REPORT

Resilient supply chains for raw materials

How the green transition is driving demand for critical minerals – and how to ensure supplies

Roland Berger

Management summary

The world's industrial base is undergoing a fundamental change. For decades driven by fossil fuels, sectors from automotive to aerospace are now shifting to renewable energies and materials to satisfy society's demands for a cleaner, sustainable future.

This green transition requires shifting from fossil-fuel-based value chains to a new generation of clean energy technologies based on non-fossil minerals. As a result, demand is rising exponentially for battery raw materials, especially lithium and nickel, copper (for cabling), and rare earth elements, such as neodymium. Indeed, clean energy technologies are set to become the fastest-growing segment of demand for most minerals – they will account for 90% of lithium demand by 2040, for example, a 15x increase on 2020.

The energy transition cannot happen without these minerals. Yet meeting demand for them is becoming challenging. Supplies of lithium and nickel, for example, are expected to only just keep up with demand until 2030. This precarious situation is likely to be further strained by the significant uncertainties around some demand and supply drivers, for example growth in electric vehicle (EV) sales and disruptive technologies. Risks, such as supply shortages and a lack of skills in the industry, compound the problem.

A solution is to build up resilient supply chains for in-demand raw materials. In this article, we outline an approach and recommendations to create more stable and flexible supply chains, as well as assessing the challenges, uncertainties and risks surrounding them.

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Market overview: Supply and demand dynamics

1.1/ Why raw material demand is rising

THE ENERGY TRANSITION IS DRIVING EXPONENTIAL GROWTH IN DEMAND FOR CRITICAL NON-FOSSIL MINERALS

The green transition is driving demand for a new cohort of raw materials. In place of coal and oil, clean energy technologies need lithium, nickel, copper and other non-fossil minerals to store power, build EV batteries and connect offshore wind farms to national grids. Demand is soaring.

Rapidly expanding sectors such as solar energy, wind power, electricity networks and EVs will account for almost 90% of lithium demand by 2040, 60%-70% of nickel and cobalt demand, and more than 40% of the demand for copper and rare earth elements (in particular neodymium), according to the International Energy Agency (IEA Sustainable Development Scenario). This represents supply requirement increases of between 1.3x (copper) and 14.6x (lithium) compared with 2020. In terms of volume, the required increase in nickel is particularly significant.

The main driver for these increases is demand for batteries, particularly lithium-ion (Li-ion) cells for electric vehicles and energy storage systems (ESS). ▶ A

1.2/ Battery demand

GROWING EV SALES, TECHNOLOGICAL ADVANCES AND NEW MARKETS WILL SEE DEMAND FOR BATTERIES AND BATTERY MATERIALS SOAR

Driven by the boom in EV sales, demand for batteries is exploding. From a base of around 265 GWh in 2020, we estimate that market demand for Li-ion and sodium-ion (Na-ion) batteries will soar to almost 5,000 GWh in 2030. China is set to remain the biggest market, and EVs the largest customer. ESS is expected to be one of the strongest-growing segment, with a CAGR of 33%.

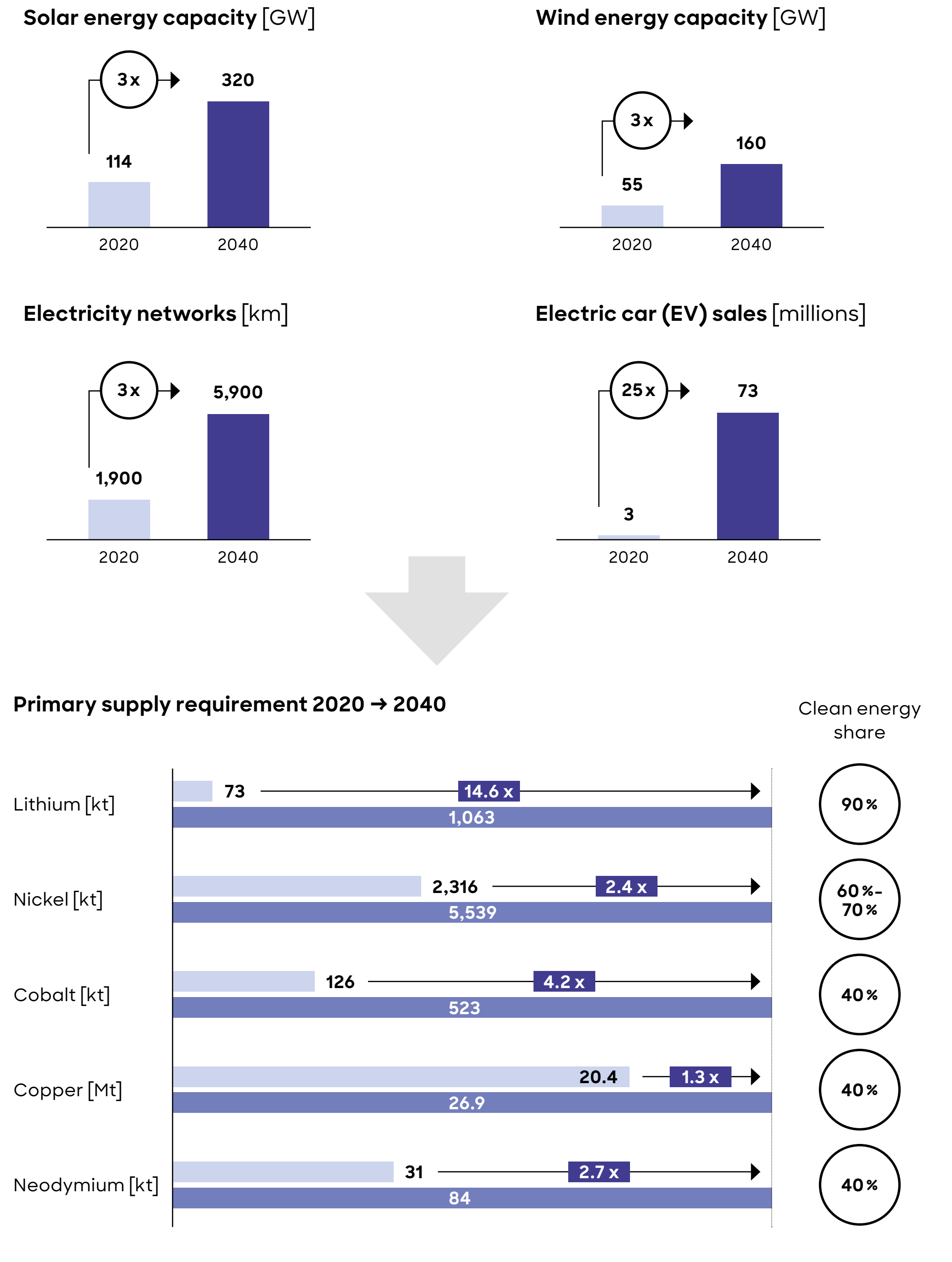
Growth is also being driven by innovations in cell chemistry and design to reduce costs, increase energy density and cut charging times. Examples include increasing the nickel share of already widely used cathode chemistries, such as NMC (nickel manganese cobalt), to increase energy densities from around 400-600 to 900 Wh/L; increasing the share of silicon used in Li-ion anodes to enhance energy densities and fast charging; and developing solid-state technologies to enhance safety and achieve energy densities in excess of 1,000 Wh/L.

