Lithium Battery Sustainability

Team Recharge

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Abstract

In this paper, the sustainability impacts of lithium manganese (Li-MN) batteries are studied using both Life Cycle Analysis (LCA) with Eco-Indicator 99 (EI99) weightings as well as with Total Beauty frameworks. Difficulties with both frameworks are explored. The analysis concludes that while the manufacture of an electric vehicle has a 57% higher EI99 impact than a similar gasoline engine car, a gasoline car has a 220% higher EI99 impact over its entire lifecycle when the electricity and fuel impacts are included. Also shown is that recycling and re-use opportunities exist for lithium batteries.

# Lithium Battery Sustainability

Later this year, the Nissan Leaf will be the first affordable electric car available to US consumers. The Nissan Leaf uses a lithium manganese (Li-Mn) type battery which will also be used in a large number of other electric vehicles. There is concern, however, that lithium batteries have a negative environmental impact and may not be sustainable. This paper looks into the sustainability impact of the Li-MN batteries and the lifecycle impact of the electric vehicles they power as well as recycling and re-use opportunities.

## Frameworks

A number of frameworks were considered for this analysis and the ones that fit best were Life Cycle Analysis (LCA) and Total Beauty. LCA was desirable because of it's comprehensive nature and emphasis on the entire useful life of a product. Total Beauty addresses social beauty (albeit limitedly) which is missing from LCA as well as issues regarding safety and cyclical, closed loop manufacturing.

To weight the LCA data, Eco-Indicator 99 (EI99) (Goedkoop et al., 2001) was used. EI99 is a weighted measure that includes damage to human health, ecosystem quality and natural resources. Human health and ecosystem quality are weighted roughly equal to each other and are each given twice the significance of the damage to resources. The weighting is shown in Figure 3.

While analysis was performed using both tools, the ultimate conclusion is based on the LCA. Data was used from existing studies, most notably from Gauch et al. (2009) in their Life Cycle Assessment LCA of Li-Ion batteries for electric vehicles, and secondarily from Vrablik, T. (2004) in the Material Safety Data Sheets published by National Power Corporation.

## LCA Analysis

Creating a Li-Mn battery requires the use of a number of chemical compounds and aluminum and polyethylene foils, copper foil, graphite, and lithium based salt brines. See Figure 4 for the composition of a cylindrical battery cell. The composition of the Leaf battery is similar but arranged in a flat laminated structure.

This study is based on a battery that provides energy at the energy to weight ratio of 100Wh/kg, providing a total of 30kWh of energy and weighing 300kg. In contrast, the battery in the Nissan Leaf provides 24kWh of energy at a weight of 200kg with an energy density of 140Wh/kg and thus would score better than the reference data. The full list of materials used in the battery can be seen in Figure 1. Figure 2 shows the full life-cycle of the production process.

The Nissan Leaf battery pack contains 48 modules with 4 cells each for a total of 192 cells. Each cell weighs 793g for a total cell weight of 152kg with the remaining weight representing module casing, terminals, cooling fan and the plastic case the entire pack is sealed within, the printed circuit board (PCB) and the battery management system (BMS). See the pack pictured in Figure 8.

Figures 5 through 7 show the environmental impact of the battery pack and cells, which is significant.

Issues that are difficult to take into account include how long the batteries will last and how soon technological improvements will cause current batteries to be replaced.

## Total Beauty Analysis

The Total Beauty framework (Shedroff, 2009) provides a simple and relatively fast framework for sustainability analysis. Both quantitative and qualitative approaches are combined for the end result. The goal of sustainability, according to Total Beauty, is to make all products 100% cyclic, solar and safe. The lithium ion battery Total Beauty fabrication data shown in Figure 11, has a typical “low” result for a technically-oriented product and its associated manufacturing processes. These design gaps, data collection challenges and design improvement opportunities can be summarized as follows:

- CYCLIC Score = 25.2%
    - Low Result: Very low recycled content, but recycled material available
    - Challenge: Multi-level bill of materials (BOM) and processes
    - Opportunity: Increase use of recycled content for Al and Cu (~40% of pack weight)
- SOLAR Score = 14.2 %

