Completing the Loop – Increasing resilience of Lithium Ion Supply Chains through an improved circular economy of Batteries.

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Met4Tech

THE FARADAY INSTITUTION ReLiB
REUSE & RECYCLING OF LITHIUM ION BATTERIES

TReFCo

Improving the resilience of the complete energy supply chains – from raw materials to advanced materials, manufacturing and end-of-life.

International Energy Agency, Experts' Group on Research & Development Priority Setting & Evaluation

European Joint Research Centre, Petten, Netherlands, 12th – 13th December

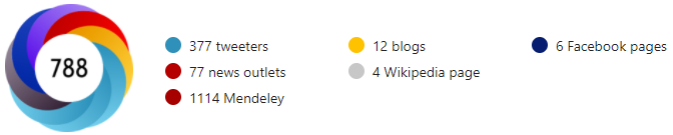
Review | Published: 06 November 2019

Recycling lithium-ion batteries from electric vehicles

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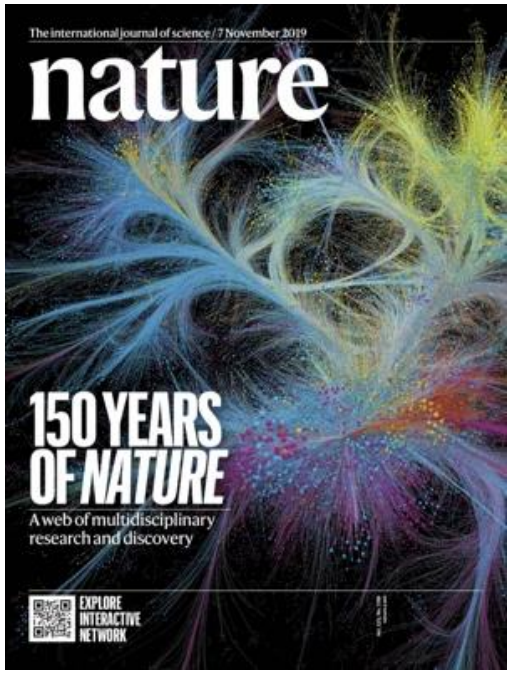
Nature **575**, 75–86 (2019) | Cite this article

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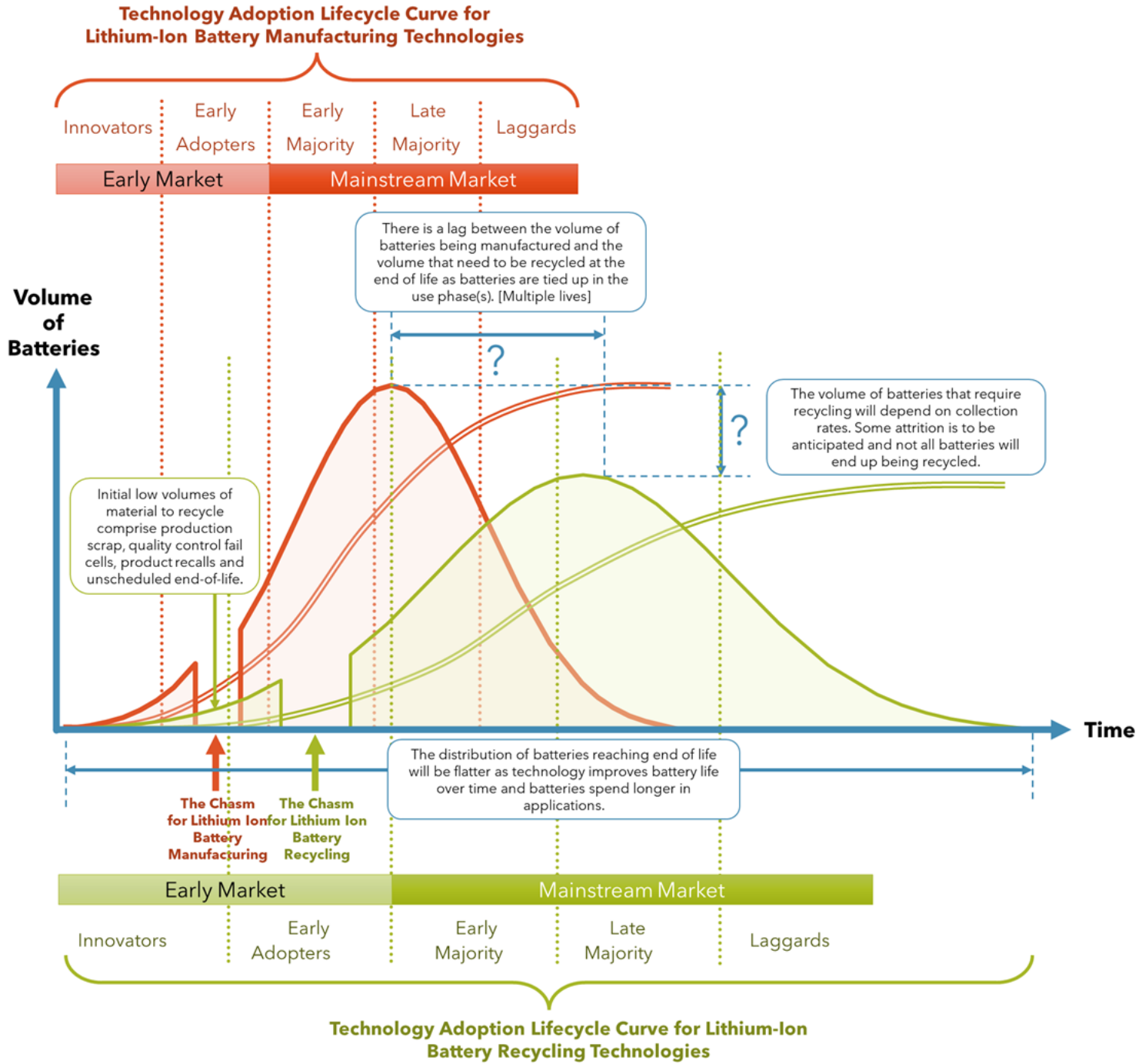


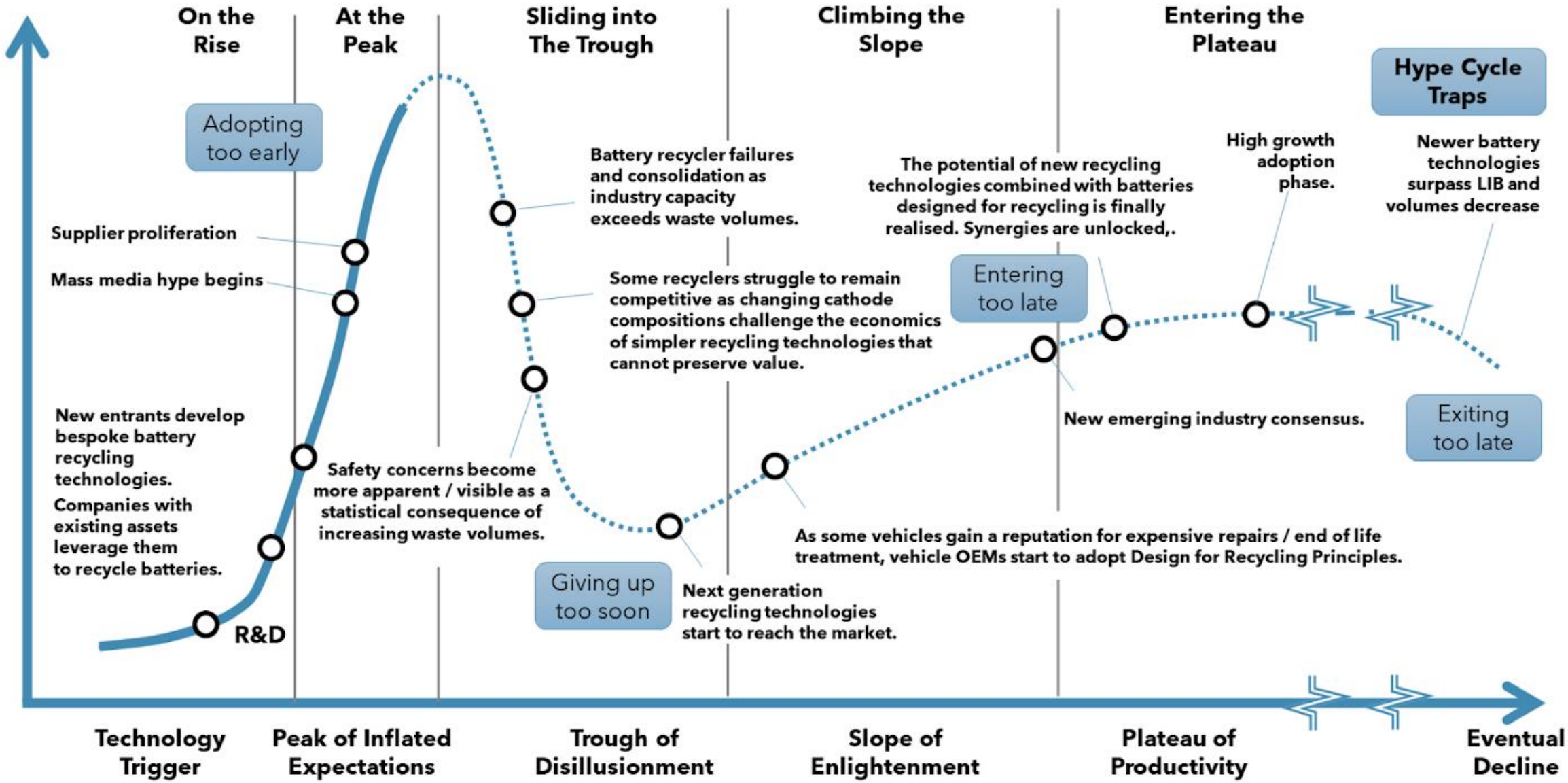
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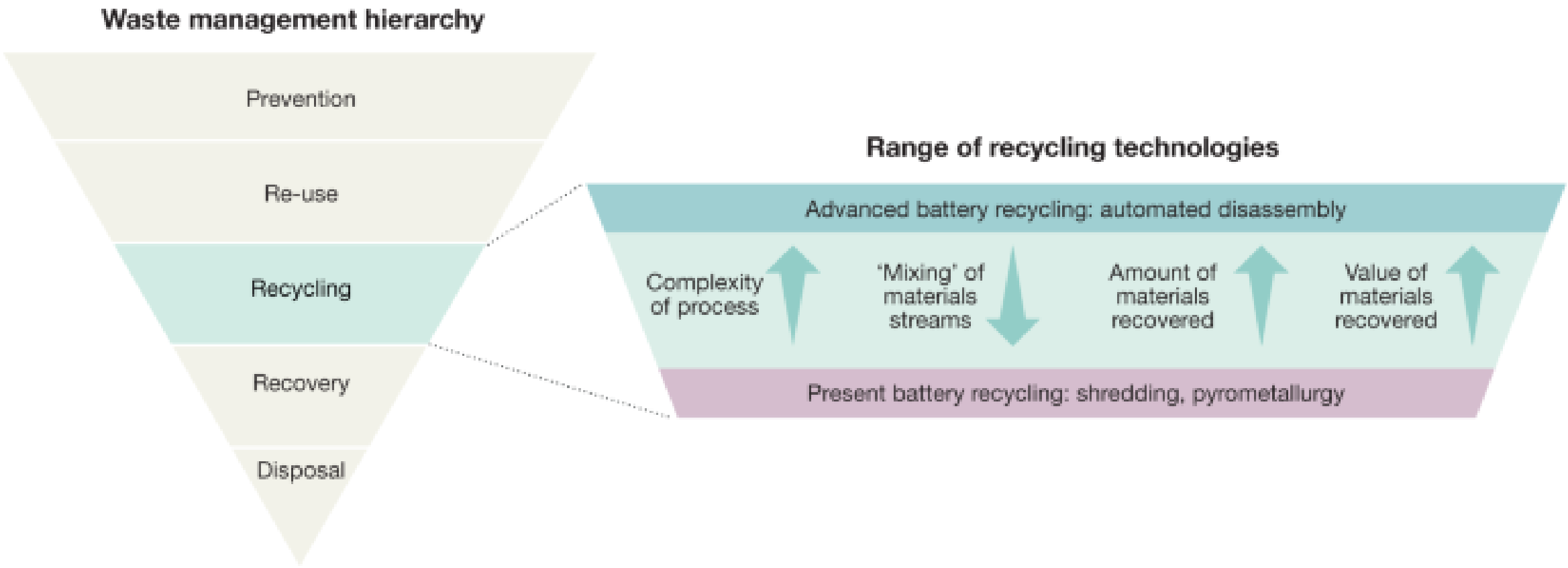


JPhys Energy:

Roadmap for a Sustainable Circular Economy of Lithium Ion Batteries


Technology Adoption Lifecycle Curve for Lithium-Ion Battery Manufacturing Technologies
Innovators
Early Adopters
Early Majority
Late Majority
Laggards
Early Market
Mainstream Market
There is a lag between the volume of batteries being manufactured and the volume that need to be recycled at the end of life as batteries are tied up in the use phase(s). [Multiple lives]
Volume of Batteries
?
?
The volume of batteries that require recycling will depend on collection rates. Some attrition is to be anticipated and not all batteries will end up being recycled.
Initial low volumes of material to recycle comprise production scrap, quality control fail cells, product recalls and unscheduled end-of-life.
Time
The distribution of batteries reaching end of life will be flatter as technology improves battery life over time and batteries spend longer in applications.
The Chasm for Lithium Ion Battery Manufacturing
The Chasm for Lithium Ion Battery Recycling
Early Market
Mainstream Market
Innovators
Early Adopters
Early Majority
Late Majority
Laggards
Technology Adoption Lifecycle Curve for Lithium-Ion Battery Recycling Technologies