In addition, lower energy density but cheaper lithium iron phosphate/lithium manganese iron phosphate (LFP/LMFP) Li-ion cells and Na-ion chemistries are gaining traction for low-cost and low-value applications. Overall, we expect a global shift toward LFP variants due to their rising share in the lower-end EV segments and ESS, which is also the main application for Na-ion batteries. For example, LFP/LFMP cathode chemistries are expected to account for 42% of all cathode chemistries by 2030, compared with around 30% today, while NMC chemistries are forecast to fall from 63% to 50% in the same period. The Na-ion share is set to jump from 3% to 8%.

The overall result is a huge increase in demand for raw materials such as lithium, nickel and cobalt. ▶ B

A Demand surge: Strong growth in clean energy technologies is creating a raw materials boom

Annual deployment of green energy technologies and required raw material supply



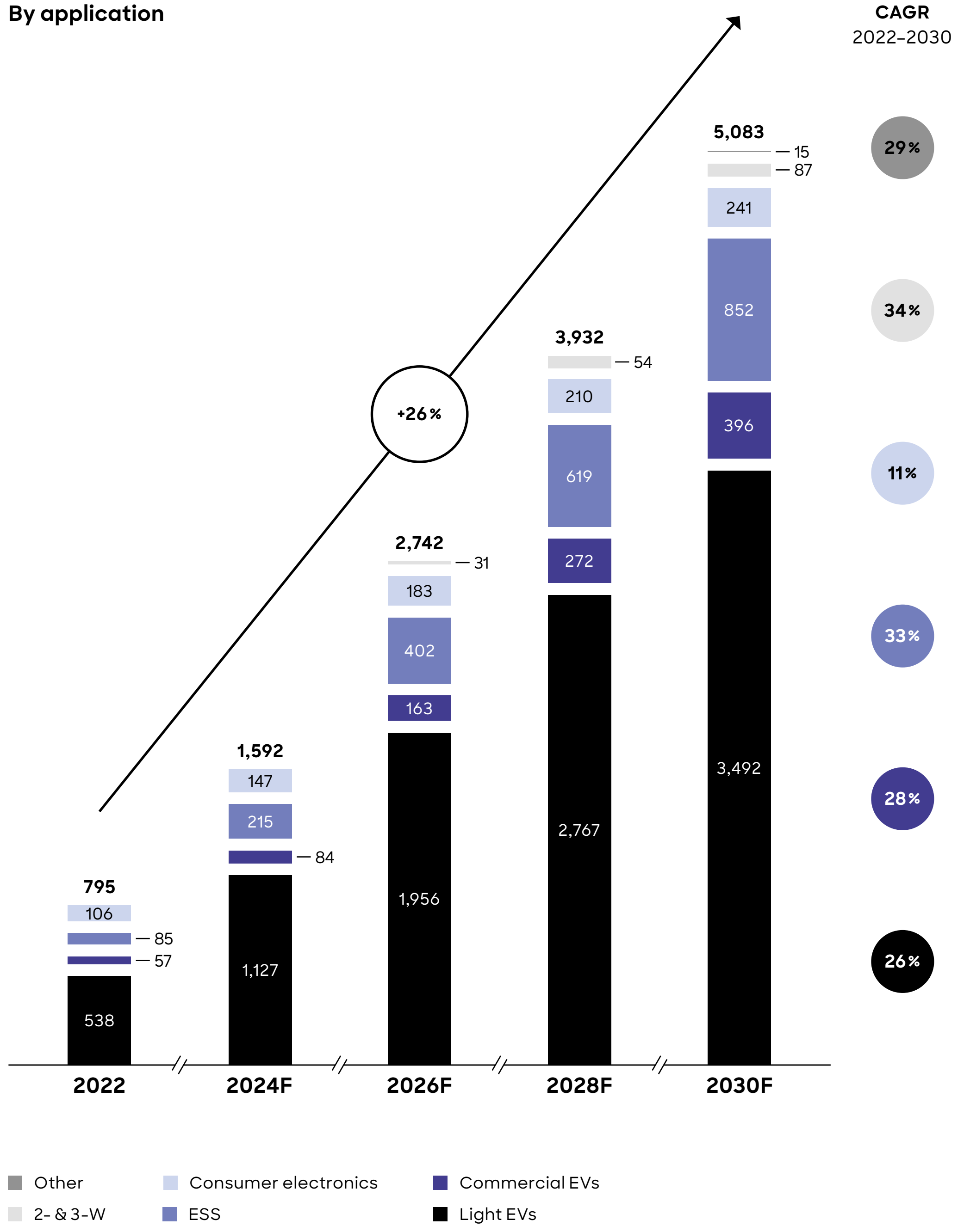
(examples, IEA Sust. Dev. Scenario 2021)

Source: IEA Sustainable Development Scenario – The Role of Critical Minerals in Clean Energy Transitions – Analysis – IEA

