Avery Dennison
Performance Tapes
White paper

North America

A three-part, PSA-tape-based strategy for thermal runaway prevention and mitigation in battery packs

An Avery Dennison white paper

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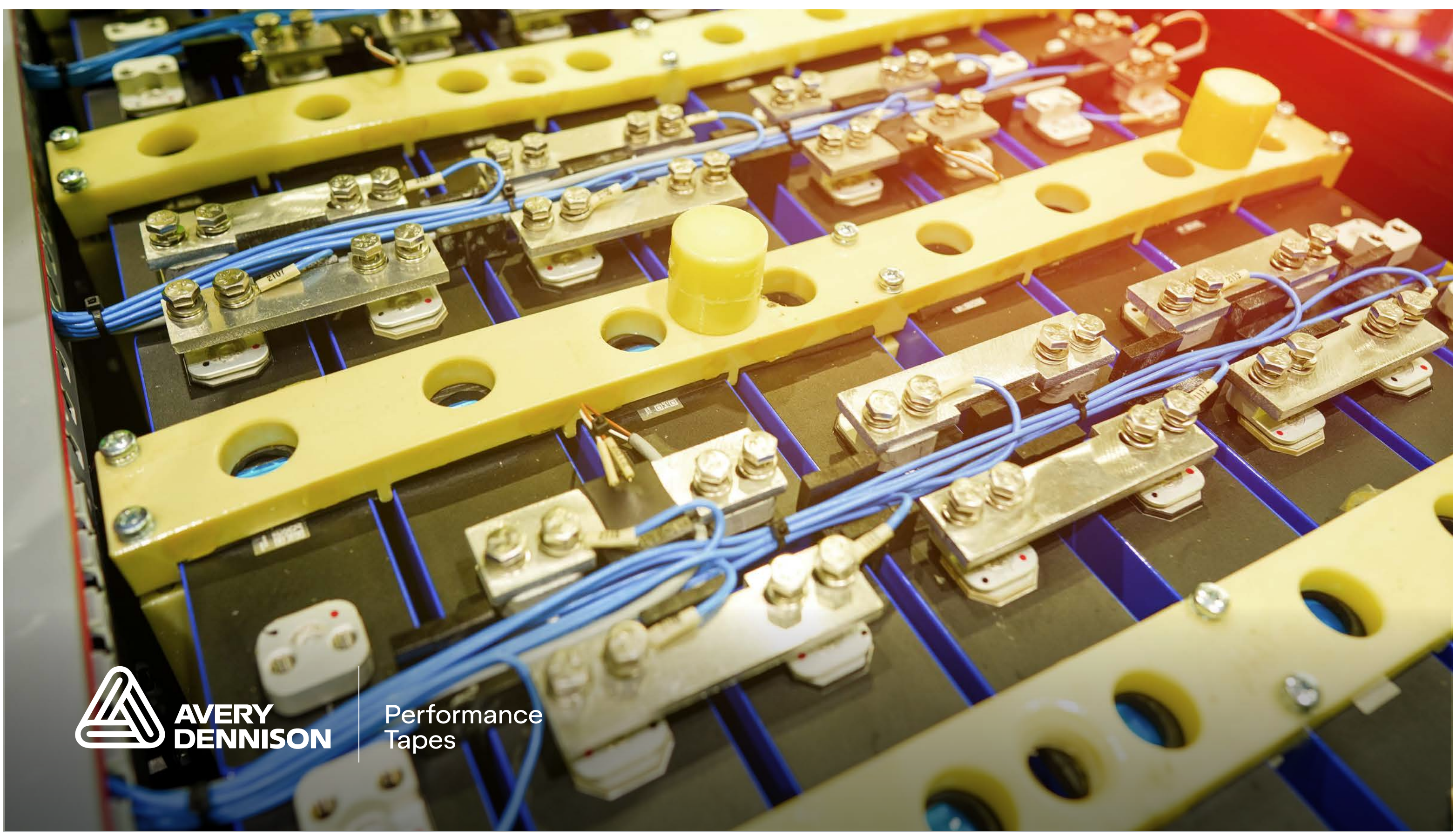
Executive summary

This white paper explores battery pack thermal runaway prevention and mitigation solutions featuring pressure-sensitive adhesive (PSA) tapes. These tapes are often paired with functional materials such as mica, aerogels, ceramic papers or dielectric films as part of a multifaceted approach to thermal management in e-mobility and battery energy storage systems (BESS) applications.



