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# New 3-in-1 Approach to Higher Energy Density for EV Batteries

Fabrice Giaume[1], Bryan Morris[2]

*[1]Celanese Engineered Materials, Meyrin, Switzerland,* fabrice.giaume@celanese.com
*[2]Celanese Engineered Materials, Meyrin, Switzerland,* bryan.morris@celanese.com

## Executive Summary

Electric vehicles (EVs) are becoming more ubiquitous every year. Demand is strong, but manufacturing vehicles that meet consumer expectations for longer driving range, faster charging, and more interior space has proven challenging and expensive. Efficient EV battery manufacturing and thoughtful next-generation designs are critical to meeting demand. OEMs and battery manufacturers want to streamline their designs while increasing the volumetric energy density of their batteries.

Celanese Engineered Materials has developed intellectual property on a 3-in-1 approach that offers higher battery pack energy density, a differentiated cooling system, a reduced number of components/manufacturing complexity, and is a more sustainable solution overall. The 3-in-1 concept consists of a semi-direct cooling system, integrated electrical interconnection plates, and a structural thermoplastic frame.

*Keywords: Energy Density, Electric Vehicle, Thermal Management, Battery, Materials*

## 1 EV Battery Challenges and Limitations

OEMs face challenges to satisfy multiple consumer expectations: longer driving range, more passenger space within the vehicle, and more efficient charging. To address these challenges, several key objectives for next-generation EV battery development are highlighted – increase the battery pack volumetric energy density, streamline design/component integration, ease manufacturing, and add elements of sustainability.

Volumetric energy density is the amount of charged energy a battery cell can hold within a set volume. Lower energy density equates to shorter battery range and/or the need for a larger battery, ultimately decreasing passenger space within a vehicle. Collaborating with several automotive OEMs, the Celanese team took the challenge to improve the packaging efficiency of battery packs, by designing a much more integrated concept than benchmark solutions. As a result, the energy density cell-to-pack (CTP) ratio rises from an average of 31.5% in existing pack designs to a much higher level (see Table 1).

### 1.1 Expense

Electric vehicles are more expensive to manufacture than comparable gasoline-powered ones, which presents another challenge to overcome. In addition to the higher costs of the metals needed for their batteries and connectivity, existing EV battery designs are complex and not well integrated, therefore more expensive to produce. An easily expandable, modular pack with fewer components and production steps would reduce manufacturing costs overall.

### 1.2 Charging and Range

Additional challenges addressed with our design strategy include the longer charging times and cold weather range reduction noted in existing packs on the market today. An efficient thermal management system of the EV battery pack is necessary to keep the battery at an ideal temperature range. Rather than use bottom plate direct cooling, the Celanese designers chose tab cooling for its streamlined efficacy.

### 1.3 Recyclability

Extracting cells from EV batteries so that they can be recycled is technically feasible, but often complicated and expensive for a number of reasons. It requires specific tools, knowledge, and safety precautions. In addition, EV batteries are made to be incredibly strong and long-lasting. Casings are often designed to be hard to open, and the cells may be packed closely together, making it tough to remove them without incurring damage.

## 2 New 3-in-1 Concept

Our innovative 3-in-1 approach to EV battery design is first introduced based on pouch cells and integrates multiple functions into one component for increased energy density, better range, and better component integration. Functions combine (a) cell cooling via tabs, (b) electrical interconnection, and (c) improved structural components into one easy-to-expand, modular design (Fig. 1). As demonstrated in Table 1, these three elements work together to achieve a **59% cell-to-pack (CTP) ratio as compared to the average 31.5%** achieved in existing battery pack modules on the market today. CTP ratios of up to 65% have been reached with optimized designs.

Figure 1a. Rendering of a battery created from multiple 3-in-1 Concept modules using pouch cells, viewed with no cover plate.

How does it work? The battery temperature is efficiently regulated by extracting heat through the cell tabs via direct cooling of the electrical interconnection plates. The interconnection plates are housed in a structural thermoplastic frame placed between cell stacks. The frame, made of Zytel® HTN PPA (polythal amide), offers lightweighting benefits by replacing metal, improving ease of design and modularity, and optimizing cooling technology – all in one element.

