BT4 Introduction to Designing Sustainable Batteries

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

THE FARADAY INSTITUTION

BT4 Introduction to Designing Sustainable Batteries

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:

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.

Notes:

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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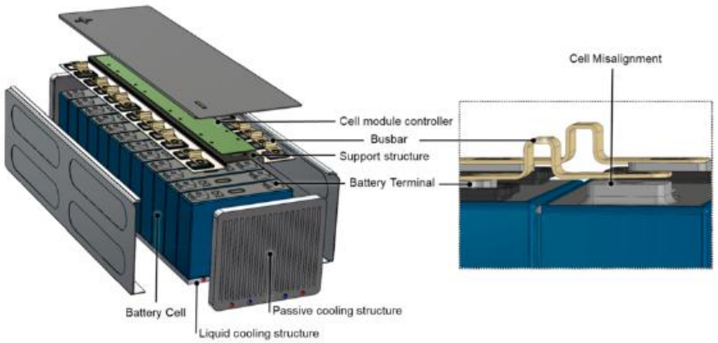

Source: mdpl.com

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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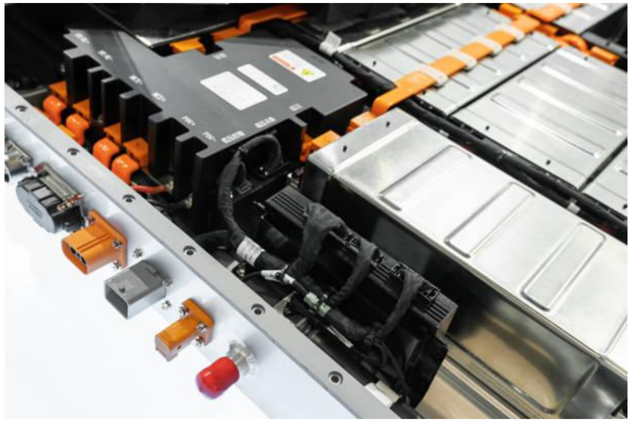
Image source: UKBIC

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:

The Battery Manufacturing Process

Notes:

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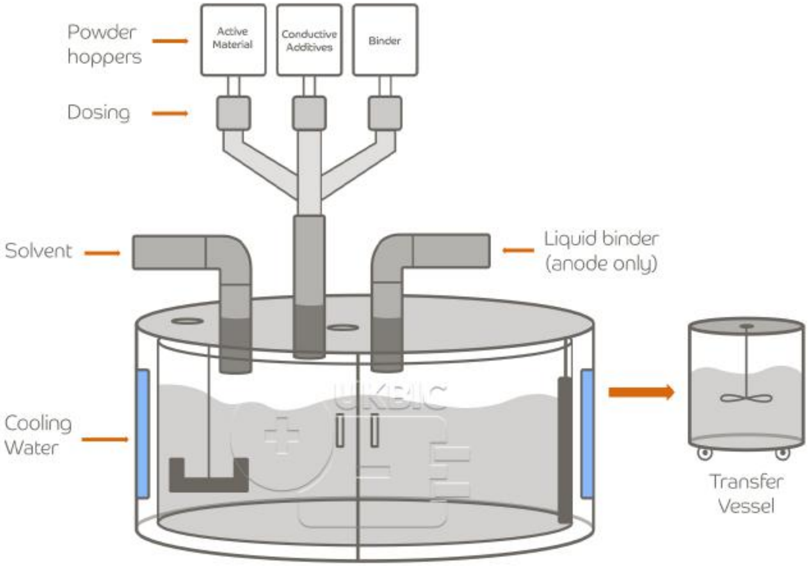

Image source: UKBIC

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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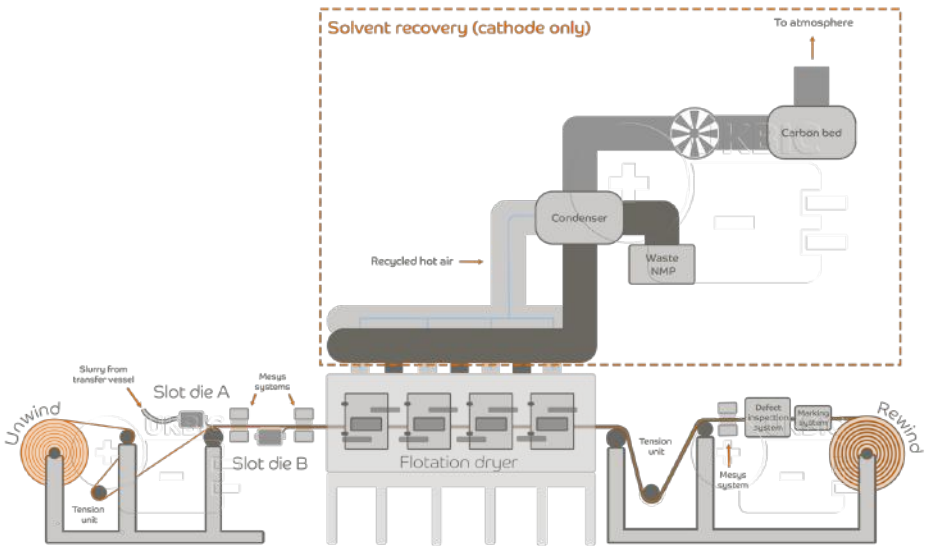

Image source: UKBIC

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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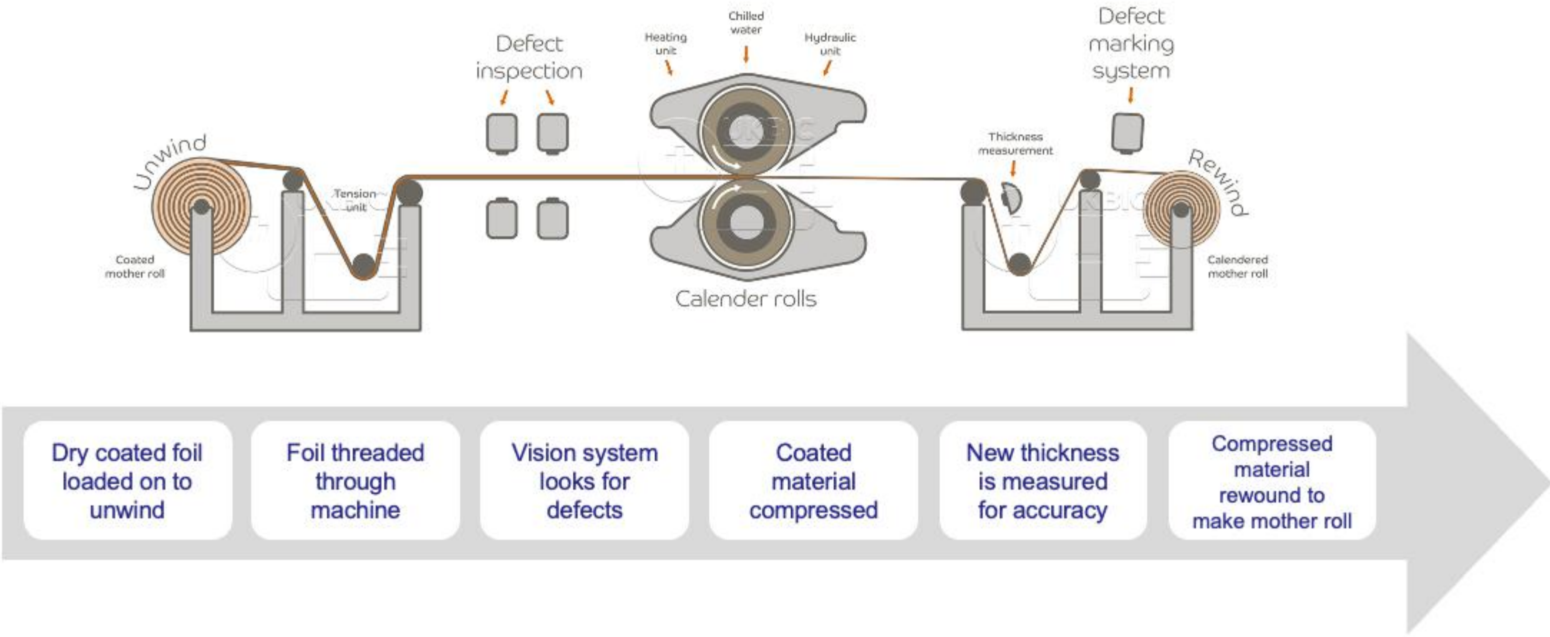

Image source: UKBIC

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:

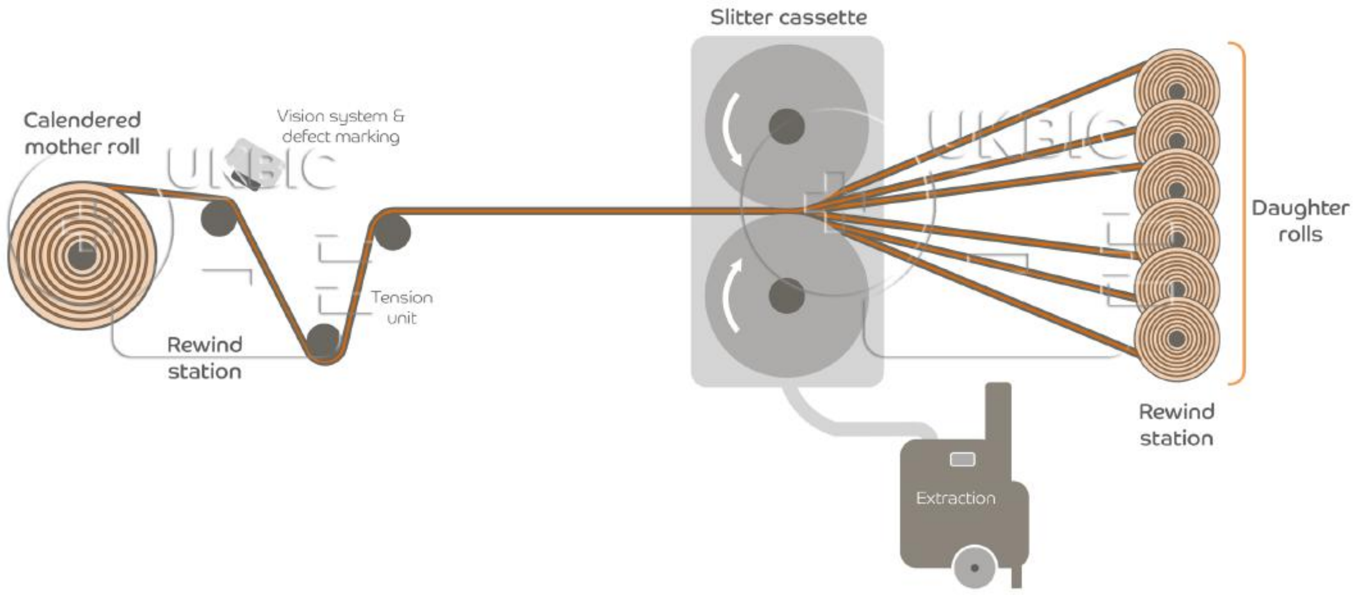

Image source: UKBIC

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

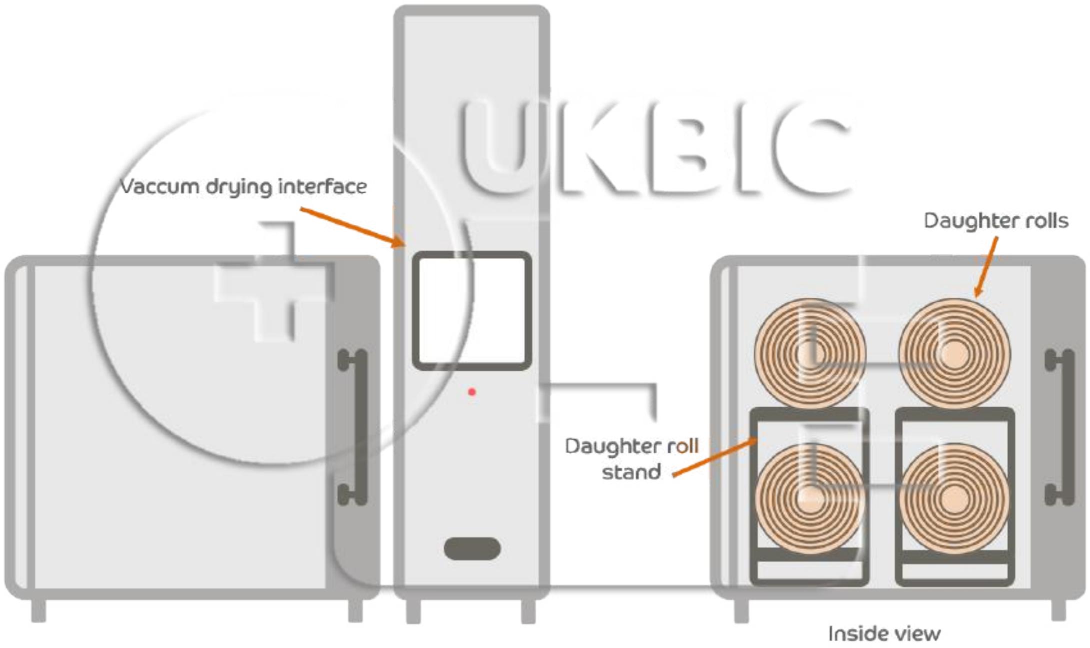

Image source: UKBIC

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.

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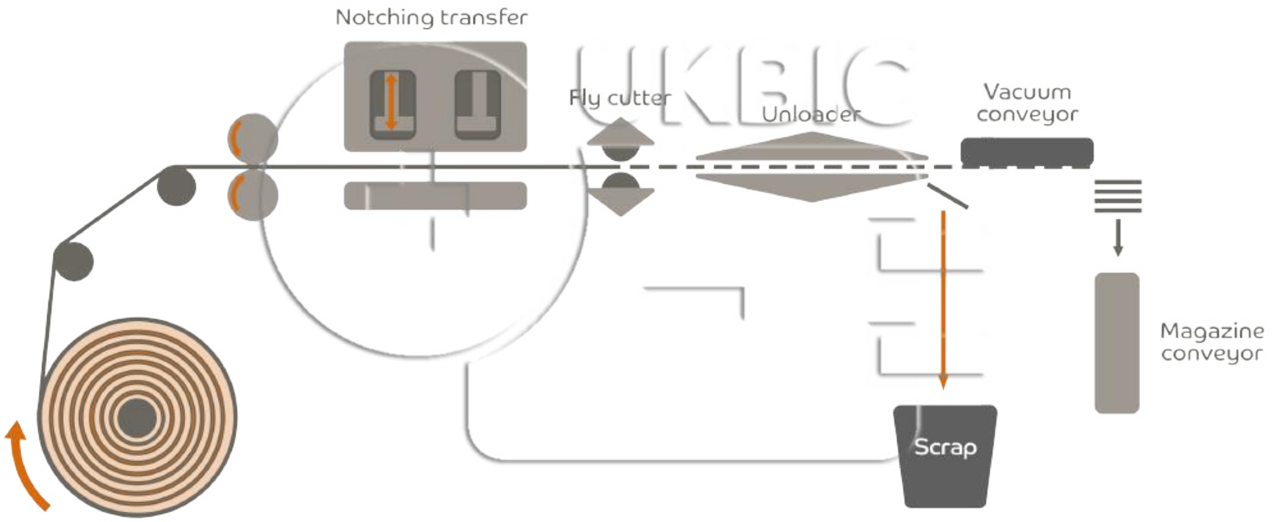

Image source: UKBIC

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.

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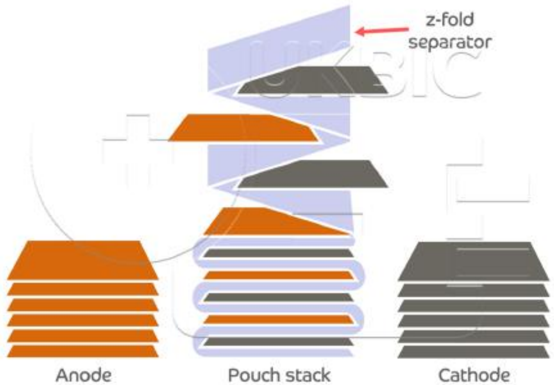


Image source: UKBIC

Notes:

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.

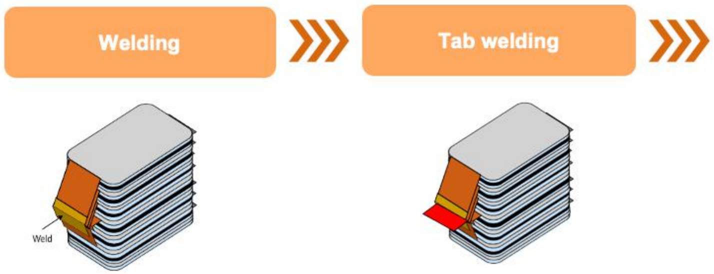


Image source: UKBIC

Notes:

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.

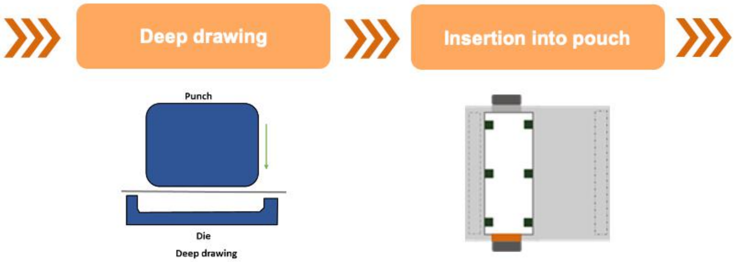
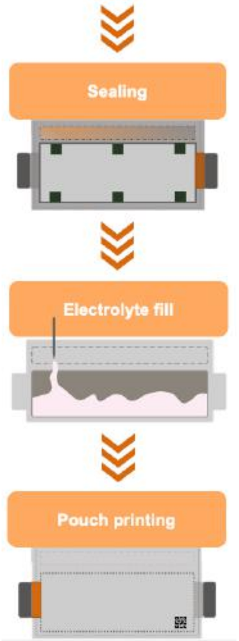


Image source: UKBIC

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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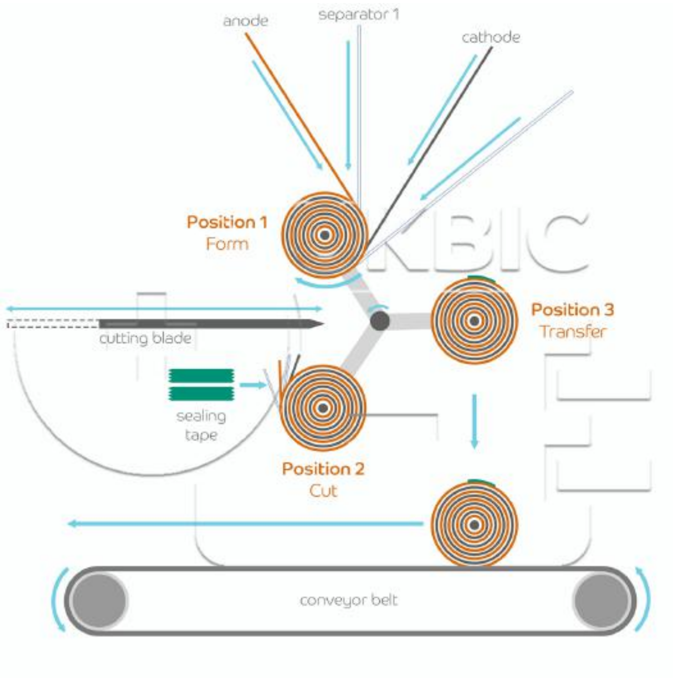

Image source: UKBIC

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.

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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

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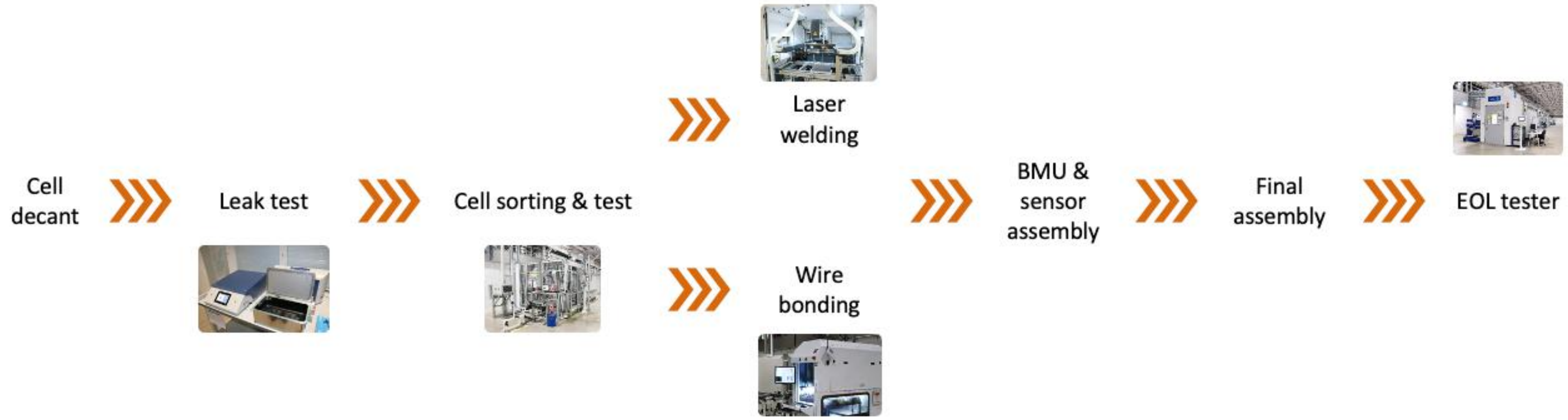
Cell Assembly (FA&T) - Packing

- 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.

