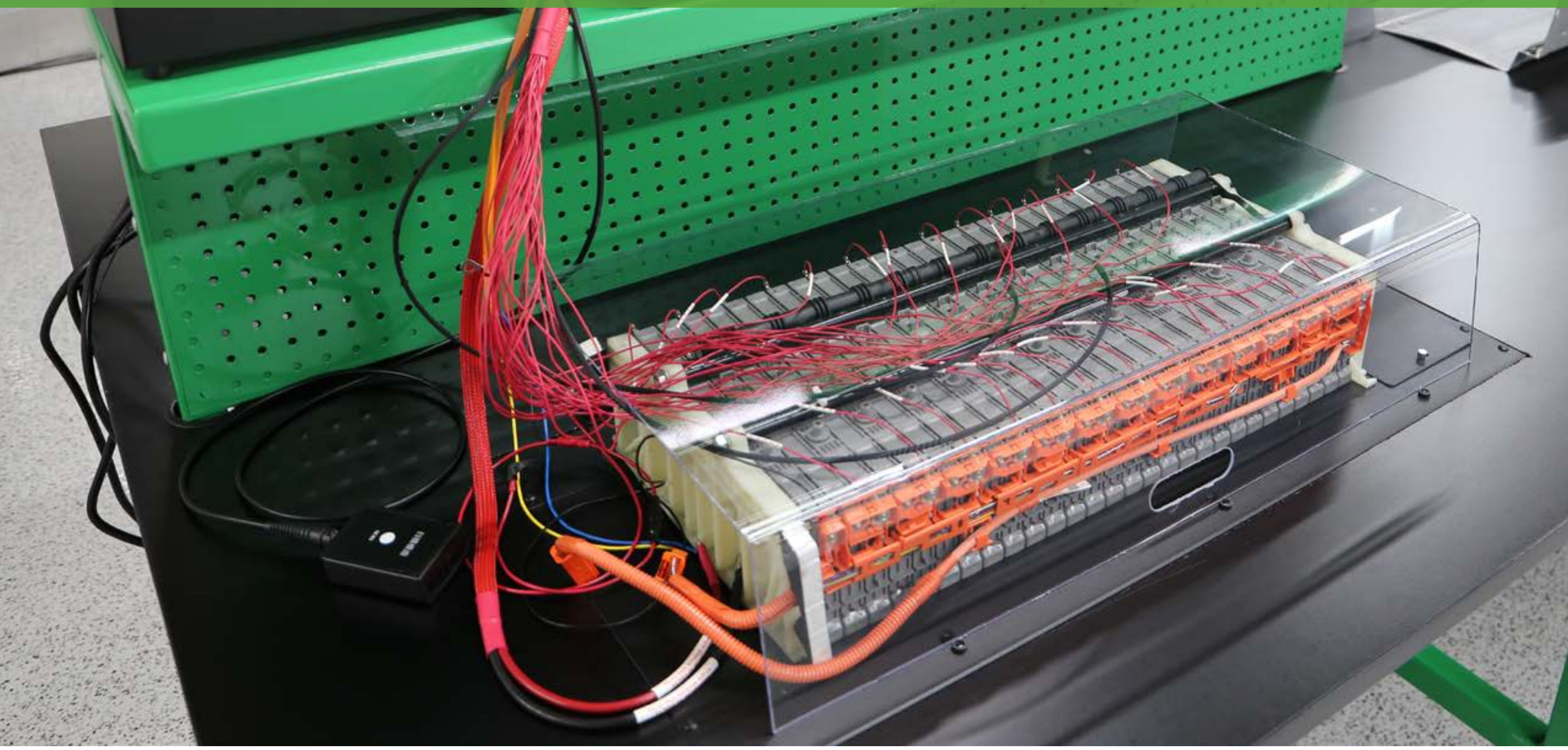
SUSTAINABLE CIRCULAR ECONOMY

The Electric & Hybrid Vehicle Battery



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IM Group

innovative mechatronics

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SUSTAINABLE
CIRCULAR ECONOMY

Over the past few decades, we have seen drastic evolution of technology from the humble calculator to smart phones, more capable and advanced than the moon landing shuttle.

Vehicle propulsion similarly has undergone drastic changes; we no longer need to rely on just fossil fuel. Manufacturing and circuitry technology have continuously advanced, leading to more energy storage solutions emerging in the market.

We can now light up the streets or power our hot water system in the home without using "dirty" electricity as we harness the sun's energy.

SUSTAINABLE CIRCULAR ECONOMY

This is similar to the events of the 20th century, when we flipped from horse drawn carriages to 'horseless' carriages, otherwise known as motor vehicles. Now, we are embarking on the alternative fuelled vehicle propulsion trend, such as battery electric, hybrid petrol electric and even fuel cell (hydrogen) electric vehicles. Imagine we could utilise these alternatives to power the transport economy.

Having these "clean" amazing new technology however may come at a compromise to battery waste. Therefore, in creating a sustainable circular economy for battery electric vehicle (BEV) and hybrid electric vehicle (HEV) battery remanufacturing, an Australian brand, Injectronics is addressing an area of concern surrounding BEV and HEV life cycles. Injectronics is leading the way in scalable hybrid battery remanufacturing in Australia and New Zealand and has launched its hybrid battery exchange program nationally.

The program was conceived in response to the number of HEV and some BEV batteries now reaching their end of service life and, crucially, to reduce the number of batteries being sent to landfill. With a desire to close the loop on these waste streams and foster a circular economy, the "reduce, reuse, recycle" mantra has never been more important.

