Six Ways to Eliminate the Need for Newly Mined Battery Minerals

Webinar

Daan Walter
E.J. Klock McCook

August 22, 2024

11:30-12:30 ET

Agenda and speakers

11:30 ET Welcome and Introduction

11:35 ET Report: *The Battery Mineral Loop*

Daan Walter

11:55 ET *Insights from RMI's Battery Circular Economy Initiative*

E.J. Klock McCook

12:10 ET Moderated Q&A

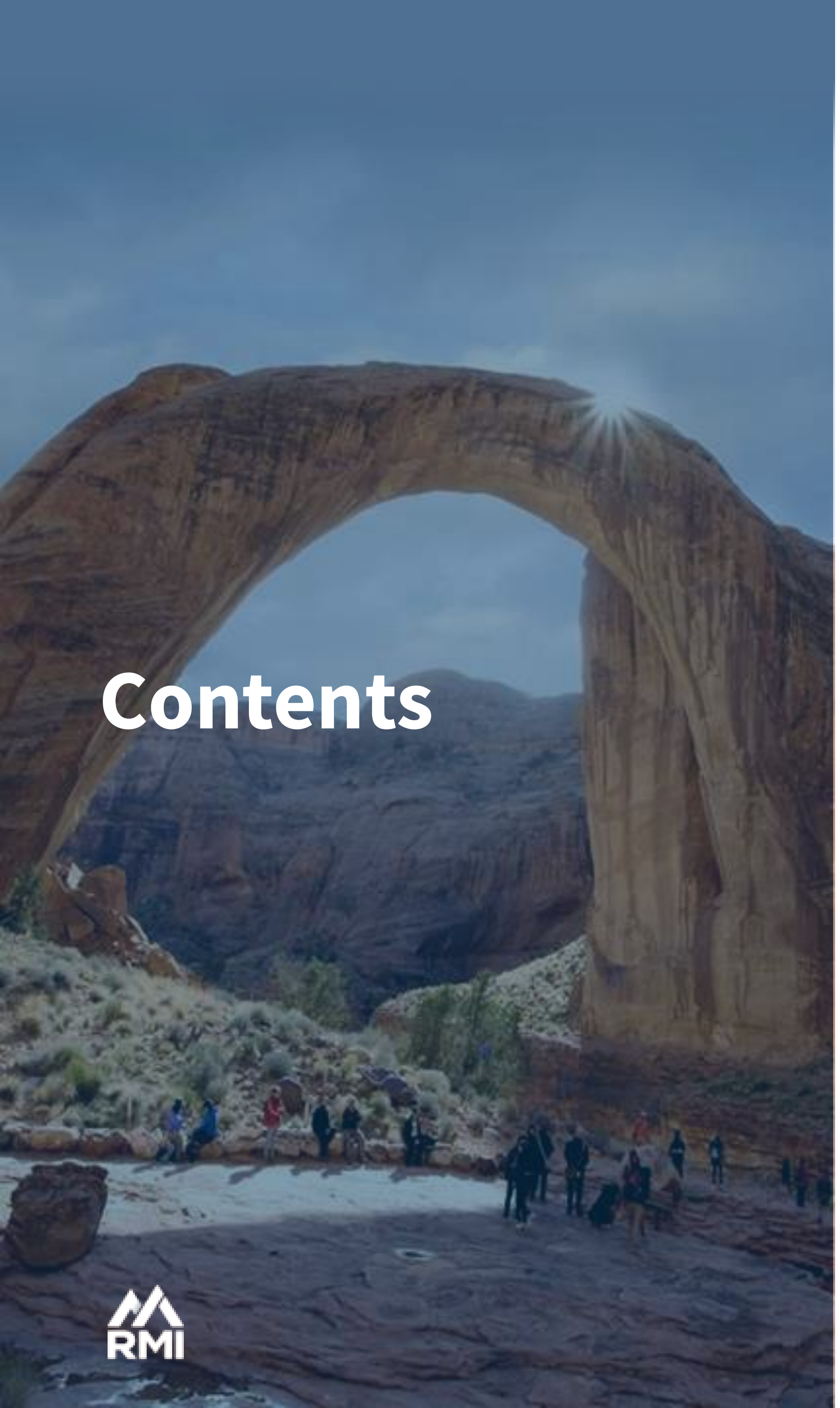
12:30 ET End of Webinar

Daan Walter

Principal, Strategy Team

E.J. Klock McCook

Principal, Carbon-Free Transportation Team



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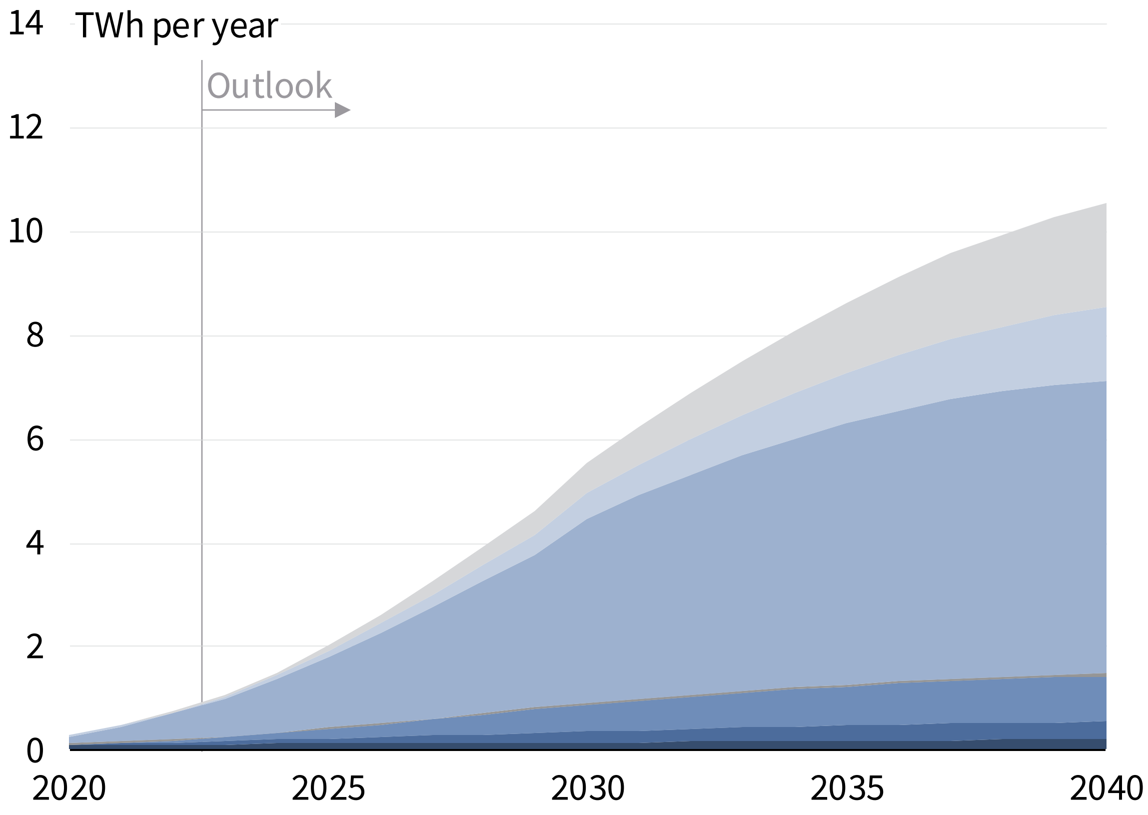
Battery demand is growing exponentially

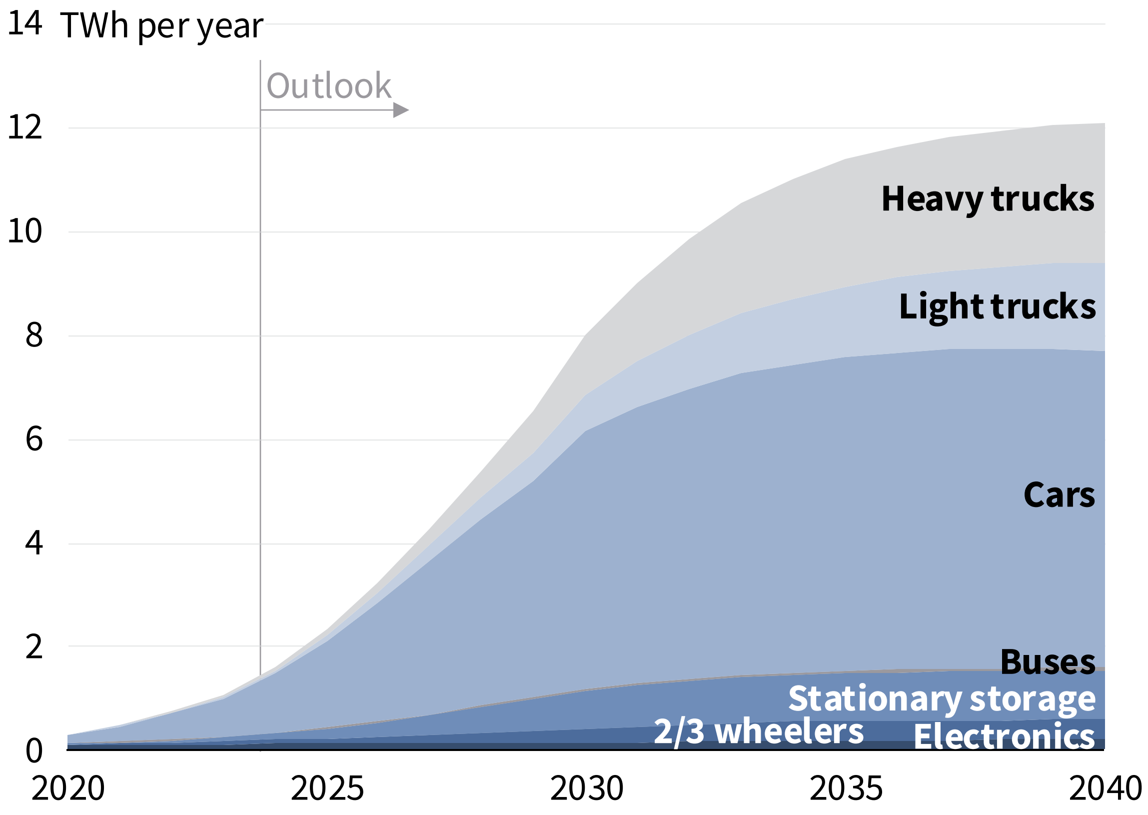
Battery demand will grow by an order of magnitude over the coming decades