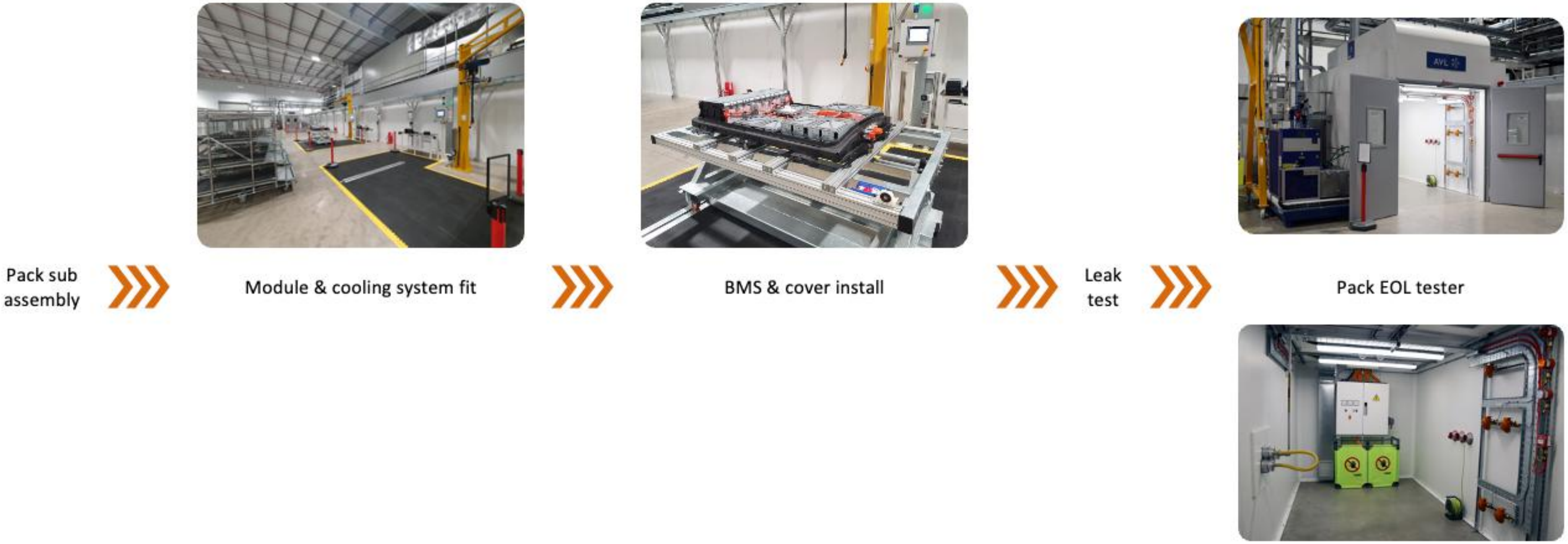


Module Assembly – Module Line (cylindrical)

- 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



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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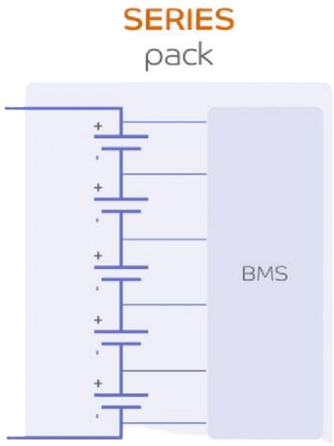

Image source: UKBIC

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.

Notes:

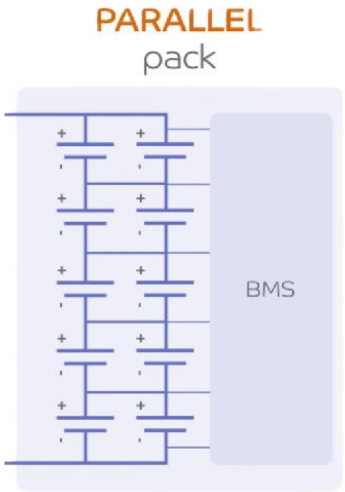

Image source: UKBIC

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.

Notes:

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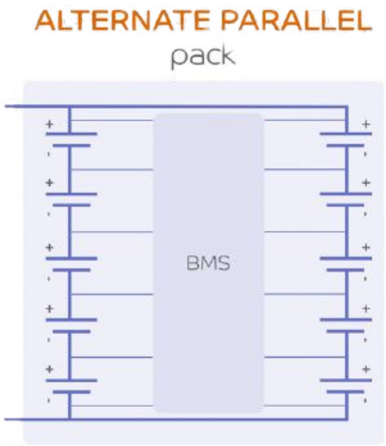

Image source: UKBIC

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:

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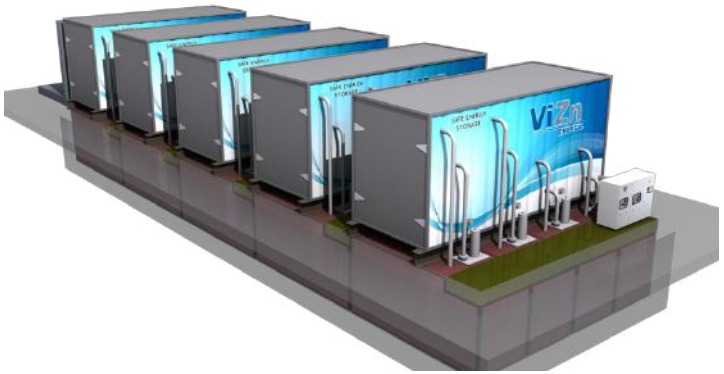
Main Considerations of Design - Rail

- 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

Notes:

Main Considerations of Design – Aerospace

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

Notes:

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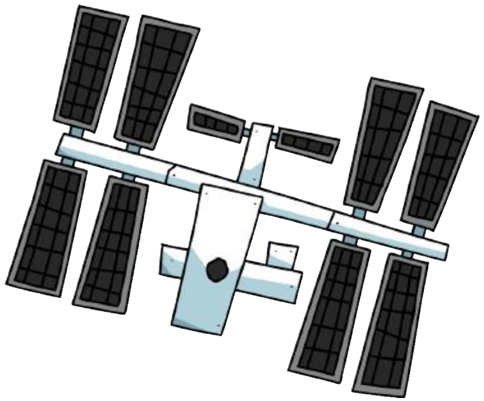

Source: imgbin.com

Notes:

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

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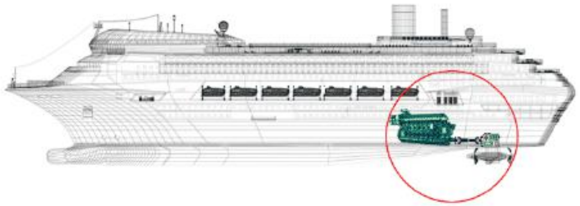

How Does Location Impact Design?

- Parameters
- Size
- Weight

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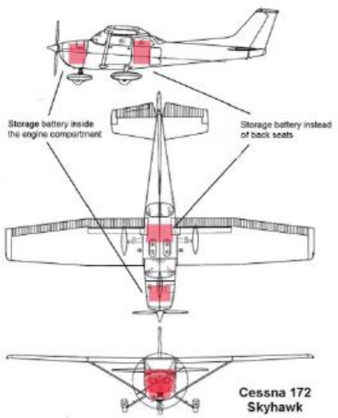

Point to Consider in Relation to Location

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

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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 – Casing and Clamping

The casing protects and compresses (pouch) cells for support and to ensure best performance.

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:

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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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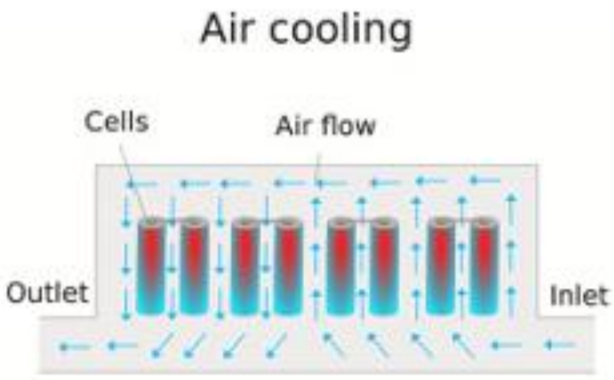

Image source: UKBIC

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:

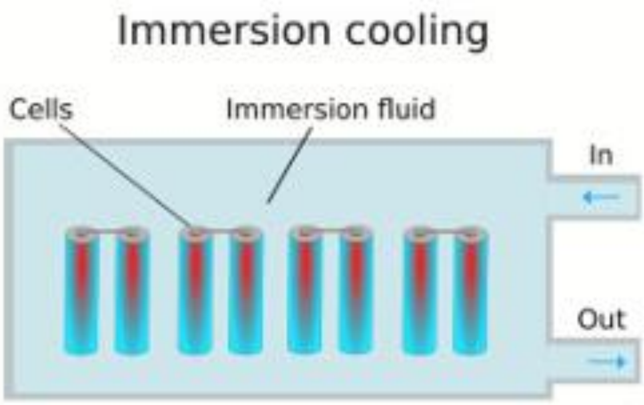

Image source: UKBIC

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:

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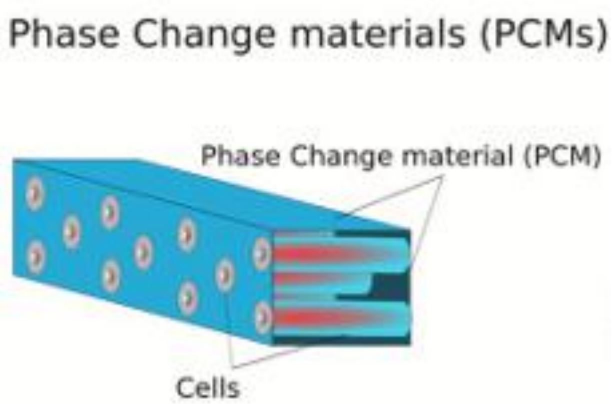


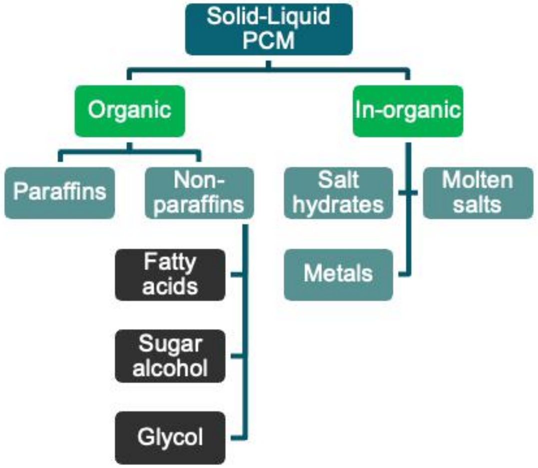
Image source: UKBIC

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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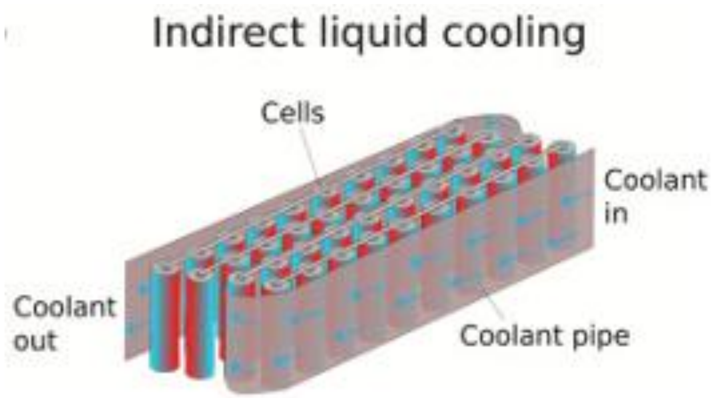

Image source: UKBIC

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:

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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.