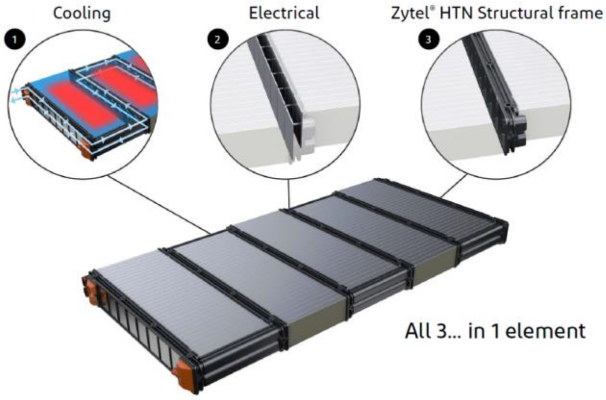


Figure 1b: New 3-in-1 concept for EV battery cell design incorporates three elements – cooling, electrical interconnection, and a structural frame – into one module.

## 2.1 Tab Cooling Results

The idea behind the tab cooling approach arose from testing performed for Celanese at the Battery Innovation Center (Indianapolis, IN, USA) that included both module and cell thermography. These tests proved the hottest spots in a representative pouch-cell battery pack are at the tabs (note orange areas in Figure 2a).

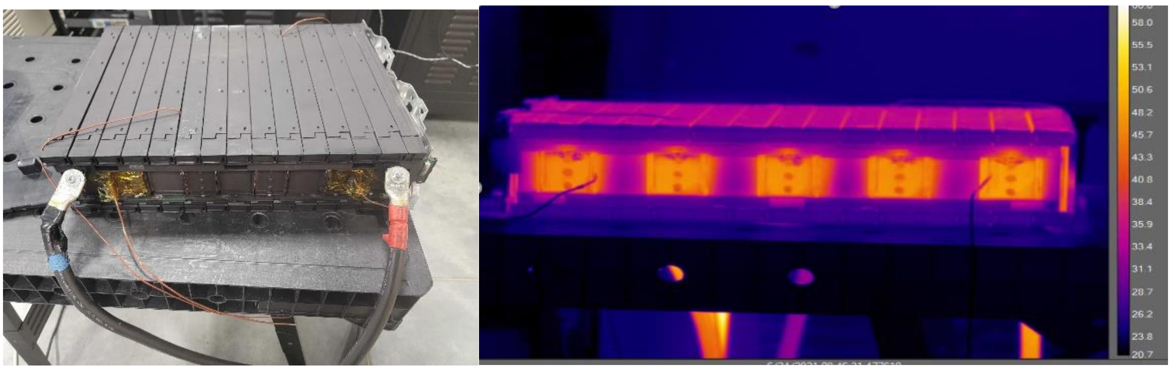

Figure 2a: Tab cooling test setup (left) and thermography results (right).

In addition to thermography testing, tab cooling performance has been investigated by the Imperial College of London, and its study concluded that tab cooling extends the lifetime of pouch cells.

While this same study proposed that tab cooling was a less-than-optimal solution for cooling compared to bottom cooling without any cell modification, it has been simulated and demonstrated that changing the tab section and the current collector thickness can lead to similar or better cooling performance compared with surface cooling.

Celanese engineers at the company's Advanced Mobility Center Of Excellence, in collaboration with the thermal management simulation department of the CEA institute in France, have conducted a full numerical study targeting a similar cooling behavior with tab-cooled cells vs. bottom-cooled cells. Bottom cooling is the reference today for pouch cells and is seen in the latest vehicles achieving the fastest charging rates on the market, such as the Porsche Taycan or the Hyundai E-GMP vehicles.