If no actions were taken to facilitate a sustainable circular economy, it would not only be unfortunate from an economic perspective, but it's also an environmental disaster. Many of these battery packs have a substantial service life ahead of them and require only a small percentage of their components to be renewed or remanufactured to be perfectly serviceable.


H2O

CYCLE OF LIFE

The innovative approach for a sustainable circular economy starts with understanding what a "Sustainable Circular Economy" is. It is more than reusing the materials/minerals going around and around forever. It is about putting in place opportunities to recoup and minimise waste, and we can do far better than we are currently doing.

THIS STEMS FROM THE IDEOLOGY AND IMPLICIT ASSUMPTION THAT EARTH HAS ENDLESS SUPPLIES OF MINERALS, MATERIAL AND RESOURCES. WE CAN USE A PRODUCT, THROW IT AWAY, MINE MORE MATERIALS, AND MAKE ANOTHER NEW PRODUCT.

THE MODEL
CIRCULAR ECONOMY

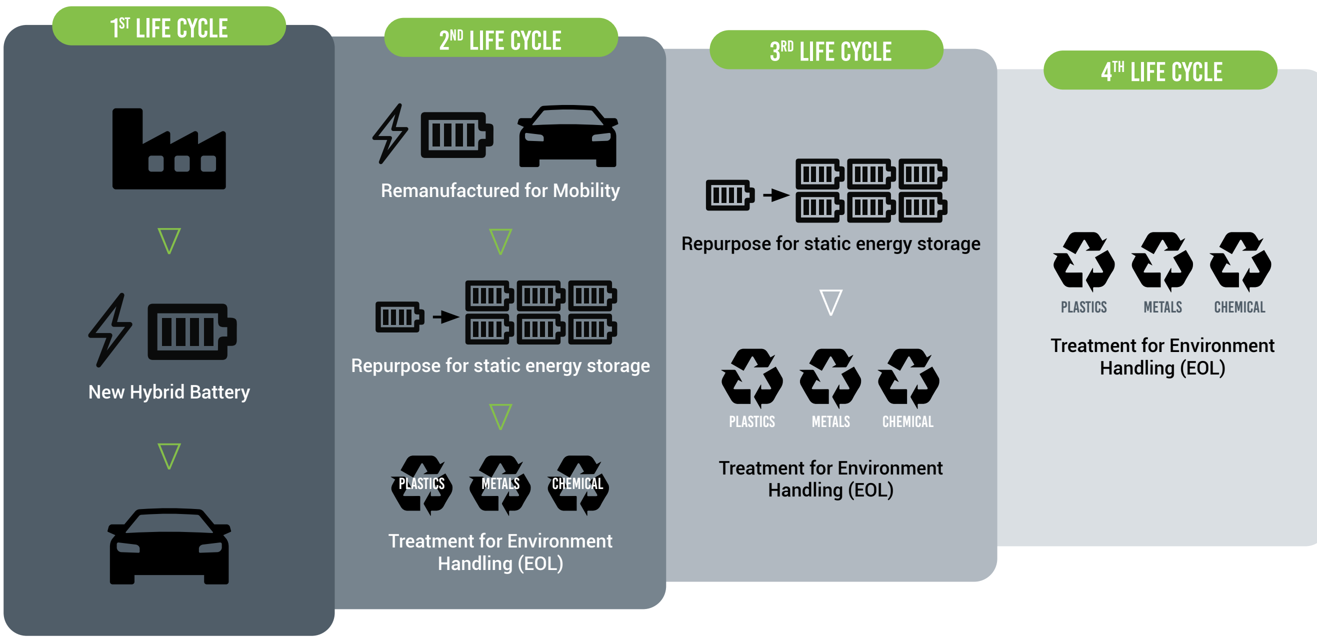


Figure 1: Concepts of Life Cycle

The holistic approach to the Sustainable Circular Economy, with support from Government, automakers and suppliers can map a journey towards this important approach. To mitigate issues and identify challenges and to assist in their recycling, remanufacturing or repurposing of used and spent EV batteries and other related automotive components.

FIGURE 1 shows the concept of 1st Cycle use and 2nd Cycle use, with potential 3rd Life cycle use and even end-of-life (EOL) treatment of 4th Life cycle.

The sustainable economy allows for batteries from vehicles which can no longer be used for their intended purposes (propel the vehicle) to be used in static energy storage or other applications. After multiple cycles, they will be treated as part of their EOL process and minerals/materials are recirculated back into the production of components such as drive batteries (again). In this process, lithium and cobalt mining are reduced significantly.

As stated in a recent Tesla (2020) environment report, some 1,300 tons of nickel was recycled, 80 tons of cobalt and some 400 tons of copper were not mined due to a closed recycling process utilised by Tesla as part of the EOL process.

WHAT DOES CIRCULAR ECONOMY LOOK LIKE?

The conventional, circular economy for motor vehicles focuses on mechatronics parts for vehicles running on internal combustion engines. With electrification of the drivetrain, steps have been taken by Injectronics to be the first to enable a sustainable circular economy solution for battery powered vehicles like BEV and HEV.

Europe and United States are often the first movers to introduce new environmental policies, followed by nations like Australia, who often reference those policies. In the early 2010s, California became the first state to pass legislation with aggressive energy storage targets (Public Utilities Commission, 2013). The socalled energy storage mandate promotes the use of renewable grid-based and distributed energy storage. Such a policy stimulates demand for ESS.