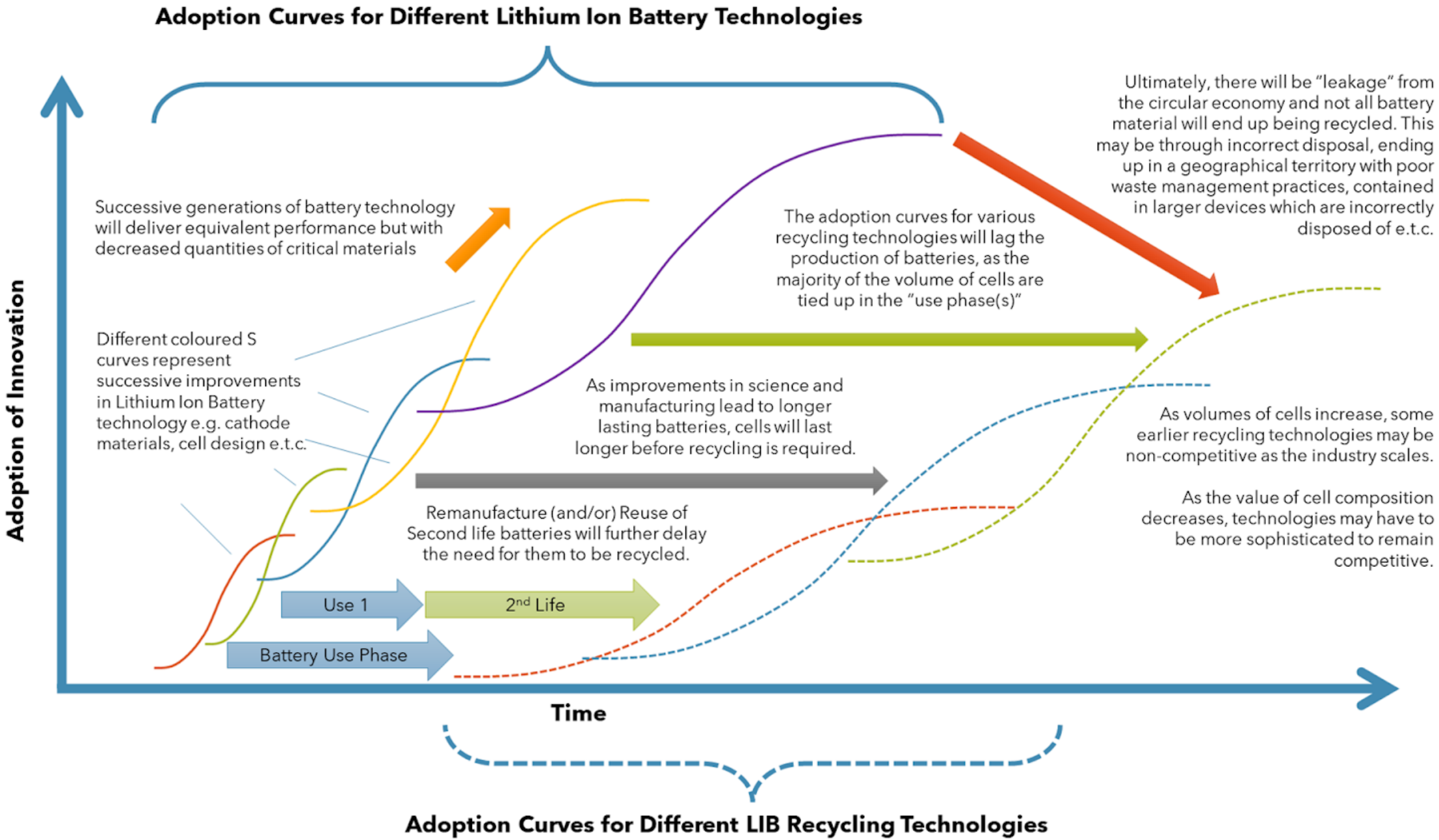

On the Rise
At the Peak
Sliding into The Trough
Climbing the Slope
Entering the Plateau
Hype Cycle Traps
Adopting too early
Supplier proliferation
Mass media hype begins
New entrants develop bespoke battery recycling technologies.
Companies with existing assets leverage them to recycle batteries.
R&D
Safety concerns become more apparent / visible as a statistical consequence of increasing waste volumes.
Battery recycler failures and consolidation as industry capacity exceeds waste volumes.
Some recyclers struggle to remain competitive as changing cathode compositions challenge the economics of simpler recycling technologies that cannot preserve value.
Giving up too soon
Next generation recycling technologies start to reach the market.
As some vehicles gain a reputation for expensive repairs / end of life treatment, vehicle OEMs start to adopt Design for Recycling Principles.
The potential of new recycling technologies combined with batteries designed for recycling is finally realised. Synergies are unlocked,.
Entering too late
New emerging industry consensus.
High growth adoption phase.
Newer battery technologies surpass LIB and volumes decrease
Exiting too late
Technology Trigger
Peak of Inflated Expectations
Trough of Disillusionment
Slope of Enlightenment
Plateau of Productivity
Eventual Decline



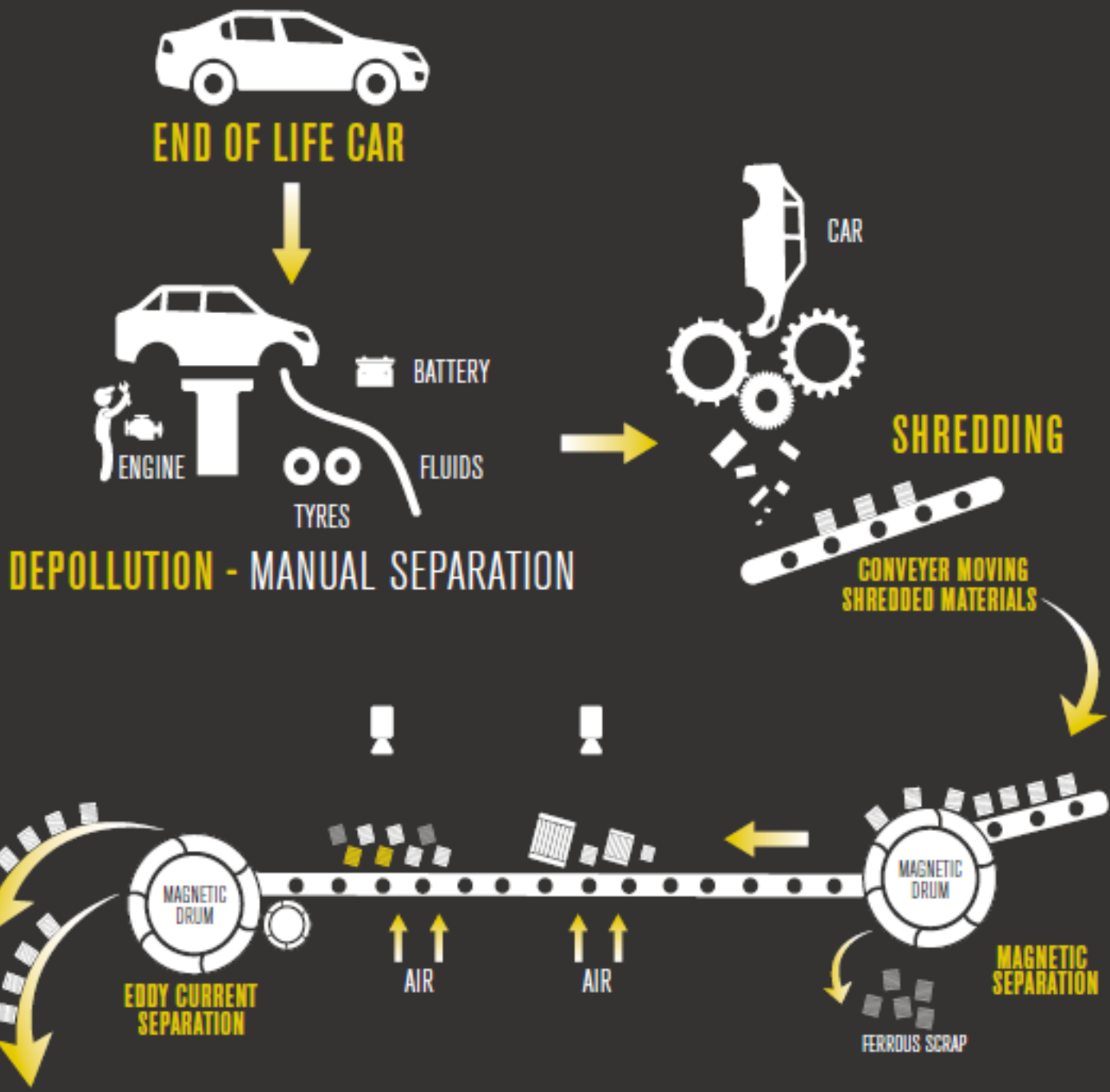
Recycling lithium-ion batteries from electric vehicles

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Nature **575**, 75–86 (2019)


Adoption Curves for Different Lithium Ion Battery Technologies
Adoption of Innovation
Time
Successive generations of battery technology will deliver equivalent performance but with decreased quantities of critical materials
Different coloured S curves represent successive improvements in Lithium Ion Battery technology e.g. cathode materials, cell design e.t.c.
The adoption curves for various recycling technologies will lag the production of batteries, as the majority of the volume of cells are tied up in the "use phase(s)"
Ultimately, there will be "leakage" from the circular economy and not all battery material will end up being recycled. This may be through incorrect disposal, ending up in a geographical territory with poor waste management practices, contained in larger devices which are incorrectly disposed of e.t.c.
As improvements in science and manufacturing lead to longer lasting batteries, cells will last longer before recycling is required.
Remanufacture (and/or) Reuse of Second life batteries will further delay the need for them to be recycled.
As volumes of cells increase, some earlier recycling technologies may be non-competitive as the industry scales.
As the value of cell composition decreases, technologies may have to be more sophisticated to remain competitive.
Use 1
2nd Life
Battery Use Phase
Adoption Curves for Different LIB Recycling Technologies

PRESENT END OF LIFE VEHICLE RECYCLING

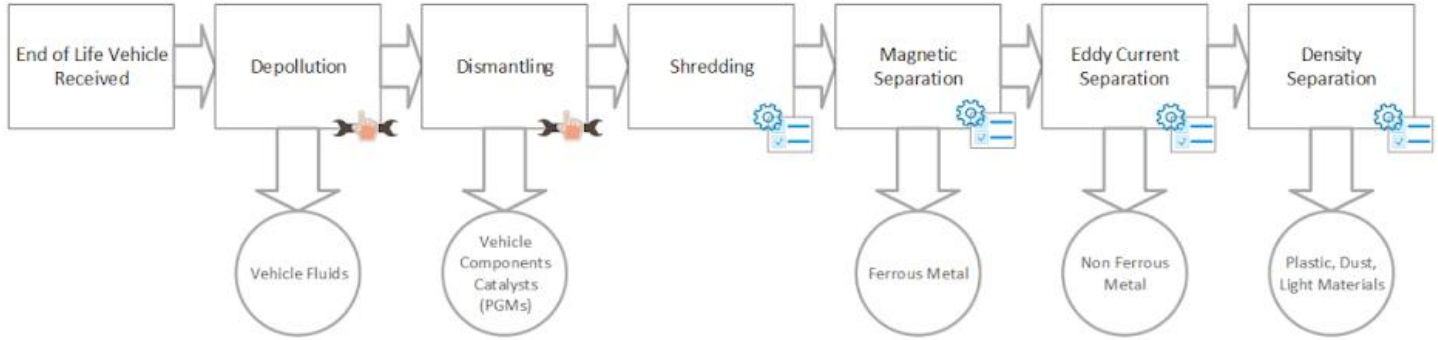


SEPARATION PROCESSES INCLUDE:

- SCREENING
- DENSITY
- INDUCTION
- ELECTRO STATICS
- SEPARATION BY SHAPE AND COLOUR

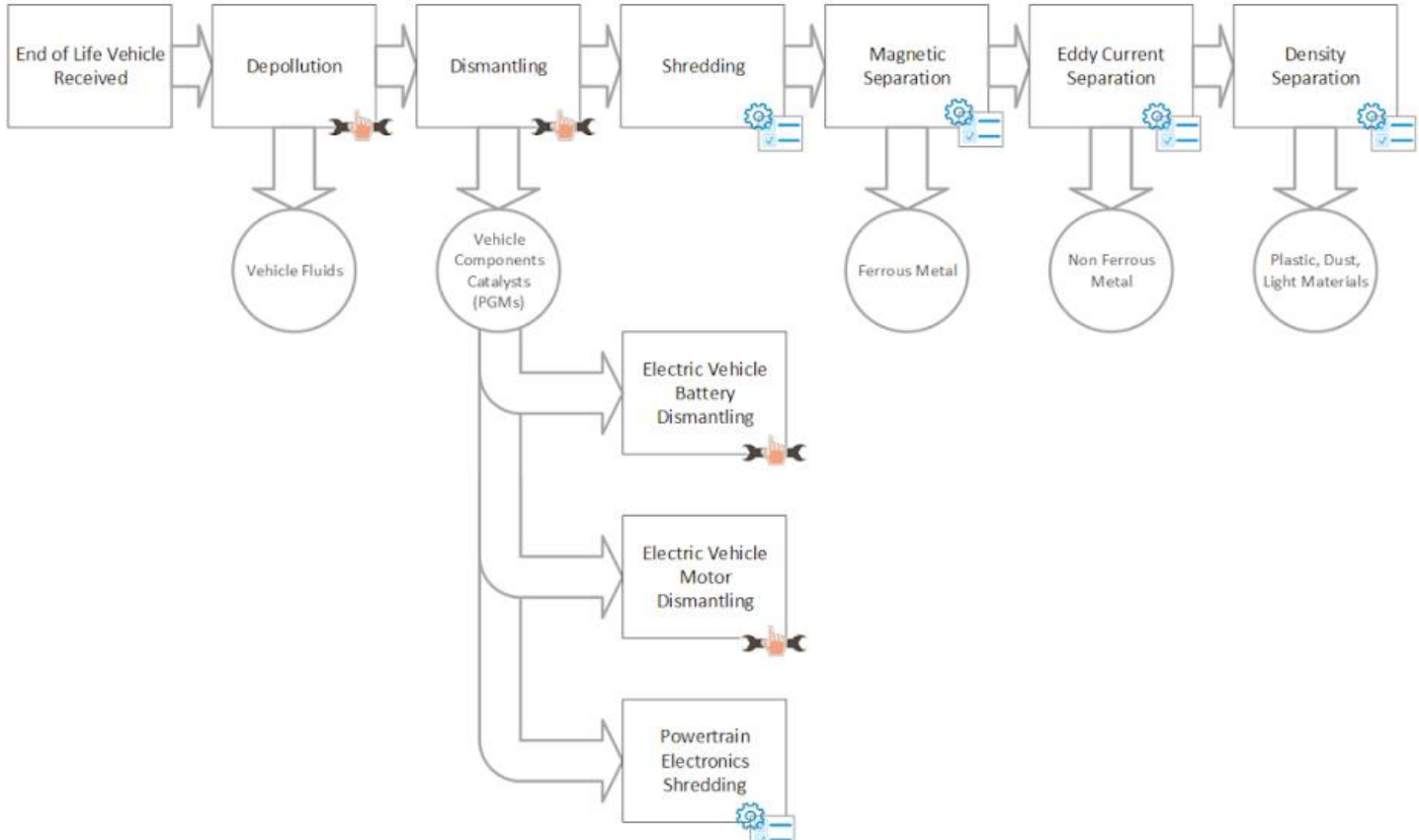
i) Internal Combustion Engine Vehicle End of Life Recycling

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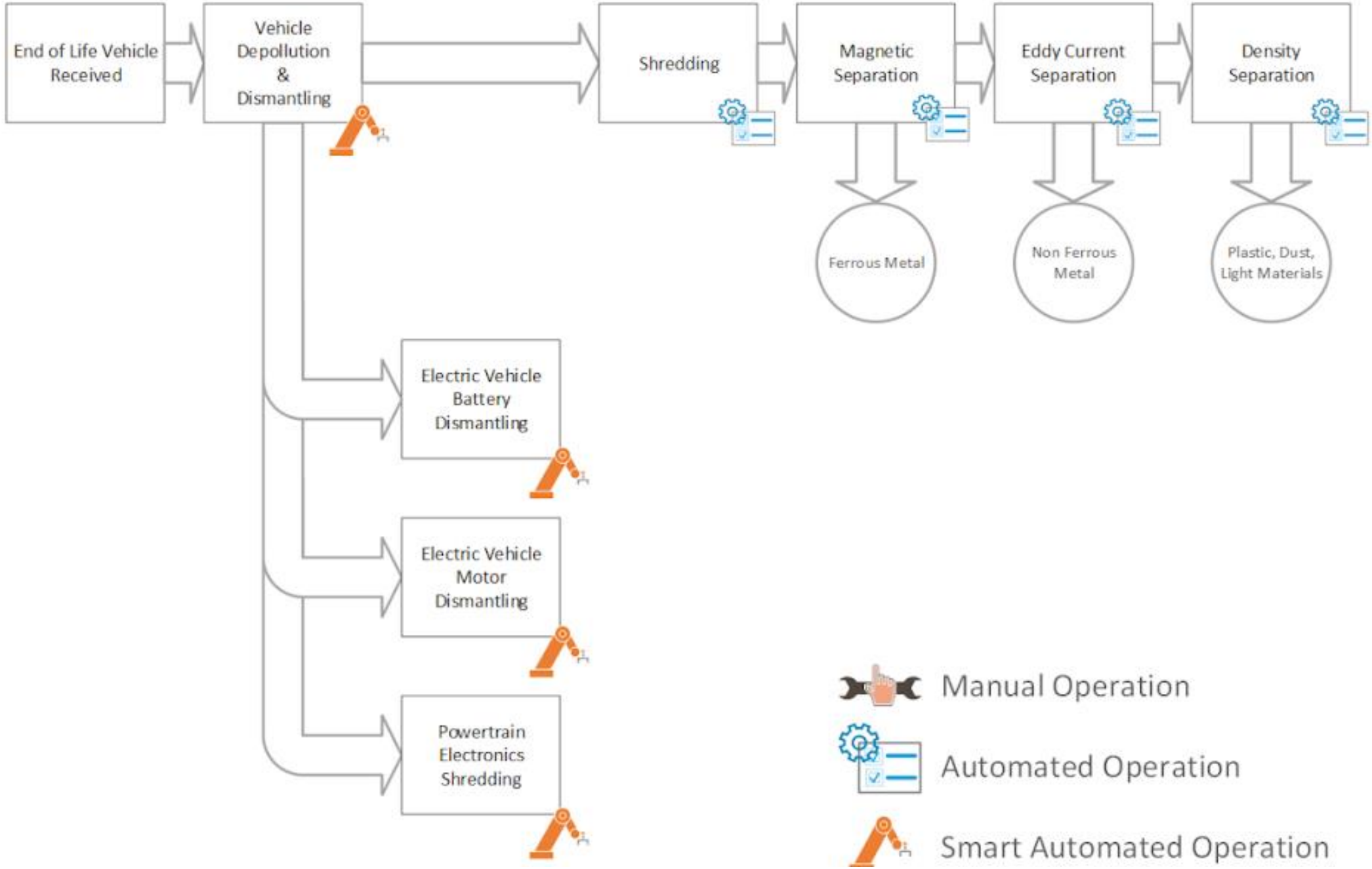
ii

ii) Present Electric Vehicle End of Life Recycling





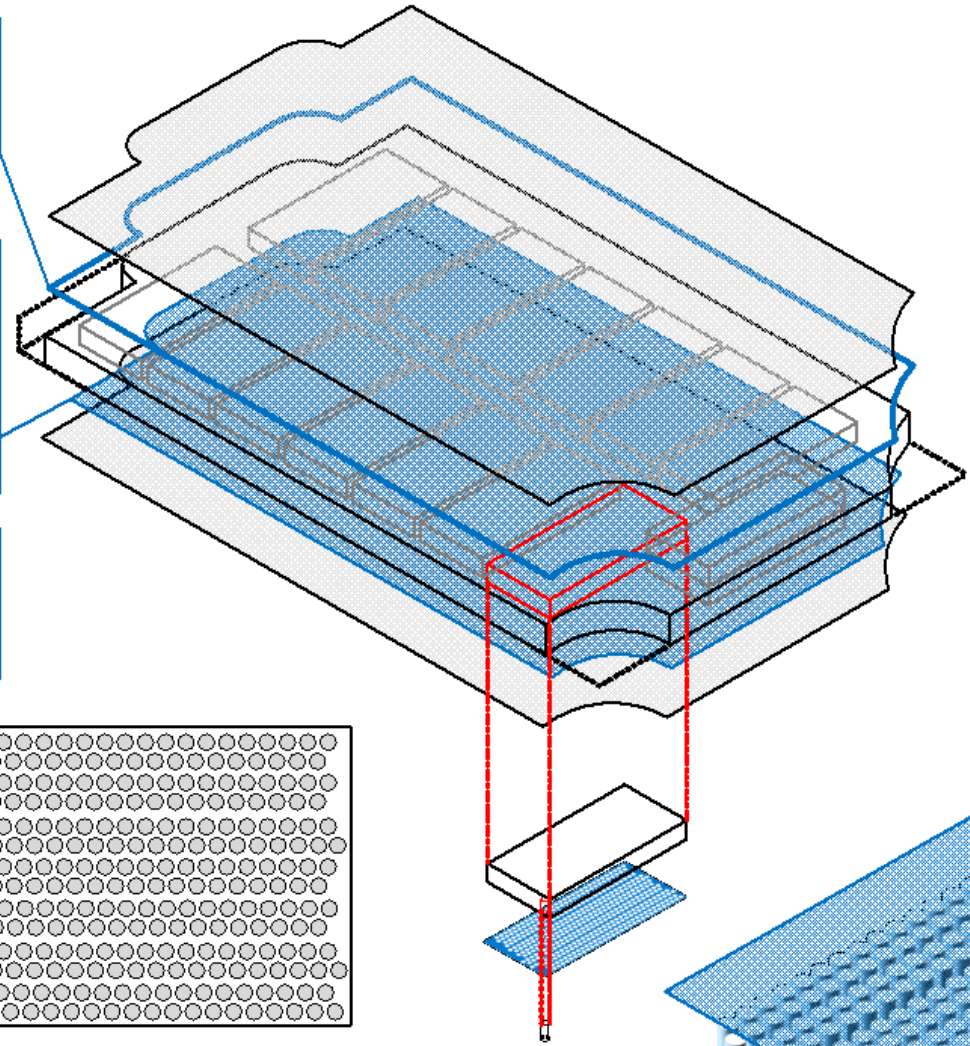
iii) Future Smart Electric Vehicle End of Life Recycling

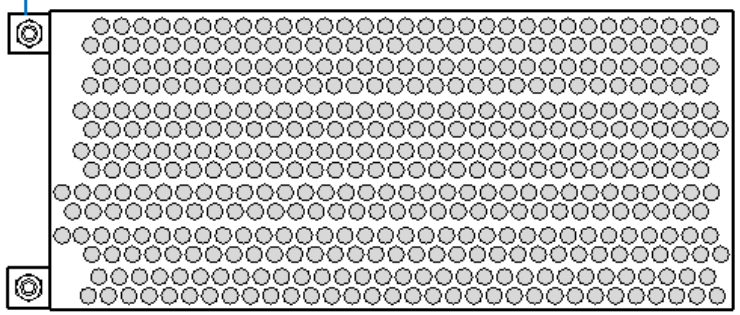


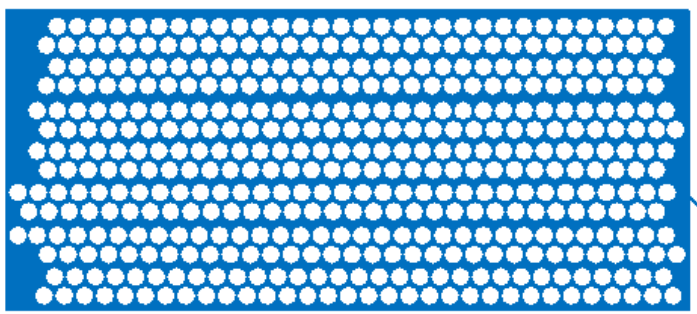
Battery Pack Sealing Gasket Adhesive

Thermally conductive mat, aids thermal conduction, damps vibration, secures components

Potting connectors / electrical insulation.



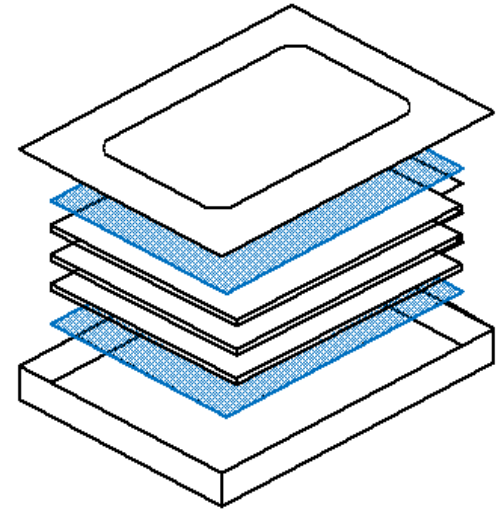


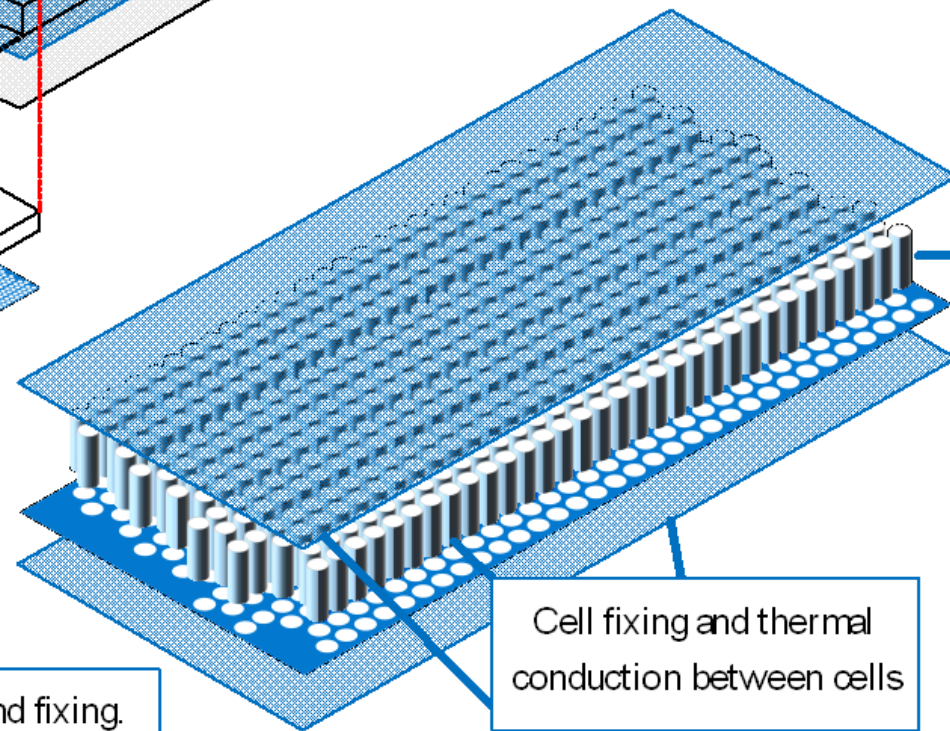


Cell location and fixing.