Graphs presented in Figure 3a represent the temperature rise of a reference case for a bottom-cooled cell with a full charge at a 2C constant rate. The cell is a pouch format of 350mm in length, 10mm in thickness, and 100mm in height.
The boundary conditions are a start of charge at 25°C, with no convection possible on all faces of the cell except where the tabs are located, and a thermal management system ensuring a constant temperature

performance of 25°C across the charging cycle. As can be seen, the average bulk cell temperature represented by the yellow dotted line at the end of charging is 45.6 °C with a delta T between the bottom and top of the cell of 18°C.
The blue and red lines represent the increase of temperature of the end tabs. The joule effect is slightly higher in the tab area, so temperatures there are higher than the cell average.

The graph presented in Figure 3b represents a similar temperature rise but in this case on a tab-cooled cell. The temperature gradient then goes from side to center, rather than bottom to top. With suitable cell modifications including wider and thicker tabs, the average bulk temperature of the cell represented by the solid yellow line rises to 46.6°C and the delta T between the tabs and the center reaches 19°C.
The blue and red lines represent the increase in temperature of the end tabs. As the cooling comes directly from the tabs, the temperature increase at this location is almost imperceptible.

As effects such as lower internal resistance due to temperature delta are not accounted for in the simulation, it goes in the direction of lower cell temperature in use vs. simulation.

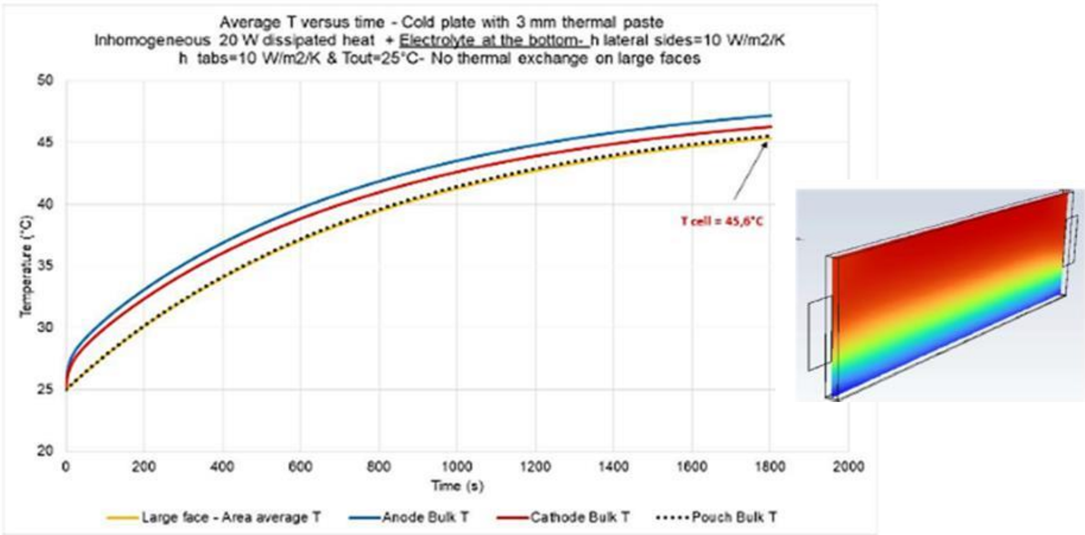


Figure 3a: Average cell temperature using bottom cooling and temperature distribution.