In December 2020, the European Union proposed a new regulation which aims to ensure that batteries placed in the EU market are sustainable and safe throughout their entire lifecycle (EC, 2020). In short, the directive defines measures and sets targets for recycling activities. Such a policy stimulates the recovery of retired batteries from EVs.

The Circular Economy investigates the necessary Circular Energy Storage concept and viability of establishing Australia's first scalable reuse and resource recovery of retired lithium ion battery packs from any electric vehicle (EVs). EV batteries are typically replaced after they lose around 20% of their capacity, which means that there is still up to 80% capacity remaining

that can be used for stationary energy storage solutions (ESS). This approach outlines the benefits as shown in **FIGURE 2.**

Beyond automotive, extending the business into energy and power storage opens significant future potential for the company as well as the benefits for the environment, and is a core strategic theme for mobility and the economy. It is a springboard to launch into the future, a sustainable circular future.

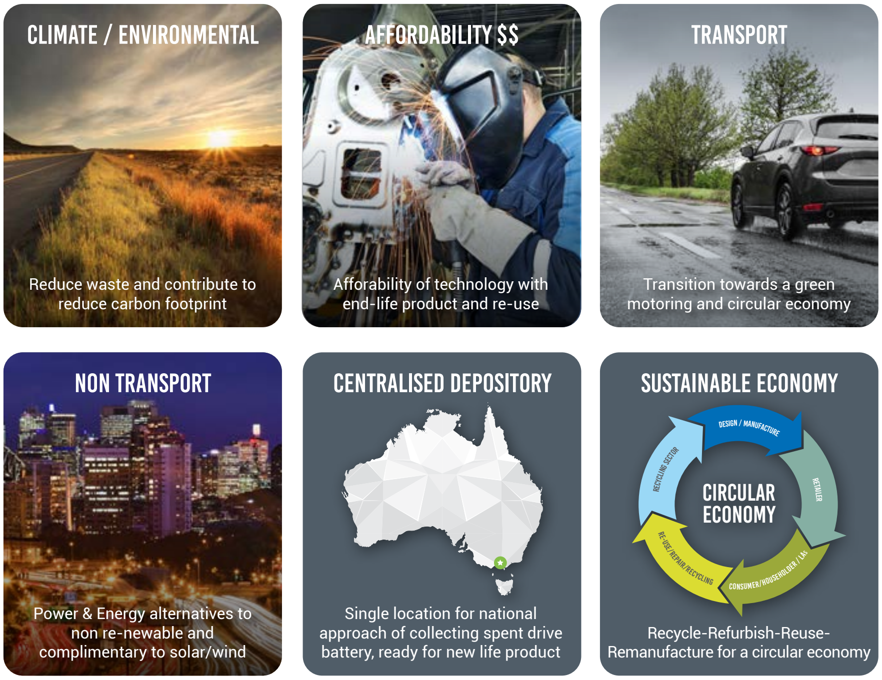


Figure 2: Concepts of benefit from Circular Economy & Sustainability (CES) consideration

REDUCE, REMANUFACTURE & RECYCLE

Circular Economy for BEV and HEV battery packs contribute towards the 3-Rs

01 REDUCE

By reusing retired HEV and BEV batteries for production of ESS, we reduce the raw materials. The potential benefit includes offsetting initial manufacturing impacts by extending battery life span. The benefits are magnified when reused in a second use such as stationary energy storage. Second life batteries can save between 15 and 70% of the cumulative energy demand and greenhouse gas (GHG) emissions compared to lead acid batteries or natural gas (Melin, 2019).

02 REMANUFACTURE

Healthy packs, cells and parts such as cases, sensors and relays are repurposed for second use applications like industrial ESS