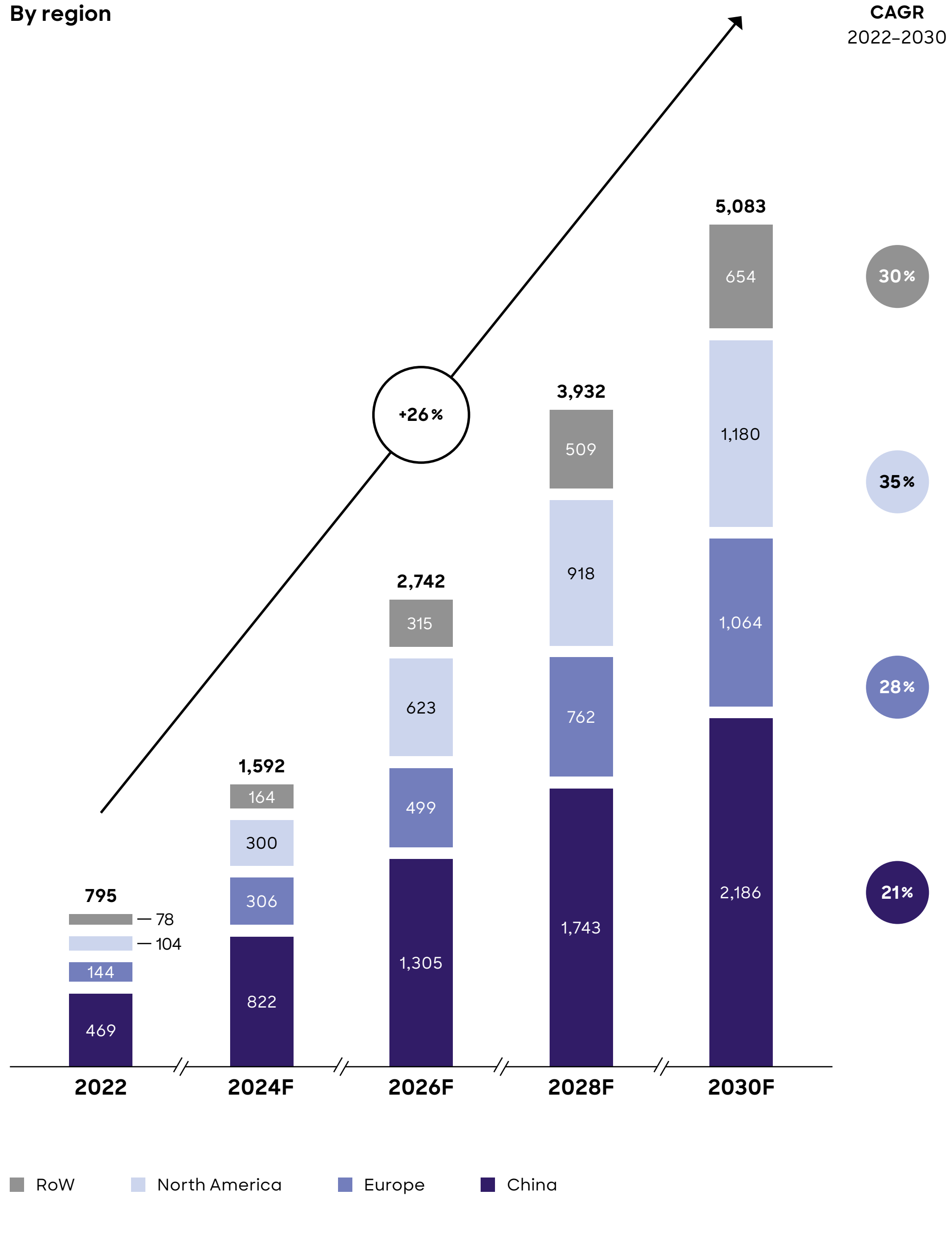
B Powering up: Market demand for batteries is growing fast, especially in the light and commercial EV and ESS segments

Market demand for Li-ion and Na-ion batteries, 2022-2030F [GWh]

By application



By region



Abbreviations:
Light EVs: passenger cars, incl. sedans, SUVs, vans and pickups, etc., c. 98% LiB, c. 2% Na-ion; commercial EVs: medium- to heavy-duty trucks and buses, ESS: storage of excess energy generated for later usage; 2- & 3-W: electric two- or three-wheelers

Source: Roland Berger LiB Supply-Demand Model

1.3/ Supply versus demand

SUPPLY OF KEY RAW MATERIALS SHOULD KEEP UP WITH DEMAND THROUGH TO 2030, BUT RISKS EXIST FOR EACH

The rising demand for minerals used in clean energy technologies is expected to seriously test supplies. According to current capacity plans, mined supplies of lithium, nickel and cobalt are forecast to be sufficient, even after probability weighting of mining projects. But gaps are appearing in supplies of refined materials, especially outside China, as outlined in our base-case scenario.

Lithium: Battery making will account for around 94% of total demand for lithium by 2030, estimated to be around 3.4 million tonnes (Mt). Existing lithium projects cover only about half of projected 2030 demand, meaning new mining projects will be required. These face significant obstacles in the form of technology, skills and financing. There are, however, sufficient viable reserves of lithium (around 79 Mt in the US alone).

