Risk assessment and success factors for mobility electrification – Why developing a robust, competitive, resilient, sustainable, and sovereign battery industry is critical to succeed in the green energy transition.

Final version, 28th February, 2024

AUTHOR: RÉMI CORNUBERT

Contracted by Concawe
Under the supervision of Dieter Walter and Roland Dauphin, Science Executives, Concawe Fuels Quality and Emissions
Contact:
Fuels@Concawe.eu
Tel: +32 2 566 91 60

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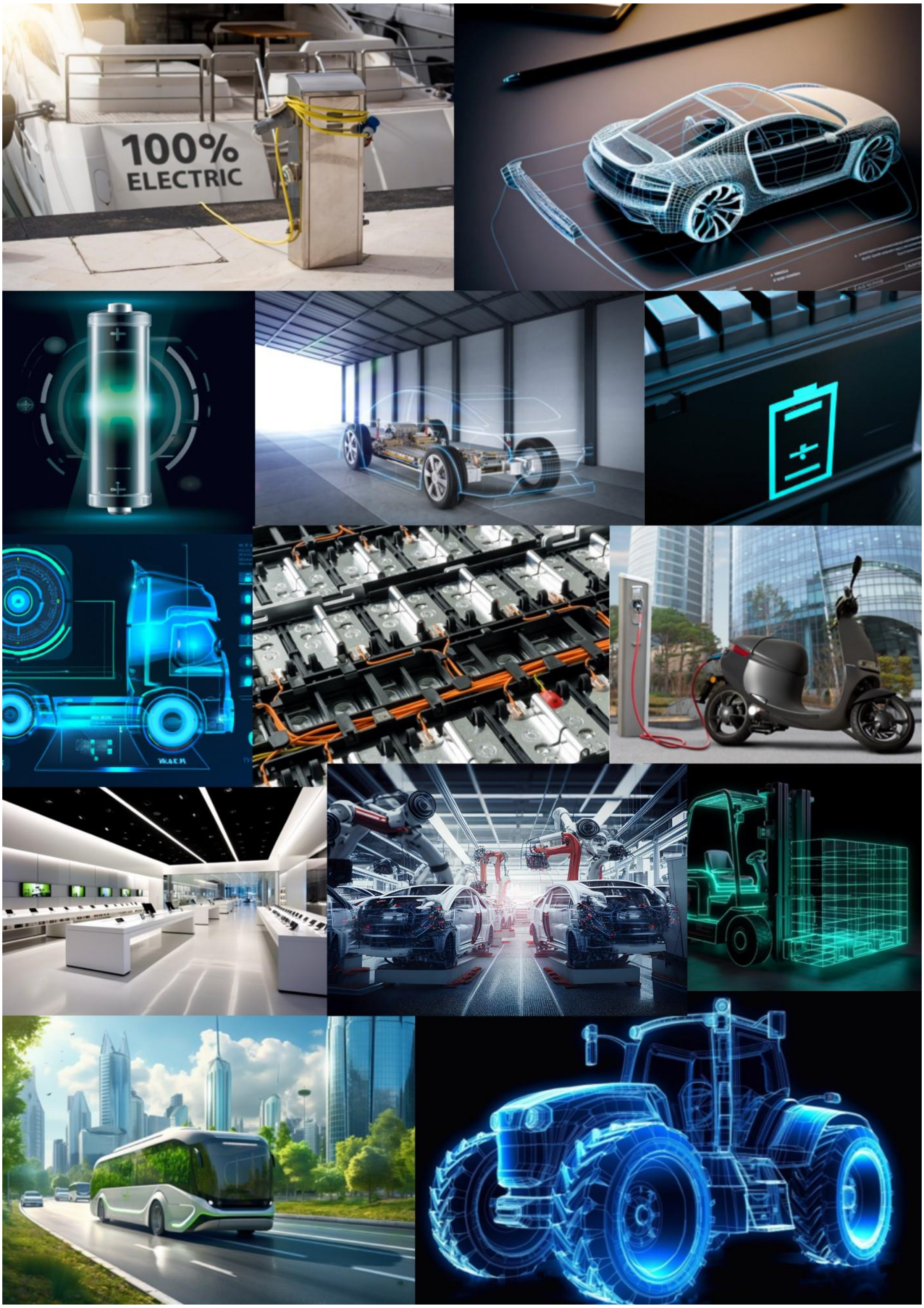

RISK ASSESSMENT & SUCCESS FACTORS FOR MOBILITY ELECTRIFICATION – WHY DEVELOPING A ROBUST, COMPETITIVE, RESILIENT, SUSTAINABLE & SOVEREIGN BATTERY INDUSTRY IS CRITICAL TO SUCCEED IN THE GREEN ENERGY TRANSITION

Final report for CONCAWE

Customer:
CONCAWE
Fuels Quality and Emissions
Boulevard du Souverain, 165
B-1160 BRUSSELS
Belgium
Tel: +32 2 566 91 60
Fax: +32 2 566 91 81

Customer Reference:

Study provider:
STRAT ANTICIPATION, 6, Alfred Roll Street – 75017 Paris, France

T: +33 9 81 18 10 86
M: +33 6 07 37 84 27
E: remi@stratanticipation.com

STRAT ANTICIPATION is qualified to analyze the global market for batteries both on the demand and supply sides. Its team has a longstanding experience in high-performance battery technologies and manufacturing.

Author:
Rémi CORNUBERT

Approved by:
CONCAWE following its validation process with 3 different committees.

Date:
28th February 2024

Strat Anticipation reference:

Ref: Global Battery Study – Issue Number 28

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ABSTRACT

High-performance batteries play a crucial role in the advancement of electric mobility. They are essential for unlocking the full potential of electrification in transportation, while also presenting challenges related to potential supply shortages if the production capacity of battery cells does not expand rapidly enough to meet the growing demand.

This study offers a detailed examination of the global and European battery markets, considering evolving regulations, consumer behaviors, and emerging technologies. The objectives of the battery study can be summarized in four main aspects:

- Develop forecasts for battery demand across various sectors, encompassing all forms of mobility, energy storage systems, and consumer electronics.
- Assess the availability of battery cell supply in different regions.
- Evaluate the impact of recycling and new chemistries on the markets for key metals.
- Determine the associated supply and strategic risks involved.

The study's main findings can be summarized as follows:

- A robust demand forecast extending up to the year 2035.
- A realistic projection of available battery production from 2023 to 2035.
- Insights into potential game-changing developments in battery technology.
- A comprehensive view of the supply, strategic, and geopolitical risks associated with the battery industry.

A detailed, bottom-up approach was employed to assess and forecast the demand and supply of Li-Ion batteries for both light and heavy-duty vehicles up to the year 2035. This granular bottom-up methodology is more robust than traditional top down and macro approaches and allows for the creation of scenarios for long-term forecasts to assess potential market outcomes.

Three scenarios were developed during this battery study: one serves as the reference scenario, referred to as "Baseline," and the other two capture the spectrum of possible outcomes. These scenarios provide a mean to evaluate the minimum and maximum market values for long-term forecasts, and specific names will be assigned to each scenario based on the assumptions made regarding application markets, demand, and supply.

Structure of the report.

The structure of this comprehensive report is designed to provide an in-depth analysis and a holistic view of the worldwide and European battery market, considering different aspects including regulation and market trends, technological advances, demand and supply, and potential challenges in scaling up production including securing the upstream value chain.

The report is organized as follows:

Chapter 1: Introduction and Overview - This chapter provides an overview of the report, explains the legislative and industrial context, outlines the scope of the study, and lists the objectives of the report.

Chapter 2: Market Needs, Regulation Trends, and Description of Technologies - This chapter provides insights into current regulatory trends impacting batteries, consumer perspectives, and a technological overview of different cell types and chemistries. It also covers battery prices and supply chain considerations.

Chapter 3: Worldwide and European Battery Demand - In this chapter, the global demand for batteries was dissected by each application market, with a focus on passenger cars and light commercial vehicles using a granular bottom-up approach. This chapter contains a comparative analysis of different trends and chemistries between China, Europe, and the USA.

Chapter 4: Worldwide and European Battery Supply - This chapter deep dives into battery supply, with a focus on main supply drivers and risks and capacity analysis. It also lays out different battery supply scenarios in Europe.

Chapter 5: Identification and Explanation of Major Bottlenecks, Enablers to scale up Battery Production in Europe - This chapter examines the challenges and opportunities in scaling up battery production in Europe. It also touches upon gigafactory risk exposure, raw material demand and supply, and the impact of battery cell production scrap and end-of-life battery recycling for supply of additional raw materials for new battery production in a so-called closed loop.

Chapter 6: Comparison between Supply and Demand and the Potential Gaps - This chapter offers a comparison between supply and demand scenarios and presents a detailed gap analysis.

Chapter 7: Annex: Cell, module and pack overview and technological overview - Chapter 7 of this report is an annex that provides an overview of various aspects related to battery technology. It is an additional section of the report that goes into specific details about cells, modules, and packs used in battery systems, along with a technological overview.

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Table of Contents

Table of figures

Figures in the main body:

Table of tables

Tables in the main body:

Glossary

Advanced Driver-Assistance Systems (ADAS): are technologies that enhance vehicle safety and driving experiences. Using sensors and advanced components, ADAS features include adaptive cruise control, lane departure warning, automatic emergency braking, and parking assistance. These systems aim to improve road safety, prevent accidents, and increase overall driver comfort.

Artificial Intelligence (AI): Artificial intelligence refers to creating computer systems that can perform tasks requiring human-like intelligence, such as learning, reasoning, and problem-solving.

Battery Cell: Basic electrochemical unit that provides a source of electrical energy by direct conversion of chemical energy; consists of an assembly of electrodes, separators, electrolyte, container, and terminals.

Battery Electric Vehicle (BEV): Vehicle powered solely by an electric motor.

Battery Module: Combination of cells into a frame in series or parallel to achieve serviceable units.

Battery Pack: Complete enclosure that delivers power to the electric vehicle; usually contains battery cells and/or modules, software (BMS), and often a cooling and heating system.

Battery Management System (BMS): Electronic regulator that monitors and controls the charging and discharging of rechargeable batteries.

Cell: Closed electrochemical system that converts chemical energy from oxidation and reduction reactions directly into electric energy.

Critical Metal: A critical metal is any essential metallic element vital for the energy transition, encompassing metals like copper, cobalt, lithium, manganese, etc.

Do-It-yourself (DIY): In the automotive context, DIY (Do It Yourself) refers to individuals independently performing tasks like car repairs, maintenance, or modifications without professional assistance.

Electric Vehicle (EV): Generic name for cars powered by electricity (electric powertrain).

Energy Storage Systems (ESS): Systems designed to store electrical energy for later use, often in the form of batteries.

FCEV (Fuel Cell Electric Vehicle): A type of electric vehicle that uses a fuel cell to generate electricity for powering an electric motor.

High-performance batteries: Advanced rechargeable energy storage devices characterized by their ability to deliver large power outputs with a large autonomy (high energy & power density), safe and a long cycle life (high number of cycles), making them well-suited for powering various mobility applications and energy storage of renewable energy.

HV (High Voltage): Classification of an electric component or circuit, if its working voltage is > 60 V and ≤ 1,500 V direct current (DC) or > 30 V and ≤ 1,000 V alternating current (AC).

Hybrid Electric Vehicle (HEV): Vehicle with an internal combustion engine supported by a small electric motor without plug charging. The battery charges itself, such as when braking or through the internal combustion engine.

IRA (Inflation Reduction Act): An acronym for Inflation Reduction Act.

Light Commercial Vehicles: Correspond to commercial vehicles under 3.5 tons.

LFP (Lithium Ferro-Phosphate): A type of lithium-ion battery using lithium iron phosphate as the cathode material, and a graphite electrode with a metallic backing as the anode.

LNMO (Lithium Nickel Manganese Oxide) battery: A type of lithium-ion battery that uses nickel, manganese, and oxygen as its key components.

LIB (Lithium-ion Battery): A type of rechargeable battery that uses lithium ions as the primary component involved in energy storage.

LCE (Lithium Carbonate Equivalent): A unit of measurement used to compare and quantify the amount of lithium in different lithium compounds, often used in the lithium industry.

LiPF6 (Lithium Hexafluorophosphate): A lithium salt commonly used as an electrolyte in lithium-ion batteries, known for its high solubility and stability in these systems.

LV (Low Voltage): Classification of an electric component or circuit, if its working voltage is ≤ 1,500 V direct current (DC) or ≤ 1,000 V alternating current (AC).

Na-Ion Battery: A type of rechargeable battery that uses sodium ions as the primary component involved in energy storage.

NAFTA (North American Free Trade Agreement): A trade agreement among the United States, Canada, and Mexico aimed at reducing trade barriers between the three countries.

NMC (Lithium Nickel Manganese Cobalt Oxide battery): NMC batteries have a cathode made of a combination of Nickel, Manganese, and Cobalt.

PHEV (Plug-in Hybrid Electric Vehicle): A hybrid electric vehicle that can be recharged by plugging into an external power source in addition to its internal combustion engine.

ROW (Rest of World): Refers to regions and countries outside of specific trade or geographic areas.

Virgin materials: are newly extracted materials that have not been previously used or recycled.

Zero-Emission Vehicle (ZEV) refers to a type of vehicle that produces zero carbon dioxide (CO_2) emissions during operation.

Acknowledgements

Through the course of this study, we have received contributions from a range of organizations and individuals through several different means (e.g., informal communications, interviews, published studies, data validation exercise responses and workshops / meetings…). We would like to formally acknowledge and thank all the contributors for their insights and for sharing their knowledge with us.

In particular, we are very grateful to Dieter Walter, Roland Dauphin, Gustav Krantz from CONCAWE who have challenged us during the course of the project and Simon Edwards & Bahareh Yazdani Damavandi from Ricardo and the FEMG team members from CONCAWE members in particular Alexis Roca, Beate Heisterkamp, Jukka Nuottimaki for guiding & advising on the key topics to be addressed. They have also spent a lot of time to review the various intermediate versions of this battery study to challenge us, help improve the report structure & flow, make sure that the report will be easy to read and understand by non-specialist readers. Strat Anticipation's team is very grateful to them. Strat Anticipation and Concawe have run several workshops to refine the methodology and to discuss market forecast and scenario assumptions.

A full list of contributor organizations from stakeholders can be seen in the table below (in alphabetic order).

Avicenne Energy
Baker McKenzie
BCG
Benchmark Mineral Intelligence (BMI)
Bloomberg NEF
Deloitte
DeLeon Energy
European Commission
EUROBAT
GlobalData/ LMC Automotive
ICCT
IEA
Lux Research
McKinsey & Company
Roland Berger
StreerGroup
Transport & Environment

0. Executive Summary

1. Legislative and Industrial Context

The Green Deal in Europe has accelerated the tightening of CO_2 regulation with a target to have only zero-emission vehicles sold in EU from 2035 onwards with Fit for 55 and the parliament just allowing an exception for vehicles running on CO2 neutral fuels.

Electric vehicles are considered by the EC to be the best technology to reduce CO_2 emissions – this will drive a strong demand for batteries in the European Union.

North America has recently tightened its EPA fuel consumption and some states are following California to allow zero-emission vehicles only after 2030.

In China, the Central Government has set a target market share for NEVs (EV, PHEV, HEV): the current target is 25% of sales in China and it is expected to be raised soon to 30% and then 35%.

Electrification of mobility was chosen to reach ambitious CO_2 reduction targets in all regions. Hybrid, Plug-in-Hybrid and full EV's call for high performance batteries Highly electrified vehicles (PHEV, EV) are crucial for OEM product plans to meet CO_2 reduction targets, leading to a surge in battery demand and future battery production.

Securing a reliable battery supply chain is critical for governments and OEMs alike as batteries typically make up ~35% of EV costs and a robust local battery supply needs to be built up.

2. Current Situation: Technologies and Supply Chain

In 2022, 78% of the total global 1092 GWh Battery Manufacturing Capacity was installed in China. Japanese and Korean manufacturers have set up plants in Europe and North America, while Chinese manufacturers still operate mostly in China.

Australia, Indonesia, and the Democratic Republic of Congo dominate mining, but China dominates the downstream supply chain especially for metal refining and cell materials. China is the largest refiner of lithium, nickel, cobalt, and graphite, as well as the top producer of battery cell components and cells by a wide margin. The country is also the largest producer of graphite. Europe and the USA have plans to play larger roles in battery manufacturing, but the IEA and Strat Anticipation, as forecasted in this study, expect China to remain the biggest player through 2030.

China continues to dominate the supply chain, with strength in sourcing and supremacy in production and refining.

In the US, the introduction of IRA set up massive subsidies which successfully attracted manufacturers all around the battery value chain. One year post the Inflation Reduction Act's enactment, the US is an attractive landscape for battery production, but with significant costs for the US government, and at the same time this is raising global tensions.

3. Existing Forecasts on Battery Demand and Battery Supply

Previous studies forecasted by 2030 a widespread lithium-ion battery demand between 2 TWh and 4.7 TWh. Battery demand for mobility accounts thereby for the major share (~ 90%) of it.

The projected range for Li-Ion battery manufacturing capacity in 2030 is even wider, between 3 and 8.2 TWh, with large uncertainties about capacity usage and battery production readiness.

Most of the already available battery demand and supply forecasts do not go beyond 2030 and therefore do not take into account Fit for 55 impacts on demand and supply.

Most of these studies used rather top-down approaches to make their forecasts. (Figures 75, 76a and 76b)

4. Global And European Battery Demand for All Application Markets

Global battery demand is forecasted to reach 3.3 TWh by 2030 and 5.2 TWh by 2035, with electrified light vehicles representing 80% of demand in 2030 and 77% in 2035. (Figure 4)

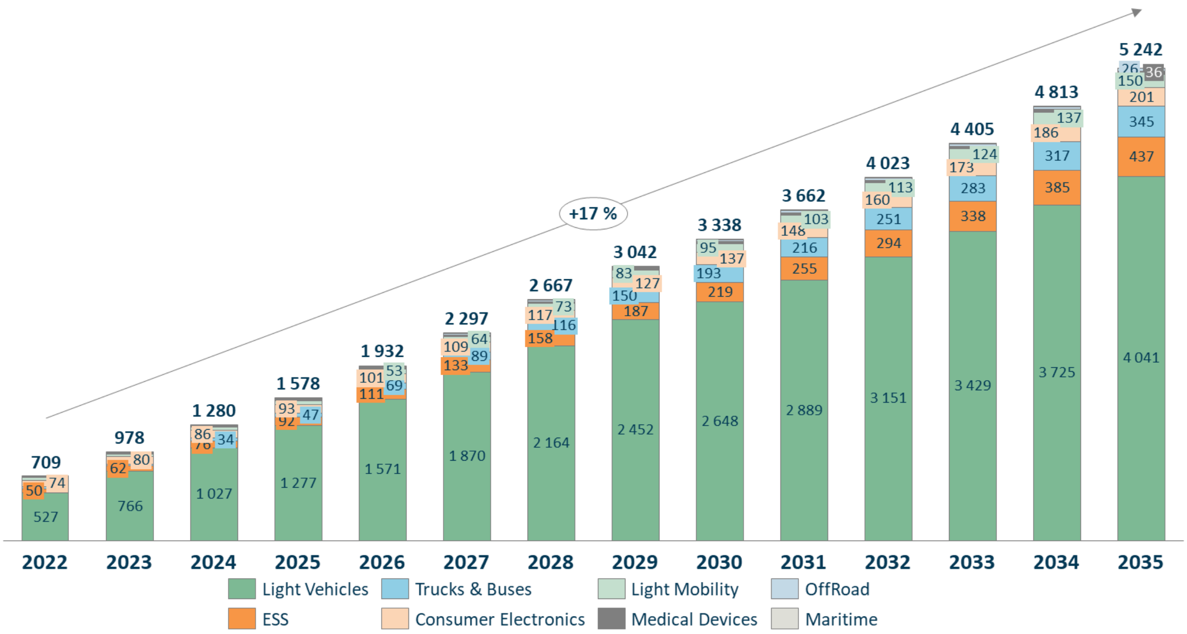


Figure 4: **BASELINE SCENARIO - LITHIUM & NA-ION BATTERY DEMAND PER APPLICATION MARKET | GWh**, Worldwide, 2022 – 2035

These new demand forecasts are on the lower range of the previous studies mentioned above both in terms of total demand and mobility market share.

China is expected to stay the largest region for battery demand although decreasing its big market share from 57% in 2023 to 33% in 2035. EU and NAFTA will go from respectively 14% and 15% market share in 2023 to 29% and 21% in 2035 (Figure 5).

Demand from light vehicle batteries will represent 87% of the total demand of 949 GWh in 2030 and 85% of 1540 GWh in 2035 in Europe (Figure 12 for Light Vehicle Battery Demand).

5. Global And European Battery Demand for Light Vehicles

Battery demand for light duty vehicles is by far the largest one of all application markets and primarily propelled by six key drivers: government policies and regulations, changing consumer behavior, expansion of charging infrastructure, technological advancements, Total Cost of Ownership (TCO) and higher number of available EV models on the market.

BEVs will make up 35% of worldwide vehicle production - 36 million units by 2030 and 50% and 54 million units respectively in 2035 (Figure 8).

China and Europe together will drive 66% of global demand for light vehicle batteries by 2030 and still 63% in 2035. Battery demand will grow at a 17% CAGR from 0.53 TWh in 2022 to 2.6 TWh in 2030 and 4 TWh in 2035 (Figure 12).

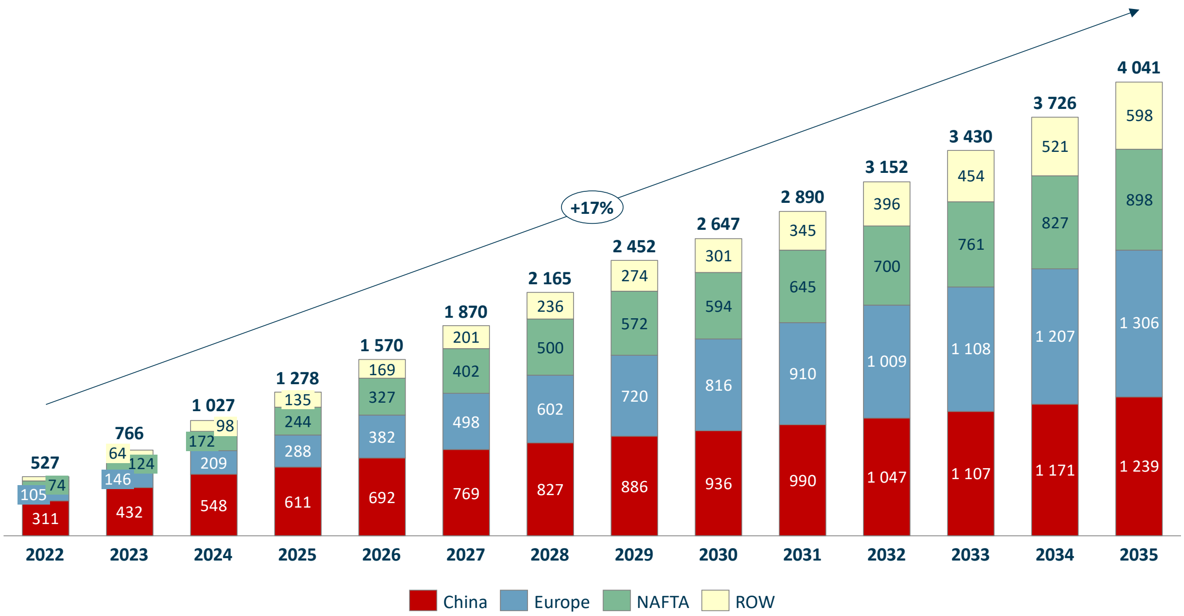


Figure 12: **ELECTRIC LIGHT VEHICLE BATTERY DEMAND PER REGION (INCLUDING LIGHT COMMERCIAL VEHICLES) |** # GWh, 2022 – 2035

NMC and LFP, the current dominant Li-ion battery technologies, will face competition from Co-free, Ni and Mn rich chemistries such as NMX, LMFP, LNMO and LMR after 2025 (Figure 13).

The three main battery geometries will essentially keep their current market shares, with prismatic holding around 70%, pouch at 20%, and cylindrical at 10% until 2035 (Figure 14).

China is proposing a diversified cathode mix and innovation in cathodes (Sodium-Ion, LFP and LMFP, LNMO…) while EU is transitioning from a focus on NMC to LFP/LNMO for entry-level and mass market cars, and USA is focusing on NMC due to its Joint Ventures with Korean battery cell suppliers and to the larger average size of American vehicles.

6. Global And European Battery Demand for Other Markets

8 key sub-segments next to light vehicles have been identified and demand for each of these market segments was evaluated and forecasted until 2030 and 2035: Energy Storage Systems (ESS), Trucks & Buses, Consumer Electronics, Light Mobility, Off-Road, Medical and Maritime.

Projected global battery demand for other markets than light vehicles is expected to reach 0.7 TWh by 2030 and 1.2 TWh by 2035, growing at 16% CAGR from 0.2 TWh in 2022. Demand is primarily driven by ESS and Trucks & Buses. China remains by far the main player (Figures 19a and 19b), with above 40% of demand by 2030, while Europe represents around 19%.

Battery chemistries from other application markets are quite different to light vehicle market, with a larger part for LFP and emerging Na-Ion batteries, driven by ESS and light mobility market (Figure 19c).

7. Global And European Battery Supply

Battery Supply and Gigafactories are mainly driven by the forces shaping Clean Energy and Electric Vehicle Markets.

8 main supply development drivers have been identified: the increase of energy storage systems, electric vehicle market expansion, government incentives and other support, energy transition and decarbonization, technological innovation, decrease of battery costs, advancement in manufacturing processes and strategical supply chain localization.

Total global capacity announcements will reach 4.4 TWh by 2030 and 5.7 TWh by 2035 with China and Europe together accounting for 72% of announcements in 2035 (Figure 26).

Total available realistic global battery supply should only reach 3 TWh by 2030 and 4.2 TWh by 2035 after risk assessment and capacity usage analysis - China supply accounts for 47% by 2035 (Figure 31), while Europe account for 1.1 TWh by 2035.

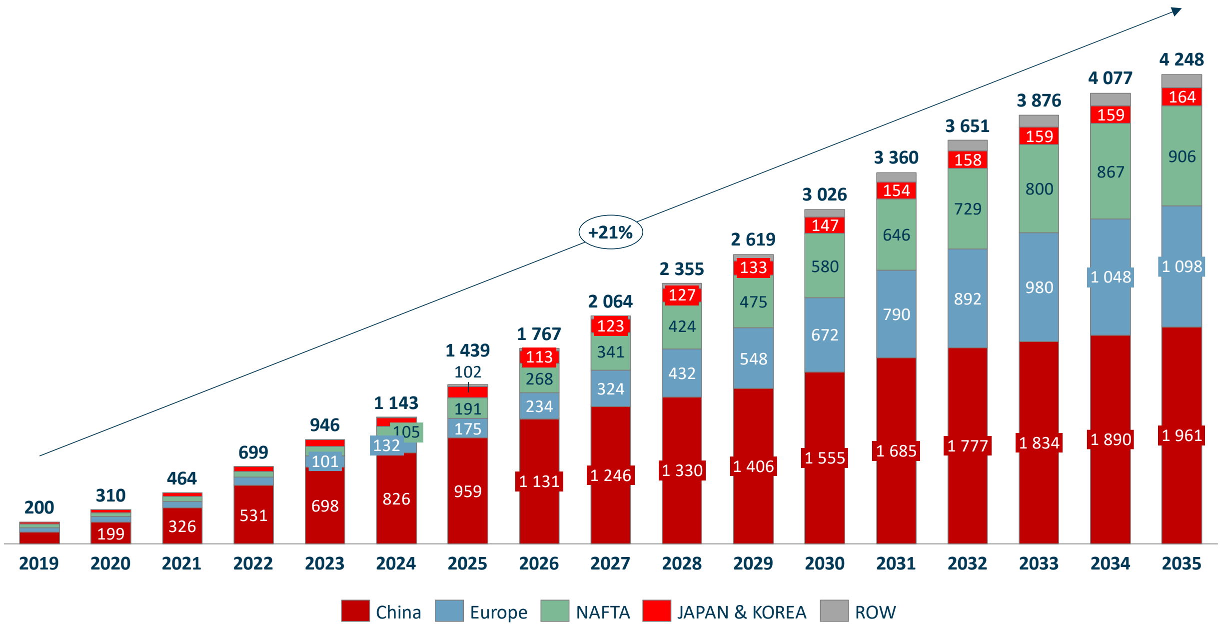


Figure 31: **BATTERY CELL REALISTIC AVAILABLE PRODUCTION PER REGION|** # Through Roll Out Analysis, GWh, 2023 – 2035

Considering all the uncertainties like high scrap rates and production delays, Europe and the NAFTA region are lagging far behind China with large gaps between announced capacity and realistically available production (Figures 28, 29, 30a and 30b).

China is the only region that will be able to meet its battery demand due to its superior battery know-how, experience, and its planned available production capacity.

8. Bottlenecks In Developing Battery Cell Supply Fast

New gigafactories face many issues and roadblocks to install their announced production capacities forcing revised forecasts downwards due to 7 main reasons:

- delays in construction and startup operation difficulties especially for new entrants
- battery cell production equipment shortage and cost competitiveness pressures from Asian players
- high scrap level for cells during production start and ramp up to full volume.
- lack of qualified workers and battery experts to build and operate gigafactories in Europe.
- uncertainties about project funding
- Limited and uncertain upstream raw materials supply for battery cells
- potential shift of capacity from Europe to USA to get better investment incentives due to IRA.

Construction delays have been observed in Europe and North America, particularly for new entrants. Funding problems have affected newcomers, exemplified by the Britishvolt factory bankruptcy due to equity unavailability. Once the factory is built, novel risks emerge for new players, including challenges to find qualified workers, raw material supply shortages, and machinery shortages.

In Europe, 61 % of announced production capacity by 2030 comes from new entrants and 12 % of Gigafactory projected volumes are already at risk due to financing difficulties (Figures 36a and 36b).

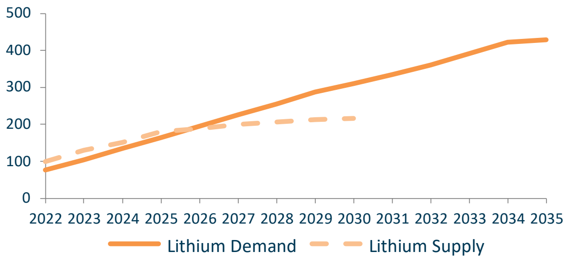
In NAFTA, about 80% of projects will be undertaken by established battery firms with substantial financial backing and only a few Gigafactories face financial difficulties (Figures 37a and 37b).

9. **Demand For Critical Metals for Batteries and Potential Gaps**

The current dominant cathodes are based on NMC and LFP chemistries and will remain the top choice until 2035, but LMNO, Na-Ion and new technologies is expected to emerge and represent around 25% market share (Figure 38).

Demand for critical metals for EV batteries will surge to 5.9 million tons thereby growing by more than 300 % and demand for Lithium Carbonate Equivalent (LCE) will reach 1.6 million by 2030 (Figure 39).

Lithium and battery grade manganese supply might be short in the next 5 years. Cobalt shortage is expected during the next decade whilst Nickel supply will be sufficient (Figures 40a, 40b, 40c and 40d).



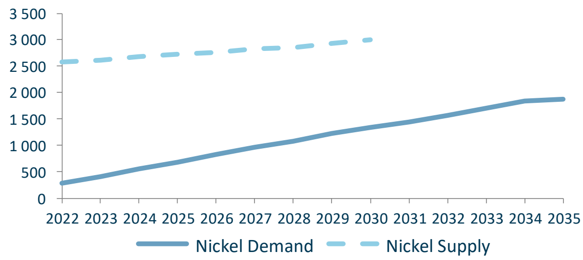
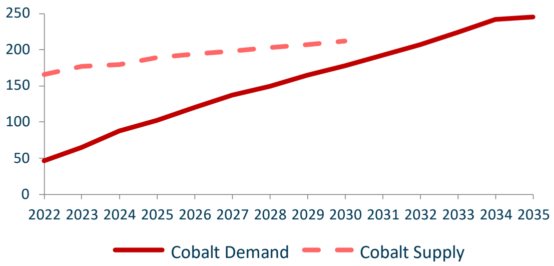


Figure 40a: **LITHIUM DEMAND FOR BATTERY APPLICATIONS & LITHIUM SUPPLY |**
KT, PC + LCV & Other Application Markets, World, 2022 - 2035
Figure 40b: **NICKEL DEMAND FOR BATTERY APPLICATIONS & NICKEL SUPPLY |**
KT, PC + LCV & Other Application Markets, World, 2022 – 2035



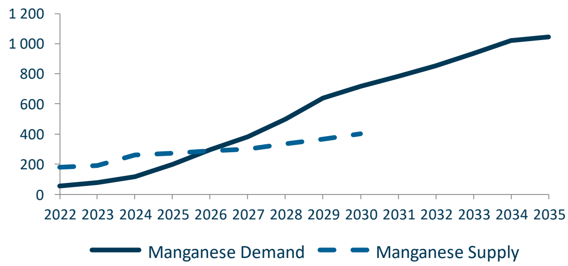


Figure 40c: **COBALT DEMAND FOR BATTERY APPLICATIONS & COBALT SUPPLY |**

KT, PC + LCV & Other Application Markets, World, 2022 - 2035

Figure 40d: **BATTERY GRADE MANGANESE DEMAND FOR BATTERY APPLICATIONS & BATTERY GRADE MANGANESE SUPPLY |** KT, All Markets, World, 2022 - 2035

10. Impact Of Recycling on Demand for Virgin Materials

285 million EVs will be on the road by 2030 and 513 million by 2035 growing at +23% per year. China is accounting for 38 % of them (Figure 41).

Initially the gigafactory production scrap will be the main waste source for recycling up and until the period between 2033 and 2036 when end-of-life batteries will become the main source. The exact crossover point will be depending on chosen respective scenario (Figure 42).

The recycling industry needs to be developed and matured using production scrap in the next decade.

Depending on scenarios and metals, the metal coming from scrap and end of life EV battery will cover, by 2030, between 9% and 18% maximum of total EV battery demand (Figure 43).

Gigafactories can meet regulatory requirements on recycling content for lithium and nickel in the baseline and high turnover scenarios but will fail on cobalt in all scenarios.

Recycling will cover between 9 and 18% of global EV battery demand by 2035 for the main battery metals.

11. **Impact Of New Battery Chemistries**

A shift in cell chemistry could release the pressure on Lithium through trade off towards other raw materials.

New technologies could cut Lithium demand by 9% in 2030 and 12% in 2035, and Cobalt demand by 15% in 2030 and 31% in 2035 (Figure 44 and Table 3).

12. **Demand and Supply Scenarios**

For the main market of Light Vehicles, 3 Demand Scenarios have been developed: “Compliance with regulation”, “More incentives", "Limited EV Acceptance". (Figure 47). These scenarios have been compiled with scenarios for demand from other market to form “Maximal Demand Scenario”, “Base Case Scenario”, and “Minimal Demand Scenario”.

These 3 total battery demand scenarios reveal main differences: after 2027 the gap between minimum and maximum demand is more than 1TWh and grows to 2.6TWh by 2035 (Figure 51). The gap between an accelerated scenario and the base case is important because higher electrification target in China and NAFTA would significantly raise demand. The ESS market might also become substantial (Figures 45,46, 47, 48, 49, 50 and 51).

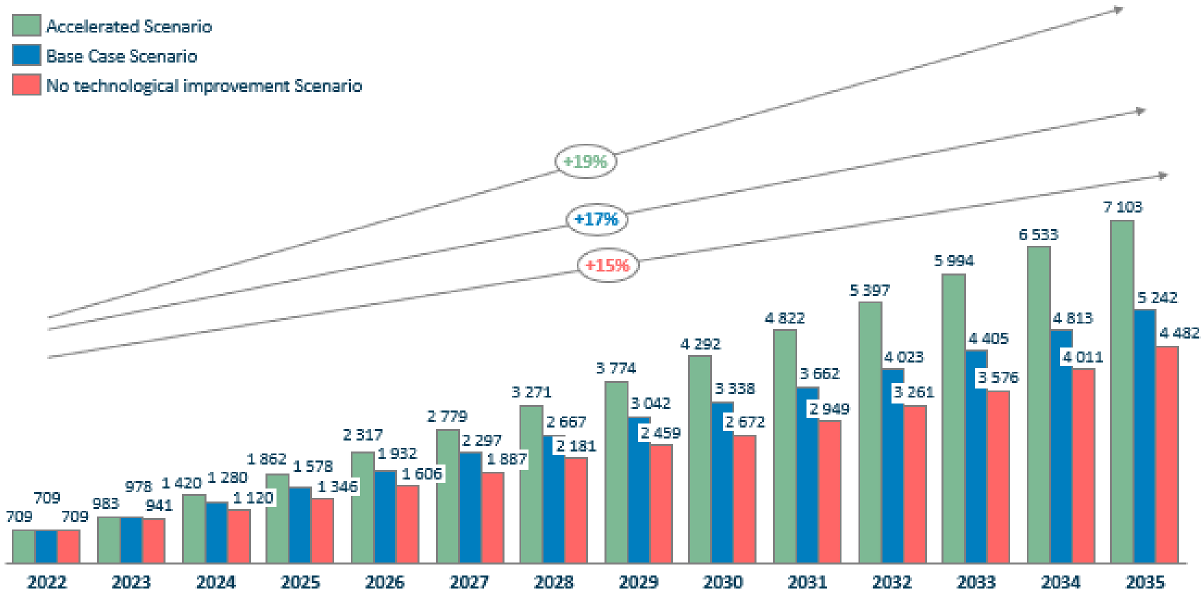


Figure 51: **LITHIUM-ION & NA-ION BATTERY GLOBAL DEMAND FORECASTS |** *GWh, Worldwide, 2022-2035*

Then, two sets of supply scenarios have been designed. First, a set of scenarios (baseline, maximal supply, minimal supply) representing various levels of industrial success of the current announced gigafactory (Figures 52, 53 and 54). Then, 2 scenarios have been designed on top of baseline to account for possible future macroeconomic environment: “Trade War” and “Price War”. These scenarios take into account geopolitical and regional trends (Figures 55, 56, 57 and 58).

13. Sensitivity Analysis

Two sets of supply scenarios have been designed: the first set represents industrial success; the second set describes possible evolutions of the macroeconomic situation.

Industrial Scenarios:

- Industrial scenarios evaluate the anticipated challenges in setting up gigafactories for battery production, considering factors such as scrap rate, player experience, and profitability.
- Battery production plants will not be sufficient to meet demand increase for baseline and maximum scenarios - there will remain a gap of at least 1 TWh depending on chosen scenario in 2035 (Figure 55).
- EU battery plants won’t be able to supply enough cells to meet European demand although a successful industrial rollout could suffice in 2030 under minimal demand. (Figure 56)

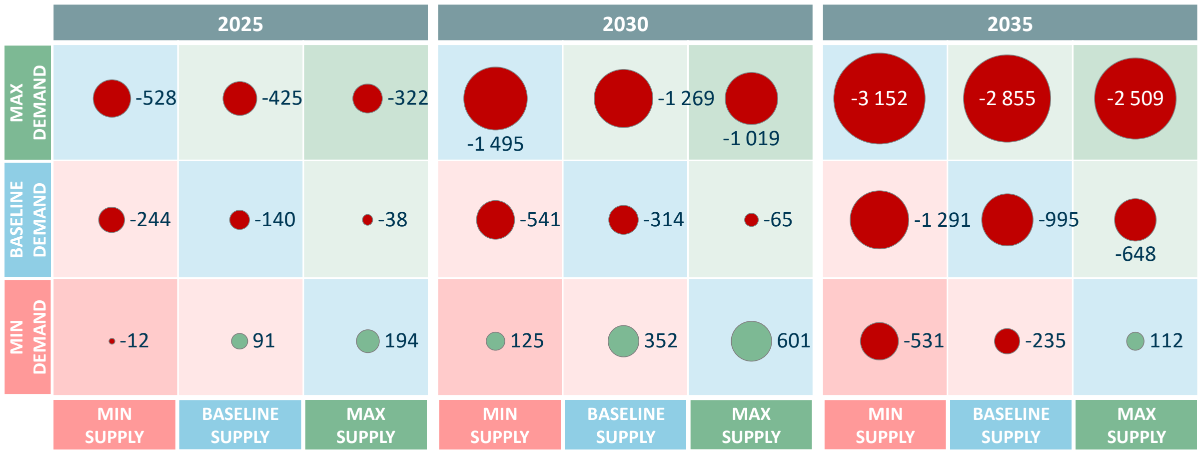


Figure 55: **SENSITIVITY ANALYSIS: GAP BETWEEN SUPPLY & DEMAND |** *# in GWh, 2025-2030-2035, Global*

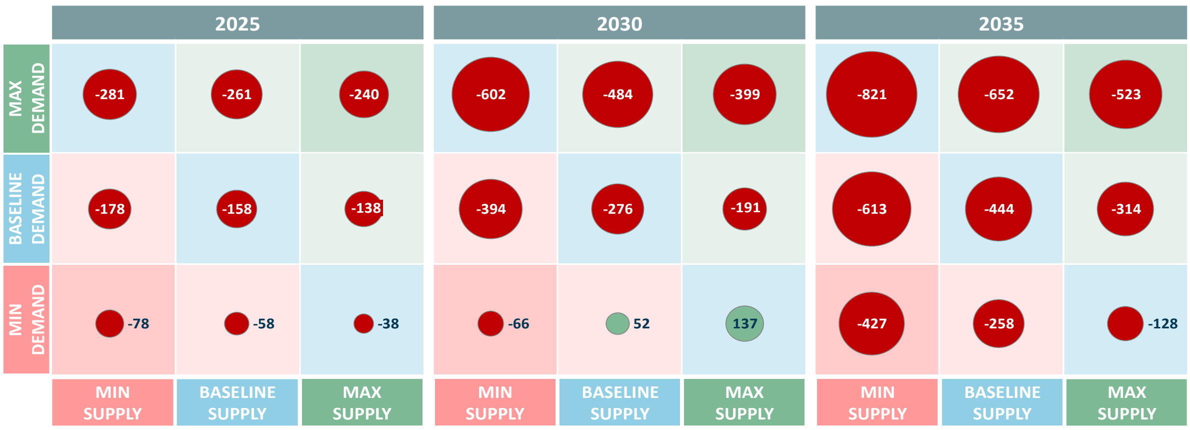


Figure 56: **SENSITIVITY ANALYSIS: GAP BETWEEN SUPPLY & DEMAND |** *# in GWh, 2025-2030-2035, Europe*

Macro-economic scenarios:

- Macroeconomic scenarios have been designed to look at environment changes and regional dynamics for new announcement and gigafactories expansion. Two scenarios were developed: “Trade War”, where NAFTA and EU restrict Imports and invest in the supply chain and “Price War”, where China extends its leadership and NAFTA and European players struggle to become cost competitive.
- In the Trade War Scenario, China remains the leader in battery supply, while Europe and NAFTA catch up rapidly and gain significant market share.
- In the Price War Scenario, China will remain clear market leader with the capability to supply at least 60% of global demand until 2035.
- European demand will be covered by local supply only in a trade war and in minimum demand scenarios. In all other scenarios significant supply gaps will remain in 2025, 2030 and 2035 (Figure 58).