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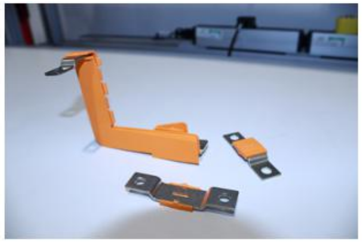

Image source: UKBIC

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:

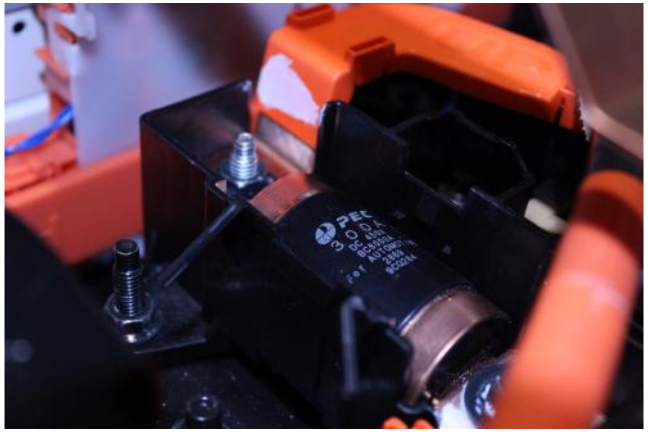
Image source: UKBIC

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:

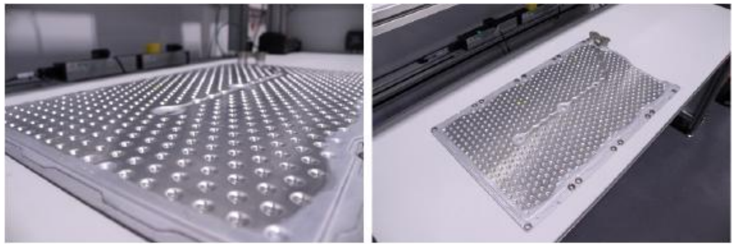
Image source: UKBIC

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:

BT4 Introduction to Designing Sustainable Batteries

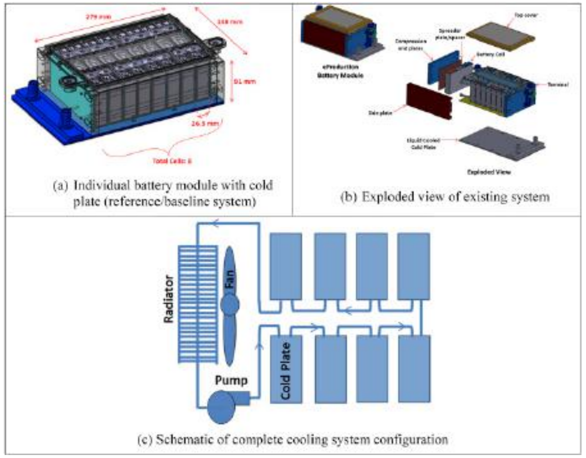

Image source: UKBIC

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:

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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.

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BT4 Introduction to Designing Sustainable Batteries

Sustainability Definition

Sustainability is the ability to maintain or support a process over time. It is often broken into three core concepts: economic, environmental, and social.

Sustainability consists of fulfilling the needs of current generations without compromising the needs of future generations, while ensuring a balance between economic growth, environmental care and social well-being.

Notes:

Pillars of Sustainability

These are the different aspects of sustainability we need to consider as a business. The best approach is the find a balance which taps into each of the perspectives without undermining the importance of the overall business.

The pillars must work with each other as they do overlap in certain areas but are usually measured independently.

Notes:

Social Sustainability

Social sustainability focuses on maintaining and improving social quality with concepts such as cohesion, reciprocity and honesty and the importance of relationships amongst people.

It can be encouraged and supported by laws, information and shared ideas of equality and rights.

Notes:

Social Sustainability cont.

Social sustainability incorporates the idea of sustainable development as defined by the United Nations sustainable development goals.

The principle of sustainable development addresses social and economic improvement that protects the environment and supports equality, and therefore the economy and society and the ecological system are mutually dependent (Diesendorf, 2000).

Notes:

BT4 Introduction to Designing Sustainable Batteries

Environmental Sustainability

Environmental sustainability, as described by Dunphy, Benveniste, Griffiths and Sutton (2000), places emphasis on how business can achieve positive economic outcomes without doing any harm, in the short- or long-term, to the environment.

According to Dunphy et al. (2000) an environmentally sustainable business seeks to integrate all four sustainability pillars, and to reach this aim each one needs to be treated equally.

Notes:

Environmental Sustainability cont.

The principle of the four pillars of sustainability states that for complete sustainability problems to be solved in relation to all four pillars of sustainability and then need be maintained. Although in some cases these may overlap, it is important to identify the specific type of green business to focus on, as the four types present unique characteristics.

Businesses need to make a strategic decision about it so as to effectively incorporate the chosen approach into their policies and price.

Notes:

Economic Sustainability

Economic sustainability aims to maintain the capital intact. If social sustainability focuses on improving social equality, economic sustainability aims to improve the standard of living. In the context of business, it refers to the efficient use of assets to maintain company profitability over time.

Source: © RMIT University 2017 - The four pillars of sustainability

Notes:

Economic Sustainability cont.

Critics of this model acknowledge that a great gap in modern accounting practices is not to include the cost of damage to the earth in market prices (Hawking, 2010).

A more recent approach to economics acknowledges the limited incorporation of the ecological and social components in this model. New economics is inclusive of natural capital (ecological systems) and social capital (relationships amongst people) and challenges the mantra of capital that continual growth is good and bigger is better, if it risks causing harm to the ecological and human system (Benn et al., 2014).

Notes:

BT4 Introduction to Designing Sustainable Batteries

Human Sustainability

In the context of business, an organisation will view itself as a member of society and promote business values that respect human capital.

Human sustainability focuses on the importance of anyone directly or indirectly involved in the making of products, or provision of services or broader stakeholders (the human capital of the organisation) (Benn et al., 2014).

Notes:

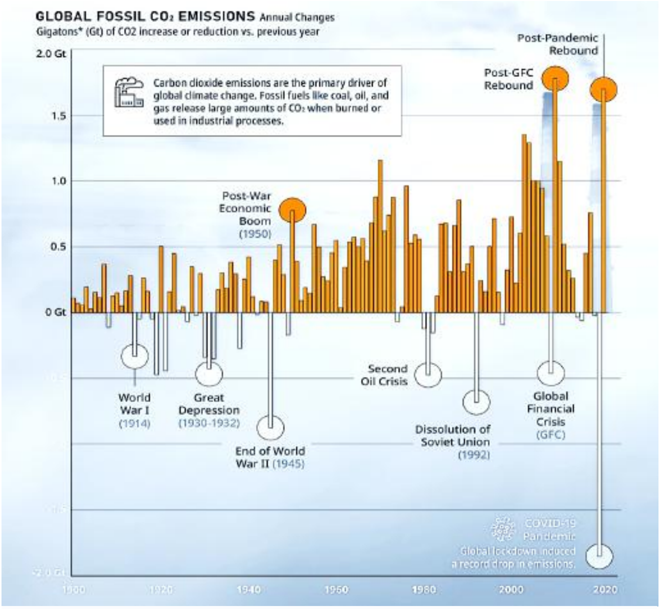
Human Sustainability cont.

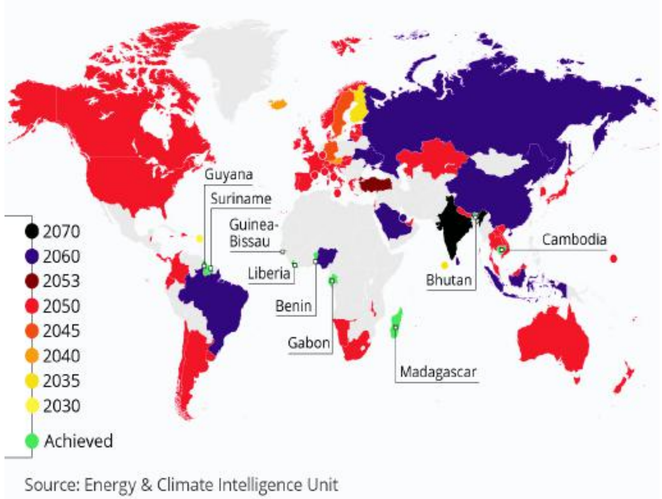
Communities around the globe may be positively or negatively affected by business activities or impacted through methods used to source raw materials.

Human sustainability encompasses the development of skills and human capacity to support the functions and sustainability of the organisation and to promote the wellbeing of communities and society.

Notes:

BT4 Introduction to Designing Sustainable Batteries





Sustainability

The government has a responsibility to set targets and to legislate towards '**Net-Zero**' and environmental improvements.

Examples of government action could include:

- Increasing public awareness of sustainable development
- Controlling planning and development
- Imposing taxes, charges or fines on businesses/products that are more polluting
- Businesses should have 'policy documents' in place to show how sustainable development is a key part of their operations. There are many ways in which a business can reduce their costs, waste and carbon footprint and could include:
- Providing their staff with training around sustainable practices (embed / promote awareness)
- Being conscientious about recycling
- Being selective over company resource purchased

Notes:

BT4 Introduction to Designing Sustainable Batteries

Emissions – Scope 1 Direct Emissions

Scope 1 emissions include direct emissions from the company's owned or controlled sources. (Fleet vehicles)

This includes on-site energy like natural gas and fuel, refrigerants, and emissions from combustion in owned or controlled boilers, and furnaces as well as emissions from fleet vehicles.

Encompasses process emissions that are released during industrial processes, and on-site manufacturing (e.g., factory fumes, chemicals).

Notes:

Emissions – Scope 2 Indirect Emissions

Scope 2 emissions represent one of the largest sources of global greenhouse gas emissions accounting for at least a third of it.

That is why assessing and measuring Scope 2 emissions present a significant emissions reduction opportunity.

Notes:

Emissions – Scope 2 Indirect Emissions cont.

Scope 2 emissions include indirect greenhouse gas emissions from purchased or acquired energy, like electricity steam, heat, or cooling, generated offsite and consumed by the reporting company.

For example, electricity purchased from the utility company is generated offsite, so they are considered indirect emissions.

Notes:

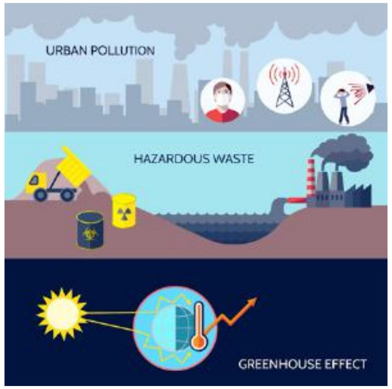
Emissions – Scope 2 Indirect Emissions cont.

However, if the reporting company, for example, an industrial facility, generates its energy on-site from owned or controlled sources, the greenhouse emissions associated with the energy generation are classified as direct scope 1 emissions.

The same applies to companies, such as electricity utilities or suppliers, which control their energy generation facilities and sell all their power into the local grid. The greenhouse gas emissions from these generation facilities are reported in Scope 1 emissions.

Notes:

BT4 Introduction to Designing Sustainable Batteries



Source: Image by macrovector on Freepik

Emissions – Scope 2 Indirect Emissions cont.

In summary, scope 2 encompasses indirect emissions associated only with the generation of purchased or acquired energy.

However, other upstream emissions associated with the production and processing of upstream fuels, or transmission or distribution of energy within a grid, are tracked in Scope 3.

Notes:

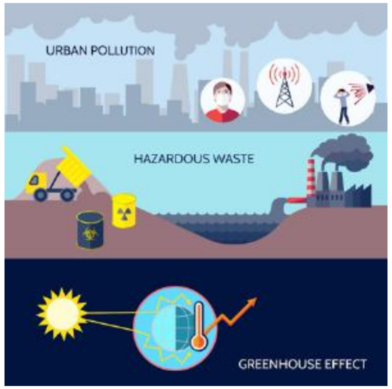
Emissions – Scope 3

Scope 3 includes all indirect emissions that occur in the value chain of a reporting company. To make a clear distinction between Scope 2 and Scope 3 categories, Scope 3 emissions are described as: "the result of activities from assets not owned or controlled by the reporting organisation, but that the organisation indirectly impacts in its value chain."