In pack designs that employ pouch cells, adhesives may also be used to provide compression between cells.

In packs with cylindrical cells this compression function is provided by the cell can.





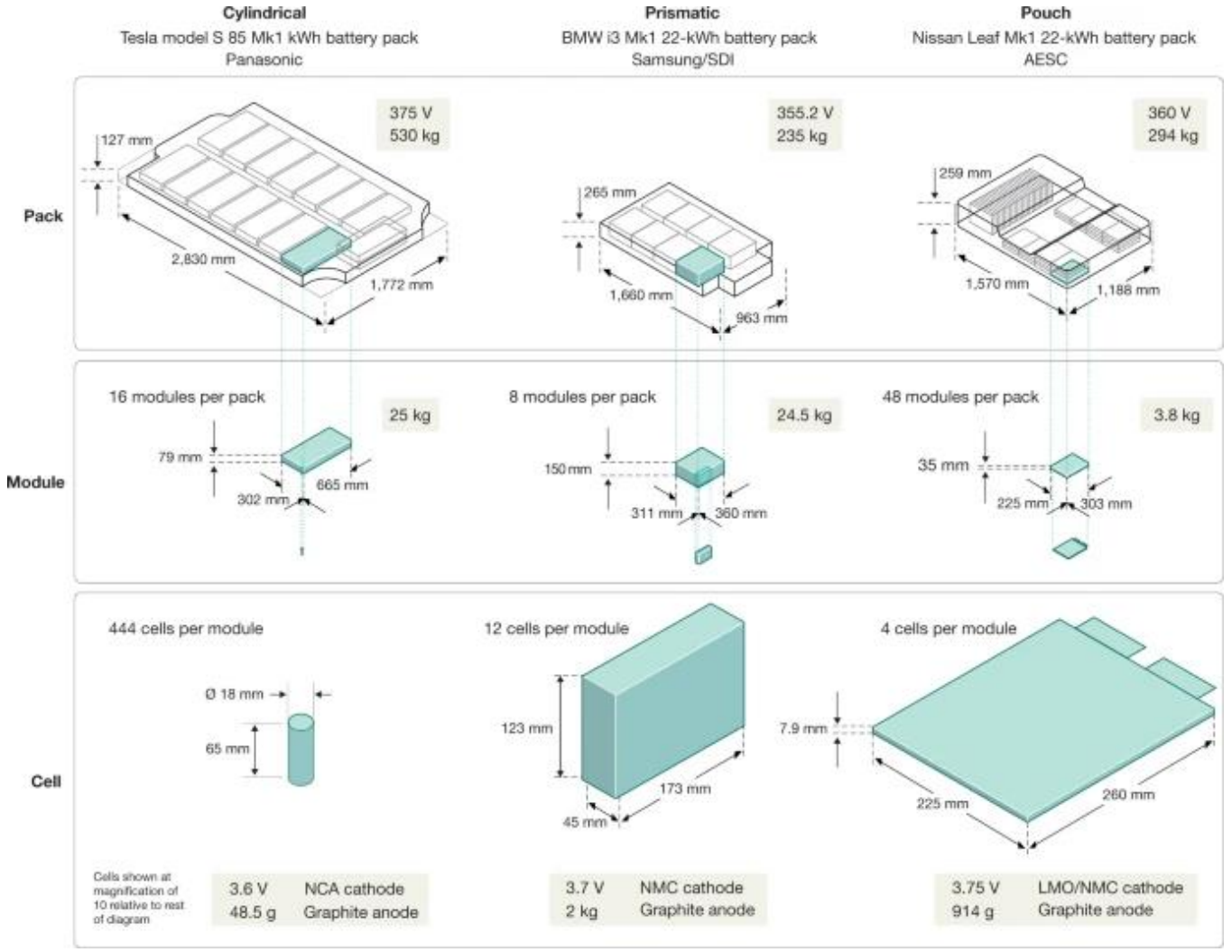
Cell to cell connection

Thermal interface materials.

Cell fixing and thermal conduction between cells

Structural adhesives improve vehicle crash performance.

COMPLEXITY AND VARIATION IN ELECTRIC VEHICLE PACK DESIGN

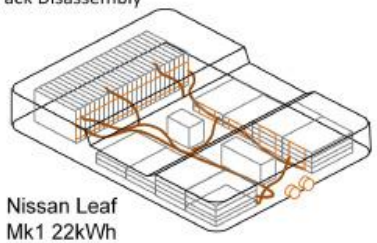


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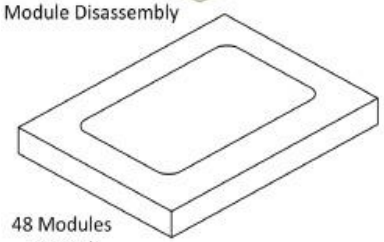
Pack Disassembly



Nissan Leaf
Mk1 22kWh
Battery Pack

- Removal of wiring looms tricky
- Manipulation of connectors (especially where locking tabs fitted)
- High voltages until wiring loom / module links removed
- Lack of data on module condition in many present EV batteries
- Lack of labelling and identifying marks
- Potential fire hazards
- Potential HF off-gassing

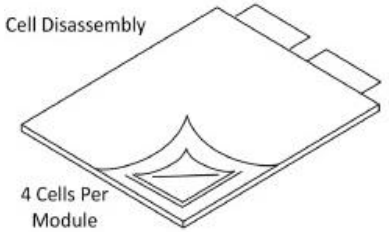
Module Disassembly



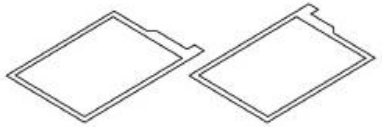
48 Modules
Per Pack

- Sealants may be used in module manufacture (difficult to remove)
- Cells stuck together in modules with adhesives (difficult to separate)
- Components may be soldered together (difficult to separate)
- Module state of charge may not be known

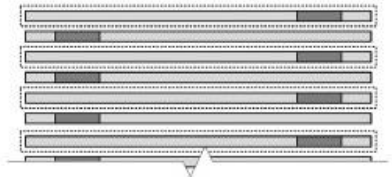
Cell Disassembly



4 Cells Per
Module



- Clean separation of anodes and cathode for direct recycling difficult.
- Very finely powdered materials present risks (nanoparticles)
- Potential for HF compounds formed from electrolyte
- Potential for thermal effects if cells shorted during disassembly
- Chemistries not always known / proprietary
- Additional challenges with cylindrical cells (unwinding spiral)
- Disassembly of stacked structure with encapsulated anodes.



Resources, Conservation & Recycling 175 (2021) 105741

Contents lists available at ScienceDirect

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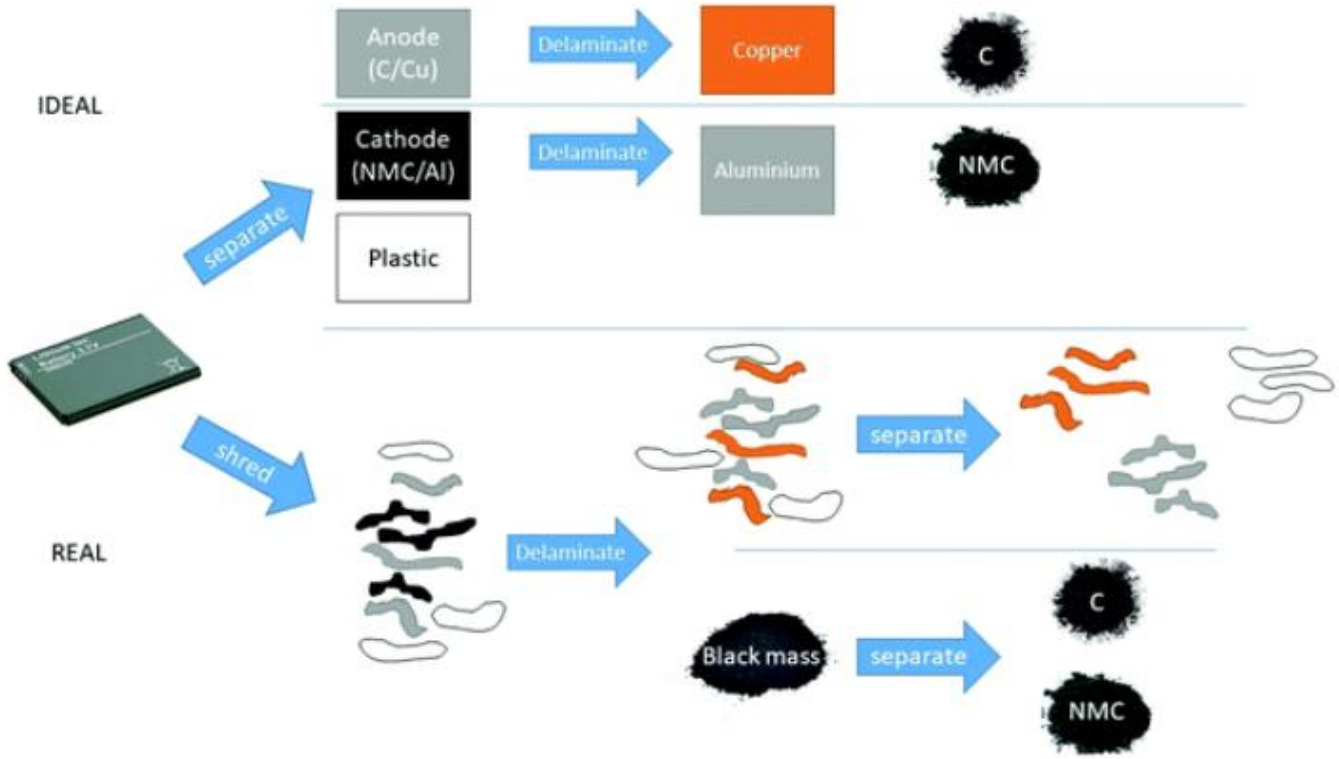
Full length article

To shred or not to shred: A comparative techno-economic assessment of lithium ion battery hydrometallurgical recycling retaining value and improving circularity in LIB supply chains

Dana Thompson [a,b], Charlotte Hyde [a], Jennifer M. Hartley [a,b], Andrew P. Abbott [a,b], Paul A. Anderson [b,c], Gavin D.J. Harper [b,d,*]

COMPLEXITY IN EV PACK DISASSEMBLY

CURRENT VS ENVISIONED ELECTRIC VEHICLE BATTERY RECYCLING



Schematic diagram of an idealised *vs.* a real battery recycling process.