Specifically, the paper explains:

- Why PSA tapes have many advantages as a material solution in battery packs
- Crucial challenges for thermal runaway prevention and mitigation in batteries:
  - Heat transfer from high-temperature cells to pack cooling systems
  - Thermal insulation of cells to prevent widespread thermal runaway
  - Management of vented gas and material ejected by compromised cells during thermal events
- A three-part strategy, incorporating PSA-tape-based solutions, that addresses these challenges

The paper will also briefly outline the capabilities offered by Avery Dennison, a leading global manufacturer of PSA tape solutions for e-mobility and BESS.

Introduction

The transition toward electrification across many industries has boosted the need for high-performance batteries. That, in turn, has accelerated the need for reliable and cost-effective thermal management solutions. This is especially true as batteries' increasing overall power, energy density and fast-charging capabilities heighten the consequences of faults such as thermal runaway.

Finding and implementing these solutions can seem challenging. Dense and complex battery packs offer minimal space for added materials. Industries' desire to trim weight means materials must be light. And the need to maximize profitability means materials must be easy to integrate into new and existing battery designs, with minimal CAPEX.

What's needed is a thermal runaway prevention and mitigation strategy built on material solutions that are effective, thin and lightweight. These solutions should also be relatively easy to integrate into existing battery designs and production processes.

Durable and versatile PSA tapes, such as those manufactured by Avery Dennison Performance Tapes, can be the material at the core of such a strategy.

A primer on PSA tapes

PSA tapes are a mature and diverse technology with a long track record of success in numerous industries. They've become an increasingly chosen bonding mechanism thanks to their many advantages: Tapes are versatile, durable, light, thin, easy to use (no cure time), and can be applied by either manual or automated processes.

The foundation of a PSA tape is the adhesive itself. These are available in numerous formulations, with each offering unique profiles for strength and long-term durability. Adhesives can also be designed to offer properties such as flame retardance, resistance to moisture and chemicals, and low VOC emissions.

PSA tapes are commonly laminated to additional materials to create multifunctional constructions. For example, a tape can be laminated to a mica sheet to create a flame barrier. Or a tape can be laminated to a dielectric film to create an electrical insulator. Additionally, tapes can be converted — stamped and die-cut — to align with unique design requirements.

This, in fact, is a key advantage of PSA tapes. Reliable bonding is just the beginning. Tapes can serve multiple purposes, be customized in countless ways, and easily scaled. In short, tapes provide multiple benefits in a single product.

PSA tapes in battery packs

It follows that engineers have devised numerous applications for PSA tapes in modern battery packs, including the following:

- Cell connection systems
- Cell wrapping
- Cell venting
- Compression padding
- Electrical insulation
- Gasketing
- General bonding, sealing and wire management
- Thermal interface materials
- Thermal runaway protection/mitigation

It's the thermal applications that the remainder of this paper will focus on.

Key thermal management challenges in batteries

First, let's discuss some of the key thermal management challenges in batteries. While not a comprehensive list of what keeps engineers awake at night, this trifecta of challenges is closely related to battery effectiveness, durability and safety.

Challenge: Promoting heat flow from cells to cooling components while providing dielectric strength

Maintaining battery pack performance and safety requires removing heat generated by battery cells as efficiently as possible. Heat needs a low-resistance pathway of thermal interface materials to travel from the cells to cooling plates, cold plates or liquid cooling systems. These materials must also electrically isolate high-voltage cells and components to prevent electrical arcing and fire.

Heat transfer across a conductive dielectric interface is governed by Fourier's Law of Heat Conduction:

$Q = k * A * \Delta T/X$

Where:

- Q is the conductive heat transfer rate (W)
- K is the bulk thermal conductivity of the dielectric material (W/[m*k])
- A is the active thermal contact area (m^2)
- ΔT is the temperature differential across the dielectric insulation layer
- X is the thickness of the dielectric interface material (m)

Equivalently, the conductive thermal resistance (R_{th}) across the dielectric layer is expressed as:

$R_{th} = X/k*A$

R_{th} is directly proportional to X. So minimizing X directly reduces R_{th}. This, in turn, maximizes Q for any given ΔT.