Battery uptake by sector

Fast



Faster

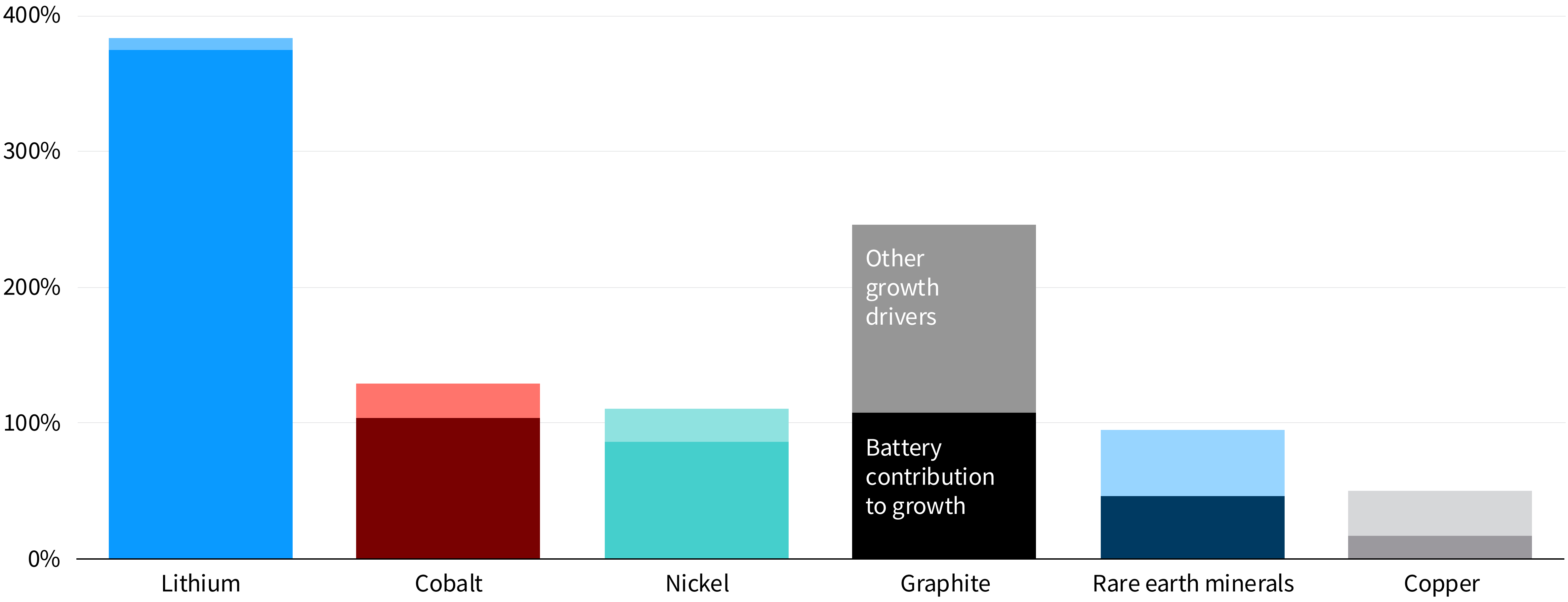


Source: RMI X-Change Batteries; RMI analysis

And that means the demand for minerals is set to boom

Battery cells are largely made of minerals — so a battery boom means a mineral boom

Battery mineral demand growth outlook, 2023-2040



Source: IEA Global Critical Minerals Outlook (2024)

There are six alternatives to mining

Including how we use them with efficiency, make them with innovation, and reuse them with circularity

A

Changing chemistries

Switch to battery chemistries that use fewer or no critical battery minerals

B

Higher energy density batteries

Pack more energy into a kilogram of battery, requiring fewer minerals to do the same work

C

Recycling

Recover battery minerals at end of life to re-use in the manufacturing process and avoid the need for new minerals

D

Reuse and extend lifetime

Use and reuse batteries for longer, to avoid having to make new batteries with new minerals

E

Efficient vehicles

Improve vehicle efficiency and right-size cars for purpose to reduce the battery size per vehicle, and therefore mineral demand

F

Efficient mobility

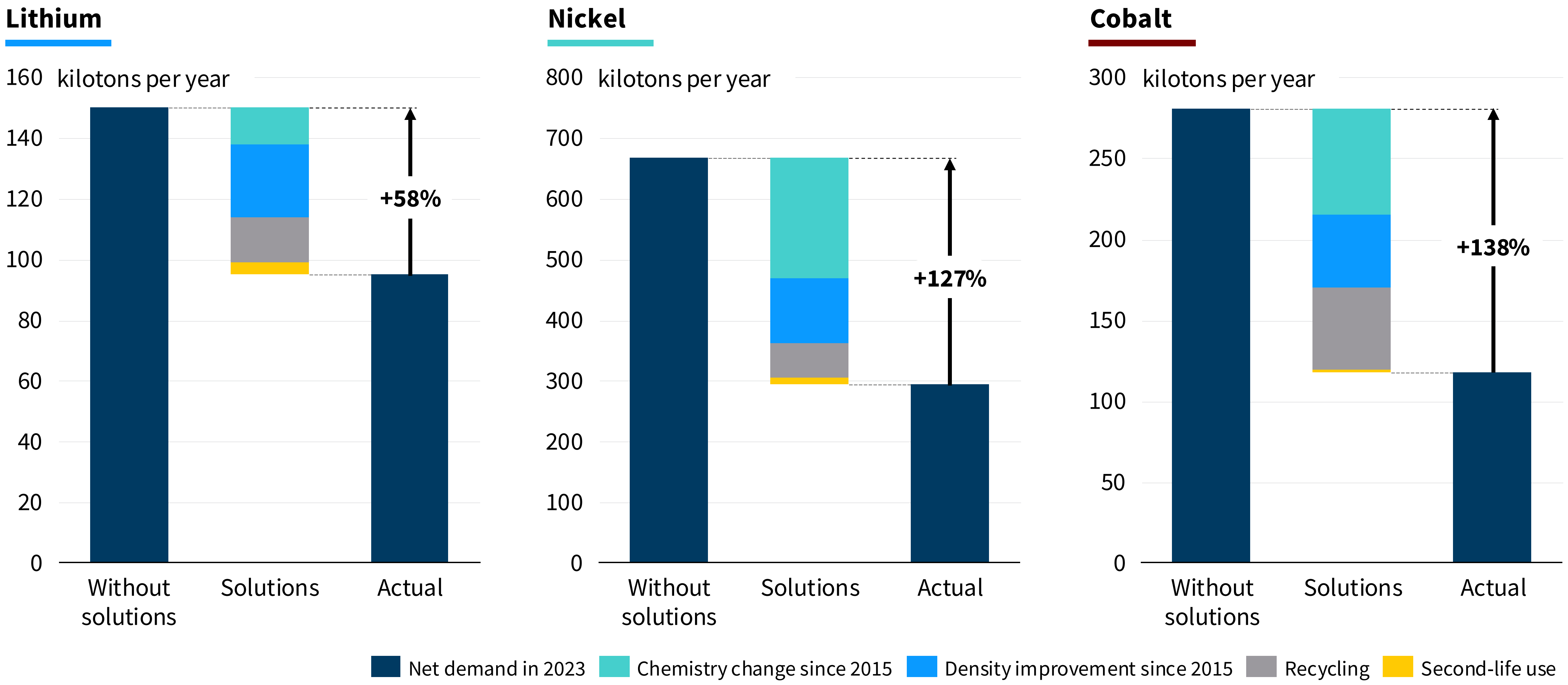
Improve urban planning, logistics efficiency, active modes, public transit, and electric micromobility to encourage alternate transport and lower EV mineral demand

RMI

Source: Amory Lovins, "Six Solutions to Battery Mineral Challenges" (2022)

Three solutions have already made a major dent

Without chemistry change, density improvements and recycling, mineral demand would be much higher

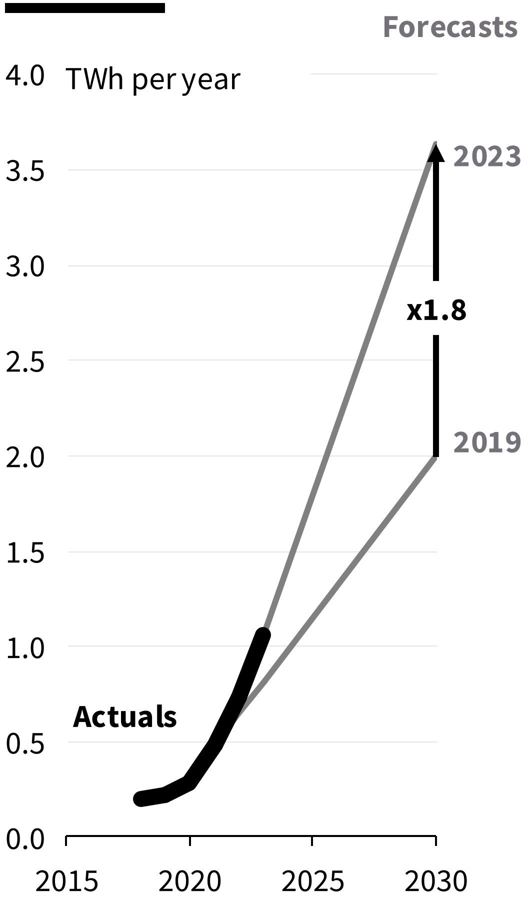


Source: RMI analysis. Recycling includes recycling of production scrap, which is generally economic already.

Change is outpacing expert forecasts

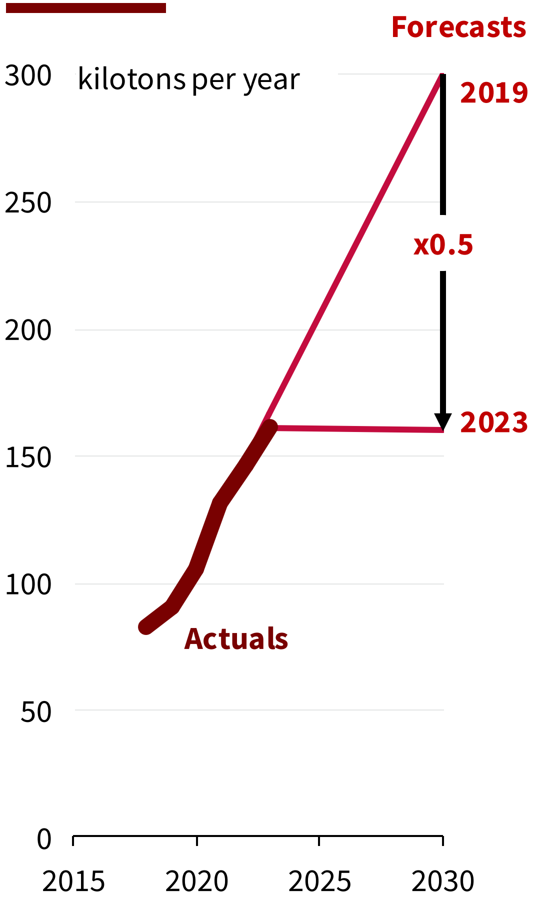
Even the leading experts keep getting surprised by how fast minerals are innovated out of batteries