    - Low Result: High use of fossil fuel energy for furnaces and smelters
    - Challenge: Determining embodied renewable energy content from municipalities
    - Opportunity: Increase use of renewable energy in production processes; follow biomimicry principles for greener chemistry
- SAFE  Score = 21.9 %
    - Low Result: Low non-toxic lifetime release due to front end manufacturing cycle and fossil fuel use
    - Challenge: Re-active chemical process output gases difficult to identify
    - Opportunity: Identify more non-toxic materials to substitute
- EFFICIENT Score = 56.7 %
    - Average Result: complexity of the manufacturing processes and efficiency increases over 20 years
    - Challenge:  Some of these processes are relatively new (new patents)
    - Opportunity: Increase durability of battery design
- SOCIAL Score = 52.5 %
    - Average Result: US workers are treated fairly well and this battery chemistry is used in BEV and PHEV applications
    - Challenge: Identifying stewardship sourcing of raw materials
    - Opportunity: Increase local production, US manufacturing base and recycling
- UGLY POINTS = -50
    - Very Low Result: Battery manufacturing
    - Challenge: N/A
    - Opportunity: New designs with less metal content

## End of Life

Recycling of lithium ion batteries is more advanced today in the EU and Japan than in the USA. Companies like AEA Technologies in Scotland, Batrec AG in Switzerland, Citron, Recupl and SNAM in France are using a variety of mechanical and pyrolysis techniques (heat treatment with metal recovery) to maximizing recovery of battery components (Waste On-line, 2005). Lithium batteries are pretreated with potassium hydroxide which deactivates the lithium battery leaving lithium salt which is virtually undetectable after pyrolysis. Copper, aluminum and manganese can be more easily recycled today with less energy inputs, than graphite and lithium.

Batteries may also find re-use in lower-power devices such as home backup batteries (Holmes 2009).

In addition, while lithium supplies should be adequate through at least 2020 to support the growth of electric vehicles (Anderson n.d.) recycling lithium will help ease the strain on new supplies.

## System Lifecycle Analysis

It has been shown that Li-MN batteries by themselves don't rate high with these sustainability frameworks, however, a system analysis that includes the entire lifecycle of electric vehicles and how this compares to gasoline powered vehicles shows a different result.

When considering just at the manufacturing process, a typical electric vehicle has a 57% higher EI99 impact than the typical gasoline powered car due to the extra impact of the batteries as shown in Figure 9. However, when looking at the entire lifecycle of the vehicles which includes the electricity for the electric vehicle and the gas and emissions for the gasoline powered vehicle for an estimated life of 100,000 miles, the gasoline vehicle is 220% worse as shown in Figure 10 (Gauch et al., 2009).

## Conclusion

In conclusion, while the Li-MN batteries themselves have a large, negative impact, the system lifecycle impact of electric vehicles that use these batteries is much less than the gasoline powered vehicles they replace. In addition recycling and re-use opportunities exist for lithium batteries.

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Exhibits

***Nissan Leaf Battery*** *(*Paukert, 2009*)*
*Type: laminated lithium-ion battery*
*Total capacity (kWh): 24*
*Power output (kW): over 90*
*Energy density (Wh/kg): 140*
*Power density (kW/kg): 2.5*
*Number of modules: 48*

| Component | Material | Formula | per kg cell (grams) | per Leaf Battery Pack (kg) |
|---|---|---|---|---|
| Cathode | Lithium Manganese Oxide | $LiMnO_2$ | 240.8 | 36.6 |
| | Collector Foil | Al | 143.7 | 21.8 |
| Anode | Graphite | C | 162.3 | 24.7 |
| | Collector foil | Cu | 124.8 | 19.0 |
| Separator | Separator Film | PE | 51.4 | 7.8 |
| Electrolyte: | Etheylene Carbonate - Solvent | $C_3H_4O_3$ | 171.2 | 26.0 |
| | Diethyl Carbonate - Solvent | $C_5H_{10}O_3$ | Unknown | Unknown |
| | Lithium Hexaflurophasphate | $LiPF_6$ | 19.7 | 3.0 |
| Electrodes | Tabs | AL | 15.8 | 2.4 |
| Total Pack | | | 1000 | 152.0 |