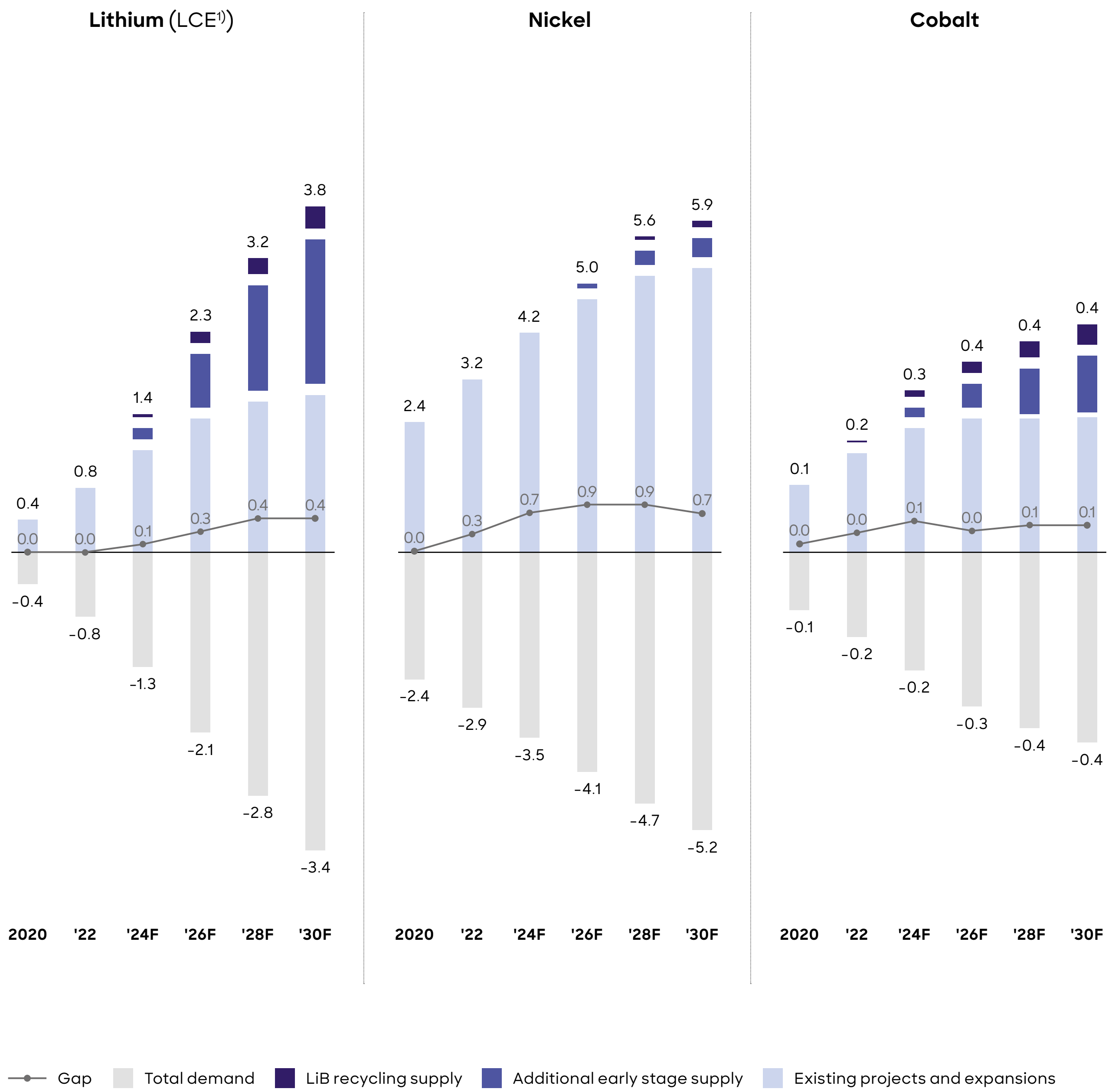
Nickel: Nickel demand is set to reach around 5.2 Mt in 2030, with overall nickel supplies forecast to hit 5.9 Mt. The biggest supplier is Indonesia, where existing and new mines are expected to produce 3.5 Mt of the metal in 2030. However, the long lead times (6-13 years) involved in setting up conventional new nickel mines in Indonesia could compromise supply estimates. Plants using new HPAL technology have much shorter lead times.

Cobalt: The shift toward LFP and cobalt-free chemistries is likely to result in an oversupply of cobalt by 2030, with supply outstripping demand by around 0.1 Mt. However, political risks exist, as most cobalt comes from the Democratic Republic of the Congo (DRC) and is refined in China. Growing output in Australia and Indonesia could ease these risks. ▶ C

> **"While there exist sufficient reserves, there is still considerable risk around the supply-side development of new mines and build-out of refining capacity."**
>
> Kyle Gordon, Principal

C Just enough: Mined supplies of lithium, nickel and cobalt are expected to cover demand through to 2030, but with little room for maneuver

Supply and demand forecast - Lithium, nickel, cobalt, 2020-2030F [m metric tons]



1) Lithium carbonate equivalent

Source: BMO, Deutsche Bank, Fastmarkets, Roskill, Wood Mackenzie, Roland Berger

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Uncertainties on the horizon

2.1/ Market uncertainties: Overview

NUMEROUS UNPREDICTABLE FACTORS CAN SERIOUSLY IMPACT ALREADY UNSTABLE RAW MATERIAL SUPPLY CHAINS

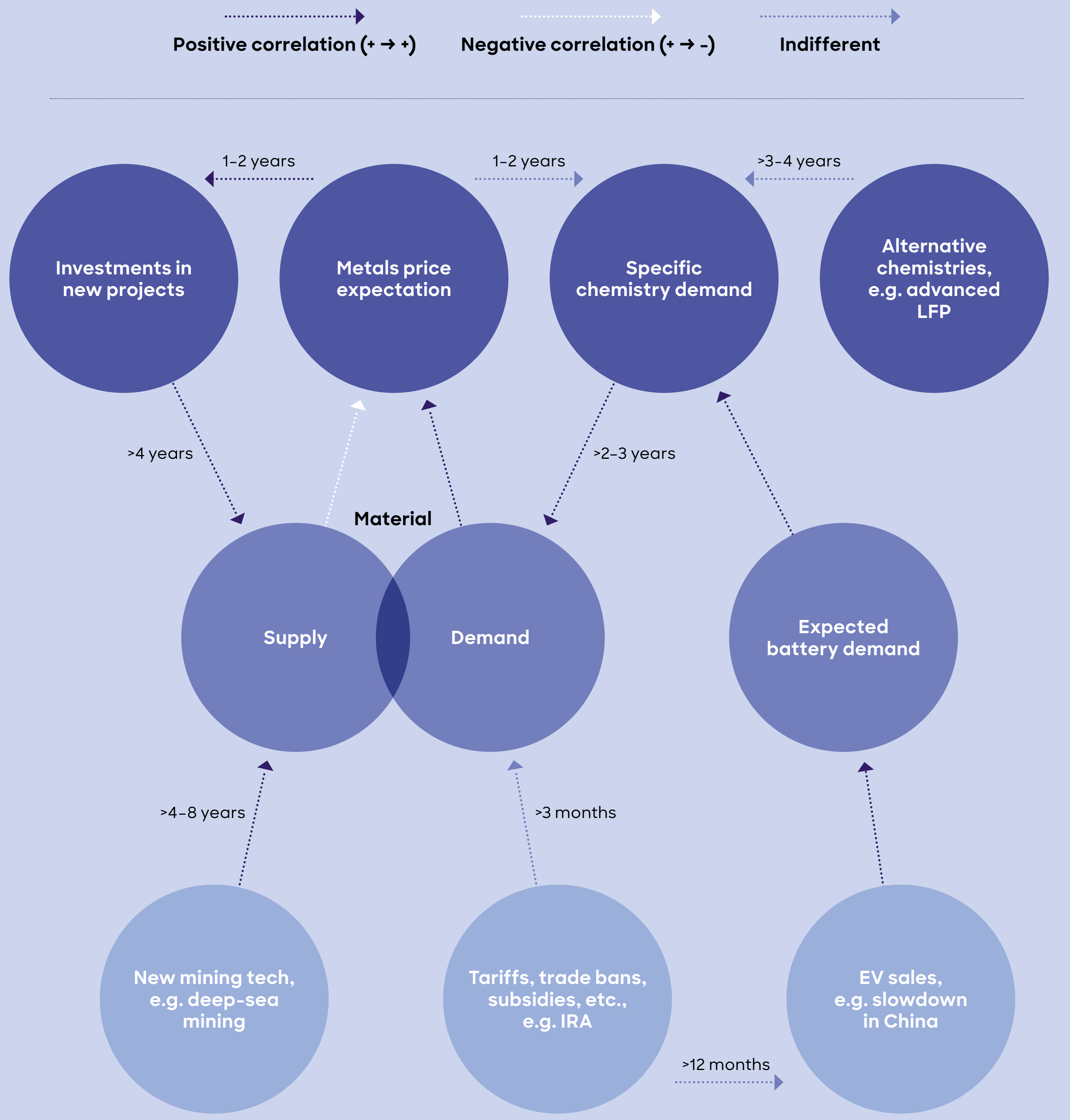
Supply and demand predictions are useful indicators. However, they are beset by significant uncertainties that can impact the entire supply chain of critical materials, which is already highly dynamic and unstable. These include:

- Future EV sales – they are currently falling, for example
- Future metal price forecasts, which can influence investment decisions
- Political measures like the pro-green-technologies US Inflation Reduction Act (IRA), which will increase demand for batteries but restrict where supplies can come from
- Disruptive technologies, such as deep-sea mining
- Preferred cell chemistries – the shift to LFP will affect demand for lithium, for example

On the next page we look in more detail at some of the key uncertainties. ▶ D

> **"Uncertainties related to EV sales, commodity prices and geopolitics deeply influence raw material supply chains. Volatile market conditions are not conducive to long-term investments in mining and refining."**
>
> Isaac Chan, Partner

D Chain reactions: The entire critical materials supply chain is at risk from uncertainties in demand and supply drivers



Source: Roland Berger

Simplified example "EV & battery materials"

2.2/ Market uncertainties: Examples

DEMAND AND SUPPLY OF RAW MATERIALS IS HEAVILY AFFECTED BY EV SALES VOLUMES AND PRICE VOLATILITY

EV sales

Uncertainty over EV sales has a significant impact on demand for batteries, cathode and raw materials and investments. The recent sales dip highlights the difficulties. For example, depending on the scenario, the cumulative estimated required investments in lithium, nickel and cobalt mining and refining, and production of cathode active materials, vary between USD 165 billion and USD 360 billion by 2030.

Raw material prices

Raw material prices cannot be reliably predicted. For example, lithium hydroxide (LiOH) prices averaged around 9.6 USD/kg in 2020. In 2021, they were forecast to remain broadly flat until 2027. But in reality, prices shot up to 72.9 USD/kg in 2022, and are now forecast to remain well above 20 USD/kg until at least 2030. Long term, most analysts expect prices to remain higher than pre-2022 levels.

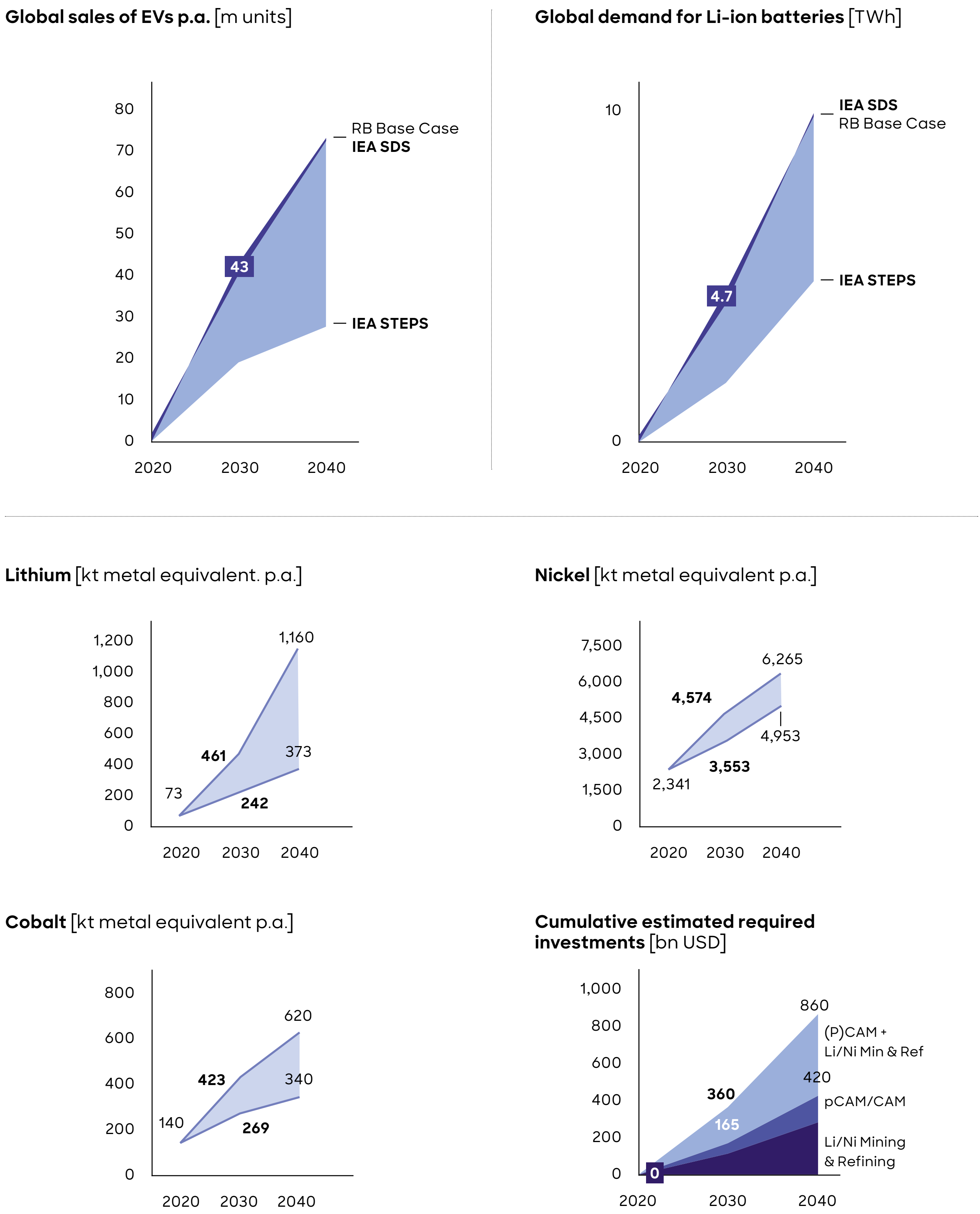
Political events

China is responsible for 49% of all lithium mining, produces more than 80% of key cathode and anode active materials, and manufactures 75% of batteries. This dominance concerns other countries, with some taking action and thus further increasing uncertainty. The IRA, for example, places restrictions or tariffs on many non-US-produced battery materials, while the EU wants to secure supply agreements with non-Chinese countries.