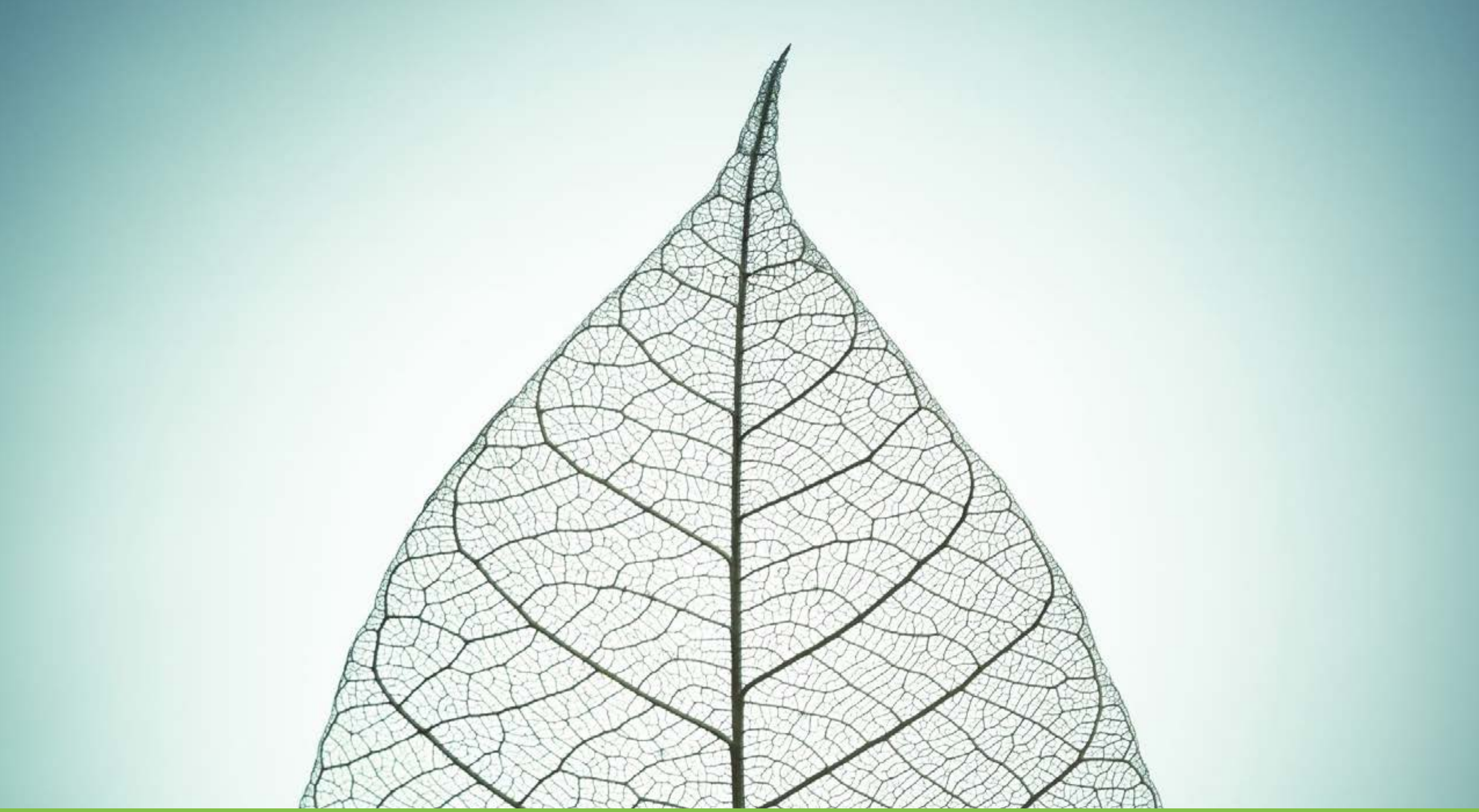
03 RECYCLE

When ‘unhealthy’ packs are no longer suitable for stationary ESS or portable power solutions. These retired packs do contain valuable materials such as lithium, manganese, cobalt, and nickel. Thus, viable avenues for materials recovery to minimise or eliminate mining of these minerals need to be identified as part of the circular economy and supply chain.

Second life applications of vehicle batteries allow us to spread the GHG emissions created during their production over a greater number of years or kilometers, thus reducing their carbon footprint over the course of their useful life. In addition, we reduce our environmental footprint by deferring the manufacture of a new battery (or other form of electricity storage facility) until a later date .

As an example, Hall (2018) estimate that GHG emissions per km travelled on a battery pack can be reduced by 42% if the battery is used in stationary grid storage.

This concept by Innovative Mechatronics Group attempts to create a win-win situation for the automotive and energy storage sectors, by repurposing the potential waste as potential supply input without fundamentally changing the product. In Europe, the batteries are treated as electronic e-waste, along with the likes of mobile phones and other electronic devices. However, these devices could have good recoverable base metals such as nickel, cobalt and copper. This is especially the case for HEV and BEV batteries. For the automotive sector, there is a social imperative to offer an end of life solution for the vehicles with battery packs.



