Swiss Re Institute

February 2023

Gearing up for the electric vehicles ecosystem

Risks along the value chain – Part II

Contents

Key takeaways

The road ahead for electric vehicles (EVs)

1. **While sales of EVs are growing, risks in the value chain must be better understood and mitigated**
Replacing combustion engines (ICEs) changes risk profiles across the entire automotive value chain. Changes include: construction of new manufacturing facilities, sometimes without adequate due diligence; transportation of EVs in unsuitable vessels; adaption of driving behaviour and usage profiles.

2. **EV transportation can cause challenges for both shipping and insurance**
Conditions such as high battery state of charge (SoC) and EV stowage in close proximity may increase fire risk. EVs can release large quantities of toxic gases such as hydrogen fluoride, which, in enclosed conditions such as a roll-on-roll-off deck environment, can cause corrosive injury.

3. **Batteries are a key risk differentiator; over 90% of EV recalls are due to battery manufacturing defects**
Battery quality resulting from rushed innovation is an emerging risk. Analysis in the United States found over 90% of EV recalls in a selected sample involved defective batteries. These could lead to an increased risk of fire and explosion.

4. **Supply chain delays and execution complexities could result in significant business interruption (BI) risks**
A breakdown in the production chain can lead to property damage and business interruption. Contractor experience in battery manufacturing is still evolving, which could cause significant delays. Longer set up time, insufficient inventory and procurement delays for IT components and microchips could also pose significant BI risks.

5. **The circular flow of EV battery components will depend on adequate recycling capacity**
By 2030, recycled lithium-ion batteries could power up to 2 million EVs (or one-in-four EVs sold in 2030 under the net zero scenario). However, there are risks related to battery recycling scale and cost, environmental damage, safe transportation of used batteries and quality of recycled batteries. For instance, use of lightweight fiber materials to balance out the higher curb weight result in low recyclability.

6. **Insurers can play a key role in risk assessment and holistic risk management within the EV ecosystem**
Insurers can get involved early on with advice on EV factory design and international and local standards. They can partner with battery research labs to better understand links between battery performance, degradation and the external environment. Real time supply chain analytics can help better identify automotive risks during transportation while risk engineering services can provide recycling risk assessments.

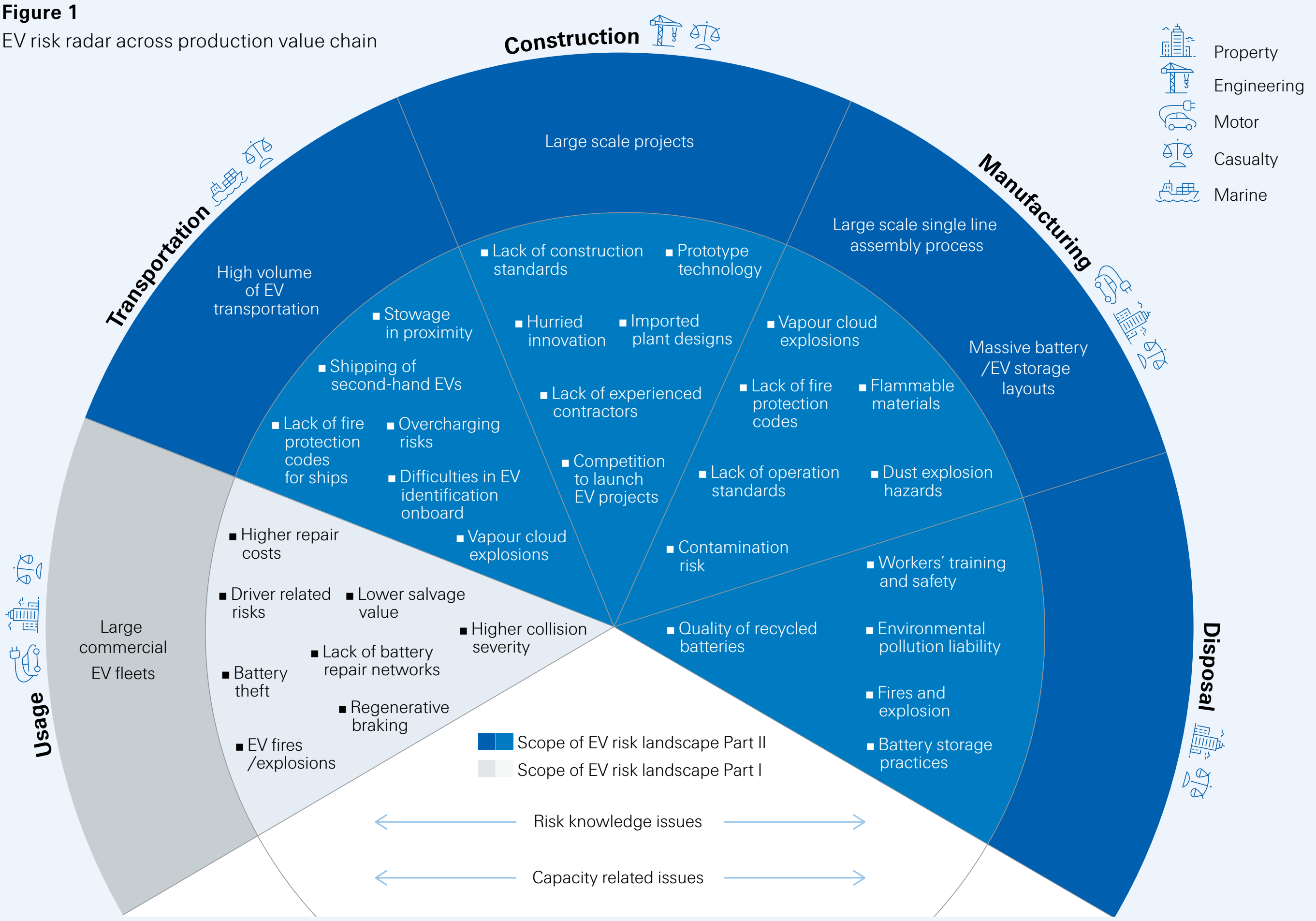
Complex risk landscape along the EV value chain

The transition to net-zero will mean switching to low-emission fuels and to electric powered vehicular transport. Mobility accounts for almost a fifth of global carbon dioxide emissions.[1] Momentum is building in the transition from internal combustion engine cars (ICEs) to electric vehicles (EVs). While the COVID-19 pandemic dampened traditional vehicle sales, global sales of electric cars more than doubled from 3.1 million in 2020 to 6.6 million in 2021 and surpassed 10 million in 2022.[2]

Bumps in the road: Risks of EV roll-out

The risk landscape around the EV value chain is complex. We focus on battery risks in particular, which is the key distinguisher of EVs from ICEs. Replacing ICEs with EVs affects the entire automotive value chain. The transition to EVs implies changes in driving behaviour and usage profile (eg, range anxiety, concerns about battery health and lifetime). New and unknown risks could arise during EV construction, distribution and ultimately disposal including: i) rapid construction of manufacturing facilities; ii) sourcing of raw materials; iii) assembly, transportation and usage of vehicles; and iv) disposal and recycling of old batteries. Each activity carries distinct risk vulnerabilities and insurers will need to develop a deeper understanding of processes to underwrite these effectively. At the same time, telematics driving data from connected EVs[3] is enabling the creation of new insurance tools. Figure 1 illustrates this complexity across insurance lines of business and the EV value chain. As this new technology is one of the key ingredients of decarbonised mobility, it is essential for insurers to take a first-mover approach and set new standards in assessing the risks of EVs and their batteries.