Disruptive technologies

The ramp-up of deep-sea mining on the seabed of the Pacific Ocean could become a game changer in the supply of nickel and cobalt, with reserves of nickel alone being more than 3x terrestrial supplies. However, the technology is likely only viable if sustainable mining methods are developed. ▶ E

E Future unknown: Forecasts for EV sales, Li-ion battery demand, raw materials demand and required investments vary widely depending on the scenario used



Two scenarios shown: Upper curve: IEA SDS – Lower curve: IEA STEPS | Material demand: IEA | Investments: Roland Berger

Source: The Role of Critical Minerals in Clean Energy Transitions – Analysis – IEA, Roland Berger LiB Demand-Supply Model Q1/2023, Roland Berger

3

The need for resilient supply chains

3.1/ The need for resilient supply chains

RESILIENT SUPPLY CHAINS HELP TO OVERCOME UNCERTAINTIES THROUGH STABILITY, FLEXIBILITY AND RISK MITIGATION

The problem with uncertainties is that they cannot be accurately predicted! Most high-impact uncertainties materialize only after a certain dead time or after weak signals are spotted. For example, this could be between the conception and execution of a project (such as a new nickel mine – 5-15 years), or the emergence and establishment of a new disruptive technology (such as solid-state cells – 5-12 years). This dead time is a risky period, as unforeseen events may render investments worthless or technology redundant. It also hampers strategic planning of supply chains.

Objectives

Making supply chains resilient is the key to dealing with uncertainties. They must be designed to maintain stability while also being flexible and able to mitigate risk. We believe resilient supply chains should fulfill five fundamental objectives:

1. Stabilize by minimizing the impact of disruptions: Players need to ensure resource availability, secure alternative sources, develop contingency plans and prepare alternatives (suppliers, technologies, etc.).

2. Increase flexibility to adapt to changing market conditions: Take into account new technologies, market demand, political decisions, etc.

3. Improve visibility across the supply chain: This includes developing the ability to detect weak signals that can forewarn players about coming high-impact events.

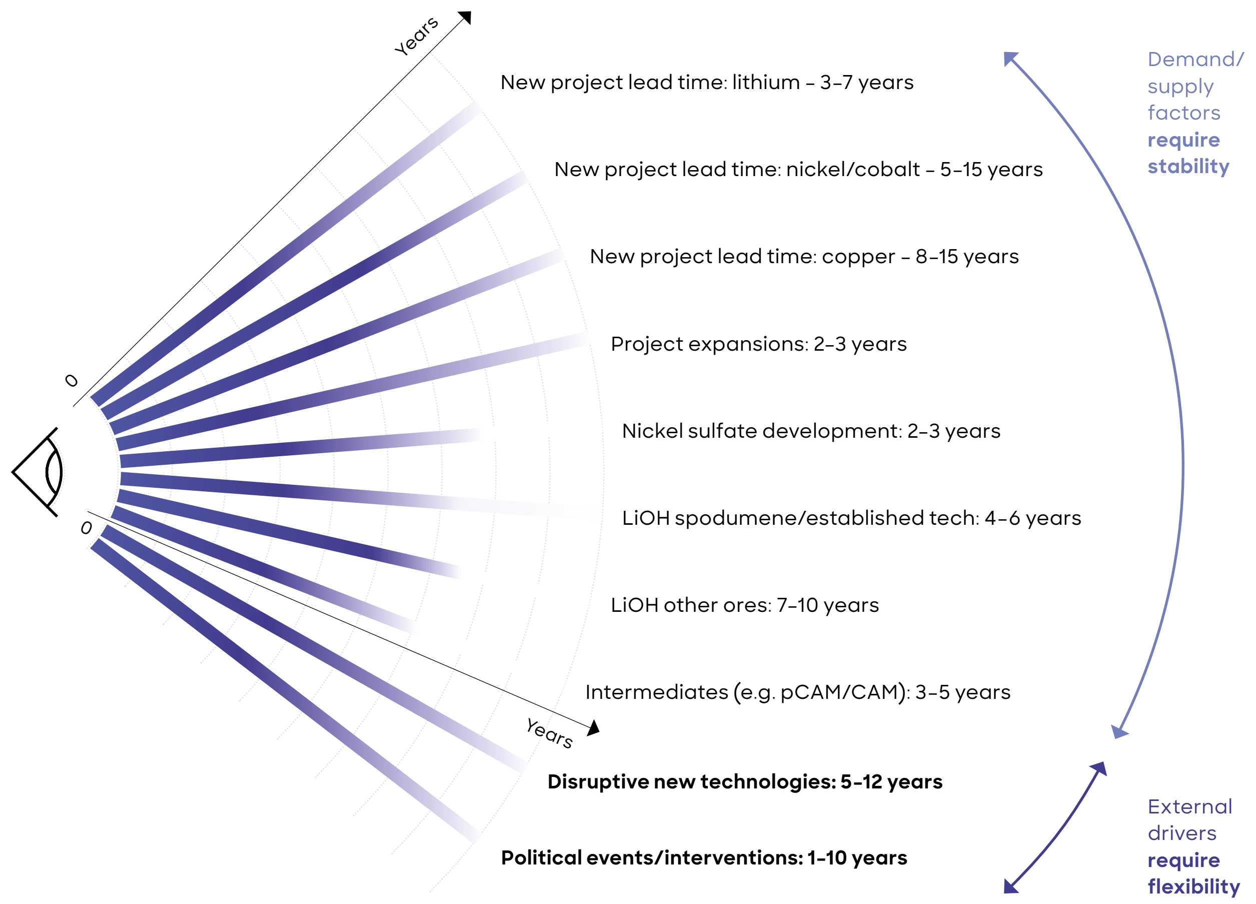
4. Enhance collaboration between all parties in the supply chain: For example, suppliers, manufacturers, logistics providers, etc.