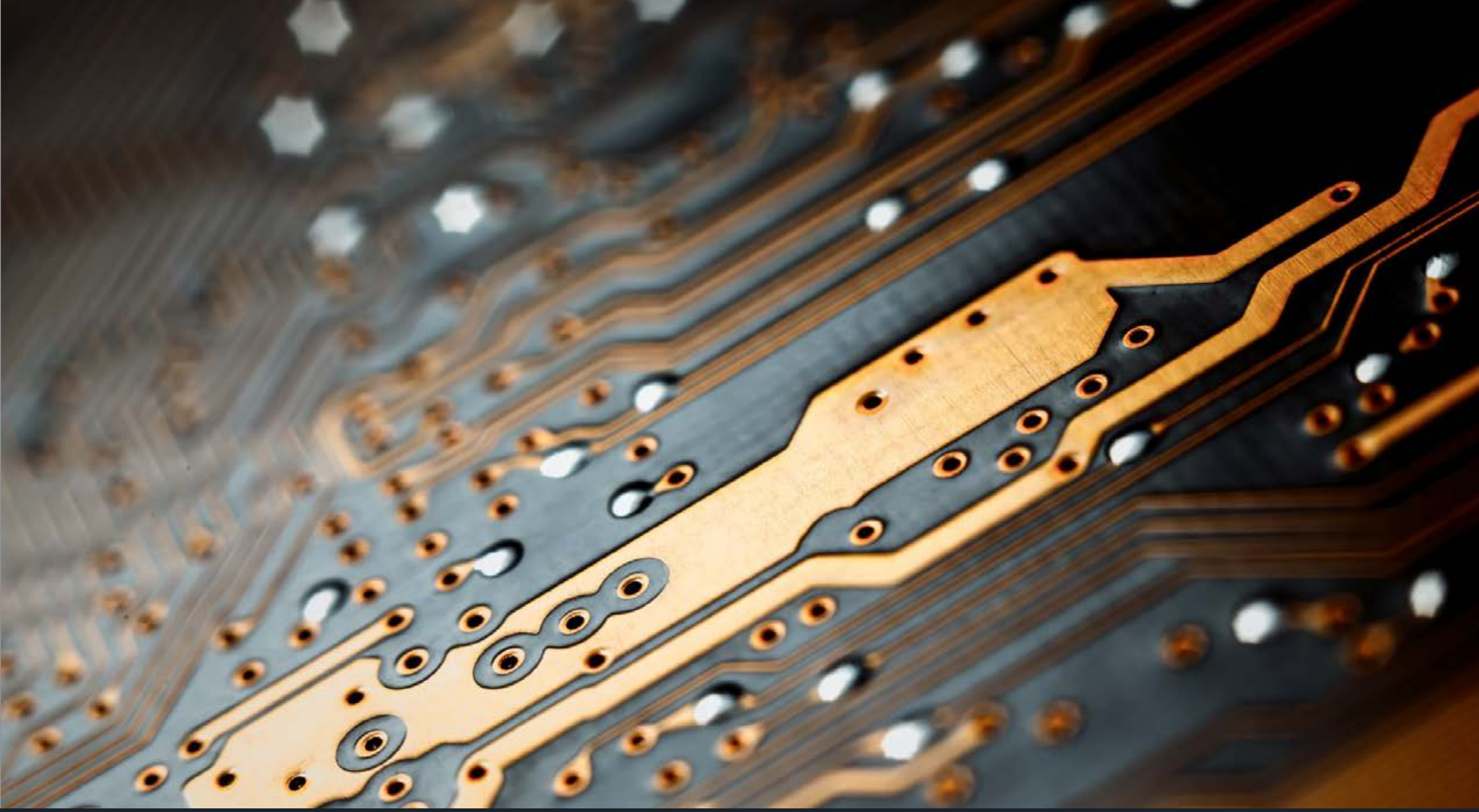
RECYCLING: END OF LIFE TREATMENT

Existing processes such as crushing and shredding the batteries can still be practical. There are many ways for end of life (EOL) treatment.

- Some crushed batteries are put into a leaching process or crushed and then smelted, or
- Some types of batteries can directly be placed into a smelter; or
- Some batteries are dismantled and thermal heat treated to remove some components, and then go to a hydrometallurgical treatment.

These processes have all been quite successful, but there are limits to what can be done economically and sustainably.

Innovative recoveries for elements like lithium, cobalt and electrolyte materials are needed. In recent times, there has been much focus on lithium recycling due to the mining requirements and practices. In Europe, there has been a push to recycle over 70% of lithium as part of the upcoming battery directive (Waste Framework Directive, 2018).



TECHNOLOGY ADVANCEMENT

In 2016, GHG emissions of 59 Mt of CO_2-equivalent were produced by light passenger and commercial vehicles in Australia. This equates to over 11% of all GHG emissions and 61% of GHG emissions from the transposer sector (GVG, n.d.). In Australia, per capita transport emissions are 3.77t CO_2-equivalent per capita, which is well above leading countries such as the EU with 1.69t CO_2-equivalent per capita (Wolfram, 2017).

This indicates that the there is a significant potential to save emissions from the transport sector as we move towards low and zero emission vehicles (LZEVs) such as BEVs and HEVs.

In order to holistically assess the environmental impact of vehicles it is not sufficient to only consider the emissions during their use phase. Emissions during extraction of raw materials, vehicle manufacturing, vehicle shipping and vehicle recycling need to be taken into consideration as well. The following sections focus on the environmental impact of LZEVs in terms of GHG emissions, referring to current and future battery technologies.

MANUFACTURING

When it comes to comparing traditional internal combustion engine vehicles (ICEVs) to EVs in terms of lifecycle GHG emissions, the on board lithium ion battery in BEVs and other derivatives of EVs makes a significant difference.

Emissions are created during (raw) material extraction, production of battery materials from the raw materials, battery cell and component manufacturing, as well as battery pack assembly (Kim et al, 2016).

Overall, manufacturing a battery pack and associated drivetrain components for an EV produces significantly more GHG emissions compared to equipping an ICEV with an internal combustion engine. However, the following points need to be considered:

- **Carbon intensity of electricity:** Energy use for battery pack manufacturing is comparable across similar sized production facilities. In contrast, GHG emissions for the energy that is used vary depending on location and carbon intensity of electricity generation. Hao et al. (2017) found that producing a vehicle battery in China creates about 3 times as many GHG emissions than in the US **(FIGURE 3)**. The largest differences are in aluminium forging and anode active materials.