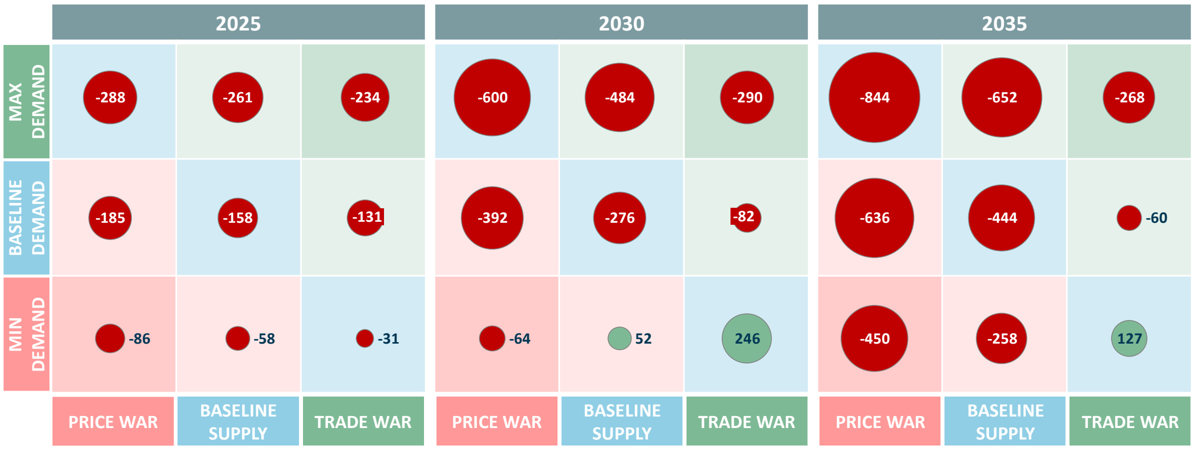


Figure 58: **SENSITIVITY ANALYSIS: GAP BETWEEN SUPPLY & DEMAND |** *# in GWh, 2025-2030-2035, Europe*

Under Scenario of high battery demand, the gap between battery supply and battery demand grows, posing significant challenges on the battery supply chain. This is amplified by regulatory approaches focusing on CO2 tailpipes emissions requiring BEVs. Emphasizing a "well to wheel" approach to minimize carbon footprint throughout the lifecycle through alternative technologies could reduce the pressure on the battery supply chain.

1. Introduction and Overview

1.1. Introduction

The global energy landscape is undergoing a massive transformation, moving from the age-old reliance on fossil fuels to low carbon, renewable sources of power. This shift is driven by the urgent necessity for CO_2 emissions reduction and curbing of GHG emissions to combat climate change. Central to this transition are batteries - the vital energy storage technology that's powering everything from our mobile devices and electric vehicles (EVs) to entire power grids.

The crucial role batteries play in our everyday lives and their increasing significance in supporting the low carbon energy revolution makes it necessary to better understand their landscape: future demand and supply, recyclability, and technological evolution. This report aims to dive into these aspects, clarifying the complex dynamics that underpin the battery industry and highlighting potential areas of risk and sensitivity.

Firstly, the report lays out possible outcomes for demand and supply in the global battery market. The recently observed fast acceleration in demand for batteries is driven by growing sectors such as EVs, energy storage systems, heavy and light mobility and consumer electronics and is driving an intensifying race for raw materials and new production capabilities. An understanding of these dynamics can help stakeholders align their strategies effectively.

Next, the report progresses toward the world of battery recycling - a critical yet often overlooked facet of the battery lifecycle. In an era where sustainability is paramount, efficient, and effective recycling mechanisms are crucial in offsetting the environmental impact of battery production and disposal. The development of recycling as well as the emergence of new battery chemistries will be critical to reduce the demand pressure on virgin materials such as lithium, cobalt, nickel, and manganese.

The report also explores new emerging battery technologies. With increasing technological innovation and investment in research and development, the future of batteries will look vastly different from what we see today. These developments offer new opportunities but also bring new risks and uncertainties. Technological development is crucial to accelerate customer acceptance and to allow for better performing, cheaper, safer, and longer life duration batteries.

Finally, we address the associated risks and sensitivities in the battery industry. From volatile raw material prices to geopolitical tensions, a myriad of factors can influence the battery industry's trajectory. Navigating these challenges requires a thorough understanding of the market and an ability to adapt to evolving circumstances.

In summary, this report offers an in-depth, comprehensive analysis of the battery industry, designed to enlighten, inform, and guide stakeholders as we evaluate and assess this dynamic and critical market. Whether you're a manufacturer, policymaker, investor, or user, the insights contained within these pages can provide valuable context for decision-making in a rapidly changing energy landscape. The success of this ongoing energy transition towards a net-zero carbon economy in 2050 is highly dependent on the development of a strong, sustainable, competitive and resilient battery industry.

This study brought together a deep understanding of car batteries manufacturing, automotive knowledge, material expertise, and a network with important players within the battery industry. It's important to note that this study was conducted in close cooperation with the various stakeholders of the battery world.

1. **Battery cell production and materials expertise:** A detailed overview was given regarding all battery electro chemistries, understanding of cell-level design and production, technical drivers behind design choices, anticipation of product-process technology roadmaps, and detailed knowledge of ongoing gigafactory ramp-ups.

2. **Access to Battery Players:** Numerous existing connections with OEM/Tier 1 suppliers and battery suppliers were leveraged for this study. This included evaluating and assessing future evolutions of current players and new entrants, as well as a good understanding of make-or-buy policies and value chain expertise.

3. **Modeling Experience and Action-Oriented Approach:** The study involves precise quantitative modeling, which includes crafting demand and supply models, conducting simulations, and thorough sensitivity analyses. It allows us to make solid, data driven conclusions by merging insights from expert interviews with quantitative analysis.

This study delivers a thorough, practical, and enlightening understanding of the battery supply and demand scenario by leveraging this collective knowledge and expertise.

1.2. Legislative and industrial context

In this fast-evolving era, the automotive, mobility and energy industries are shaped by five macro trends:

Environment and Regulation: Increasing concerns over climate change, air quality and resource scarcity have prompted government intervention. Emphasis on lower carbon energy and the push for sustainable practices are key considerations in this context. The European Green Deal, for instance, has accelerated the tightening of CO2 emissions regulations with a result to potentially ban ICE (Internal Combustion Engine) new vehicles by 2035, with the exception of CO2 neutral fuel.

Society and Demography: Urbanization, the rising middle class, population growth, and an aging population are influencing shifts in the market. The millennial generation, in particular, brings unique consumer behaviors and expectations that industry players must adapt to. They have high expectations to address environmental issues to preserve the planet.

Economic Change and Collaboration: A changing balance of power, new non-traditional competitors, and cross-country collaboration present both challenges and opportunities. Economic forces and collaborations are ushering in an era of squeezed profitability and a need for new financing modes. After decades of globalization, more regionalization is expected in the coming years driven by geopolitical and trade tensions.

New Technologies and Digitalization: The digital revolution is driving unprecedented changes in the industry. Developments in Artificial Intelligence (AI), additive manufacturing, blockchain, virtual reality, and cloud technology are changing how businesses operate. For the automotive industry, this includes connectivity features and Advanced Driver-Assistance Systems (ADAS). On batteries, there is significant research and development to introduce new technologies which will increase battery performance, improve affordability, reduce weight, improve safety, durability, and sustainability.

Changing Consumer Behavior: Changing Consumer Behavior: Increasing comfort levels with technology have led to shifts in consumer preferences. Notably, there's a growing attraction towards Electric Vehicles (EVs) perceived as green, innovative, and appealing products.

When it comes to mobility, electrification is one of the key technologies for decarbonization. Its benefits are underpinned by the high e-powertrain efficiency and the capacity to decarbonize energy production. There are several technologies on the market: Mild Hybrid Electrical Vehicles (MHEV), Hybrid Electrical Vehicles (HEV), Plug in Hybrid Vehicles (PHEV), Battery Electrical Vehicles (BEV) and Fuel Cell Electrical Vehicles (FCEV). All these new power trains use high-performance batteries whose size and capacity depend on the vehicle type. Therefore, OEMs have considerably increased their EV production forecasts for 2030 to meet tighter emission regulations in the EU. In 2022, the largest EV producers were Tesla and BYD, with 10 Chinese players among the top 18 producers, and European OEMs only as challengers.

Securing a reliable battery supply chain is critical for governments and OEMs alike. Batteries account for approximately 35% of total EV costs, and with the expected surge in EV demand by 2030, securing a local battery supply chain becomes a strategic imperative. Battery packs should be assembled close to the final assembly line of OEMs. Battery cells are fragile and risky parts to transport due to potential fire risks. In a cell, raw materials account for 60-70% of the costs. Surging battery demand up to 2035 will put pressure on the mining and refinery companies for key metals (Lithium, Nickel, Cobalt, Manganese) with potential shortages. If battery suppliers want to cope with such a strong growth and be competitive, they need to secure access to these critical metals in a sustainable way for the long-term.

However, the carbon intensity of primary energy production varies significantly across countries, raising questions about the life-cycle assessment (LCA) of widespread EV usage. Even from a well-to-wheel (WTW) perspective, the CO_2 emissions of an EV can vary a lot from one country to another based on different carbon intensities for the electricity generation in these countries. Considering cradle to grave, it is even more challenging since producing an EV consumes twice as much energy as an ICE vehicle. The largest share of production carbon footprint of EV is linked to the battery pack since producing battery cells is an energy intensive process. Then, the EV production location choice is key: battery cell should be produced in a country with a low-carbon energy mix and the gigafactory to assemble the battery modules and packs ideally should be close to the Final Assembly Line of OEMs which are mainly integrated into pack assembly. It will limit the carbon footprint of transporting the battery cells and reduce the safety risks.

In the meantime, battery pack prices have risen for the first time in 2021 and 2022, according to the BNEF 2022 annual price survey ending a 10-year period of decreasing battery costs. In 2022, the estimated average battery price stood at about $150 per kWh, according to the IEA. According to BENF battery prices have fallen by 88% since 2010 and BNEF was forecasting a price decrease below $100/kWh before 2030, which is now less likely to occur. Reaching price parity for consumers and TCO parity for fleet between ICE and BEVs would accelerate consumers adoption.

China continues to dominate the global battery supply chain, with 78% of cathode and 90% of anode production, and 78% of cell manufacturing capacity. Furthermore, China controls at least 55% of global battery refining capacity depending on the critical metal. (Figures 77a and 77b and 78)

Conversely, most resource-rich countries rank low due to their lack of domestic battery manufacturing capabilities and EV demand. But it has changed recently: Chile, with large Lithium resources, has announced that the country wants to go downstream the battery value chain to be able to produce batteries for Energy Storage applications at least and Indonesia, with large resources in Nickel, wants to integrate cell production and even EV assembly…. Mining of key metals has only recently started to develop in North America but is essentially not existent in Europe.

China accounts for around 78% of worldwide battery cell production as of today. CATL and BYD are the 2 clear market leaders as battery manufacturers and are expected to remain the leading players at least until 2025. The market shares of Farasis and LG Chem are projected to almost double at the expense of CATL. SVOLT and CALB also are strong Chinese battery cell producers. CATL and BYD in the last 2 years have installed 200GWh and 140GWh of new capacity in China and hired 100k and 35k employees respectively. Our forecast shows that China will keep its leadership regarding market share. Some Chinese players have announced that they plan to increase battery cell production capacity by 500GWh.

Understanding these trends and the legislative and industrial context is crucial to be able to formulate effective strategies for a sustainable and profitable future of the nascent European battery industry.

1.3. Scope of the Study: Battery Supply and Demand and Concawe Context

The overarching landscape of battery supply and demand is shaped by several significant macro trends, which are transforming the automotive and mobility industries and necessitating an increased focus on the legislative and industrial context. These trends underscore the evolving landscape of battery demand and supply, a crucial factor within the realm of automotive electrification and mobility.

Automotive Industry Transformation: This industry transformation is largely driven by tighter emissions and fuel economy requirements like new Green House Gas (GHG) targets, the new Worldwide Harmonized Light-Duty Test Cycle (WLTP) now to be used for vehicle homologation and hefty penalties associated with non-compliance. Regulatory bodies like the European Commission have been tightening CO_2 emission regulations annually since 2019, and the 'Fit for 55' package in July 2021 set up critical new targets reducing GHG emissions by at least 55% in 2030 compared to 1990 to converge towards a net-zero carbon economy by 2050. Fit for 55 is part of the European Green Deal initiated by the current European Commission when it was elected.

Europe has set a target to reduce CO_2 emissions from light vehicles by 55% in 2030 compared to 2021 and stands out as the only developed region planning to potentially only allow the sales of zero-emission vehicles after 2035. This regulation means banning the sales of vehicles with an ICE with the exception agreed in the co-legislative process to allow vehicles running on CO2 neutral fuels. Norway has decided to mandate Zero-Emission Vehicles sales for LDV's already in 2025. The UK initially decided to mandate the sale of Zero-Emission Vehicles for light duty vehicles as soon as 2030 but this target was only recently postponed to 2035 like in the EU. North America is also joining the race with the Biden administration proposing the EPA to reduce every year the average fuel consumption with a new target of 68 miles per gallon (TBC). California has set more ambitious targets similar to Europe. It might be followed by other states. China is setting up tax reduction for New Energy Vehicles, as well as global percentage of sales objectives which are raising. To comply with these regulations in the EU and China and to a lesser extent North America, Original Equipment Manufacturers (OEMs) must accelerate their electrification efforts, requiring a significant increase in R&D and CAPEX.

Battery Production Surge: This massive shift towards electrified vehicles requires a massive increase in battery production to prevent bottlenecks and/or shortfalls. Batteries need to be produced in close proximity to vehicle assembly plants for logistical reasons (considering weight, volume, and cost) and strategic considerations. Several projects have emerged over the last two years to establish new capacity, especially in Europe and the USA, with an anticipated capacity of more than 2 TWh to be installed by 2030. The critical period lies before 2025, where delays in plant building could result in battery shortages, and an urgent need for a reliable upstream supply chain. Asian battery suppliers will keep increasing battery production capacity in the meantime, especially China, which will add approximatively 1 TWh by 2030.

Risks and Challenges: This transition is not without risks, especially for European players. China, once lagging in ICE technology, has now taken the leadership in battery technology and production. This domination is present at all steps of the supply chain: refining, cell components manufacturing, battery cell production and EV production. The Biden Administration's Investment Tax Credit (ITC) and the Inflation Reduction Act (IRA) have created a competitive advantage for the USA, attracting EU players with a total subsidy of $50/kWh for a battery pack which costs $150/kWh in average. Many European projects, often headed by industry newcomers, are delayed and have yet to secure their financing.

Battery Demand and Supply Forecasts: Looking at previous studies, there is a large spread in the projections of global demand for lithium-ion batteries by 2030 for all application markets, with forecasts ranging from 2.0 to 4.7 GWh. Similarly, for the global demand for mobility, the forecasts range between 1.8 and 4.2 TWh by 2030. Despite these large differences between these older studies, the total share of Lithium-Ion Battery demand from mobility remains close to 90% for all of them, and the segment consisting of passenger cars (PC) and light commercial vehicles (LCV) makes up around 80%. Projections for Lithium-Ion battery manufacturing capacity by 2030 from these studies again vary significantly, between 3 TWh to 8.2 TWh indicating considerable uncertainties around the actual availability of these batteries.

This study is aimed at consolidating and examining these multiple factors shaping the battery supply and demand landscape, and the associated uncertainties, to inform strategic planning and decision-making in this evolving and challenging context.

1.4. Scenario Construction Description

To create a comprehensive outlook for the global battery market, it is vital to consider the various factors and uncertainties that could influence future trajectories. This necessitates the development of diverse scenarios that contemplate potential changes and challenges in the landscape.

The chosen approach to scenario development for various topics involves creating three distinct scenarios for each region under study: baseline, maximal, and minimal. Each scenario represents a unique possible future for the battery market, taking into account a range of influencing factors including technological advancements, policy changes, demand shifts, and geopolitical influences.

The baseline scenarios take into account current trends, policy commitments, planned capacity expansions, and anticipated technological developments. They represent a 'business-as-usual' state, projecting forward based on existing knowledge and conditions.

The maximal scenarios assume a future where advancements in battery technology outpace current expectations, policy support for electric vehicles and renewable energy storage is strengthened, and the growth in demand for batteries outstrips current projections. In these scenarios, gigafactories scale up more rapidly, and new market entrants disrupt the status quo, pushing the supply side of the market to its maximum potential.

On the other hand, the minimal scenarios envision a future in which hurdles such as slower technological development, inadequate policy support, and unexpected geopolitical or macroeconomic events impede the battery market's growth. These scenarios see a more restrained expansion of gigafactories, with battery supply struggling to keep pace with demand.

Developing multiple scenarios for each region facilitates a more nuanced understanding of potential market dynamics, allowing us to anticipate a range of challenges and opportunities. The aim is not to predict the future with certainty but to establish a flexible framework that can inform strategic decision-making and risk management amidst an uncertain future landscape.

1.5 Objectives of the study and terms of reference

Recognizing the pivotal role of high-performance batteries in the global shift toward mobility electrification, Strat Anticipation undertook a comprehensive worldwide study. The overarching objective was to assess the long-term risk of supply shortage, underpinned by a thorough exploration of various aspects of battery supply and demand.

A bottom-up granular approach to forecast both demand and supply and to develop market scenarios to assess more precisely battery demand and supply in the future was chosen for this study.

Battery Demand Forecasts Across All Sectors: Battery demand forecasts for Light Vehicles were updated with the latest data from GlobalData projections and extended to 2035. In parallel, battery demand forecasts were developed for heavy and off-road vehicles up to 2035, considering various market scenarios including proposed Euro 7 regulations and the 2035 ICE ban. Furthermore, battery demand forecasts were constructed for Energy Storage Systems and other markets (Light Mobility, Consumer Goods, Maritime, Medical) up to 2035. For ESS, a different approach was made to forecast battery demand. The larger the share of renewable energy in the energy mix, the more intermittent is the electricity production, calling for an increased need to store it. Typically, Solar and Wind farms produce electricity most often when demand is low and do not produce enough during demand peak hours, driving the need for storage. The most widely used technology is hydro storage. The need for energy storage was quantified and forecasted up to 2035 by anticipating the roll out of renewable energy production. Utilities have different options to store energy: hydraulic, batteries and green hydrogen production. The most common technology used so far is hydraulic storage, as a cheap and easy to implement solution. For batteries, several technologies can be used: lead acid, zinc-bromine, sodium-ion and lithium ion. The emergence of cheaper high-performance batteries is an opportunity to accelerate the roll out of solar and wind energy production. Based on current market share of the different technologies and their recent evolution, a prediction for the future market share of the various ESS options has been made.

Realistic Supply Assessment Per Region: A detailed and rigorous assessment of battery supply forecast was carried out, meticulously evaluating, and assessing existing battery production supply forecasts in China, Japan, Korea, Europe, and North America up to 2025, 2030, and 2035 using a rigorous bottom-up approach. Every gigafactory producing battery cell and its production announcements were screened systematically to assess a timeline of how much capacity is going to be installed and how much battery capacity will be produced in the future. Forecasts were built for China, Korea, Japan, and other relevant countries. To capture the complete picture of global supply and demand, a gap analysis between supply and demand was done in China, Europe, and North America, allowing to describe the import and exports needed for each region.

Impact of Recycling and New Chemistries on the Market: A macro forecast for the production of key recycled metals was created and the battery cell technology roadmap was updated, assessing the maturity of various new battery technologies. The impact of these technological changes on the market before and after 2030 has been thoroughly evaluated. The objective was to investigate how new technologies could reduce the demand pressure on critical metals and how recycling could help to limit the demand on virgin metals.

Identification of Various Supply and Geopolitical Risks: An evaluation of supply shortage risks for the years 2025, 2030, and 2035, was undertaken, incorporating a sensitivity analysis based on various scenarios. The potential for battery imports from China was assessed to compensate at various levels (cell, pack,) potential shortfalls in Europe. Commercial and trade risks as well as geopolitical risks with China concerning materials, technology, supply, and production were considered.

The study resulted in a robust demand forecast up to 2035, a realistic available battery production forecast from 2023 to 2035, a vision of potential game changers with technology, a detailed view of supply and autonomy risks for Europe to support the development of its battery industry in order to be able to succeed with the Green Deal implementation.

2. Market Needs, Regulatory Trends and Description of Technologies

2.1. Introduction

To understand the electric vehicle revolution, this report describe market needs, regulations, and technologies that shape its development.

In this section, an assessment of the current market needs as dictated by consumers, fleet operators, and various other stakeholders in the EV ecosystem is done. This analysis encompasses a range of factors, from vehicle range and charging time, to safety and affordability, which will significantly impact consumers adoption and perception of EVs.

The ever-evolving regulatory landscape is also a focus of the study. As governments worldwide strive to combat climate change, they are setting ambitious targets for carbon neutrality and are implementing policies to encourage the adoption of EVs. These regulatory trends, often differing from one region to another, play a crucial role in steering the course of the EV market.

Technological advancements are at the heart of EV development providing the tools to meet market demands and comply with regulations. A detailed exploration of these technologies is done, specifically the battery technologies that form the heart of EVs. Lithium-Ion to Solid-State and Sodium-Ion batteries is analyzed regarding composition, advantages, limitations, and the potential these technologies hold for the future of electric mobility.

Navigating through these market needs, regulatory trends, and technological advancements, the study aims to provide a comprehensive understanding of the current state and future development of the electric vehicle industry, to foresee the opportunities and challenges laying ahead for sustainable transportation.

2.2. Regulation trends for batteries

Regulatory trends for batteries have considerable implications on technological advancements and affect market requirements across different geographical areas. The regulatory landscape in China, Europe, and the USA, and the resulting effect on the global battery sector are presented below.

China: China is a trendsetter in regulatory standards, particularly in battery safety. The “nail test”, the key regulation for thermal runaway is coming from China. It mandates that if a cell experiences thermal runaway, it must not cause a fire or explosion in the vehicle cabin for at least 10 minutes. This is a significant increase from the previous 5-minute requirement, providing more time for passengers to escape during emergencies. Initially, this rule applied to electric buses with a 30-minute duration, and plans are in motion to extend it to passenger cars, enhancing safety standards. Due to important know-how regarding electric buses, China is also leading the way concerning regulations for buses.

Europe: The European Union's approach to battery regulations and policies is multifaceted, focusing on the development of a robust value chain, environmental sustainability, and job creation. To this end, the Union is set to provide subsidies to European countries as well as foreign companies that are willing to establish a value chain in Europe.

Currently, the European Commission has just released a new Directive on Batteries, which is slated to introduce bonuses and penalties based on the CO_2 footprint associated with battery production. While this marks a significant step towards sustainable production, it is fraught with contentions, primarily due to the lack of consensus on how to calculate the CO_2 footprint. Initially planned for 2024, this updated regulation may be delayed to 2027 due to these disagreements.

This Directive is comprehensive in its coverage, incorporating provisions for battery repairability, recycling, and the use of open-source software for enhanced accessibility and innovation.

USA: Under the leadership of President Joe Biden, the US regulatory framework focuses on self-sufficiency and domestic growth. To stimulate domestic production of minerals necessary for battery production for electric vehicles and long-term energy storage, the Defense Production Act was enacted, leading to the introduction of the IRA regulation. This was a game changer for the EV industry in the US. It is limiting subsidies only to EVs assembled in the US with domestically manufactured batteries. This strategic move not only prioritizes American manufacturing but also effectively bars sourcing minerals from non-friendly nations such as Iran, Russia, and RDC and does impact the choice of battery chemistries for the US market significantly.

These new regulations will have a massive impact on the battery and EV industry in the US. It will enforce the localization of the value chain within the US. Foreign automotive companies will have to set up operations in the US in order to be able to participate in the US market and be eligible for subsidies. It will also drive the promotion of Lithium Iron Phosphate (LFP) batteries, which are Nickel and Cobalt Free in the US, and this will also have a major impact on the European market.

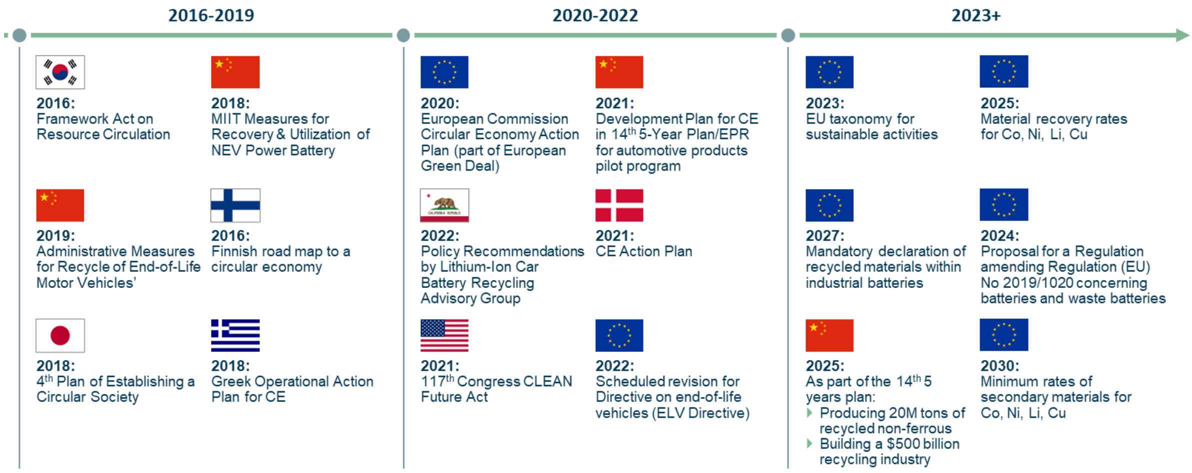


Figure 1: **REGULATION PAST & FUTURE DEVELOPMENTS**

Regulatory pressure on the automotive industry, driven by environmental concerns, is increasing at a rapid pace worldwide, with battery regulation being a significant area of focus (Figure 1). Governments globally are keen to promote a circular economy, imposing regulations that enforce battery recycling and mandate minimum recycled material content.

In line with this, digital reporting is gaining prominence in the battery regulation space, providing necessary transparency and traceability. Milestones on this journey include battery classification into carbon footprint performance classes, compliance with supply chain, due diligence on social and environmental risk, and the declaration of recycled content of key materials like Lithium, Nickel, Cobalt, and Lead.

To address these multifaceted challenges, Europe is devising a comprehensive package that regulates the entire lifecycle of batteries, from the sourcing of critical raw materials to their end of life. The Battery Value Chain encompasses various steps such as Mining, Refining, Battery Cell and Battery Pack Production, Primary Use in EVs, Repairability, Second Life Use, and End of Life management. Each stage entails specific requirements and standards, ensuring a thorough and responsible approach to battery lifecycle management.

Despite the considerable efforts made by Europe, President Biden's various investment programs worth 369 billion dollars have catapulted the US ahead in the EV race, putting European investments at risk (Table 1). The introduction of the IRA regulation coupled with rising energy prices have left Europe trailing the US concerning battery prices. Indeed, the IRA tax credits will reduce light-duty EV purchase costs by $3,400 to $9,050 in America according to ICCT.

SECTION	DESCRIPTION	ESTIMATED VALUE (BILLIONS OF $)
30D: CLEAN VEHICLE TAX CREDIT	• Up to $7,500 for new EVs, $4,000 for used • Material sourcing requirements, EV price cap, and consumer income limits	8.9
45W: COMMERCIAL EV TAX CREDIT	• Eligible for tax credit equal to 30% of the vehicle cost	3.6
30C: ALTERNATIVE FUEL VEHICLE REFUELING INFRASTRUCTURE TAX CREDIT	• Individual : Lesser of 1 000 $ or 30 % of the installed cost • Commercial : Maximum incentive for project is 30 %, up to 100 000 $	1.7
45X: ADVANCED MANUFACTURING PRODUCTION CREDIT	• 35 $/kWh for cells, 10 $/kWh for modules • Production in US or US possession • Phase out starting in 2029, reducing by 25% each year	30.6
ADVANCED ENERGY PROJECT TAX CREDIT	• Includes technologies, components, materials for EVs, and associated charging or refueling infrastructure • Also applies to processing, refining, or recycling	6.3
POSTAL SERVICE VEHICLE ELECTRIFICATION	• $1.3 billion for vehicles, $1.7 billion for supporting infrastructure	3.0
LOAN PROGRAMS OFFICE	• Increases existing and new loan authorities by up to $350 Billion	11.7

Table 1: **INFLATION REDUCTION ACT**

The IRA has been a formidable success in the USA. One year post the enactment, the IRA is estimated to have attracted around $86B in private investment for 210 projects. Successful projects in mining, refining and equipment production have been set up in the US. The subsidies are projected to vastly exceed the $390B expectations from the US Government.

In response to the IRA and to align with Europe's ambitious goal of carbon neutrality by 2050, the European Commission has proposed the Net Zero Industry Act. In conjunction, Transport & Environment (T&E) has proposed organizing an effective European response to the IRA to secure the future of the electric vehicle industry.

Key elements of these proposals include simplifying and streamlining existing EU funding mechanisms, reforming state aid rules for strategic projects in the battery value chain and establishing the European Sovereignty Fund (ESF) to back operations in pivotal economic sectors.

Strategic partnerships with third countries, especially in Africa and Asia, are also crucial for a reliable supply of metals. Europe must ensure tariff suspension for all the feedstock and machinery required to scale up its battery value chain in the coming years. Additionally, introducing a special EV tariff may be necessary to avoid Europe becoming a dumping ground for cheap EVs.

Supporting energy-intensive businesses in the battery and metals processing field is also vital, particularly while energy costs remain high due to Russia’s invasion of Ukraine.

In conclusion, the divergent regulatory trends across the globe demonstrate the pivotal role of regulation in shaping the battery sector. Through balanced and robust regulation, governments can pave the way for the sustainable growth of the battery and EV industries while maintaining environmental sustainability.

2.3. Consumer Perspective

Consumer decisions towards adopting electric vehicles (EVs) are driven by their expectations in several key areas. Among these, the safety of the vehicle, its affordability, the driving range, its reliability, and the efficiency and convenience of charging solutions are the most critical ones. This section will explore these facets from a consumer perspective and offer insights into how the industry is responding to meet these expectations.

Safety: When it comes to selecting a vehicle, safety is a top priority for consumers. They demand their vehicle to be safe in any situation, including collision safety, exposure to air pollution, and protection from mechanical and electrical hazards, including fire risks. Many prospective EV buyers look to the EURO NCAP rating, a non-mandatory but highly regarded safety performance assessment, to make informed purchasing decisions with regards to safety.

Affordability: As car prices rise more rapidly than core inflation, the average age of car buyers continues to increase. Today EVs are still more expensive than internal combustion engine (ICE) vehicles despite large incentives handed out by European countries (e.g., in Germany, €6000 in 2022 from the government and €4500 in 2023 for buying an EV). As EVs move towards mass-market adoption, consumers expect essentially price parity or equivalence regarding Total Cost of Ownership. In fact, consumers are only prepared to pay a small premium for the environmental advantages offered by these vehicles as shown in the *Electric Vehicles: Consumer Information Review* Report by StreerGroup.

Range: Diesel engines, with their high vehicle mileage range (500-1000 km), have set high range expectations for customers considering EVs. Despite daily commuting distances in Europe averaging a mere 40 km, consumers expect EVs to provide a range of at least 400 km, as shown in the *Electric Vehicles: Consumer Information Review* Report by StreerGroup. This disparity between range expectation and actual usage patterns shows the deep-rooted range anxiety that continues to plague potential EV adopters.

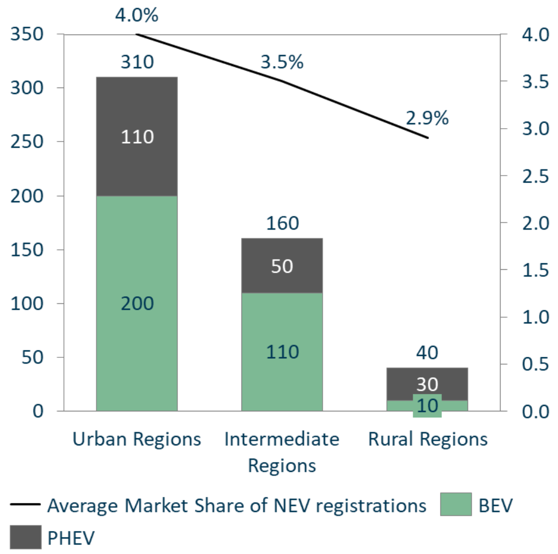
Reliability and Longevity: Just as with any vehicle purchase, consumers anticipate their EVs to be reliable and durable. In the context of EVs, this expectation particularly applies to battery performance and longevity. A significant concern is the residual value of the vehicle after a few years. It adds to consumers' worries about potential battery issues in EVs.

Charging Infrastructure: Much like the expectations for fuel availability in ICE vehicles, consumers want the charging infrastructure for EVs to be widespread and easily accessible.

This expectation extends to a desire for a multitude of charging options, such as at home, at the office, at public parking lots, at supermarkets, and other public areas.

Fast Charging: Time for recharging of their vehicles is an important aspect for consumers. Waiting for more than half an hour or even an hour to charge their EVs is generally seen as unacceptable. Consumers expect the EV charging time to be comparable to ICE vehicle refueling times - ideally less than 15 minutes, as shown in the *Electric Vehicles: Consumer Information Review* Report by StreerGroup.

The above expectations represent a clear roadmap for the EV industry to develop and expand. This fact is supported by urban areas continuing to dominate EV adoption in Europe, a trend that surveys suggest will persist. For example, in 2019, the percentage of new electric light vehicle registrations in urban, intermediate, and rural regions in Europe were 4%, 3.5%, and 2.9%, respectively (Figure 2). Moreover, urban regions exhibit a higher inclination towards purchasing electric vehicles, with a substantial number of households in these areas actively considering or already having concrete plans to acquire an EV (Figure 3).



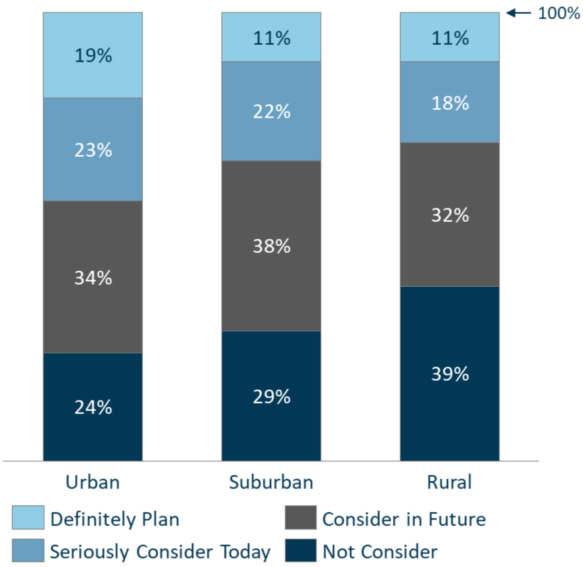


Figure 2: **TOTAL NEW ELECTRIC LIGHT VEHICLE REGISTRATIONS |** Europe, in k Units, 2019
Figure 3: **IF I BOUGHT/LEASED A VEHICLE I WOULD TAKE A BEV VEHICLE** | European Survey, %, 2022

Original Equipment Manufacturers (OEMs) must rise to the occasion and meet these customer expectations in order to maintain production volumes and meet emissions targets, particularly in the European and Chinese markets.

Preventing Fire and Electrocution: OEMs are investing heavily in research and development to counteract the two primary safety risks associated with EVs - the risk of fire, and the risk of electrocution. Lithium-Ion batteries with liquid electrolytes, the current dominant technology in EVs, present a significant fire risk. For example, according to the Environmental Services Association (ESA), 48% of all waste fires in the UK each year are caused by lithium-ion batteries.

Reducing Vehicle and Battery Costs: In terms of cost, OEMs are targeting price parity between ICE and EV vehicles before 2030. For example, Renault expects EV/ICE price parity to be reached by 2027/2028. This goal implies a substantial cost reduction for EVs - around 40% versus today. However, with battery prices surging over the past two years, achieving this target is a considerable challenge.

Maximizing Effective Range: To increase the range of EVs, OEMs are focusing on enhancing battery energy and power density, both per liter and per kg. Projections suggest that this density could double by 2030, significantly boosting range. Additionally, OEMs are working on improving vehicle efficiency and reducing weight, contributing further to maximizing effective range.

Increasing Battery Lifetime: To reassure customers about battery longevity, several OEMs are offering extended warranties, typically for 7-8 years or 120 000 to 140 000km. In an innovative approach, some OEMs are even leasing batteries to customers. This approach removes battery longevity-related anxieties but changes the nature of the automotive market.

Contributing to Infrastructure Roll-out: Charging infrastructure roll-out is lagging behind, presenting a substantial hurdle to EV adoption. Given the lack of standardization, OEMs have taken matters into their own hands, setting up private entities or forming partnerships to accelerate infrastructure deployment.

Reducing Charging Time: Distinguishing between home charging and station charging, where the consumer waits to resume their journey, is essential. The speed requirements for these distinct charging scenarios are likely to vary significantly. Current EV charging technologies, although continually advancing, are still not sufficiently rapid. Presently, it takes several hours to charge an empty battery to 80% capacity, a duration well beyond what consumers deem acceptable.

To provide a concrete example, a typical electric car with a 60kWh battery takes just under 8 hours to charge from empty to full using a standard 7 kW charging point. It's important to note that this standard charging point is commonly used for both public station chargers and personal home chargers. However, there is room for improvement in home charging if the grid infrastructure allows for it since a three-phase electricity supply will probably be needed. Upgrading a home charger to a 14 or 22kW charger can significantly reduce charging times to 3 to 4 hours, enhancing the convenience for EV owners. This consideration must be put in comparison with battery size: while a typical A-Segment vehicle will have a 25kWh battery, a Ford 150 Lighting (a large electric pickup) will have at least 98kWh of battery, changing drastically the charging times needed at charging stations. Moving forward, the industry's overarching objective is to further reduce charging times, targeting a range of 15-30 minutes. Attaining this ambitious goal would significantly boost the attractiveness of electric vehicles, offering quicker and more convenient charging options. This is particularly crucial at public charging stations, where drivers often require a swift charge to resume their journeys.

However, this development is reliant on DC fast charging stations, which operate at 50-400 kW, necessitating substantial grid upgrades, installation efforts, and carrying higher costs.

In conclusion, meeting these consumer expectations is critical to fostering the mass adoption of EVs. The industry needs to strike a balance between ensuring safety, achieving affordability, and delivering performance, all whilst accelerating the development of a convenient charging infrastructure. OEMs have set ambitious targets to meet these demands, and their strategies and actions in the coming years will significantly shape the EV market's trajectory.

3. Worldwide and European Battery Demand

3.1. Introduction: Global Demand Overview

In order to evaluate the total global demand for Li-ion batteries, the following 8 major battery application markets were considered: light duty vehicles (LDV), heavy-duty trucks & buses (HDV), energy storage systems (ESS), consumer electronics, light mobility, maritime, off-road, and medical systems. The road transportation sector (LDV together with HDV) constitutes the largest share (84 %) of the total global demand for Li-ion batteries.

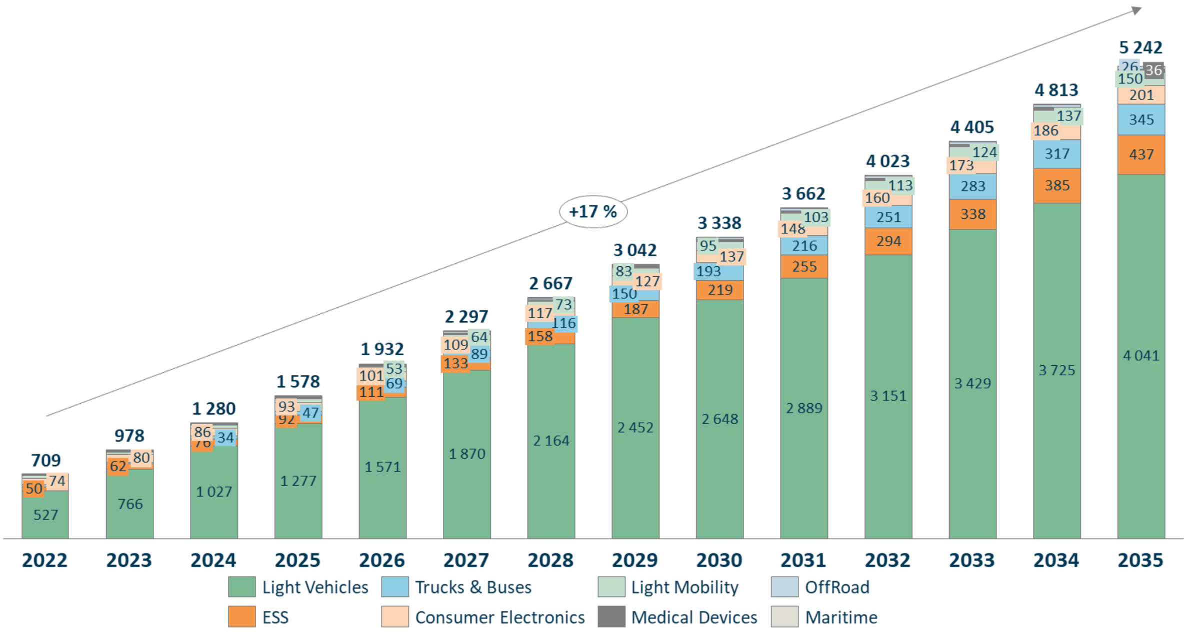


Figure 4: **BASELINE SCENARIO - LITHIUM & NA-ION BATTERY DEMAND PER APPLICATION MARKET | GWh**, Worldwide, 2022 – 2035

Projections show that total global battery demand is set to reach 3.3 TWh by 2030 and will be growing to an impressive 5.2 TWh by 2035. The driving force behind this demand is the electrified light vehicle segment, accounting for 80% of demand in 2030 and 77% in 2035 (Figure 4). This amounts to a compounded annual growth rate (CAGR) of 17% from 2022 to 2035. ESS and trucks & buses are the next largest contributors to demand (7 % in 2030 and 8 % in 2035 for ESS and 6 % in 2030 and 7 % in 2035 for trucks & buses).