Figure 1
EV risk radar across production value chain



Source: Swiss Re Institute. Note: The diagram is purely illustrative. Placement of risk drivers in different phases does not necessarily indicate their relative importance.

We structured the risks along the EV value chain into two broad sections. The first part of the report focussed on the major risks faced during usage and repair of EVs[4], while this report discusses in greater detail the risks faced along transportation, construction, manufacturing, and disposal phases of EVs.

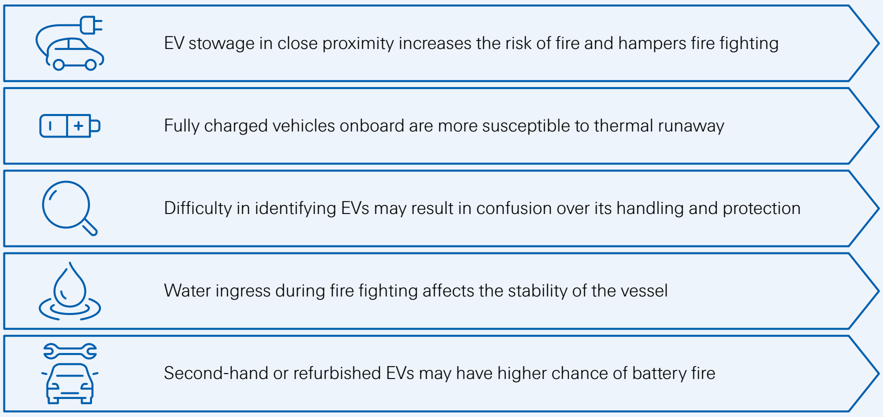
[1] *EMIT database, Sustainability Insights*, McKinsey, September 2021.
[2] *Energy Transition in 2023: Into a New Era*, BloombergNEF, 10 January 2023.
[3] High end EVs have more than 100 sensors on an average.
[4] *Gearing up for the electric vehicles ecosystem*, Swiss Re, 2023.

Transportation and storage of EVs

Key takeaway: Recent fires on ro-ro vessels carrying EVs have shown how a rise in battery temperature can ignite EVs and result in very different loss dynamics compared to traditional ship fires. Conditions such as high battery state of charge (SoC) and EV stowage in close proximity may increase the risk of fire. EVs can release large quantities of toxic gases and metals when exposed to conditions involving overpressure. Firefighting and protection standards for EV transportation are not yet well defined – a key concern for the insurance industry.

The transportation of EVs through multi-modal transport mechanisms increases challenges for both the shipping and insurance industries. Currently EVs are shipped alongside ICEs through roll-on-roll-off vessels (ro-ros), such as PCCs (Pure Car Carriers) and PCTCs (Pure Car and Truck Carriers).[5] Although causes of loss are difficult to determine, the presence of EVs on board of may potentially contribute to fire and eventual sinking of a typical vessel (refer to Figure 2 for further EV related reasons causing vessel accidents). Carriage of EVs on vessels will invariably need changes in the design and construction of vessels, fire detection and protection capabilities, as well as cargo loading and identification procedures.

Figure 2
Possible reasons for accidents of vessels carrying EVs



Source: Swiss Re Institute.

EVs are usually charged to a high degree before transportation since they lose charge during transit. However, fully charged EVs may be more susceptible to battery thermal runaway and resulting ignition can be long lasting. As of now, there is no standard for battery SoC for EVs on board a vessel; although thermal runaway is unlikely at a SoC below 30%.[6] However, subject to suitable controls, ships could be redesigned to have onboard charging facilities if vehicles need to maintain at least 30% charge during transit. Second-hand EV transportation is more complex due to a higher probability of thermal instability due to battery degradation.[7]

EV battery fires are extinguished by using large quantities of water to cool down batteries. However, using lot of water can destabilise a vessel. EV batteries can reignite hours or even days after the fire, especially if there is a lot of charge left. Mitigating this risk requires thermographic equipment to make sure that the battery has reached ambient temperature. More research is needed to develop heat release rate curves of different EVs to calibrate fire protection mechanisms and model insurance losses.

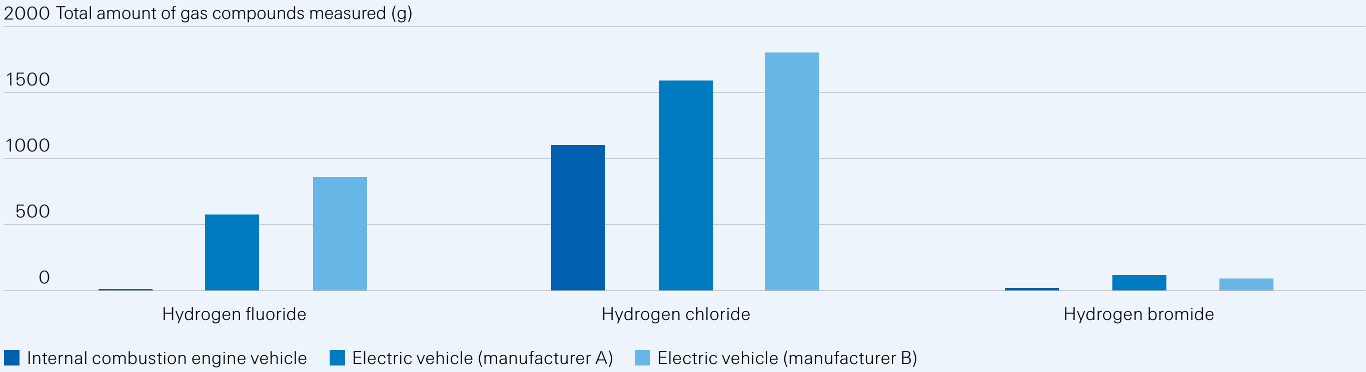
EVs are also stowed in close proximity to maximise storage space on vessels. This makes access to burning vehicles and firefighting extremely challenging. Research shows that ship sprinkler systems alone are not effective at extinguishing EV fires.[8] Firefighting and protection standards for EV transportation are not yet well defined given that regulations and standards governing EV batteries are not yet harmonised across original equipment manufacturers (OEMs) and countries, even for land-based use. Ships are enclosed spaces where EV fires can lead to additional complexities such as gas or vapour cloud accumulation. Vapour clouds can be toxic and explode; fire fighters need special training and breathing equipment to operate in such environments. Salvage and wreck removal practices for ships carrying EVs can also be different due to potentially toxic materials in batteries.