5. Find the sweet spot between acceptable risks and costs. ▶ F

> **"Resilient supply chains need to ensure stability and flexibility at the same time. Informed scenario planning is a prerequisite to define the right mix of measures: off-take volumes and partners, potential project investments, financial hedging contracts, as well as investments in developing technologies and rapid response actions to black swan events."**
>
> Wolfgang Bernhart, Senior Partner

F Risky times: High-impact uncertainties materialize only after significant dead time, with certainty increasing as events get closer

Dead time for key uncertainties and emergence of weak signals



Source: Roland Berger

3.2/ Our approach to resilient supply chains

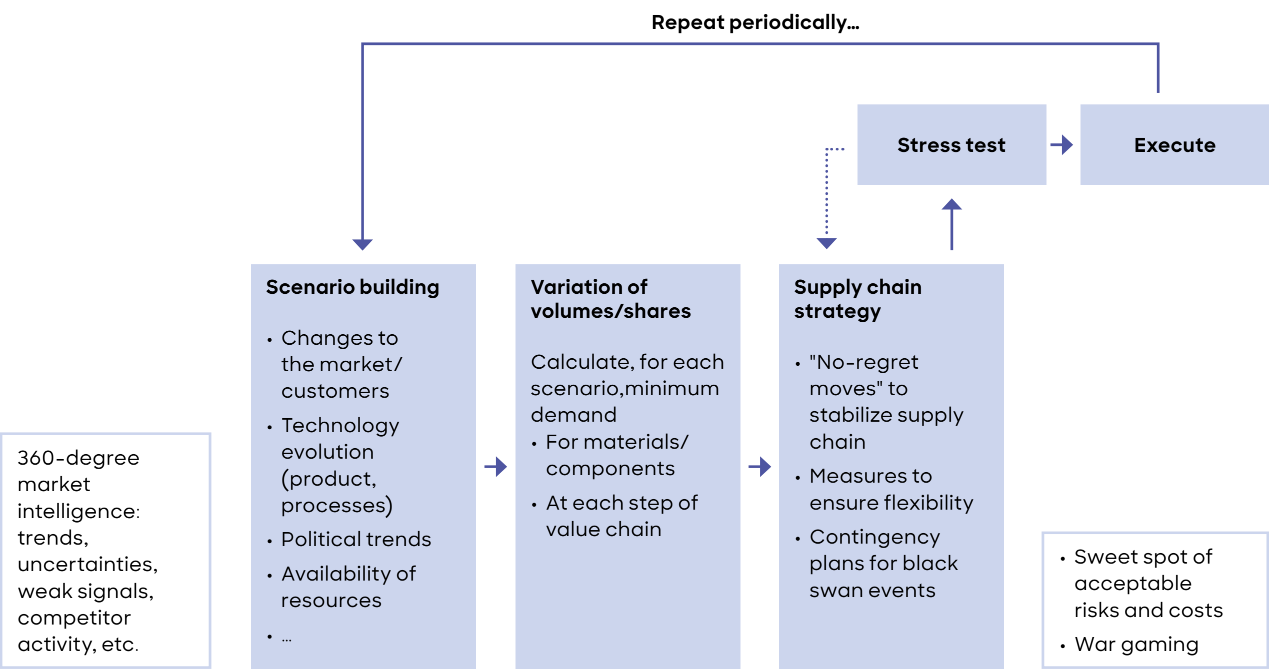
WELL-INFORMED SCENARIO PLANNING THAT IS REGULARLY UPDATED ENSURES STABLE, FLEXIBLE SUPPLY CHAINS

To realize a resilient supply chain, and to define the right mix of risk containment measures, we suggest a cyclical, scenario-based approach.

This begins with the gathering of 360-degree market intelligence to inform scenario building, covering trends, uncertainties, weak signals and competitor activity. Next, build scenarios based on variable factors such as market changes, technological evolution, political trends and resource availability. In a second step, we propose using various estimates of volumes/shares to calculate the minimum demand for materials/components in different scenarios. This provides the basis for a supply chain strategy built around stability, flexibility and contingencies – and based on "no-regret moves." War gaming is a useful tool to define the sweet spot between acceptable risks and costs.

Finally, the strategy should be stress tested for all possible scenarios, including black swan events. Repeating the process periodically ensures new information and forecasts can be worked into the plans. Repeating the steps in our approach will ensure you are up to date, managing uncertainties and constantly monitoring events. ▶ G

G A solid base: Our scenario-based approach to building resilient supply chains ensures they are stable, flexible and adaptable



Source: Roland Berger

4 Recommendations

4.1/ Recommendations: Risk containment

MITIGATION MEASURES SHOULD MAXIMIZE STABILITY AND FLEXIBILITY WHILE ALSO ADDRESSING SECONDARY RISKS

Risk management is key to the success of resilient raw material supply chains. With a wide range of risks present throughout the materials value chain, containment options must be selected based on their suitability to address particular risk types for the necessary time scale. For example:

- Financial hedging is the favored option to mitigate against short-term price rises.
- Long-term off-take agreements (LTOAs) and project investments help to hedge supply risks.
- Majority investments protect against long-term price increases.
- While these tools are useful for increasing the stability of the supply chain, flexibility must also be ensured. This can be achieved through:
- Investments in technology – placing bets on disruptive technologies to counterbalance potential negative impacts on sunk costs.
- As well as directly addressing the supply chain, risk-containment measures should tackle secondary risks that could impact operations in different value chain steps. Raw materials players should therefore consider actions to address the following:
  - Shortages of capital and skills (for example, there might not be enough qualified engineering capacity available to realize all planned refining projects)
  - Intellectual property risks
  - Equipment delays ▶ H

" Effective risk containment in raw material supply chains balances stability and flexibility, addressing both primary and secondary risks for resilience."