Balancing K with strong dielectric performance is a significant materials engineering challenge, as properties that improve Q often conflict with those needed for electrical insulation. Engineers need advanced thermal management materials that optimize both characteristics without sacrificing manufacturability or durability.

Challenge: Isolating cells during thermal runaway events in confined spaces

A thermal event in a compromised cell can move quickly to adjacent cells if heat is not effectively contained. Because modern battery packs are designed to maximize energy density, cells are packed into increasingly confined spaces with minimal room for physical barriers or air gaps. This makes it difficult to isolate a compromised cell.

Engineers need thin, lightweight materials and designs that can create effective thermal barriers. These barriers must effectively slow or prevent heat transfer from a compromised cell to its neighbors long enough for safety systems to respond, minimizing the likelihood of widespread thermal runaway.

These solutions often include mica and other materials. However, such frangible materials can be challenging to integrate into high-speed, automated robotic assembly.

Challenge: Allowing flames, particulates and gas to vent without affecting uncompromised cells

When a thermal event occurs in a cell, internal pressure rises until intensely hot gases, flames, and particulate matter are vented. If these gases and materials are not effectively managed, they can ignite nearby materials, damage uncompromised cells and create excessive pressure within the battery pack.

Engineers need to design cell vents and pathways to manage this process carefully. But they also need flame-resistant barriers and protective materials that allow controlled pressure relief while reducing the likelihood that a single cell failure escalates into a pack-level safety event.

A three-part strategy for thermal runaway prevention and mitigation

Battery pack thermal management is a highly complex engineering challenge. No single material can address every concern.

Instead, engineers need a multifaceted strategy that relies on combinations of specialized materials. These materials must work together to improve heat transfer, electrically isolate components, contain thermal runaway events, and manage the gases and flames released during cell failures.

PSA tape technologies from Avery Dennison can play an important role in each of these areas. They enable multifunctional material constructions that are thin, lightweight, scalable and compatible with high-volume automated manufacturing.

Here are three key elements of a thermal runaway prevention and mitigation strategy using PSA tapes.

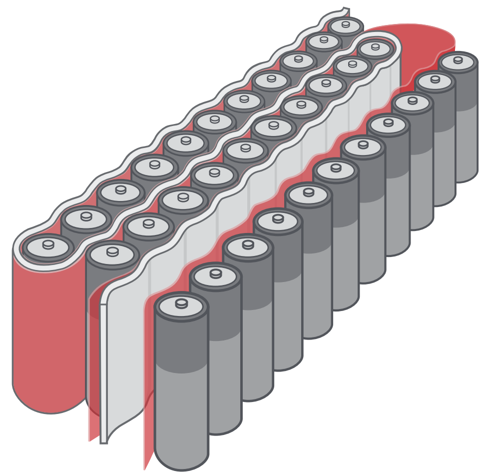
1. Improve heat transfer while maintaining electrical isolation

One of the primary objectives of battery thermal management is efficiently moving heat away from cells while preventing electrical faults between high-voltage components. This requires materials that are thermally conductive and electrically insulating — a challenging combination of properties.

The Avery Dennison Volt Tough™ line of PSA tapes offers this combination. Volt Tough features a dielectric film carrier and acrylic adhesive that can be used for bonding between cells, modules and components such as cooling plates, cooling fins, cooling ribbons, heater films and heat spreaders.

And because these tapes are significantly thinner than traditional powder-coated dielectric insulating layers, they reduce thermal resistance. This allows heat to flow more efficiently from the cell to the cooling component. The result is improved thermal performance that won't compromise dielectric strength or require additional assembly steps.

These tapes are also designed for scalability and efficient manufacture. Conformable versions of Volt Tough dielectric tape stretch easily around corners and edges, while stampable versions can be applied to metal blanks before stamping to accommodate automated workflows.