There are several toxic gases present when smoke from a vehicle fire is inhaled, regardless of the type of vehicle burning. However, EVs may release larger quantities of specific toxic gases and metals, such as hydrogen fluoride (HF), compared to ICEs[9] (Figure 3). The possibility of HF inhalation is particularly concerning as it can cause toxic exposure or corrosive injury. In the case of an enclosed ro-ro

[5] Some of these vessels can carry more than 8000 vehicles stored on multiple decks.
[6] Guidance on the carriage of AFVs in Ro-Ro spaces, *European Maritime Safety Agency*, May 2022.
[7] Admiral, Pros and cons of buying a used electric car, March 2020.
[8] *Loss Prevention Insight, Issue Number 1*, Britannia, August 2021.
[9] Results are based on three full-scale fire tests comprised of two battery electric vehicles and one internal combustion engine vehicle. Please see RISE, Toxic Gases from Fire in Electric Vehicles, 2020.

deck environment, the toxicity of an EV fire can be even higher without sufficient ventilation. However, ventilation and other openings may also assist growth and intensity of fire and burning time.

Figure 3
Toxic gases released by electric vehicles and internal combustion engine vehicles



Source: RISE, Toxic Gases from Fire in Electric Vehicles, 2020.

Conditions, such as SoC, influence the growth and peak of heat release. Experiments have demonstrated that higher SoC resulted in higher Heat Release Rate (HRR) peaks and more thermal reactive responses along with rapid temperature increases[10]. Table 1 below summarises the various hazards associated with transportation and stowage of EVs.

Table 1
Influencing factors of EV fire during vessel transport, and considerations for safety

Factors influencing fire	Key hazards	Considerations for safety
Transporting environment (enclosed or open)	▪ In closed ro-ro environment, the relative toxicity of smoke/gas from EV fire is higher than conventional vehicle fire	▪ Appropriate ventilation conditions (eg, for closed ro-ro space, appropriate percentage limits of openings in the side plating and closed ends for self-extinguishing)
Charging conditions a) State of Charge (SoC) b) Charging while being transported	▪ High SoC results in higher Heat Release Rate (HRR) peaks, more thermal reactive responses along with rapid temperature increase, and flammable gas production ▪ High occurrence probability of fire while on charging	▪ Ensure SoC within safety limits while being transported (<30% recommended) ▪ Avoid charging onboard unless safety is proven for parameters including electrical and explosion protection, IP55 protection, electromagnetic compatibility, voltage and frequency deviations etc.
Engine type of EV	▪ Failure mechanisms may be different for hybrid and pure battery EVs ▪ Difficulty in identifying engine type ▪ Fire risks associated with different different engine types are not well distinguished/understood	▪ Incorporate separate management and firefighting protocols for pure and hybrid battery EVs
Battery type of EV	▪ Nickel-manganese-cobalt (NMC) battery cells may release more toxic gas and metals; could self-ignite the vented gas (relative to lithium iron phosphate (LFP) cells)	▪ NMC EV transportation requires advanced monitoring and firefighting measures due to high metal toxicity and gas release
Overpressure due to battery exposure to elevated temperatures, short circuit, overcharge, cell failure etc.	▪ Production and release of toxic compounds including hydrogen fluoride and toxic metals	▪ Use of off-gas detectors for early identification of a thermal event ▪ Proactive measures to deal with highly toxic compounds such as hydrogen fluoride
Stowage in close proximities	▪ Rapid propagation of fire ▪ Difficulty in accessing burning vehicle and firefighting	▪ Hazard distances between vehicles and for firefighting need to be determined in advance; stowage spaces should be designed and managed accordingly

Source: Literature surveys, Maritime and Coastguard Agency (2021)[11], Larsson, Fredrik, et al. (2014), DNV GL[12] , Allianz[13], Swiss Re Institute.

[10] Larsson, Fredrik, et al. "Characteristics of lithium-ion batteries during fire tests." Journal of Power Sources 271 (2014): 414-420.
[11] Maritime and Coastguard Agency, Marine guidance note: MGN 653 (M) - electric vehicles onboard passenger ro-ro ferries, 2021.
[12] DNV GL, Fires on ro-ro decks, 2016.
[13] Allianz, Lithium-ion batteries: Fire risks and loss prevention measures in shipping, August 2022.

Manufacturing and assembly of EVs

Key takeaway: Over 90% of EVs recalled in a selected sample were related to an increased fire risk due to battery manufacturing defects. Battery and vehicle innovations to meet growing demand may generate additional risks. Long lead times and higher concentration of production could pose significant business interruption (BI) risks, especially when emergency stocks are not available. Risks, such as heat accumulation, could be moderated through refined battery component design.

Construction and operational risks for EV batteries
Growing demand for EVs will lead to a sharp increase in large-scale battery and component manufacturing investments. Existing construction codes for ICE automotive plants may not to be applicable for EV and battery manufacturing projects. Table 2 addresses specific construction and operational risks of these new projects. Moreover, plant designs from Asia (largely China and South Korea) may not be easily transferable to western markets due to different construction and protection standards. The composition of battery cells and units vary across manufacturers and can lead to heterogeneity and complexity in plant layouts.

Table 2
Construction and operational risks of battery and component manufacturing projects

Key risks	Root causes	Challenges	Impact	Risk solutions
Fire and explosion	▪ Chemicals stored onsite ▪ Combustible packaging ▪ Inflammable equipment ▪ Energised battery cells ▪ Combustible loads from the components during assembly ▪ Mechanical, thermal, electrical treatments on lithium ion battery (LIB) cells	▪ Different battery types may need different safety measures ▪ Fire suppression systems may not be comprehensive ▪ Environmental risks exist	▪ Property damage and business interruption (PD & BI) ▪ Liability ▪ Project professional indemnity loss	▪ Fire separation, sprinkler protection etc. ▪ Non-combustible construction ▪ Appropriate type & capacity of fire detection & suppression ▪ Safe handling of materials ▪ Appropriate storage measures ▪ Fire protection standards ▪ Incoming quality control
Machinery breakdown	▪ Breakdown in electrode production and separator preparation equipment ▪ Breakdown in assembly equipment for battery cells, modules, and packs	▪ High potential for damage during testing, commissioning, and operations due to high prototypicality	▪ Revenue loss ▪ Repeated testing costs ▪ Serial losses ▪ Maintenance period losses ▪ PD & BI	▪ Require developers to rely on the warranties from manufacturers ▪ Consider level of cover against warranties, ensure no specific gaps in cover in event of loss ▪ Ensure relevant quality standards are followed
Prototypicality	▪ New process methodologies with solid electrolytes, artificial graphite, new cathode materials including LFP and NMC 811	▪ Non-insurability of prototypical risks	▪ High-cost cover or no cover ▪ Product recall ▪ Testing costs ▪ Serial losses ▪ PD & BI	▪ Attention to process methodology ▪ Ensure process has a proven reference plant, or that any "first of a kind" plants are simply scale-ups of existing technology
Delay risk or business interruption (BI)	▪ Supply chain risk: concentration of components in few regions ▪ Interdependencies: centralised production of electrodes and supply to multiple lines	▪ Manufacturing move to high-throughput continuous process with large single machines ▪ Interplay of multiple components in batteries	▪ Loss due to long-lead replacement times ▪ Delay in start-up risks ▪ Revenue loss ▪ Environmental liability	▪ Ensure in-house production capacity and alternative supply (especially electrodes) ▪ Examine revenue streams in detail (projected revenue, assumption in the operation of factory, degree of redundancy designed into the system, lead times for replacement)
Environmental and health risks	▪ Consequences of fire hazards ▪ Requirement of massive amount of cooling water ▪ Release of hydrogen fluoride which can affect respiratory system	▪ Toxicity of evolving cell chemistries not well understood ▪ Heterogeneity of safety codes	▪ Third party and environmental liability	▪ Fully understand emergency procedures to ascertain how far the effect on the surrounding environment will be contained and controlled