**Figure 1 - Li-Ion Battery Materials List, (Gauch et al., Vrablik)**

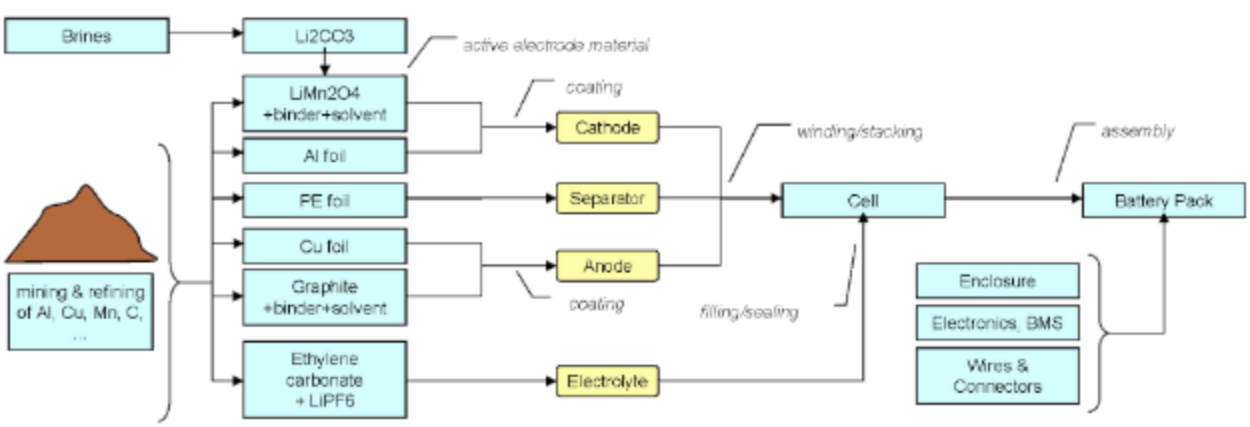


**Figure 2 - Li-Ion Battery Assembly, (Gauch et al., 2009)**

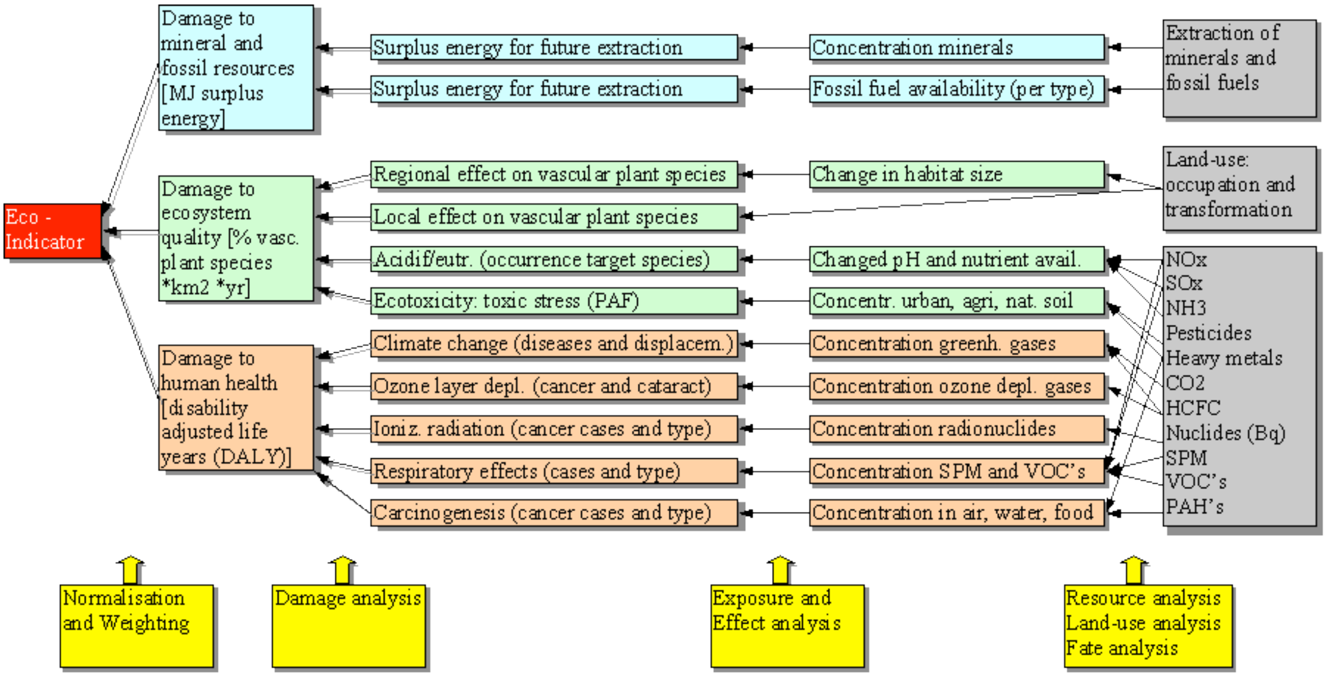


**Figure 3 - Eco-Indicator Elements and Weighting (Goedkoop, et al. 2001)**

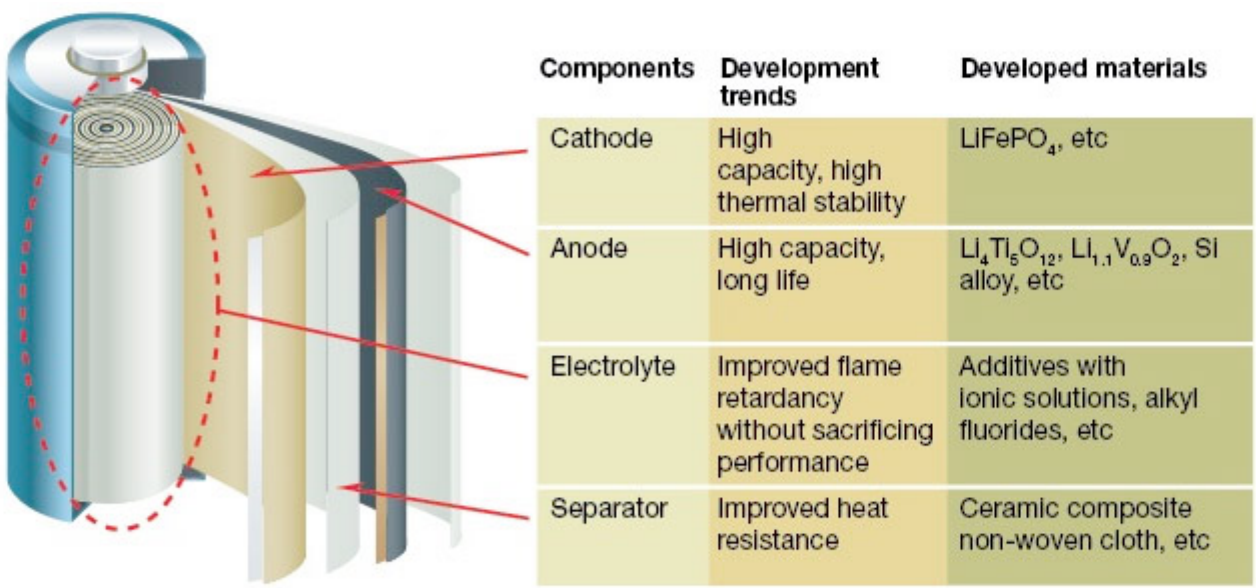