Even though these emissions are out of the control of the reporting company, they can represent the largest portion of its greenhouse gas emissions inventory.

Notes:

BT4 Introduction to Designing Sustainable Batteries



Source: Image by macrovector on Freepik

Emissions – Scope 3 Upstream Emissions

Upstream emissions encompass the indirect greenhouse gas emissions within a company's value chain related to purchased or acquired goods (tangible products) and services (intangible products) and generated from cradle to gate.

Notes:

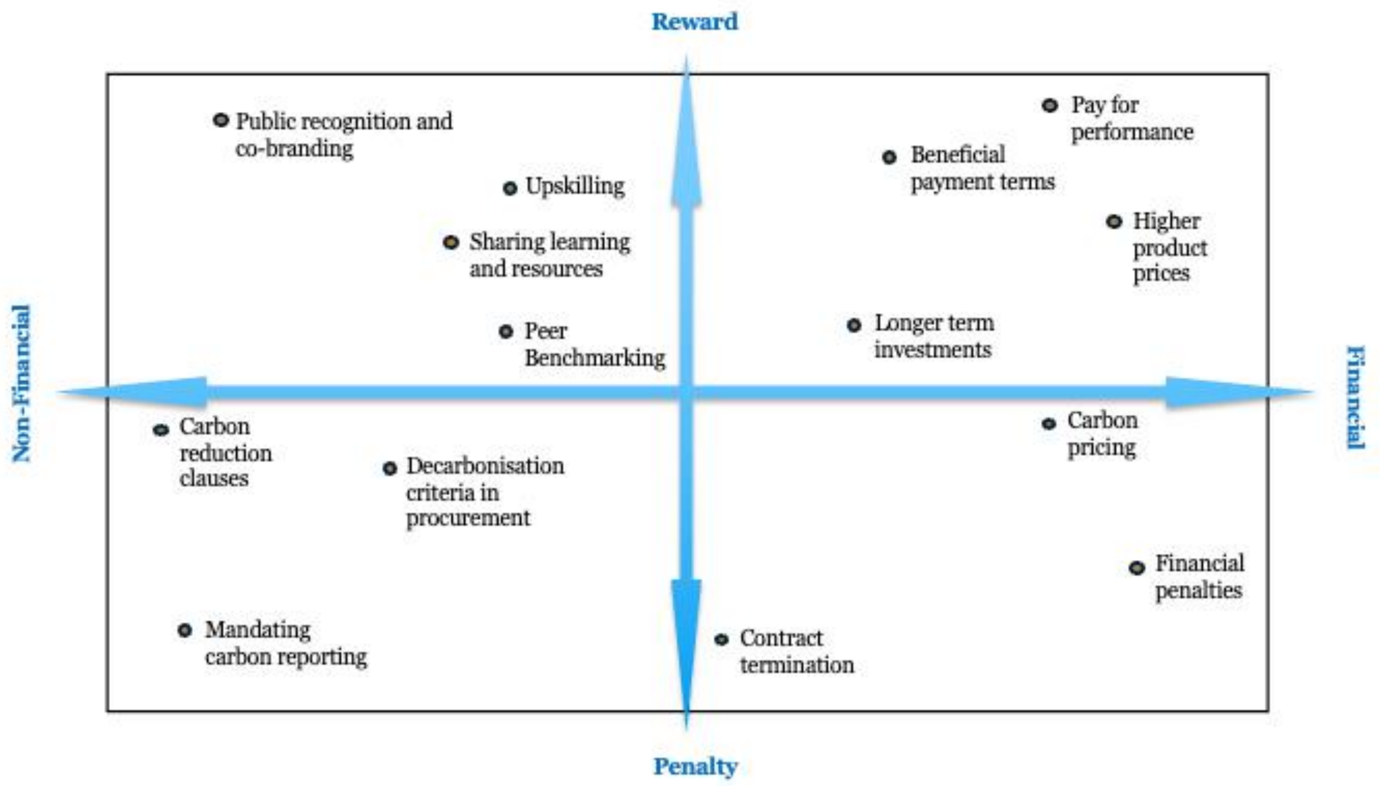

Source: Image by vectorjuice on Freepik

Scope 3 – Downstream Emissions

Downstream emissions include the indirect greenhouse emissions within a company's value chain related to sold goods and services and emitted after they leave the company's ownership or control.

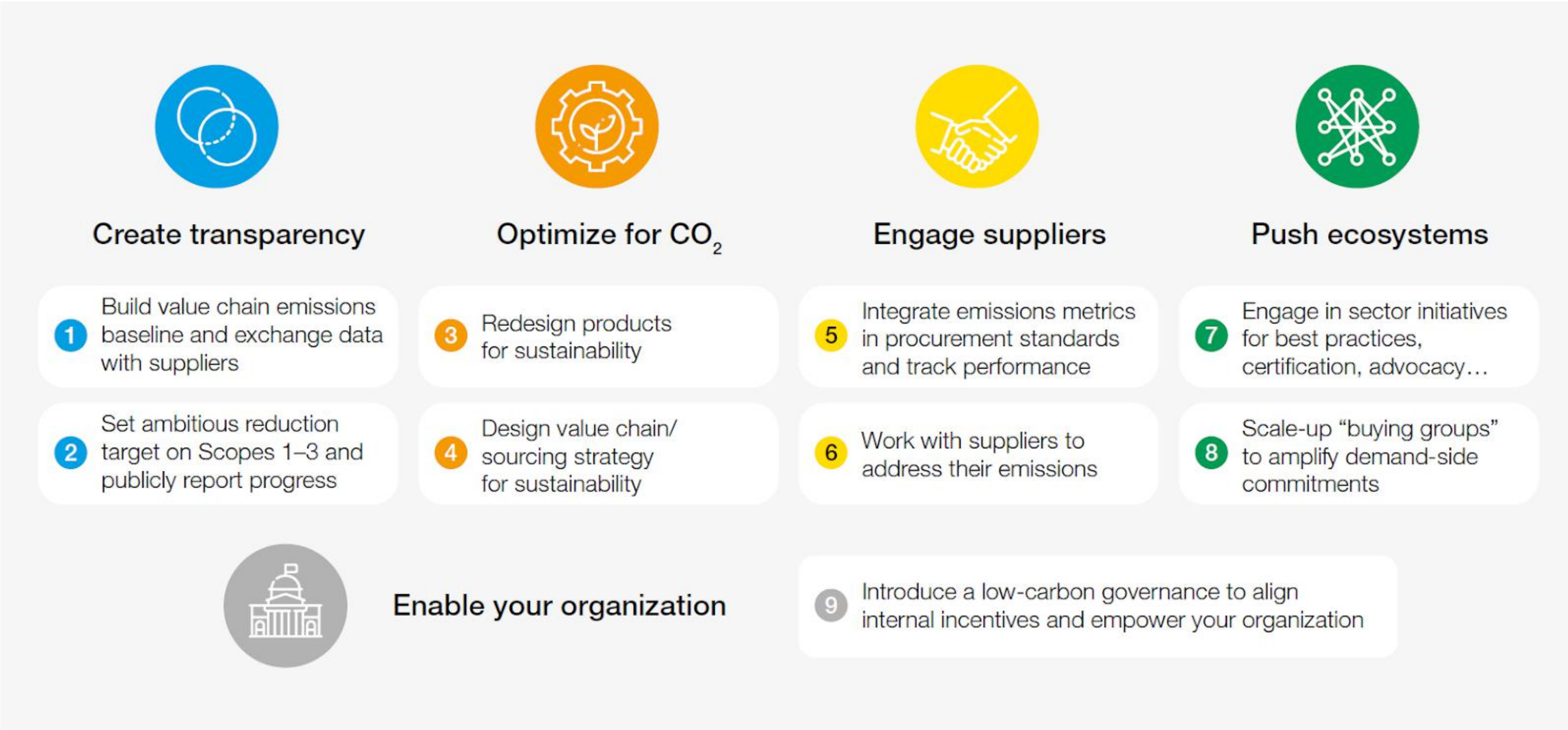
Notes:

Solutions to Incentivise Supply Chain Decarbonisation



Notes:

Enabling Decarbonisation in the Supply Chain



Notes:

BT4 Introduction to Designing Sustainable Batteries

Questions - Balance

When considering sustainability as a business it may be necessary to 'strike a balance'. Here are a few points to consider.

1. What is balance?
2. How do we find balance?
3. Why is balance important?
4. Who is responsible for finding balance?

Notes:

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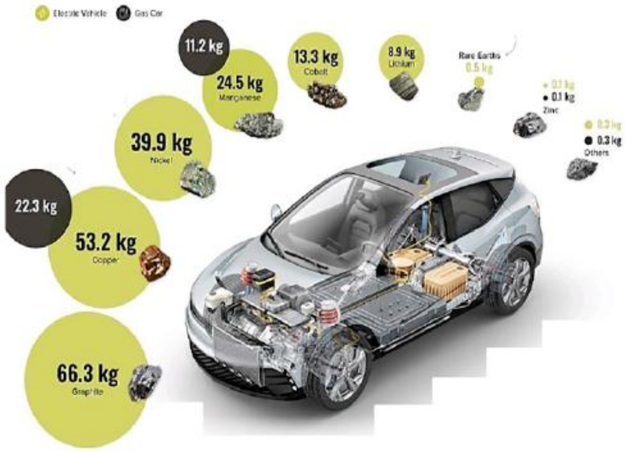

Materials Used in Production (2022)

This image is only a general representation. You can see the total weight of the various materials used in an electric vehicle.

The black circles represent the materials used in an internal combustion engine vehicle as a comparison.

Graphite makes up the largest proportion of material (by weight), mainly due to it being the anode material in a lithium-ion battery. Copper is a close second due to an electric vehicle's stator winding being made up of more than a mile of copper wire, to convert electric energy into mechanical energy.

Notes:

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Three Pillars of Sustainability

- Social inclusion
- Environmental protection
- Economic growth/sustainability

Notes:

Source: Image by rawpixel.com on Freepik

Battery Cell Manufacturing – Social Inclusion

Social inclusion aspects for battery cell manufacturing include ensuring that the global supply chains for battery materials are benefitting local communities. Training, upskilling, safe mining practices and no use of child labour are some aspects which are particularly applicable to battery supply chains.

Notes:

BT4 Introduction to Designing Sustainable Batteries

Source: https://www.crowncommercial.gov.uk/

Battery Cell Manufacturing – Environmental Protection

Environmental impact must be net zero in order to align to net zero targets, which in the UK is Net Zero 2050.

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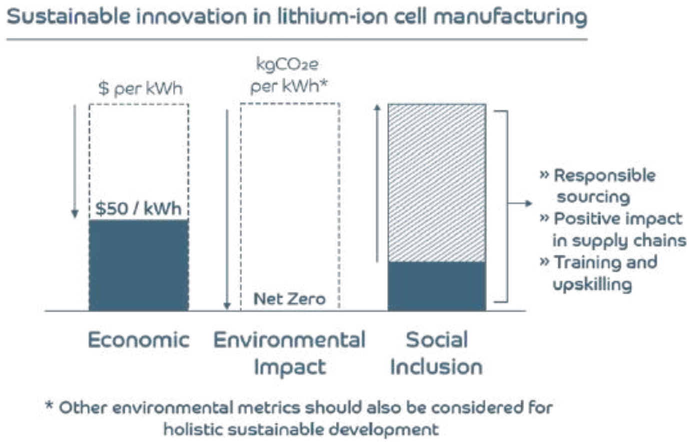

Battery Cell Manufacturing – Economic Growth/Sustainability

Economic sustainability means that cells can be produced at profit and reach cost parity against comparable technologies.