Source: Literature surveys, Marsh[14], Swiss Re Institute.

[14] Marsh, Lithium-ion battery manufacturing plants – risk and insurance considerations, March 2022.

Fire and explosion: Battery manufacturing is a hazardous occupation. The process involves flammable liquids, powder mixing and heat transfer boilers. Conditions could create dust explosions and contamination risks. Even if batteries are manufactured elsewhere and installed in vehicles at the OEM's plant, inventory management involves storing and charging huge stacks of batteries. These create fire and explosion risks, especially when batteries are rapidly charged and discharged. As with construction risk, standards and protection codes are still developing for EV manufacturing facilities. The National Fire Protection Association (NFPA), a global non-profit organisation, provides the standards most insurers use for Battery Energy and Storage System (BESS) risks. However, some BESS-compliant facilities have seen recent losses despite obtaining required certification.

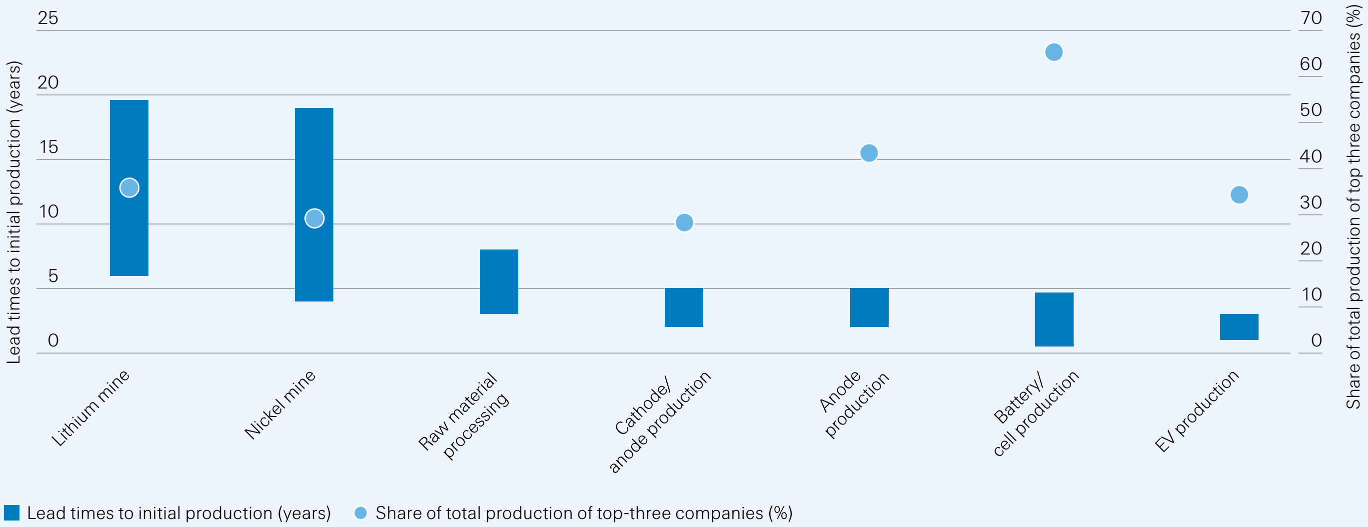
In some instances, regulatory inspections of established plants have necessitated retrofits or change orders to comply with more stringent risk standards. This can lead to construction delays. It is therefore critical to adapt designs to local contexts by consulting regulators early and vetting new designs before construction. Early involvement of insurers through risk engineering and data collection can enable more capacity for these projects.[15]

Defects and machinery breakdown: The need for a rapid expansion of energy density at a lower material cost often necessitates the adoption of new materials and process methodologies in battery manufacturing operations. The industry is witnessing accelerated progress in developing solid state batteries, artificial graphite and new cathode materials including lithium iron phosphate (LFP). Such advancements may pose novel risks to the industry leading to non-insurability or higher costs of cover. Insurers need to examine new process methodologies that may cause damages during testing, commissioning and operations. When process methodologies are highly prototypical, developers may have to rely on guarantees and warranties issued by suppliers and manufacturers.

Delay risks or business interruption: EV battery manufacturing is mostly a single line process comprising of different sections from powder mixing to casting, calendaring, notching, charging and storage. A breakdown in the production chain can lead to property damage and business interruption. With contractor experience in battery manufacturing still developing, especially outside Asia, projects are exposed to supply chain delays and execution complexities. Construction sites for large factories need significant amount of land, water, skilled labour, access routes and other resources. These are in short supply in remote areas, where projects are now being set up due to cheaper land and subsidies. Moreover, loss mitigation and firefighting capabilities in these areas may not be at par with more developed industrial clusters.

Longer set up time and higher concentration of production could pose significant BI risks, especially when sufficient inventory is not available (Figure 4).[16] [17] Production facilities that require longer lead times can extend plant construction and restoration periods. Insurers should also consider additional time required for other construction stages such as setting up equipment in clean room environments. BI insurable values also vary significantly in accordance with cell types and capacities. This calls for specific EV and risk engineering advice. Besides battery related supply chain disruptions, the global semiconductor chip shortage may also result in significant production delays.

Figure 4
Share of top three companies in EV supply chain and typical set up time for each process



Source: IEA (2022); Swiss Re Institute.