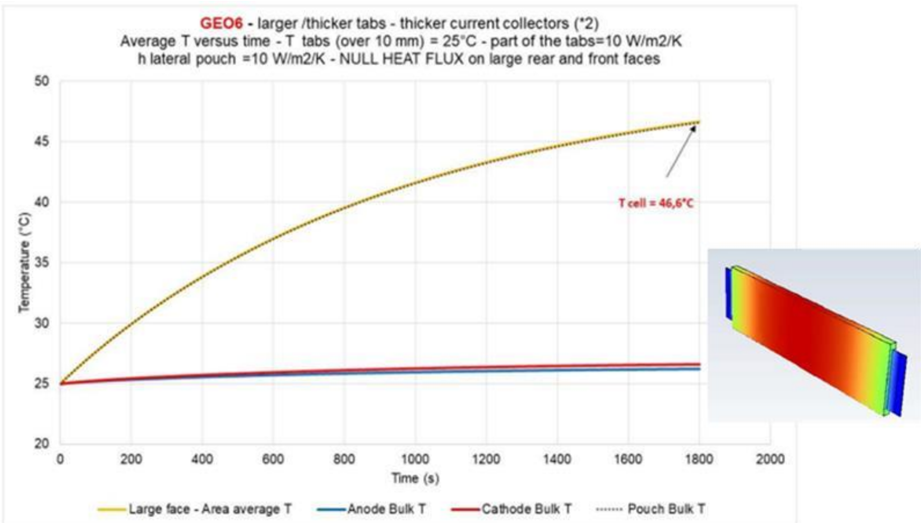


Figure 3b: Average cell temperature using tab cooling and temperature distribution.

# 3 Benefits

There are a multitude of benefits to the 3-in-1 EV battery concept including increased energy density, optimized cooling, an integrated and modular design, and a reduction in manufacturing complexity, and thus costs, all of which combine for a more sustainable solution.

First, increasing the battery's energy density through smarter design choices allows for greater vehicle range and a more compact battery, thus equating to more passenger room and a lighter-weight vehicle. As compared to the energy densities of four other platforms in Table 1, the 3-in-1 approach is a runaway winner.

Table 1: Energy densities of four existing battery pack designs compared to 3-in-1 concept

| | 64kWh | 78kWh | 100kWh | 62kWh | 3-in-1 concept 61.5kWh |
|---|---|---|---|---|---|
| Specific energy (Wh/kg) | 147 Wh/kg (60% CPT* ratio) | 169 Wh/kg (67% CTP) | 156 Wh/kg (58% CTP) | 167 Wh/kg (62% CTP) | 190 Wh/kg (74% CTP ratio) |
| Energy density (Wh/L) | 167 Wh/L (27% CTP ratio) | 224 Wh/L (32% CTP) | 212 Wh/L (31% CTP) | 249 Wh/L (36% CTP) | 370 Wh/L (59% CTP ratio) |

Data from: A2Mac1

* CTP: Cell-to-Pack

Second, our differentiated cooling system makes use of heat scavenging to enable more uniform temperatures across cells at the pack level, reducing the cell-to-cell temperature delta to less than 1°C. A visual of this scavenging principle can be seen on Figure 4.

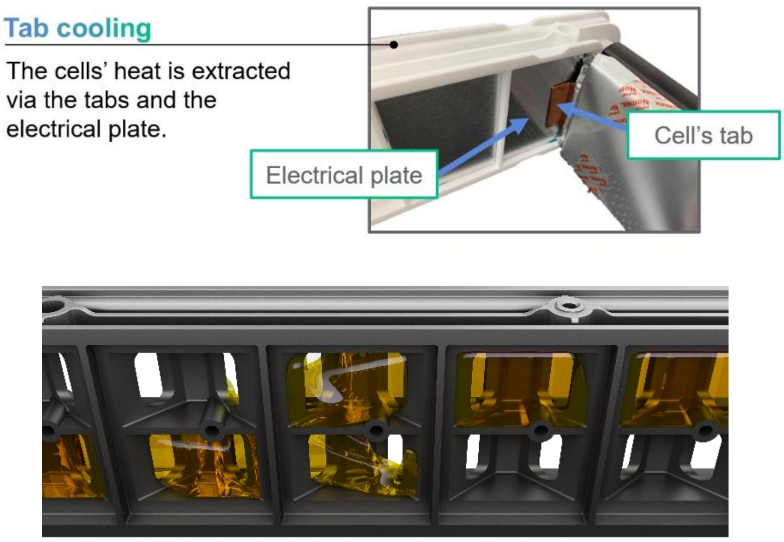


Figure 4: Closeup of the electrical interconnection plate and tab interface, where coolant is directed to reduce overall battery temperature (top), and a rendering of the bi-directional coolant flow behind the electrical plate that takes place within the structural Zytel® HTN frame (bottom).

The consolidated design with fewer components also reduces manufacturing complexity, offering scalability and configuration freedom. Additionally, the multi-functional Zytel® HTN frame with integrated cooling channels and electrical connections supports sustainability goals by replacing metal and reducing the pack's overall weight.