For example, an electric car costing the same or less than a petrol car means that economic sustainability is reached, for the transition to electric vehicles.

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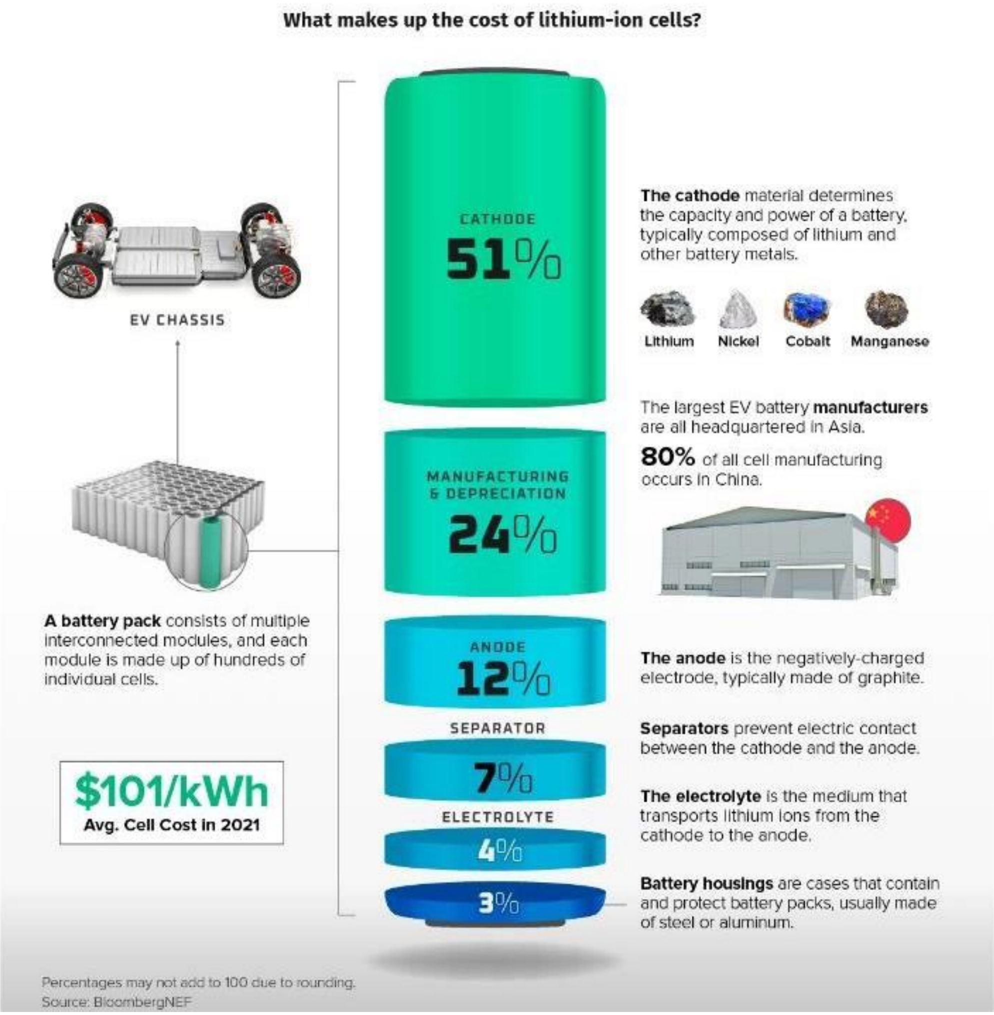
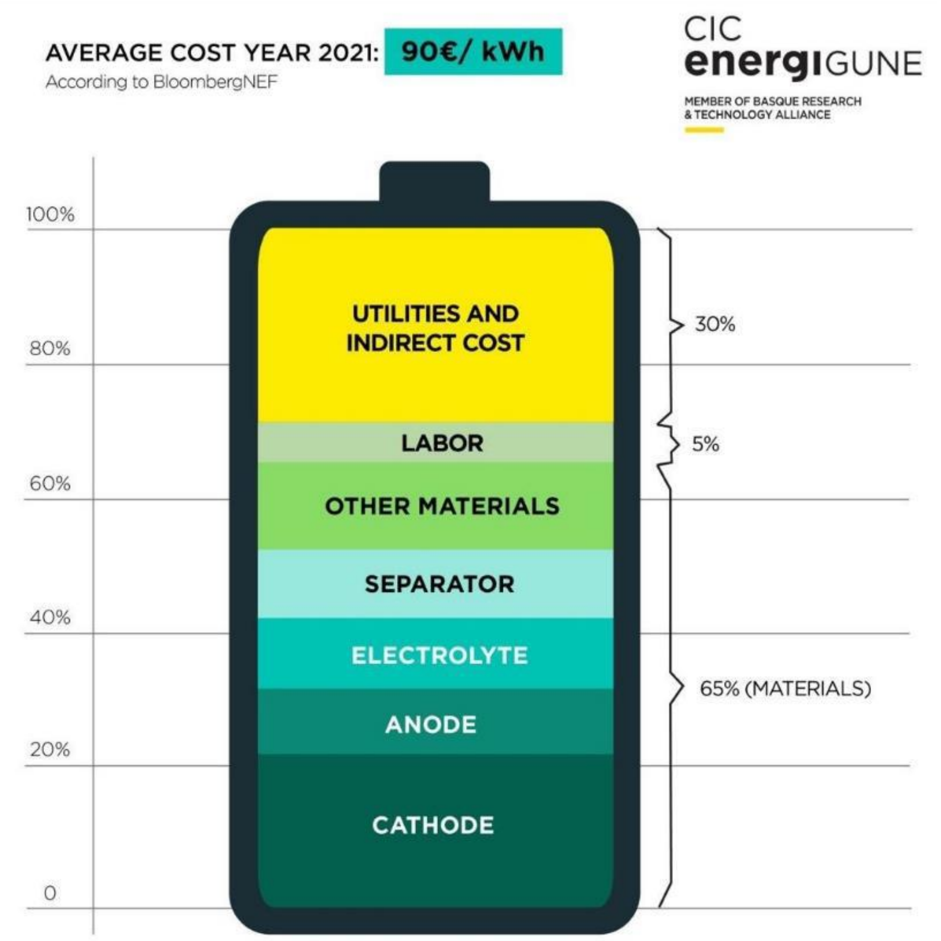
Costings (2021-2022) – Currently equivalent to £60 - £82 per kWh and reducing

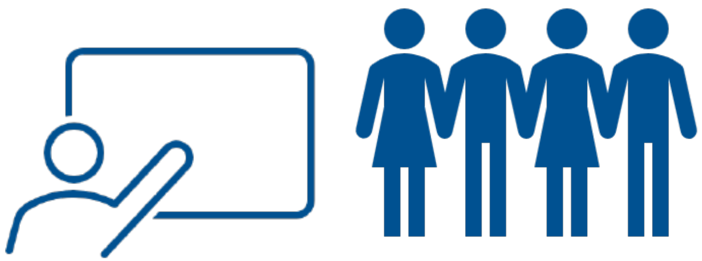




Source: Figure estimated and based on industry sources and public data.

BT4 Introduction to Designing Sustainable Batteries

Notes:



Tools to Measure Social Inclusion

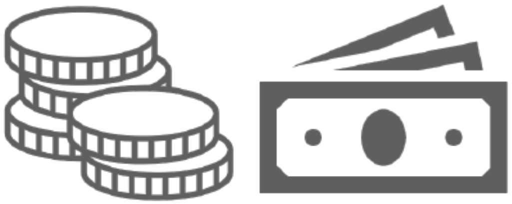
- Supply chain auditing
- Training matrices
- Social life cycle assessment

Notes:

Tools to Measure Environmental Impact

- Life cycle assessment
- Environmental profit and loss
- Circular economy indicators

Notes:



Tools to Measure Economic Sustainability

- Cost benefit analysis
- Financial forecasting

Tool examples	Measures	Pros	Cons
Life cycle assessment	Environmental impacts across whole product life cycle	• Covers whole product life cycle • Widely used methodology • Can cover a wide number of KPIs • Can identify where in the product value chain to focus efforts on impact reduction	• Complicated • Time consuming
Environmental profit & loss	Environmental impacts given a monetary valuation to assess "profit" and "loss" across operations.	• Businesses already understand economic profit and loss accounts so EP&L is easier to understand	• Complicated • Assigning monetary value to environmental impacts is difficult • Time consuming • Assesses just 6 KPIs
Circular economy indicators	How "circular" a product system is, e.g. how many times a material is recycled.	• Circular economy and product longevity is not well covered by other methodologies	• Immature methodology • Difficult to assign values to intangible things e.g. upgrading a material
Social life cycle assessment	Social impacts across whole product life cycle.	• Attempts to quantify social benefits/impacts	• Difficult to assign values to e.g. education and healthcare
Supply chain auditing	KPIs across supply chains, usually measuring social impacts such as modern slavery risks.	• Can be tailored to cover items of specific interest	• Audits are not always a true representation, risk items can be hidden
Training matrices	Education level and training plan for staff.	• Provides overview of training level of staff and future training plan	• Only covers training
Cost benefit analysis	Assess decisions, systems or projects by assigning a value to benefits of actions and subtracting the costs.	• Can be used to assess "what if" scenarios • Evidence based view to aid decision making	• Some intangible costs are difficult to measure e.g. customer satisfaction
Financial forecasting	Estimate future financial outcomes.	• Longer term view of what the business finances may look like	• Uncertainty

Sustainability Considerations for Battery Manufacturing

For battery manufacturing, energy use is the largest contributor to environmental impact. More efficient energy use reduces environmental impact and cost.

Notes:

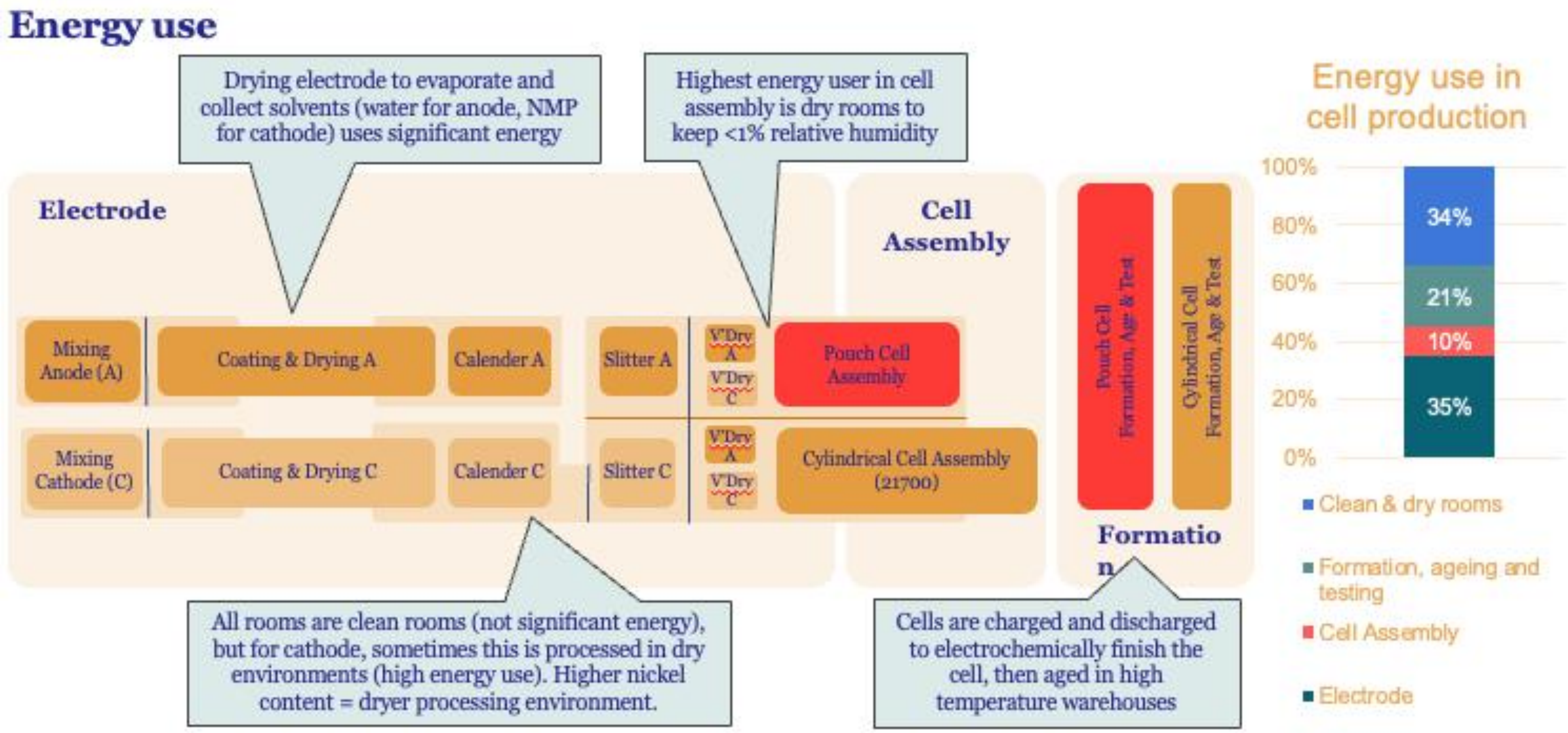
Sustainability Considerations for Battery Manufacturing cont.