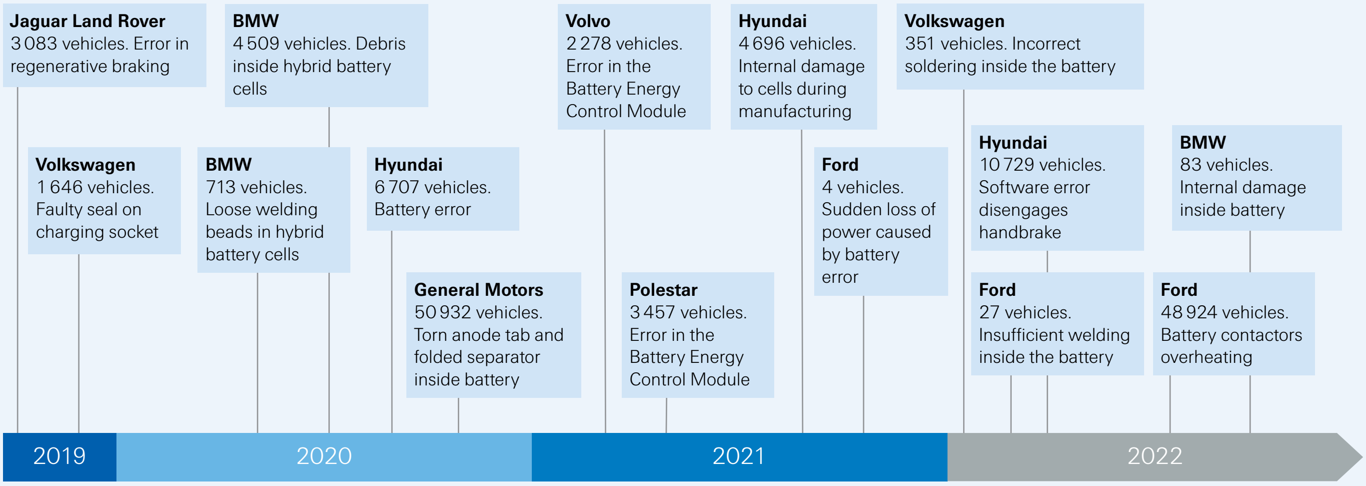
[15] *Webinar: Building for the future of EVs,* Marsh McLennan , 01 June 2022.
[16] IEA's lead time calculations for mines are from completion of the preliminary feasibility study to the start of production. Lead times for other elements are from investment decision to production. Please see IEA, Global EV Outlook, 2022.
[17] Production percentages of top-three companies for 2021 are based on IEA analysis. Please see IEA, Global EV Outlook, 2022.

Specific material design considerations

Recent EV recall incidents (Figure 5) highlight key issues (both battery-related and other), as OEMs are still adapting car designs and manufacturing lines. Recall issues have ranged from software bugs to welding errors, internal damage and debris inside batteries. However, SRI analysis of the largest US EV recalls shows that over 90% of vehicles recalls were because of increased fire risk due to battery manufacturing defects. Thermal runaway occurs when a battery cell short-circuits and the exothermic reaction goes out of control. If a cell is abused, chemical reactions generate heat and flammable gases by replacing normal electrochemical reactions. As the temperature rises, the chemical reaction rate increases and further heats up the cell, which may result in events including fire and explosion. Also ICEs are not immune to recalls, but any meaningful comparison with EVs will only be possible over time as we acquire larger recall data sets.

Figure 5

Timeline of major EV recalls in the US (selected)



Source: Swiss Re Institute and National Highway Traffic Safety Administration (NHTSA) (USA) data on vehicle recalls.

A number of material issues can lead to thermal events. Table 3 describes their root causes and ways to address the associated design challenges to mitigate the possibility of a recall/loss event.

Table 3
Challenges posed by material design defects

Issues	Causes	Considerations for safety[18]	Related recall events
Onset of overheating	Dendrite formation	▪ Reliable anode material ▪ Multifunctioning liquid electrolytes and separators	▪ 2020 General Motors recall: 50 932 vehicles, torn anode tab and folded separator inside battery. High state of charge often identified as cause in alleged claims of fire.[19]
	Overcharging, aggressive charging profiles	▪ Overcharging protection: redox shuttle additives, etc.	
Heat accumulation and gas release	Decomposition of cathode materials	▪ Reliable cathode materials: LFP	▪ 2021 Hyundai recall: 4 696 vehicles, internal damages to cells during manufacturing. Folded anode tab that could allow lithium plating to contact the cathode resulting in an electrical short. Remedy battery produced with insulation coating on the cathode.[20] ▪ 2022 BMW recall: 83 vehicles, internal damage inside battery. A cathode plate may have been damaged during cell production which could have allowed pieces/debris to enter a battery cell.[21]
	Electrochemical reactions during battery temperature increase	▪ Thermally switchable current collector	
	Direct electrical contact between the cathode and anode	▪ Thermal shutdown separators	
	Low thermal stability of battery separators	▪ Separators with high thermal stability	
	Inadequate regulation of temperature	▪ Battery packages with cooling function	
Thermal events including combustion and explosion	Accumulation of heat and oxygen leading to combustion	▪ Flame retardant additives ▪ Non-flammable liquid electrolytes ▪ Solid electrolytes	▪ 2020 BMW recall: 4 509 vehicles, debris inside hybrid battery cells. Vehicle had a thermal event. High rate of impurities might have entered one or more cells during production process.[22]

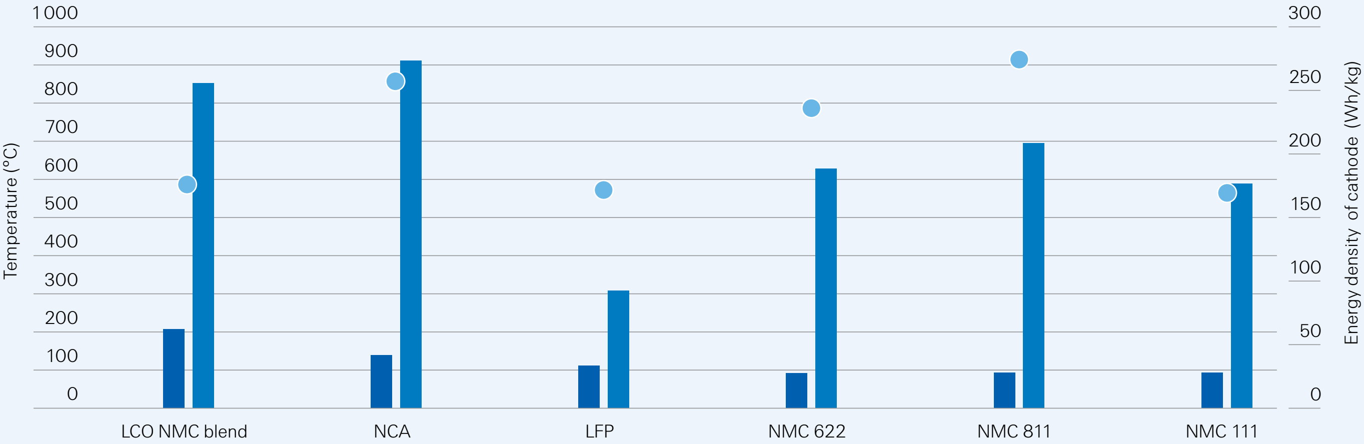
Source: Liu, Kai, et al. (2018); NHTSA (USA) data on vehicle recalls; Swiss Re Institute.