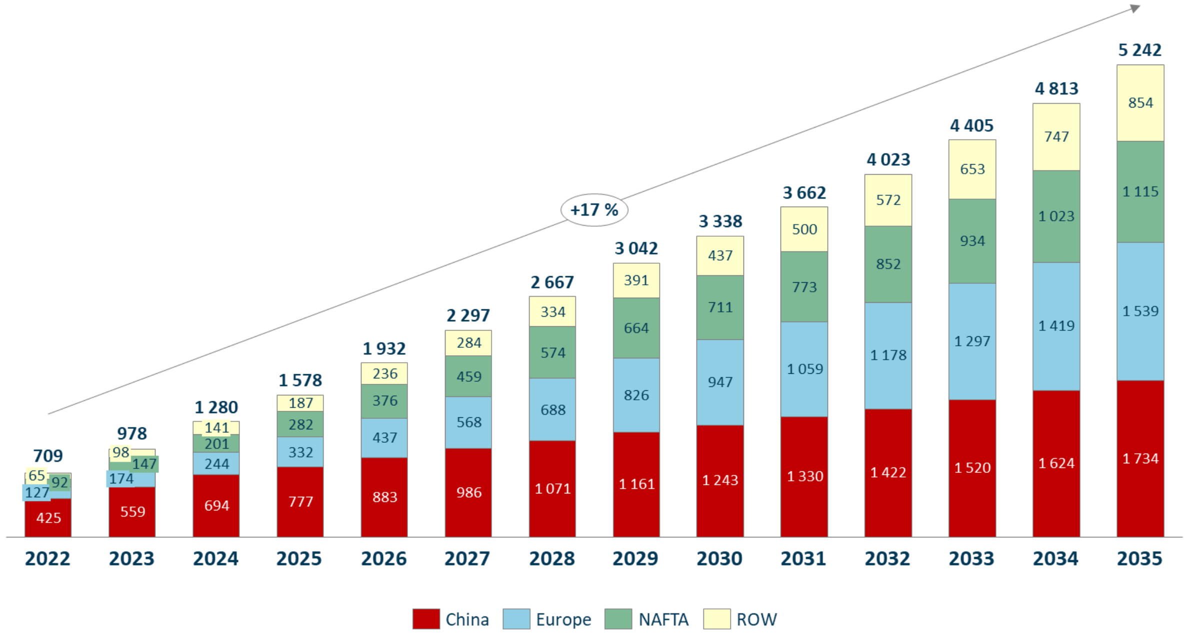


Figure 5: **BASELINE SCENARIO - LITHIUM & NA-ION BATTERY DEMAND PER REGION| GWh**, Worldwide, 2022 – 2035

China continues to lead in battery demand, though its global market share is expected to decline from 57% in 2023 to 33% in 2035. Interestingly, the Western world – particularly NAFTA and Europe – is catching up, predicted to jointly account for over half of the GWh demand by 2035 (Figure 5).

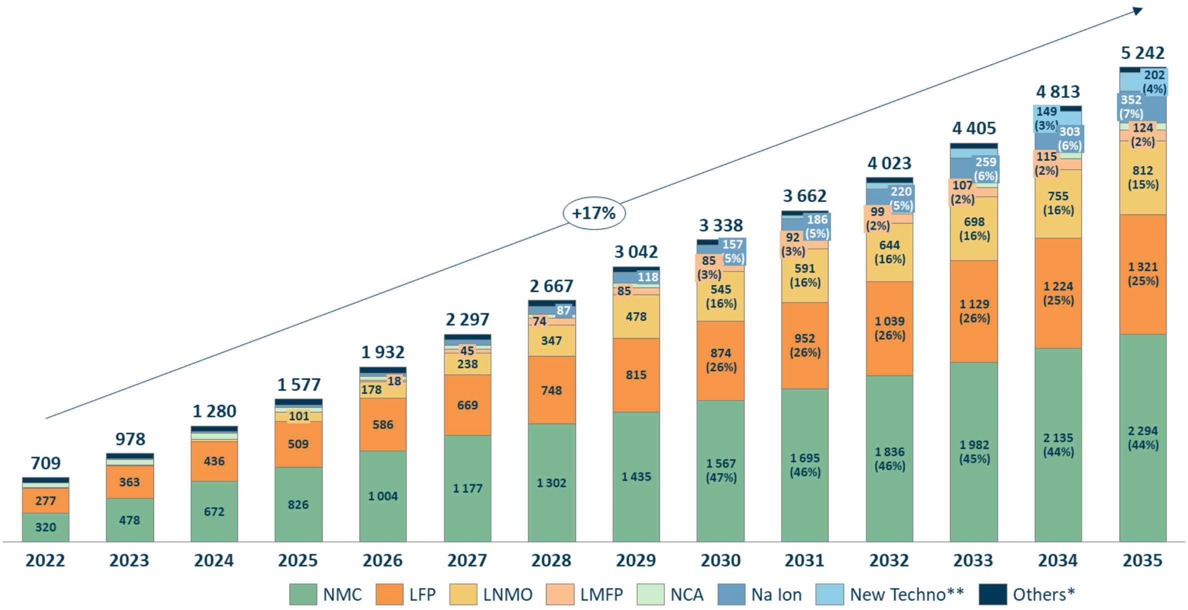


Figure 6: **BASELINE SCENARIO - LITHIUM & NA-ION BATTERY DEMAND PER CATHODE MATERIALS| GWh**, Worldwide, 2022 – 2035

As we examine demand across different battery technologies, the current dominant cathodes based on LFP and NMC are expected to remain top choices until 2035. However, we anticipate the emergence of LNMO, Na-Ion and other new technologies. Particularly noteworthy is

LNMO, which is predicted to become a major battery technology from 2030, accounting for around 16% of the market (Figure 6). A detailed description of battery technologies is available in annex, Chapter 7 of this report.

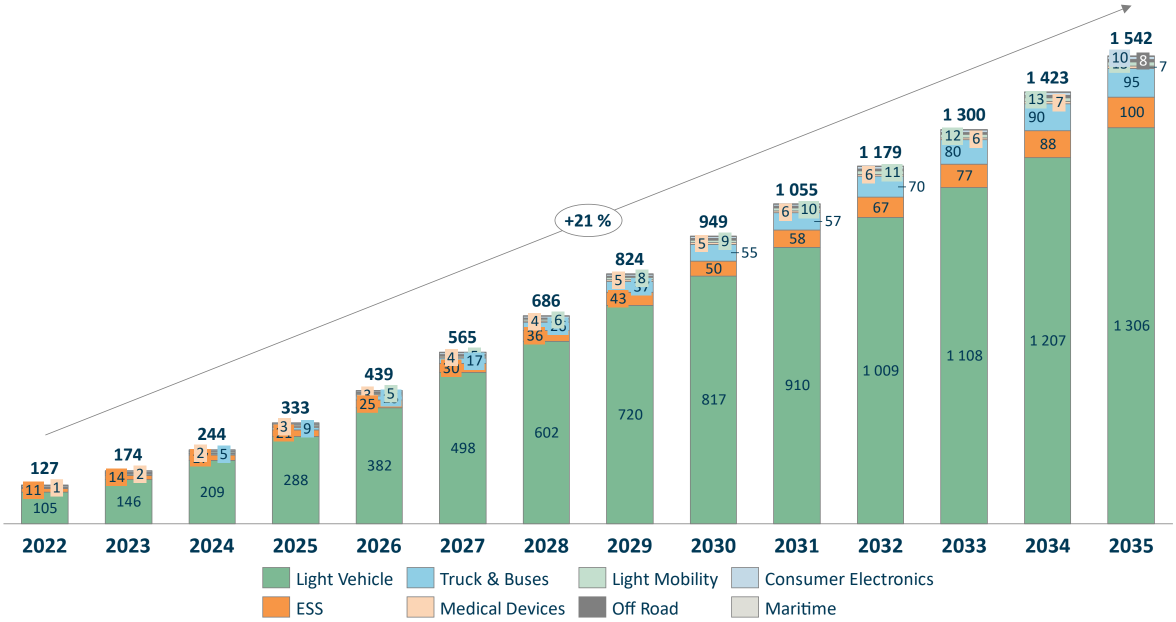


Figure 7: **BASELINE SCENARIO - LITHIUM & NA-ION BATTERY DEMAND IN EUROPE PER SEGMENT | GWh**, Europe + Russia, 2022 – 2035

Zooming in on Europe, the total demand from light vehicle batteries is projected to make up 87% of the 949 GWh in 2030 and 85% of demand in 2035, with total demand reaching 1542 GWh in 2035 (Figure 7). The other two significant demand markets in Europe are expected to be trucks & buses and ESS.

3.2. Demand arising from Passenger Cars and Light Commercial Vehicles

3.2.1. Battery Demand Drivers

The surge in demand for batteries in the passenger cars and light commercial vehicles sector can be attributed to a range of factors, key among them being:

Government Policies and Regulations
Tightening fuel economy and CO_2 standards have considerably amplified the role of Electric Vehicles (EVs) in meeting these stringent requirements. Notably, the EU has declared a ban on the sale of new Internal Combustion Engine (ICE) passenger and light commercial vehicles from 2035. Furthermore, new EU targets aim to reduce CO_2 emissions by 55% by 2030. This trend isn't confined to Europe; both the USA and China are setting up increasing electrification objectives. In addition, various governmental subsidies incentivize consumers to transition towards EVs.

Changing Consumer Behavior
The EV market has demonstrated its ability to increasingly meet quality and technological requirements, earning the confidence of some car buyers. Environmental concerns and the various government incentive programs are increasingly prompting consumers to switch to EVs. With a projected 50% of the global population living in cities by 2030, demand is likely to increase as EVs are particularly prevalent in urban areas.

Expansion of Charging Infrastructure
Global installation of public charging points increased by 55% in 2022 versus 2021, especially in vital urban areas. Currently, most of the charging demand is met by home charging. Slow chargers still dominate the landscape compared to fast chargers, with a ratio of approximately 2:1. Moreover, efficient battery swapping ports are being introduced in China, a strategy expected to be a long-term solution for electric power.

Technological Advancements
Battery technology is advancing at a swift pace, delivering longer ranges, reduced charging times, and extended lifetimes. The introduction of new battery chemistries, geometry, and sizes has led to a significant increase in energy density.

Total Cost of Ownership (TCO)
In May 2023, the average transaction price for EVs was down 14 percent compared to the same period in the previous year. Many EV manufacturers are engaged in a price war, with some facing an oversupply of EVs, leading to lower prices. Global declines in battery pack prices have also been observed, thanks to technological and chemical advancements as well as increased manufacturing volumes, which have resulted in economies of scale. Yet, due to pressure on raw materials, this decrease is not guaranteed as a raise in battery price has been observed in 2021 and 2022.

Higher Number of EV Models on the Market

In 2021, the number of electric car models worldwide was around 450, marking a 15% increase from 2020 and double the number compared to 2018. The entry of new EV Original Equipment Manufacturers (OEMs), especially from the Chinese market, has rapidly expanded the number of EV models. About half of these new models originate from China.

3.2.2. Global Battery Demand Forecast by Engine Type and by OEM

The tide of vehicle production is notably shifting towards electrified vehicles. By the year 2030, Battery Electric Vehicles (BEVs) are projected to constitute 36 million units, making up 35% of worldwide production (Figure 7), while Plug-in Hybrids (PHEVs) are expected to remain relatively stable throughout the decade, representing approximately 4.6 million units by 2030 and maintaining a share of around 4% of the total global production.

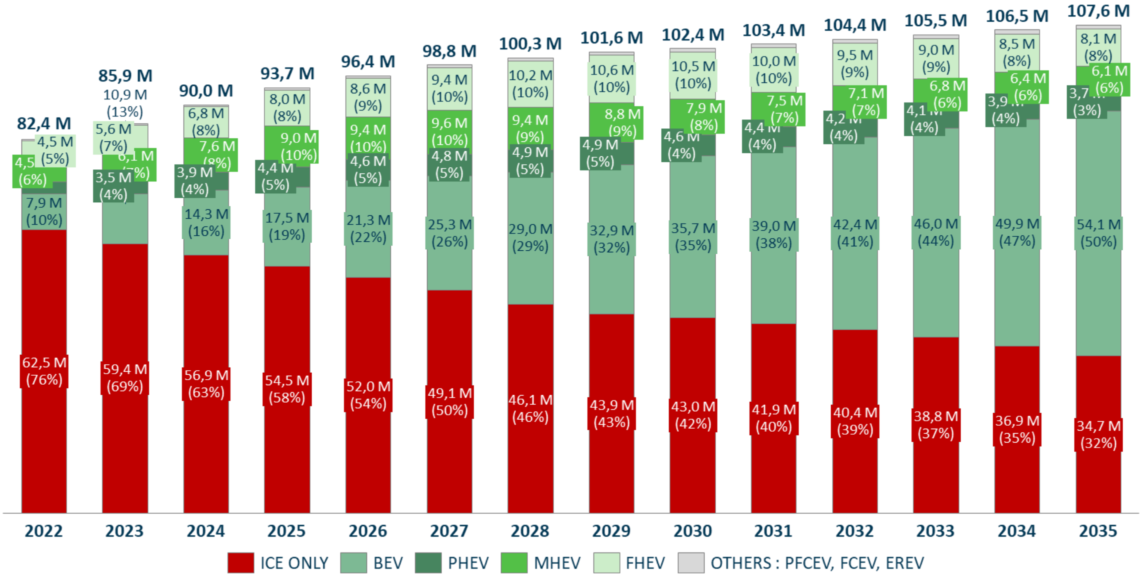


Figure 8: **LIGHT VEHICLE PRODUCTION PER ENGINE TYPE (INCLUDING LIGHT COMMERCIAL VEHICLES) | #** M Units, 2020 – 2030, Global

Battery demand for electrified light vehicles is anticipated to experience substantial growth, soaring from 527 GWh in 2022 to 2,650 GWh by 2030. The top 13 Original Equipment Manufacturer (OEM) groups are predicted to account for 75% of this demand by 2030. Among these, the largest OEMs requiring batteries include the Volkswagen Group, Tesla Motors, and Stellantis, closely followed by the General Motors Group and the Chinese player, BYD.

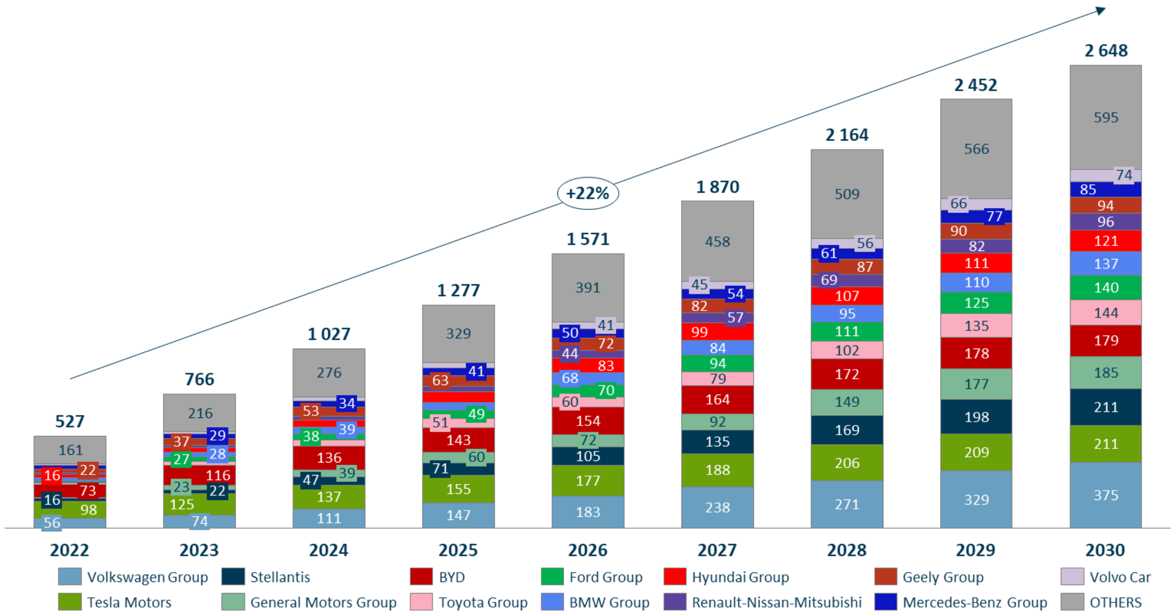


Figure 9: **ELECTRIC LIGHT VEHICLE BATTERY DEMAND PER OEM (INCLUDING LIGHT COMMERCIAL VEHICLES) | #** GWh, 2022 – 2030, Global

The Volkswagen Group is expected to have the highest demand in 2030, estimated at 375 GWh. In contrast, the largest demand in the current year of 2023 comes from Tesla (125 GWh), followed by BYD (116 GWh) (Figure 9). This trend demonstrates the dynamic nature of the EV market and underscores the ongoing shifts in demand among major players.

3.2.3. Battery Pack Power

The trend in battery pack power presents an interesting observation: over time, battery pack power will stabilize as vehicles reach higher levels of efficiency, and as entry-level EVs with smaller batteries follow the premium market.

For Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs), battery capacity is expected to grow only slightly post-2025.

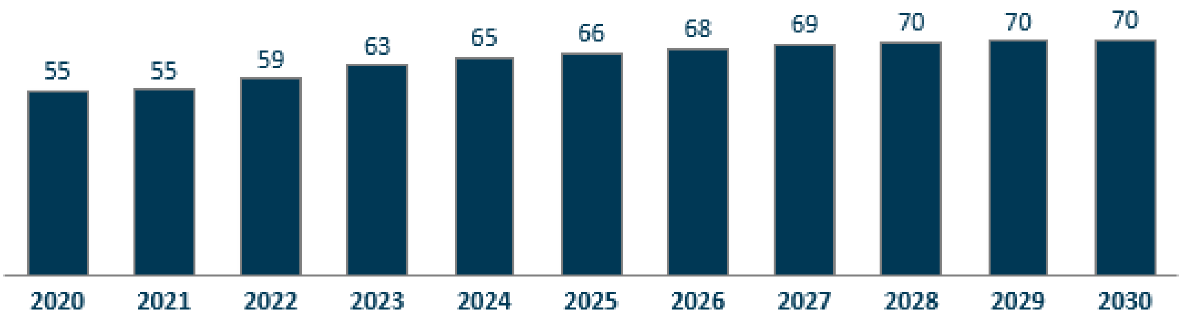


Figure 10: **AVERAGE BEV BATTERY PACK POWER PER YEAR |** *kWh, 2020-2030, Worldwide*

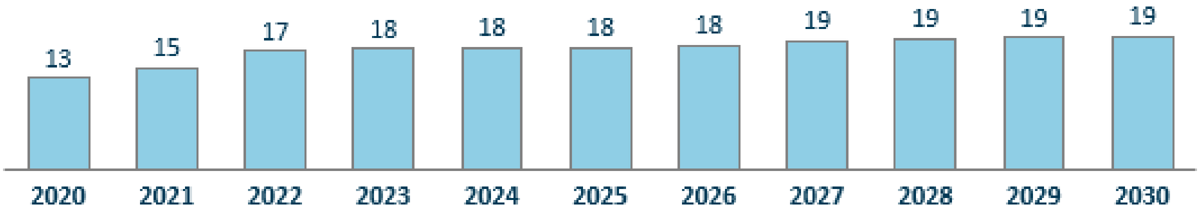


Figure 11: **AVERAGE PHEV BATTERY PACK POWER PER YEAR |** *kWh, 2020-2030, Worldwide*

These trends reflect the different strategies in play for BEVs and PHEVs. While BEVs are working towards optimizing efficiency with stable battery capacity, PHEVs are capitalizing on increased battery size to extend their 0-emission range.

3.2.4. Comparison of Different Trends and Chemistries between regions

The history of lithium-ion batteries is characterized by continuous innovation and development, particularly in Asia. Initially emerging in the realm of consumer electronics, Li-ion technology has evolved significantly over the years. South Korea and Japan played pivotal roles in the early stages of Li-ion battery development. In the consumer electronics sector, both Korea and Japan made substantial contributions, with Japanese companies such as Panasonic being notable pioneers in the 1990s. As Li-ion batteries gained prominence in portable electronic devices, the focus shifted towards enhancing energy density, safety, and overall performance.

During this evolution, cathode materials became a key area of innovation. South Korea and Japan led the development of cathodes such as NMC and NCA, which found applications in electric vehicles due to their improved energy density. Concurrently, China pursued a different cathode technology, namely LFP. LFP cathodes offered advantages in terms of safety, stability, and lower cost, making them particularly well-suited for applications in buses, light mobility vehicles, and smaller electric cars. The distinct advantages of LFP, coupled with its lower cost, led to a boom in its adoption in China. LFP batteries became the preferred choice for certain vehicle segments, outpacing the installation rate of NMC batteries in the country. The economic viability of LFP cathodes contributed significantly to their rapid deployment, especially in the context of China's ambitious electric mobility goals.

China as technology leader has now recognized the need for different battery types for various markets and market segments. They're developing LMFP and LMNO batteries for this purpose. Chinese companies aim to cut battery costs, influenced by BYD and CATL and have also started to industrialize sodium-ion batteries in 2023, with the first urban EV announcement Pursuing the same goal, they're exploring mixed battery chemistries in the same pack.

At the outset, European car manufacturers preferred high-nickel NMC battery chemistries for better performance and extended range in electric vehicles (EVs). However, mass-market OEMs, such as Stellantis, VW Group, and BMW, recognized the necessity of more affordable batteries to make EVs accessible in lower market segments. Some are planning now to utilize

2 or 3 different battery chemistries such as LNMO and LFP alongside NMC, and Stellantis has plans to use Cobalt-free batteries only.

Several upcoming gigafactories in Europe are primarily focused on high-nickel NMC battery production, but a few are considering LFP production in the near future, including ACC, Northvolt, and Morrow. This shift toward LFP may offer cost-effective battery options. The expiration of the originally Chinese patents has made LFP more accessible to all manufacturers in Europe.

European manufacturers may prioritize integrating cells into packs or even chassis for simplified production, lightweighting and cost reduction while decreasing ease of repairability.

Tesla pioneered high-performance battery development in the US a decade ago, using NCA and cylindrical cells from Panasonic. Legacy automakers subsequently embraced high-nickel NMC chemistries to align with the market leader and extend the range of heavier vehicles.

Newcomers such as Rivian, Lucid, Fisker, and Canoo also adopted NCA or NMC chemistries. Gigafactories in the US are primarily focused on producing high-nickel NMC batteries, with cathode manufacturers such as BASF and Posco following suit.

LFP batteries gained traction in the US and Europe. Tesla initially adopted them for entry-level cars in China and is currently expanding their use to all models. Other OEMs will follow.

Global battery markets show a trend of diversification in China, a transition to LFP/LNMO chemistry in Europe, primarily for entry-level cars, and a concentration on NMC batteries in the US except for Tesla.

3.2.5. Worldwide battery demand forecast for light and light commercial vehicles.

To date, China has been the undisputed leader, but a gradual shift is occurring with the rise of NAFTA and Europe, who will collectively drive 55% of global demand for light vehicle batteries by 2035. In particular, Europe is poised to be the largest demand region, accounting for over 40% of demand by 2035 (Figure 12).

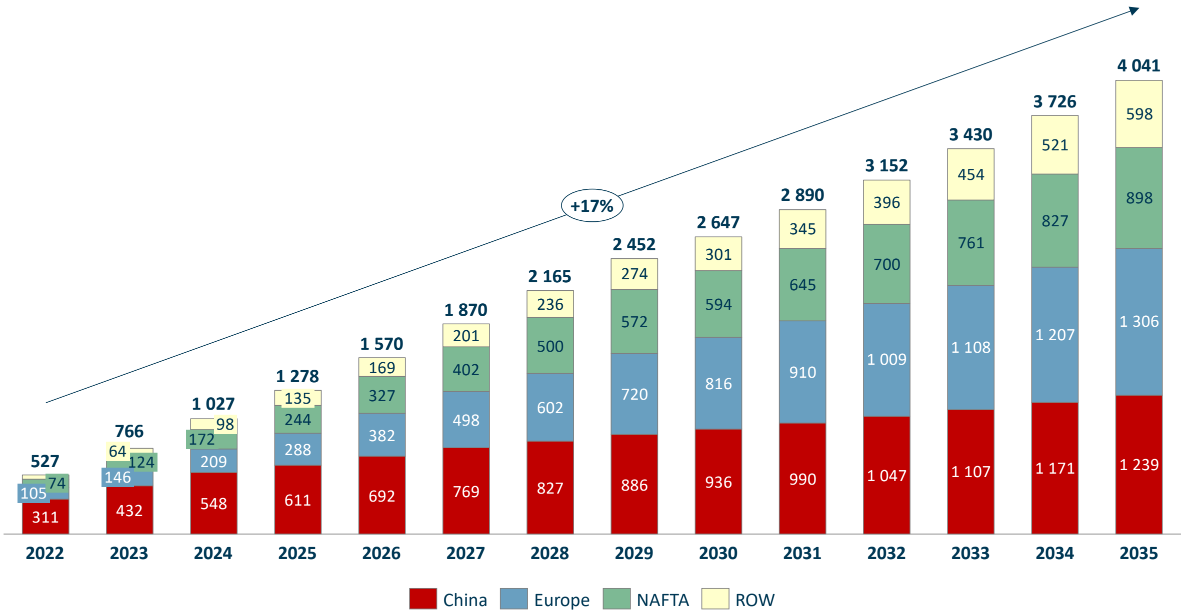


Figure 12: **ELECTRIC LIGHT VEHICLE BATTERY DEMAND PER REGION (INCLUDING LIGHT COMMERCIAL VEHICLES) |** # GWh, 2022 – 2035

Looking at battery technology or chemistry, NMC and LFP currently dominate. However, this will change post-2025, as cobalt-free cathode chemistries like NMX, LMFP, LNMO, and LMR make their way into the market. In this competitive landscape, LNMO is predicted to carve out a significant market share, becoming the third largest technology starting in 2025 (Figure 13).

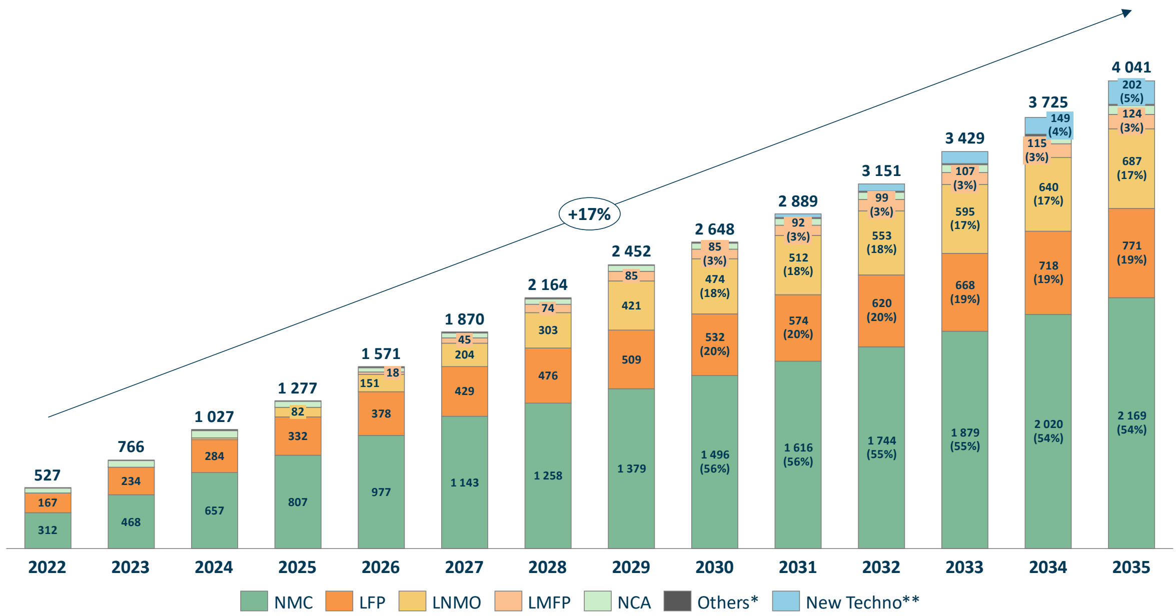


Figure 13: **ELECTRIC LIGHT VEHICLE BATTERY DEMAND PER CATHODE CHEMISTRY (INCLUDING LIGHT COMMERCIAL VEHICLES) |** # GWh, 2022 – 2035, Global.

As for battery geometry, a major shift in market share is not anticipated over the coming decade. The three dominant geometries - prismatic, pouch, and cylindrical - are expected to maintain their current shares, with prismatic leading at 70%, followed by pouch at 20%, and cylindrical trailing at 10% (Figure 14). Cylindrical geometries may grow their market share in the future if the trend by OEMs such as BMW to shift from prismatic to cylindrical geometries for safety reasons continues. The latter geometry reduces thermal runaway propagation and the risk of fire. This consistency underscores the stability and reliance of the market on these geometries and the technologies they represent globally.

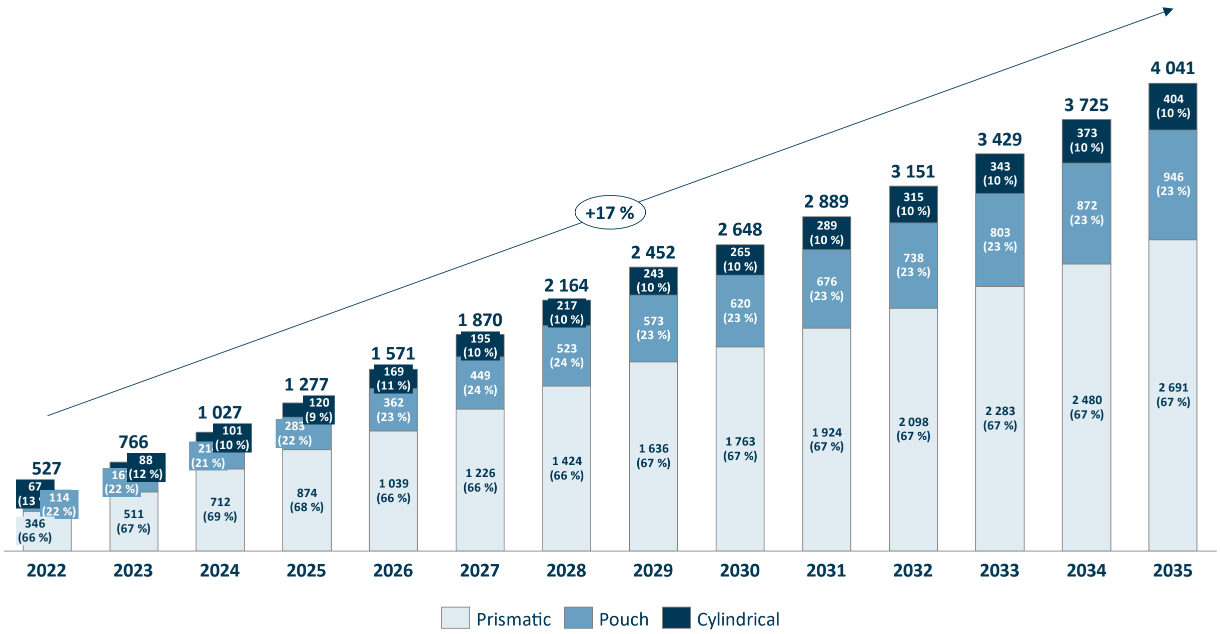


Figure 14: **ELECTRIC LIGHT VEHICLE BATTERY DEMAND PER CELL GEOMETRY (INCLUDING LIGHT COMMERCIAL VEHICLES) |** # GWh, 2022 – 2035, Global.

3.2.6. European Battery Demand Forecast for Light Vehicles

By the year 2030, Europe is anticipated to have 11 million Battery Electric Vehicles (BEVs), constituting 53% of global production, as illustrated in Figure 15. The term "Europe + Russia" encompasses an expanded scope, including Eastern European countries such as Russia, Ukraine, and Turkey. Notably, Turkey is expected to contribute significantly to the market, manufacturing 1.3 million vehicles in 2023, while Russia is projected to produce 500,000 vehicles in 2022.

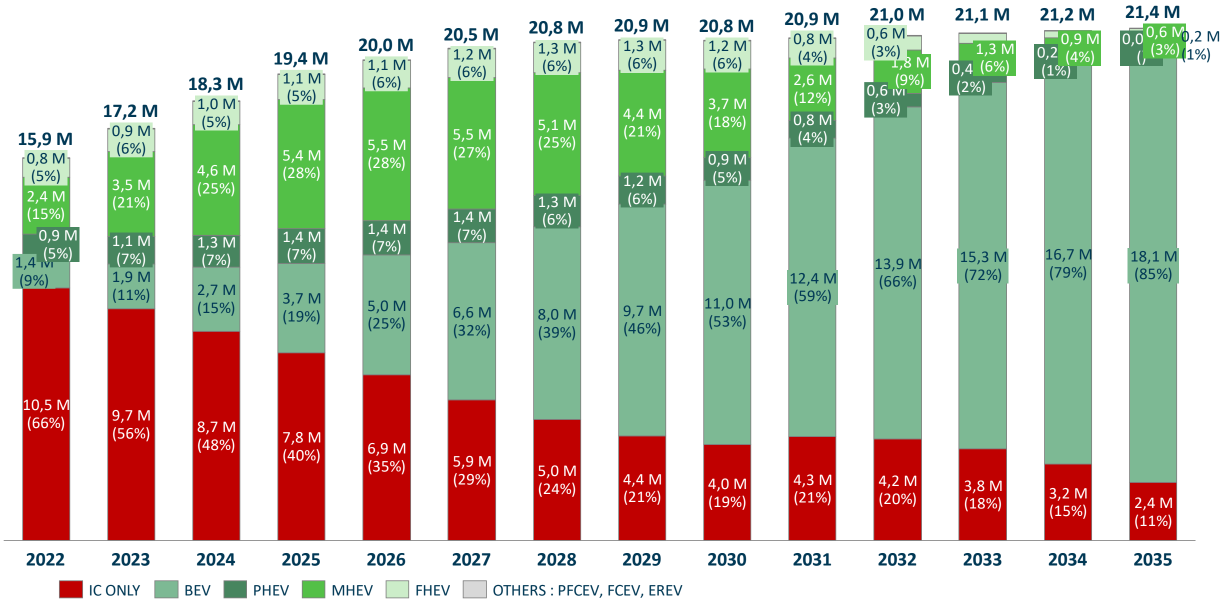


Figure 15: **LIGHT VEHICLE PRODUCTION PER ENGINE TYPE (INCLUDING LIGHT COMMERCIAL VEHICLES) | #** M Units, 2020 – 2030, Europe + Russia.

Battery demand for electrified light vehicles is expected to grow from 105 GWh in 2022 to 817 GWh in 2030. 13 major Original Equipment Manufacturer (OEM) groups will account for 97% of the demand by 2030, with the top two OEMs Volkswagen Group and Stellantis representing almost 50% in 2030 (Figure 16).

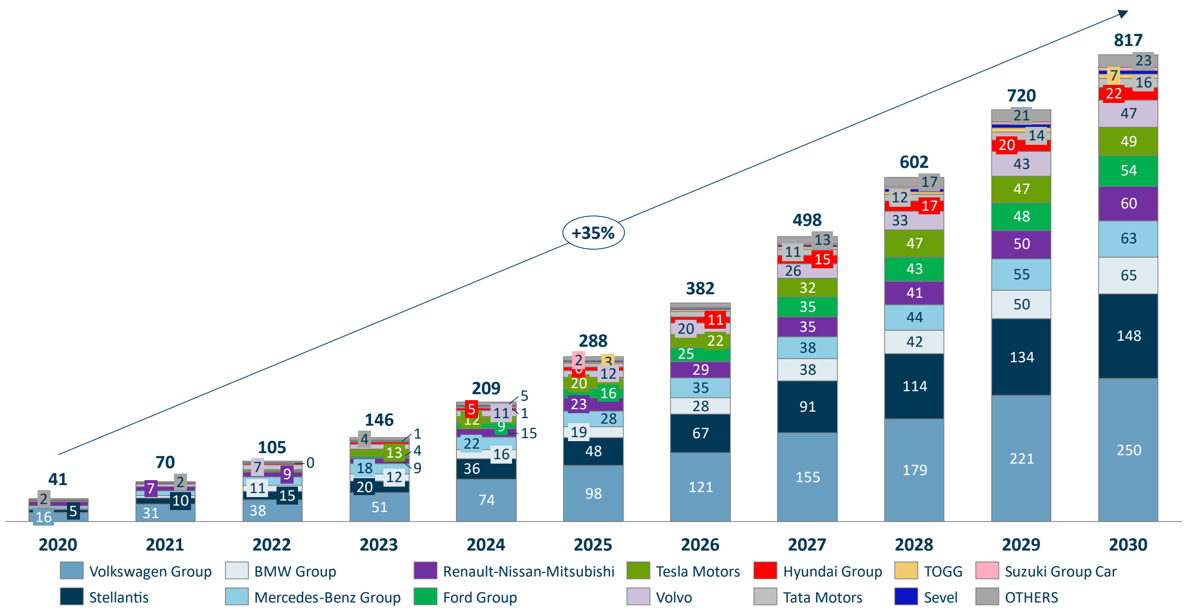


Figure 16: **ELECTRIC LIGHT VEHICLE BATTERY DEMAND PER LEADING OEM (INCLUDING LIGHT COMMERCIAL VEHICLES) | #** GWh, 2020 – 2030, Europe + Russia.

Demand forecast per chemistry shows that LFP, LMFP, and LMFP are poised to take a significant market share from traditional NMC cathodes. These 3 chemistries together will constitute 35% of Europe's demand in 2030. Nevertheless, NMC will continue to be the predominant battery technology until 2035 (Figure 17).

In the figure 17, *Na-Ion** corresponds to Sodium-Ion Battery, and *New Techno*** to Li-metal, Li sulfur or solid state battery.

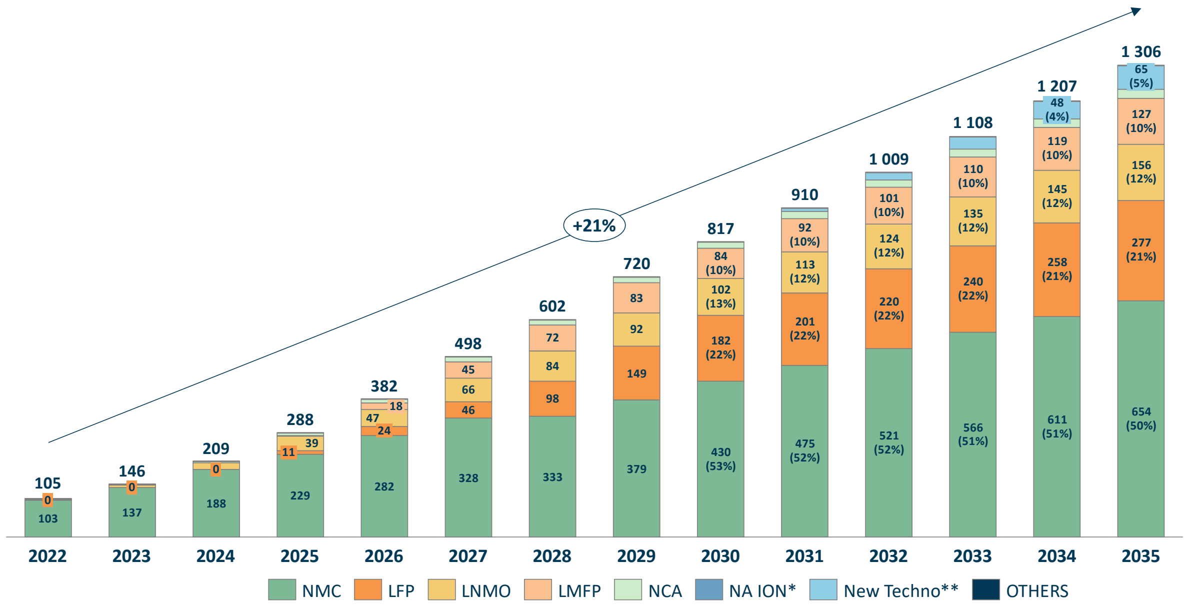


Figure 17: **ELECTRIC LIGHT VEHICLE BATTERY DEMAND PER CHEMISTRY (INCLUDING LIGHT COMMERCIAL VEHICLES) | #** GWh, 2022 – 2035, Europe + Russia.

Battery demand forecast by cell geometry shows that prismatic cells are expected to become dominant, reaching a market share of 68% in 2030 (Figure 18). This is due to the fact that prismatic cells offer a better battery safety performance and is the historic solution used by dominant Chinese players.