Battery demand forecasts

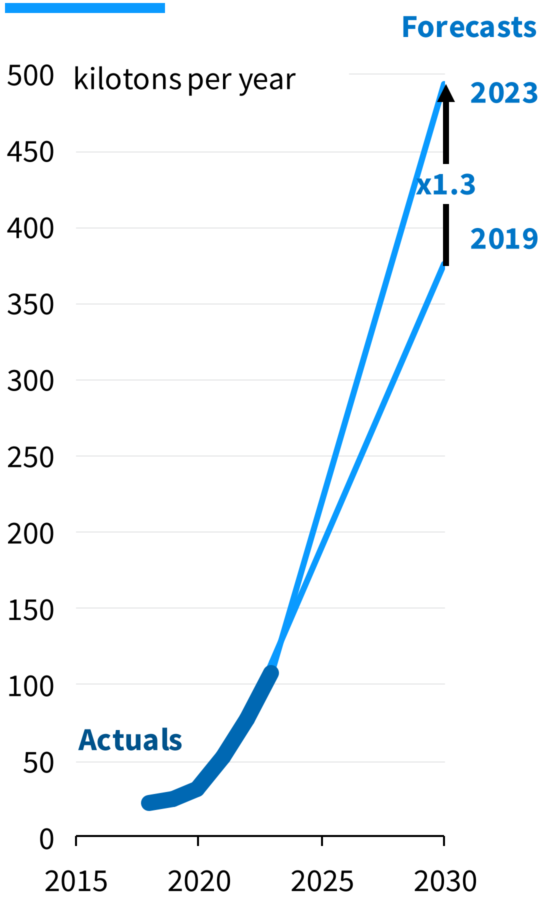


Battery mineral demand forecasts

Cobalt



Lithium



Implied reduction of 2030 unit mineral demand*

Cobalt

3.6x

less in 2023 vs. 2019 outlook

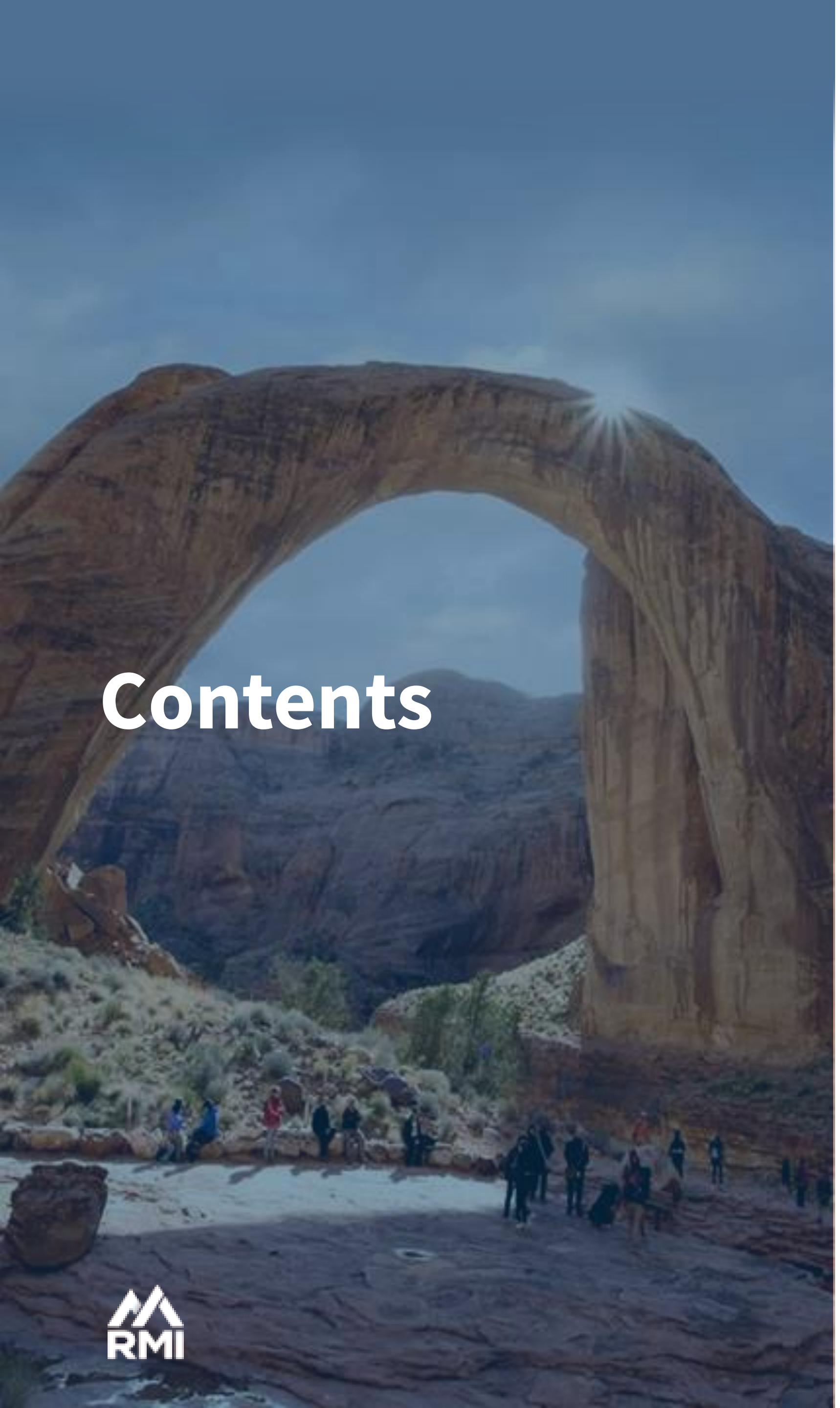
Lithium

1.4x

less in 2023 vs. 2019 outlook

** Derived by dividing the battery demand increase by the change in mineral demand between the 2019 and 2023 outlook.*

Source: BNEF Long-Term Electric Vehicle Outlook (2019—2023), RMI analysis



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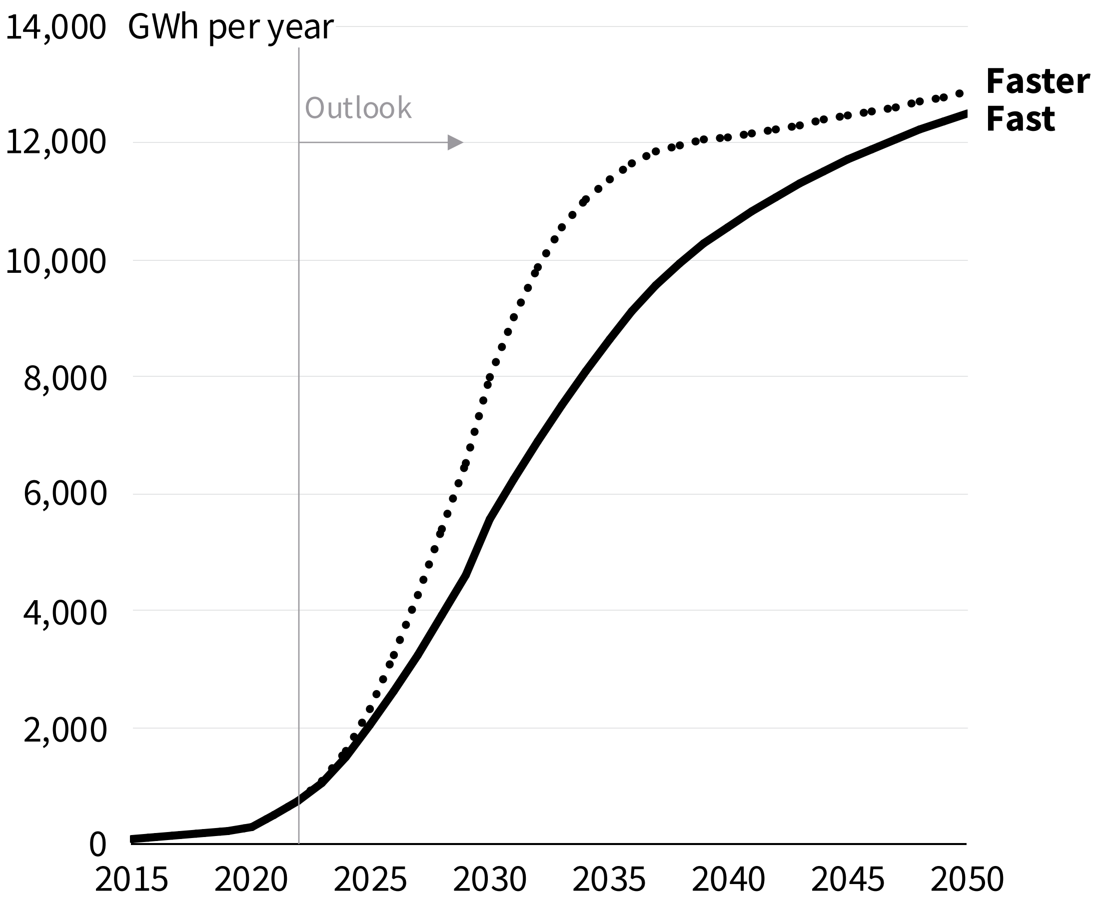
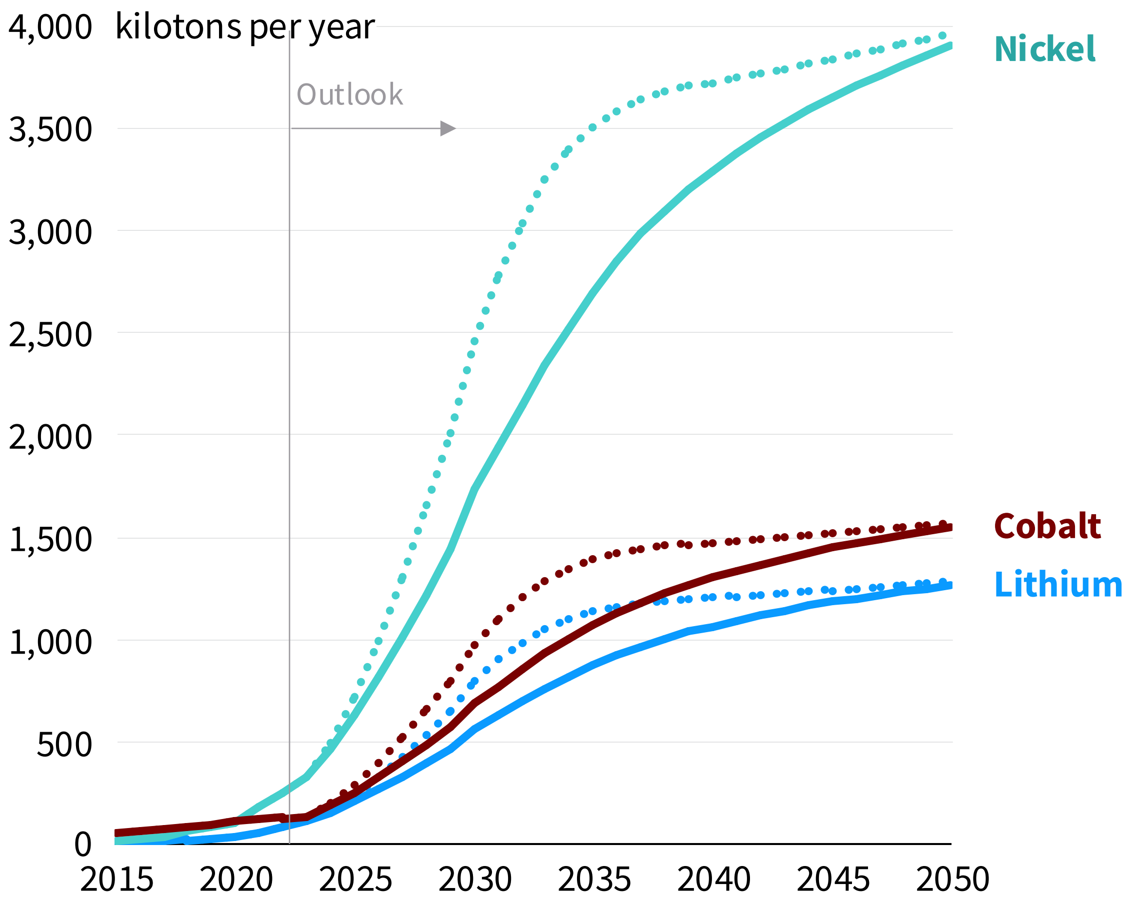
The wrong, linear view

Growing to 12 times as many battery sales means 12 times as much mineral demand

Annual battery demand



Battery mineral demand outlook under simple linear scaling



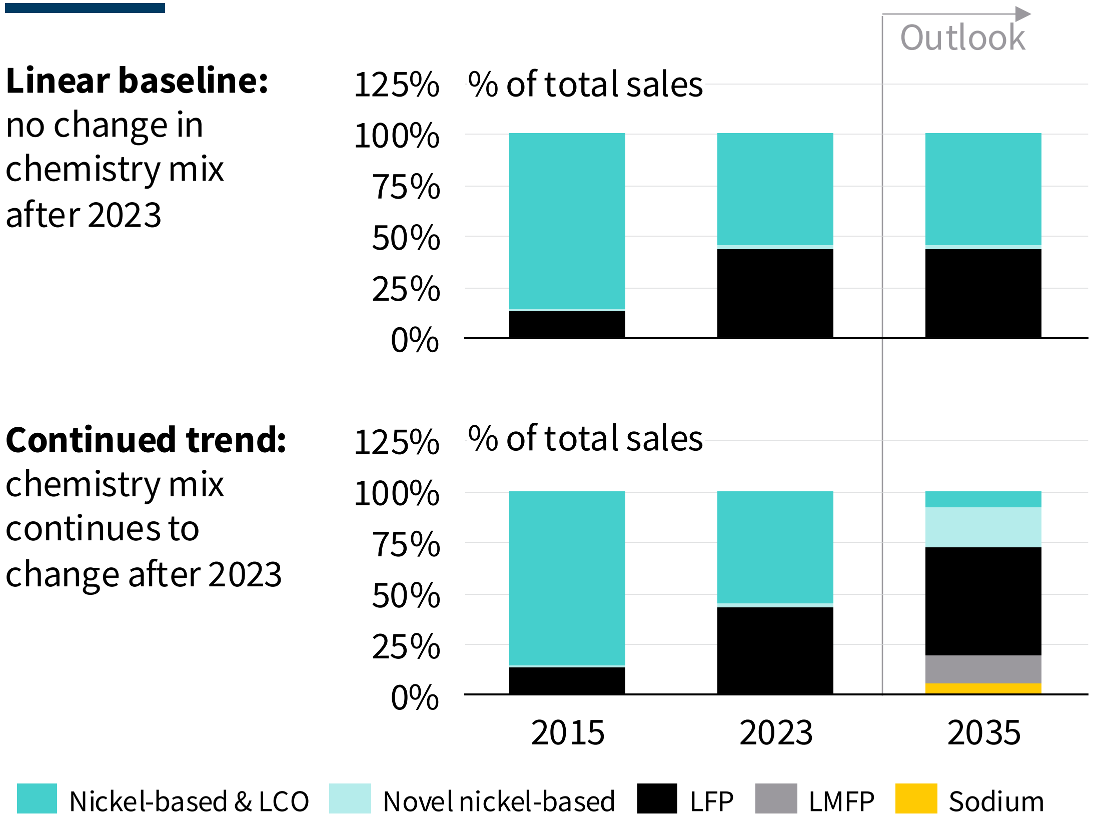
Note: This outlook only includes simply scaling up current battery mineral demand in line with battery demand. It is not representative of a realistic scenario and is purely illustrative.

Source: RMI X-Change Batteries, RMI analysis

The impact of chemistry change

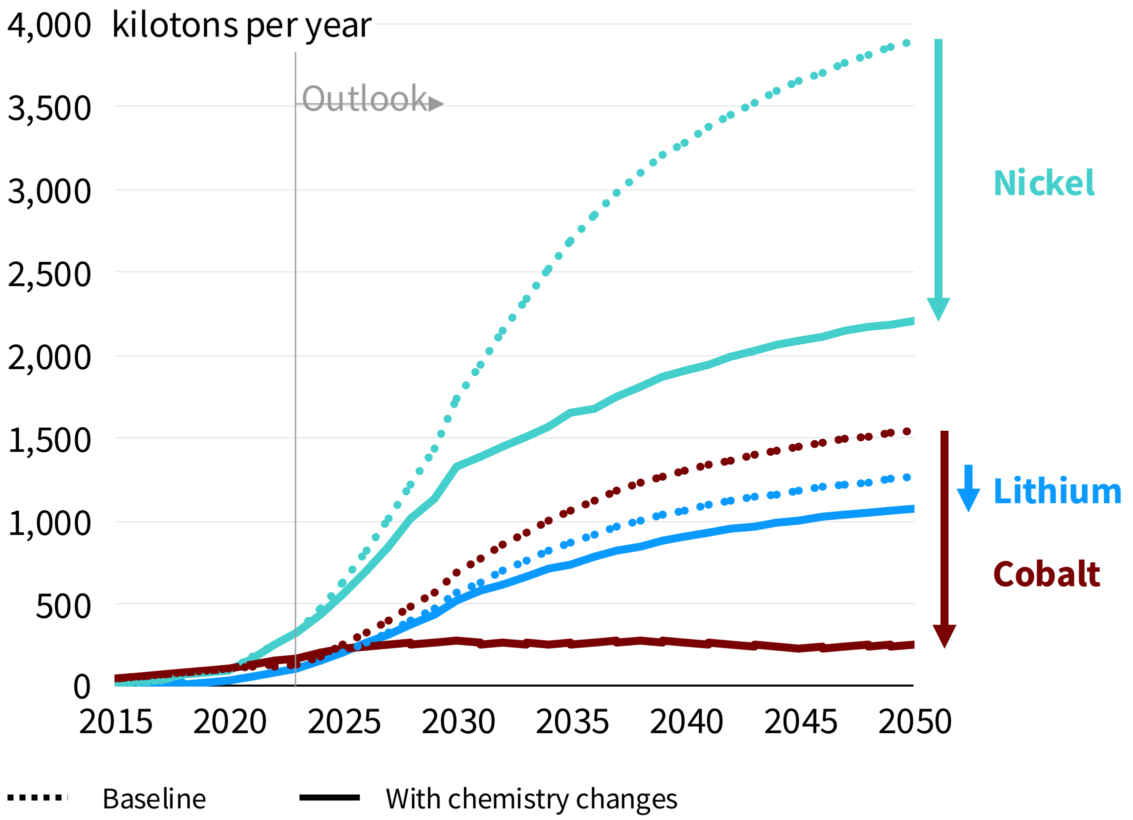
Different battery chemistries curb demand, especially for nickel and cobalt

Chemistry mix



Note: This outlook only includes simply scaling up current battery mineral demand in line with battery demand. It is not representative of a realistic scenario and is purely illustrative.

Battery mineral demand before and after chemistry mix change, Fast scenario



Note: Part of the decline for cobalt comes from the sectoral redistribution of demand.

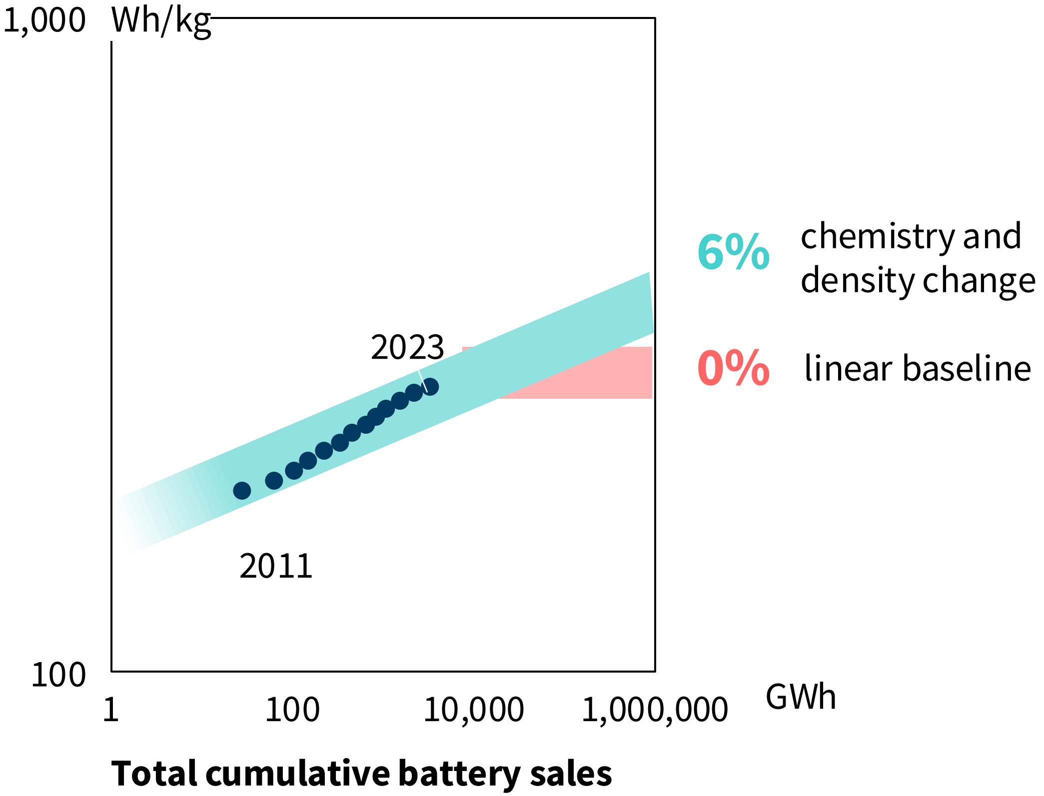
Source: BNEF Long-Term Electric Vehicle Outlook (2024), RMI analysis

The impact of energy density change

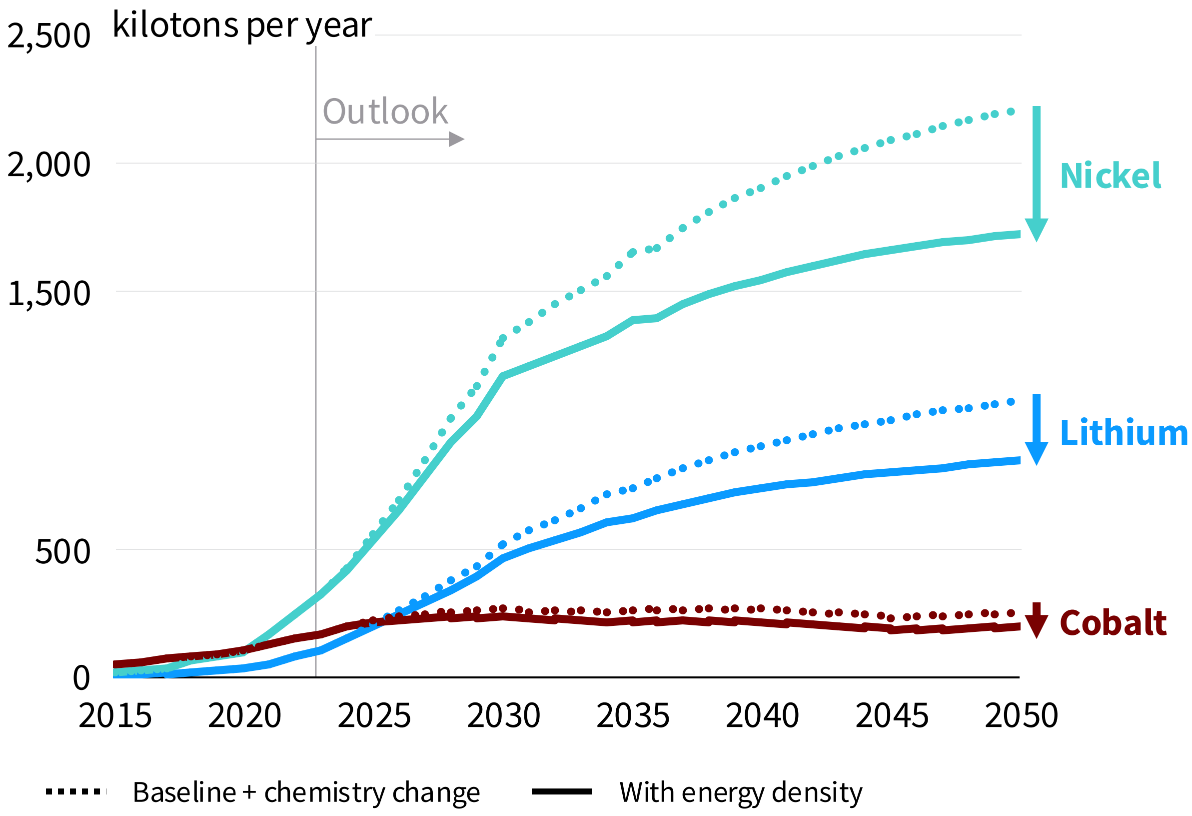
Energy density rises 6% for every cumulative doubling of installed batteries

Average battery energy density of traditional lithium-ion batteries

Learning rate



Battery mineral demand before and after density improvements, Fast scenario

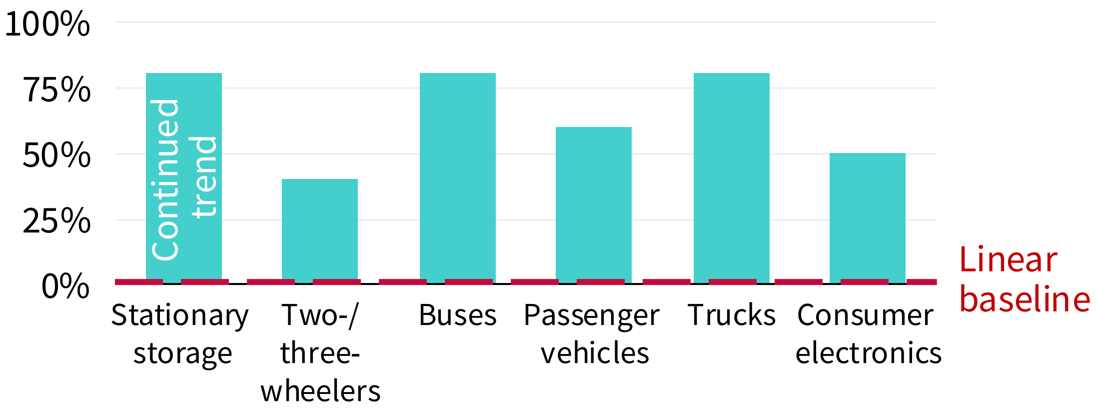


Source: BNEF Lithium-Ion Batteries: State of the Industry (2023), RMI analysis. Outlook chart excludes the density effects of chemistry change to avoid double-counting.

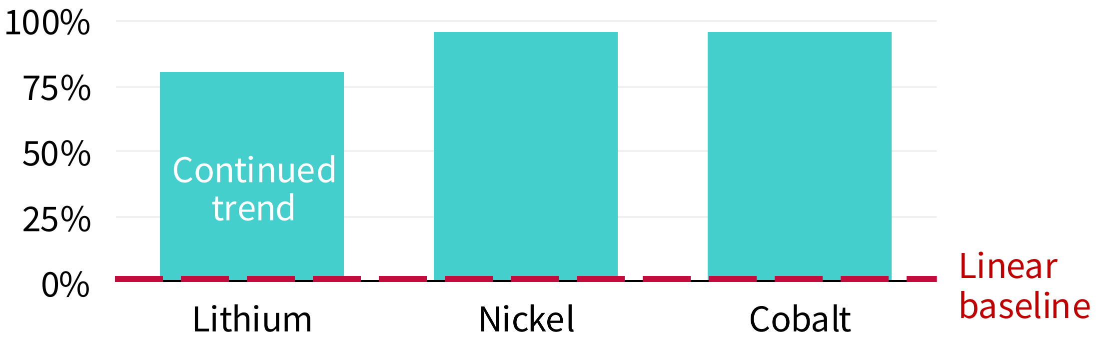
The impact of recycling

We recycle over 10 times more than common knowledge would have it; not 5% but >50% globally

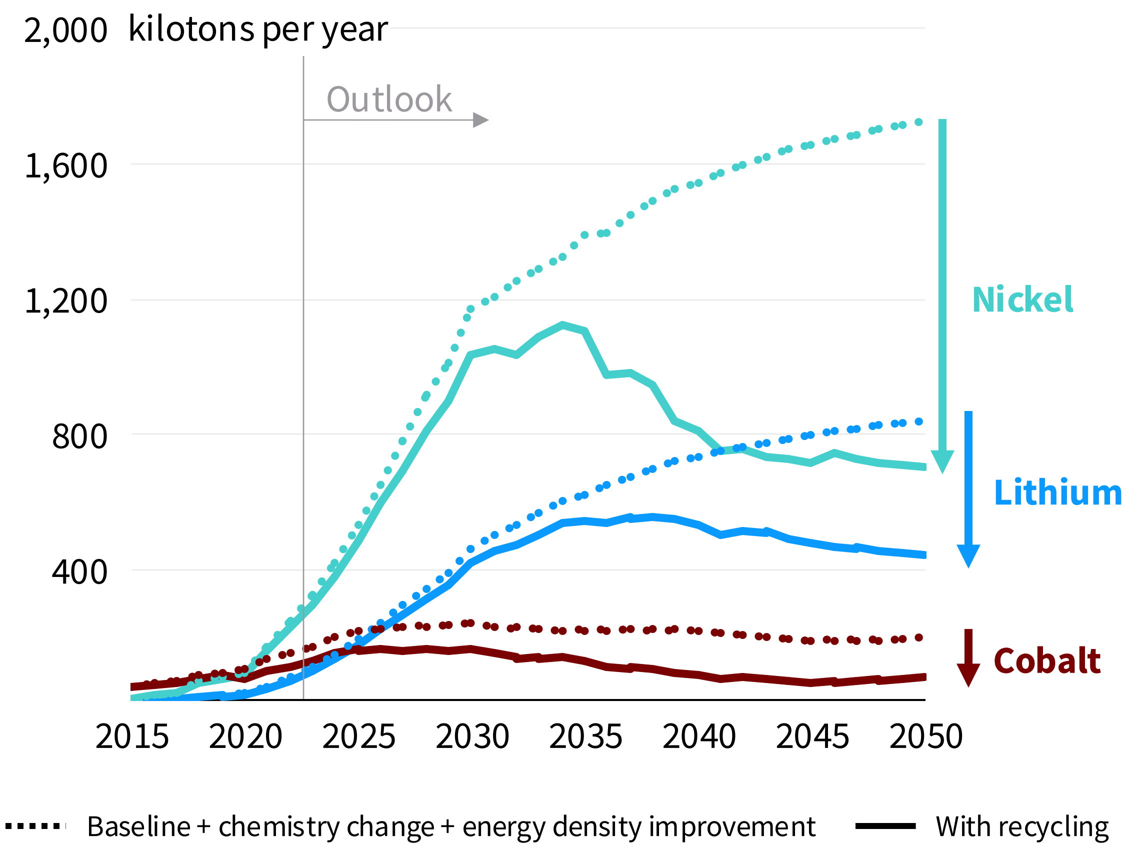
Collection rate



Recovery rate



Net battery mineral demand before and after recycling, Fast scenario



Source: BNEF Lithium-Ion Battery Recycling Availability Model (2024), Gaines et al. (2023), RMI analysis

Recycling economics are improving

Newer, cheaper technologies are coming

Incumbent technology

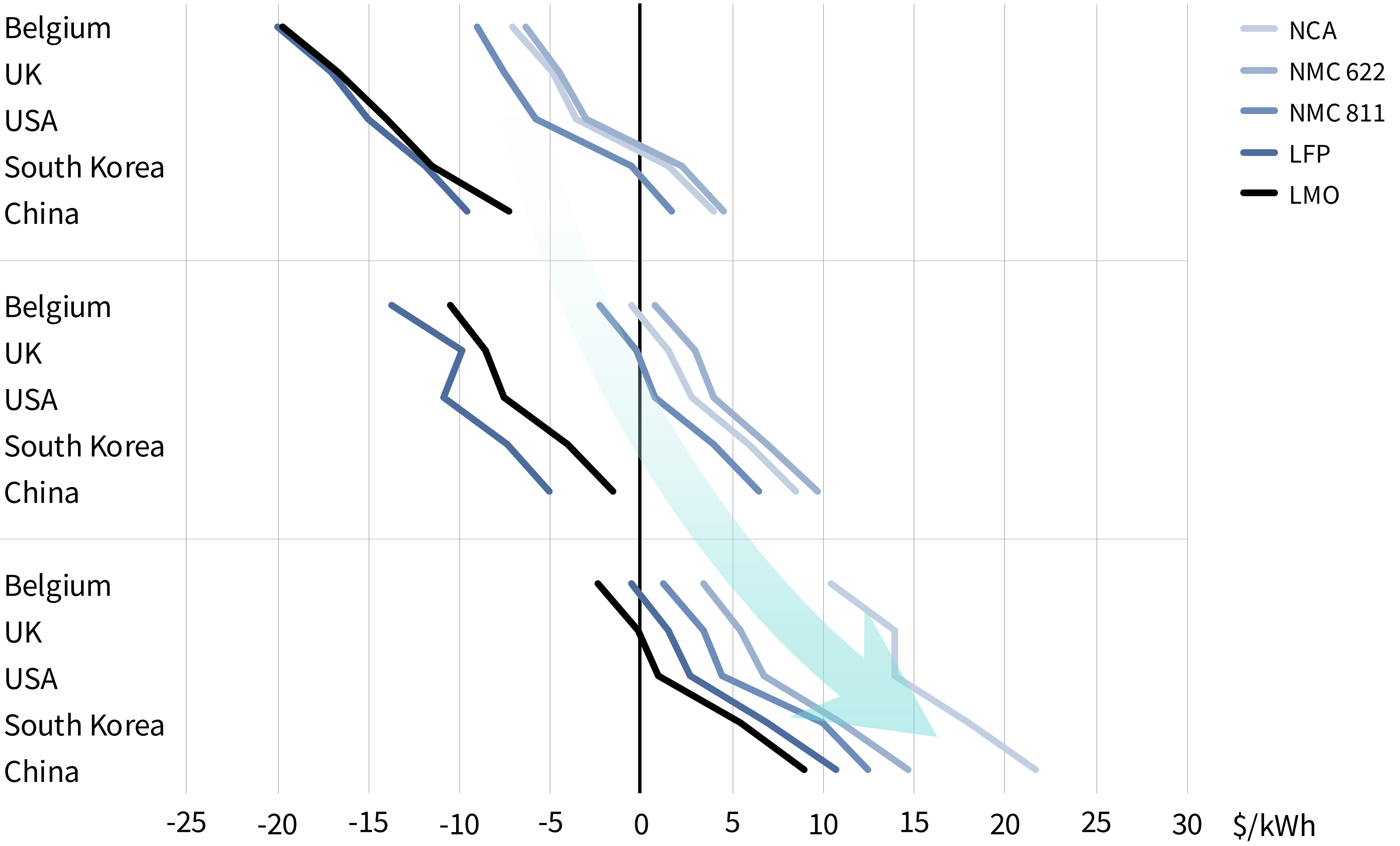
Pyrometallurgical recycling

Scaling entrant technology

Hydrometallurgical recycling

Emerging entrant technology

Direct recycling



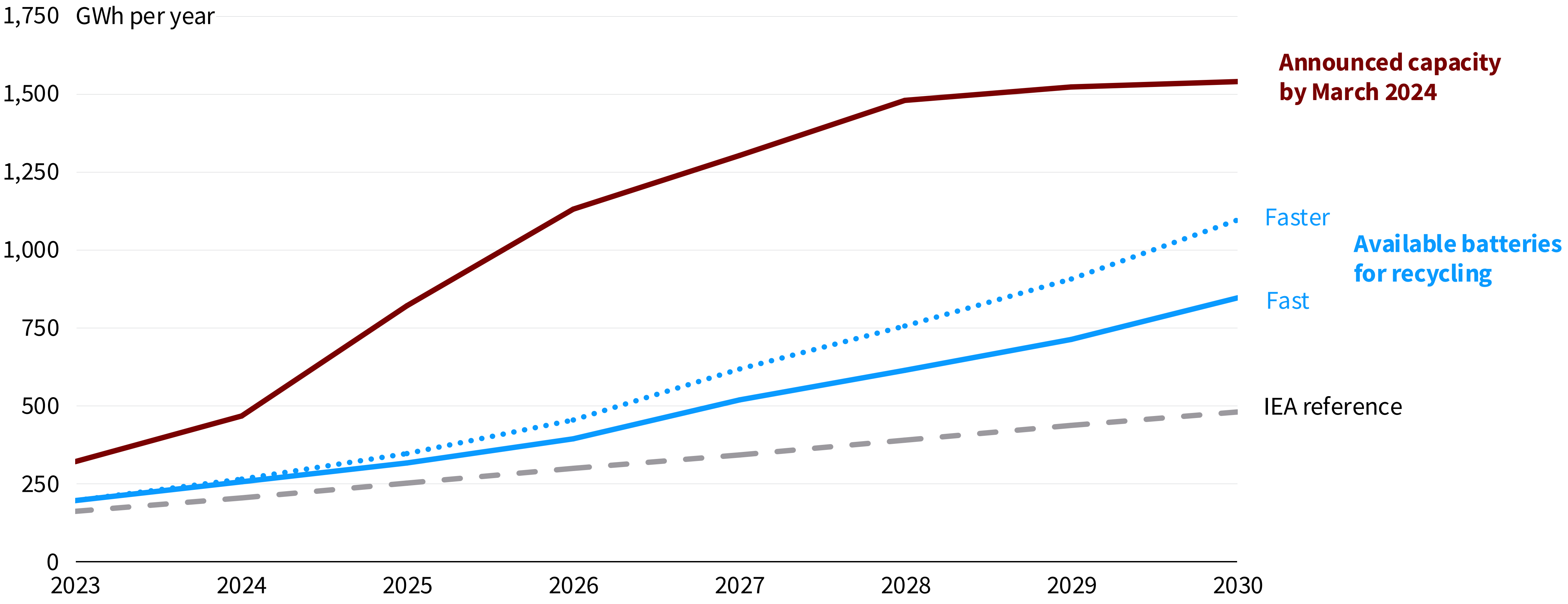
Note: NCA: Nickel Cobalt Aluminum; NMC 622: Nickel Manganese Cobalt (6:2:2 ratio); NMC 811: Nickel Manganese Cobalt (8:1:1 ratio); LFP: Lithium Iron Phosphate; LMO: Lithium Manganese Oxide.

Source: ETC Material and Resource Requirements for the Energy Transition (2023), Biswal et al. (2024), RMI analysis

The capacity is already in place

In anticipation of a great battery retirement wave, recycling capacity is ramping up

Recycling capacity, global

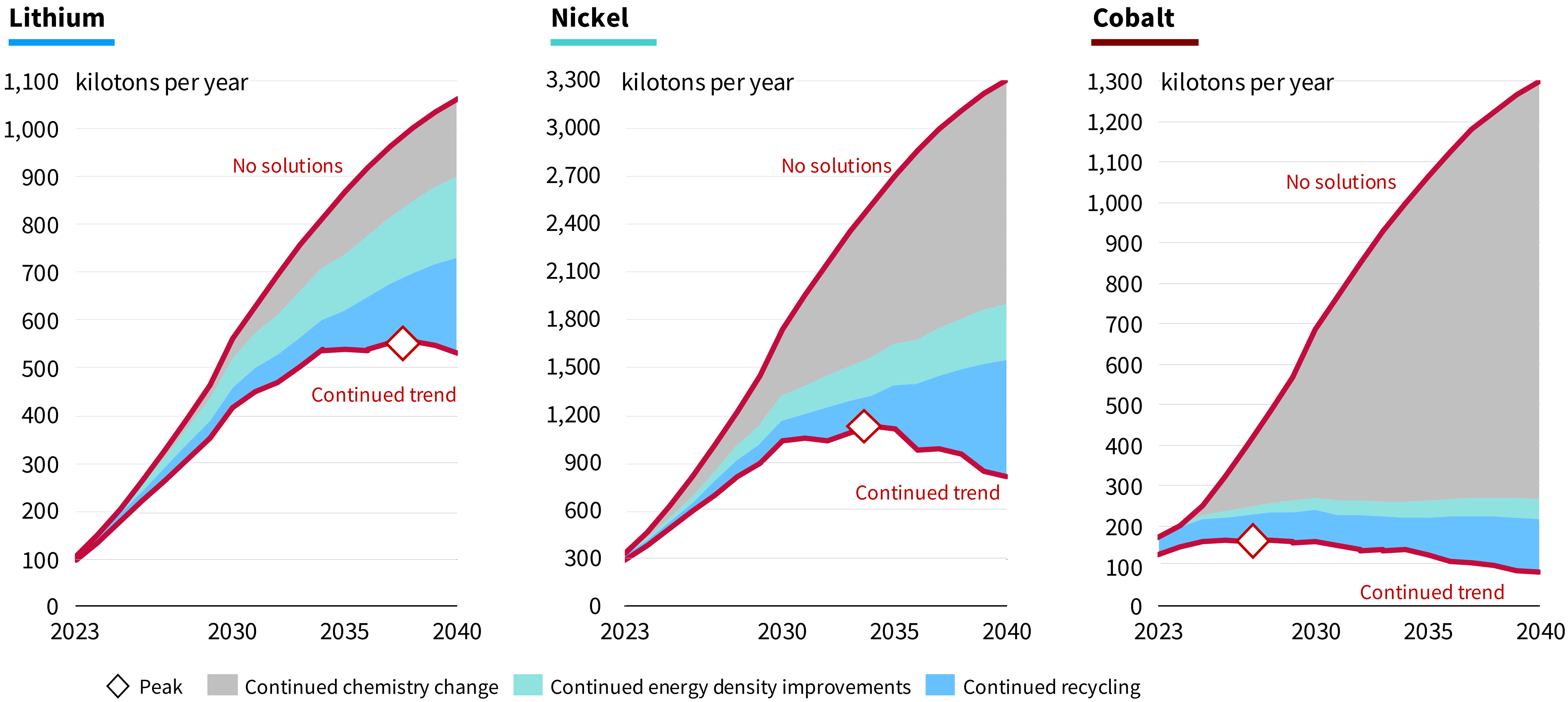


Note: Includes recycling of production scrap.

Source: IEA Global EV Outlook (2024), RMI analysis

Peak battery mineral demand in a decade

Chemistry change, density improvements and recycling will peak virgin mineral demand

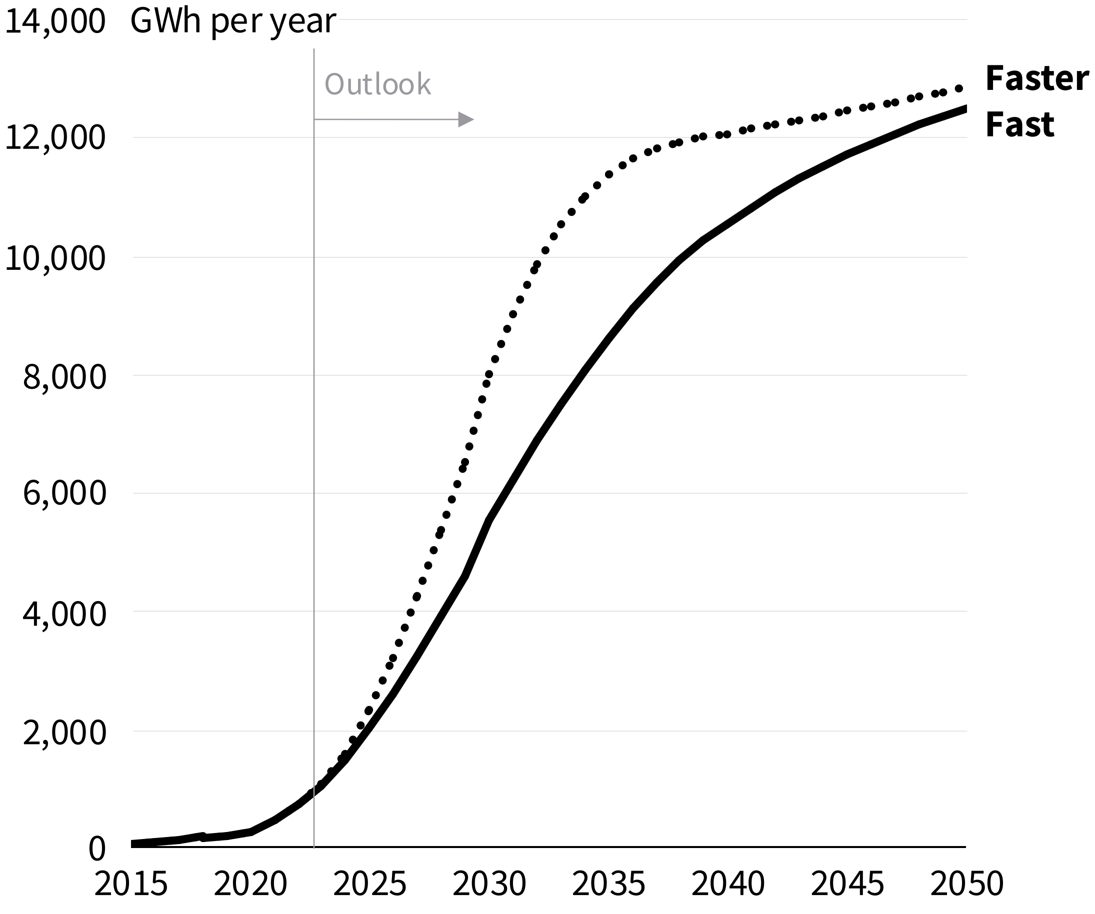


Source: RMI X-Change Batteries, RMI analysis. Note: Part of the effect of cobalt chemistry change comes from the sectoral redistribution of demand.

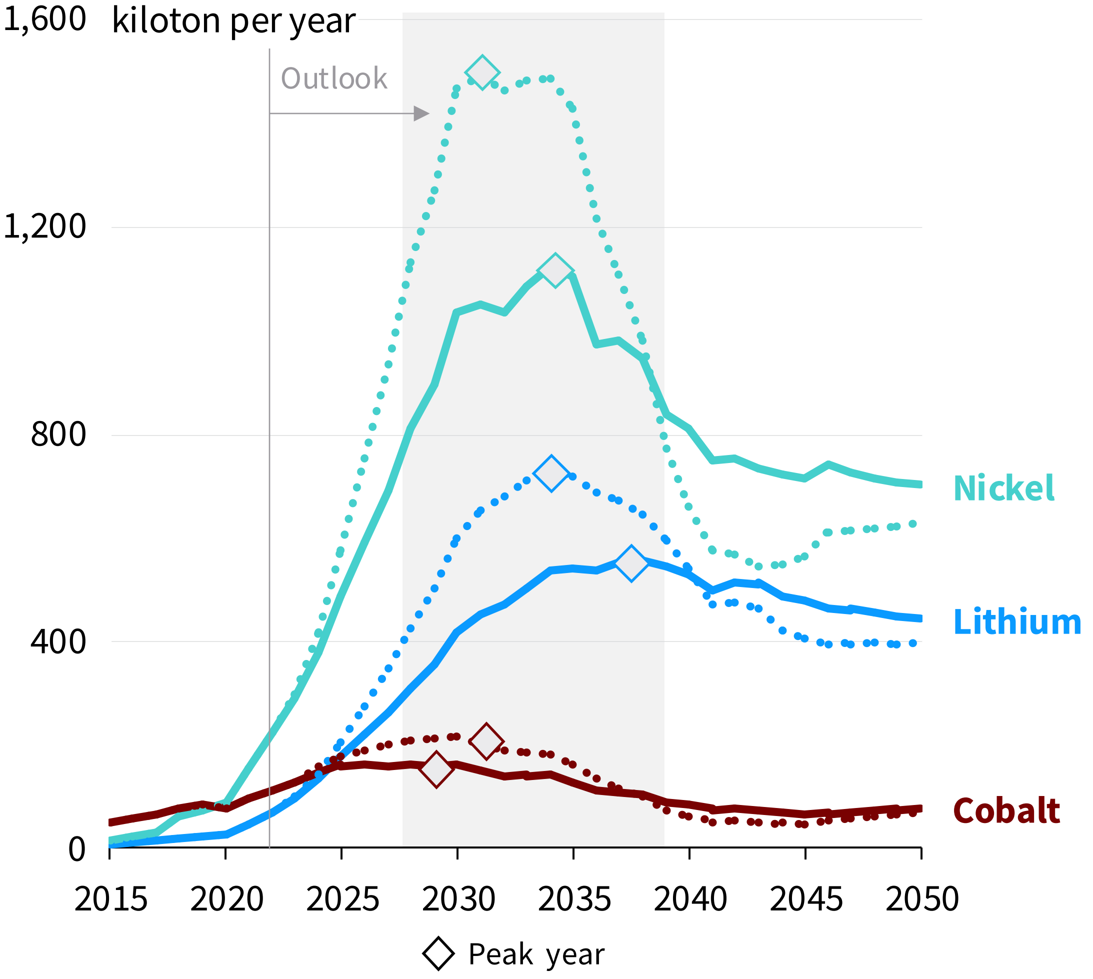
Going faster means a higher but earlier peak

In a faster battery roll-out scenario, the peak comes even earlier for nickel and lithium

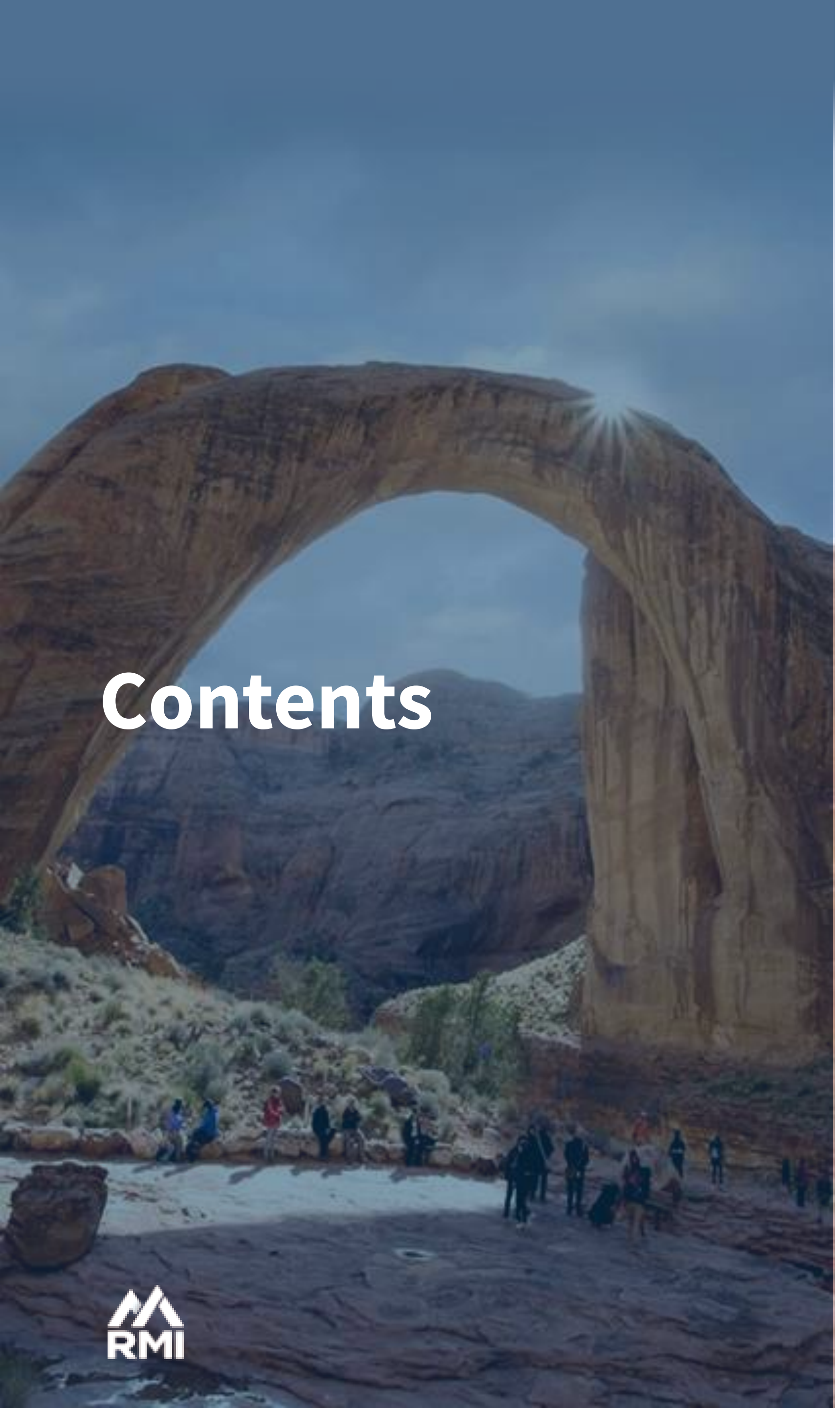
Annual battery demand



Net battery mineral demand outlook under continued trend



Source: RMI X-Change Batteries, RMI analysis



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The accelerated case

Change begets change and action begets action — the plausible acceleration case

Accelerated trends outlook

A Changing chemistries

- Speed up sodium battery scaling in EVs

B Higher energy density batteries

- Raise learning rate to match top-tier battery level

C Recycling

- Raise collection rates
- Raise recovery rates to best-in-class
- Lower production scrap rate to best-in-class

D Reuse and extend lifetime

- Reuse transport batteries in stationary storage
- Extend lifetime of EV batteries

E Efficient vehicles

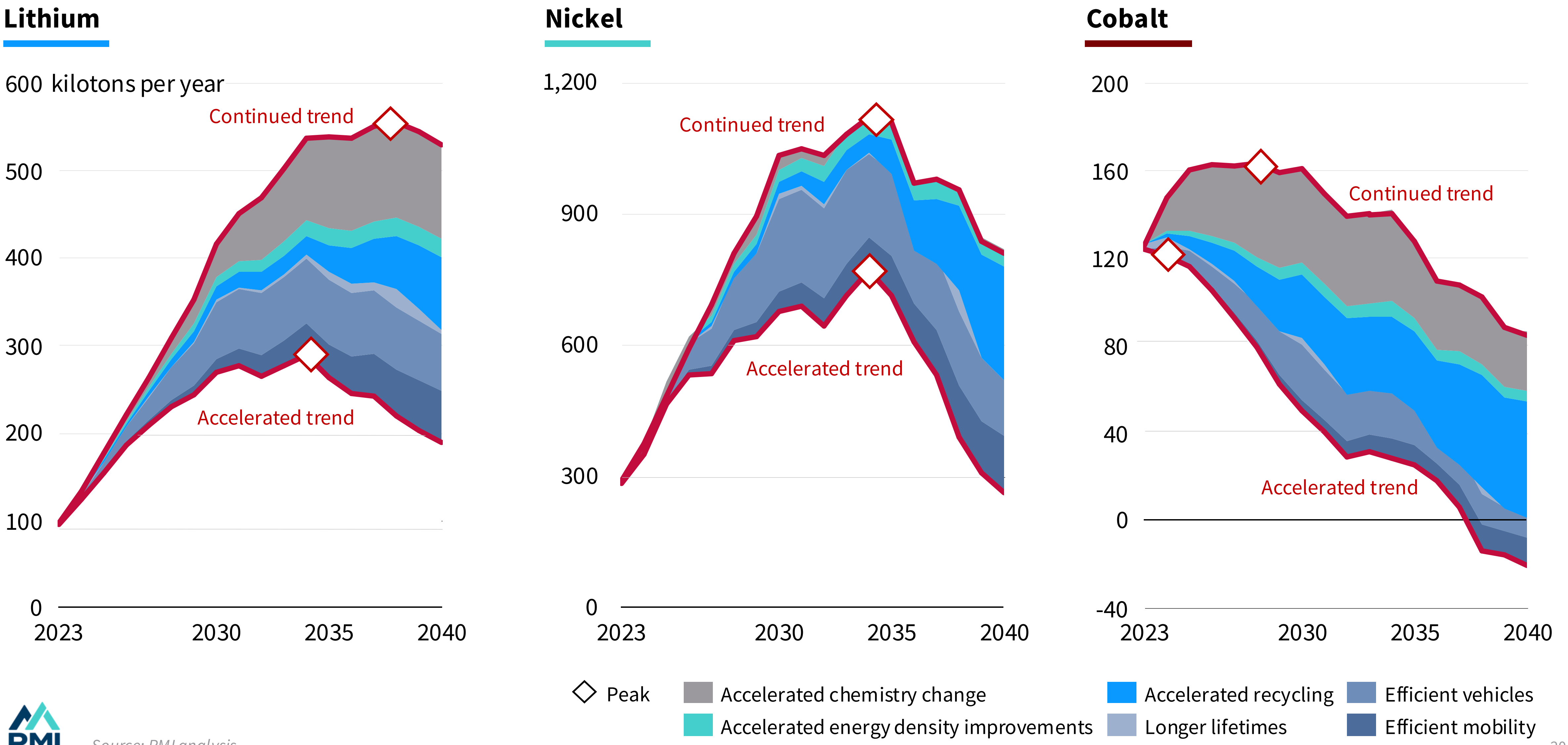
- Cut EV energy needs through better design efficiency and right-sizing

F Efficient mobility

- More modal shifting via electric micromobility, urban planning, active modes, and public transit
- Better freight efficiency