The material issues described above could be addressed to a significant extent through design modifications in key battery components, such as cathode, electrolyte and separators.

Material considerations for cathode chemistry (addressing heat accumulation and gas release): As evident from recent announcements, OEMs are taking a diversified approach by adding multiple battery chemistries to their portfolio. This could change the risk profiles of future EV fleets. For instance, Ford expressed its intention to add LFP capacity alongside NMC to reduce reliance on supply constrained minerals.[23] LFP cells offer several safety, durability and cost advantages. NMC cells generally have a lower runaway onset temperature and can reach a higher temperature in a thermal runaway event, releasing large amounts of electrochemical energy. They are therefore less safe compared to LFP cells (Figure 6). On the other hand, NMC batteries are less durable and have shorter lifecycles (Figure 7).[24]

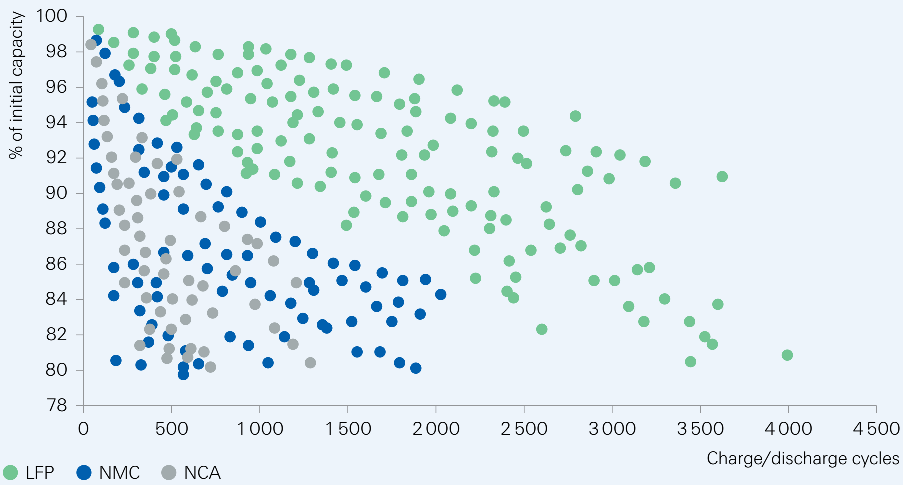
[18] Liu, Kai, et al. "Materials for lithium-ion battery safety." Science advances 4.6 (2018): eaas9820.
[19] NHTSA, Part 573 Safety Recall Report 20V-701, 2020. *RCLRPT-20V701-2513.PDF (nhtsa.gov).*
[20] NHTSA, Part 573 Safety Recall Report 21V-127, 2021. *RCLRPT-21V127-1095.PDF (nhtsa.gov).*
[21] NHTSA, Part 573 Safety Recall Report 22V-541, 2022. *RCLRPT-22V541-1655.PDF (nhtsa.gov).*
[22] NHTSA, Part 573 Safety Recall Report 20V-601, 2020, *RCLRPT-20V601-2497.PDF (nhtsa.gov).*
[23] Ford, Ford Releases New Battery Capacity Plan, Raw Materials Details to Scale EVs, 2022.
[24] Preger, Yuliya, et al. "Degradation of commercial lithium-ion cells as a function of chemistry and cycling conditions." Journal of The Electrochemical Society 167.12 (2020): 120532.

Figure 6
Difference in thermal runaway temperature triggers by cathode chemistry



Source: Literature surveys, Swiss Re Institute.

Figure 7
Discharge capacity retention comparison relative to initial capacity



Source: Preger, Yuliya, et al. (2020).[25]

Considerations for electrolyte (addressing development of thermal events): Replacing flammable liquid electrolyte with non-flammable solid electrolyte could improve battery safety. However, in solid state batteries (SSB) the use of lithium metal anodes is essential to improve the energy density.[26] The use of lithium as an anode causes dendrite growth, suggesting additional risk and potential safety concerns. Dendrite formation could lead to overheating and eventually thermal runaway. The choice of electrolyte in SSB could also determine the safety level. For instance, sulfide electrolyte in SSB could react with water and may produce toxic and inflammable hydrogen sulfide (H_2S) gas.

Material considerations for separator (addressing overall safety issues): The strength of the separator can influence the temperature of the internal short circuit, which can impact thermal runaway. Reducing the thickness of the separator to obtain high energy density can lead to internal short circuits and therefore possible thermal events. This is compounded by the fact that the volumetric energy density of batteries has increased almost nine times, from 55 to 487 Wh/l between 2008 and 2022; and is expected to further increase to 750–950 Wh/l levels by 2030.[27] Some suppliers are proactively managing this problem through mitigation measures, such as usage of thermal shutdown separators or tri-layer separators (eg, Samsung SDI 94Ah).

[25] NCA stands for Nickle-Cobalt-Aluminium and it is used as a cathode material.
[26] Paul Albertus, "Challenges for and Pathways toward Li-Metal-Based All-Solid-State Batteries," *ACS Energy Letters*, 22 March, 2021.
[27] Fraunhofer, Solid state battery roadmap 2035+, April 2022. *Solid-State Battery Roadmap 2035+ (fraunhofer.de).*

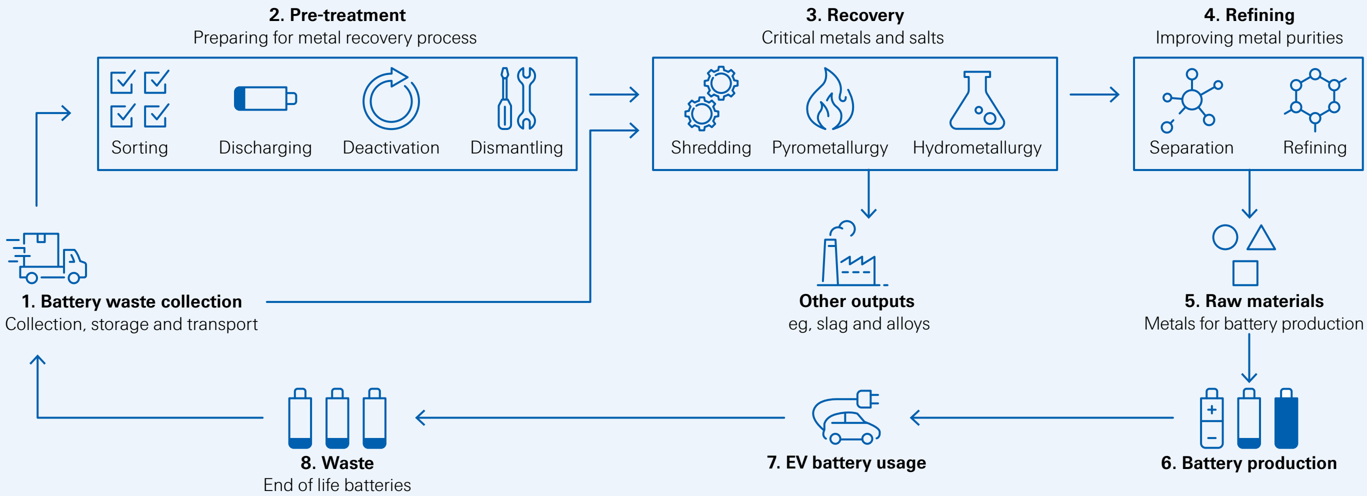
End of life recycling and disposal of critical battery components

Key takeaway: Lithium-ion recycling is yet to scale sufficiently and become economically profitable. Not all recycling technologies are at the same maturity level. Current battery designs are not optimised for easy disassembly and the wide variety of cell types and chemistries poses a major challenge, especially regarding process automation. The current lack of a large-scale commercial recycling solution for lithium-ion batteries is resulting in many uncertainties around battery decommissioning and associated costs.

The lithium-ion battery recycling market is expected to grow 12-fold to USD18 billion by 2030.[28] Recycling lithium-ion batteries is essential to help serve the global demand for lithium, while not putting undue pressure on environmental resources. SRI analysis indicates that by 2030, recycled lithium-ion batteries will be able to power up to 2 million EVs (or one in four EVs sold under the net zero scenario).[29]

Recycling risks
Lithium-ion recycling is yet to scale sufficiently and become economically profitable, unlike the relatively mature lead-acid battery recycling. Currently, end of life lithium-ion batteries can go to either: i) multiple recycling facilities (MRFs) which cater to a variety of waste; or to ii) landfills used for dumping batteries alongside other waste. According to reports, lithium-ion batteries are more likely to cause severe fires at MRFs than in landfills. As a result, some MRFs have stopped collecting lithium-ion batteries.[30] However, landfills too can have serious environmental consequences as dumped batteries can corrode and leak toxic chemicals into the soil and ground water. Dedicated lithium-ion battery recycling is a much safer option, although the high cost of building and operating battery recycling infrastructure is a major obstacle (see Figure 8 for the complexity of the process). Dedicated recycling facilities even specialise in particular chemistries to achieve higher product quality. However, for dedicated battery recycling to become well established, a number of unique risks along the recycling value chain have to be identified and mitigated. For instance, use of lightweight materials such as carbon fiber-reinforced plastic (CFRP) and glass fiber-reinforced plastic (GFRP) materials to balance out the higher curb weight result in low recyclability.[31]

Figure 8
EV recycling value chain and related risks



Source: Swiss Re Institute.

The current lack of a large-scale commercial recycling solution for lithium-ion batteries is giving rise to uncertainty about battery decommissioning and associated costs.[32] In addition, there are no global policies and standards to govern end of life management of lithium-ion batteries. Several policies have been announced, mainly in the EU, China, Japan, and the US. China is one of the few with technical guidelines on dismantling and restoring spent EV batteries, along with retraining staff at carmakers. The European Commission proposed new Batteries Regulation by 2023/24 as an update to older directives and could legislate OEMs to increase the share of recycled metal in a battery.

[28] ESG risk briefing, "The role of lithium in a low carbon economy and associated challenges", *agcs.allianz.com*, 26 May 2021.
[29] Estimations based on data from *CATL*, *Circular Energy Storage* and IEA.
[30] *An Analysis of Lithium-ion Battery Fires in Waste Management and Recycling*, EPA, United States Environmental Protection Agency, July 2021.
[31] Ahmad T. Mayyas and Mohammad Omar, "*Eco-Material Selection for Lightweight Vehicle Design*", *IntechOpen*, 25 March 2020.
[32] *Battery Energy Storage Systems*, Swiss Re Institute, July 2021.

The first step of the recycling process is the safe collection, storage and transport of used batteries. Transportation carries the risk of fire, explosion and leakage due to constant movement of older batteries which have varying degrees of cell degradation. More stringent safety measures to handle and transport used EV battery packs are needed, especially if this process is sub-contracted at various levels. In the recycling plant, batteries are first sorted based on their cell chemistries and then either completely discharged or thermally deactivated before shredding them to avoid explosion risks. However, the need for thermal deactivation can be avoided if batteries can be shredded in inert environments or treated through cryogenic crushing. Batteries are shredded, powdered and then either liquefied in a smelter (pyrometallurgy) or dissolved in acid solution (hydrometallurgy), before being refined and precipitated out as salts. The process helps in recovering valuable metals such as lithium, copper, nickel, cobalt and manganese. However, not all recycling technologies are at the same maturity level (see Figure 9).

Figure 9
Comparison of maturity for battery recycling technologies

Parameters	Shredding	Pyrometallurgy	Hydrometallurgy
Technology maturity	Low	High	Moderate
Execution complexity	High	Low	Moderate
Capital cost	Moderate	High	Moderate
Operational cost	High	Low	Moderate
Material loss	Moderate	High	Moderate
Emissions intensity	Moderate	High	Moderate

Low Moderate High

Source: Swiss Re Institute.

A fire resulting from batteries or associated components can damage the treatment facility and surrounding properties as well as result in fatalities. The blast at the Brunp Recycling Co. factory in Hunan, China, killed one person and seriously injured six others in January 2021. The explosion was caused by fire from waste aluminium foil.[33] Metal products should not be used in moving or storing batteries as they could puncture the battery shell; metals should also not come in contact with old batteries as this may cause short-circuit accidents. Lithium-ion batteries should be stacked neatly and with the use of anti-static wraps. Workers in recycling plants should be trained to extinguish blazing lithium-ion batteries.

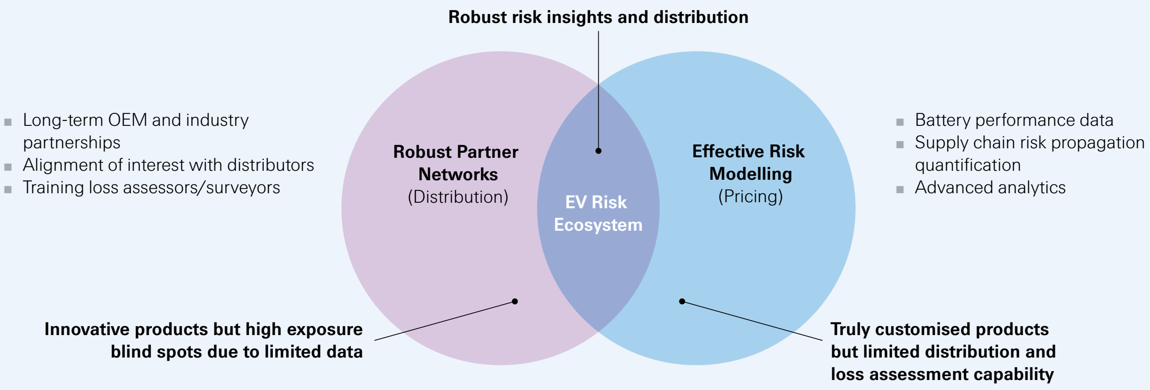
Current battery designs are not optimised for easy disassembly. OEMs, battery makers and recyclers rarely collaborate in product engineering and design. A wide variety of cell types and chemistries pose major challenges, especially to process automation during disassembly. Each pack and module type requires different approaches for disassembly. Battery manufacturers need to include labels or QR codes on battery cells or battery packs, with information on battery components, chemistries and substructures. This is addressed in the EU Battery Directive 2006/66/EC, which aims to develop a battery passport. This process will help streamline recycling and reduce fire hazards during battery disassembly and smelting. Closed loop recycling is important for OEMs aiming to boost revenues through repair and refurbishing of batteries.[34] Post-recycling, it is important to ascertain the sustainability and quality of the recycled product as well as dispose of end-of-life lithium-ion battery components safely with minimal environmental damage.

[33] Annie Lee, "*Blast at Chinese Battery Recycler Draws Attention to Industry's Supply Chain Risks*", Insurance Journal, 8 January 2021.
[34] *Long Term Strategic Plan*, Stellantis, 1 March 2022.

Role of insurers

Technology transition from ICEs to EVs will entail changes across the entire value chain. For the insured, sound risk management of exposures will be important; as will supply chain mapping to quickly identify critical material bottlenecks. Insurers will have to invest new resources in data collection, research risk and partnership creation (see Figure 10). This will provide insurers with the opportunity to pivot their risk knowledge and deliver effective risk transfer and services.

Figure 10
Insurance opportunities in the EV risk ecosystem



Source: Swiss Re Institute.

Effective risk modelling

Limited data hampers risk assessment of manufacturing, transporting and driving EVs compared to ICEs. Insurers´ awareness of new data requirements and preparing themselves for the collection and analysis of this data represents a first step towards more effective future risk modelling. With the increasing availability of connected data and cross-testing with claims data, initial models can then be refined over time.

Battery performance data: Development of depreciation scales, excess tables and indemnity values depend on battery performance data, especially for partial losses. However, the risks of battery ageing may take some time to be realised and cannot be priced into current coverage programmes. Dedicated testing facilities can help insurers collect risk and pricing data more quickly. Further, given the wide variety of unknowns and complexity of EV batteries, insurers need to monitor design, manufacture and testing of batteries. Through battery management systems (BMS) attached to individual batteries, EV OEMs also collect battery performance, charging and discharging profiles. Early insurer involvement can enable them to benefit from this data. In return, insurers can close the loop by providing loss data to OEMs.

Supply chain risk propagation quantification: Insurers can provide risk mitigation tools to identify inherent risks. These can be mitigated through structured risk assessment. Insurers can translate risk into potential losses, including non-physical risks such as non-physical damage business interruption (NDBI), business interruption (BI) or contingent business interruption (CBI). Unfortunately, protection gaps can remain large, impacting BI values and higher aggregate CBI exposures. Understanding the supply chain network, particularly at Tier 2 and Tier 3 suppliers, where most disruptions are likely, will be of great importance to insurers. Data is also critical for prevention. Supply chain disruptions must be recorded diligently and stored in a way that the data can be easily mined and reported. Closing these limitations will narrow the protection gap.

Robust Partner Networks

Collaboration models should be built on long-term partnerships based on mutual trust regarding data and revenue sharing, rather than short term tactical considerations. The right partnership approach will gain even more relevance with entry of new partners, such as battery manufacturers and analytics vendors, focussing on battery research.

Long-term OEM and industry partnerships: EVs do not have established battery performance and depreciation schedules, which account for up to 40% of the vehicle cost. Long-term partnerships with OEMs can help insurers understand the dynamics of EV propulsion technology and create property, business interruption and marine coverage most suitable for such vehicles. Customisation can apply to multiple OEMs as well as multiple vehicle models offered by a single OEM. Insurers can also be part of projects and initiatives working on finding permanent solutions to extinguish EV fires (including thermal runaway) onboard ships, eg, CFIS LASH FIRE[35], the IMO's Ship Systems and Equipment (SSE) sub-committee.

Alignment of interest with distributors: Insurer-OEM partnerships provide insurers access to consumers at the point of distribution. As OEMs transition to circular battery value chains and closed loop recycling, insurers, as long-term partners, can assess and price exposures. Data sharing is also important because of the variety of battery chemistries and resulting differences in performance and decay.

Training loss assessors/surveyors: Motor surveyors and loss assessors are the eyes of insurers and play an important role in underwriting and claims settlement functions. With the increasing number of EVs, both in-house and out-sourced surveyors may need training to assess EV damages. Historically, automotive technical experts have carried out this task, but the skillset may change with more demand for electronics and electrical experts. Specifically, understanding thermal runaway losses requires deep insight into battery operation and repair dynamics. Insurers will need to work with OEMs and data vendors to develop a curated curriculum for loss assessment.

[35] Conference on Fire Safety at Sea (CFIS), Legislative Assessment for Safety Hazards of Fire and Innovations in Ro-Ro Ship Environment (LASH FIRE), International Maritime Organisation (IMO).

Conclusion

More than a fifth of the total carbon dioxide emissions currently come from the transport sector. EVs can contribute to lowering these emissions. However, there are hurdles to EV adoption. Some of these challenges are customer facing (such as range anxiety and inadequate charging infrastructure); while others are production related (availability of materials, quality control, unknowns of battery or vehicle degradation). These risks provide insurers with a commercial opportunity to actively participate in the ecosystem by creating innovative risk coverage products.

In this publication, we have guided the reader through a forward-looking and holistic view of certain elements of the EV ecosystem risk. In particular, our focus has been on the risks associated with battery manufacture, transport, and recycling. Thermal runaway and release of toxic fumes related to battery fire, business interruption due to breakdown of the battery supply chain and contamination of soil and ground water due to dumping of batteries into landfills are just some of the many risks along the value chain that need to be recognised and addressed. Future battery solutions such as lithium-air, lithium-metal, solid state, lithium-sulphur and hydrogen fuel cells may mitigate some of the existing risks, while also creating new ones.

It is abundantly clear that the EV industry is evolving. Traditional vehicle insurance models are no longer enough to accurately capture the overall risk. We need risk models that can focus on the particularities of EVs; of the driving experience of an EV; of the production and transportation of EVs; and of the disposal and recycling of EVs. Ultimately, it is about finding the sweet spot- where environmentally friendly modes of transport (with a low carbon footprint across the value chain of production, use and disposal) meet financial viability for all ecosystem players (OEMs, insurers and service providers). Technology, data and innovation will all play a central role in the journey to arriving at the optimum balance.

Published by:
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The editorial deadline for this study was 30 January 2023.

The internet version may contain slightly updated information.

Graphic design and production:
Corporate Real Estate & Logistics / Media Production, Zurich

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