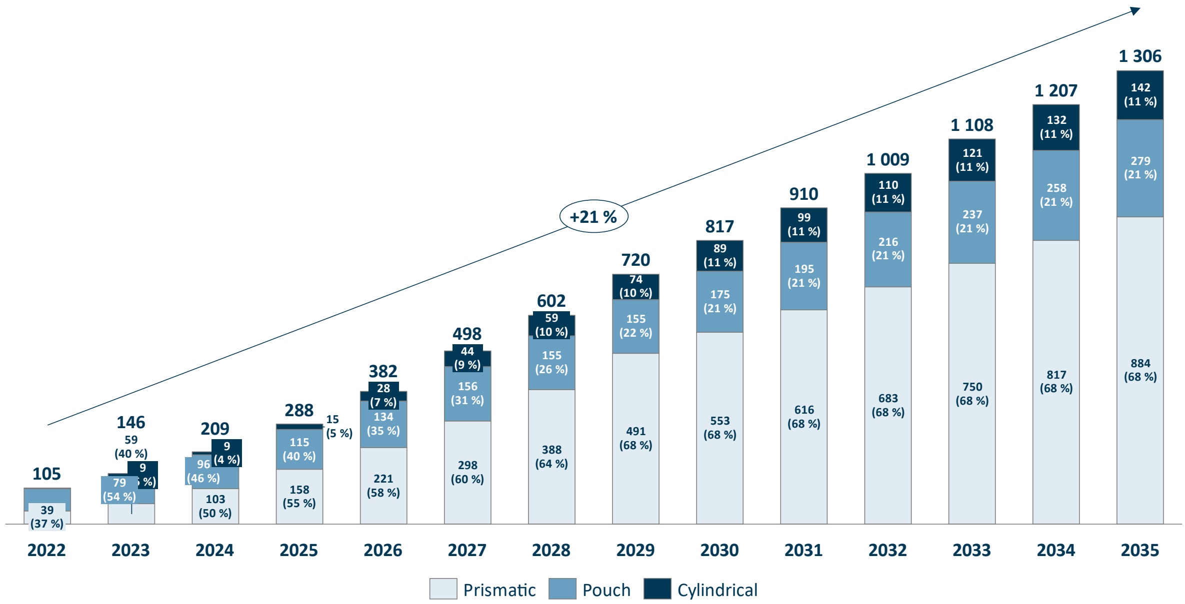


Figure 18: **ELECTRIC LIGHT VEHICLE BATTERY DEMAND PER CELL GEOMETRY (INCLUDING LIGHT COMMERCIAL VEHICLES) | #** GWh, 2022 – 2035, Europe + Russia.

We can see that cell geometry is expected to remain stable in Europe, but significant changes will occur regarding the choice of cathode. Manufacturers are going away from NMC to go toward Cobalt Free Battery like LFP, LMFP and LNMO. This is led by Volkswagen developing its own Cobalt Free Battery through Powerco and Stellantis announced to shift completely to Cobalt Free battery by 2030.

3.3. Other Demand Markets

The focus on the light vehicle market so far has been a consequence of its sheer size, which is about 80% of the total market. Nevertheless, there are eight key application sectors apart from light vehicles, each possessing unique dynamics and drivers that influence battery demand. These markets encompass Energy Storage Systems (ESS), Trucks and Buses, Consumer Electronics, Light Mobility, Off-Road Vehicles, Medical Equipment, and Maritime Applications.

ESS (Energy Storage Systems) are vital for integrating renewable energy sources into power grids and ensuring stable and reliable electricity supply. The impressive growth of the EV market drives the need for an increase in production capacity of robust energy storage systems.

Trucks are gradually move towards electrification for some use applications, a shift encouraged by government initiatives and enhanced by advancements in battery technology that increase range and performance. Depending on the region, heavy-duty vehicles can represent a large share of transportation emissions and electrification is one of the lever to reduce emissions if adapted to the use application.

The **Bus** sector is rapidly adopting electric technology due to its lower operational costs compared to traditional diesel buses. Moreover, the visibility of electric buses raises public awareness and supports demand. In the face of pollution in cities, there is a rising consideration, particularly in regions like Europe, to transition towards electrification in public bus. In Europe, discussions are underway regarding the potential mandate for all new city buses to be zero-emission by 2035.

In **Consumer Electronics**, the relentless pace of technological advancement necessitates advanced, high-capacity batteries. The ongoing cycle of device replacements, a result of rapid obsolescence and shorter device lifespans, maintains a steady battery demand in this sector.

Light Mobility is emerging as a sustainable transport alternative. It can provide more affordable means of transportation and can fulfill commuting needs. Electric two-wheelers have been increasingly adopted.

Off-Road vehicle manufacturers are responding to the demand for environmentally friendly and quieter alternatives by introducing high-capacity batteries in the market.

The **Medical** sector is increasingly dependent on battery-powered services, telehealth, wearable technology, and portable equipment. Furthermore, batteries are integral to medical research and development.

The **Maritime** sector is gradually embracing battery technology to reduce emissions in ports, starting with hybrid motors for entry in port or small electrified leisure boats.

The global battery demand for these other markets is projected to reach 0.7 TWh by 2030 and 1.2 TWh by 2035, with the bulk of this demand coming from ESS and Trucks & Buses. Looking at regional trends, China is expected to remain the largest player. Technologically, these markets will diversify battery usage, with a significant portion for LFP and emerging Na-Ion, driven primarily by ESS. (Figures 35 a, b and c for further details).

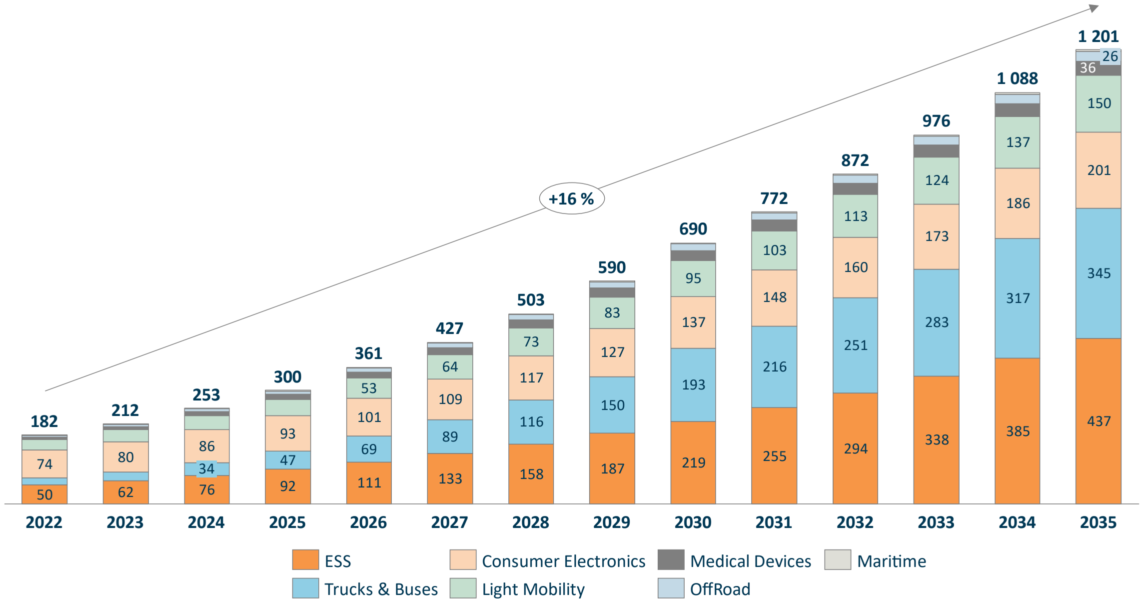


Figure 19a: **BASELINE SCENARIO - LITHIUM & NA-ION BATTERY DEMAND PER APPLICATION MARKET | GWh**, Worldwide, 2022 – 2035

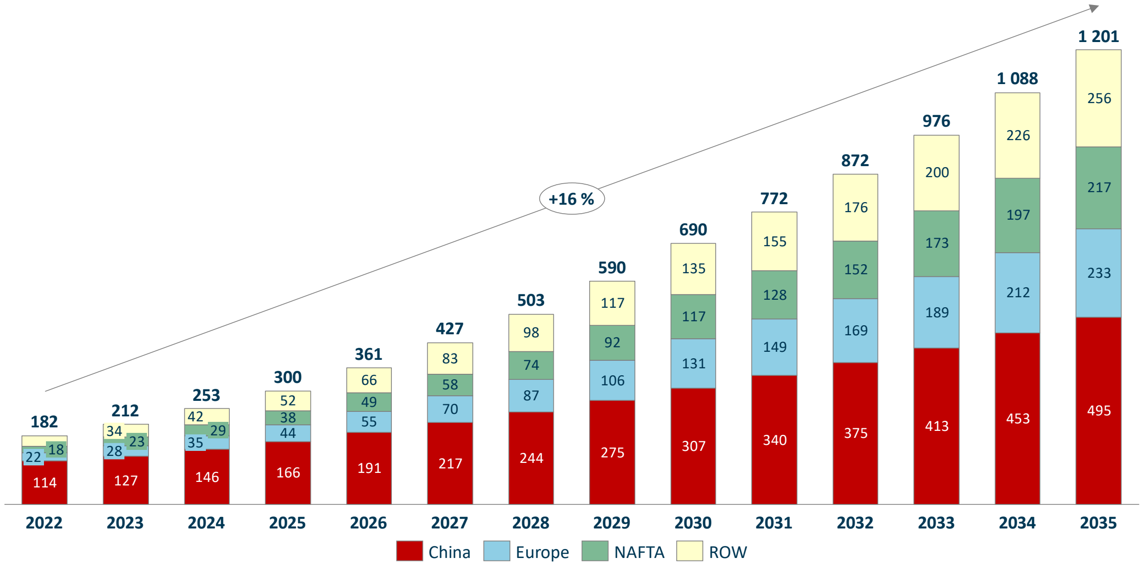


Figure 19b: **BASELINE SCENARIO - LITHIUM & NA-ION BATTERY DEMAND PER REGION | GWh**, Worldwide, 2022 – 2035

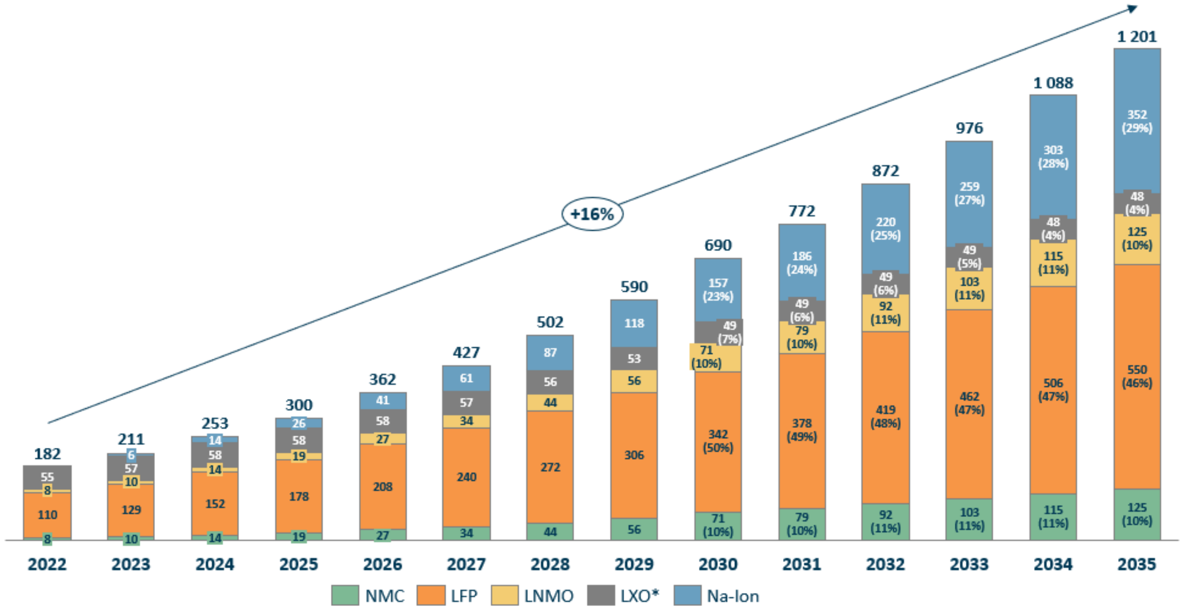


Figure 19c: **OTHER MARKETS BATTERY DEMAND PER CATHODE CHEMISTRY | #** GWh, 2022 – 2035

4. Worldwide and European Battery Supply

4.1. Introduction

At the heart of the electric vehicle and renewable energy storage revolution is a vital component: the battery cell. To understand battery supply, it is important to grasp that battery packs are assembled from individual battery cells, and these cells are really the essence of the pack in terms of costs, technology, and performance.

Battery packs consist of numerous cells organized into modules, much like bricks coming together to form a wall. These cells, whether prismatic, pouch, blade, or cylindrical in shape, serve as the foundational building blocks of the pack (Annex A 7.1) Notably, as technology advances, we are witnessing the emergence of innovative pack designs.

Each battery pack operates under the supervision of a Battery Management System (BMS) (Annex A 7.1). This intelligent system utilizes algorithms to continuously monitor voltage, current, and temperature throughout charge and discharge cycles, upholding strict safety protocols. This meticulous oversight is crucial in preventing overcharging or discharging and preserving the overall health and durability of the battery pack.

Apart from the cells, the battery pack contains other crucial components (Annex A 7.1). These include a cooling system, to dissipate the heat generated during operation, and structural elements such as the battery pack tray and cover. Each component plays an essential role in ensuring the overall performance, safety, and durability of the pack.

At the heart of the battery supply chain are the massive manufacturing facilities known as 'gigafactories.' Their gargantuan sizes are a testament to the scale of production needed to meet global battery demand. For instance, Tesla's Gigafactory in Nevada stands as the largest building in the world, covering an area of 1 million square meters over two floors. It is larger than the Pentagon, AT&T Stadium, and US Capitol combined, illustrating the scale at which battery production needs to occur to power our future. A total investment of $6 billion into this facility underscores the economic significance of these operations.

In the following sections, we will delve deeper into the main drivers behind the supply of batteries, which are increasingly becoming a fundamental component in our transition towards a more sustainable and energy-efficient future.

4.2. Main Supply Drivers

The global battery market is undergoing an unprecedented expansion, shaped by a multitude of complex and interrelated supply drivers. They range from the necessity for renewable energy storage to a booming electric vehicle market, government initiatives, decarbonization efforts, technological advancements, falling battery costs, improvements in manufacturing processes, and the strategic emphasis on supply chain resilience and localization.

Renewable Energy Storage
In a world where the renewable energy sector is increasingly taking center stage, batteries provide the cornerstone of this transformation. Renewable sources such as solar and wind generate power intermittently, necessitating efficient energy storage solutions. Batteries, particularly lithium-ion, have emerged as reliable energy storage systems, driving a concurrent growth in their supply to match the demand.

Electric Vehicle Market Expansion
The global expansion of the EV market is another significant catalyst for battery supply. As the world grows more environmentally conscious, electric vehicles are becoming a more attractive mode of transportation. This shift is fueling an increased demand for batteries, urging manufacturers to ramp up production, thereby driving supply.

Gigafactories and Battery Production
The term "gigafactory" has become synonymous with large-scale battery production. Initially coined by Tesla for their Nevada-based production facility, it now refers broadly to any large-scale battery manufacturing plant. Gigafactories, due to their enormous production capacity, play a crucial role in meeting the escalating global battery demand. As more companies invest in setting up these massive manufacturing facilities, they are poised to become a major driver in the expansion of battery supply.

Government Support and Incentives
Policy measures play a critical role in shaping the battery market. Government support, in the form of subsidies for battery manufacturing or tax incentives for EV buyers, fosters a supportive framework for the growth of the battery industry. This support not only spurs demand but also encourages manufacturers to increase supply.

Energy Transition and Decarbonization
As nations worldwide commit to decarbonization in line with the Paris Agreement, the demand for batteries in renewable energy systems and electric transportation is set to rise dramatically. This global energy transition is a potent driver for the expansion of battery supply.

Technological Innovation and R&D
Advancements in technology and concerted R&D efforts are ushering in a new era of more efficient, durable, and safer batteries. These technological breakthroughs drive demand and simultaneously streamline production processes, encouraging a growth in supply.

Falling Battery Costs
The substantial drop in battery prices over the past decade has been a game-changer. As technological advancements and economies of scale continue to drive down costs, the demand for batteries is set to rise, thus stimulating an increase in supply. Yet, due to pressure on raw materials, this decrease is not guaranteed as a raise in battery price has been observed in 2021 and 2022.

Advancements in Manufacturing Processes
The evolution in manufacturing processes, marked by increased automation and efficiency, is another significant driver. These improvements have not only reduced the time and cost of battery production but also resulted in higher-quality products. This has led to a boost in supply to meet the escalating demand.

Supply Chain Resilience and Localization
Considering recent global disruptions, the focus on building resilient and localized supply chains has never been more critical. Many nations are now investing in domestic battery production capabilities to insulate their supply chains from external shocks and reduce foreign dependency. This move is catalyzing an increase in local battery supply worldwide.

The confluence of these diverse factors is fueling an unprecedented expansion in the global battery supply. Navigating this complex landscape requires a deep understanding of these drivers and their interdependencies.

4.3. Gigafactory Announcements Per Region

In order to assess the availability of batteries, a thorough bottom-up approach was taken. For each company or entity involved, we diligently recorded all the announcements they made about their planned gigafactory capacities spanning the years from 2020 to 2035.

4.3.1. Zoom on Europe's Gigafactories

Europe presents a fascinating case study in the battery market. With its numerous players, the market is notably fragmented, fostering a dynamic and competitive landscape. Several major manufacturers have established their foothold, with LG Energy Solution, Samsung, and CATL standing out due to their significant contributions to the overall capacity. Beyond these Asian legacy players, there are many new entrants: Northvolt, ACC, Powerco, Freyr, Morrow, Verkor, BasqueVolt, ItalVolt, Prologium, etc.

LG Energy Solution has established a formidable presence, operating the biggest European gigafactory in Poland, with a production capacity of 115 GWh. SK Innovation, another influential player, operates two plants in Hungary. CATL is expected to become one of the largest players in Europe despite having currently only a small production facility in Germany.

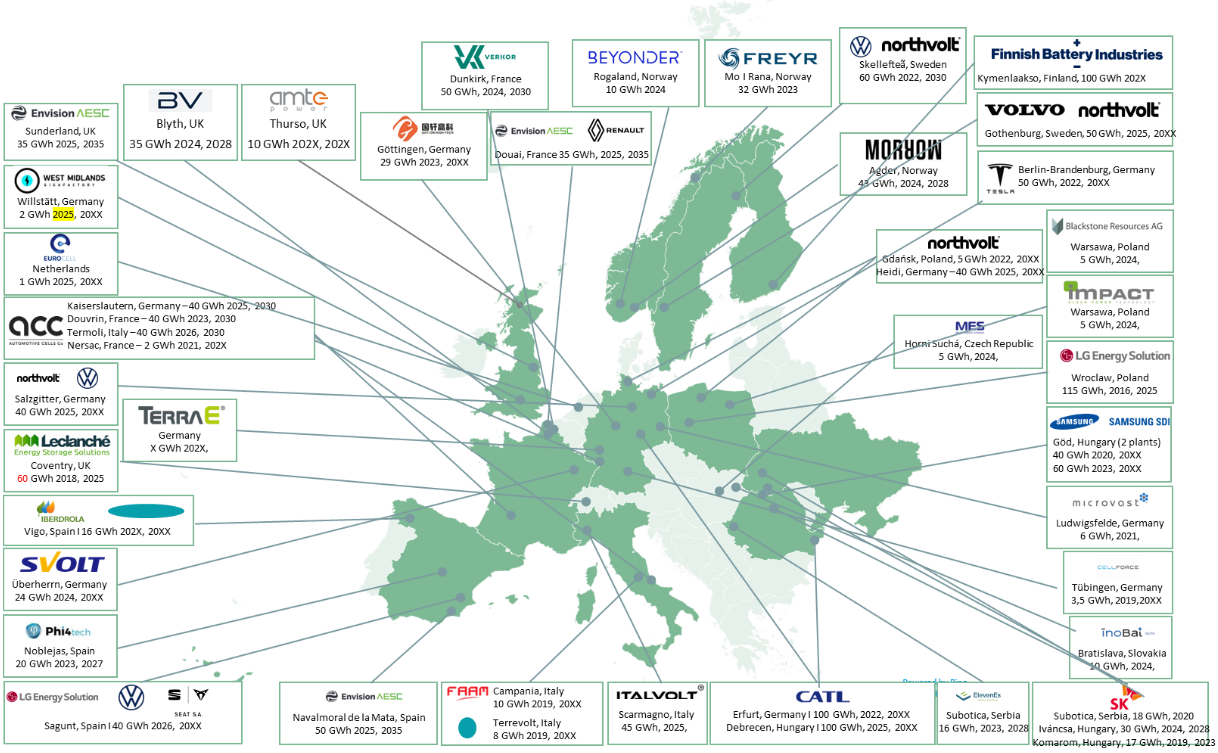


Figure 20: **MAPPING GIGAFACTORY – EUROPE |** June 2023 Mapping

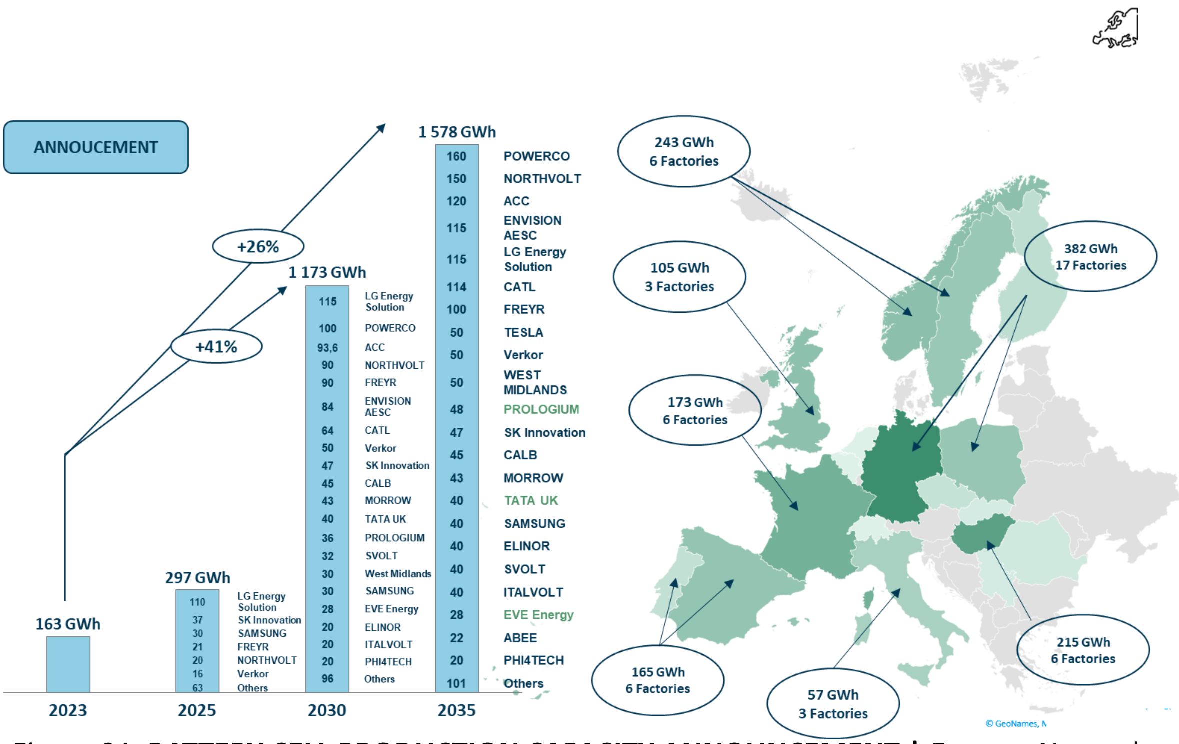


Figure 21: **BATTERY CELL PRODUCTION CAPACITY ANNOUNCEMENT |** Europe, Nameplate Production Capacity Through Roll Out Analysis in GWh 2023-2035

In the European market, we're seeing both new players and joint ventures trying to break into the battery industry. Northvolt, for example, has teamed up with VW and Volvo (as shown in Figure 20). Additionally, new entrants backed by OEMs like Automotive Cells Company (funded by Mercedes and Stellantis) and Powerco (a Volkswagen subsidiary) are making their mark in the European Gigafactory scene.

The current projections suggest a fast development of European gigafactories. Capacity announcements forecast a capacity of 1,173 GWh by 2030, expected to rise further to 1,578 GWh by 2035.

Geographically, these production sites are located in Germany, Poland, Hungary, and the Nordic countries. For example, Germany and Poland are anticipated to host by 2030 11 and 6 factories respectively, while France and Hungary will each be home to 6 factories, presenting a market with many players but still highly concentrated in Eastern Europe, due to the previously existing factories (Figure 21).

The European Gigafactory market presents a diverse landscape. In addition to established Korean and Chinese players, new entrants and OEM-backed Gigafactories are emerging independently.

4.3.2. Zoom on NAFTA's Gigafactories

The North American Free Trade Agreement region, comprising the United States, Canada, and Mexico — presents a distinctive scenario. Notably, joint ventures between Korean and Japanese players with American Original Equipment Manufacturers stand out. The strategic decision to source technological and industrial expertise from experienced Korean players is driven by several factors. Firstly, by collaborating through JV with a friendly nation, the U.S. gains more influence over the supply chain. Additionally, this choice provides a protective measure against Chinese leadership in the sector.

Standing at the top of battery production is Tesla, with five planned Gigafactories expected to deliver over 330 GWh by 2030. A close contender is LG Energy Solution, anticipated to contribute over 200 GWh by the same year (Figure 22).

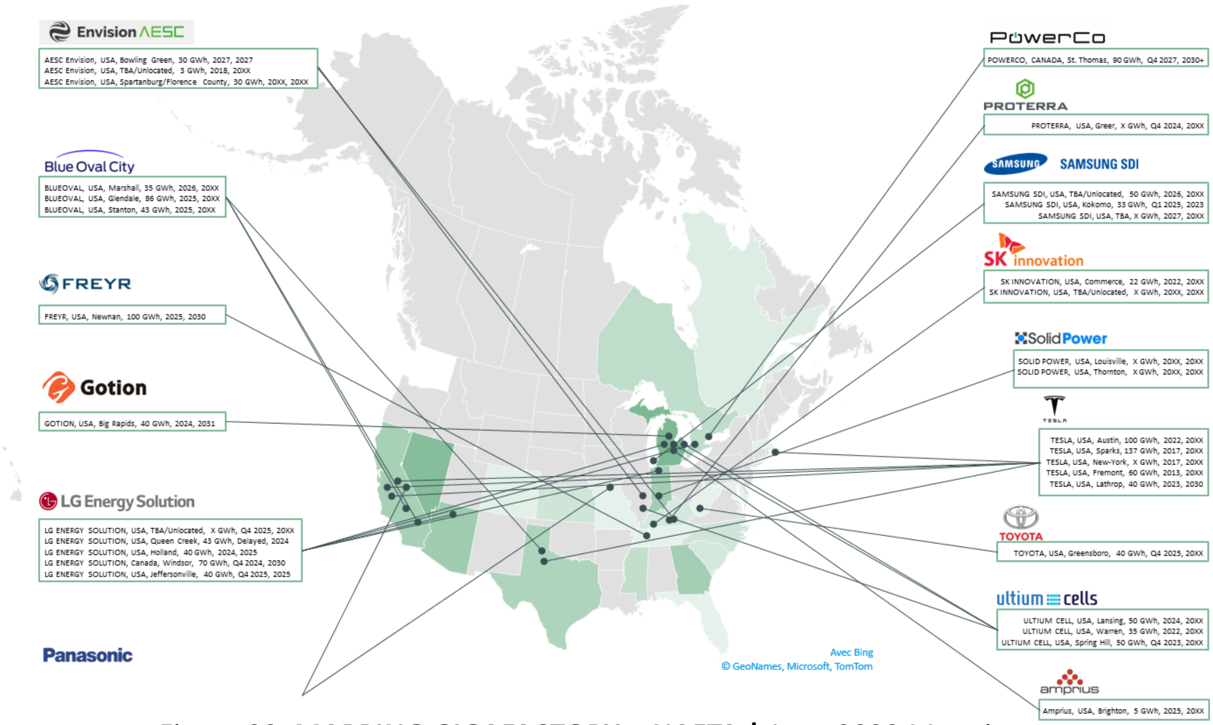


Figure 22: **MAPPING GIGAFACTORY – NAFTA |** June 2023 Mapping

In terms of capacity announcements, the US and Canada, at 874 GWh by 2030, are inching closer to Europe's projections. Interestingly, the market dynamics in this region are shaped by strategic JVs between historical OEMs and Korean or Japanese battery manufacturers. These partnerships underline the emphasis on combining innovative battery technologies from Korean or Japan with the robust manufacturing capabilities of North American OEMs.

One unique aspect of the NAFTA region's gigafactories is the significant presence of Tesla. As the pioneer and leader in EV production, Tesla's massive gigafactories not only exemplify the potential scale of battery production but also highlight the essential role of vertical integration in ensuring a reliable supply of high-quality batteries (Figure 23).

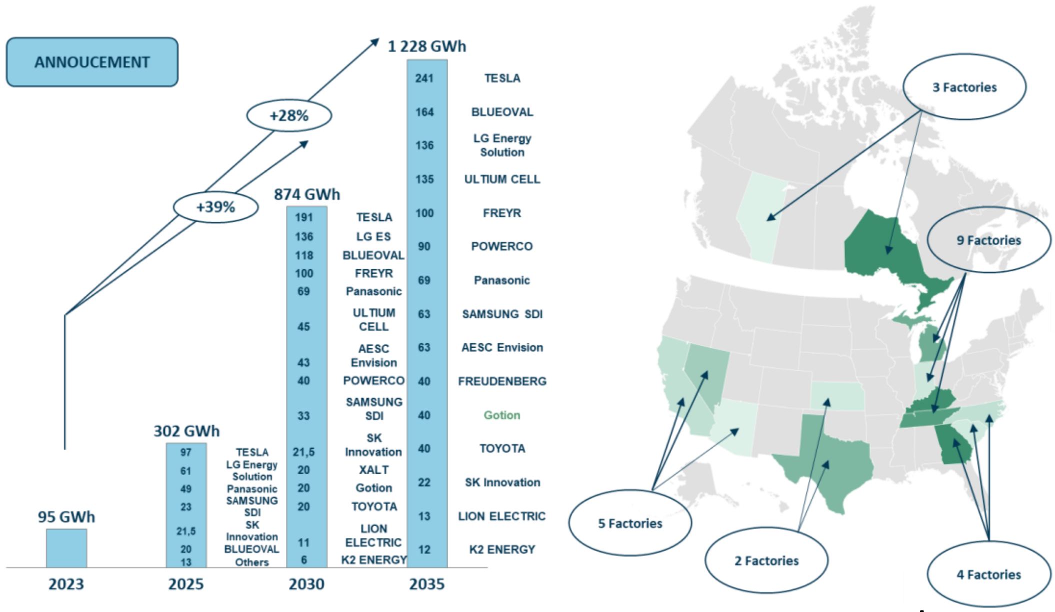


Figure 23: **BATTERY CELL PRODUCTION CAPACITY ANNOUNCEMENT |** NAFTA, Nameplate Production Capacity Through Roll Out Analysis in GWh 2023-2035

In summary, the NAFTA region's gigafactory landscape portrays the exciting confluence of technological innovation, strategic partnerships, and robust manufacturing capabilities. The result is a rapidly growing battery production capacity.

4.3.3. Zoom on China's Gigafactories

China's leadership in the battery manufacturing sector is undisputable. As the largest battery supplier worldwide, it plays a crucial role in the global supply chain. The sheer magnitude of this leadership is best embodied by the extensive operations of CATL and BYD in China. CATL has announced 16 plants with a combined capacity exceeding 750 GWh. CATL is already operating 9 plants. On the other hand, BYD operates 17 plants, delivering more than 435 GWh. These impressive gigafactories reinforce China's leadership position in the battery market (Figure 24).

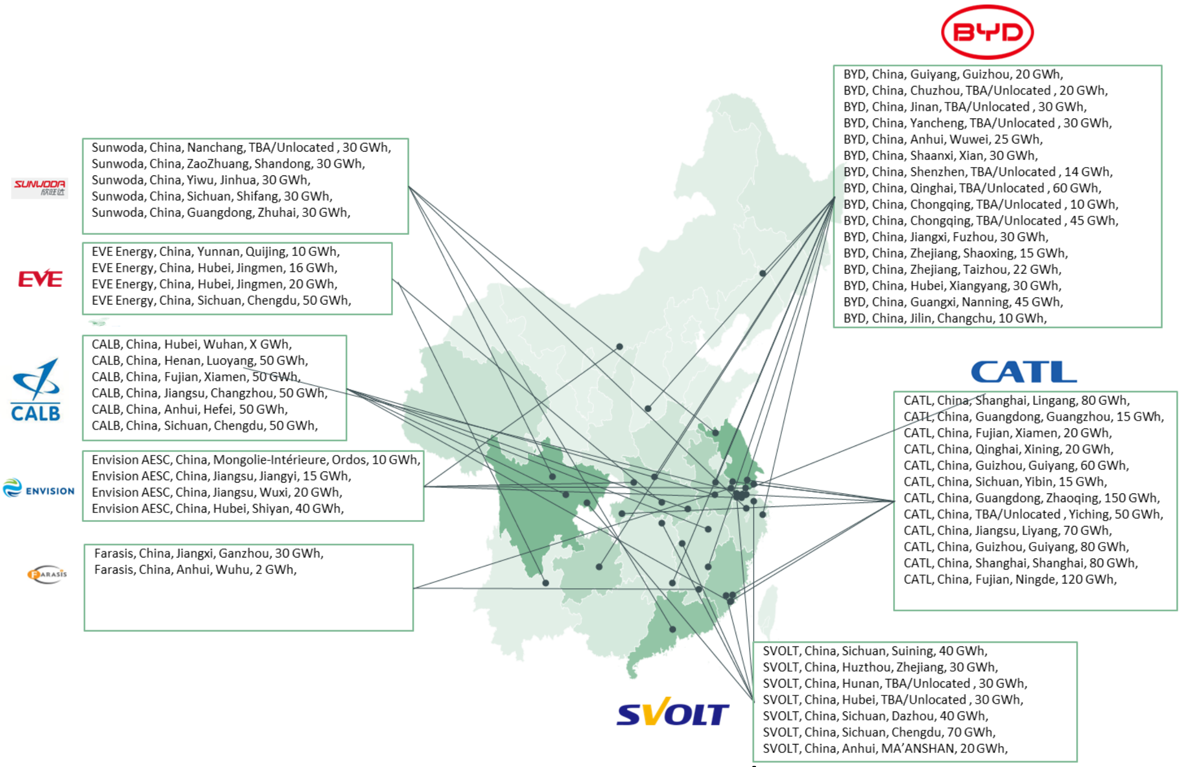


Figure 24: **MAPPING GIGAFACTORY – CHINA|** June 2023 Mapping

The market is dominated by several large players, including CATL, BYD, CALB, Sunwoda, EVE, and Envision. These industry giants demonstrate the country's manufacturing prowess and commitment to technology innovation in the battery sector. Their high-class facilities and high output underline China's strategic focus on capturing a significant share of the growing demand for batteries worldwide. Some of the biggest factories are strategically located near ports, and will keep exporting batteries toward Japan, Korea, Europe, and NAFTA.

With approximately 70% of the global manufacturing share, China is the world's leading battery manufacturer. The country has ambitious plans to further expand its capacity, targeting over 2,400 GWh by 2035, a massive increase from 857 GWh in 2022. This anticipated growth represents an impressive CAGR of 11% over 13 years, demonstrating China's determination to maintain its leadership in the global battery production sector (Figure 25).

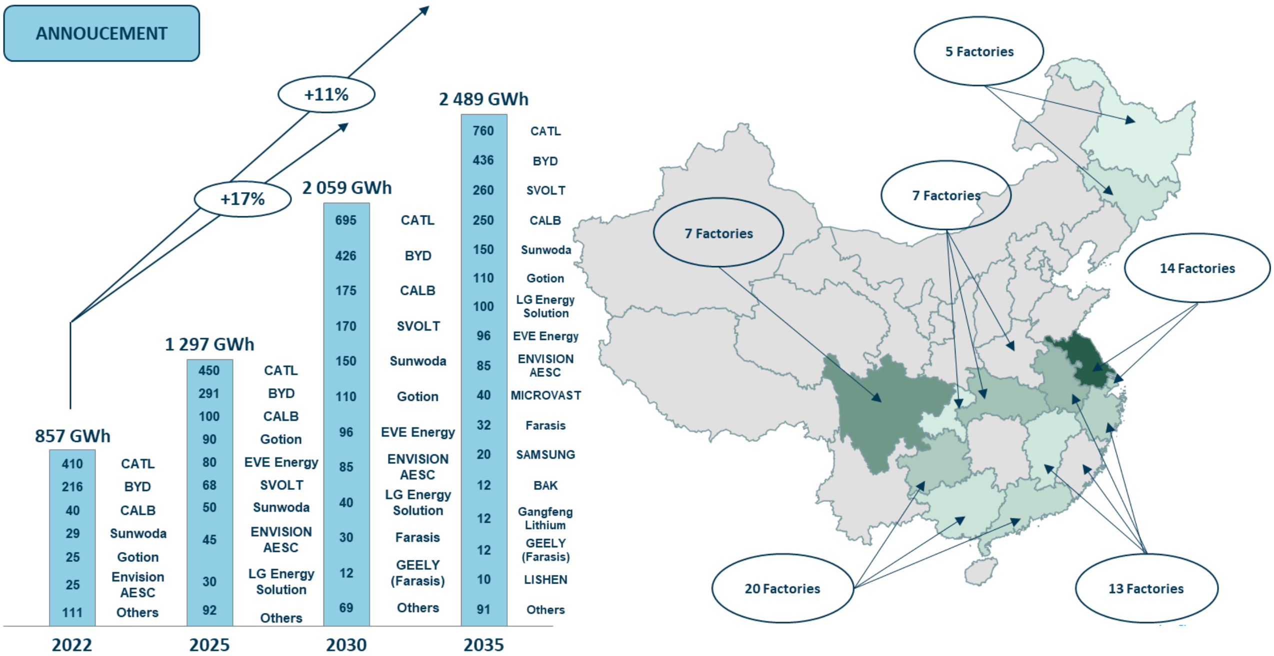


Figure 25: **BATTERY CELL PRODUCTION CAPACITY ANNOUNCEMENT |** China, Nameplate Production Capacity Through ROLL OUT in GWh 2022-2035

In summary, China's robust and rapidly growing battery production capabilities, along with its commitment to technological innovation, position it at the forefront of the global battery market. As the world transitions toward a more electrified and sustainable future, China's role as a leading battery supplier will undoubtedly be critical.

4.4. Global Battery Production Capacity: Current Trends and Future Projection

4.4.1. Global announcements descriptions

The world is witnessing an unprecedented acceleration in the expansion of global battery production capacity, largely driven by the growing demand for electric vehicles (EVs) and to a lesser extent by renewable energy storage. This bottom-up analysis provides an in-depth perspective on this significant shift.

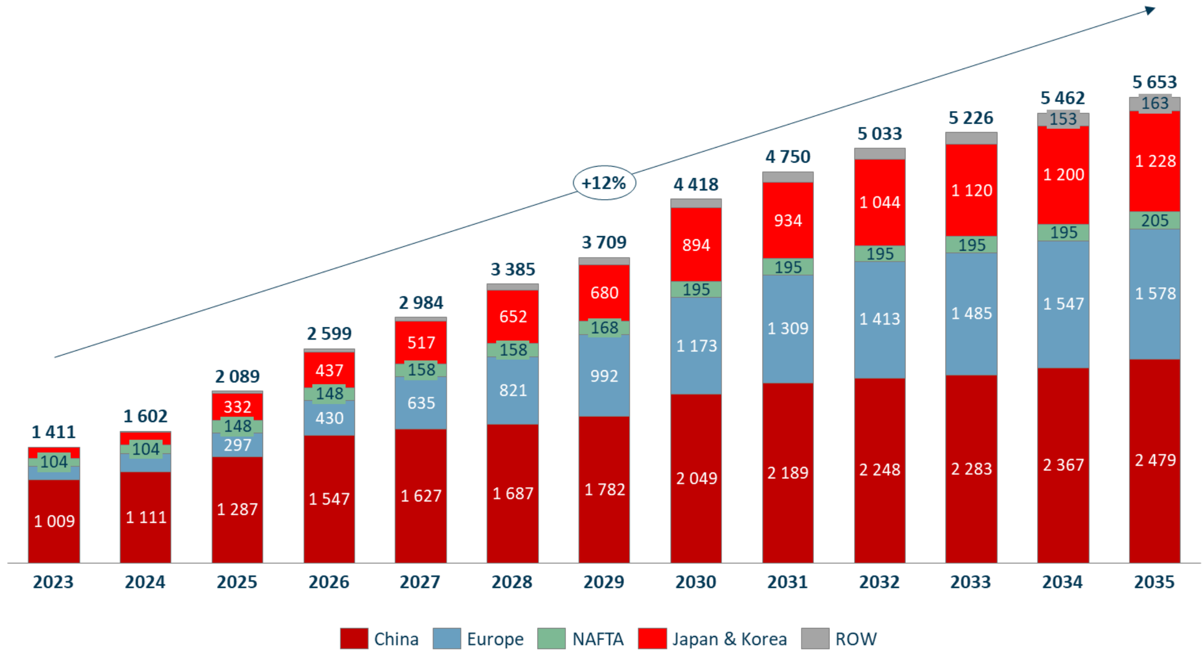


Figure 26: **BATTERY CELL PRODUCTION CAPACITY ANNOUNCEMENT PER REGION | #**
Through Roll Out Analysis, GWh, 2023 – 2035

Capacity announcements for battery production have hit a high of 4.4 terawatt-hours (TWh) by 2030 and are projected to reach 5.6 TWh by 2035 (Figure 26). This enormous supply growth is driven essentially by China and Europe, which together will account for a staggering 72% of all capacity announcements expected by 2035.