Avery Dennison Volt Tough tapes can be applied to metal blanks before stamping, helping accommodate efficiency and automation

A thermal resistance quantitative comparison: 85 μm PSA tape vs. 250 μm powder coating

Thermosetting dielectric powder coatings (primarily epoxy or polyurethane formulations) are frequently applied to aluminum cooling plates, cooling fins, and busbars. This process requires controlled electrostatic spraying followed by thermal curing in high-temperature ovens. A nominal dry film thickness of 250 μm is common to guarantee pinhole-free dielectric coverage across complex metal geometries.

Dielectric PSA tapes with PET or PI films combined with high-performance acrylic or silicone adhesives achieve equivalent or superior breakdown voltage at a total thickness of only 85μm.

Assuming comparable bulk thermal conductivities (k ≈ 0.20-0.25 W/M*K) for the powder coating and the PSA tape, the relative ratio of conductive thermal resistance is determined strictly by their thickness ratio:

$$\frac{R_{th,\text{coating}}}{R_{th,\text{tape}}} = \frac{X_{\text{coating}}}{X_{\text{tape}}} = \frac{250\mu\text{m}}{85\mu\text{m}} \approx 2.94$$

The 85 μm PSA tape thus delivers a ~66% reduction in conductive thermal resistance compared to the 250 μm powder coating layer. This physical path reduction enables heat to transfer nearly three times faster from the cell casing to the cooling fluid under identical thermal gradients, suppressing maximum internal cell temperatures during high-current fast charging protocols.

2. Create barriers that mitigate the effect of thermal runaway

Slowing the transfer of heat from a compromised cell to neighboring cells can provide valuable time for safety systems to respond and reduce the likelihood of widespread thermal runaway.

Low-thermal-conductivity PSA tapes from Avery Dennison can laminate and encapsulate highly insulative materials such as mica, aerogels, ceramic papers and other thermal barriers. This turns them into robust and easy-to-handle constructions. By combining multiple materials into a single laminated assembly, battery manufacturers can achieve a balance of thermal insulation and mechanical strength that would be difficult to accomplish with individual materials.

High-temperature adhesive formulations capable of withstanding temperatures approaching 500°C for short durations of time further enhance their effectiveness in helping isolate thermal runaway events. Tapes must maintain mechanical position and avoid complete combustion, severe off-gassing, or loss of adhesion before safety venting systems engage.

These PSA tape constructions can be converted to fit at all levels of the battery pack:

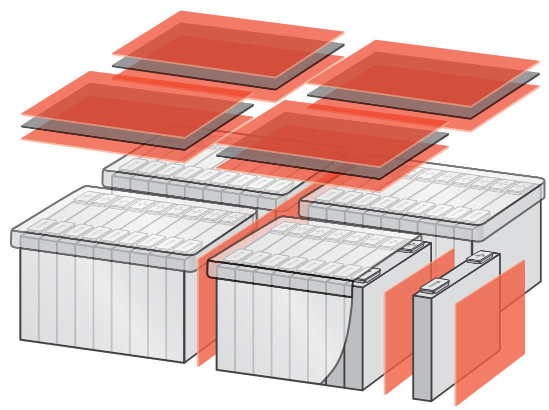
- Between cells to prevent or drastically slow cell-to-cell thermal propagation. Tapes can encapsulate materials, be an assembly aid and provide dielectric strength.
- At the module level to bond and encapsulate thermal protection materials. Tapes' viscoelastic behavior helps manage vibration.
- At the pack level, typically on the lid

These laminated constructions are also well suited to high-volume automated manufacturing, making them very scalable.

In high-speed, automated assembly, the force required to peel a protective liner from a PSA tape can easily exceed the internal cohesion strength of the frangible mica or ceramic paper. This can cause interlaminar tearing, substrate delamination and high scrap rates.

Avery Dennison offers specialized liner release formulations and patterns that enable reliable automation. Liners can even be engineered to release from fragile materials such as mica without causing damage.

To achieve this, advanced PSA tape systems utilize inline-coated differential release liner systems. Adhesive formulations are categorized as low release force (<20gf/50mm).