The materials used in cell manufacturing have their own environmental impact associated with their own production, so reducing waste material and using materials in the most efficient way will also save environmental impact as well as cost.

The impact of materials production is usually allocated to the supply chain, so for cell manufacturing, the largest environmental impact is energy.

Notes:

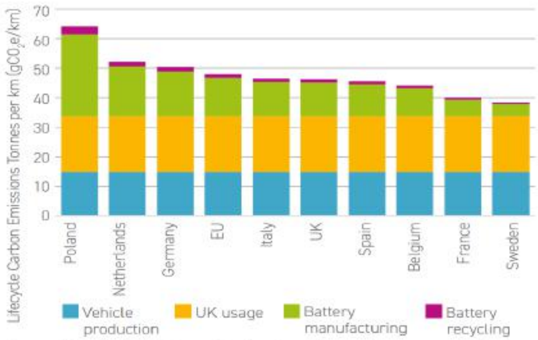
Sustainability in Battery Manufacturing



Notes:

BT4 Introduction to Designing Sustainable Batteries

Figure 4: Total life cycle carbon emissions from UK EVs sold in 2025, by location of manufactured EV battery

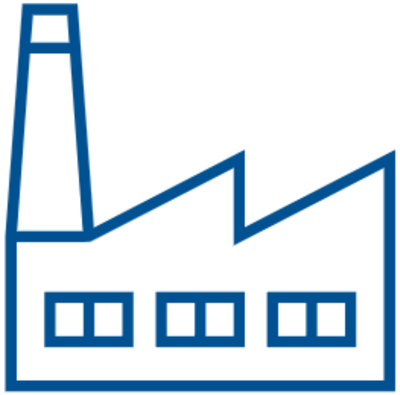


Source: Faraday Institution estimates, based on various sources including Global EV Outlook, EEA, IVL and T&E.

Environmental Impact in Battery Manufacturing

To assess the carbon dioxide equivalent impact for energy use in manufacturing, the location of the manufacturing must be known. The method of producing electricity differs by country and therefore has different carbon intensity per kWh produced.

Notes:



Environmental Impact in Battery Manufacturing cont.

Direct emissions in cell manufacturing include:

- Solvent from the electrode drying process
- Electrolyte (in very small amounts)
- Boiler emissions if gas boilers are used for heat production

Notes:

BT4 Introduction to Designing Sustainable Batteries

Environmental Impact in Battery Manufacturing cont.

Regulation in different countries will determine emissions limits and how much must be captured rather than emission to atmosphere.

In order to improve sustainability of operations, all harmful emissions should be captured and disposed of safely, regardless of local regulation.

Notes:

Social Considerations in Battery Manufacturing

Social considerations for battery manufacturing are wide ranging.
In the materials supply chain, social development of the communities where materials are mined and processed is important for social sustainability. Issues have been highlighted such as artisanal mining, where mine workers are not employed by a company and are therefore at higher risk of health and safety issues, lack of training and lack of access to proper equipment for mining activities. These types of issues must be overcome to ensure social sustainability.

Notes:

Social Considerations in Battery Manufacturing cont.

Across all parts of the battery value chain, training of workers is another important part of social development.

At the battery manufacturing facility, the use of any hazardous chemicals must be done with care. Workers must be trained appropriately to handle such materials and provided with the correct protective equipment to ensure no impact to health.

Notes:

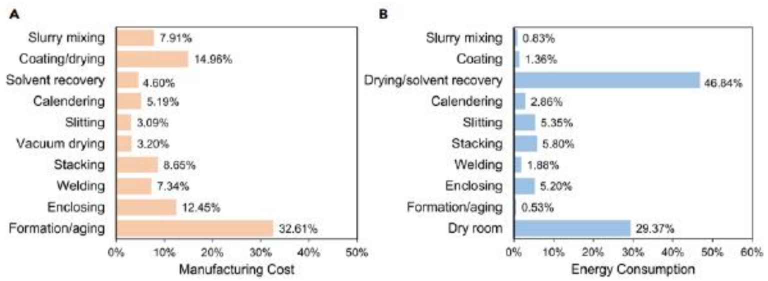


Figure 2. Cost and energy consumption breakdown of LIB manufacturing processes
(A and B) (A) Cost breakdown and (B) energy consumption breakdown.

Economic Considerations in Battery Manufacturing

Economic sustainability can be defined as long-term profitability of the business.

Capital investment in equipment, labour, operating and maintenance costs must all be considered to ensure economic sustainability.

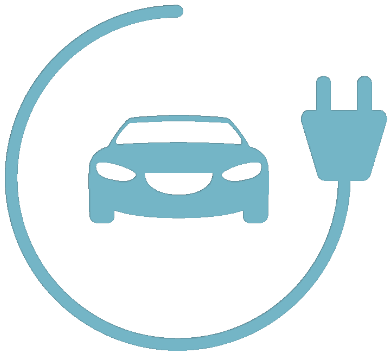
Notes:

Economic Considerations in Battery Manufacturing cont.

The price of raw materials needed for cells depends on the type, and therefore material requirements. For example, NMC materials are more expensive than LFP.

Efficient use of materials and energy can help to reduce operational costs.

Notes:

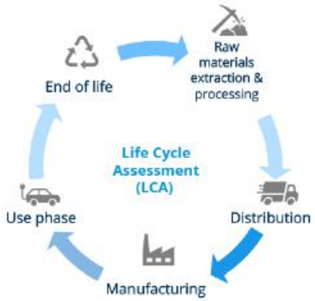


Economic Considerations in Battery Manufacturing cont.

For electric cars, to be economically sustainable they must become the same price or cheaper than comparable petrol and diesel cars.

Notes:

BT4 Introduction to Designing Sustainable Batteries



Toolsets to Measure Environmental Impact

When we are assessing environmental impact of a product, process, or system, a tool called **Life Cycle Assessment (LCA)** is often used. Understanding environmental impact and where in the life cycle they occur can help us to make decisions about how to protect the environment.

Notes:

Toolsets to Measure Environmental Impact cont.

LCA looks at impacts for the whole life cycle of the product, process or system, from the beginning of a product life through to end-of-life disposal and recycling.

LCA can provide a range of environmental impact categories. The most commonly used one is called Global Warming Potential.

Notes:

BT4 Introduction to Designing Sustainable Batteries

Toolsets to Measure Environmental Impact cont.

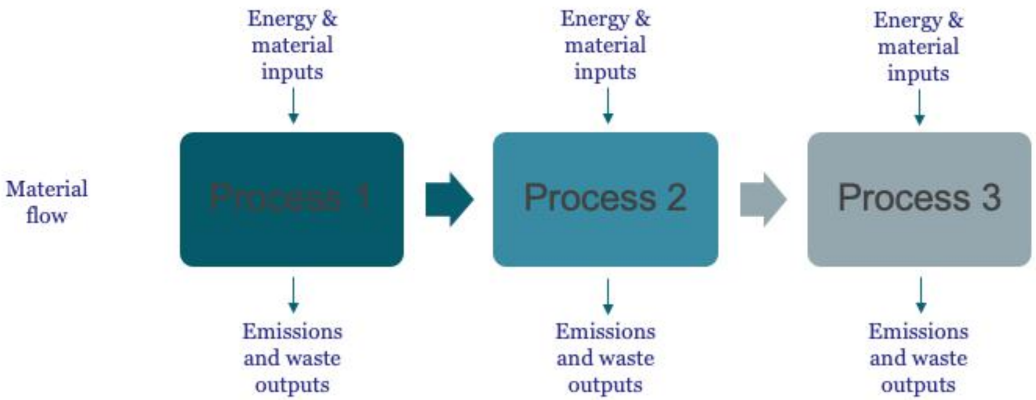
Global Warming Potential measures all greenhouse gases and equates them to carbon dioxide equivalent (CO_2e), so that we can measure the contribution to global warming. Sometimes this is called a carbon footprint.

Other impact categories look at other environmental impacts such as contribution to acid rain, damage to ecosystems, land use and water use

Notes:

Life Cycle Assessment

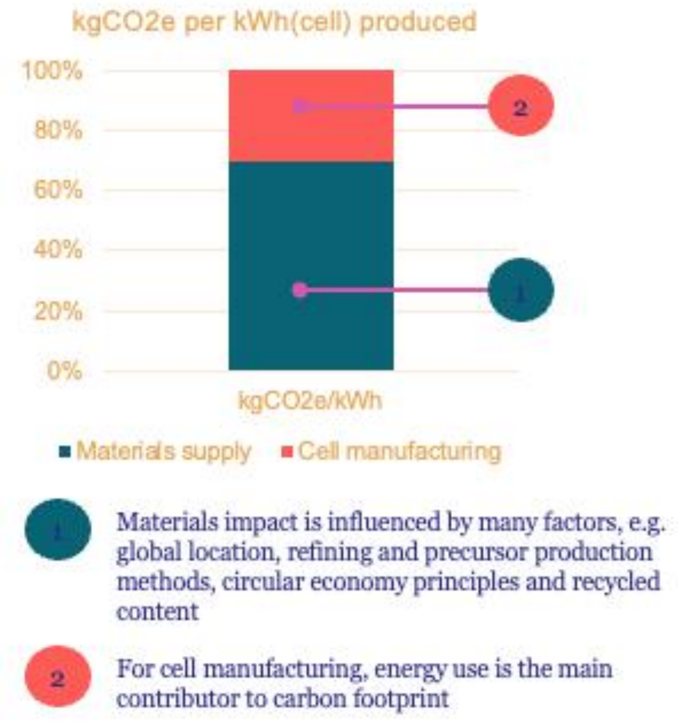
To measure environmental impacts of a product, process or system, the inputs and outputs at each stage must be quantified.