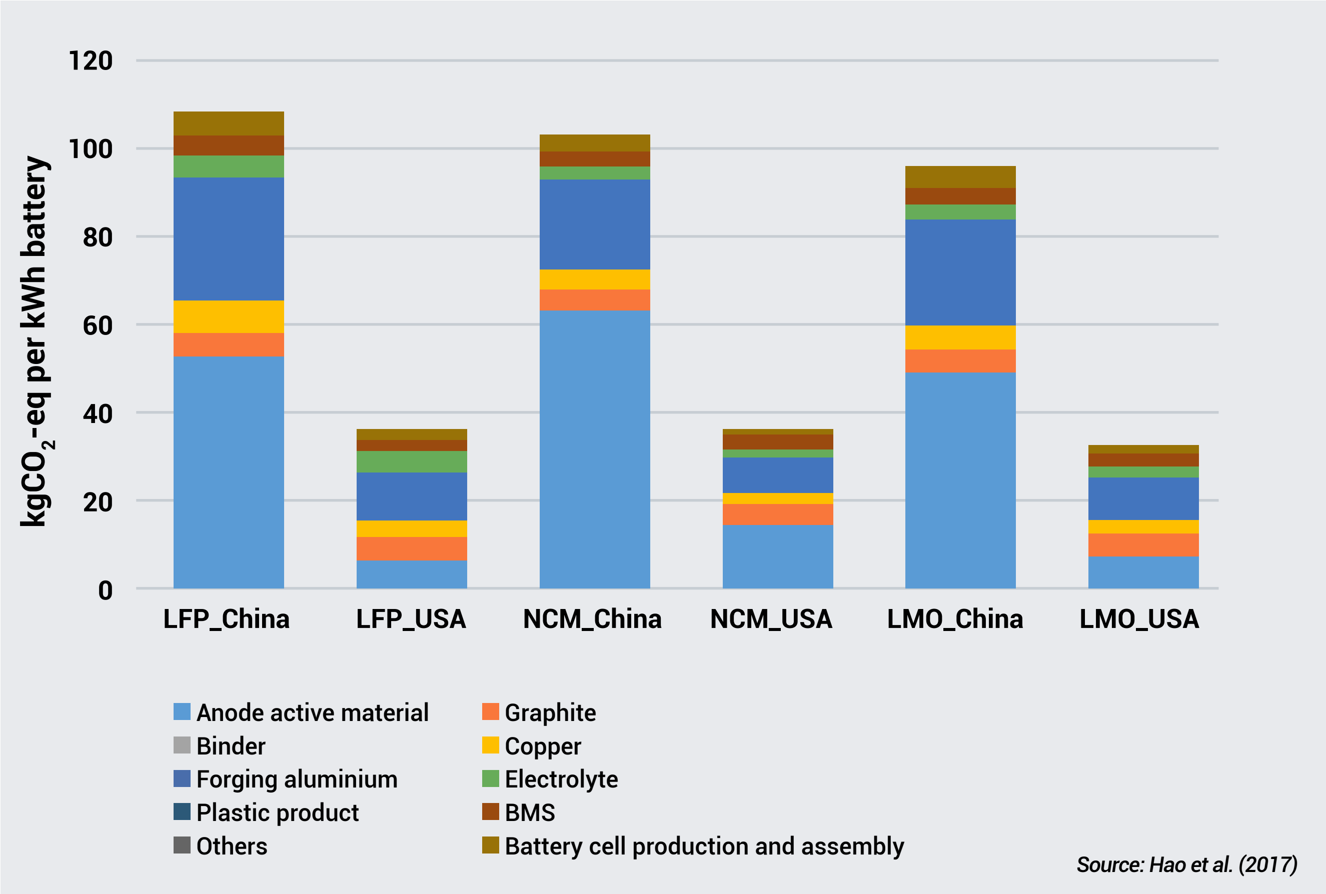


Figure 3: Emissions from battery pack manufacturing in China and the US

MANUFACTURING

This example highlights the impact that low carbon electricity can have on the manufacturing emissions of a battery, and thus the entire vehicle.

- **Future decarbonisation of electricity:** In addition, some studies assume a national average electricity mix as a basis for battery manufacturing emissions estimation.(Dai, 2017).

This can be true for some facilities but is not in others. More importantly, however, future decarbonisation of the electricity needs to be factored into the assessment. This means that past studies would have assumed carbon intensities of electricity mixes that are already lower today (Hoekstra, 2020). Also, the example of Tesla's low carbon manufacturing facilities **(see FIGURE 4)** shows where we are heading with solar and wind power and energy storage capabilities.

- **Production efficiencies:** Hoekstra (2020) also finds that many studies on battery manufacturing emissions use outdated assumptions about production volumes. For example, small scale production used to lead to high emissions per battery but will no longer be an accurate estimate as production is scaled up and efficiencies increase.

Figure 4: Vision of Tesla's Giga Factory in Nevada, US

Source: https://www.tesla.com/Gigafactory

EV ANXIETY

The fear that EVs may run out of battery energy midway during a trip discourages people from adopting the technology. This is understandable if we consider the case of the mobile phone, laptop or electric bike. EV road charging seems a viable and critical solution, enabling EVs to power up on the move and on its journeys.

EV road charging can be achieved through four components: copper coils under the road in the middle of traffic lanes (inductive charging), a receiver placed under the vehicle chassis, power units that transmit electricity from the grid to coils, and a system managing billing and charging.

Demonstration projects have been launched in Sweden and Israel and many other countries. Once proven to be feasible technologically and economically, it could be a promising path to our zero emission future. (Leow, D., 2020)

An article by Stuff magazine (Tang, M., 2015) suggested that Formula E will play an important role in the acceptance of EVs as an alternative drivetrain, just like how Formula 1 technologies have trickled down to everyday vehicles over time (like brakes and tyres).

BATTERY PACKS

Batteries for vehicle propulsion need to be enclosed to protect the battery from variables such water, dust, debris as well as from harsh external conditions. One of the concerns with a vehicle battery is the dangerous thermal runaway condition when the battery experiences cooling issues.

On top of challenges unique to the battery pack along with exposure to the various elements experienced by other automotive components, battery packs present additional challenges due to their location, size, and chemical makeup. The size of battery packs also presents challenges, weighing up to over 500kg for a light passenger vehicle (depending on types). If lithium ion battery cells are damaged by puncturing, overcharging, manufacturing defect, or other causes, they can release gas and heat, which leads to a potential dangerous thermal runaway condition (Sanders, 2021).

Innovators and scientists alike have attempted to replace chemicals like graphite anodes with lithium metal anodes currently used in EV batteries to extend rechargeable battery power, so battery powered vehicles can travel for hundreds of kilometres on a single charge.

But while lithium metal extends an EV's driving range by 30 to 50%, it also shortens the battery's useful life due to lithium dendrites. However, researchers have developed a new class of soft, solid electrolytes made from both polymers and ceramics that suppress dendrites in the early nucleation stage, before they can propagate and cause the battery to fail (L.B.Nat Lab, 2021).

NEW LABOUR FORCE

Over the next decade, the required knowledge and skill sets of existing manufacturers and suppliers will need to shift dramatically due to several variables and factors driving this. As vehicles get "smarter" and communicate with each other including infrastructure, the software and connected sensors becomes critical, and the needs of these digital talents are essential.

There are number of research that suggests there could be a shortage of employees across the industry supply chain as we transition from mechanical components to electronic and electrical circuitries. However, wireless "over the air" updates to diagnose faults could be the norm rather than having to book your vehicle in for a mechanic to check your faults.

AS THE CHEMISTRY OF THE VEHICLE CHANGES, THE AUTOMOTIVE WORKFORCE WILL ALSO FOLLOW SUIT. NEW KINDS OF "MECHANICS" AND "TECHNICIANS" ARE NEEDED TO COMPLEMENT THE FUTURE VEHICLE LABOUR FORCE.

A BETTER TOMORROW

Although the uptake of EV and derivatives such as plug in hybrid electric vehicles (PHEV) and HEV has been slow in Australia, their numbers are increasing rapidly each year. In the eight months to August 2021, EV had an increase of 138% in sales compared to the year prior (Davis, 2021). With such an increase and expansion on the uptake of these alternative fueled vehicles, state and local government must consider the ways these vehicles will impact road operations and the potential opportunity of harnessed energy it creates.

ACCORDING TO THE AUSTRALIAN BUREAU OF STATISTICS (ABS), AS OF 2019, THERE WERE 19.5 MILLION REGISTERED VEHICLES ON AUSTRALIAN ROADS, WITH AN AVERAGE AGE OF 10.2 YEARS.

A BETTER TOMORROW

According to VFACTS, an average of about one million vehicles are sold, of which Zero Emission Vehicles (ZEVs) accounts less than one per cent.

There are many reasons attributed to the low uptake rate in Australia including vehicle price, model availability, access to charging infrastructure, charging time, incentives, service support and education. However, as mentioned sales are encouraging over the past 3 years. Many manufacturers are waking up to the trend and allocate an alternative fueled vehicle to the mix in their model line up. You can now purchase an EV across many car brands, including Hyundai, MG and Mini.

In an interview with Infrastructure Magazine, the Chief Technology Leader and National Leader, Future Transport Systems at ARRB, said, "By supporting the transition to EVs and ZEVs, road operators can help shape how charging infrastructure is modelled as opposed to random third party install what incentives could be considered to generate greater uptake, and how road design, planning, maintenance, build and implementation could be influenced." (Leow, 2020)

An article by Infrastructure Magazine (IM, 2020) also stated the benefits of supporting the transition, which include:

- Life saving technology and contribution to 'Towards Zero'
- EVs and ZEVs have fewer GHG emissions than fossil fuel powered vehicles, and reduce energy consumption by returning energy to the grid
- Reduce dependence on the importation of fossil fuels and could create tens of thousands of jobs

In the same article, according to Chief Technology leader of ARRB, another benefit with battery powered vehicles is the potential of data sharing with insights to many sensors monitoring the road surfaces or vehicle movements. Also, the information on origin and destination information could be collected to better plan road network loading and peak periods of charging.

"CHARGING OF EVs HAS AN INDIRECT IMPACT ON THE OPERATIONAL REQUIREMENTS OF THE ELECTRICITY COMPANY AS THE LOAD MAY TRIP A BLACKOUT SCENARIO. THE INFORMATION WILL ALLOW FOR BETTER OPTIMISATION OF ENERGY REQUIRED AND PRODUCTION."
(IM, 2020).

It can also be noted that "...factors such as safety, renewable and sustainable materials for roads, the suitability of technology and its regulations, best practice with learnings from affiliation internationally and direct collaboration with industry stakeholders are available..." (Leow, 2020).

POLICIES & SUPPORT

To highlight the impact of battery GHG emissions on the vehicle lifecycle emissions, the use phase has to be considered as well. Typically, for an ICEV, the use phase contributes to the majority the vehicle's lifecycle GHG emissions through the use of fossil fuels (e.g. petrol or diesel). For EVs, this not necessarily the case, as a comparatively large amount of emissions is generated during vehicle (battery) manufacturing and use phase emissions depend on the carbon intensity of electricity that is used to charge the vehicle.

As Australia's electricity mix is still relatively carbon intensive compared to other developed nations **(see TABLE 1)**, the potential for EV to lower net carbon footprint from road transport in Australia is lower on average. However, it also depends greatly on where the vehicle is used or how it is charged. For example, charging a BEV from the average Victorian grid mix at 1.00 kg CO_2-equivalent/kWh does not make a BEV very environmentally friendly. However, charging it with hydro power in Tasmania at 0.16 kg CO_2-equivalent/kWh does, and plugging a BEV into a charge point fueled by solar power is likely to be similar.

This means that the impact of high GHG emissions during vehicle (battery) production can be offset more quickly during the vehicle use phase the "cleaner" the electricity is which is used to charge the vehicle. To illustrate this, **FIGURE 5** shows curves that compare lifecycle GHG emissions from a petrol ICEV to different types of BEVs (with a smaller and a larger battery of 40 or 80 kWh) and a HEV.