**Figure 4 - Lithium-Ion Cylindrical Battery Composition**

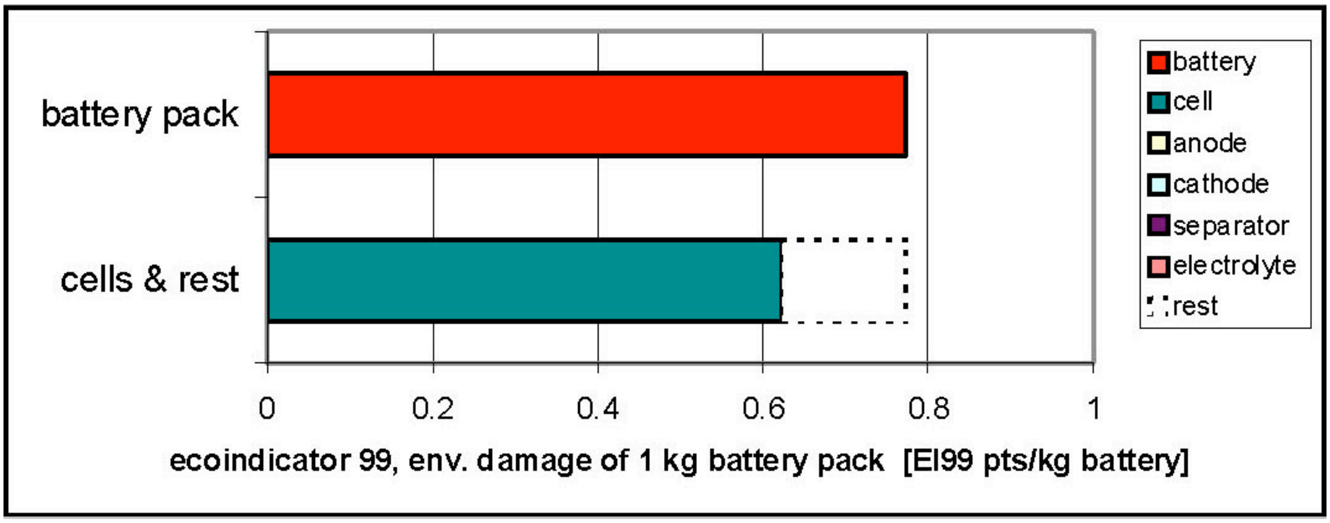


**Figure 5 - Li-ion Battery Pack Composition: 81% of impact is from cells, remainder from assembly plant, battery management system (BMS), printed circuit board (PCB), wiring, enclosure, production and transport (Gauch et al., 2009)**