Tim Hotz, Principal

H Managing risk: Containment measures should be applied according to the type of risk and the required time frame

Suitability to mitigate...	Financial hedging & spot market	Long-term off-take agreements (LTOAs)	Project investments (in capacity, minority)	Insourcing (or majority investment)	Technology investment
Supply risks	□□□□	■■■□	■■■□	■■■■	■□□□
Short-term price risks	■■■■	■■□□	■■■□	■■■■	□□□□
Long-term price increases	□□□□	■■□□	■■■□	■■■■	■■■□
Risks from disruptive technologies	□□□□	□□□□	□□□□	■□□□	■■■■
Supply option period	Now – 36 months	Up to 8 years	Up to 30 years	Up to 30 years	10 to 30 years
Typical lead time (until supply)	n/a	2 to 5 years (<2 years only for existing projects)	2 to 5 years (<2 years only for existing projects)	2 to 8 years (<2 years for acquisitions)	5 to 10 years, depending on maturity level

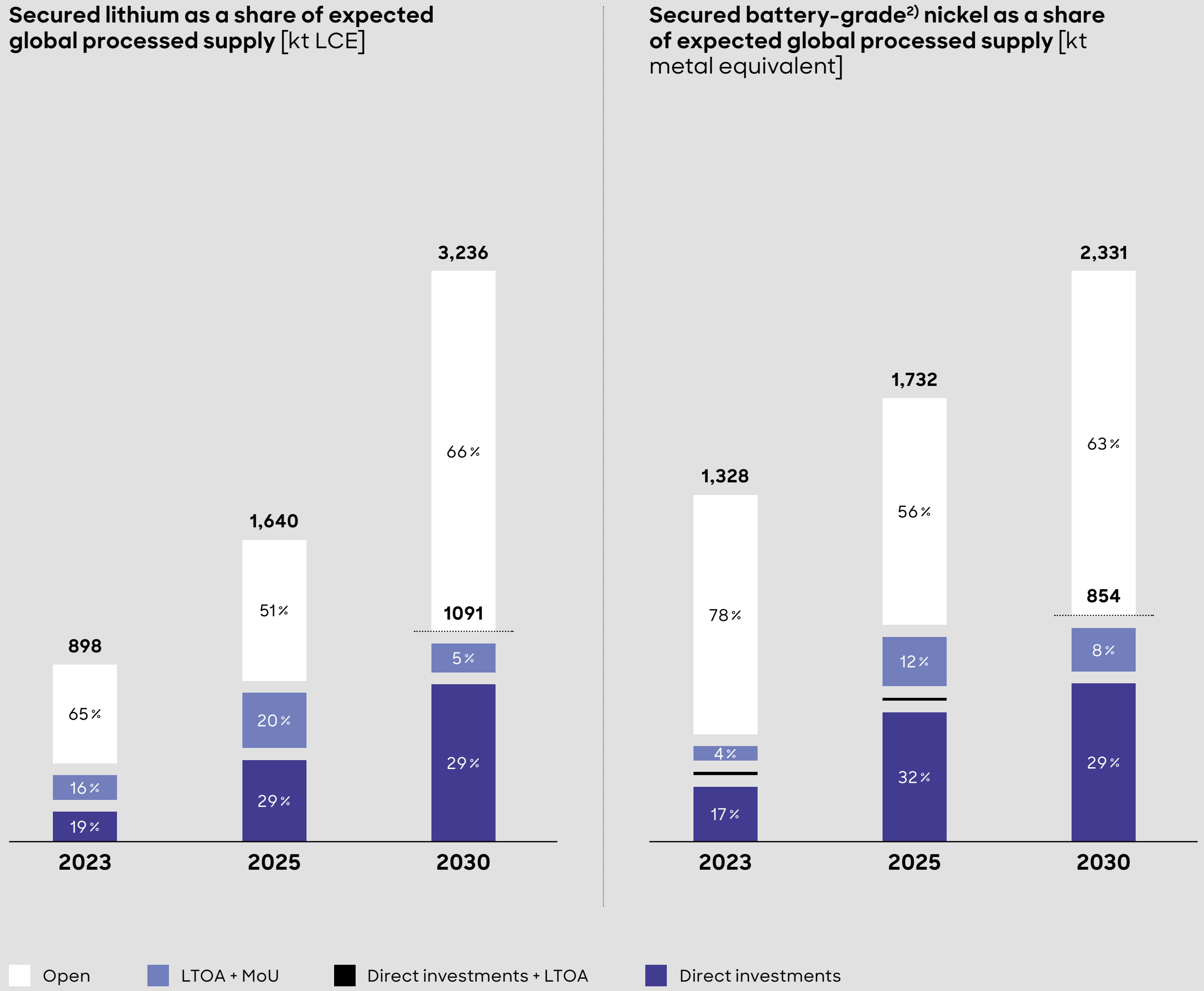
◄ **Stability** ► (Financial hedging & spot market to Insourcing) ◄ **Flexibility** ► (Technology investment)

□□□□ Low suitability ■■■■ High suitability

Source: Roland Berger

I Going, going, gone: Almost half of expected global processed lithium and nickel supplies for 2025 were secured by the beginning of 2023

Announced securitization efforts by battery-related players[1] on projected global supply [as of Q1/2023]



LTOA: long-term off-take agreement, MoU: memorandum of understanding

1) Including pCAM and CAM manufacturers, cell manufacturers and automotive OEMs; including mining and refining activities, assuming that refiners have no raw material shortages and mined material can be refined

2) Class 1 nickel, assuming that battery players who invest in the nickel supply chain convert to battery-grade nickel if secured at mining or intermediate stage

Source: Roland Berger LiB Demand-Supply Model Q1/2023, Roland Berger Mining/Refining database

4.2/ Recommendations: Key messages

OEMS AND CELL MAKERS CANNOT AFFORD NOT TO STRATEGICALLY SECURE THEIR CRITICAL VALUE CHAINS

The overall message is clear – OEMs and cell makers must secure their raw materials value chains with resilience measures that both stabilize them and ensure they are flexible in the face of uncertainties. And they must do this quickly – roughly half of the projected processed lithium and nickel supply for 2025 had been reserved by early 2023, for example.
We believe resilient supply chains are founded on five key pillars:

1. All value chain steps need to be fully understood and addressed. This should include secondary risks to ensure suppliers have access to resources where needed.

2. Covering all risks is too expensive – companies must define the "sweet spot" of acceptable costs, including hedging, and risks.

3. Companies need to be better than rivals at defining resilient supply chains to ensure a competitive edge, especially in times of crisis. This requires the gathering of comprehensive market intelligence, including competitor activities.

4. Risk hedging does not come for free. Strategic hedging of supply chain risks must be proactively marketed to customers, or it will negatively impact operative business results.

5. Defining a resilient supply chain is not a one-time exercise. Tools and processes need to be adapted to updated scenarios and stress testing carried out on an ongoing basis.
▶ I (previous page)

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