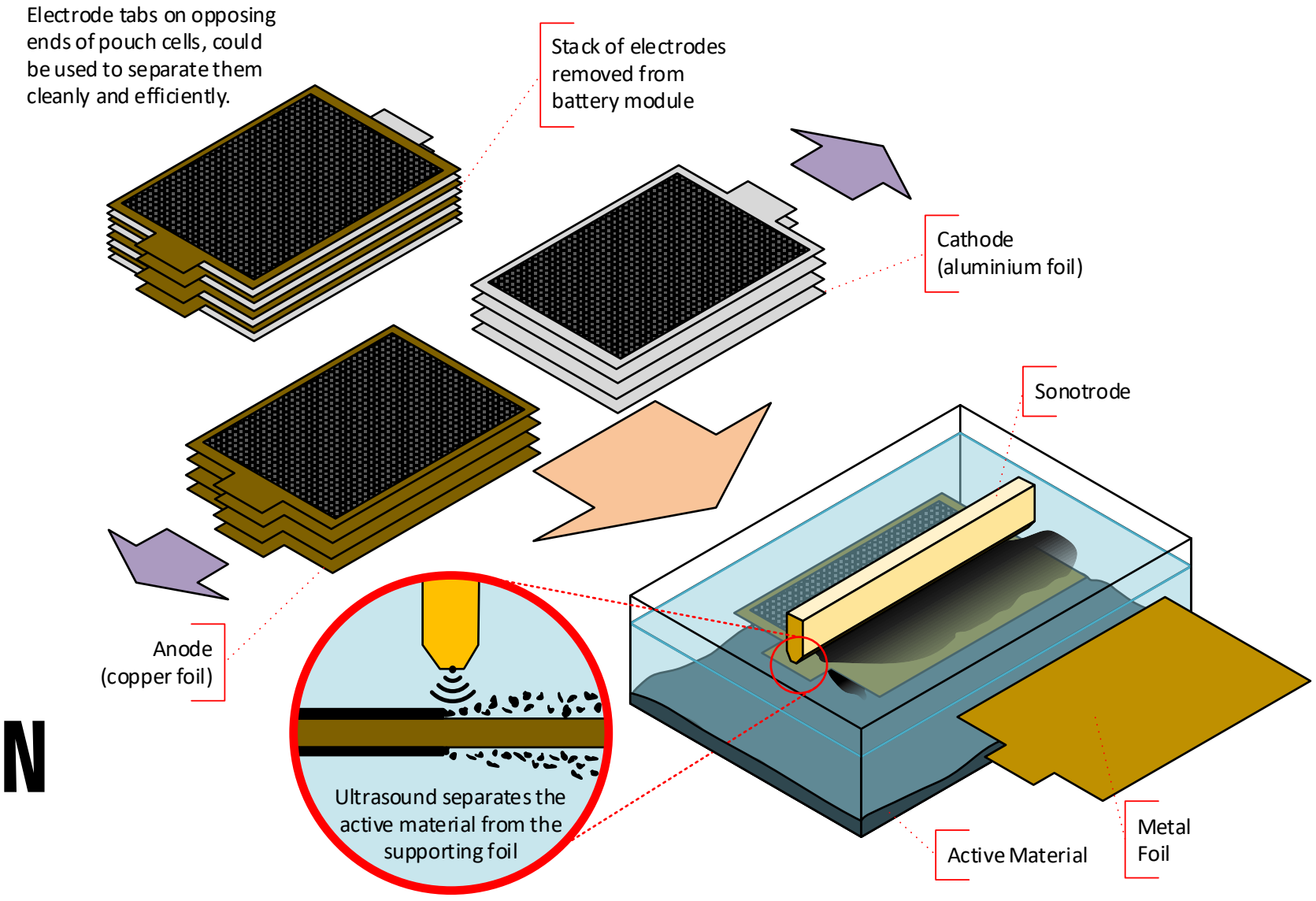
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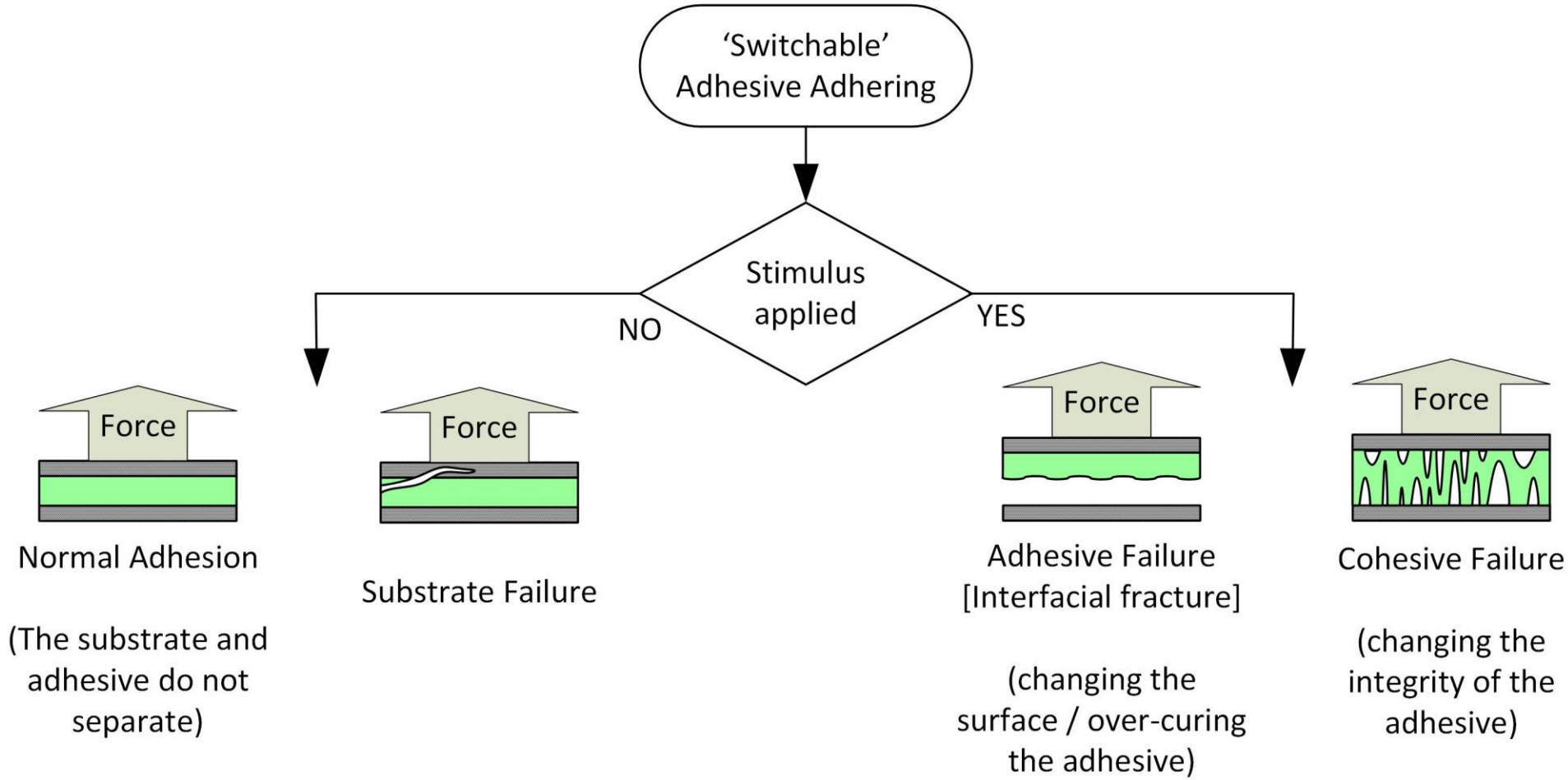
DOI: 10.1039/D0GC02745F (Critical Review) *Green Chem.*, 2020, **22**, 7585-7603

The importance of design in lithium ion battery recycling – a critical review†

Dana L. Thompson [ab], Jennifer M. Hartley [ab], Simon M. Lambert [bc], Muez Shiref [bc], Gavin D. J. Harper [db], Emma Kendrick [db], Paul Anderson [be], Karl S. Ryder [ab], Linda Gaines [f] and Andrew P. Abbott [*ab]

LITHIUM ION BATTERY RECYCLING USING HIGH INTENSITY ULTRASONICATION



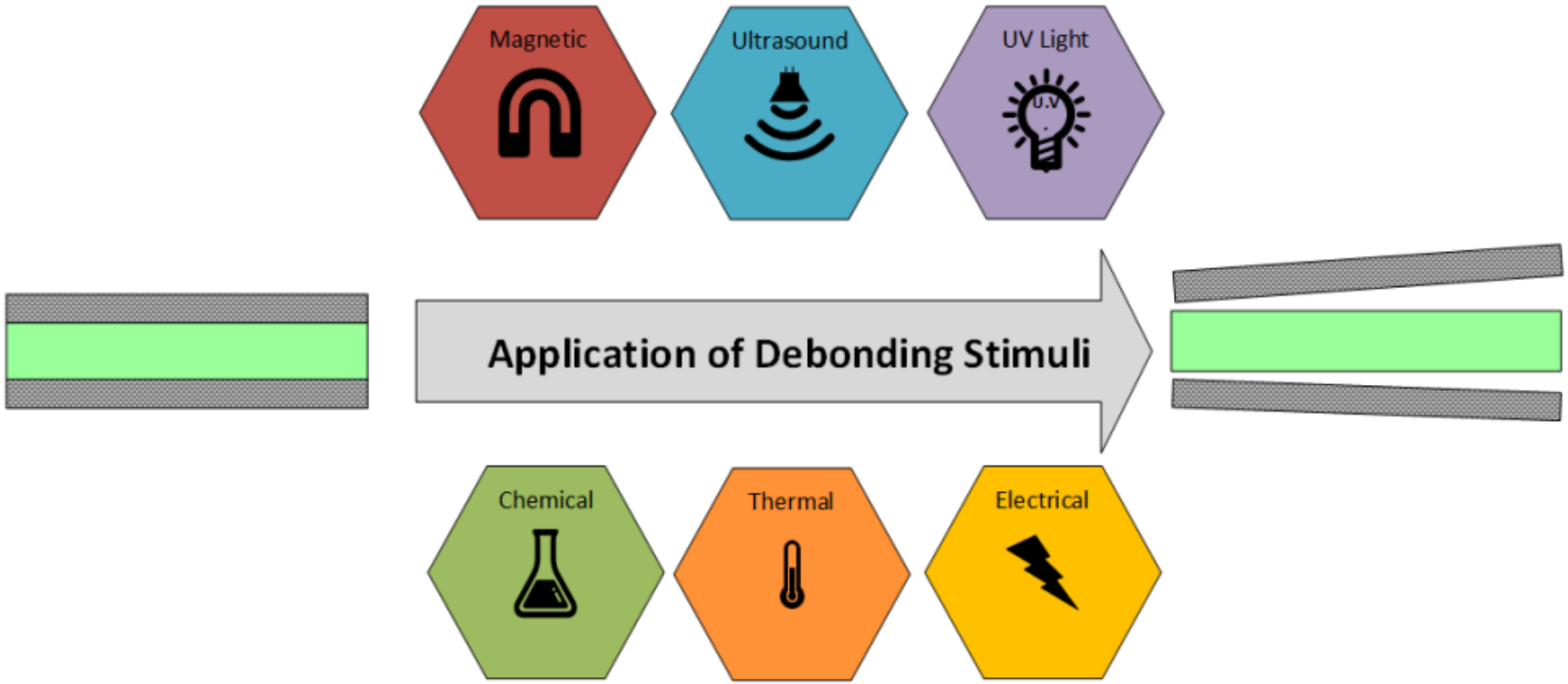


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Debondable adhesives and their use in recycling
Kira R. Mulcahy, Alexander F. R. Kilpatrick, Gavin D. J. Harper, and Andrew P. Abbott
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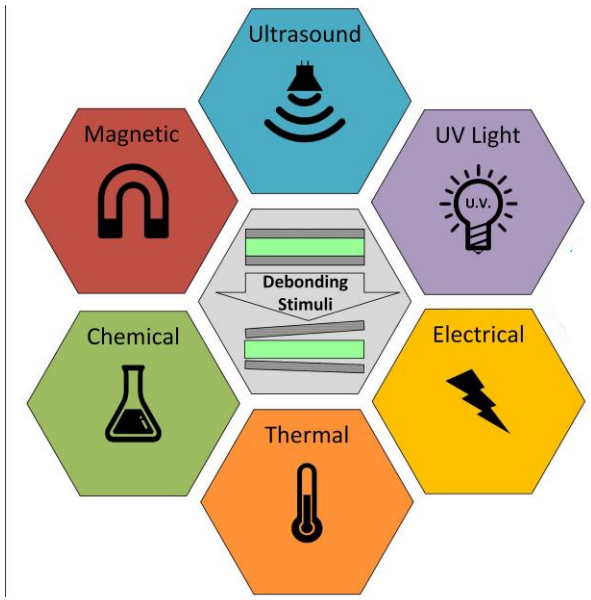


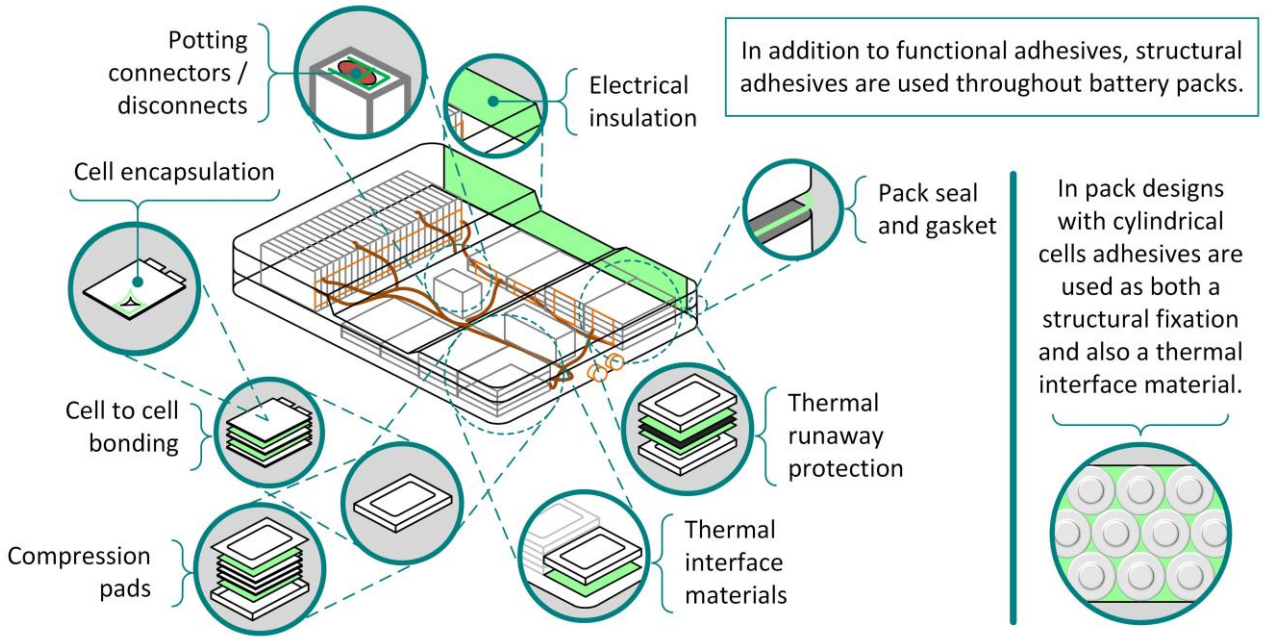


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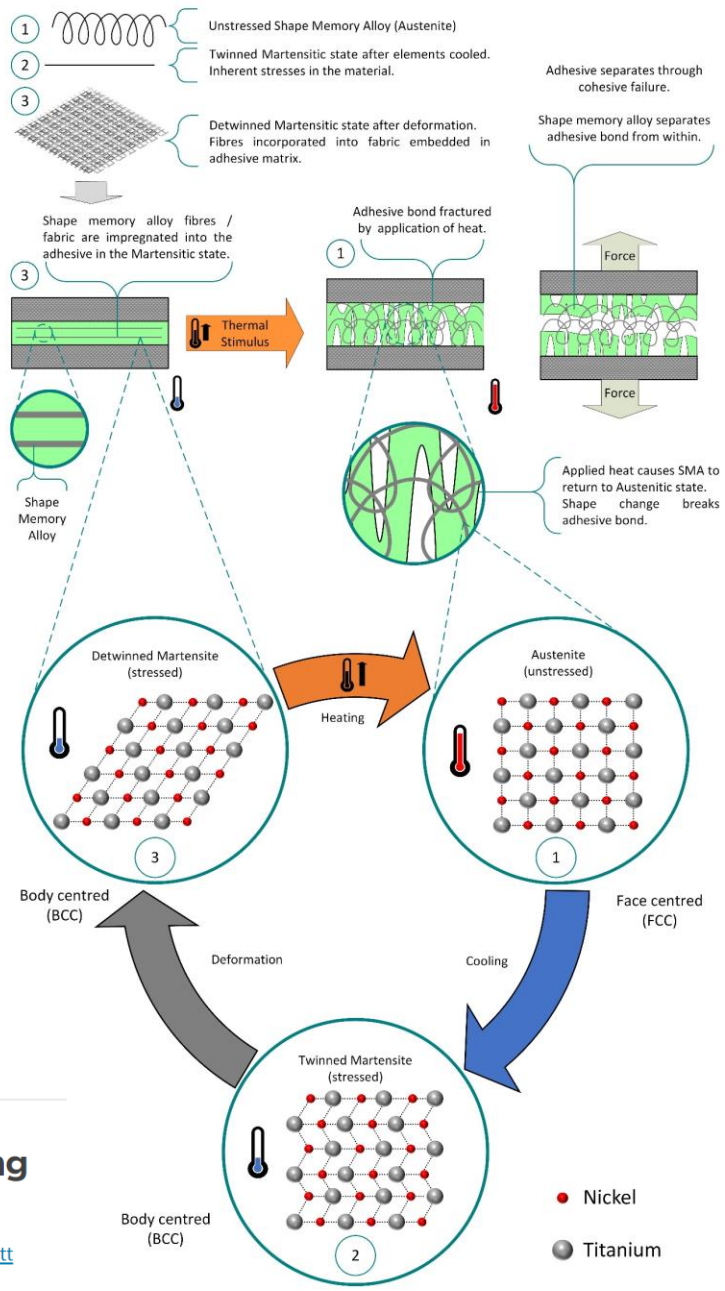
DEBONDABLE ADHESIVES AND THEIR USE IN RECYCLING

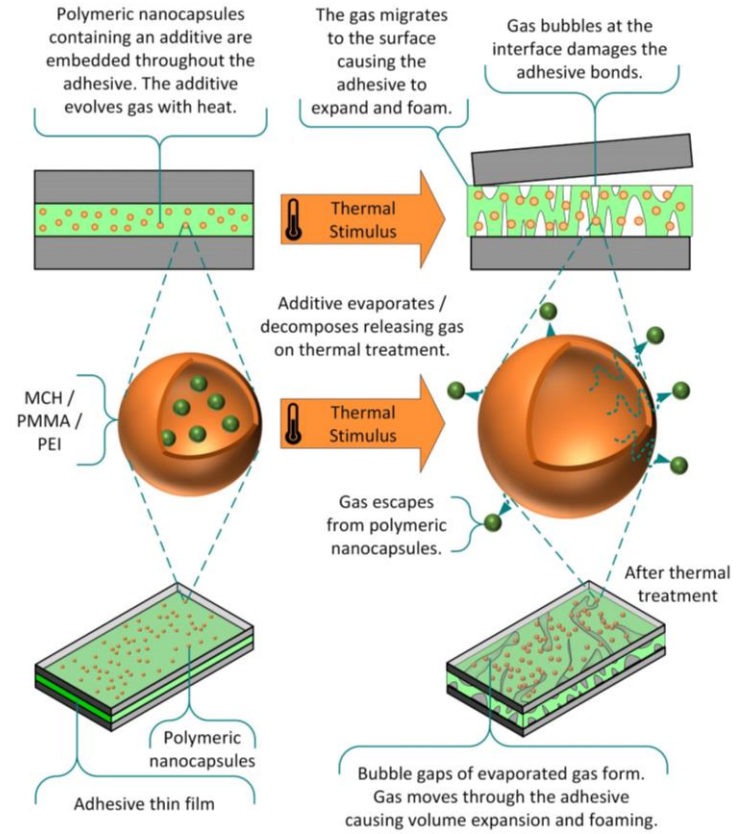


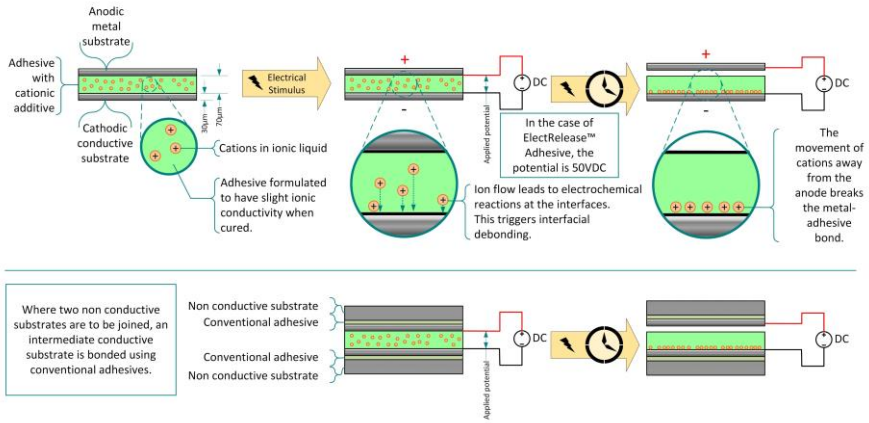
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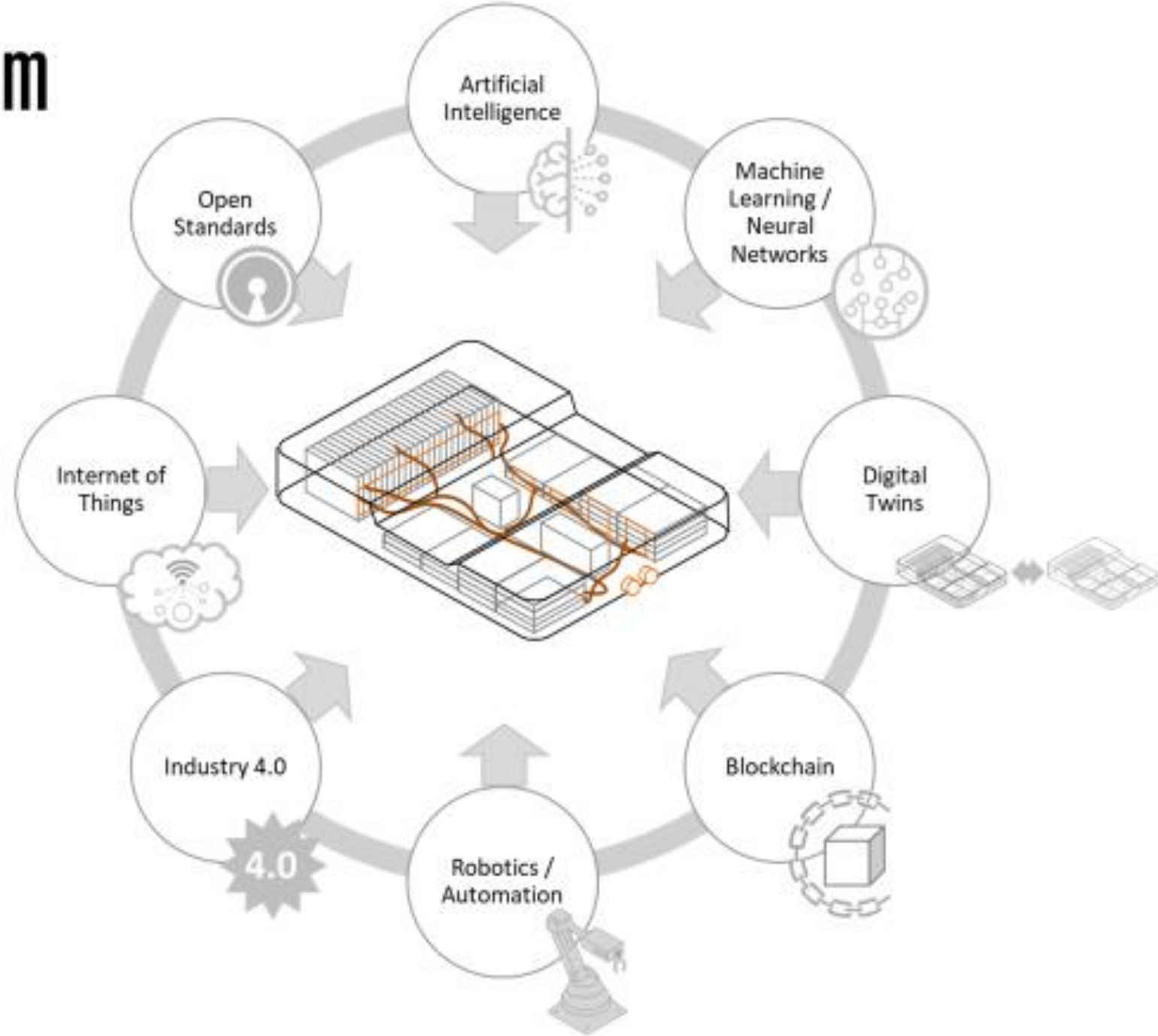
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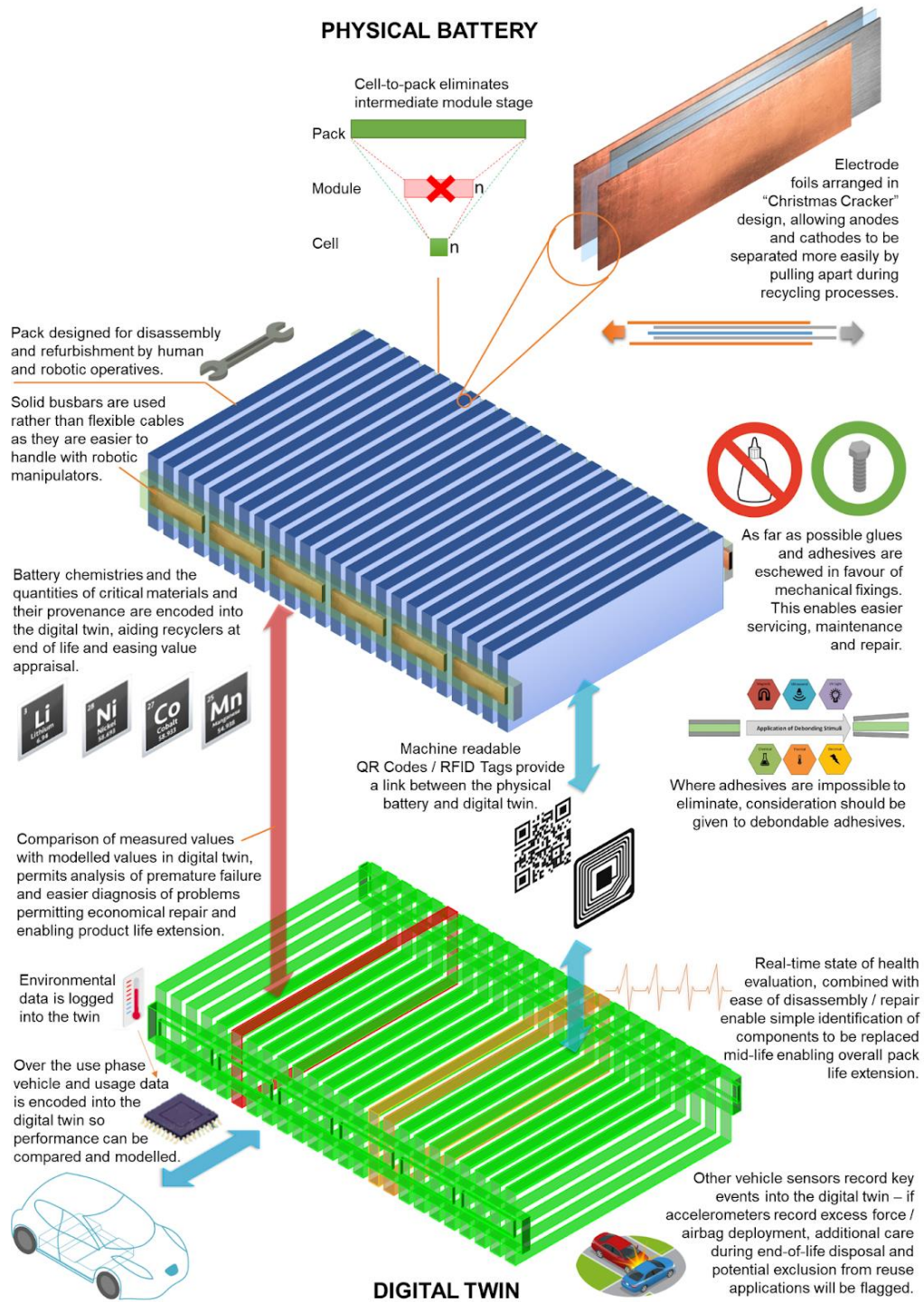


Digitalisation of Lithium Ion Battery Recycling

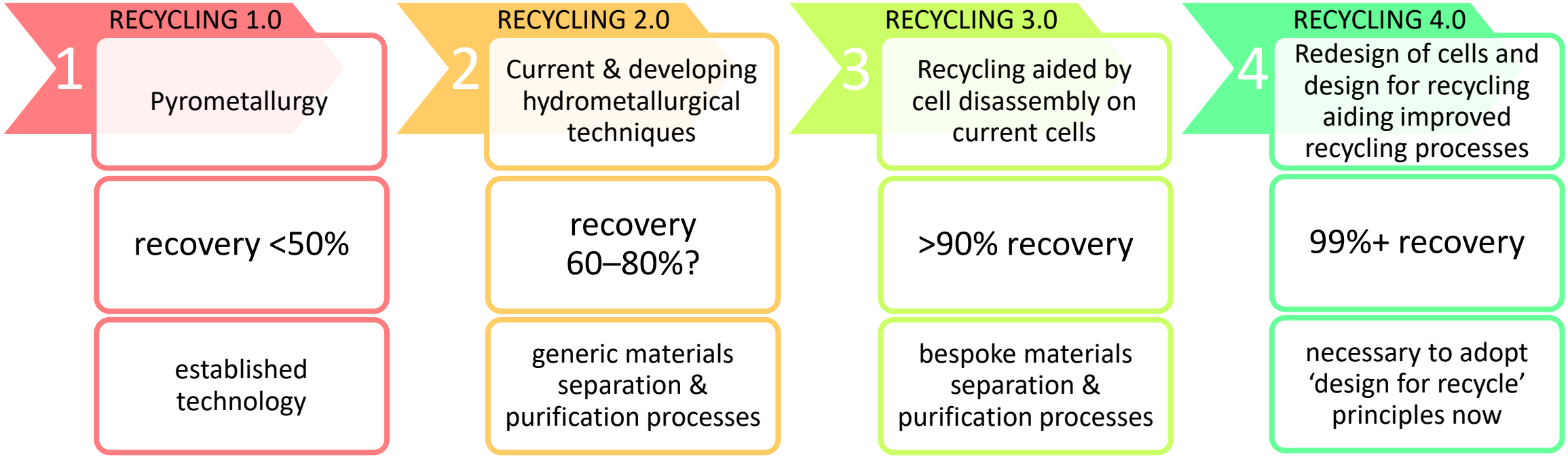


Key messages

- recycling needs automation to be cost and time effective
- cell disassembly coupled with tailored short-loop/direct recycling and upcycling processes could make recovery of lower materials viable
- design for recycle is vital to minimize structural adhesives, binders, connectors and retooling
- LCA and TEA can provide key information on problems with pack/module/cell design
- novel binders and adhesives are essential in all aspects of pack manufacture and disassembly
- process engineering is required to achieve reproducible separation and purification



ReLIB technology pipeline



Recycling 3.0: cell disassembly coupled with bespoke separation processes based on short loop/direct recycling and upcycling maintains value in recovered materials streams

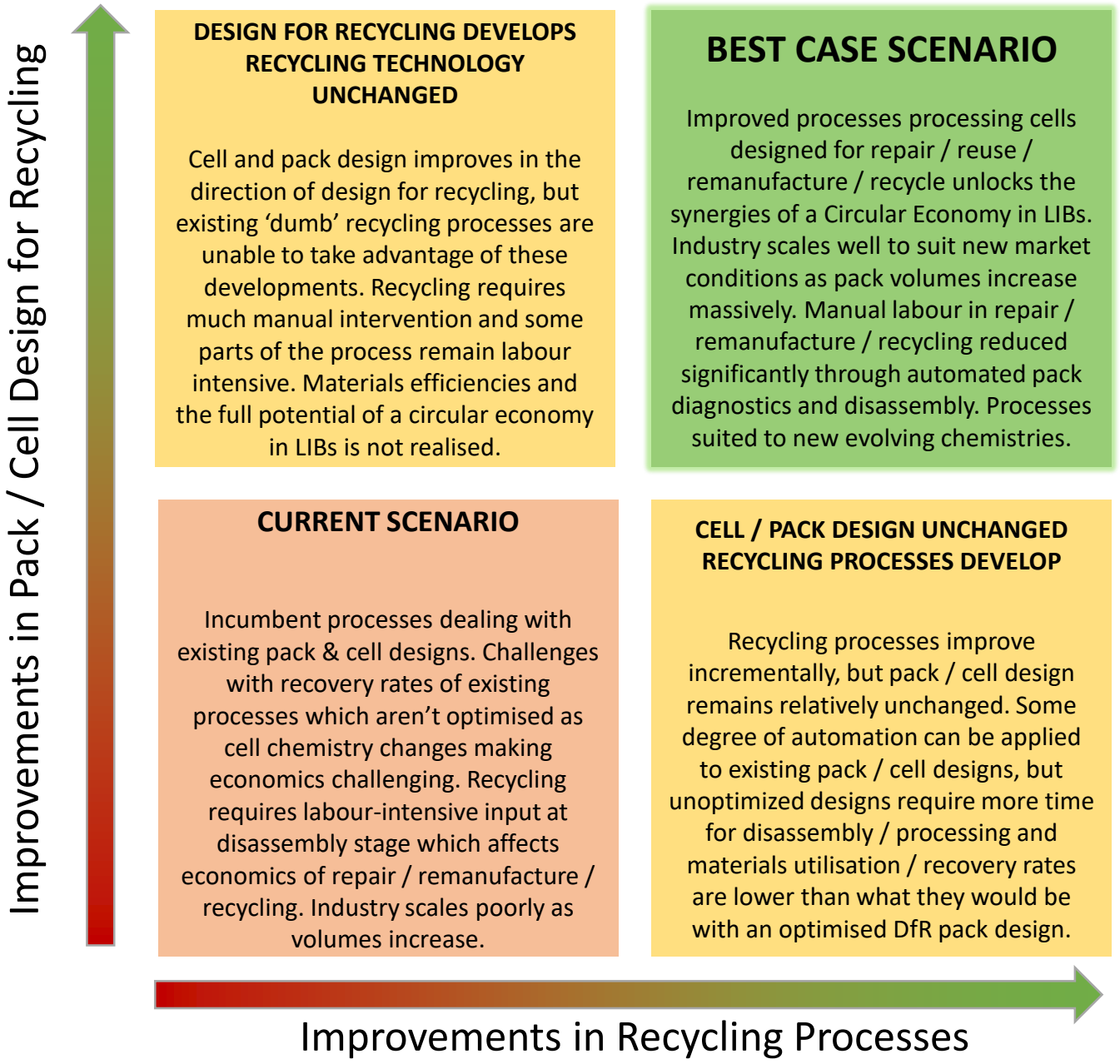
- brings lower value materials into play

Recycling 4.0: maximum recovery rates will require ***both adoption of 'design for recycle'* and *commitment to zero-waste recycling***

- materials recovery from waste streams from waste processing—biorecovery?

**pack wt%*

Unlocking the potential of a circular economy of battery technology critical metals requires the development of recycling processes and design for recycling in tandem.



Geospatial Modelling for Optimisation of Industrial Configuration

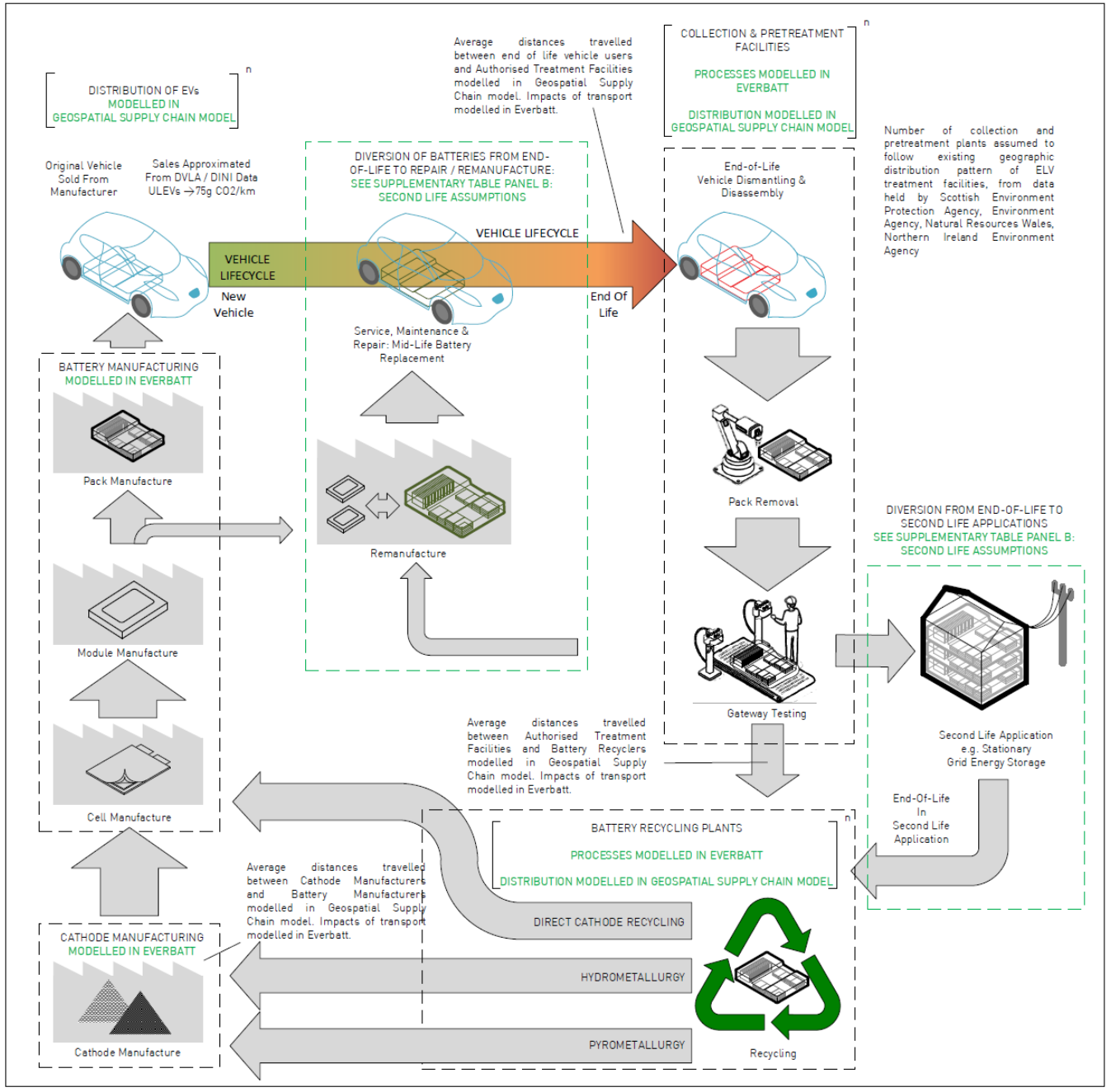
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Applied Energy
Volume 321, 1 September 2022, 119230



Optimising the geospatial configuration of a future lithium ion battery recycling industry in the transition to electric vehicles and a circular economy ☆

Viet Nguyen-Tien [a, b], Qiang Dai [c], Gavin D.J. Harper [b, d, e] ✉, Paul A. Anderson [b, d, f], Robert J.R. Elliott [b, d, g]



Geospatial Modelling for Optimisation of Industrial Configuration

Optimising the Geospatial Configuration of a Future Lithium Ion Battery Recycling Industry in the Transition to Electric Vehicles and a Circular Economy.