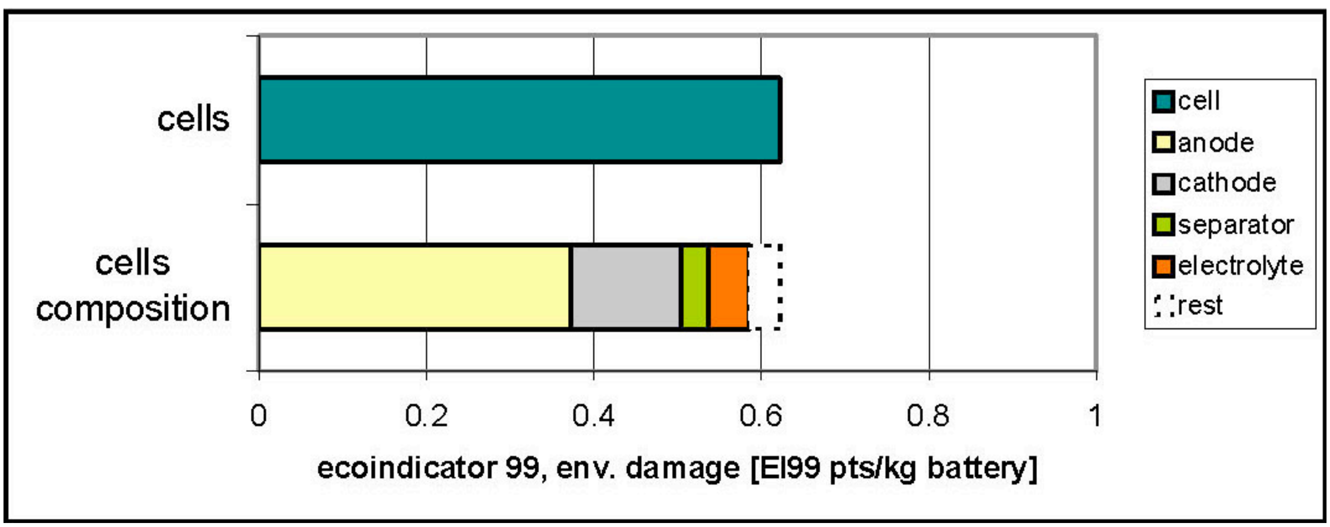


**Figure 6 - Li-ion Cell Composition: Main impact (60%) from cathode (Gauch et al., 2009)**

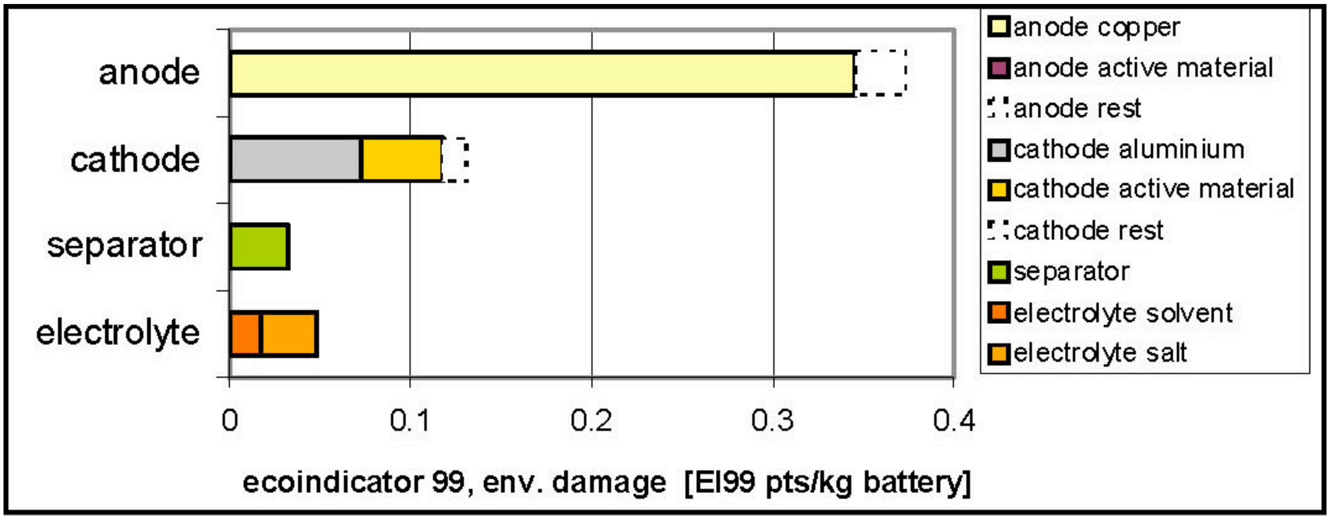


**Figure 7 - Li-ion Cell Details: Dominant Impact from Copper and Aluminum, secondary impact from lithium compound (LiMn2O4) and from electrolyte salt (Gauch et al., 2009)**