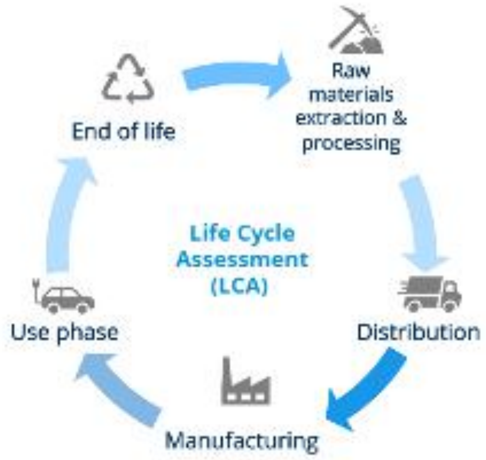


Notes:

BT4 Introduction to Designing Sustainable Batteries

LCA for Battery Cell Manufacturing





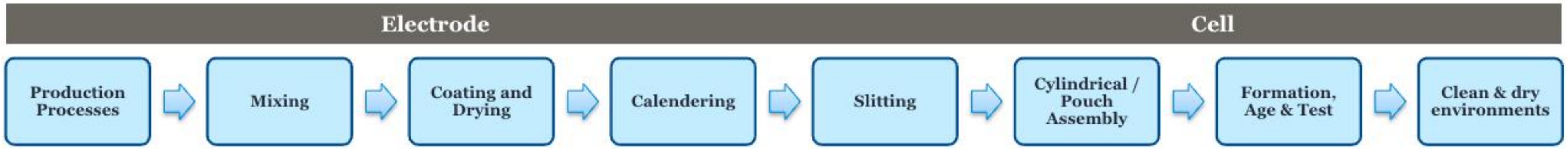
For battery production, we can complete a "cradle-to-gate" life cycle assessment, which looks from mining through to a finished cell.

It does not look at the use phase and end of life, so is not a complete life cycle assessment but does allow us to make decisions about manufacturing techniques and material choices.

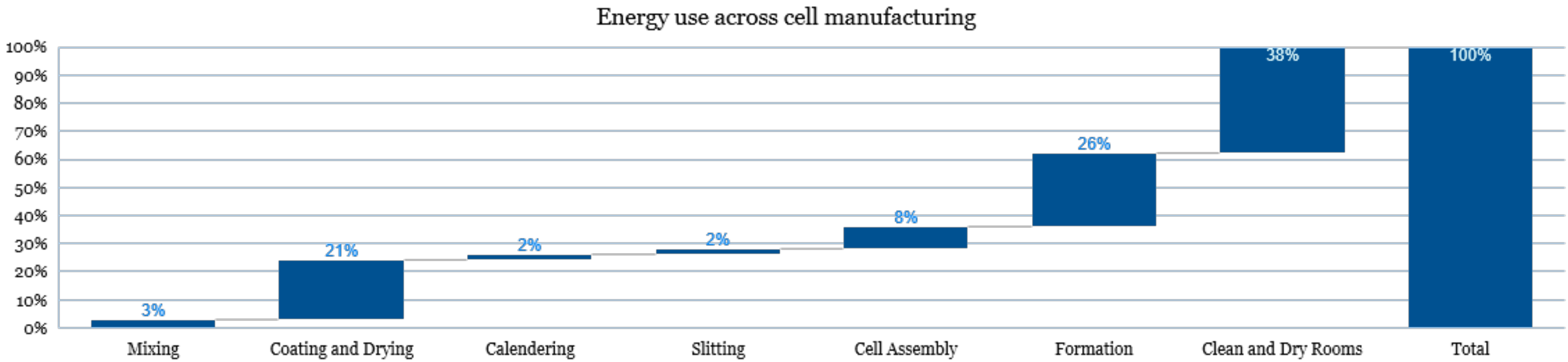
This allows us to focus on the parts of the value chain where we have most influence as a cell manufacturer.

Notes:

Energy Use in Manufacturing – Scope 2



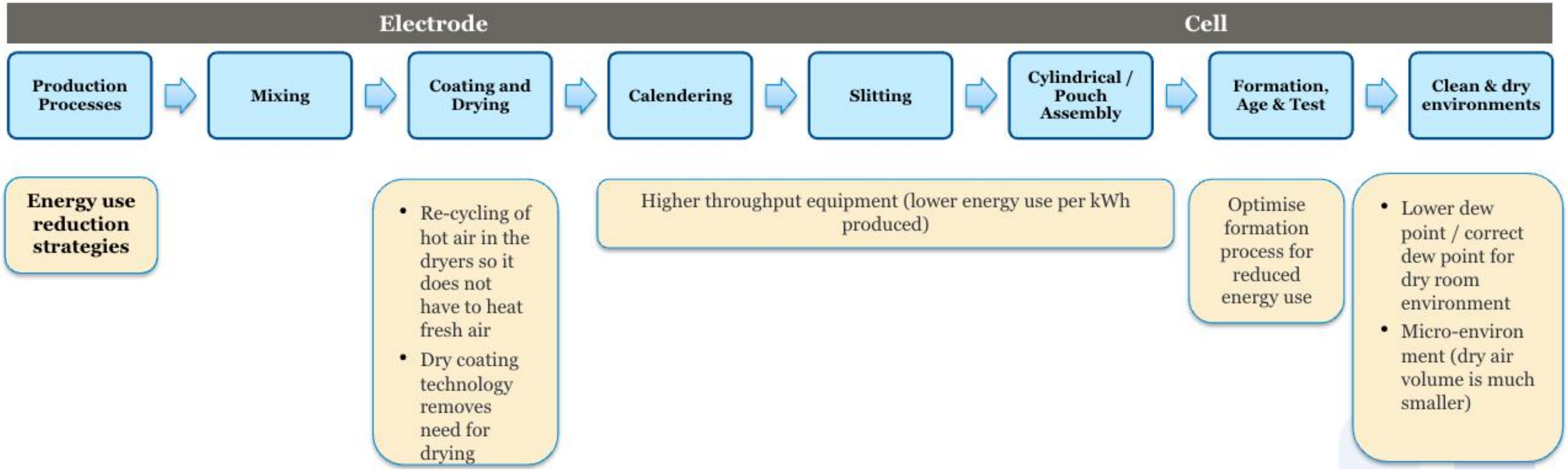
Source: UKBIC data



As energy use is the largest contributor to environmental impact in the cell manufacturing process, a deeper dive is required to find out where exactly the energy is being consumed.

Notes:

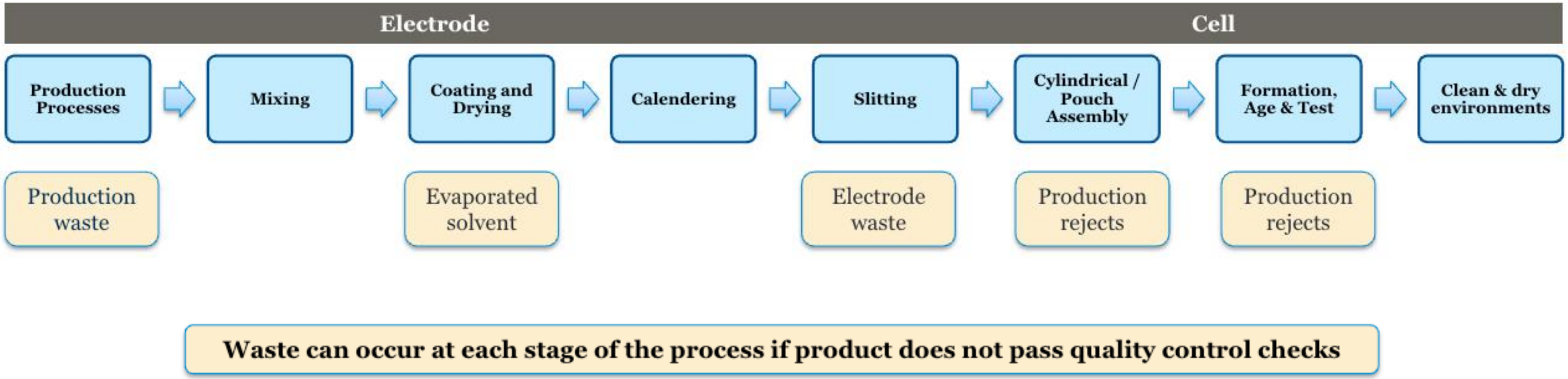
Energy Use in Manufacturing – Actioning Points Related to a Scope 2 Assessment



Energy use
Once it is known where the energy is being used, strategies to improve energy efficiency in battery cell manufacturing can be considered.

Notes:

Driving Sustainability in Manufacturing – Waste Sustainability in Manufacturing



Waste

Identify where in battery manufacturing waste and emissions occur, and therefore where to target with waste reduction through improved processes and designs.

Notes:

BT4 Introduction to Designing Sustainable Batteries

Waste Reduction

The waste hierarchy can be used to prioritise actions to reduce waste.

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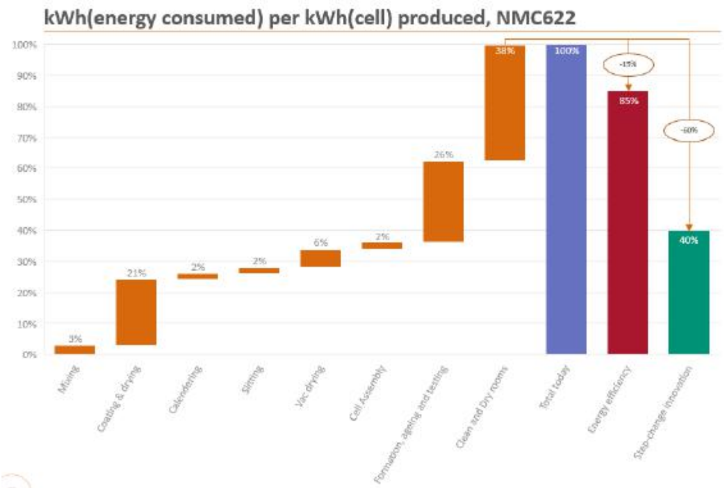

Driving Sustainability with New Technologies

Improving energy and material consumption efficiency with current manufacturing technologies will only go some way towards reaching sustainable manufacturing.

In order to gain large steps towards environmental impact reduction, new technologies must be developed. The graph below demonstrates this for energy use.

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Driving Sustainability with New Technologies cont.

By realising energy efficiency measures with current processes, a 15% reduction in energy use per kWh cell produced may be possible.

Investment in new technologies such as dry coating (removing the solvent entirely), this saves 21% of the energy consumed as no drying is required.

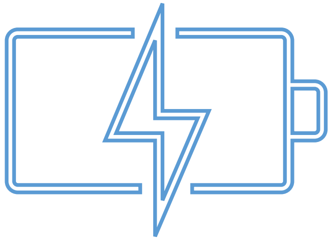
Notes:

Driving Sustainability with New Technologies cont.

Micro-environments can replace the need for a full dry room, enclosing the equipment only, meaning the volume of air required to be dry is much smaller. This could achieve a 20% reduction in overall energy use.

Other new technologies such as higher capacity equipment (increasing the kWh of cell produced for only a smaller increase in kWh consumed) and increased digitalisation to optimise processes like formation will enable further gains.

Notes:



Driving Sustainability with New Technologies cont.

New technology development will not only save energy, it can be used to address other sustainability issues such as the use of harmful chemicals (by changing cell design and/or manufacturing techniques).

Notes:

Driving Sustainability with New Technologies cont.

Dry coating technology not only saves energy but also removes the need for NMP, and the need for the dryers entirely which saves on factory space.

The best kind of new technology development addresses more than one sustainability issue.

Notes:

BT4 Introduction to Designing Sustainable Batteries

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