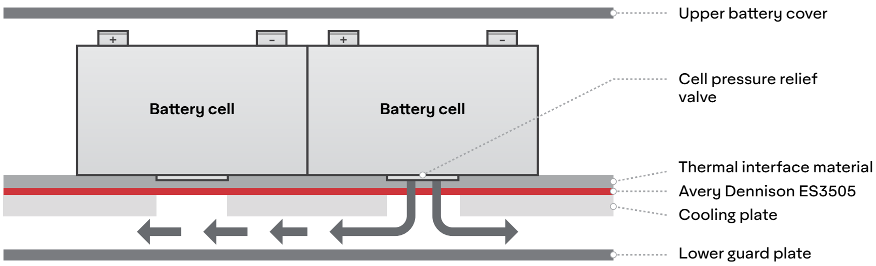


Low-thermal-conductivity PSA tape constructions can be applied at the pack, module and cell level

3. Manage vented gases and flames during cell failures

Anisotropic venting tapes are designed to seal strategically placed holes in venting channels. These tapes have a unique flame-retardant coating, giving each side a different burst property when exposed to flame. If a thermal event occurs, the tape bursts to allow gases and flames to escape into the venting channel adjacent to the affected cell. At the same time, the tape prevents those gases and flames from escaping the channel to affect nearby cells.

It's an elegant solution that's thin and lightweight, cost-effective, easily scalable and designed to help manufacturers meet production targets.



Anisotropic tapes allow venting from a compromised cell while protecting other cells from vented materials and gases

Avery Dennison offers specialized PSA tape technologies that help manage the venting of flames, gas and materials during thermal events. ES 3505 is for sealing continuous, large surface areas. During a cell failure, the tape is engineered to burn through locally but remain adhered to seal other areas. ES 3507 is a rubber-ceramic hybrid construction. This tape is typically die-cut for individual venting ports, and is engineered to burst as a result of the pressure emerging from the cell.

Either solution allows a compromised cell to relieve pressure, while corresponding tapes on neighboring cell vents remain securely sealed, providing protection.

These tapes can even be used together within a single battery pack, providing complementary layers of protection that address different aspects of thermal event management.

Avery Dennison can replicate various battery failure conditions, in its ISO-9001 laboratory, to verify the ideal anisotropic tape choice for a customer.

Thermodynamic impact on nickel manganese cobalt (NMC) and lithium iron phosphate (LFP) chemistries

Implementing engineered venting strategies requires aligning an anisotropic PSA tape's performance characteristics with the distinct thermodynamic failure modes of the battery's cell chemistry.

NMC chemistry venting dynamics

NMC cathode materials exhibit lower thermal stability, triggering thermal runaway at lower temperatures. During failure, the transition-metal oxide cathode decomposes exothermically and releases elemental oxygen directly into the cell interior. This oxygen feeds combustion inside the cell, generating peak cell surface temperatures of 800–1050°C and direct flame jet temperatures exceeding 1500°C .

These events eject substantial solid particulates, including molten copper, aluminum droplets and disintegrating graphitic anode material, representing 40-50% of total cell mass. Total gas generation volume is high (1.8-2.8L/Ah), dominated by carbon monoxide (36%), carbon dioxide (24%) and hydrogen (19%).

Due to these factors, venting strategies in NMC packs must prioritize flame channeling and solid-particle deflection. Tapes such as ES 3505 facilitate rapid top-side burn-through (<4s) to divert high-velocity torching jets directly into exhaust ducts. Ceramic-rubber hybrid tapes such as ES 3507, or plate mica bonded with high temperature PSA tapes can prevent abrasive ejecta from puncturing adjacent structural dividers.

LFP chemistry venting dynamics

LFP cathode materials feature strong covalent phosphorus-oxygen bonds. These provide high thermal stability with a thermal runaway onset threshold of 270-300°C. Crucially, LFP cathodes do not release oxygen during thermal breakdown. As a result, the interior of an LFP pack remains oxygen-starved, suppressing open combustion inside the module and yielding lower peak cell surface temperatures (620-700°C).

Solid particulate ejecta in LFP events is minimal, accounting for 20-25% of total cell mass. Total normalized gas volume is also lower (~0.569L/Ah). However, the off-gas composition contains a high concentration of molecular hydrogen (~41%). This hydrogen lowers the lower flammability limit (LFL) of the gas mixture. If hydrogen-rich LFP gases accumulate within an enclosure and mix with ambient air outside the cell vent, they present a severe secondary deflagration and explosion hazard.