Country/Region	Carbon Intensity of electricity (kg CO_2-equivalent/kWh)
Australia - National Average	0.81
Australia - Victoria	1.00
Australia - Tasmania	0.16
EU	0.27
USA	0.41
China	0.61

Table 1: Carbon intensity of electricity in Australia and different regions worldwide
Sources: IEA Data, 2020; DISER, 2021

POLICIES & SUPPORT

In Victoria, assuming the vehicle is charged from the grid, the initial high carbon footprint of the BEV (40-80% more emissions than for an ICEV, green lines) cannot be recovered within the first 120,000 km of the vehicle's life. However, in Tasmania, it can already be recovered during the first 20,000 to 30,000 km.

Also, in Tasmania, BEVs are likely to outperform HEVs (which still use fossil fuels – just less than an ICEVs). In contrast, this is not the case in Victoria where HEVs remain the better option compared to BEVs charged from the grid.

It is important to note that these curves do not take into consideration the future decarbonisation of the electricity mix. The faster this happens, the sooner BEVs will become the best option from a GHG emissions point of view, and they have the potential to also outperform ICEVs and HEVs in Victoria in the future.

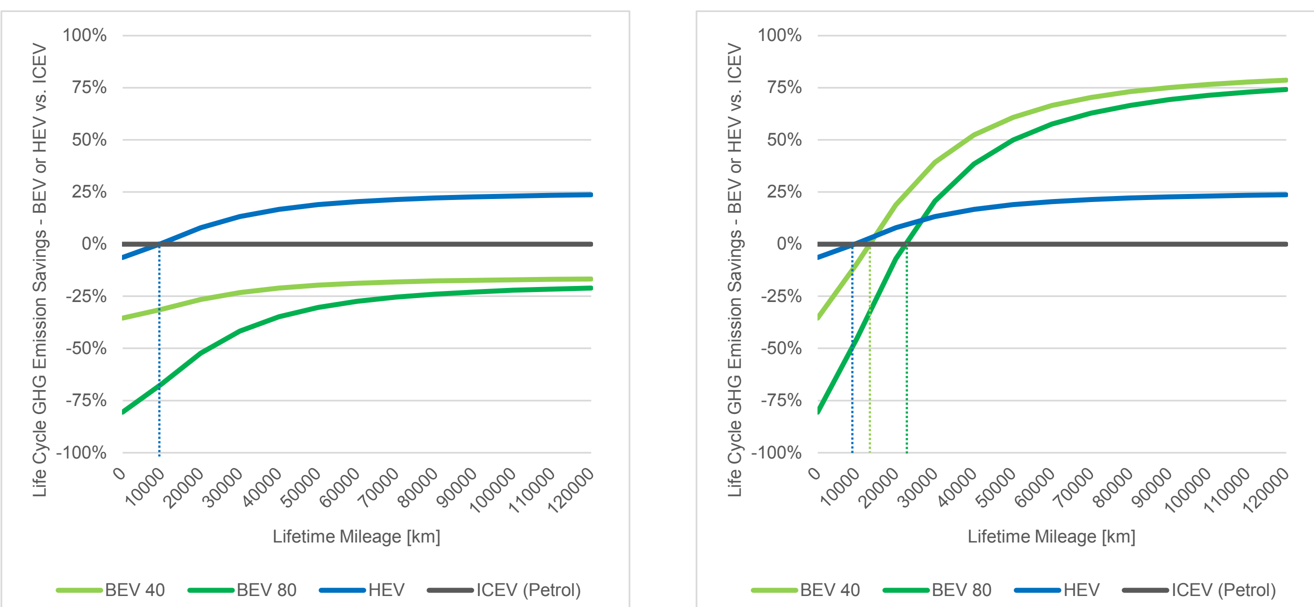


Figure 5: Lifecycle GHG emission savings in Victoria (left) and Tasmania (right) considering manufacturing emissions of different powertrains
Notes: vehicle manufacturing emissions according to IEA 2020. BEV 40 and BEV 80 refers to a BEV with a 40 and 80kWh battery respectively.

CIRCULAR ECONOMY

As we enter a new era of battery driven mobility, it will be a matter of short years before spent batteries from these mobility units containing rich minerals such as lithium and cobalt are discarded in mass volume. Therefore, it is critical that a sustainable circular economy be established to ensure a holistic ecosystem.

As suggested by Kong, 2021, "...in the ideal world, we hope that there's no virgin minerals needed to be mined and all the minerals, materials that are already produced could be reused indefinitely".

In creating a sustainable circular economy for BEV and HEV battery remanufacturing, IM Group is addressing and investigating areas of concern surrounding BEV and HEV EOL treatment and life cycles. It is leading the way in a scalable battery program and has launched its hybrid electric battery exchange program within Australia.

This sustainable circular economy needs a holistic perspective and was conceived in response to the very likely increase in the number

of HEV batteries, PHEV batteries and BEV batteries now reaching their end of service life. Crucially, to reduce the number of these batteries being sent to landfill is the environmentally desired outcome to close the loop on waste and foster a sustainable circular economy. The 3Rs of "reduce, reuse, recycle" concept is critical in achieving this important feat.

IF NO ACTIONS WERE TAKEN TO FACILITATE A SUSTAINABLE CIRCULAR ECONOMY, IT WOULD NOT ONLY BE UNFORTUNATE FROM AN ECONOMIC PERSPECTIVE, BUT IT IS ALSO AN ENVIRONMENTAL DISASTER.

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