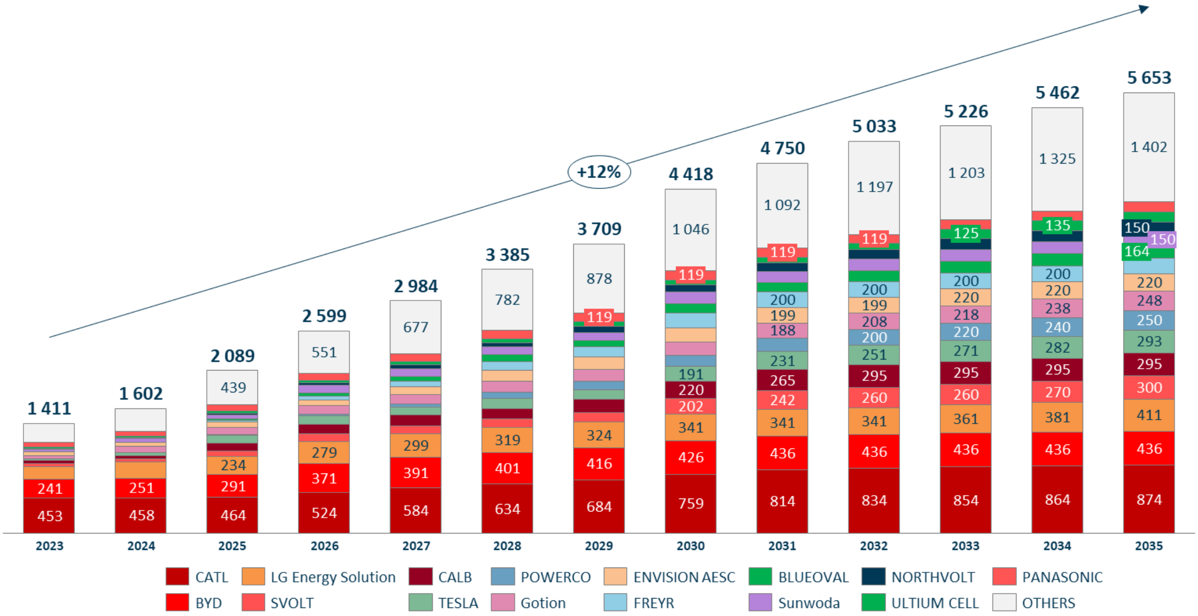


Figure 27a: **BATTERY CELL PRODUCTION CAPACITY ANNOUNCEMENT PER LEADING BATTERY MANUFACTURER |** # Through Roll Out Analysis, GWh, 2023 – 2035

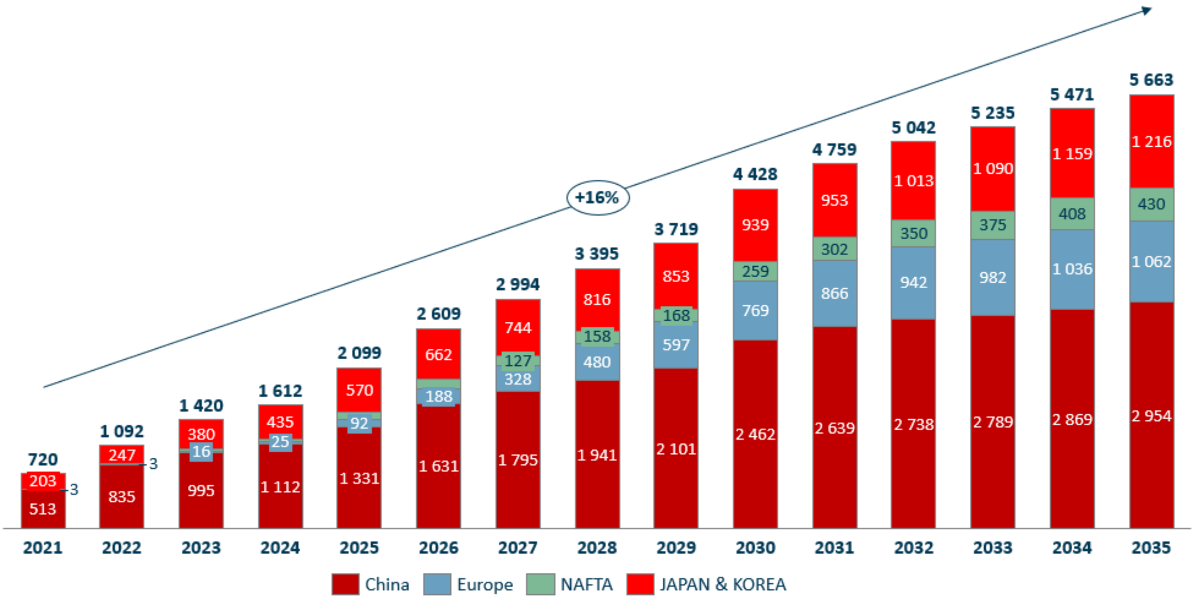


Figure 27b: **BATTERY CELL PRODUCTION CAPACITY ANNOUNCEMENT PER REGION OF ORIGIN OF BATTERY MANUFACTURER |** # Through Roll Out Analysis, GWh, 2023 – 2035

In terms of market players, the top 15 battery cell manufacturers represent 75% of the capacity announcements. Seven of these key players are based in China, including industry giants and current market leaders BYD and CATL. However, the landscape is expected to change massively as the market share is likely to be diffused among other players, especially since a host of new entrants will be coming in by 2035. This increasing competition in the market is driving a healthy Compound Annual Growth Rate (CAGR) of +12% from 2023 to 2035 (Figure 27a).

Figure 27b illustrates a significant trend in the battery industry, highlighting the leading role of Chinese and Korean battery manufacturers. Impressively, these players account for over 73% of battery capacity announcements, showcasing their substantial influence. This lead is further accentuated by the strategic establishment of Chinese manufacturers within Europe and other global regions. Moreover, Korean players play a pivotal role in the construction of gigafactories in the NAFTA region. The collaborative efforts between Chinese manufacturers expanding globally and Korean involvement in NAFTA gigafactory development underscore the global impact of these key players in shaping the landscape of battery production.

4.4.2. Risk and capacity analysis – Methodology

The second phase of this approach involves conducting a risk analysis to determine a realistic capacity estimate. The analysis was carried out in a systematic way, focusing on three key aspects:

First Point: Several assumptions were formulated to account for potential delays and production (Figure 28) start and shortfall risks in the gigafactory rollout based on data from historical precedents. These hypotheses include:

- A 2-year timeline between the start of construction and the commencement of production. This considers a 1.5-year construction period and an additional 0.5 year for setting up equipment and initiating mass production.
- Capacity ramp-up ranging from 10 to 20 GWh/year based on the gigafactory's stated objectives.

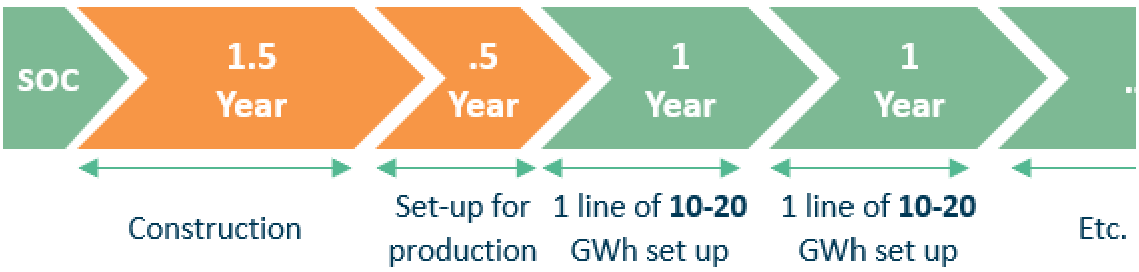


Figure 28: **MODELING - GIGAFACTORY ROLL OUT**

Second Point: Subsequently, risks associated with factors such as experience, funding, and technological aspects were assessed for each factory.

1 - Experience Risks: In this category, risks associated with a factory's experience level are associated. Players are classified into two groups.

Existing Players: These are companies that have already achieved mass production (>2GWh) of battery cells by 2022. They generally have a track record in battery manufacturing and are considered to have a higher level of experience.

New Players: New players face inherent risks, which can be grouped into three key areas:
- Execution Risk: This involves the ability to successfully deliver on commitments and generate revenue, despite potential challenges such as scrapped production and technological difficulties.
- Equipment Shortage Risk: New players may encounter competition for battery cell production equipment, leading to fierce competition between legacy players and newcomers.
- Workforce Risk: There can arise issues related to workforce management and recruitment, which can severely impact on a new player's ability to meet production goals.

2 - Funding Risks: This category pertains to the financial aspects of gigafactory projects. We determine funding types based on three criteria:
- Adequate Funding: If the funding secured for the project exceeds 30% of the total funding needs, it indicates a relatively low funding risk.
- Backed by Major Entity: Companies that enjoy support from a major original equipment manufacturer (OEM) or are valued at over $10 billion are considered to have reduced funding risks.
- Stability of Funding: The absence of concerns regarding funding availability or project cancellation also contributes to lower funding risk.

The combination of these criteria leads to three funding categories: “Good” for meeting all criteria, “Medium” for meeting two criteria, and “Bad” for meeting one or less of these criteria.

3 - Technological Exposure Risks: This category focuses on the risks associated with relying on only one specific battery cell. Gigafactories that rely on a single cell chemistry are exposed to two main risks:
- Material Price Risk: This involves vulnerability to fluctuations in raw material prices, particularly for components such as cobalt in NMC (Nickel Manganese Cobalt) technologies.
- Technological Breakthrough Risk: These factories may face exposure to technological advancements that affect NMx technologies or new emerging technologies like e.g., Na-Ion

We assessed that each of these risks comes with a level of probability of defect of the factory. The references are existing players, with good funding, and no technological risks, which will not face any probability of defect.

EXPERIENCE RISKS			FUNDING RISKS				TECHNOLOGICAL RISKS		
PLAYER TYPE	NEW PLAYER	EXISTING PLAYER	FUNDING TYPE	BAD	MEDIUM	GOOD	RELY ON ONE CELL CHEMISTRY	YES	NO
PROBABILITY OF DEFECT:	10%	0%	PROBABILITY OF DEFECT:	10%	5%	0%	PROBABILITY OF DEFECT:	5%	0%

Figure 29: **MODELING – PROBABILITY OF DEFECT DUE TO RISK EXPOSTION**

Third Point: Finally, two factors are considered, Scrap Rate and Capacity Usage, which impact gigafactory capacity utilization (Figure 30). Notably, even experienced players are still facing challenges with high scrap rates. This is primarily due to the intricacies of manufacturing cells, where scrap may occur at various stages, including aligning cathodes and anodes, laser welding/punching, electrolyte insertion, and aging. Moreover, transferring production know-how from lab-scale to production-scale proved to be a formidable challenge due to the numerous consecutive process steps and their influence on material properties, composition, and cell design processes.

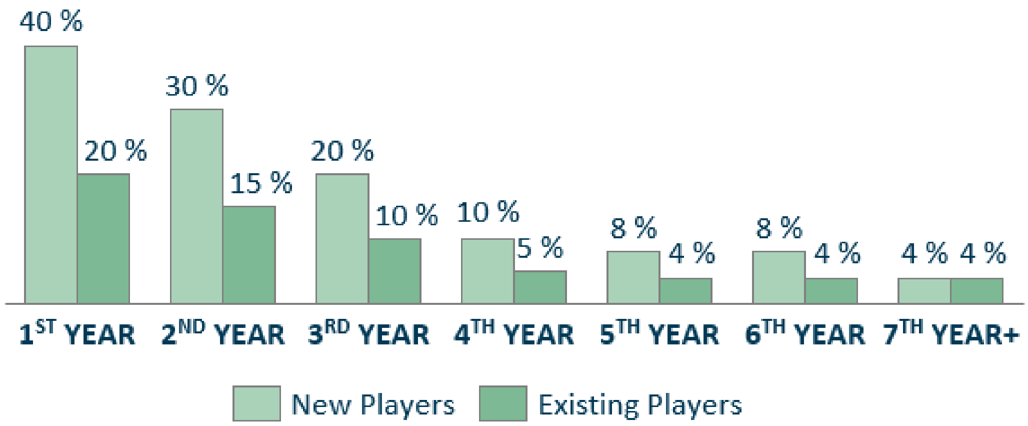


Figure 30a: **MODELING - SCRAP RATE PER PLAYER TYPE AND YEAR OF PRODUCTION |**
%, Through the Factory Production Life

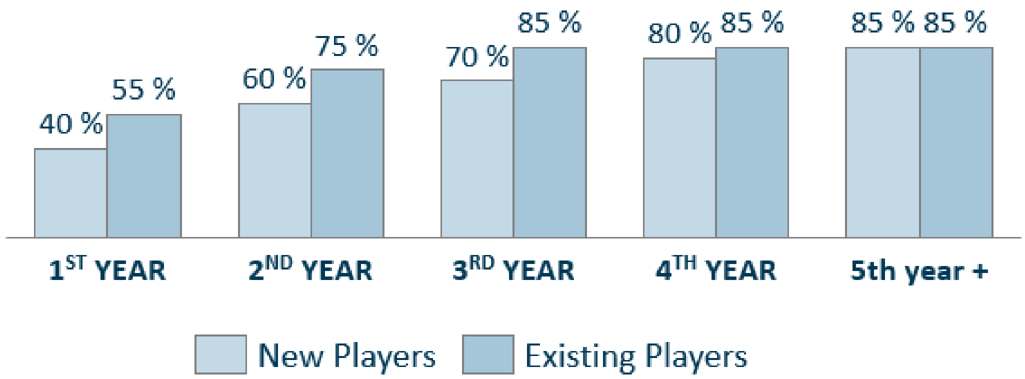


Figure 30b: **MODELING - CAPACITY USAGE PERPLAYER TYPE AND YEAR OF PRODUCTION |**
%, Through the Factory Production Life

These three points formed the foundation of our risk analysis, enabling us to arrive at a pragmatic assessment of realistically available gigafactory capacity.

4.4.3. Risk and capacity analysis- Results

After a rigorous analysis of risk and capacity utilization this study forecasts that realistic battery supply will reach 3.0 TWh by 2030 and grow to 4.2 TWh by 2035. China will continue to be the dominant player in this sphere, commanding 47% of the market share by 2035. Europe–is predicted to increase its market share substantially post 2027 and become a significant player in the global market (Figure 31).

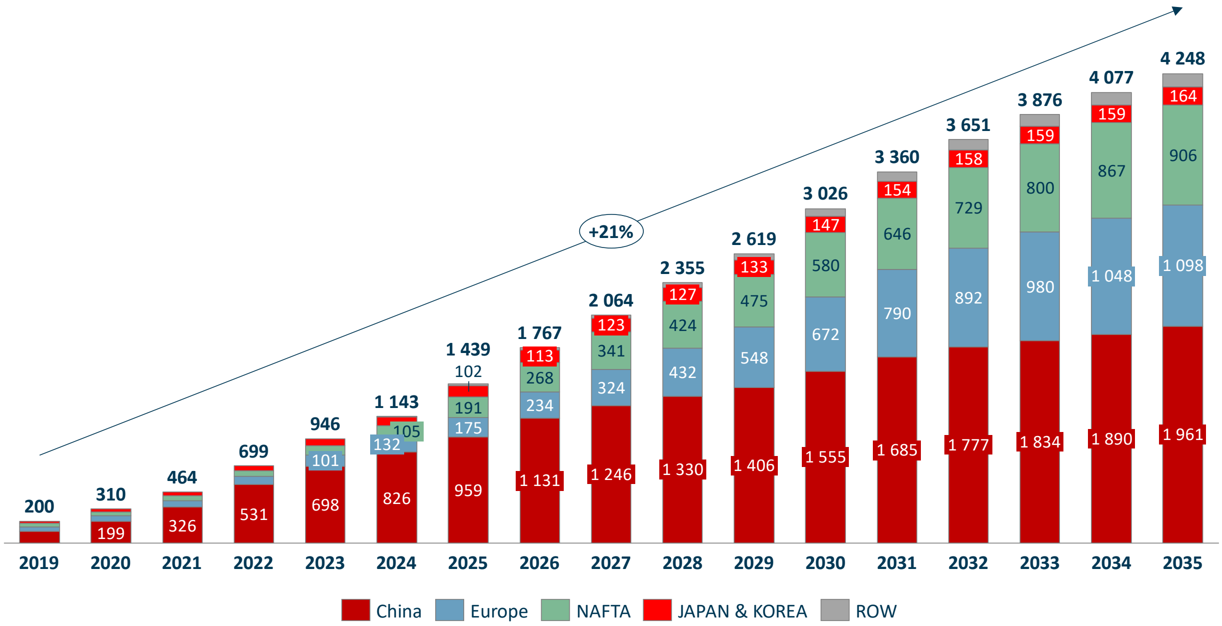


Figure 31: **BATTERY CELL REALISTIC AVAILABLE PRODUCTION PER REGION|** # Through Roll Out Analysis, GWh, 2023 – 2035

It is becoming increasingly important to analyze and understand the specific risk factors and capacity constraints that different regions will have to face. The focus here is to scrutinize the situations in Europe, NAFTA, and China.

4.5. Battery Supply and Battery Demand Gap Analysis

4.5.1. Europe

Europe is a region witnessing substantial developments in the electric vehicle market. Yet, it is also a region plagued by uncertainties and significant production challenges, especially in the initial phase of production capacity installation. One of the significant roadblocks has been the exceptionally high scrap rates at the beginning of production. This means reduced output and delays effectively leading to an under-utilization of the installed capacity.

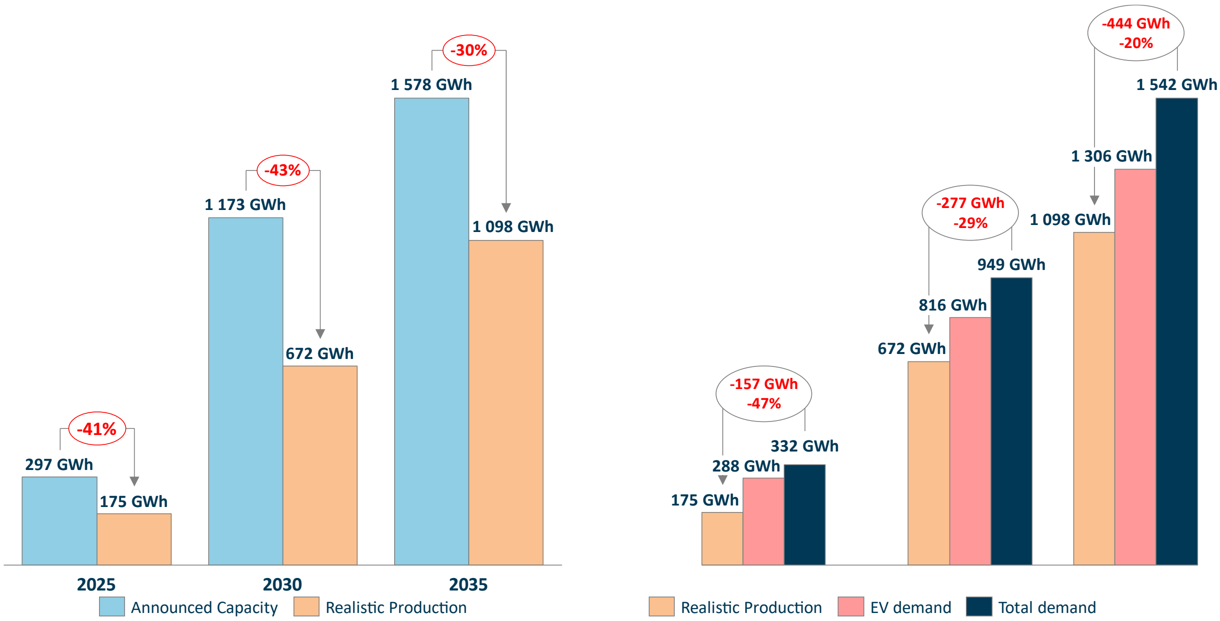
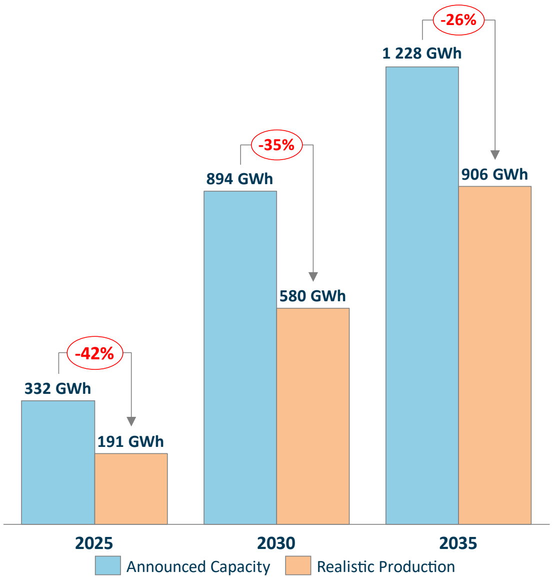


Figure 32a: **BATTERY CELL REALISTIC AVAILABLE PRODUCTION FORECAST |**
Europe, Forecast, GWh, 2025-2030-2035
Figure 32b: **BATTERY CELL REALISTIC AVAILABLE PRODUCTION, EV DEMAND & TOTAL DEMAND |**
Light Electric Vehicle, Europe, Forecast, GWh, 2025-2030-2035

The forecasts project 672 GWh of realistically achievable production by 2030 in Europe. Given the escalating demand from OEMs driven by regulatory push and consumer pull, this projected output falls short of expectations. This under-supply scenario emphasizes the need for improved manufacturing efficiencies, increased investment in additional production capabilities, and better scrap management (Figure 32b and 48b).

4.5.2. NAFTA

Similar to Europe, the NAFTA region is also facing challenges that potentially disrupt the balance between supply and demand. Chief among these challenges are the significant scrap levels and production delays. These factors present substantial roadblocks to achieving optimal production levels.



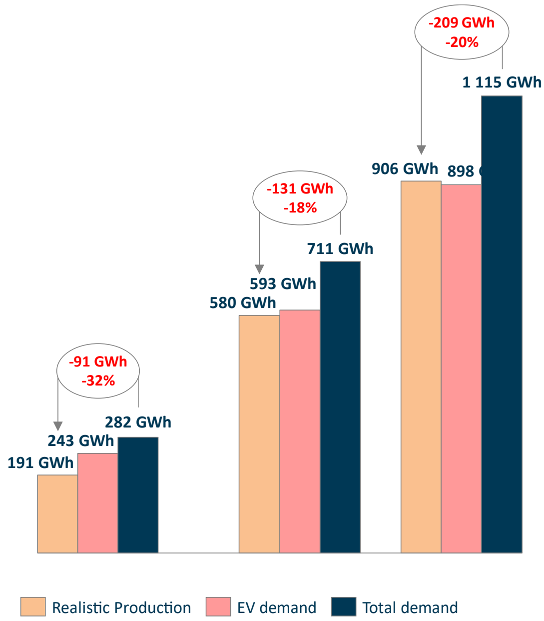
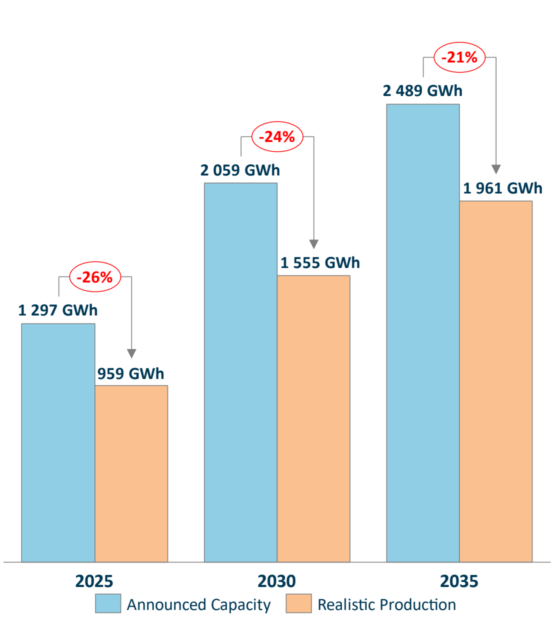


Figure 33a: **BATTERY CELL REALISTIC AVAILABLE PRODUCTION FORECAST |**
NAFTA, Forecast, GWh, 2025-2030-2035
Figure 33b: **BATTERY CELL REALISTIC AVAILABLE PRODUCTION, EV DEMAND & TOTAL DEMAND |**
Light Electric Vehicle, NAFTA, Forecast, GWh, 2025-2030-2035

NAFTA is expected to realistically produce 580 GWh by 2030. Gaps in NAFTA are smaller than those in Europe, primarily because of lower demand for EV cars, given the absence of a scheduled ICE ban. This significant supply-demand gap needs strategic interventions focused on enhancing production efficiency, technological upgrades, and overall capacity enhancement (Figure 33b and 49b).

4.5.3. China

In contrast to Europe and NAFTA, China's story is one of notable success in the EV market. The nation's significant know-how, coupled with its ability to ramp up production quickly, has placed it at a distinct competitive advantage. China's strengths lie in its robust industrial base, technological prowess, and ambitious government support.



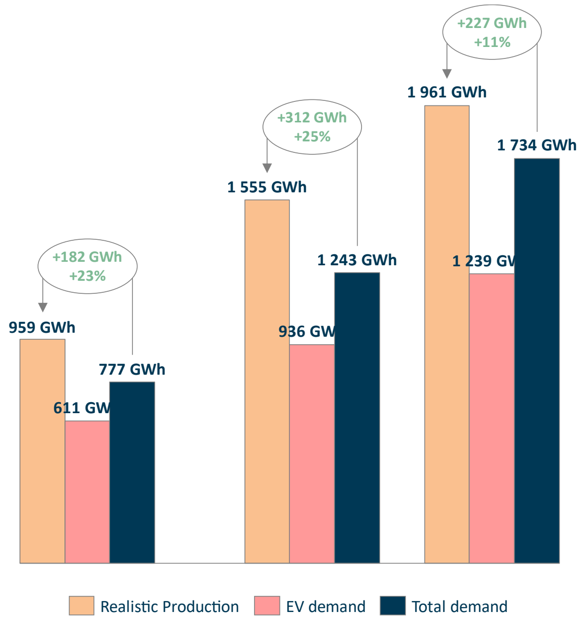


Figure 34a: **BATTERY CELL REALISTIC AVAILABLE PRODUCTION FORECAST |**
China, Forecast, GWh, 2025-2030-2035
Figure 34b: **BATTERY CELL REALISTIC AVAILABLE PRODUCTION, EV DEMAND & TOTAL DEMAND |**
Light Electric Vehicle, China, Forecast, GWh, 2025-2030-2035

For China the forecasts show that it will not only fulfill its domestic demand by 2025 and beyond but it will also be able to export substantial amounts of battery capacity in 2025, 2030 and 2035 namely 182 GWh, 312 GWh and 227 GWh respectively. This potential surplus underpins China's leading role in the global EV market and its ability to manage global supply chains effectively (Figure 34b and 50b).

Each region is presented with different challenges. The road ahead will be defined by how these regions and others respond to the evolving demands of the EV market and mitigate the risks associated.

4.5.4. Worldwide

A comprehensive comparison of battery supply and battery demand on a global scale was generated by compiling and analyzing all this new data and is depicted in Figure 35:

Figure 35: **DIFFERENCE BETWEEN SUPPLY & DEMAND, WORLWIDE, CHINA, EUROPE AND NAFTA |** # IN GWh, 2025-2030-2035

This analysis reveals that the realistic supply based on current announcements made by industry players fall short of adequately addressing the increasing global battery demand in both 2025 and 2030. Moreover, this shortfall is projected to grow significantly, reaching a staggering 1 TWh deficit by the year 2035. This substantial gap is driven by deficits in Europe and the NAFTA region whereas the China region will have a sizeable production surplus, but not sufficient to cover the shortage of the rest of the rest of the world.

It is crucial to acknowledge that our assessment extends beyond these regions, incorporating both production and demand figures from the rest of the world (Korea, Japan) to derive the global worldwide gap.

This projection underscores the persistent challenge the global battery market is facing: an ongoing mismatch between supply and demand. From the year 2023 to 2035, the battery market is poised to experience a sustained period where supply lags demand. As a result, the industry will need to continuously make announcements and invest in factory expansions to bridge this gap and ensure that global battery needs are met. These dynamic highlights the critical importance of proactive strategies and investments to ensure the stability and sustainability of the battery supply chain.

5. Identification and explanation of major bottlenecks, enablers to upscale battery production in Europe.

5.1. Introduction

The ambition to upscale battery production in Europe faces numerous challenges. Gigafactories, which are crucial in achieving this goal, will face numerous obstacles to reach their projected production capacities. Seven main reasons are highlighted here:

1. Delays in Construction and Start-up Operation Difficulties for New Entrants: Construction of Gigafactories is a massive undertaking, involving a wide range of variables that can contribute to delays. These range from unforeseen technical difficulties to bureaucratic roadblocks e.g., missing approvals from local authorities. Additionally, for newcomers to the battery production industry, setting up a Gigafactory from scratch results initially in operational inefficiencies and delays. A steep learning curve by the whole organization is needed in order to get this under control and to achieve a smooth production ramp up.

2. Battery Cell Production Equipment Shortage and Cost Competitiveness vs Asian Players: The global supply of battery cell production equipment is constrained, leading to potential shortages. Additionally, European manufacturers often face stiff competition from Asian counterparts, who may have cost advantages due to larger scales of production and established supply chains.

3. High Scrap Level for Cells at Production Level: The process of manufacturing battery cells is complex and requires precise control over the production parameters. This complexity can result in a high percentage of cells being scrapped due to minor defects, impacting overall production efficiency and output.

4. Lack of Qualified Workers to Build and Operate Gigafactories in Europe: The battery production industry is still relatively new in Europe, and there is a shortage of skilled and experienced workers, technicians, and battery experts to build and operate Gigafactories. This lack of skills can result in operational inefficiencies and difficulties in scaling up production.

5. Uncertainties About Project Funding: Battery production facilities represent significant capital investments. Uncertainty about the availability and stability of funding sources can delay or even derail Gigafactory projects.

6. Limited Upstream Raw Materials Supply for Battery Cells: The production of battery cells requires various raw materials. Any disruption or constraint in the supply of these materials can impact battery production.

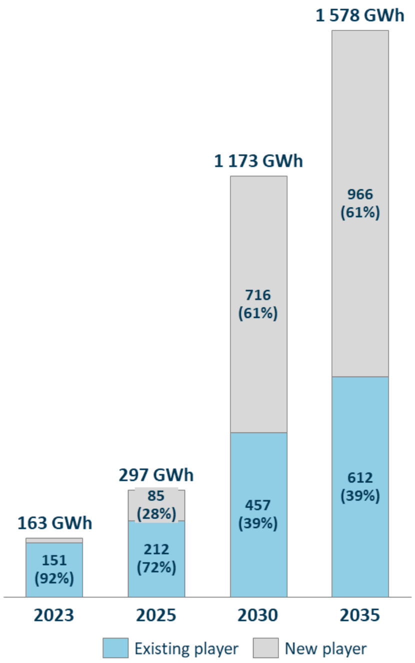
7. Shift of capacity from Europe to USA to get better investment incentives: Due to the IRA, battery players all along the value chain have delayed investments in Europe to shift them towards USA thanks to subsidies and possible further upsides concerning supply chain and cheap energy.

These bottlenecks represent considerable challenges to the upscaling of battery production in Europe. Understanding and addressing them will be crucial in ensuring the successful expansion of this important sector.

5.2. Gigafactory risk exposition

Nearly two-thirds of the announced projects in Europe up to 2030 are spearheaded by new entrants into the battery industry. This poses a very large risk as these new entrants navigate the intricacies of large-scale battery production for the first time. Additionally, some Gigafactory projects are marked as high-risk due to financing difficulties. A comparison of announcements versus the quality of financing reveals that currently, a significant part (51%) of gigafactories in Europe might be exposed to financing risks (Figures 36a and 36b).

Europe is consequently encountering significant risks in the ramp-up of battery production. Inexperienced players may struggle with industrialization, and financial challenges may arise due to the increased scale of production.



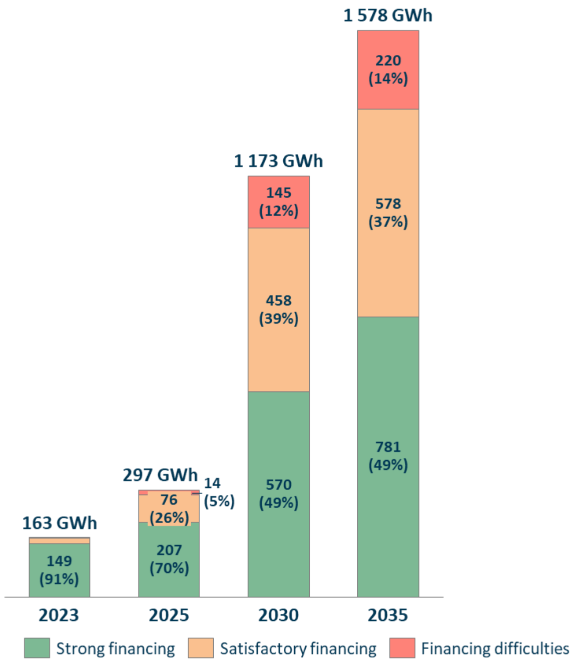
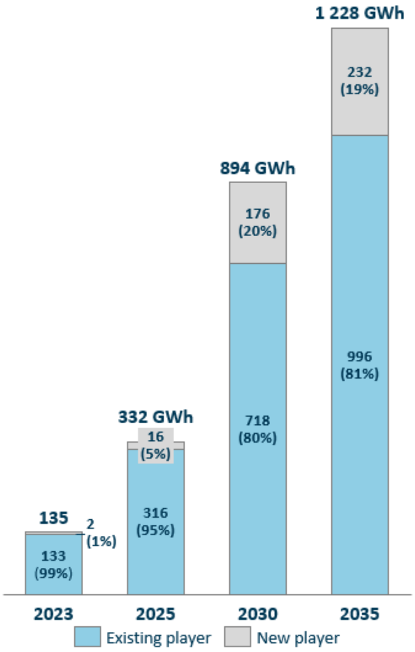


Figure 36a: **BATTERY CELL CAPACITY ANNOUCED BY TYPE OF PLAYER |** Europe, Forecast, GWh, 2023-2035, non-exhaustive.
Figure 36b: **BATTERY CELL CAPACITY ANNOUNCED BY FINANCING QUALITY |** Europe, Forecast, GWh, 2023-2035, non-exhaustive.

In contrast to that nearly 80% of the Gigafactory projects in the NAFTA region are driven by experienced battery companies, which possess significant investment capacity and robust funding. Consequently, only a few gigafactories in this region are at risk due to financing issues. For instance, by 2035, it is anticipated that only 5% of projects will face financing difficulties compared to 14% in Europe, as shown in Figures 36a and 52b. The greater industry experience and stronger financial backing in the NAFTA region help mitigate the risks associated with Gigafactory construction and operation.



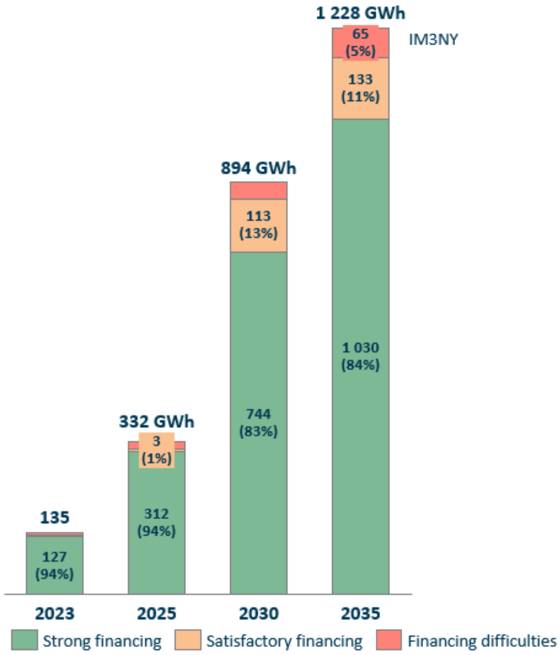


Figure 37a: **BATTERY CELL CAPACITY ANNOUCED BY TYPE OF PLAYER |** NAFTA, Forecast, GWh, 2023-2035, non-exhaustive.

Figure 37b: **BATTERY CELL CAPACITY ANNOUNCED BY FINANCING QUALITY |** NAFTA, Forecast, GWh, 2023-2035, non-exhaustive.

5.3. Raw materials supply

Availability of enough raw materials is essential for reliable battery production. Constraints on raw material availability and market dynamics in the supply chain can significantly impact production capacities. This section explores the state of these raw materials and their impact on battery production.

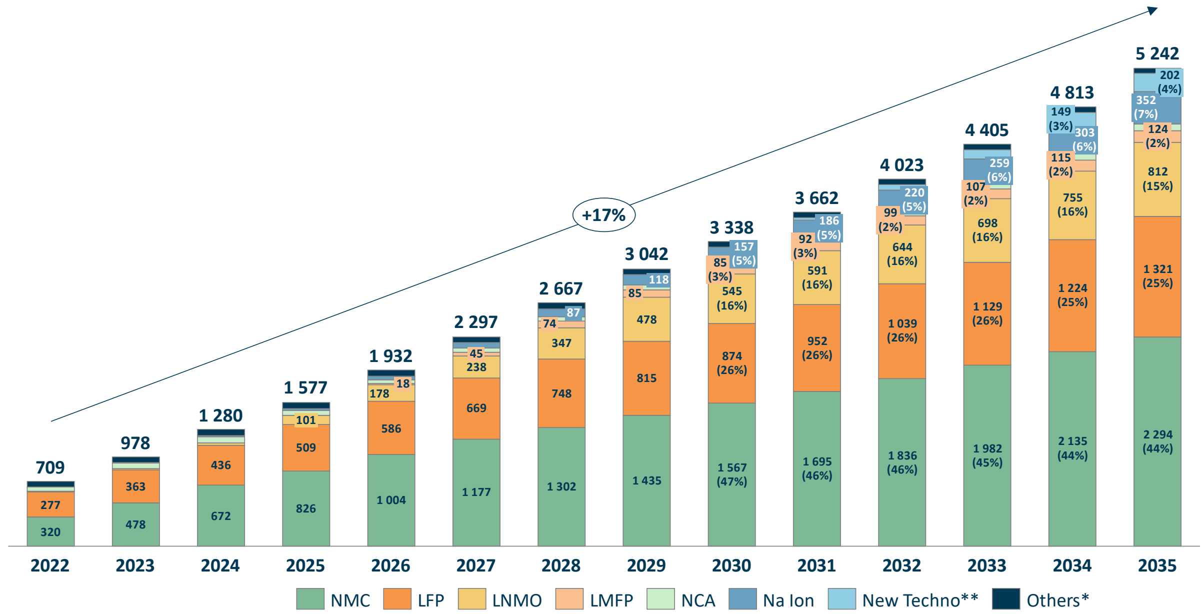


Figure 38: **BASELINE SCENARIO - LITHIUM & NA-ION BATTERY DEMAND PER CATHODE MATERIALS| GWh**, Worldwide , 2022 – 2035

In the figure 38, *Others** corresponds to technologies dedicated to consumer electronics like LCO battery, and *New Techno*** to Li-metal, Li sulfur or solid state battery.

Presently, the most used cathode materials are Lithium Iron Phosphate (LFP) and Nickel Manganese Cobalt Oxide (NMC). These types of cathodes are anticipated to continue their dominance in the battery market until 2035, reflecting their proven efficiency and established manufacturing processes. Nevertheless, the battery market is not static. New technologies are continuously being explored and developed. Lithium Nickel Manganese Oxide (LMNO), Sodium-Ion (Na-Ion) batteries, and other emerging technologies are expected to gain more prominence over time (Figure 38).

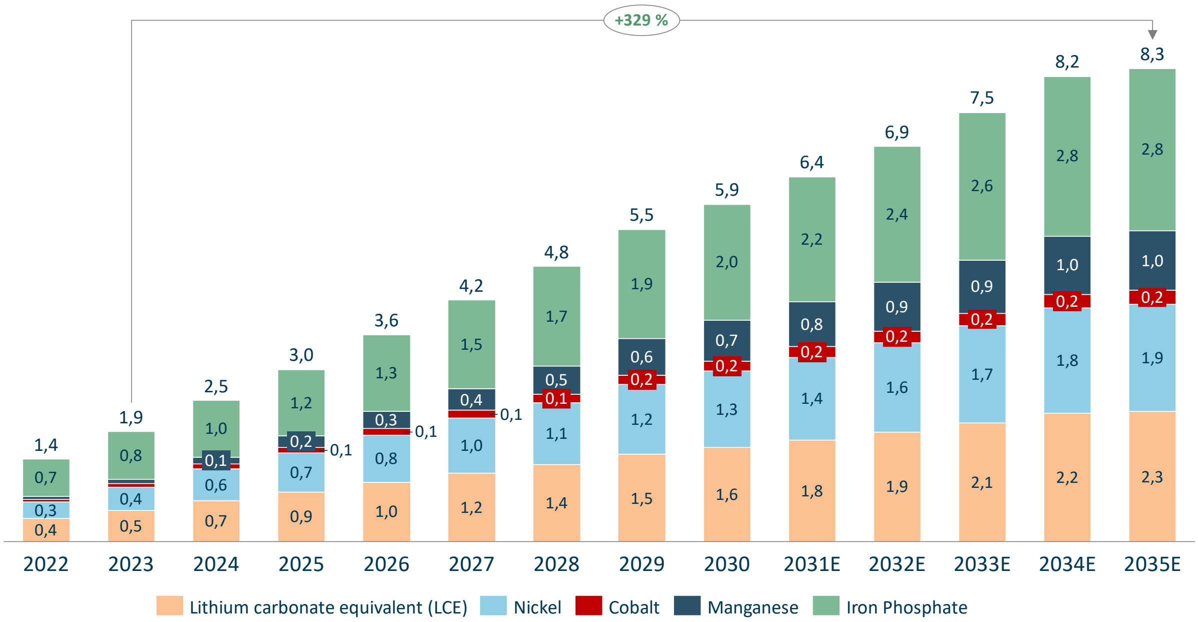
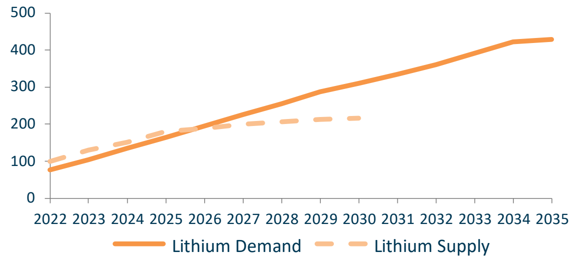


Figure 39: **KEY METALS DEMAND FOR BATTERY PRODUCTION AT GIGAFACTORY LEVEL FORECAST |** Mt, for PC, LCV and other Application Markets, World, 2022-2030

In terms of raw materials required for battery production, significant growth is expected in the coming years. By 2030, the demand for rare materials in EV batteries is projected to surge to a staggering 5.9 million tons. Simultaneously, the demand for Lithium Carbonate Equivalent (LCE), a critical component in many battery chemistries, is estimated to reach 1.6 million tons (Figure 39).

For supply of key raw metals, the forecasts of mining production done by GlobalData have been used. These forecasts use a bottom-up approach based on a mapping of mines operating and in construction.

This rapid increase in battery demand brings its own set of challenges. For instance, the lithium market is currently under pressure, and the pressure is expected to increase over the next five years due to supply constraints. The battery-grade manganese supply is currently sufficient but will require a fast adaptation to adjust to the fast-growing demand. The cobalt market, another key raw material for batteries, has some time to adjust to the growing demand, but is under pressure due to important political and health issues. Indeed, Cobalt is nearly exclusively sourced from the Democratic Republic of Congo and poses political challenges with a single supplier and ethical concerns as it originates from an unstable market characterized by small mines potentially involving child labor. However, preemptive measures should be taken to avoid a potential supply-demand mismatch in the future (Figures 40a, 56b, 56c and 56d).



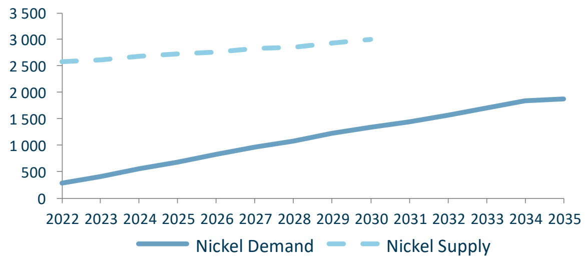
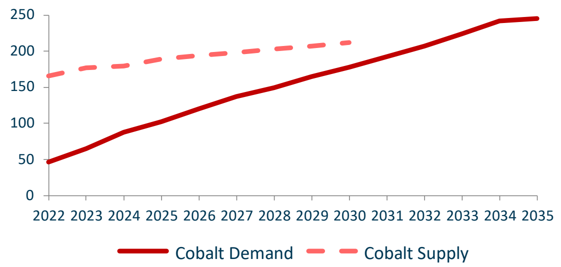


Figure 40a: **LITHIUM DEMAND FOR BATTERY APPLICATIONS & LITHIUM SUPPLY |**
kt, PC + LCV & Other Application Markets, World, 2022 - 2035
Figure 40b: **NICKEL DEMAND FOR BATTERY APPLICATIONS & NICKEL SUPPLY |**
kt, PC + LCV & Other Application Markets, World, 2022 – 2035



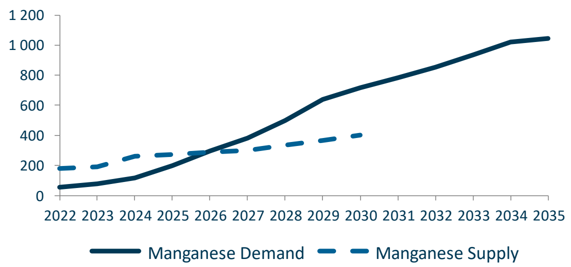


Figure 40c: **COBALT DEMAND FOR BATTERY APPLICATIONS & COBALT SUPPLY |**
kt, PC + LCV & Other Application Markets, World, 2022 - 2035
Figure 40d: **BATTERY GRADE MANGANESE DEMAND FOR BATTERY APPLICATIONS & BATTERY GRADE MANGANESE SUPPLY |** kt, PC + LCV & Other Application Markets, World, 2022 - 2035

5.4. Effect of recycling coming from battery production scrap and EOL battery

It is crucial to understand the potential impact of recycling - both from battery production scrap and end-of-life (EOL) batteries on raw material supply for future battery production.

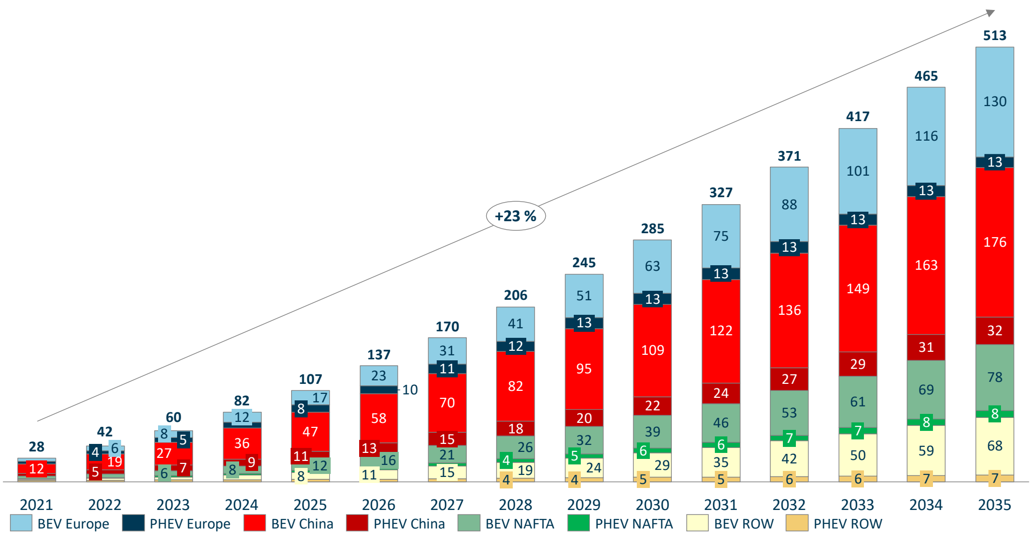


Figure 41: **BASELINE SCENARIO - ELECTRIC VEHICLE ON THE ROAD PER PRODUCTION REGION |** *PC & LCV, BEV & PHEV, Million Units, Worldwide*

By 2030, the circulation of electrified vehicles is expected to reach 285 million units, with China accounting for more than a third of this number (Figure 41). The journey of these vehicles doesn't simply end once they reach their so called EOL; instead, they present a significant opportunity for recycling and reuse.

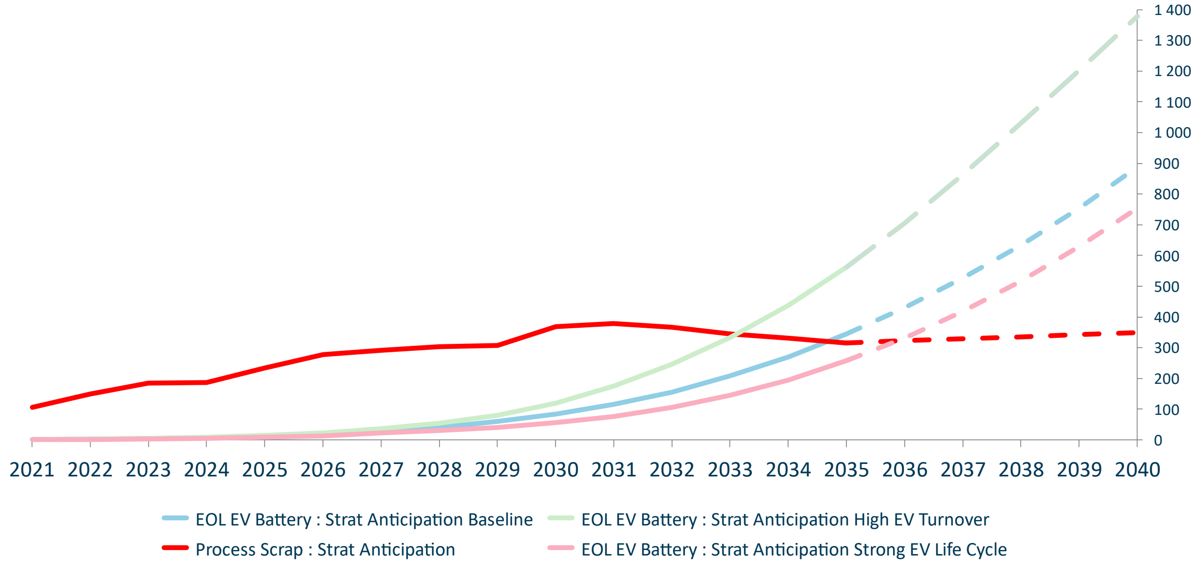


Figure 42: **AUTOMOTIVE BATTERY CAPACITY AVAILABLE FOR REPURPOSING OR RECYCLING & PRODUCTION SCRAP |** *GWh, Worldwide, 2021-2040*

Up until 2033, the primary source of battery recycling material is expected to stem from battery production scrap. However, as manufacturing processes improve and scrap rates stabilize and EV sales keep increasing, the contribution of EOL batteries to the recycling pool will experience exponential growth (Figure 42).

The following three scenarios were considered to assess the potential impact of recycling on battery raw material supply:

Baseline Scenario: This scenario assumes that vehicle demand, battery supply, scrap rate, and fatal crash rates continue to trend as currently observed. The EOL curve for EV cars aligns with the trends observed in regions with an average rate of vehicle fleet turnover, such as Europe and Japan.

High Turnover EV Car Fleet Scenario: This scenario assumes the EOL curve for EV cars follows the trends observed in regions with a rapidly changing car fleet, such as China, where EV adoption is strong and evolving quickly.

Lags in EV Adoption and longer EV Lifetime Scenario: This scenario assumes a slower rate of EV adoption, leading to a 10% reduction on demand from 2024 to 2035. The EOL curve for EV cars aligns with the trends observed in regions such as Europe and Japan.

Depending on the respective scenarios and the specific metals involved, the recycling of scrap and EOL EV batteries could account for between 8% and 16% of the total demand for EVs by 2030 (Figure 43).

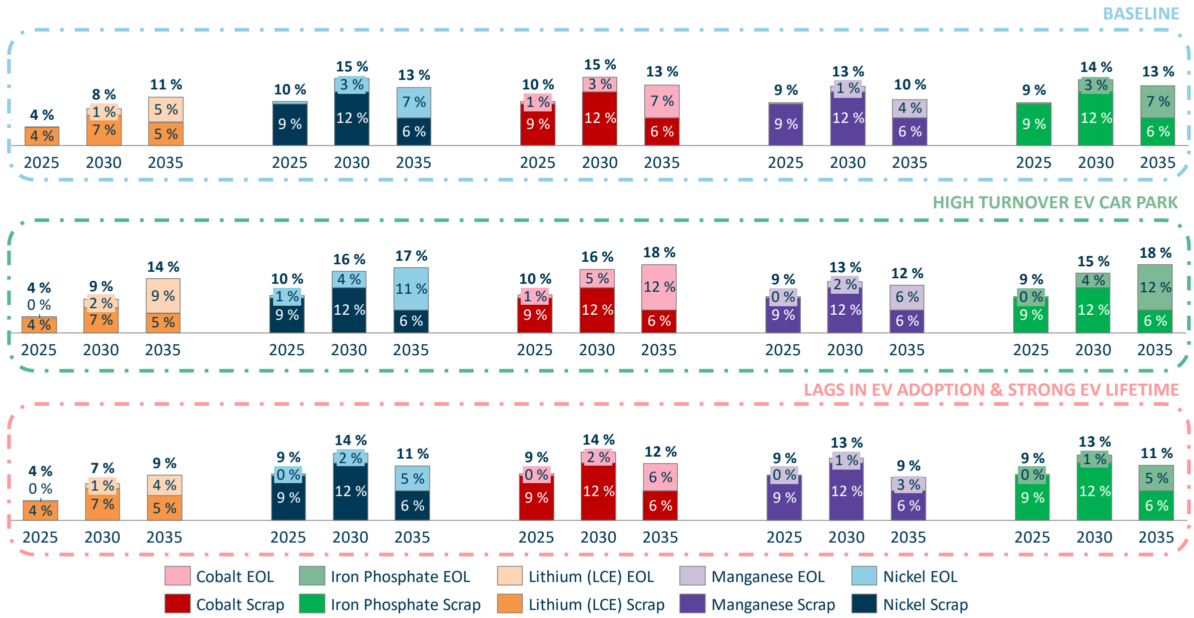


Figure 43: **KEY METALS COMING FROM EOL AUTOMOTIVE BATTERY & PRODUCTION SCRAP**
|*Percentage of Total EV Demand, Worldwide, 2025-2030-2035*

The European Union has set ambitious targets for battery collection and recycling. By 2025, 65% of end-of-life batteries must be collected, increasing to 70% by 2030. The focus on material recovery is evident in specific targets for key elements: cobalt must be recycled at 90% efficiency by 2027 and 95% by 2030, lithium at 50% efficiency by 2027 and 80% by 2030, and nickel at 90% efficiency by 2027 and 95% by 2030.

In a bid to enhance circularity, the EU mandates that batteries contain increasing percentages of recycled materials. By 2031, batteries must have 16% cobalt, 6% lithium, and 6% nickel sourced from recycling, with these figures rising to 26%, 12%, and 15%, respectively, by 2036.

In the Baseline and High Turnover scenarios, the Gigafactories can meet these regulatory requirements for lithium and nickel but may face uncertainties regarding cobalt (Table 2). The pool of nickel and lithium from production scrap and EOL batteries should support satisfactory recycled contents, but sourcing for cobalt must be sought elsewhere.

2030	EU REGULATORY TARGET	BASELINE		HIGH TURNOVER EV CAR PARK		LAGS IN EV ADOPTION & STRONG EV LIFETIME	
LITHIUM	6%	8%	√	9%	√	7%	√
NICKEL	6%	15%	√	16%	√	14%	√
COBALT	16%	15%	≈	16%	√	14%	x
2035	**EU REGULATORY TARGET**	**BASELINE**		**HIGH TURNOVER EV CAR PARK**		**LAGS IN EV ADOPTION & STRONG EV LIFETIME**	
LITHIUM	12%	11%	≈	14%	√	9%	x
NICKEL	15%	13%	≈	17%	√	11%	X
COBALT	26%	13%	xx	18%	x	12%	xx

Table 2: **PERCENTAGE OF EV DEMAND FUELLED PER RECYCLED METALS FROM EV COMPARED TO EU REGULATIONS**

Despite industry efforts to develop cobalt-free chemistries, cobalt-dependent batteries are expected to remain dominant in the market throughout the decade. Cobalt presents the greatest supply shortage risk among critical materials. Earth reserves are estimated at around 8 million tons, while the cumulative cobalt need for EV demand from 2020 to 2035 is approximately 2.1 million tons.

Considering these factors, it's clear that recycling will have to play a vital role in meeting global demand for EVs, not only to preserve earth natural resources, but also to prevent large key metals shortages and to reduce dependency in the battery supply chain, which is by far dominated by China. By 2035, recycling could account for approximately 10 to 20% of global demand for EVs' main metals. In summary, recycling will contribute to a reasonable share of metals demand but cannot account for 100%. The development of sustainable upstream supply chain needs to be developed in parallel.

5.5. Impact of new chemistries on raw materials demand

We have developed potential scenarios to forecast the evolution of battery demand with a specific focus on cathode chemistry (Figure 44). These scenarios aim to model how cathode chemistry might evolve leading up to 2035, taking into account various market shares of different chemistries, including the development of Na-Ion and Cobalt-free alternatives like LFP and LMNO.

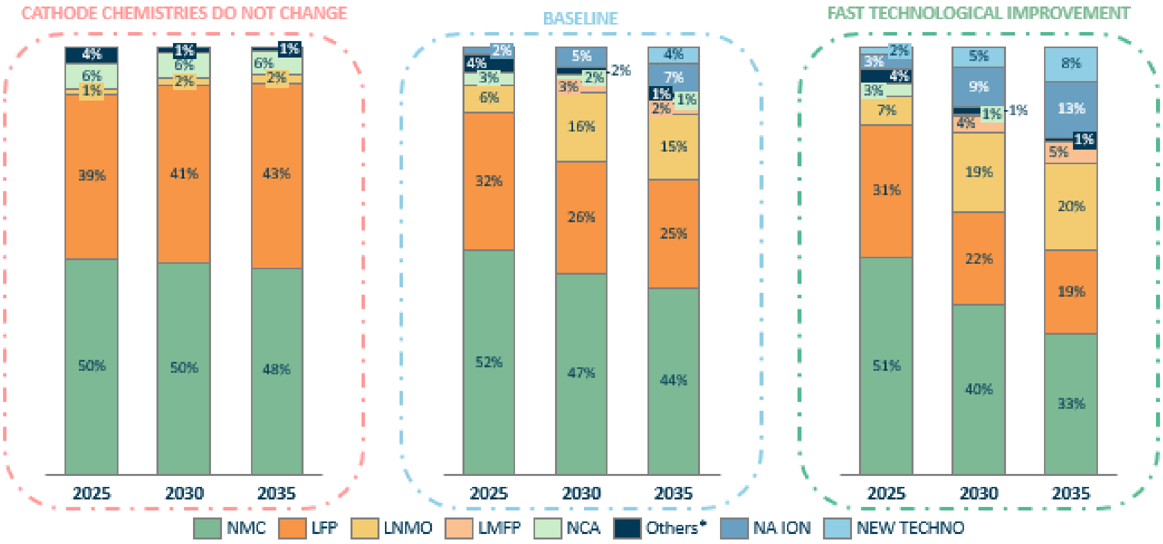


Figure 44: **3 SCENARIOS FOR BATTERY CELL CATHODE DEMAND |** Worldwide, Forecasts, %, 2025-2030-2035

One significant factor influencing lithium demand is the choice of cathode chemistry. Notably, LFP, LMNO, and LMFP chemistries are more efficient in terms of lithium consumption per kilowatt-hour (kWh) compared to NMC batteries. Furthermore, the emergence of lithium-free options such as Na-Ion and cutting-edge technologies like Li-metal and Li-sulfur is expected to further reduce lithium requirements per kWh. The surge in lithium prices experienced in 2022 has brought the management of price fluctuations to the forefront of industry concerns. This has driven innovation in cathode materials, with a concerted effort to decrease dependence on lithium.

A notable solution to mitigate the pressure on lithium demand in the 2030 to 2035 timeframe is the adoption of new battery technologies, such as Na-ion. In a scenario with fast technological improvement, these new technologies could potentially reduce lithium demand by approximately 9% in 2030 and 12% in 2035. Additionally, they have the potential to decrease cobalt demand by 15% in 2030 and an impressive 31% in 2035 (see Table 3).

Efforts to alleviate the demand for cobalt are also underway. This is primarily motivated by the limited reserves of cobalt and the challenging conditions associated with its mining. Reserves are concentrated in a limited number of countries: Democratic Republic of Congo, Russia, and Australia. The first one accounts for more than 70% of global reserves and has raised some concerns about the non-respect of ethical and health rules. Russia, which accounts for 5%, is not seen as a trustworthy partner after the Ukrainian war. Australia is a stable country compliant with international rules but has only 5% of the cobalt reserves.

However, it is important to note that refining capacities for battery-grade manganese have not yet been established to support the steep increase in demand.

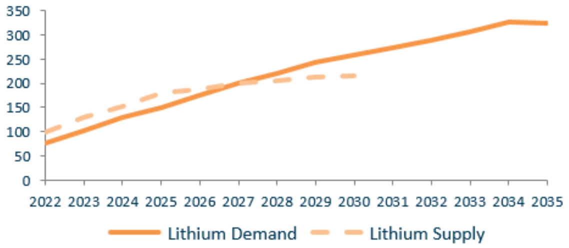
	BASELINE			FAST TECHNOLOGICAL IMPROVEMENT			NO CHANGE IN CATHODE CHEMISTRIES COMPARED TO 2023		
	Demand in KT	Demand in KT	Demand in KT	Comparison to Baseline	Comparison to Baseline	Comparison to Baseline	Comparison to Baseline	Comparison to Baseline	Comparison to Baseline
MATERIAL	2025	2030	2035	2025	2030	2035	2025	2030	2035
LITHIUM	868	1 649	2 279	-4%	-9%	-12%	+5%	+15%	+19%
NICKEL	685	1 338	1 877	-1%	-7%	-13%	-2%	+6%	+9%
COBALT	102	178	245	-2%	-15%	-31%	+5%	+25%	+34%
MANGANESE	199	718	1 043	+4%	+17%	+27%	-77%	-268%	-334%

Table 3: **IMPACT OF CATHODE TECHNOLOGY ON RAW MATERIALS DEMAND IN THREE SCENARIOS**

In summary, the integration of new technologies into the battery landscape holds the promise of significantly decreasing lithium demand, by approximately 10% by the end of the decade, thus contributing to the ongoing evolution of the battery industry. They will also bring different levels of performance to cover the various market needs.

5.6. Conclusions on recycling and impact of new chemistries on battery demand

Regarding recycling and the influence of emerging chemistries on battery demand, if there is a rapid turnover in electric vehicle fleets and continuous technological advancements, the strain between supply and demand for lithium is expected to decrease, with tensions emerging after 2027. However, a noteworthy observation is that cobalt is not anticipated to face any significant risks in the coming decade. In contrast, meeting manganese demand will necessitate the implementation of numerous new supplying and refining projects, as illustrated in Figure 40 bis a, b, c & d.



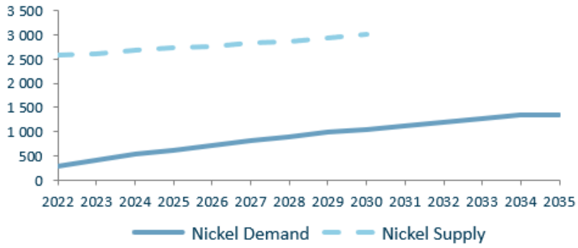
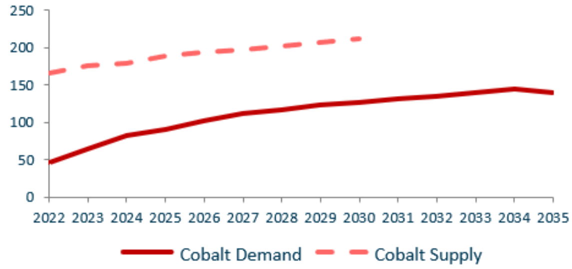


Figure 40 bis a: **LITHIUM DEMAND FOR BATTERY APPLICATIONS & LITHIUM SUPPLY |** In case of fast technological improvement & high turnover EV fleet**,** KT, PC + LCV & Other Application Markets, World, 2022 - 2035

Figure 40 bis b: **NICKEL DEMAND FOR BATTERY APPLICATIONS & NICKEL SUPPLY |** In case of fast technological improvement & high turnover EV fleet**,** KT, PC + LCV & Other Application Markets, World, 2022 - 2035



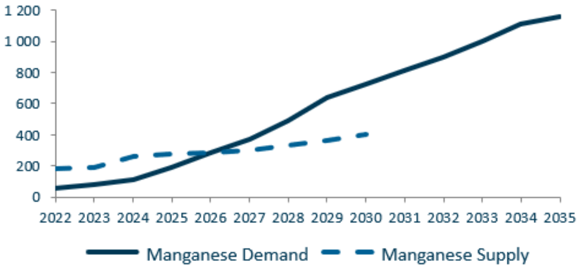
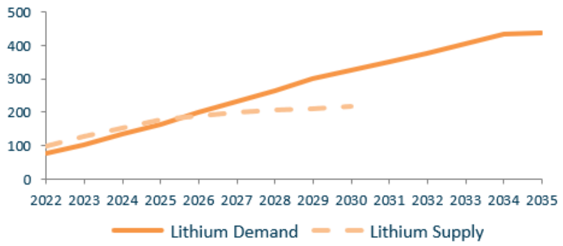


Figure 40 bis c: **COBALT DEMAND FOR BATTERY APPLICATIONS & COBALT SUPPLY |** In case of fast technological improvement & high turnover EV fleet**,** KT, PC + LCV & Other Application Markets, World, 2022 – 2035

Figure 40 bis d: **BATTERY GRADE MANGANESE DEMAND FOR BATTERY APPLICATIONS & BATTERY GRADE MANGANESE SUPPLY |** In case of fast technological improvement & high turnover EV fleet**,** KT, PC + LCV & Other Application Markets, World, 2022 – 2035

Summing up the findings on recycling and the impact of new chemistries on battery demand: In the scenario of a slow turnover in the electric vehicle fleet and no changes in cathode chemistries, there will be heightened pressure between supply and demand for lithium, leading to tensions emerging after 2025. The major transformation is observed in cobalt, which is projected to be at risk towards the end of the decade, along with a notable change in manganese demand. It is noteworthy that there will be no additional installation of manganese refining capacities. A significant numerical shift is evident when comparing this scenario to the previous one, as lithium demand is expected to reach 330 kt in 2035, compared to the earlier projection of 440 kt.



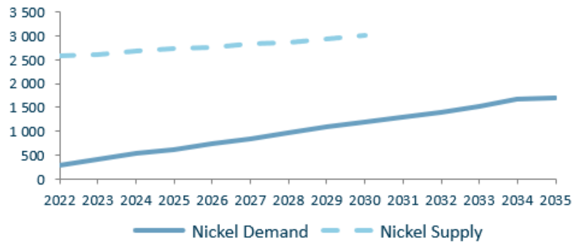
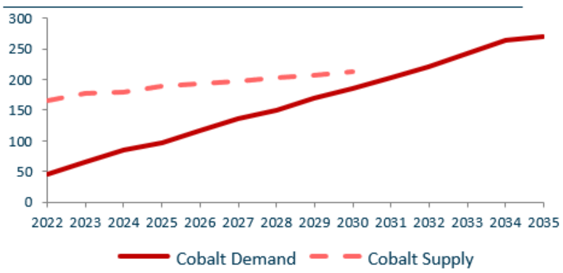


Figure 40 ter a: **LITHIUM DEMAND FOR BATTERY APPLICATIONS & LITHIUM SUPPLY |** In case of no changes in cathode chemistries & low turnover EV Parc**,** KT, PC + LCV & Other Application Markets, World, 2022 - 2035

Figure 40 ter b: **NICKEL DEMAND FOR BATTERY APPLICATIONS & NICKEL SUPPLY |** In case of no changes in cathode chemistries & low turnover EV Parc**,** KT, PC + LCV & Other Application Markets, World, 2022 – 2035



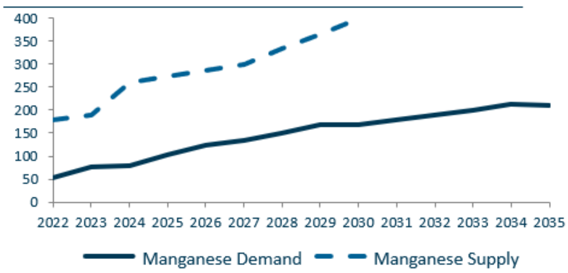


Figure 40 ter c: **COBALT DEMAND FOR BATTERY APPLICATIONS & COBALT SUPPLY |** In case of no changes in cathode chemistries & low turnover EV Parc**,** KT, PC + LCV & Other Application Markets, World, 2022 – 2035

Figure 40 ter d: **BATTERY GRADE MANGANESE DEMAND FOR BATTERY APPLICATIONS & BATTERY GRADE MANGANESE SUPPLY | In** case of no changes in cathode chemistries & low turnover EV Parc**,** KT, PC + LCV & Other Application Markets, World, 2022 - 2035

6. Comparison between Supply and Demand and the Potential Gaps

6.1. Sensitivity Scenarios for Demand

As described in the Introduction, our approach to scenario development for battery demand involves creating three distinct scenarios for each region under study: baseline, maximal demand, and minimal demand. Each scenario represents a sensitivity for the future of the battery market.

6.1.1 Battery Demand for Light Vehicles Scenarios

The future demand for Light and Light Commercial Vehicles in Europe is explored under three distinct scenarios, namely Baseline, High EV penetration, and Low EV penetration. These scenarios account for possible future evolutions of factors like government regulations, technological advancements, infrastructure development, consumer acceptance, and global economic conditions. The following sections detail the individual scenarios and their potential impact on electric vehicle and battery electric vehicle demand within Europe and beyond.

Baseline - "Demand complies with regulation without sales drop":

The Baseline Scenario approach is rooted in production data sourced from LMCA which is part of GlobalData, establishing the industry standard. This method comprises the subsequent steps:

1. Analyzing each OEM's strategy and product plan
2. Describing the battery of each model in terms of capacity in kWh and chemistry
3. Assessing battery demand for each model using volume forecasts from OEM’s
4. Consolidating OEM battery demand per region.
5. Forecasting total battery demand for light vehicles.

It is based on the following assumptions concerning EV market:

- EV adoption continues at the current rate.
- Government regulations and incentives remain stable, promoting EV adoption.
- Gradual improvements in battery technology result in moderate increases in energy density and cost reductions
- Steady progress in EV charging infrastructure development
- Automakers continue to introduce various electric models but face challenges in scaling production.
- Consumer acceptance of EVs grows steadily but at a moderate pace.
- Stable global economic conditions with steady growth in the automotive industry.

Higher EV penetration Scenario - "More incentives and technology adaptation":
This scenario forecasts earlier attainment of the projected baseline 2035 volume baseline for BEVs in Europe, China, NAFTA, and the rest of the world:

- Significant breakthroughs in battery technology, leading to substantial improvements in energy density and cost reductions. A relative price parity between ICE and EV is achieved by 2030.
- Extensive expansion of EV charging infrastructure, including fast-charging networks and wireless charging options.
- Automakers overcoming production challenges and achieving economies of scale, resulting in a wide range of affordable EV models.
- High consumer acceptance of EVs, driven by improved driving range, lower prices, and environmental awareness.
- Robust global economic conditions, with a surge in demand for electric vehicles.
- Rapid acceleration in EV adoption due to strong government policies and incentives for consumers and fleets. This results in the quantified acceleration of the BEV market share described below:
- In Europe, Battery Electric Vehicles (BEVs) are expected to reach the baseline 2035 volume baseline by 2032.
- In China, BEVs are projected to capture 70% of the market share by 2035, with a linear growth from 2023. This is compared to 51% in the baseline.
- In NAFTA, BEVs are set to achieve 66% market share by 2035, with linear growth from 2023. This is compared to 50% in the baseline.
- For the rest of the world, BEVs are anticipated to reach 40% market share by 2035, growing linearly from 2023. This is compared to 29% in the baseline.

Low EV penetration Scenario - "Price difficulties and low consumer acceptance":
In this scenario, price parity with ICE vehicles does not materialize, and consumer acceptance remains low.

- Parity in Price is not achieved, leading to low demand from consumers.
- All OEMs across Europe adjust their production mix to meet, but not exceed, the 55% CO_2 reduction target by 2030 by selling enough electrified vehicles.
- This creates a smaller market than expected in Europe, leading to a 10% decrease in global volumes.
- A slower electrification process leads to a 35% BEV volume drop in 2025 vs. baseline, followed by a 37% decline in 2030 compared to the baseline in Europe.
- High prices outside Europe lead to an approximate 10% reduction in BEV volume production.
- Limited progress in battery technology results in marginal improvements in energy density and cost reductions.
- Insufficient investment in EV charging infrastructure increases range anxiety and limited accessibility for consumers.
- Automakers face significant production challenges, resulting in limited availability and high prices of EV models.

Regarding Europe, the three scenarios essentially converge in 2035 for BEV volumes due to the fact that all vehicles produced in the EU in 2035 will mostly have to be vehicles without tailpipe CO2 emissions. Electrification accelerates notably in the baseline and maximal demand cases (Figure 45).

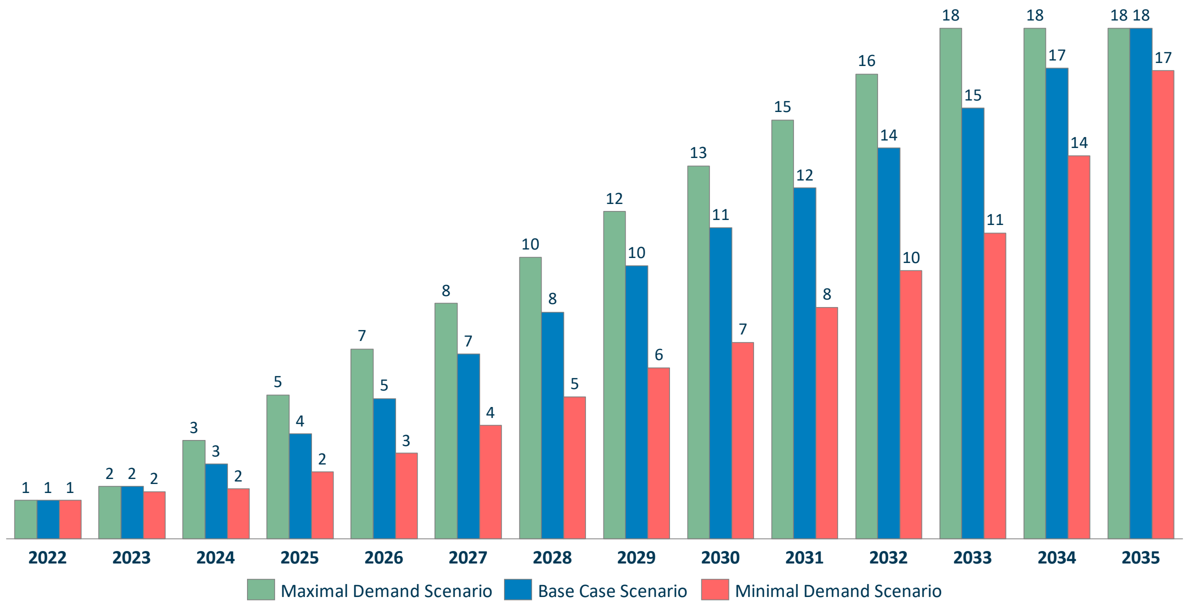


Figure 45: **BEV PRODUCTION VOLUME PER SCENARIO | #** Million Units, 2022 – 2035, Europe + Russia

For regions outside of Europe, the differences between baseline and minimal demand scenarios are minor, but fast electrification could swiftly boost BEV production (Figure 46).

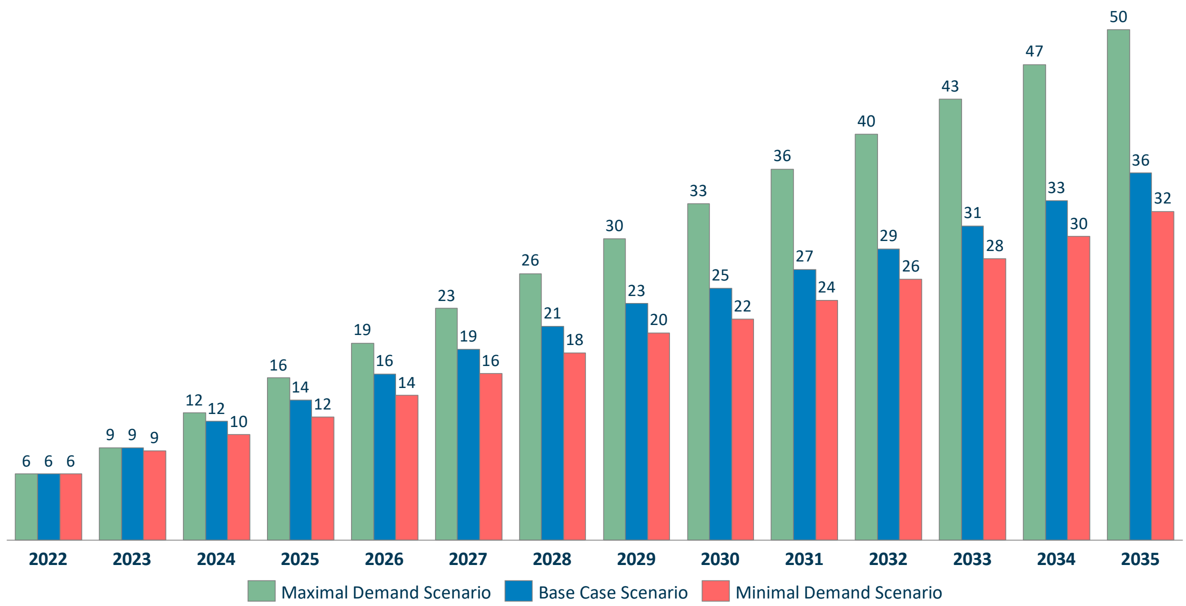


Figure 46: **BEV PRODUCTION VOLUME PER SCENARIO | #** Million Units, 2022 – 2035, Outside Europe

These analyses lead to the conclusion that by 2030, the battery demand in terawatt-hours for light-duty vehicles is projected to range from 2.1 TWh to 3.3 TWh, with a baseline estimate of 2.65 TWh. Furthermore, by 2035, this gap is expected to widen significantly, driven by substantial demand increases in China and the NAFTA region (Figure 47).

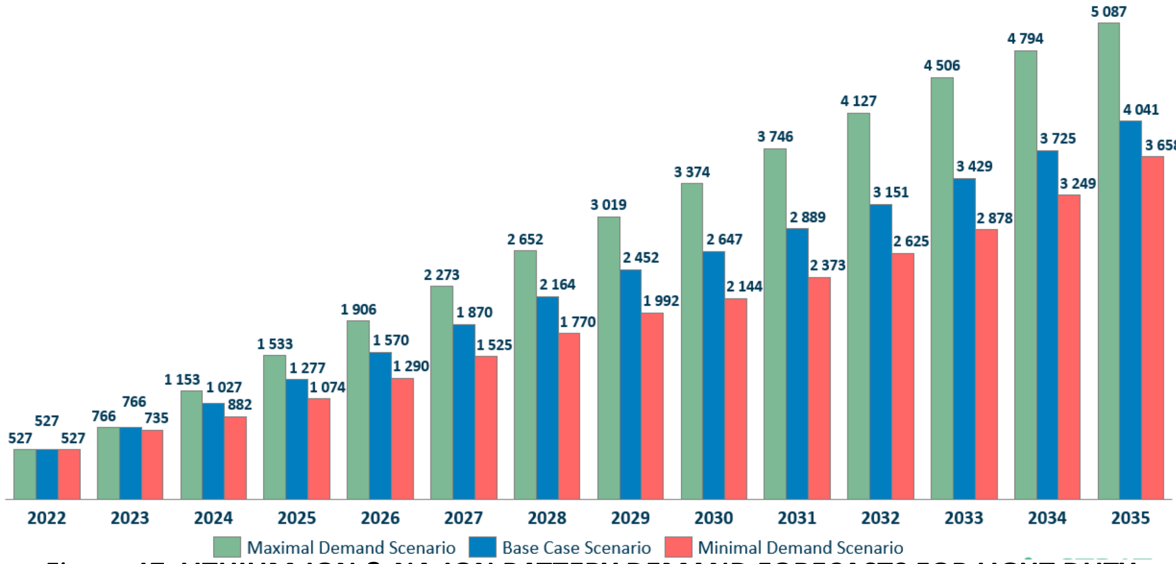


Figure 47: **LITHIUM-ION & NA-ION BATTERY DEMAND FORECASTS FOR LIGHT DUTY VEHICLE |** *GWh, Worldwide, 2022-2035*

6.1.2 Battery Demand for Other Application Market Scenarios

Among the others application markets for battery (ESS, Heavy Duty, Consumer Electronics, Light Mobility, Off-Road, Medical and Maritime), a forecast of the battery demand has been developed, using three scenarios: Baseline, Maximal Demand, and Minimal Demand.

We will detail in this section the two markets that stand out by their sizes: ESS & Heavy Duty (Truck & Buses).

One thing that makes the ESS market stand out is that it has some strong drivers in the maximal demand scenario:

- The rise of Sodium Batteries, which are well adapted to the needs of ESS.
- Batteries are becoming cheaper.
- More global support for renewable energy with faster adoption of renewable power sources
- Many people use electric vehicles, which helps with storing energy in various locations.
- Better solutions for dealing with renewable energy's intermittent nature.

This creates a significant gap between fast and slow development, as shown in Figure 48.

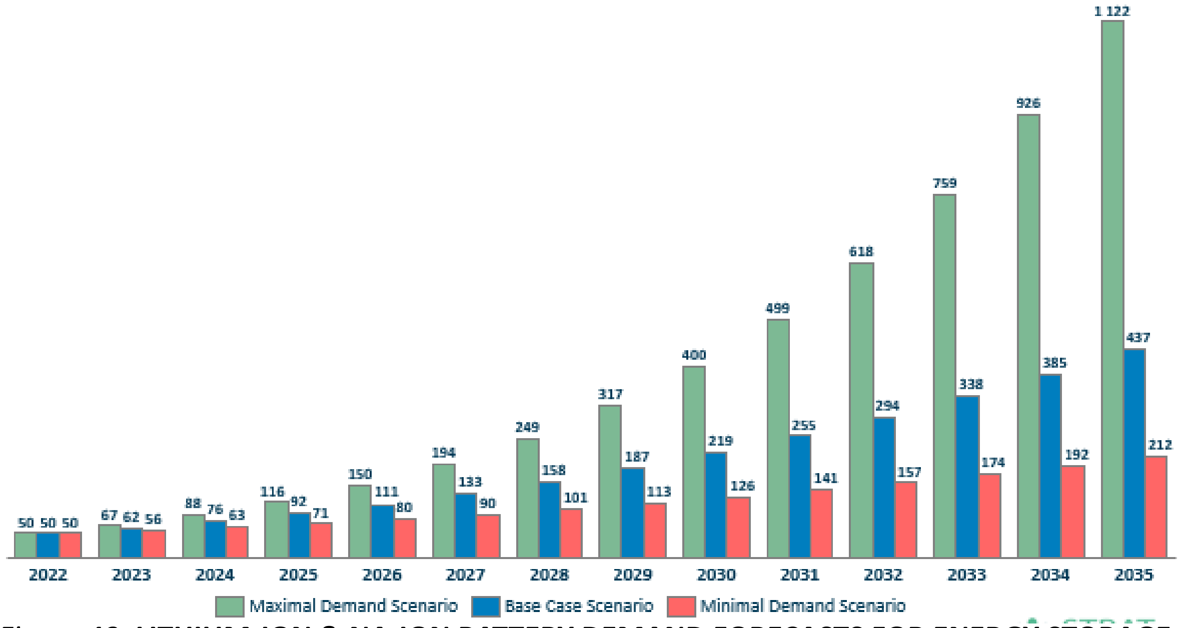


Figure 48: **LITHIUM-ION & NA-ION BATTERY DEMAND FORECASTS FOR ENERGY STORAGE SYSTEM |***GWh, Worldwide, 2022-2035*

Conversely, markets such as Trucks & Buses depend more on factors like government policies, sound business strategies, technological advancements, and enhanced infrastructure. In particular in Europe, the European Commission has prepared a new emission regulation for heavy duty vehicles where emissions should be reduced by 90% in 2040 compared to 2019. This regulation should be voted in 2024 and would be driving electrification of trucks & buses to hit the target. Associated battery demand is expected to take off thereafter. A key enabler to reach this very ambitious target will be to roll out high-power fast charging and hydrogen refueling stations along the main highways and in transportation warehouses. Another important challenge is whether logistics companies will buy electrical trucks. They need to be convinced that the Total Cost of Ownership (TCO) will be at least breakeven with diesel trucks. Key drivers of EV TCO are the purchasing price (today up to 3 times more than an ICE truck), the electricity costs and the lifetime of the battery (a truck is used intensively).

The Consumer Electronics market is the historic market for batteries and is already well established. It is influenced by the global economy and people's access to consumer electronics, but also by the growing size and power of battery needed within electronics. No regulation is expected to materially change the dynamics of this market. Consequently, the forecasts for these markets exhibit much less variation than for LDVs.

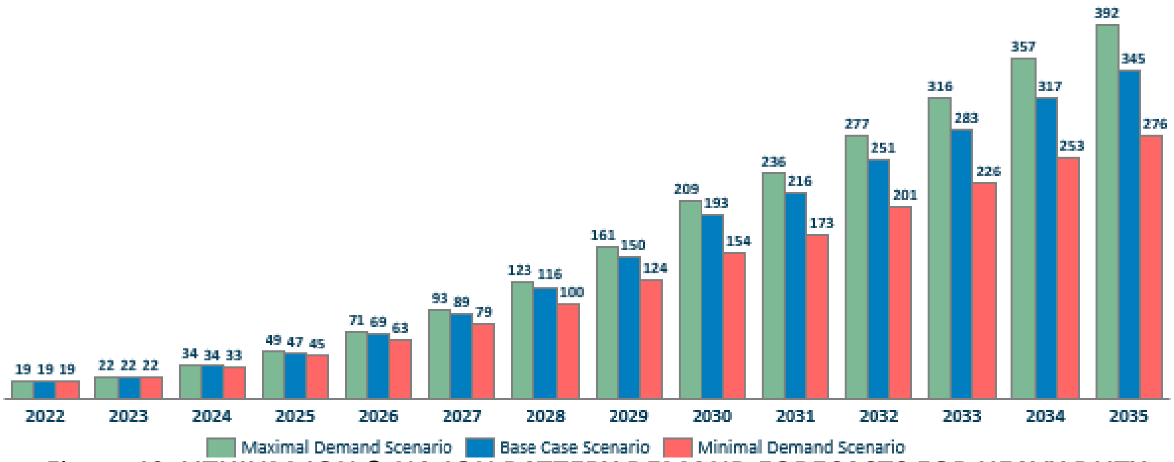


Figure 49: **LITHIUM-ION & NA-ION BATTERY DEMAND FORECASTS FOR HEAVY DUTY VEHICLE |***GWh, Worldwide, 2022-2035*

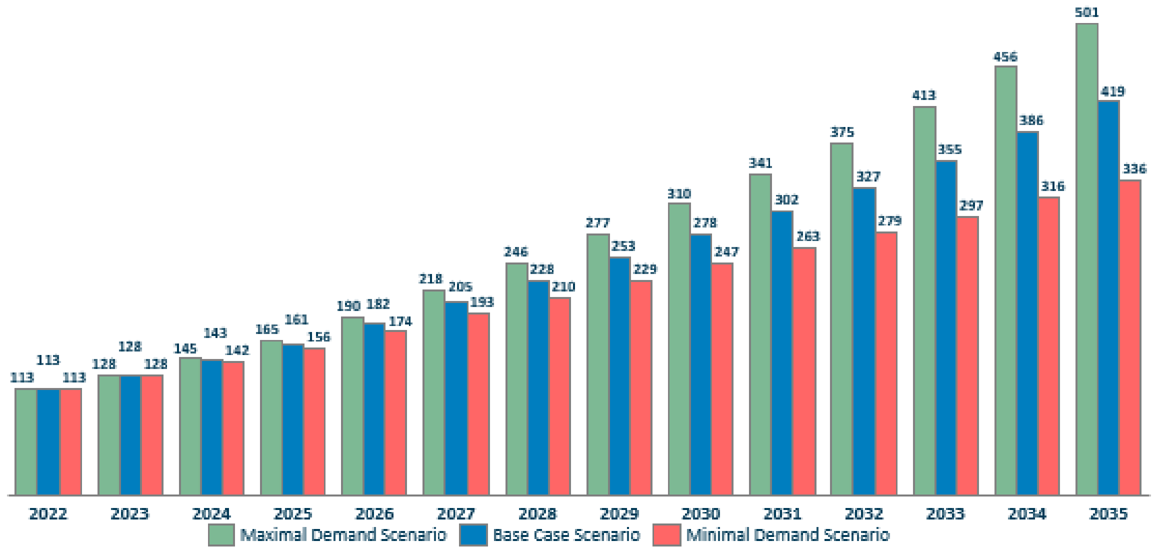


Figure 50: **LITHIUM-ION & NA-ION BATTERY DEMAND FORECASTS FOR OTHER APPLICATION MARKETS |** *GWh, Worldwide, 2022-2035*

6.1.3 Consolidated Battery Demand Scenarios

Forecast data from both the vehicle and other applications markets was compiled to analyze the demand (Figure 51). It shows that the demand gap among the three scenarios is steadily growing, especially after 2027. This gap is projected to widen significantly, going from 0.9 terawatt-hour (TWh) in 2027 to a substantial 2.7 TWh by 2035.

The most notable difference is seen between the accelerated scenario and the base case. This large difference is mainly due to the more ambitious electrification targets in China and the

NAFTA region in the accelerated scenario, which are expected to drive up demand considerably.

Additionally, it's worth mentioning that the energy storage system market also has the potential for significant growth. The growth is driven by the development of renewable energy to reduce the carbon footprint of electricity production which requires the roll-out of large storage systems. The batteries for ESS applications have taken off already in the last two years especially in China and North America but also in EU.

In summary, the takeaway is that the demand has the potential to be exceptionally high.

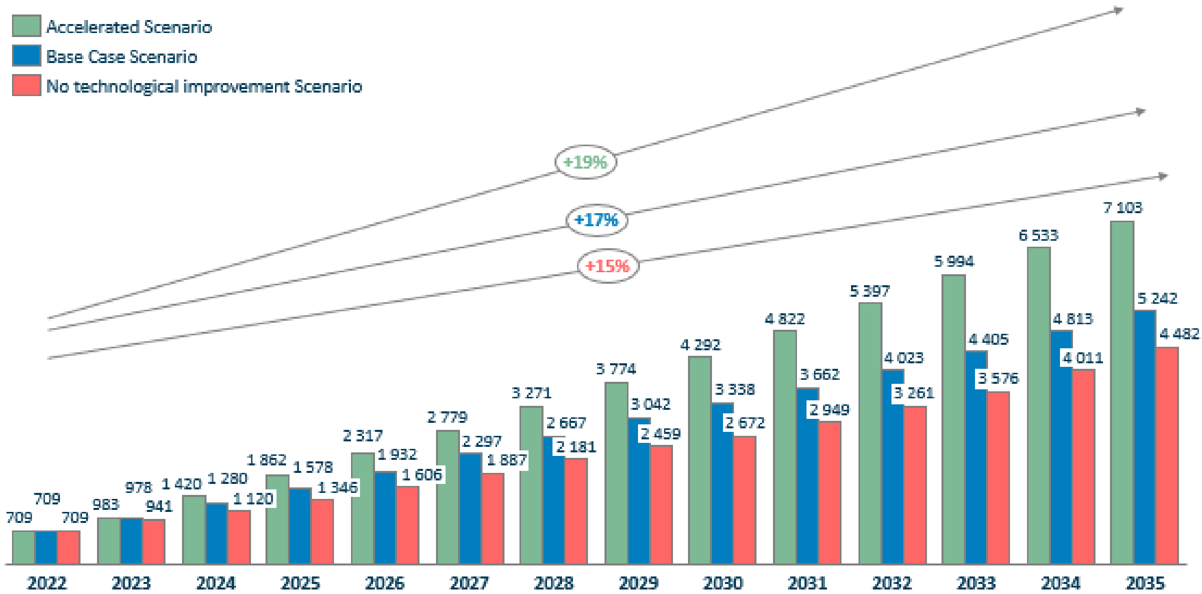


Figure 51: **LITHIUM-ION & NA-ION BATTERY GLOBAL DEMAND FORECASTS |** *GWh, Worldwide, 2022-2035*

6.2. Scenarios for Supply

6.2.1. Approach

We have defined three levers in the battery supply model to use to build the scenarios.

Lever 1: Capacity Usage and Scrap Rate — It considers how efficiently the existing and upcoming manufacturing facilities utilize their capacities and manage their scrap. This directly impacts the operational efficiency of battery plants.

Lever 2: Risk Exposure - Funding, Technology and Experience — It involves the level of risks associated with financial aspects, the adoption of new technologies, and the overall experience of the involved players in the EV battery industry.

Lever 3: Announcement of New Gigafactories and Unannounced Extension of Existing Lines — This takes into account the potential for future growth in the industry, including new factory announcements and expansions of existing production lines.

To construct possible outcomes, two different approaches have been developed, each leading to a different set of scenarios:

- Assessing industrial success based on current announcements and how players can effectively establish and optimize production.
- Assessing macroeconomic environments and regional dynamics that could either facilitate continuous production expansion and announcements or present major challenges for industry players.

Actioning Lever 1 and 2 leads to **a so-called Industrial Scenario:** It assumes that the current participants in the industry will continue on their announced paths, focusing on their capacity usage, scrap rate, and the risks they face in terms of funding, technology, and experience. The progression of these factors can shape the overall industry's success in terms of supply.

Actioning Lever 2 and 3 leads to a so-called **Macroeconomic Scenarios:** It considers the wider economic conditions, including the availability of funding, risk management, and the potential for industry growth through the announcement of new Gigafactories or the extension of existing production lines. These factors will collectively shape the macroeconomic climate for EV battery production, influencing the future supply landscape.

6.2.2. Industrial Scenarios

To provide a comprehensive understanding of the industrial aspects, we have developed three distinct scenarios based on the challenges and successes that industries could face while setting up factories. These scenarios are referred to as the Baseline, the Strong Adaptability and Industrial Amelioration, and the Difficult Process Assimilation and Delays in Production.

Baseline Scenario: It represents our current simulation. It considers the capacity roll-out plans and potential risks, including funding risks tied to the required factory capacities, experience risks associated with the ability of players to manage the process, and technological risks involved in deploying the technology needed for the roll-out. This scenario also involves an evaluation of scrap and capacity usage, assessing the factory's efficiency in utilizing its capacity and managing waste.

Scenario "Strong Adaptability and Industrial Amelioration": This scenario anticipates a smoother, more efficient industrial process with the following aspects:

- Experience: less-experienced players face minor difficulties in setting up and ramping up production, while experienced players quickly achieve maximum capacity.

- Funding: players with poor or average funding experience a lower default rate than in the baseline
- Scrap: New players have a fast-learning curve on their manufacturing processes and reduce their initial high production scrap rates during launch rapidly, while experienced players maintain a low scrap rate right from the start and continue to control it effectively.

Scenario "Difficult Process Assimilation and Delays in Production": It assumes significant difficulties during the industrial process, with the following components:

- Experience: All players struggle to some extent with technological difficulties while setting up their plants efficiently, leading to lower capacity utilization rates. This constitutes a major issue for the less experienced players, driving down their operational efficiency massively.
- Funding: Players with poor funding face substantial challenges in reaching their production capacity.
- Scrap: Players encounter issues in reducing the scrap rate, which remains high, particularly during the initial years and in particular among new players.

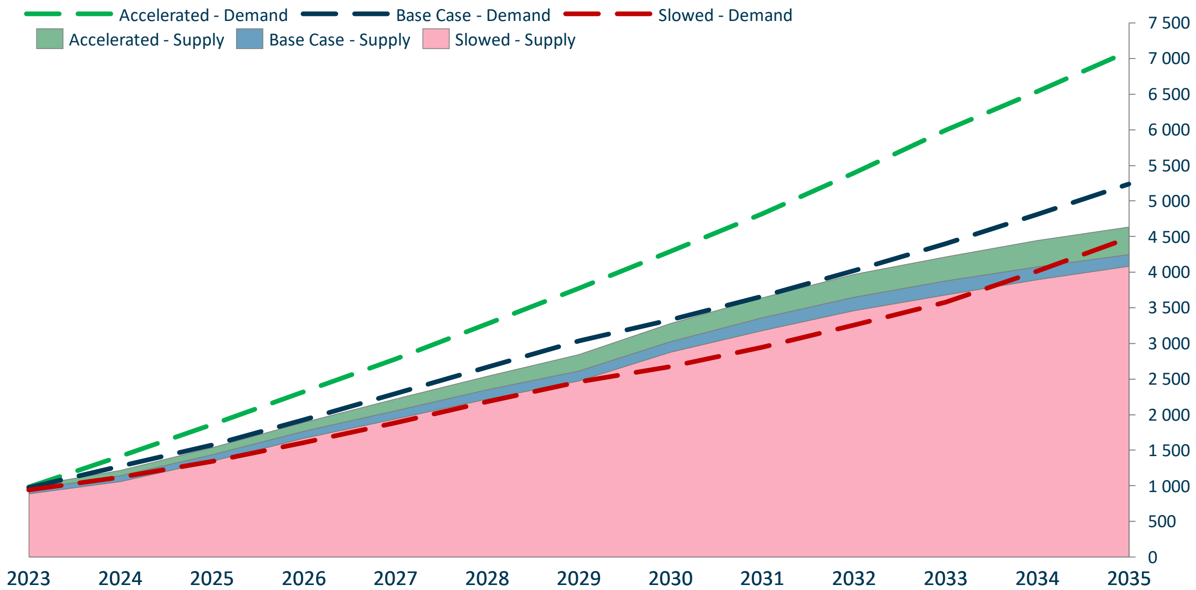


Figure 52: **LITHIUM-ION & NA-ION BATTERY DEMAND AND BATTERY SUPPLY FORECASTS, INDUSTRIAL SCENARIOS |** *GWh, Worldwide, 2022-2035*

According to the model, the projected supply by 2030 falls within the range of 2.9 to 3.3 TWh. Even in an industrially successful scenario, the baseline demand is expected to be nearly fulfilled by 2030 but may encounter challenges, thereafter, necessitating new projects and Gigafactory extensions. Another significant observation is that accelerated demand results in notable gaps. The ongoing projects announced by industry players may not adequately support a robust acceleration in electrification and battery usage across all application markets.

This potential difficulty in meeting baseline demand indicates pressure on the battery supply market, emphasizing the need for industrial players to consistently announce and establish new gigafactories.

Achieving industrial success alone will not suffice, and gigafactories will require a more supportive environment leading to new factory and line expansion to be successful in responding to the battery demand.

6.2.3. Macroeconomic Scenarios

Macroeconomic considerations play a vital role in defining the future of the EV battery industry. Three distinct scenarios based on potential regional macroeconomic influences, the emergence of future Gigafactory projects, and risk exposures were developed. These scenarios are identified as the Baseline, the Trade War, and the Price War scenarios.

1. Baseline Scenario: It represents our current simulation. It considers the capacity roll-out plans and potential risks, including funding risks tied to the required factory capacities, experience risks associated with the ability of players to manage the process, and technological risks involved in deploying the technology needed for the roll-out. It also involves an evaluation of scrap and capacity usage, assessing the factory's efficiency in utilizing its capacity and managing waste. This baseline is the same as in the industrial scenario.

2. Trade War "Trade War and Financial Support for the Green Deal": This scenario reflects the impact of global trade war between regions and enhanced policy measures supporting the energy transition. In this scenario, global trade is reduced by protectionist measure in key regions to develop their own battery industry in the long-term for economic and sovereignty reasons:

- In Europe, more robust policies supporting Gigafactories will be established, with a strong commitment to financing gigafactories at risk. Quantitively, this will strongly mitigate risks related to funding, inexperience, or technological exposure.
- The implementation of an effective battery passport incentivizes Gigafactories to be set up or expanded in Europe, leading to a gradual increase in production of up to 20% in 2035.
- In NAFTA, the IRA will be extended, and government funding continues to secure the supply chain, effectively removing identified risks (funding, technology, experience) and

leading to a gradual increase in production due to Gigafactory expansions and new Gigafactories, up to 20% in 2035.

- In China, production remains similar to the baseline level. Players are not incentivized to roll out massive production due to export restrictions.
- In the rest of the world, production remains the same as in the baseline.

This scenario will allow China still to maintain its lead in battery supply, while Europe and NAFTA gain significant market share, almost meeting global baseline demand (Figure 53).

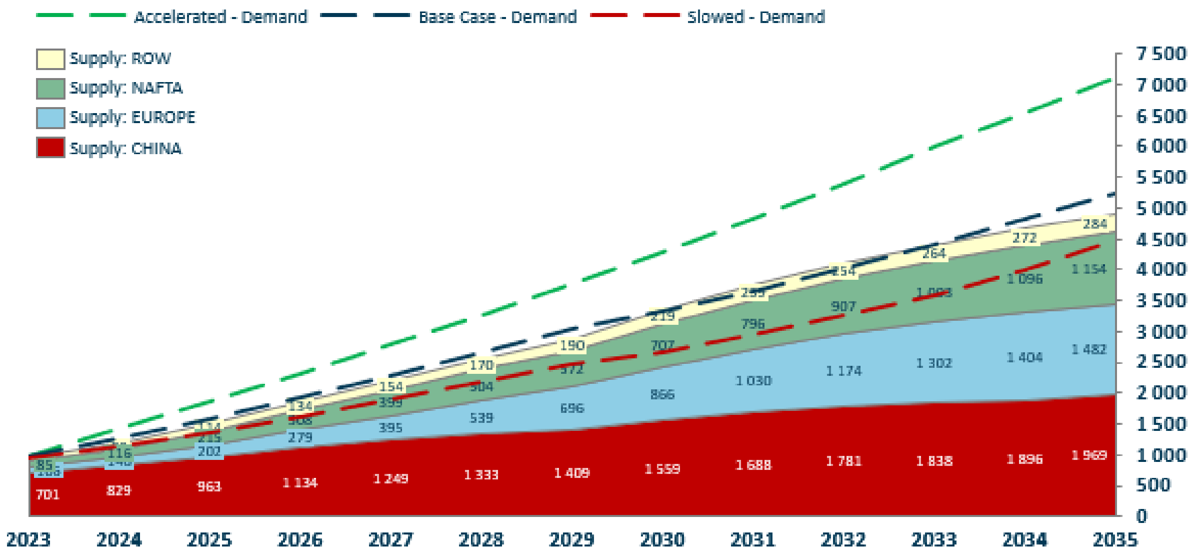


Figure 53: **LITHIUM-ION & NA-ION BATTERY DEMAND AND BATTERY SUPPLY FORECASTS, TRADE WAR |** *GWh, Worldwide, 2022-2035*

~~3.~~ **3. Price War "Maximum Chinese Capacity Roll-Out":** This scenario represents a highly competitive market condition.

- In China, experienced players continue to expand capacity rapidly and capitalize on their current experience and leadership in the value chain. This translates into a steep increase in projected capacity, by 40% in 2030 and 70% in 2035 and a need to export since supply outgrow domestic demand; Chinese players will start a price war to make use of their available capacity.
- In Europe, CO_2 regulations and battery passports are inefficient, and the market is flooded by cheap battery manufactured in China. Inexperienced players will be fully exposed to giants of the industry like CATL and BYD. European players struggle to adjust their costs and lose the price war. Due to a lack of profitability, risks concerning funding and experience are enhanced, and no new Gigafactories are announced.
- In NAFTA, the price war and low profitability of the market cause the government to shift focus from supporting battery manufacturing projects to other fields. Lack of funding and foreign currency are posing problems to industry players, resulting in a sharp increase of probability of defect.
- In the rest of the world, production remains the same as in the baseline.

In this price war scenario China will emerge as the dominant leader of the market, meeting more than 60% of global demand until 2035 (Figure 54).

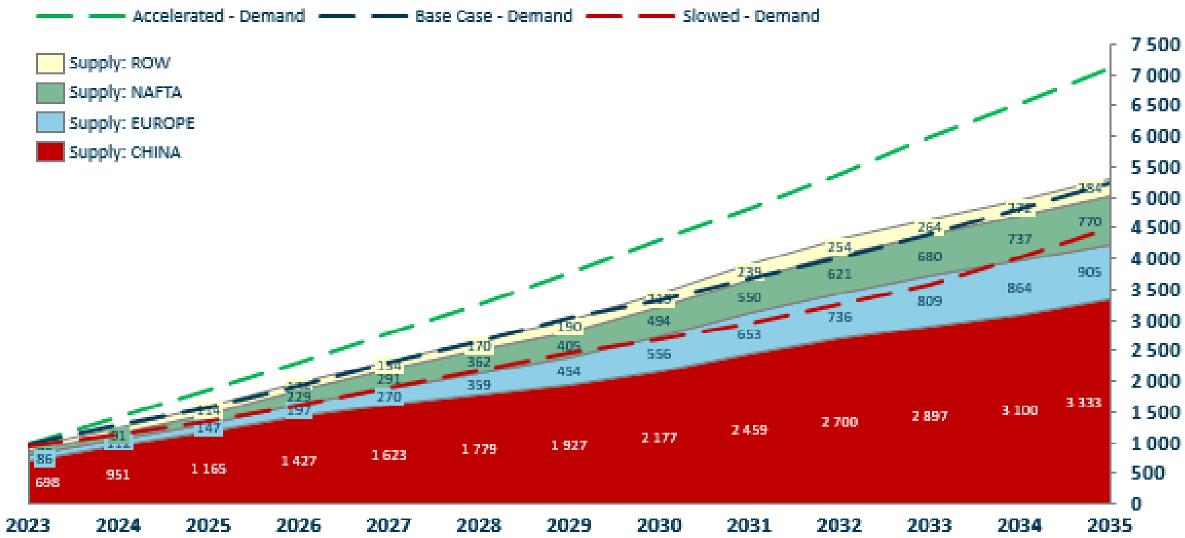


Figure 54: **LITHIUM-ION & NA-ION BATTERY DEMAND AND BATTERY SUPPLY FORECASTS, PRICE WAR |** *GWh, Worldwide, 2022-2035*

6.3. Gap Analysis

In the rapidly changing world of battery technology, understanding the gap between supply and demand is crucial for strategic planning and decision-making. With the increasing demand for electrification in various sectors, particularly in the automotive industry, the need for advanced battery technologies has never been more pronounced. This chapter aims to delve into the details of these potential gaps, the implications they hold for the global and European market, and to outline a strategic path moving forward.

6.3.1. Industrial Scenarios Gap Analysis

Global Industrial Scenarios:

The global sensitivity analysis (Figure 55) shows a glaring discrepancy between the future supply and demand for batteries. Current and planned battery manufacturing projects will nearly be able to fulfill global baseline demand by 2030, falling short of just 300 GWh at a global level. After 2030, the gap in supply vs demand in the baseline scenario will widen, with a predicted 1 TWh of deficit.

Achieving industrial success will not be enough; gigafactories necessitate a more supportive environment, leading to new factory and line expansions to effectively meet the growing demand for batteries. Additionally, whether or not industrial success is achieved, the presently announced gigafactories will be inadequate to support an accelerated demand scenario. Therefore, if global electrification progresses rapidly, substantial changes to the current gigafactory landscape will need to happen swiftly.

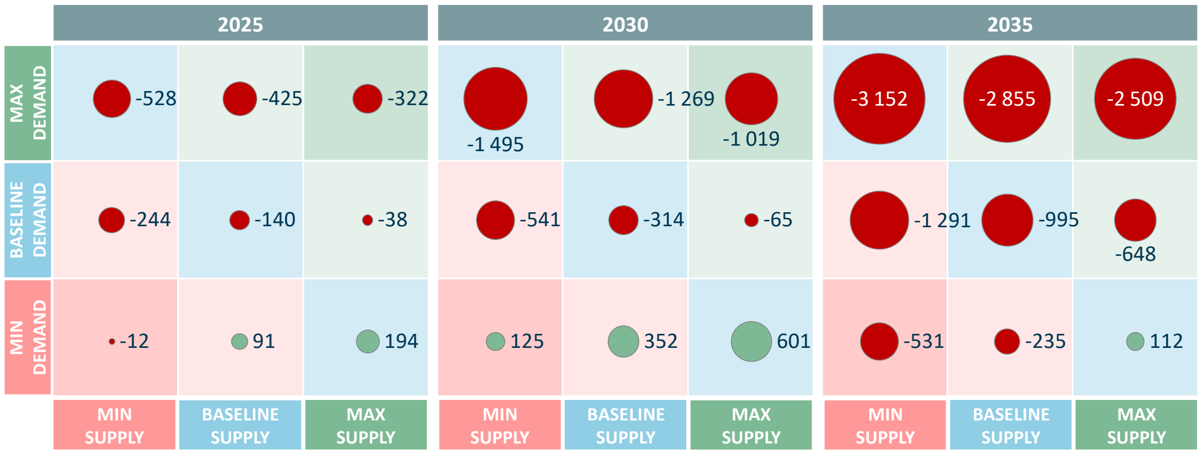


Figure 55: **SENSITIVITY ANALYSIS: GAP BETWEEN SUPPLY & DEMAND |** *# in GWh, 2025-2030-2035, Global*

In almost all industrial scenarios (as seen in Figure 55), significant gaps emerge particularly in the maximum demand situations. Supply shortages are expected to almost triple every five years from 2025 to 2035. Even in the baseline demand scenario, the picture remains bleak, albeit with lower gaps compared to the maximum demand scenario. Even under minimum demand conditions sizeable shortages are forecasted in 2035.

Addressing the looming battery supply-demand gaps is crucial, as current and planned manufacturing projects will not be sufficient to meet future demand, particularly under maximum demand scenarios.

Focus on Europe:

Turning our attention to Europe, the supply-demand gap is even more pronounced. In the context of the industrial scenarios, Europe's gaps are massive, except under the minimum demand scenario with either baseline or maximum supply by 2030. Currently planned and installed battery production capacities are inadequate to meet Europe's demand in 2025 or 2035 (Figure 56).

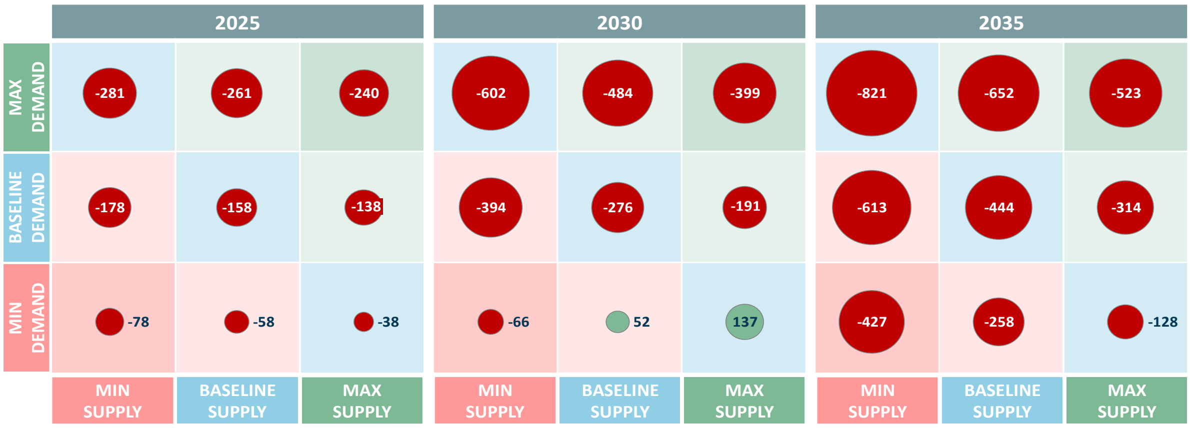


Figure 56: **SENSITIVITY ANALYSIS: GAP BETWEEN SUPPLY & DEMAND |** *# in GWh, 2025-2030-2035, Europe*

Only with successful industrial development, Europe's battery production could come close to satisfying low demand by 2030.

Under Scenario of high battery demand, the gap between battery supply and battery demand grows, posing significant challenges on the battery supply chain. This is amplified by regulatory approaches focusing on CO2 tailpipes emissions requiring BEVs. Emphasizing a "well to wheel" approach to minimize carbon footprint throughout the lifecycle through alternative technologies could reduce the pressure on the battery supply chain.

Otherwise, urgent action is needed to bridge the significant battery supply-demand gap globally, especially in Europe, through enhanced production, innovation, funding of additional gigafactories and strategic policies.

6.3.2. Macroeconomic Scenario Gap Analysis

Global Macroeconomic Scenarios:

The macroeconomic scenario offers a very different perspective on the global battery supply than the industrial scenario. Both the Price War Scenario and Trade War Scenario shows that there will be sufficient battery supply to meet Baseline demand by 2030 at a global level. In the Price War Scenario, baseline demand could be covered by 2035, while the Trade War Scenario might fall slightly short of covering baseline demand by 2035 (as shown in Figure 57).

Consequently, a substantial strengthening of the local supply chain and support for gigafactory projects in Europe and NAFTA (Trade War Scenario) or China's continued and accelerated gigafactory expansion, coupled with a strong emphasis on their industry leaders (Price War Scenario), would pave the way for global sufficiency in battery supply.

There are two distinct pathways to cover baseline battery demand, each with its unique dynamics and implications.

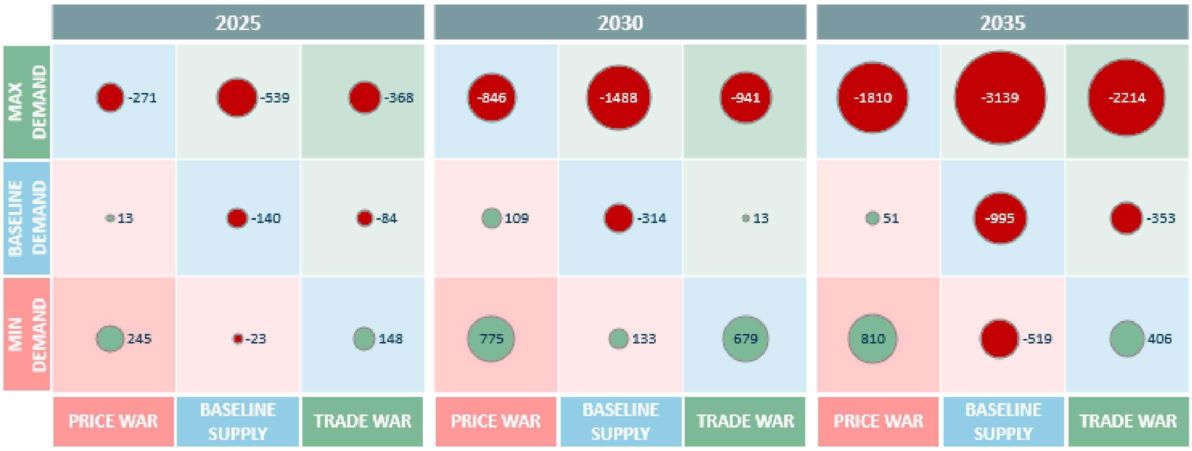


Figure 57: **SENSITIVITY ANALYSIS: GAP BETWEEN SUPPLY & DEMAND |** *# in GWh, 2025-2030-2035, Global*

Still, large supply-demand gaps on a global level are particularly evident in the maximum demand scenarios for 2025, 2030, and 2035.

European Macroeconomic Scenarios:

The outlook for Europe is very different depending on the scenario considered. Under current project trajectories. In every trajectory, European battery supply falls short of meeting the baseline demand in 2025, 2030 and 2035 (Figure 58).

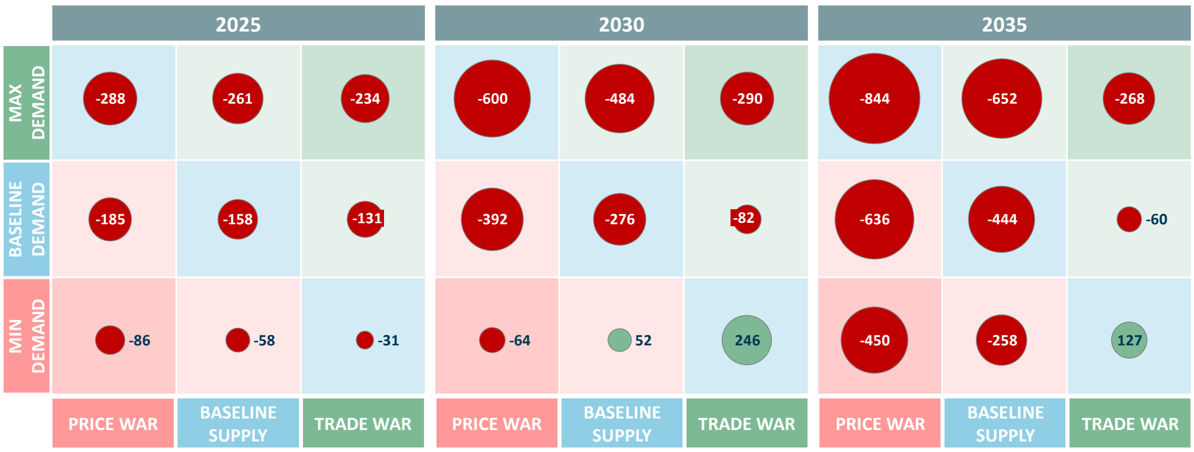


Figure 58: **SENSITIVITY ANALYSIS: GAP BETWEEN SUPPLY & DEMAND |** *# in GWh, 2025-2030-2035, Europe*

Despite this, there is a significant difference between all 3 scenarios. The Price War scenario affect European supply-demand dynamics due to inability of European player to become cost competitive against Asian players and would lead to enormous import needs from European player of nearly 400 GWh in 2030. On the other hand, within the Trade War Scenario, Europe will be able to nearly fulfill its battery supply for all applications markets, and the supply gap will be under 100 GWh both by 2030 and 2035 and would set up a nearly sufficient battery supply chain.

The analysis of battery supply and demand dynamics brings into focus a stark reality - a significant gap exists between the global supply and demand for advanced batteries. This gap is particularly pronounced in Europe, revealing the need for intensified efforts and potentially strategic measures.

Achieving a successful implementation of the Green Deal and establishing a significant presence in crucial markets such as electrified Heavy-Duty vehicles, Energy Storage Systems, and light mobility is contingent upon successfully addressing this gap and setting up a robust battery supply, highlighting that it goes beyond the scope of the automotive and battery industry.

In the face of a rapidly increasing demand for batteries, robust industrial strategies need to be deployed. Enhanced production capabilities, technological innovations, and strategic policies all play a critical role in averting potential market instability. At the same time applying new strategic policies and support measures are vital to ensuring a sustainable future for the battery industry. Europe needs to act fast and decisively to reduce dependencies, fill the supply-demand gap, and quickly build up and reinforce its standing in the global battery market.

These findings underscore the importance of strategic policy implementations, robust support systems, and aggressive efforts to expand battery production capacities. These measures are particularly crucial in the European context to overcome the persistent gaps and foster a more sustainable and stable battery market.

Additionally, exploring alternative technological pathways like new fuels can offer complementary solutions to alleviate pressure on the battery supply chain. By adopting a multi- technology approach that incorporates both strategic policies and diverse technological pathways, we can develop a more robust and stable mobility market in Europe (the analysis of alternative solutions is outside the scope of the study).

7. Annex A: Cell, module and pack overview and technological overview

7.1. Cell Geometry: Prismatic, pouch, cylindrical

A typical battery pack, the essential energy store for an electric vehicle, comprises several sub-modules, namely the housing, module casings, thermal management system, bus bars and high voltage connectors, cells, and the battery management system (BMS) and sensors (Figure 4).

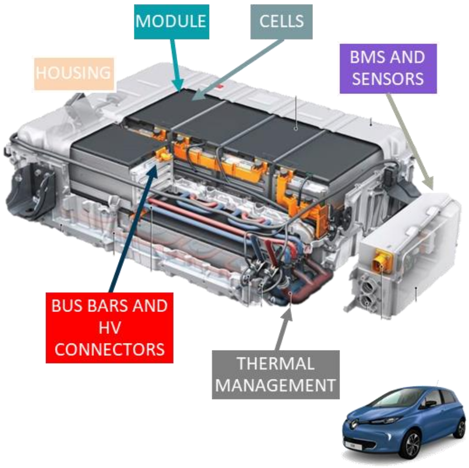


Figure 59: **BATTERY PACK COMPONENT OVERVIEW**

The housing ensures the mechanical stability of the battery pack and provides protection from the external environment. Modules, made up of cells combined into a frame in a series or parallel configuration, form the serviceable units within the battery pack. Thermal Management is essential to control the temperature and maintain the battery pack within the optimal operating range. Bus bars and HV connectors link the various electrical elements of the battery pack. Cells are the key energy storage units, and the BMS and sensors monitor and manage the operating conditions of the battery pack.

			CELL LEVEL		PACK LEVEL[2]		
SAFETY[1]	ELECTRICAL	Protection against contact	✓	or	✓		✗
		Isolation resistance	✓	or	✓		✗
		Functional safety	✓	or	✓		✗
	MECHANICAL	Mechanical shock	✓	or	✓	or	✓
		Crash/crush	✓	or	✓		✗
		Vibration	✓	or	✓	or	✓
	ELECTRICAL (ABUSE)	Ext. short circuit protection	✓	or	✓		✗
		Over-(dis)charge protection	✓	or	✓	or	✓
	ENVIROMENTAL	Thermal shock and cycling	✓	or	✓		✗
		Over-temperature protection	✓	or	✓	or	✓
		Fire resistance	✓	or	✓	or	✓
	EMC	Electro-magnetic insulation	✗		✓		✗
PERFORMANCE	PERFORMANCE	Power	✓	or	✓	or	✓
		Energy (Ah, kWh)	✓	or	✓	or	✓
	CAR INTEGRATION	Capacity (kwh)	✓	or	✓		✗
		Weight (kwh/kg)	✓	or	✓	or	✓
		Volume (kwh/l)	✓	or	✓		✗
	USER EXPERIENCE	Lifetime	✓	or	✓	or	✗
		Durability	✓	or	✓	or	✗
		Charging time	✓	or	✓	or	✗
		Recyclability	✓	or	✓	or	✓

Figure 60: **FUNCTIONAL REQUIREMENTS OF A BATTERY PACK/CELL |** [2] Including pack for Cell2Pack architecture

Safety is the primary functional requirement guiding the design of these battery packs. This requirement is addressed at the cell, pack, or vehicle level, depending on OEM and model. The high-energy density nature of the battery necessitates prioritizing safety. The battery also needs to maintain electromagnetic (EM) compatibility, which requires substantial EM shielding, to prevent disruption to other critical vehicle functions. Functional requirements can be addressed by specific material selections or design features. For example, cylindrical and pouch cells may require stiffer module casing than prismatic cells due to their geometry.

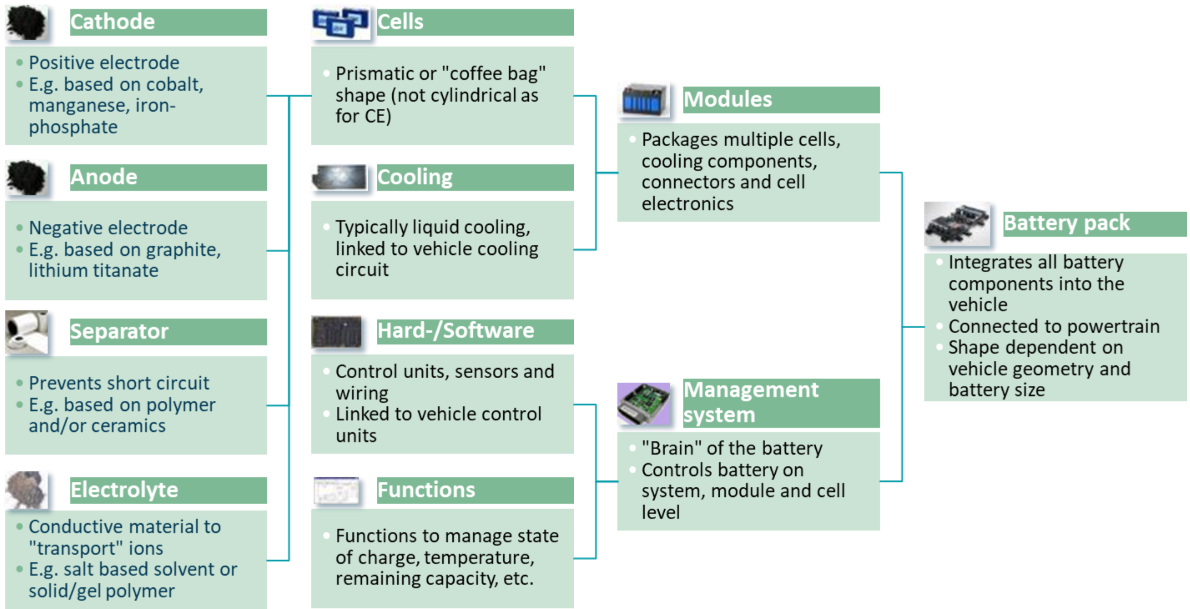


Figure 61: **MANUFACTURING PROCESS OF A BATTERY PACK**

Battery cells, given their crucial role in energy storage, necessitate complex manufacturing processes and technical expertise (Figure 61). Moreover, the manufacturing of a battery pack involves a multi-system integration process, demanding precise assembly and rigorous testing (Figure 61).

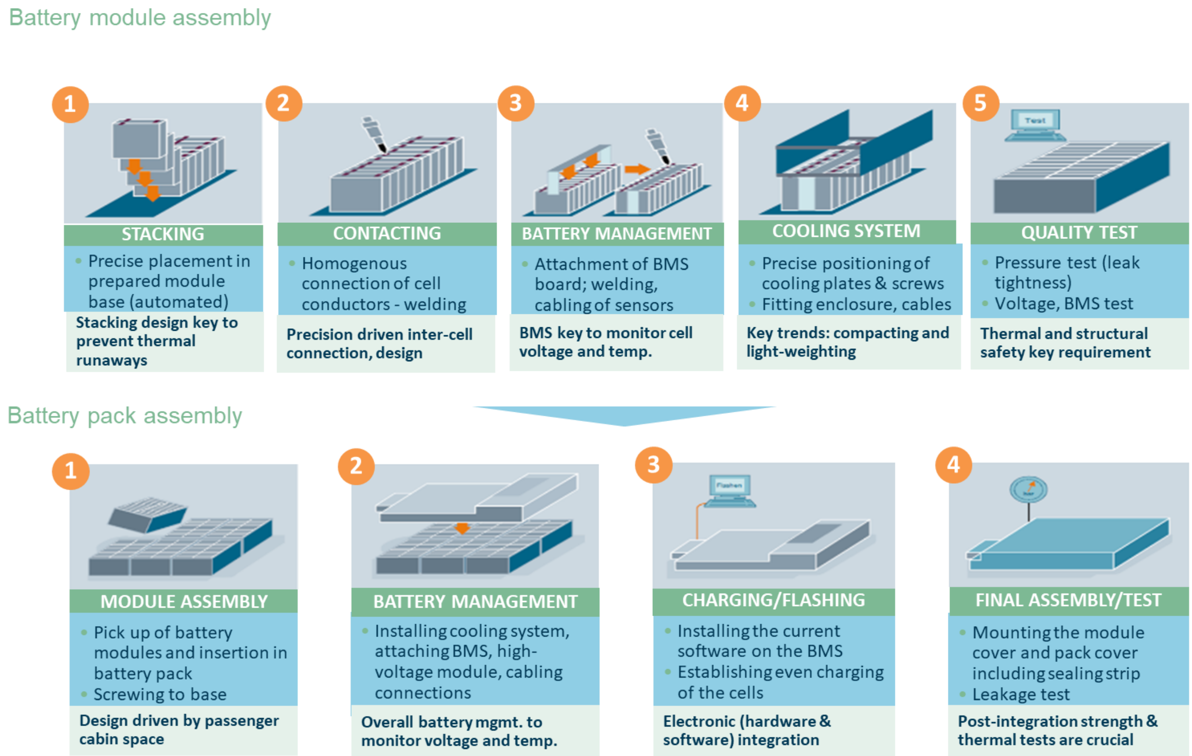


Figure 62: **BATTERY MODULE AND BATTERY PACK ASSEMBLY**

Lithium-ion battery (LIB) cells primarily consist of five components: Cathode, Separator, Electrolyte, Binder, and Anode. The cathode and anode material choices are pivotal as they most significantly define the performance of the battery cell. The active materials in these components are responsible for generating current. Here's a brief overview of these components (Figure 62):

1. **Cathode:** Made primarily of lithium, combined with Nickel, Manganese, and Cobalt (NMC), the cathode defines the battery's chemistry. Its thickness determines the power, lifecycle, safety, and cost of the battery.

2. **Separator:** A thin layer of polyolefin with high porosity, the separator keeps the electrodes apart and serves a critical safety function.

3. **Electrolyte:** Usually lithium salt in a solvent, it enables ion transport and current creation. It often includes additives to improve performance.

4. **Binder:** This polymer binds the materials and affects the cyclability and capacity retention of the battery.

5. **Anode:** Composed mainly of carbon, often graphite, the anode contributes to battery performance metrics like lifetime, capacity, and chargeability. Availability and cost are typically not an issue.

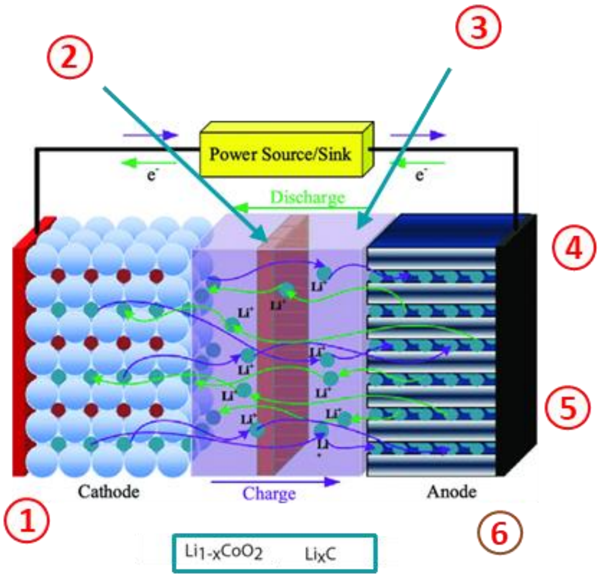


Figure 63: **LI-ION BATTERY COMPONENTS**

There are typically three different Li-ion battery cell designs in use: cylindrical, prismatic, and pouch. The cylindrical was historically the dominant type, while the prismatic has taken its place and pouch type keep a small portion of the market.

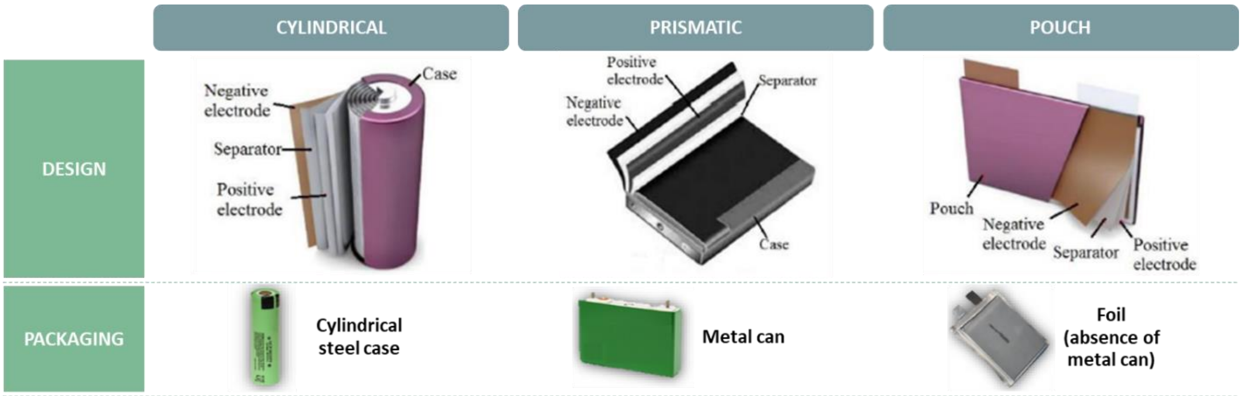


Figure 64: **LI-ION BATTERY CELL GEOMETRIES**

Cylindrical cells are known for their affordability, widespread availability, and modulable possibilities. The air cavities between cells are useful for thermal management, though the design's bulky size can result in inefficient space utilization.

Prismatic cells offer high energy density and good mechanical protection. Prismatic cells offer excellent safety regarding thermal runaway thanks to their metal cans and structure and space management properties. They are available in large sizes.

Pouch cells present advantages during manufacturing process, a flexibility in design, can fit for various applications and presents the higher energy density. They come in a broad variety of forms and sizes.

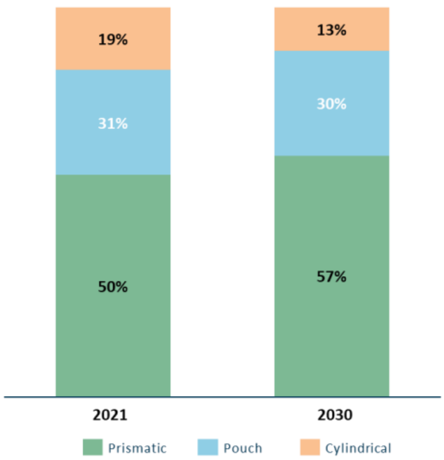


Figure 65: **CELL TYPE DEMAND PER CELL GEOMETRY |** demand in % of total GWh demand, 2021-2030

Key suppliers in the battery industry include Panasonic, CATL, Samsung SDI, LG Chem, Northvolt, BYD, and SK Innovation. Market trends suggest a global increase in the adoption of prismatic cells, driven by their usage among major players and their safety benefits in anticipation of upcoming regulations. However, pouch and cylindrical cell markets are also anticipated to expand due to the overall growth of the global market. These trends show that the automotive industry is adapting to meet consumer demands while improving upon the efficiency, safety, and reliability of battery technologies.

7.2. Existing Cell Cathode: NMC, NMCA, LFP, LMNO and Sodium-Ion battery

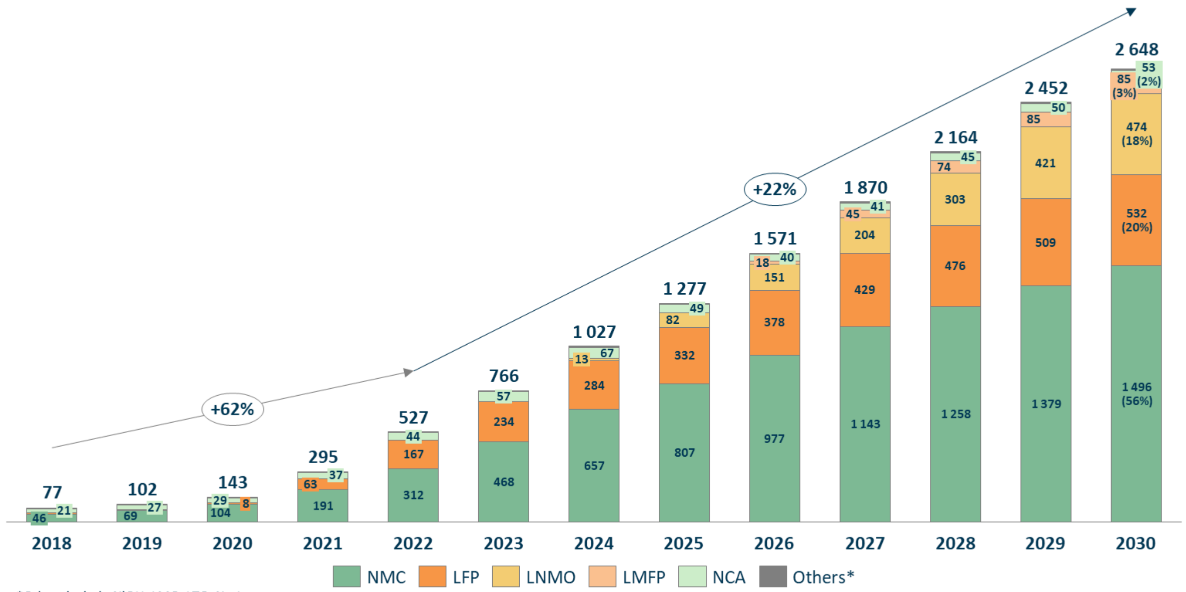
Battery technologies mainly distinguish themselves by the metal they utilize in their cathodes. Various existing and future battery technologies come with their own set of advantages and disadvantages, making their use highly specific to the application.

Lead-Based Batteries: These batteries are affordable, proven to be safe and sustainable. They are used in almost every vehicle to power the auxiliaries at low voltage (12V system). However, they have a low energy density, shorter cycle life, and higher self-discharge rate compared to other battery families.

Lithium-Based Batteries: These batteries are characterized by their high energy density and lightweight nature. The downside, however, lies in their expensive production and safety concerns. Lithium-based batteries encompass NMC, NCA, LFP, and LMNO chemistries and are used for electrified vehicles at higher voltage. NCA was initially developed in Japan by Sony, Sanyo and Panasonic for the consumer electronics industry and used by Tesla as standard high-performance battery cell. NMC was developed by Korea and its 3 markets leaders Samsung SDI, LG Energy Solutions and SK Innovation have filed many patents. LFP was initially developed by China about 15 years ago when they realized that NMC and NCA battery designs were protected. It was also an opportunity for China to develop a cheaper technology to make EVs more affordable to most of its citizens.

Nickel-Based Batteries: Known for their long life and reliability, nickel-based batteries are the main batteries used today. However, they have lower cycle life and higher self-discharge rates, and suffer from memory effect, a phenomenon where rechargeable batteries seem to 'remember' the amount of discharge and only accept that amount of charge in subsequent charging sessions.

Sodium-Based Batteries: Sodium-based batteries provide reasonable energy density and cost-effectiveness compared to other battery types. They offer three key benefits: not relying on critical metals such as e.g., Li, Ni, Co and Mn for production, sodium being abundantly available globally and exhibiting exceptionally good safety characteristics. However, their significant drawback lies in sodium's reactivity with air and moisture, as well as limited power output, restricting their application in the automotive industry. China is the first country to industrialize Sodium-Ion which is even cheaper than LFP and that will be applied for light mobility and ESS. Europe is still in the development phase for this technology.



*Others include NiOH, LMO, LTO, Na-Ion

Note: LNMO refers to Cobalt Free Nickel Magnesium cathodes. These cathodes can be Manganese Rich as the one developed by Powerco for VW, with high-purity Nickel as developed by ACC for Stellantis, or using Aluminium.

Figure 66: **ELECTRIC LIGHT VEHICLE BATTERY DEMAND PER CATHODE CHEMISTRY (INCLUDING LIGHT COMMERCIAL VEHICLES) | #** GWh, 2018 – 2030

Currently, NMC and LFP are the dominant technologies in lithium-based batteries. After 2025, however, cobalt-free cathode chemistries like LNMO and LFP variants such as LMFP are projected to gain traction (Figure 66). NMC tends to excel in premium vehicles while LFP is mainly used in A and B car platform vehicles. Manganese-rich cathodes target C and D car car platform markets. It's important to note that in each vehicle car segment almost all these battery technologies can be found, but depending on OEM strategy certain technologies are targeted for specific applications (Figures 67 and 68).

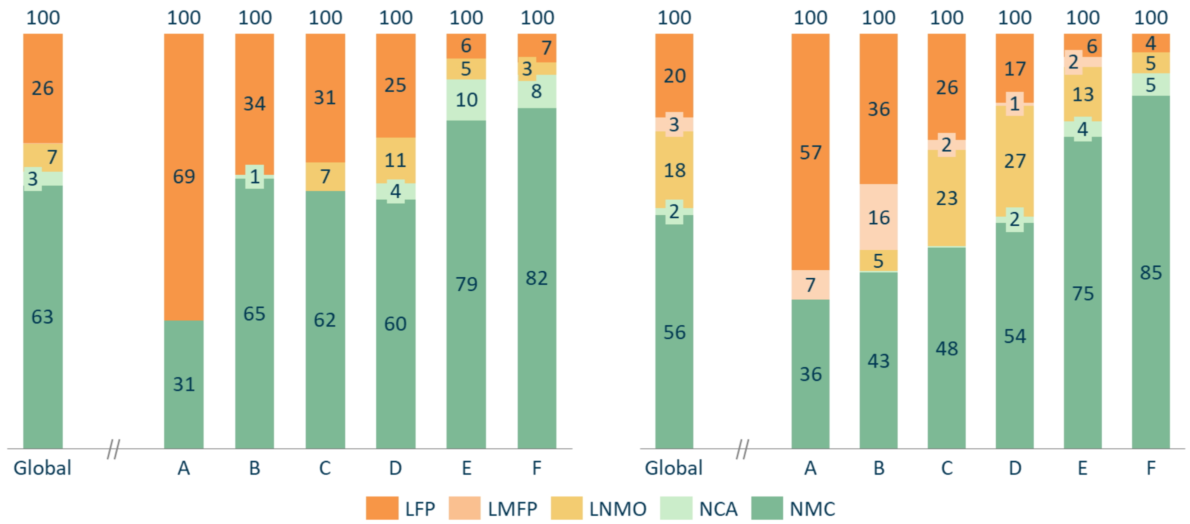


Figure 67: **BATTERY CATHODE CHEMISTRY BY BEV SEGMENTATION**
In % of GWh within each segment of vehicle, 2025
Figure 68: **BATTERY CATHODE CHEMISTRY BY BEV SEGMENTATION**
In % of GWh within each segment of vehicle, 2030

For example, in the Volkswagen model range, the segmentation of cell types depends on the power of the models. NMC is used for powerful models, LNMO for compact models, and LFP for city cars.

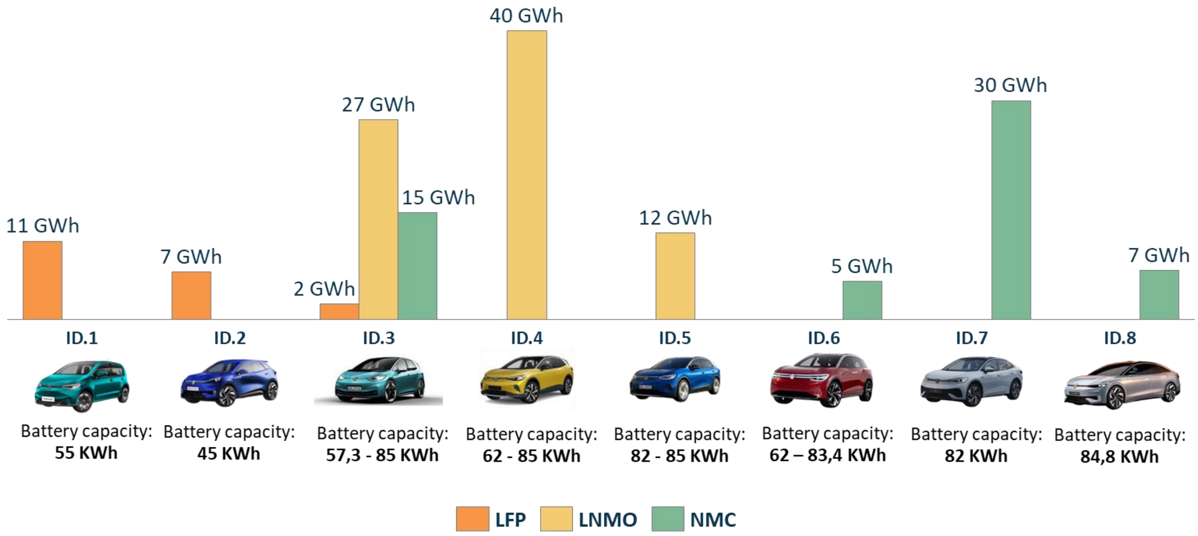


Figure 69: **Battery chemistry by VW "ID" range model**
In % of GWh in each vehicle model, 2030

As the battery technology market evolves, a clear trend is emerging where small and compact cars will be equipped with LFP and high manganese cathodes like LNMO while large and premium cars will opt for high nickel cathodes such as NMC and NCA to boost performance. This market segmentation strategies are adopted by Tesla and Chinese manufacturers. Major NMC manufacturers such as Umicore, BASF, Ecopro, Easpring, and Nichia are working on developing a high manganese grade (60 to 70% Mn) cathode that they believe will be cheaper than LFP, as part of their 'Design to Cost' approach.

Furthermore, no major barriers exist in the development and scale-up of Lithium-Manganese Rich layered Oxide cathodes, with standard operating procedures expected from 2026. This technology with a voltage of 4.2V or less is being produced in China and very soon in Europe. However, for the Spinel High voltage $LiNi0.5Mn1.5\ O4$-like cathode, a significant barrier is the high voltage operation at 4.6V, which needs a suitable electrolyte not currently ready/available. Standard operating procedures for this are not expected before 2030.

Notably, all major producers of LFP or future LFMP (Dynanonic, Hunan Yuneg, BTR, Pulead…) are based in China and are significantly expanding their capacity. They are keeping a close eye on the European and US markets, and large chemical corporations in these regions are currently re-evaluating their strategies.

7.3. Battery Prices and Supply Chain

Historically, the cost of battery cells has been decreasing in line with a drop in the prices of raw materials and manufacturing improvement. However, the current surge in raw material prices has introduced significant challenges, especially for new players in the market who did not have the chance to lock in raw material prices through long term agreements in the past.

Key Trends in the Market: Across the entire value chain, raw material prices have been increasing, mainly spurred by the strong price hikes in cathode active material, electrolyte, and current collectors. This has led to cell cost increases of over 40% as of January 2022, and over 85% as of March 2022. The troubling macroeconomic situation during 2022 and large uncertainties in the batteries demand have triggered substantial fluctuations in raw material prices. Notably, NMC material prices have almost tripled in the last 1.5 years, largely due to almost twofold price increases for nickel and cobalt, and especially due to the 4-8 times lithium hydroxide price increase compared to 2020/21. LFP variants have been affected by the surging prices of lithium carbonate, which experienced 6-10 times increase over 2020/21 levels. Dependence on lithium price has doubled the cost of electrolyte components, like conductive salt LiPF6. Additionally, the prices of aluminum and copper have increased by more than 50%.

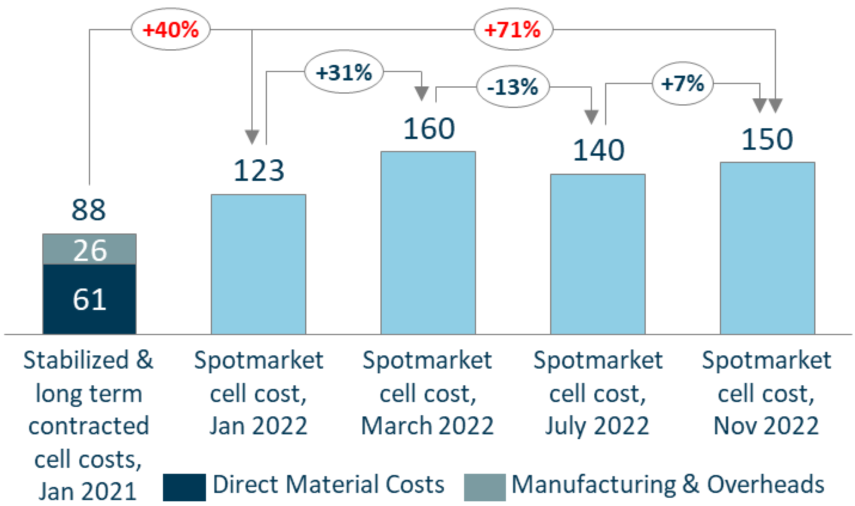


Figure 70: **IMPACT OF RAW MATERIAL PRICE INCREASES ON CELL COSTS**
$/kWh, Worldwide, 2021 & 2022

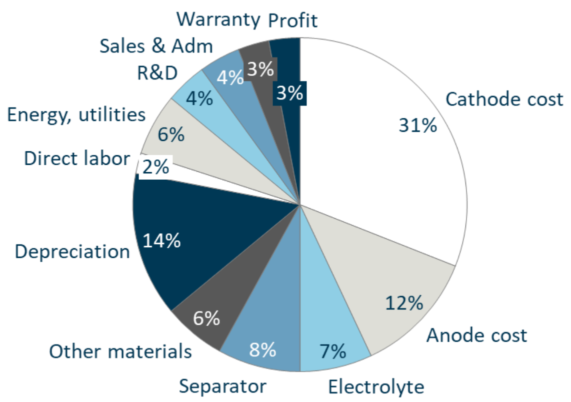
The rising prices pose extra challenges for new market entrants, who cannot leverage the benefit of previously established long-term contracts. The impact of raw material price increases on cell costs is illustrated in Figure 70.

According to Avicenne, battery prices increased in 2022 for the first time, reversing a long period of steady decline, and reaching now an average of $138/kWh for BEVs, and $169/kWh for ESS. Prices vary based on application, region, and chemistry. For instance, passenger BEVs

($138/kWh) had lower prices than stationary storage ($169/kWh) and passenger PHEVs ($345/kWh). Regionally, prices were lowest in China ($127/kWh), followed by the U.S. ($157/kWh) and Europe ($169/kWh). Regarding chemistry, LFP cells were 20% cheaper than NMC cells.

Even though some OEMs have secured long-term supply contracts, it is predicted by Goldman Sachs in *The Greenflation Challenge* that battery pack prices will remain above $100/kWh until 2026, which is two years longer than originally expected.

Raw materials account for 60-70% of the cost of Lithium-Ion Cells, which means that variations in raw material prices drastically impact battery production costs. The main costs in 2021 for a lithium-ion cell priced at $125/kWh were cathode costs (31%), followed by costs related to manufacturing equipment ("Depreciation") (14%), and anode costs (12%). In 2022, the price of LI-Ion has raised to $160/kWh.



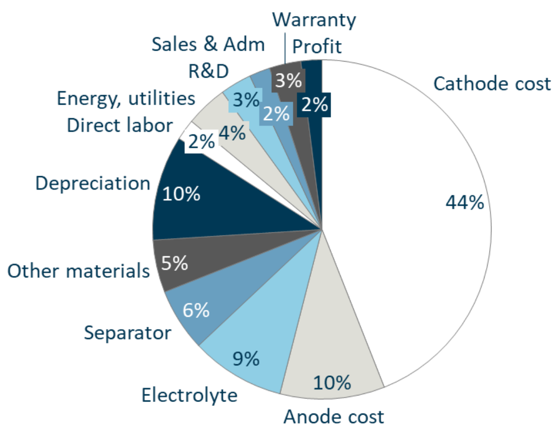


Figure 71: **AVERAGE PRICE STRUCTURE OF LI-ION CELL |** *%, Worldwide, $125/kWh, 2021*
Figure 72: **AVERAGE PRICE STRUCTURE OF LI-ION CELL |** *%, Worldwide, $160/kWh, 2022*

For lithium-ion cells, the largest portion of the price comes from raw materials, making up 60 to 70% of the overall cost, while energy accounts for 6%. Therefore, changes in raw material costs drastically impact the profit margins of battery manufacturers.

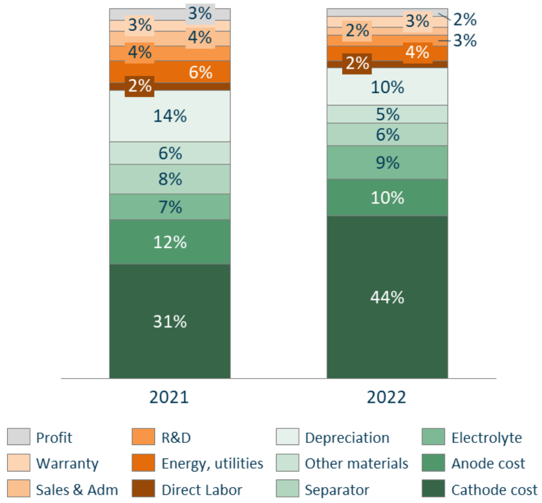


Figure 73: **DETAILLED PRICE STRUCTURE OF LI-ION CELL**
%, 65 Ah NMC 622 Pouch cells, Worldwide, 160 $/kWh, 2021 & 2022

According to Transport and Environment, the average EV battery with a 60kWh capacity contained about 185 kg of materials in 2020, with graphite, aluminum, nickel, and copper being the top materials by weight. Nonetheless, the five crucial minerals in EV batteries due to their rarity are lithium, nickel, cobalt, graphite, and manganese.

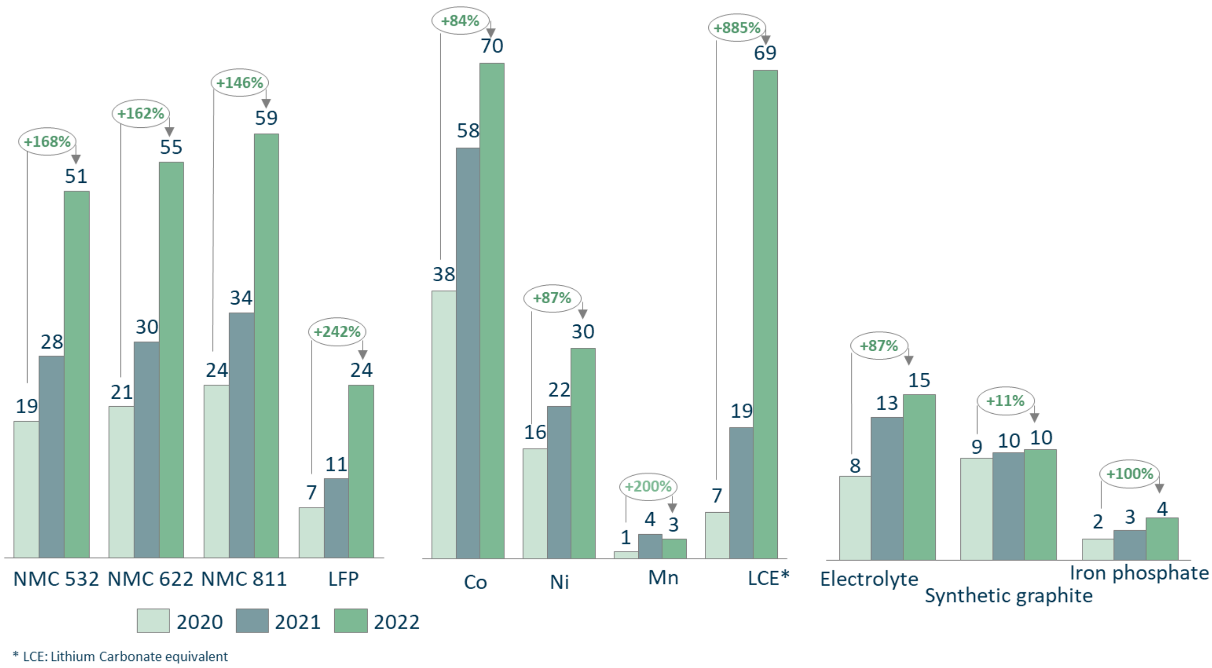


Figure 74: **CATHODE ACTIVE MATERIALS PRICE & KEY METALS PRICE EVOLUTION**
$/kg, Worldwide, 2020 & 2021 & 2022

Since 2020, the price of cathode materials has risen significantly. Except for manganese, prices for each type of raw material have almost doubled (Figure 74)

Battery Costs were expected to experience a steady decrease due to technological and process improvements. Despite this, since raw materials are the main driver of battery cells, we have seen rises in cells prices in 2021 and 2022 due to the important tensions in raw materials markets. There is a risk that battery prices will struggle to decrease in the mid to long term. This is due to the fact that impact of increased price from raw materials, driven by reinforced demand, could outpace the reduction in prices resulting from technological and industrial process improvements.

8. Annex B: Existing Forecast on battery demand and supply and current battery supply

8.1. Existing Forecast on battery demand and supply

Earlier studies projected a substantial lithium-ion battery demand ranging from 2 to 4.7 terawatt-hours (TWh) by 2030, with the mobility sector accounting for the majority (approximately 90%) of this demand. The anticipated capacity for Li-Ion batteries in 2030 has an even broader range, spanning from 3 to 8.2 TWh. However, there are significant uncertainties regarding capacity and these forecasts don't go beyond 2030.

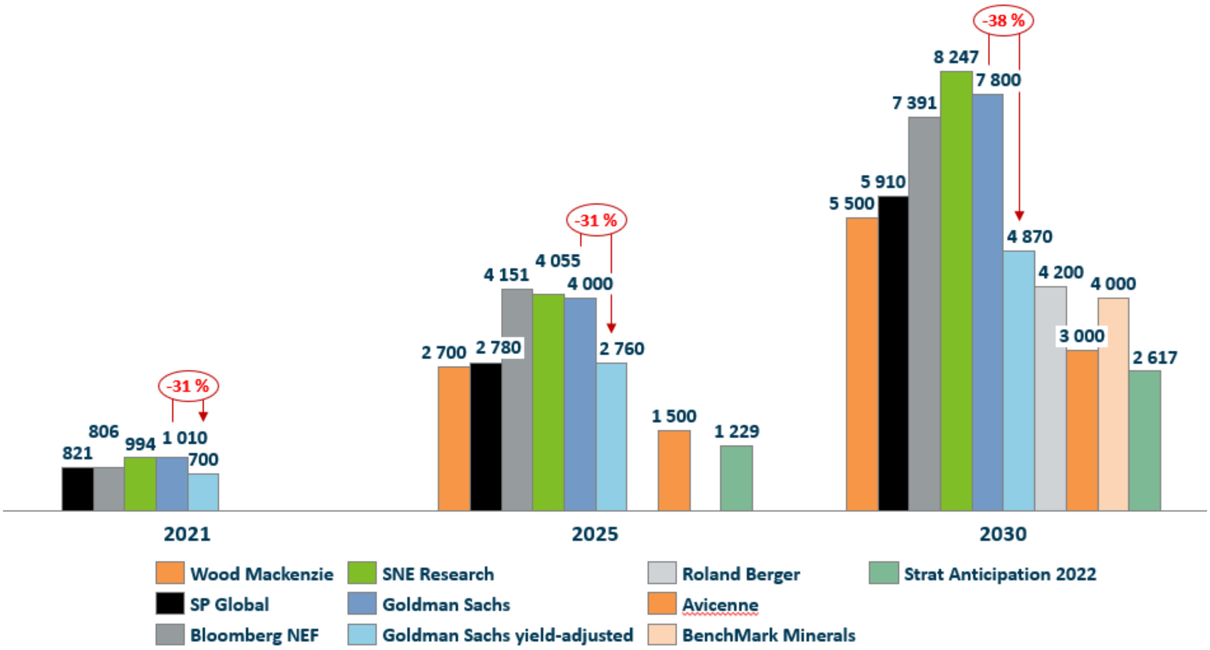


Figure 75: **TOTAL LITHIUM-ION BATTERY MANUFACTURING CAPACITY FORECASTS |** *GWh, total Worldwide Manufacturing Capacity, 2021-2030*

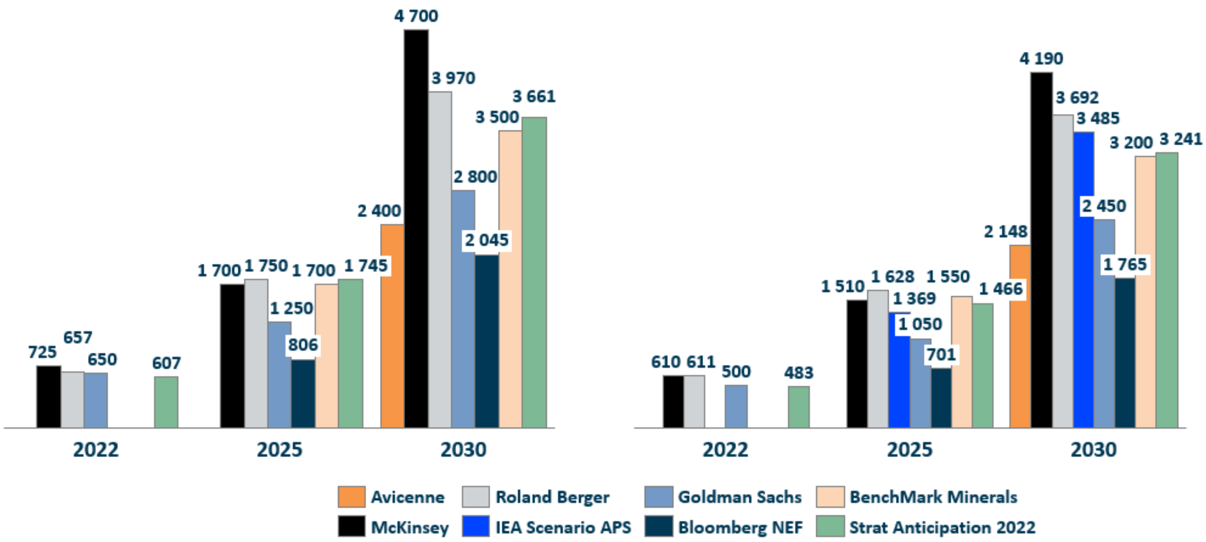


Figure 76a: **TOTAL LITHIUM-ION BATTERY DEMAND FORECASTS | ***GWh, total Worldwide demand, 2022, 2025 & 2030*

Figure 76b: **TOTAL LITHIUM-ION BATTERY DEMAND FOR MOBILITY FORECASTS | ***GWh, total Worldwide demand, 2022, 2025 & 2030*

8.2. Currently Installed Battery Manufacturing Capacity

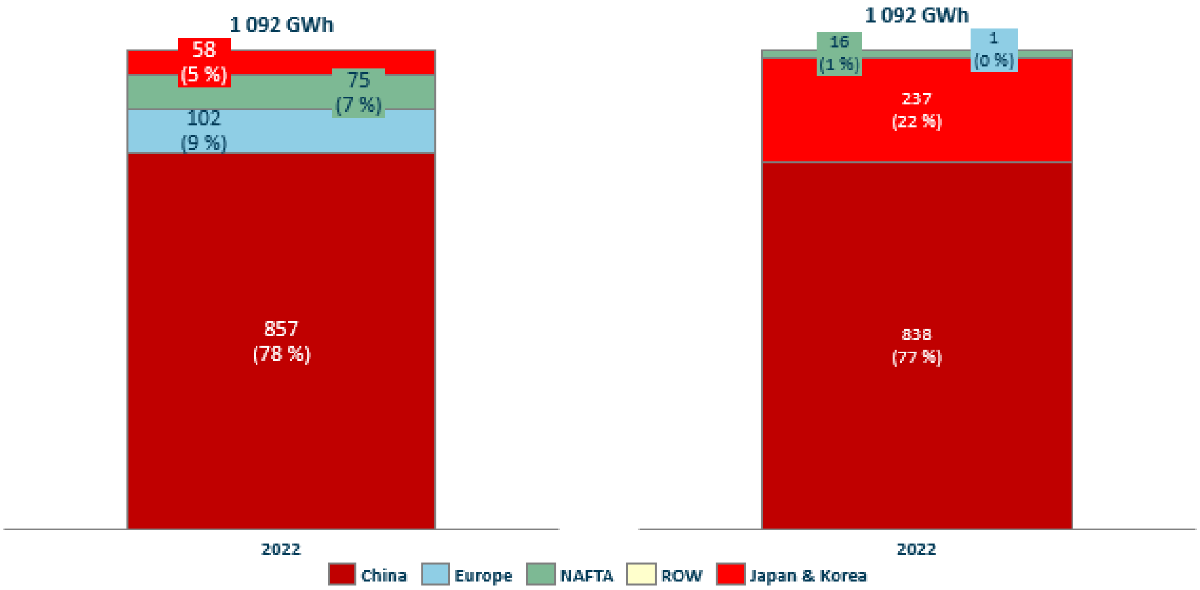


Figure 77a: **BATTERY MANUFACTURING CAPACITY INSTALLED PER REGION | ***GWh, Worldwide, 2022, Lithium Ion Battery*

Figure 77b: **BATTERY MANUFACTURING CAPACITY INSTALLED PER MANUFACTURER COUNTRY OF ORIGIN | ***GWh, Worldwide, 2022, Lithium Ion Battery*

In 2022, China retained its dominant position in the global battery manufacturing landscape, hosting an impressive 78% of the total 1092 GWh battery manufacturing capacity worldwide. This staggering concentration underscores China's pivotal role as a major hub for battery production.

While Japanese and Korean manufacturers have expanded their footprint by establishing manufacturing plants in Europe and North America, most Chinese cell manufacturers continued to operate within China itself. This geographical concentration highlights China's continued stronghold on battery production, maintaining its leadership in the global supply chain (Figure 77a and 77b).

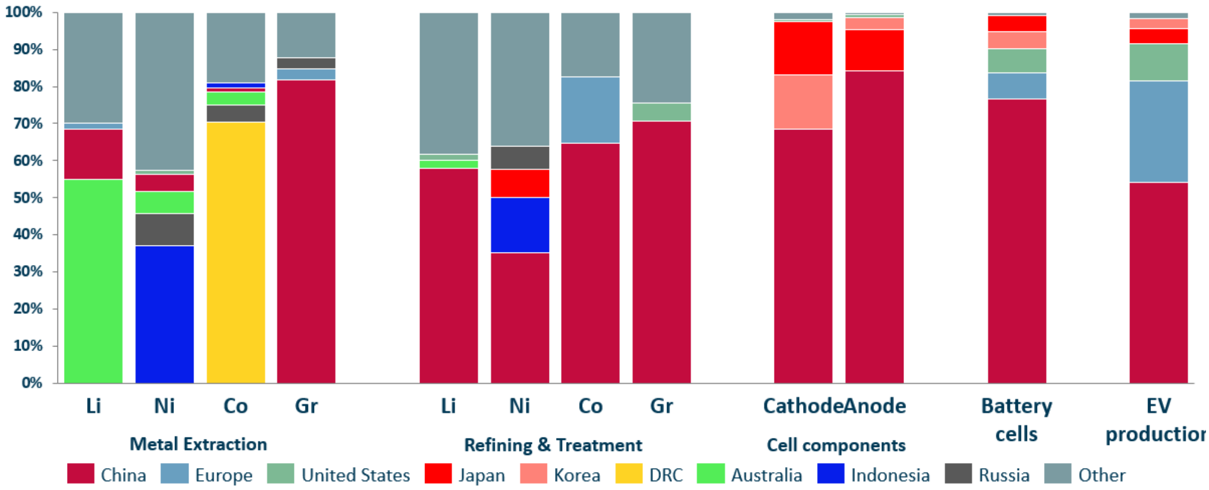


Figure 78: **GEOGRAPHIC DISTRIBUTION OF THE GLOBAL EV BATTERY SUPPLY CHAIN, FROM THE IEA |** *kg & %, Worldwide, 2021 & 2022, TNE*

According to the IEA, Australia, Indonesia, and the Democratic Republic of Congo have emerged as key players in the mining sector, dominating the production of critical battery materials. However, China stands as the unrivaled leader in the downstream supply chain, particularly in refining and manufacturing cell components. The geographical landscape of the supply chain highlights China's comprehensive dominance in processing lithium, nickel, cobalt, and graphite, as well as its position as the leading producer of battery cell components and cells by a substantial margin. Notably, China also claims the title of the largest producer of graphite globally (Figure 78).

STRAT ANTICIPATION
6 rue Alfred Roll – 75017 PARIS – FRANCE
Mobile: +33 6 07 37 84 27
E-Mail: remi@stratanticipation.com