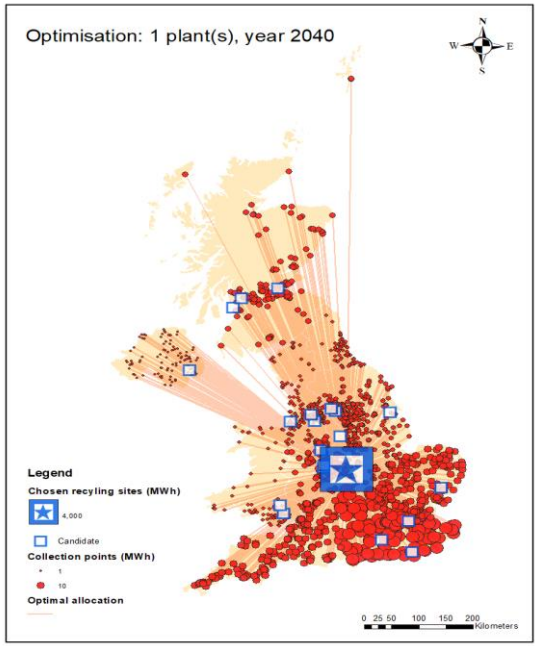
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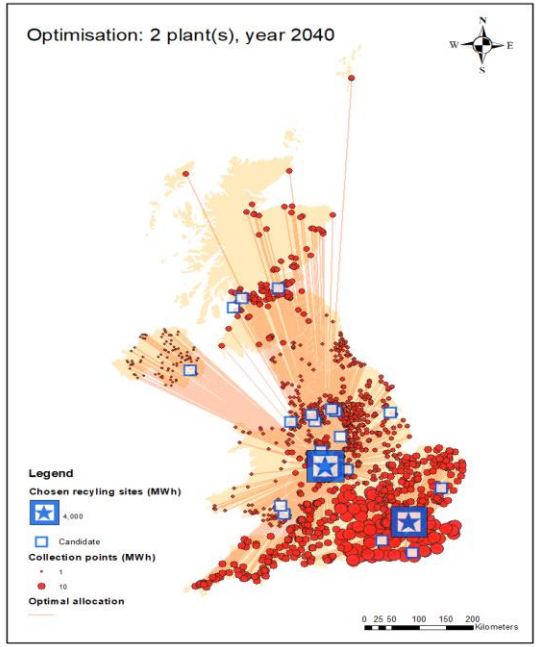
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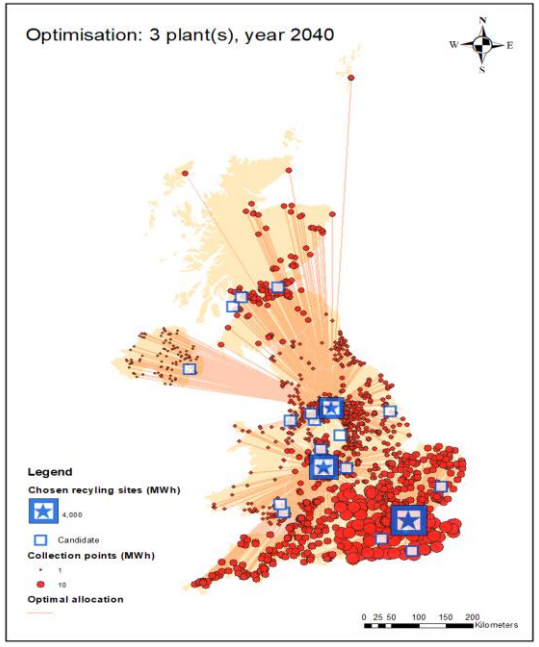
Optimising the geospatial configuration of a future lithium ion battery recycling industry in the transition to electric vehicles and a circular economy ☆

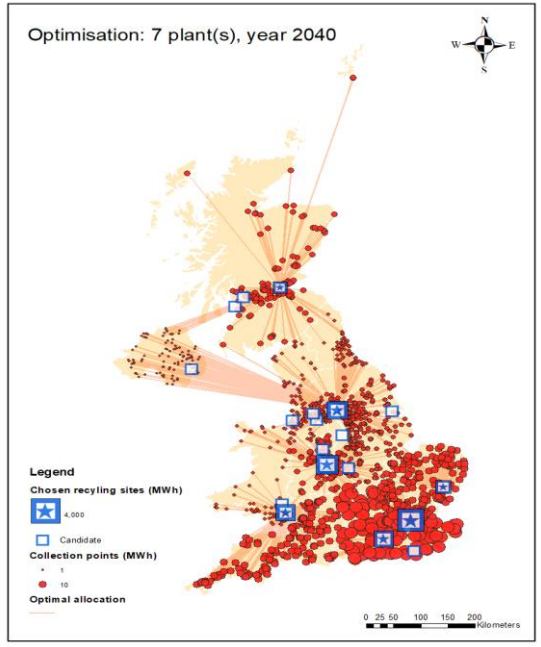
Viet Nguyen-Tien [a, b], Qiang Dai [c], Gavin D.J. Harper [b, d, e], Paul A. Anderson [b, d, f], Robert J.R. Elliott [b, d, g]

GABREAL: An Economic, Environmental and Geospatial Analysis of Recycling Electric-vehicle Lithium-ion Batteries

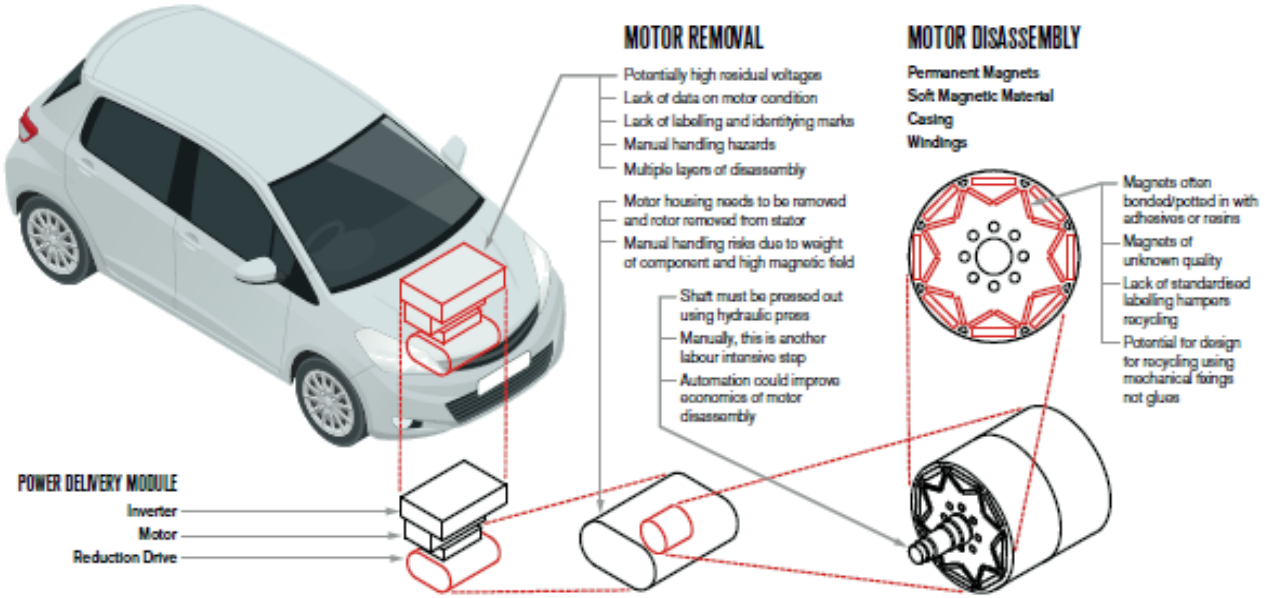




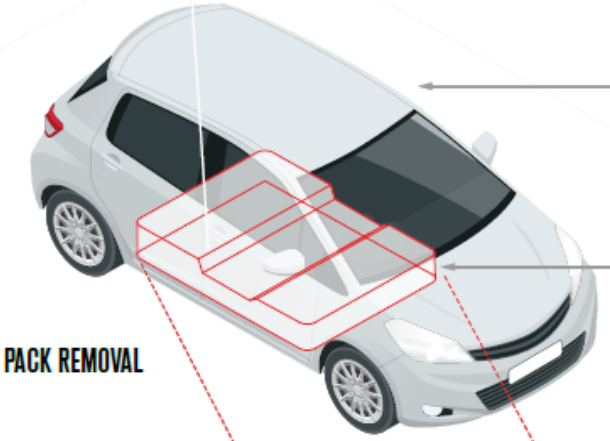




Synergy between the automated disassembly of Lithium Ion Batteries and Electric Vehicle Motors



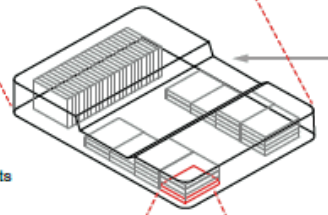
THE SPECIFIC CHALLENGES AROUND RECYCLING LITHIUM-ION BATTERIES ARE EXPLORED IN MORE DETAIL ON PAGE 113



PACK REMOVAL

- Variety of vehicle shapes / sizes
- Different pack configurations / locations
- Different fixings / tooling required
- Bolts / fixings may be rusted
- Heads of fixings may be rounded / sheared
- Position of bolt heads not always fixed
- Vehicle bodywork may be distorted
- Vehicle may be crash damaged
- Weight of battery

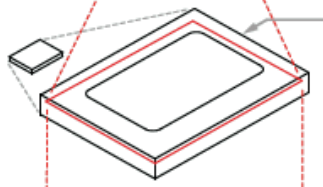
PACK DISASSEMBLY



Recovered Components:
- Bus bars
- Electronics
- Wiring looms
- Modules > Cells
- Other components

- Removal of wiring looms tricky
- Manipulation of connectors (especially where locking tabs fitted)
- High voltages until wiring loom / module links removed
- Lack of data on module condition in many present EV batteries
- Lack of labelling and identifying marks
- Potential fire hazards
- Potential HF off-gassing

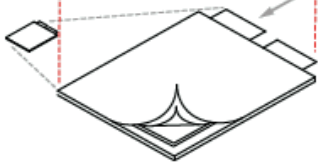
MODULE DISASSEMBLY



Recovered Components:
- Casings
- Terminals
- Cells

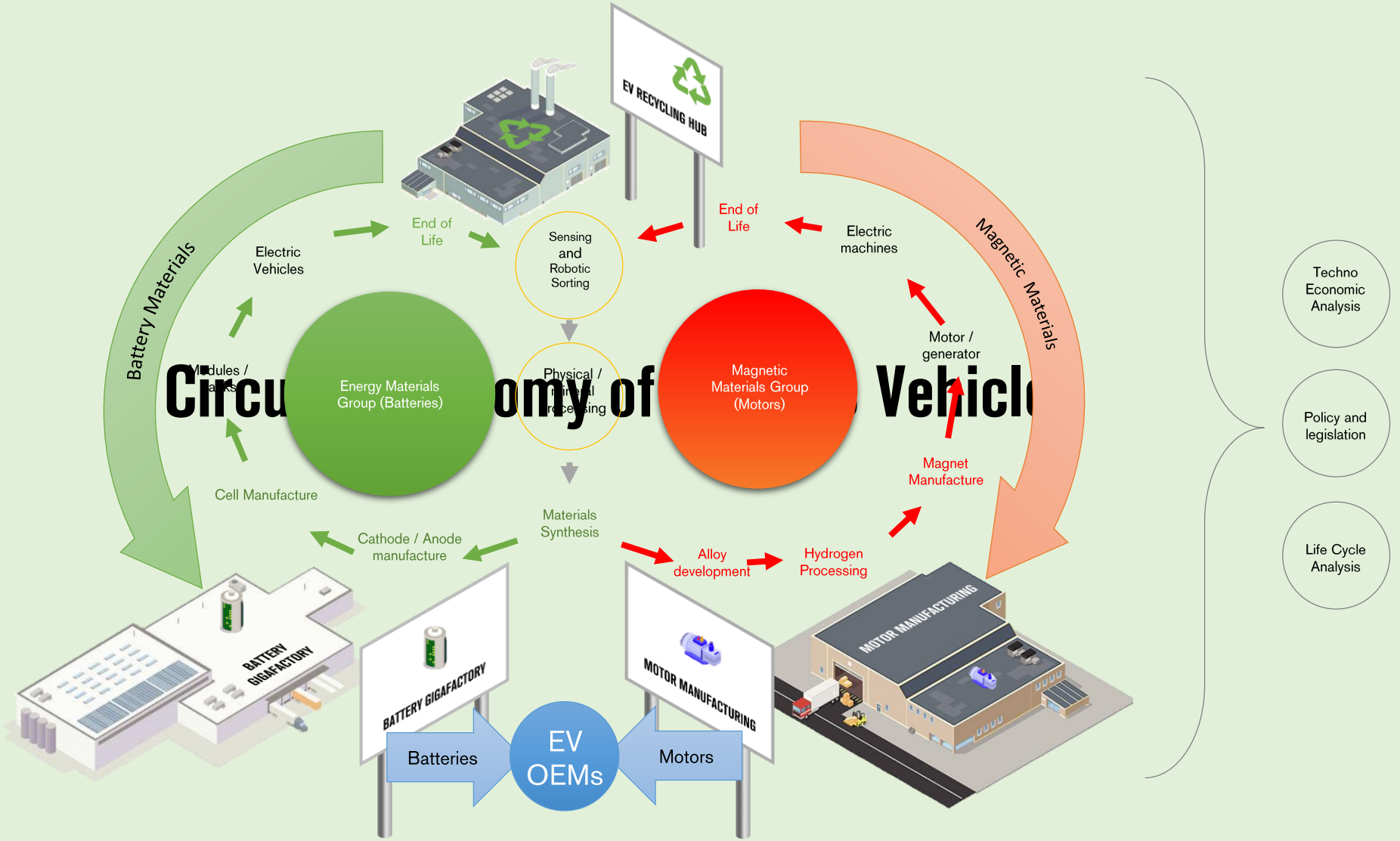
- Sealants may be used in module manufacture (difficult to remove)
- Cells stuck together in modules with adhesives (difficult to separate)
- Components may be soldered together (difficult to separate)
- Module state of charge may not be known

CELL DISASSEMBLY



Recovered Materials (depending on cell chemistry & recycling process):
- Cobalt
- Nickel
- Lithium
- Graphite
- Manganese
- Aluminium
- Plastics

- Clean separation of anodes and cathode for direct recycling difficult
- Very finely powdered materials present risks (nanoparticles)
- Potential for HF compounds formed from electrolyte
- Potential for thermal effects if cells shorted during disassembly
- Chemistries not always known / proprietary
- Additional challenges with cylindrical cells (unwinding spiral)


EV RECYCLING HUB
Battery Materials
Magnetic Materials
End of Life
Electric Vehicles
Sensing and Robotic Sorting
End of Life
Electric machines
Energy Materials Group (Batteries)
Physical / Material processing
Magnetic Materials Group (Motors)
Modules / Packs
Motor / generator
Cell Manufacture
Magnet Manufacture
Materials Synthesis
Cathode / Anode manufacture
Alloy development
Hydrogen Processing
BATTERY GIGAFACTORY
BATTERY GIGAFACTORY
MOTOR MANUFACTURING
MOTOR MANUFACTURING
Batteries
EV OEMs
Motors
Techno Economic Analysis
Policy and legislation
Life Cycle Analysis

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