By removing module housings, cooling plates, gap fillers, and bus bars commonly used in existing modules, **the 3-in-1 concept shows a 49% reduction in part weight.** The use of lower Global Warming Potential (GWP) materials together with the unique design - making end-of-life cell extraction easier - produce a win-win for sustainability.

### 3.1 Performance Summary

In comparisons and evaluations, the 3-in-1 approach to higher energy density for EV batteries has displayed the ability to improve and optimize the following:

- Pack energy density
    - Specific energy (Wh/kg) - Up to 200 Wh/kg (~75% CTP ratio)
    - Energy density (Wh/L) - Up to 400 Wh/L (~65% CTP ratio)
- Cooling performance
    - Differentiated performance with scavenging and tab cooling
- Manufacturability
    - Up to 30% fewer components
    - Fewer production steps vs. reference modules/packs
    - Compatible with cell-to-chassis
- Sustainability
    - Low GWP materials
    - Easy end-of-life cell extraction

## 4 Sustainability and Future Considerations

EVs are considered by consumers and governments to be a more sustainable choice than gas-powered internal combustion engines, especially if the electricity used to charge the vehicles is generated from renewable solar and wind sources. However, repairability and end-of-life issues for EV batteries currently create a challenge for sustainability.

Repairability refers to consumers being able to take an EV to the dealer or a garage and affordably "revive" the battery to extend the life of the vehicle. At present, the only solution is to remove and replace battery modules, or often the entire battery pack. However, the battery pack is the most expensive component in the vehicle, and its high cost prohibits EV owners from this more sustainable practice of keeping their vehicles in service longer.

Instead, it would be much more affordable for the consumer if the dealer or local car repair provider could restore full functionality of the battery pack, handle this locally and swiftly, and shore up the entire battery's energy output. We are evaluating the capability of our 3-in-1 approach to solving this challenge, and are encouraged by early results.

End-of-life issues are another component in the sustainability picture. Numerous sources cite the ability of "retired" EV batteries to be recycled and reused in stationary energy storage or lower voltage battery applications, but the reality is that the cells are difficult to extract from current battery designs.

Our CTP 3-in-1 concept enables a technician to cut the tab ends and extract still-viable pouch cells that are not adhesively bonded. These can then be repurposed in other applications. It is a unique solution for the CTP approach used by several pouch-cell battery builders. For cylindrical cells, there are current designs in which you can replace the packs in a cell-to-body design, but these are merely replaceable as a whole, not repairable.

One final consideration regarding more sustainable EV batteries is that research is now trending toward solid-state battery cells as a solution to increasing energy density. This, of course, would increase range further and improve safety. We are investigating this trend, and find the 3-in-1 modular approach perfectly suited to accommodate any future types of cells chemistry.

# 5 Further Investigations

The topics for future study below are currently being investigated by Celanese and include:

- Examination and comparison of the 3-in-1 concept based on pouch cells versus other types of battery cells (e.g. prismatic, cylindrical, etc.)
- Investigations into solid-state battery (future trend in EV battery design) compatibility for this approach
- Further study and reinforcement for differentiated results of tab cell cooling versus bottom plate cooling
- Ongoing projects with multiple OEMs on initial projects

# Glossary

*CTP:* Cell-To-Pack

*EV:* Electric Vehicle

*GWP:* Global Warming Potential

*OEM:* Original Equipment Manufacturer

# Acknowledgments

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- A2MAC1, for providing reputable benchmarking data

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## Presenter Biography

Fabrice Giaume is a graduate of the Ecole Supérieure des Techniques Aéronautiques et de Construction Automobile, where he earned a Master of Transportation Engineering (M.Eng.) degree in 2008. After interning with Valeo and Nissan-Renault, he joined DuPont Mobility & Materials and rose in the organization to the role of global leader of the company's Automotive Centers of Excellence. Since the November 1, 2022 acquisition of the Mobility & Materials business by Celanese, Fabrice retains this role. He is based in Geneva, Switzerland.