So it follows that venting strategies in LFP packs must focus on low-restriction pressure relief to exhaust non-combusted gases rapidly from the pack before hydrogen concentrations reach explosive limits. Because LFP events produce minimal abrasive solid ejecta, lightweight pressure-actuated die-cut burst valves (e.g., ES 3507) effectively clear gas into exhaust manifolds while maintaining intercell thermal isolation to prevent conductive thermal propagation.

Why Avery Dennison?

Avery Dennison combines an extensive portfolio of PSA tape products with support battery manufacturers can count on to develop unique thermal management solutions.

A portfolio of solutions aligned with battery manufacturers' needs

The Avery Dennison portfolio features functional bonding and protection tapes built on multiple PSA technologies. These are engineered to help solve some of the most common challenges in battery design:

Reducing flammability

Acrylic- and silicone-based adhesives with Flame Tough™ flame-retardant adhesive properties allow composites and materials to meet UL® 94 V-0 and other flame requirements.

Boosting dielectric strength

Single-coated Volt Tough™ tapes and double-coated tapes that incorporate dielectric films. Our materials and adhesives are tested for breakdown voltage and dielectric strength requirements using GB/T 1408.1-2016 and ASTM D3755 test methods.

Optimizing design and assembly

Functional tapes can replace mechanical fastening methods while offering a thinner profile, lighter weight, repositionability and instant bond.

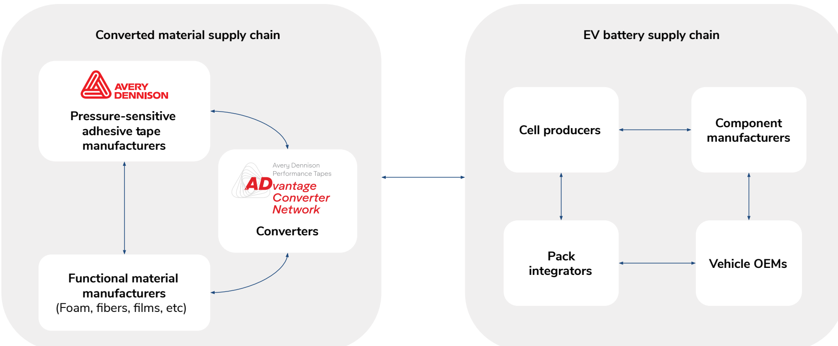
Extensive support beyond the portfolio

Avery Dennison offers extensive support beyond its product portfolio. This includes providing access to testing and collaboration with subject matter experts to develop unique, PSA-tape-based solutions for battery applications.

Collaboration	Testing capabilities
New product development for creating custom solutions for specific applications	Flame performance testing at the tape and composite level
Business development and specification support for emerging applications	Dielectric strength testing at the tape and composite level
Application engineering and technical support	Traditional bulk property testing (peel, tack and shear) Environmental conditioning (temperature, humidity, UV, chemical and more)

A network of trusted converters and material manufacturers

Avery Dennison works with a network of converters and functional material manufacturers, many with deep expertise in the battery industry. These trusted collaborators play a lead role in providing unique, effective and scalable solutions.



Avery Dennison works with a complex chain of suppliers to help battery manufacturers develop unique solutions

Global reach, local presence

Avery Dennison is a U.S.-based manufacturer that engineers PSA tapes for a wide range of industries. Our global reach is augmented by local presence in all of the regions where we do business, including access to both domestic and global supply chains.

Summary and next steps

Thermal runaway prevention and mitigation is a critical engineering challenge for battery manufacturers. And it's a challenge with no single, simple solution. Instead, manufacturers need to develop multifaceted thermal management strategies that address all of the following:

- Transference of heat from cells to cooling components
- Thermal insulation of cells and other pack components
- Management of vented materials and gases

PSA tapes — such as those from Avery Dennison — combined with functional materials should be at the foundation of such a strategy.

We welcome the opportunity to discuss your battery design challenges and explore thermal management strategies using PSA tapes. To take the next step, please contact me directly at max.vanraaphorst@averydennison.com. You can also visit www.tapes.averydennison.com/evbattery for more information.

Connect with us on: