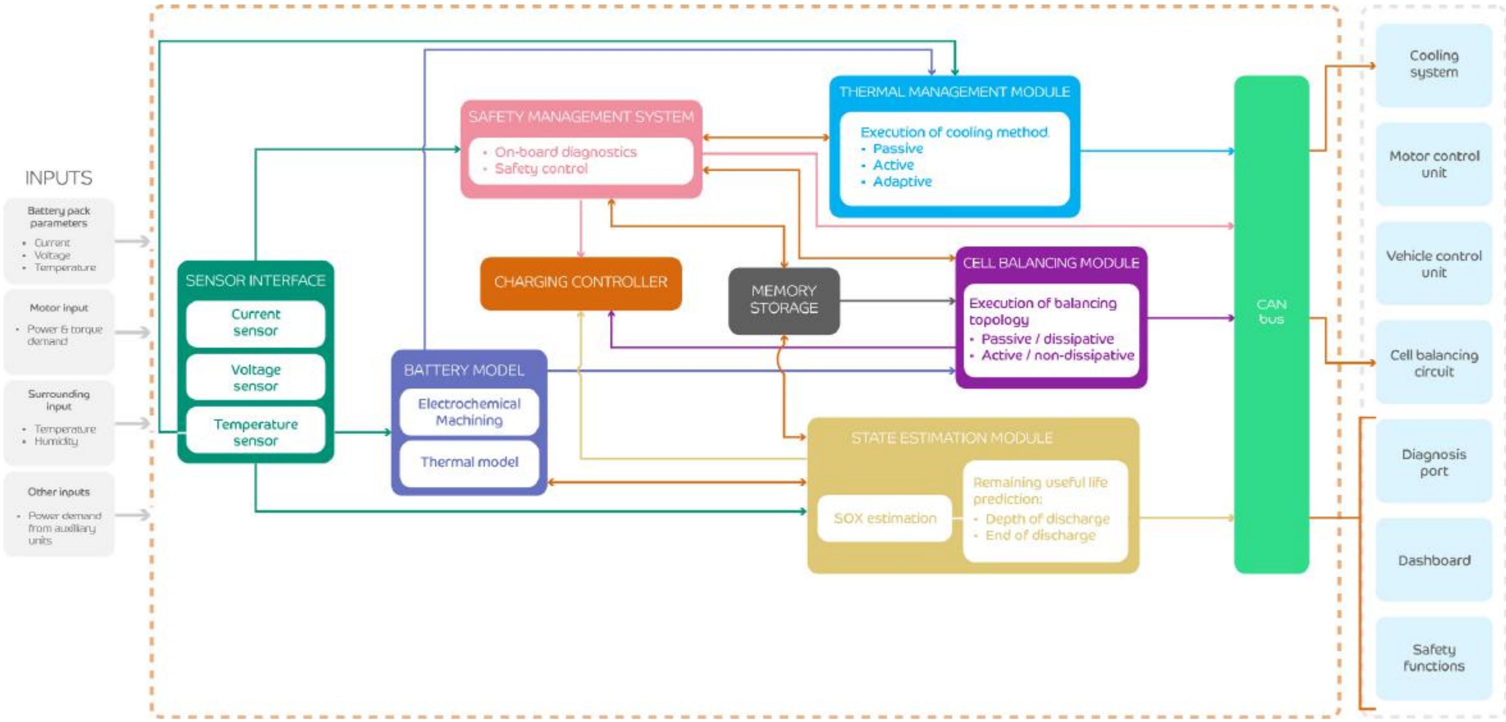
Mechanical Design

The structure needs to be safe for extreme conditions. It needs to be easy to assemble and service, in addition to being cost effective and reliable.

Aesthetics, compactness and weight are also important considerations of the mechanical design.

Notes:

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

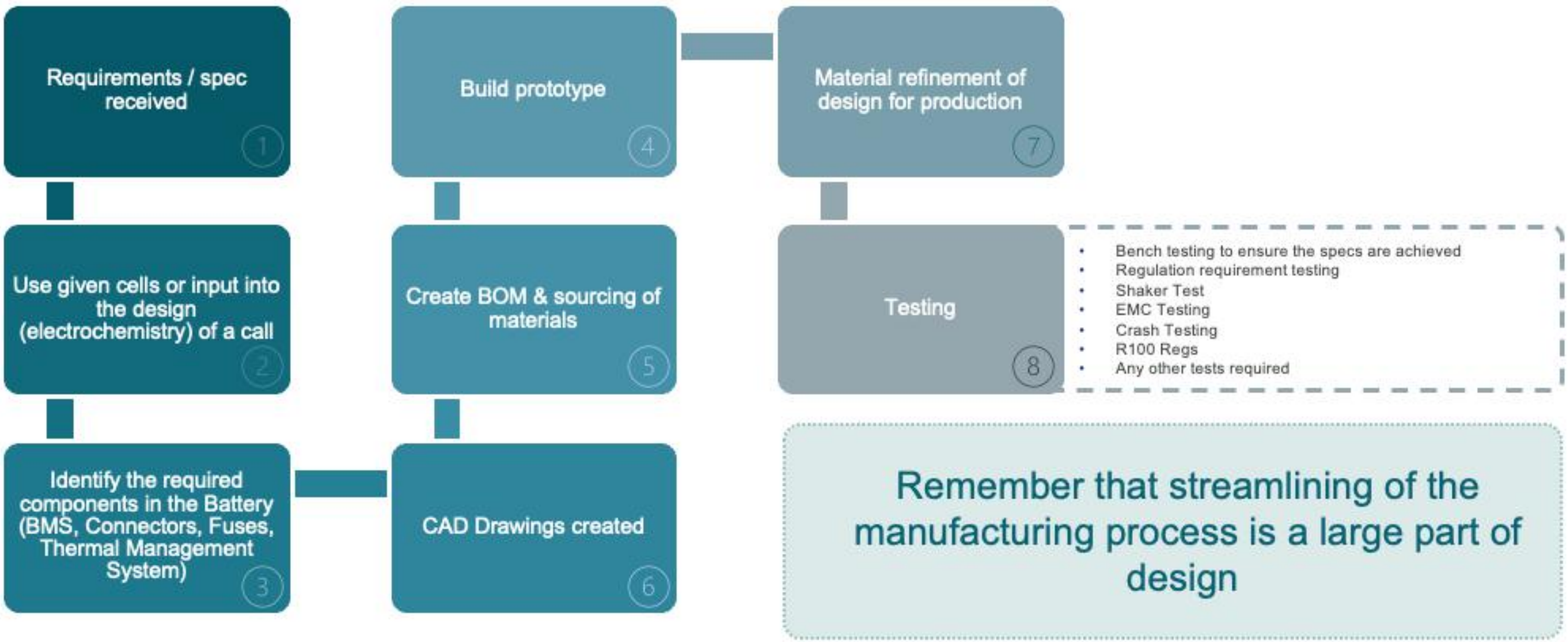


Notes:

How Does the BMS Work?

The BMS works by monitoring values and undertaking real-time calculations to ensure the battery is safely working within its pre-set limits. These values include charge, remaining charge, temperature, battery health and the balance across the cells.

Recap – The process Steps in Designing a Module or a Pack



Notes:

BT3 Familiarisation of Battery Manufacturing Module and Pack Design

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