**Figure 8 - Nissan Leaf Battery Pack**

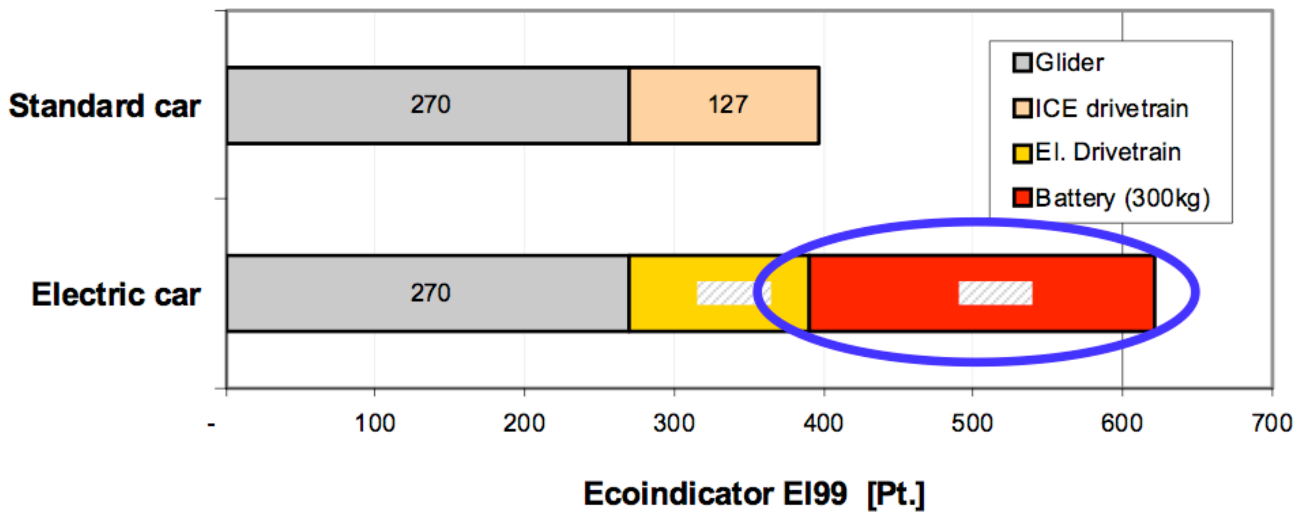


**Figure 9 - Manufacturing Impact Comparison (Gauch et al., 2009)**

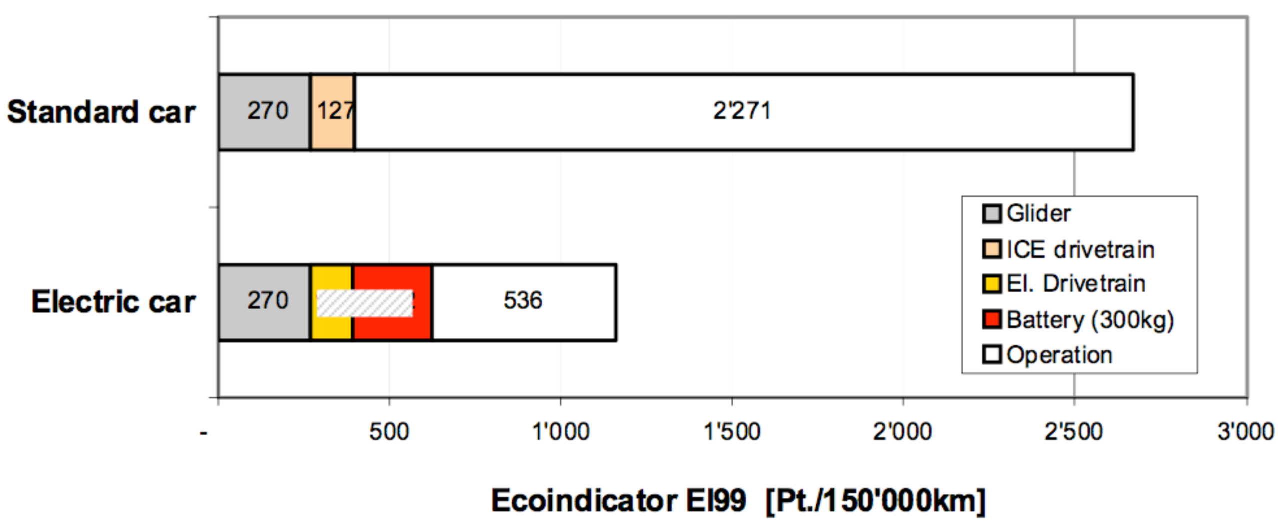


**Figure 10. Lifecycle Impact Comparison (Gauch et al., 2009)**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total Beauty | | | | | | | | | |
| | Li-Mn Laminated Batt | | | | | | | | | 4 packs = |
| | | | | | | | | | | 1.0kg pack |
| | Component | Material | Mfg Process | Cyclic | Solar | Safe | Efficien | Social | W | Ugly Points |
| 1 | cathode (pos) | Lithium Manganese Oxide ($LiMnO_2$) | A manufacturing method of spinel type manganese oxide for a lithium ion secondary cell, includes pre-firing a mixture of lithium salt including lithium carbonate, manganese oxide, and heterogeneous metal, firing the mixture at 900 to 1200° C. to form a raw material, adding in the raw material at least one of crystal growth accelerators selected from the group consisting of lithium hydroxide, lithium sulfide and a mixture thereof, and firing the resulting compound at 750 to 850° C. to form an excess lithium heterogeneous metal-doped spinel compound having a BET specific surface area of 0.5 m2/g or less. | 30 | 10 | 30 | 60 | 60 | 0.240 | |
| | | | natural manganese dioxide ore is mined then reduced with oil or coal to manganese oxide. | 0 | 0 | 0 | 0 | | | |
| | | | Lithium carbonate ore is refined from salines/brine | 0 | 0 | 0 | 0 | | | |
| 2 | cathode collector foil | Aluminum (Al) | The aluminium oxide (a white powder) is obtained by refining bauxite. Aluminium oxide has a melting point of about 2,000 °C (3,632 °F). Therefore, it must be extracted by electrolysis. In this process, the aluminium oxide is dissolved in molten cryolite and then reduced to the pure metal. The operational temperature of the reduction cells is around 950 to 980 °C (1,796 °F). | 25 | 10 | 15 | 50 | 40 | 0.143 | |
| 3 | anode (neg) | Graphite (C) | Made from petroleum coke after it is mixed with petroleum pitch, extruded and shaped, then baked to sinter it, and then graphitized by heating it above the temperature (3000°C) that converts carbon to graphite. | 30 | 10 | 30 | 70 | 60 | 0.162 | |
| 4 | anode collector foil | Copper (Cu) | Currently, the most common source of copper ore is the mineral chalcopyrite ($CuFeS_2$), which accounts for about 50% of copper production. The minerals are leached then smelted at 1200 °C, reduced and refined for copper concetrate. | 25 | 10 | 5 | 50 | 40 | 0.124 | |
| 5 | electrolyte | Ethelene carbonate-solvent ($C_3H_4O_3$) | An improved process for making ethylene carbonate wherein ethylene oxide and carbon dioxide are passed over an anion exchange resin catalyst and wherein the ethylene oxide and carbon dioxide reactants are absorbed from the effluent of an ethylene oxide reactor, desorbed and used as feed to the ethylene carbonate plant without further purification. | 5 | 21 | 30 | 50 | 60 | 0.171 | |
| | | | In manufacturing ethylene oxide by catalytic vapor phase oxidation of ethylene, a process comprising adding, as liquid, an organic halide as a reaction inhibitor into the ethylene raw material gas flow is provided. According to this process, ethylene oxide can be manufactured stably and in high selectivity. | 0 | 0 | 0 | 0 | | | |
| | | | Ethylene is produced in the petrochemical industry by steam cracking. In this process, gaseous or light liquid hydrocarbons are heated to 750–950 °C, inducing numerous free radical reactions followed by immediate quench to freeze the reactions. This process converts large hydrocarbons into smaller ones and introduces unsaturation. Ethylene is separated from the resulting complex mixture by repeated compression and distillation. | 0 | 0 | 0 | 0 | | | |
| | Alt solvent | Diethyl carbonate-solvent ($C_5H_{10}O_3$) | Also, it is now prepared from catalytic oxidative carbonylation of methanol with carbon monoxide and oxygen, instead of from phosgene making its production non-toxic and environmentally friendly | 0 | 0 | 0 | 0 | | | |
| 6 | | Lithium Hexaflurophasph salt ($LiPF_6$) | In order to provide a method for producing lithium hexafluorophosphate of a higher purity than in the related art without the necessity for after-treatment for removal of impurities, a method is characterized by filtering lithium hexafluorophosphate coexisting with a solvent and then carrying out after-filtering drying in a gas atmosphere containing $PF_5$. | 30 | 21 | 5 | 50 | 60 | 0.019 | |
| 7 | seperater film | Polyethelene (PE) | Polyethylene is made from ethane, which is found in natural gas. Natural gas is found deep under the surface of the earth, usually in pockets of crud oil. Before the process of making polyethylene can begin, the oil must be pumped up to the surface, and the natural gas must be separated from the oil. Ethane is converted into ethylene and then finally into polyethylene polymer. | 30 | 21 | 40 | 70 | 60 | 0.051 | |
| 8 | packing | polyethelene and aluminum envelope (PE, Al) | see mfg process above | 27 | 15 | 27 | 60 | 50 | 0.070 | |
| 9 | electrode tabs | Aluminum (Al) | see mfg process above | 25 | 10 | 15 | 50 | 40 | 0.015 | |
| | electrolyte production | | | 0 | 0 | 0 | 0 | 0 | | |
| | battery production | | | 0 | 0 | 0 | 0 | 0 | | |
| | | | | 25.2 | 14.2 | 21.9 | 56.7 | 52.2 | 1.0 | -50.0 |

**Figure 11. Lithium ion battery Total Beauty fabrication data**