Acceleration means a lower and earlier peak

All six solutions help bring the mineral peak down and forward

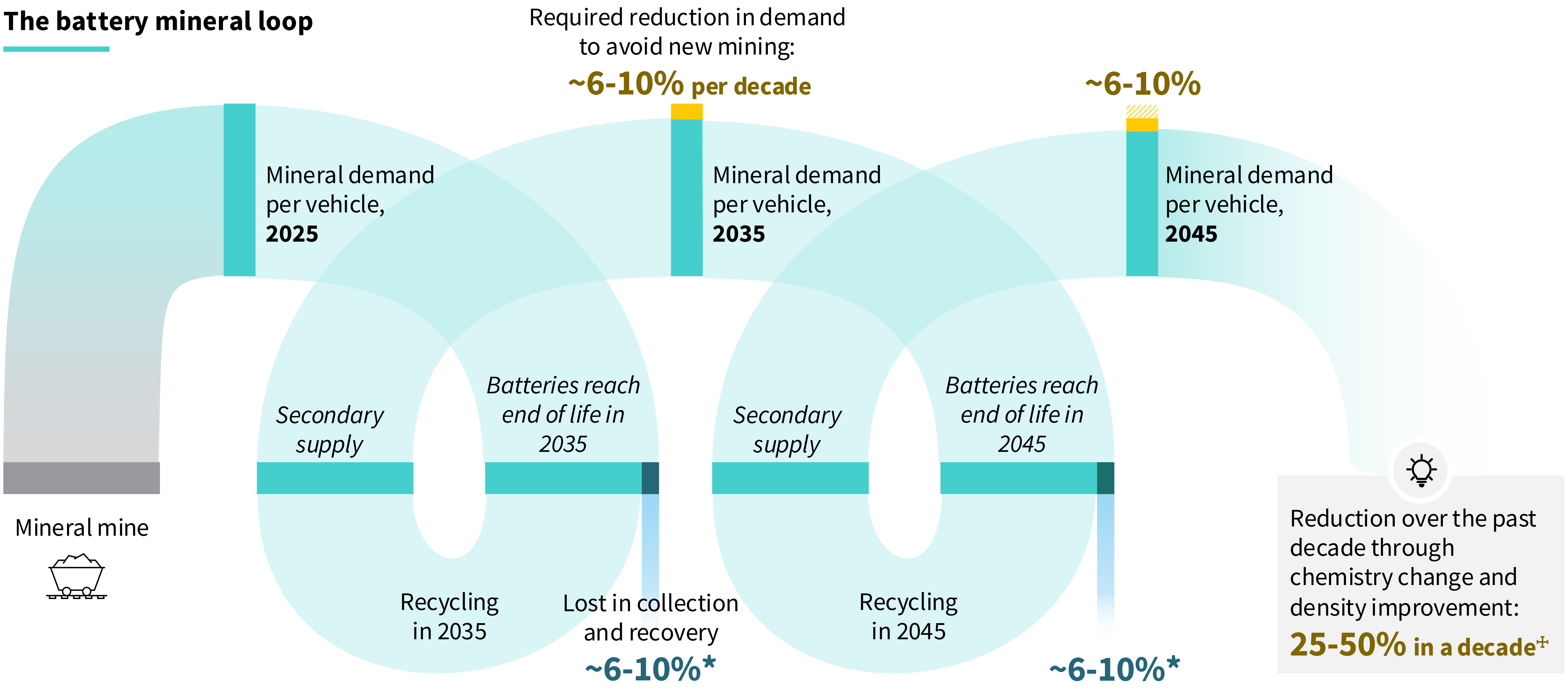


Source: RMI analysis

Circular self-sufficiency is possible

Innovation and efficiency only need to outpace (small) recycling losses

The battery mineral loop



* Accelerated case

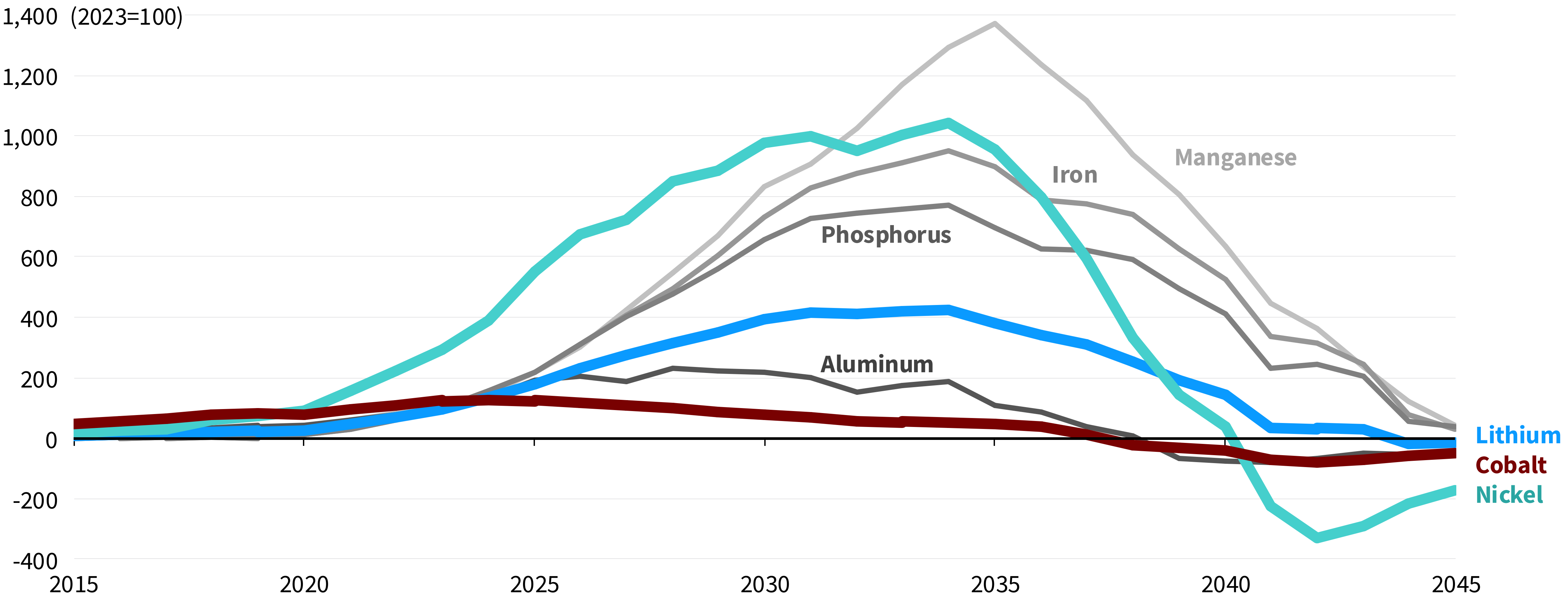
⸸ *About 25% for lithium, about 50% or more for nickel and cobalt*

Source: RMI analysis. Useful battery lifetime of a decade is indicative; lifetimes are likely longer.

Net-zero mineral demand before 2050 is possible

As batteries start reaching end-of-life, recycling minerals can offset all of demand

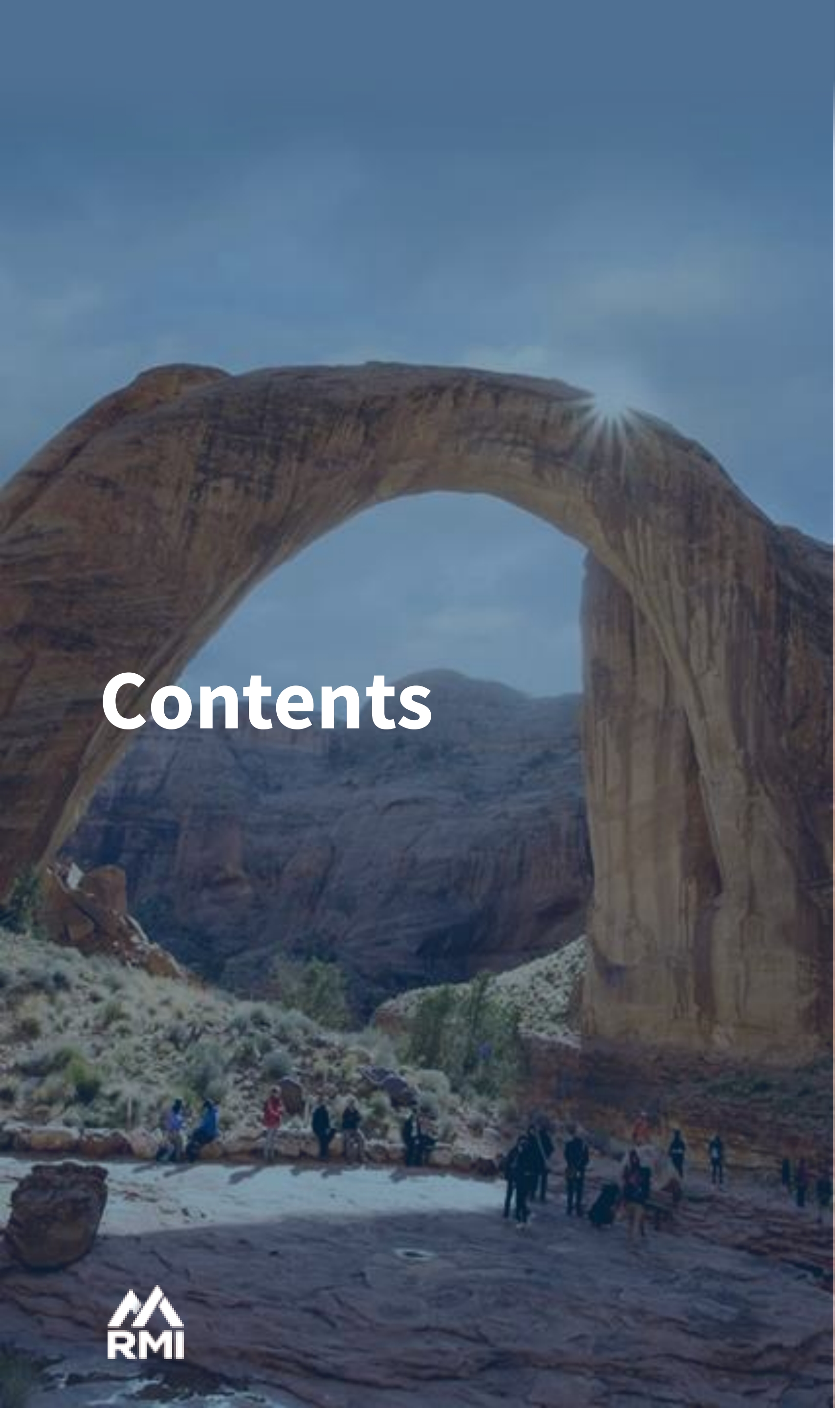
Mineral demand, accelerated trend, faster battery uptake scenario



Note: Assumes recycling of all minerals in batteries.

Source: RMI analysis

RMI



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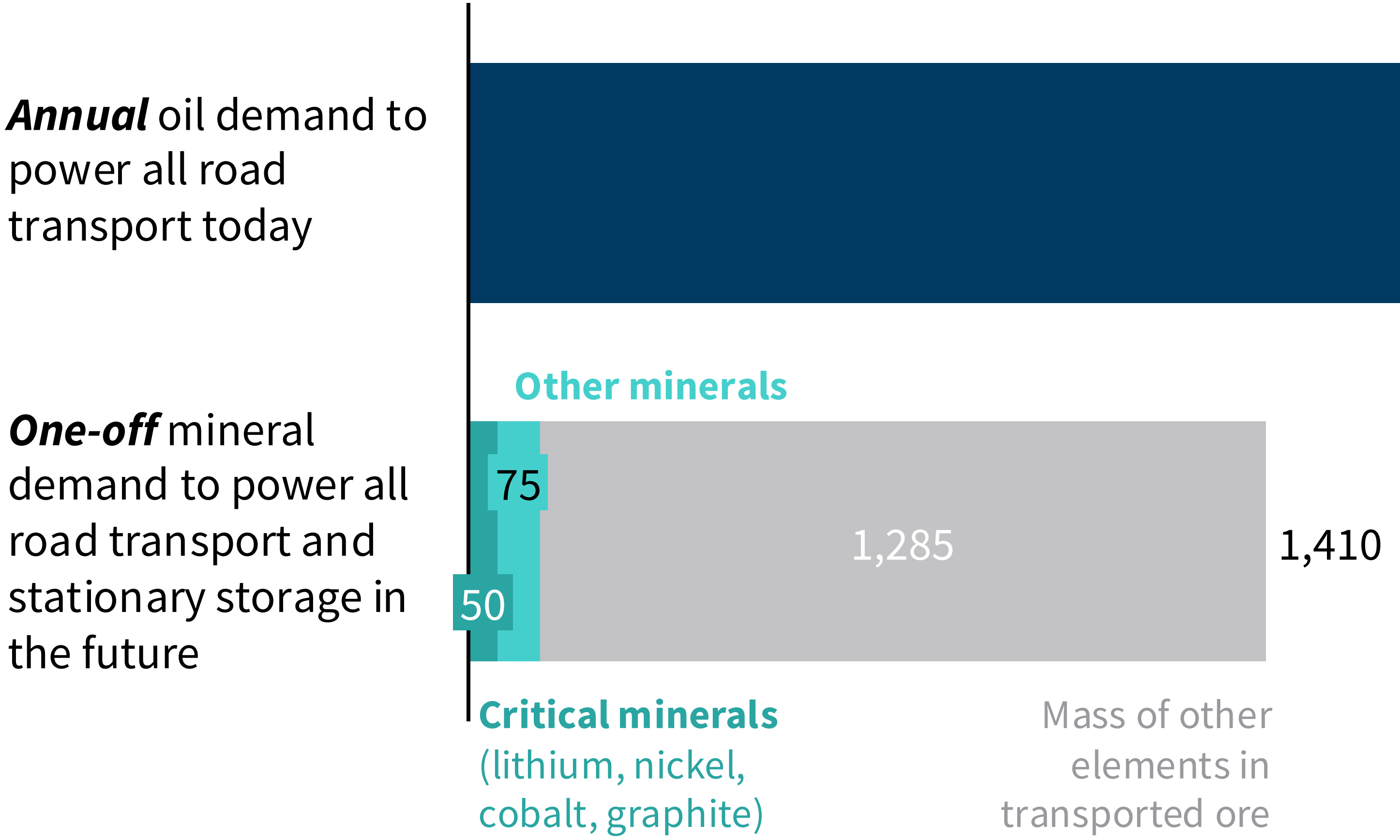
One-off minerals versus continuous oil extraction

Minerals are small and only need extracting once; oil needs continuous extraction and is expensive

Virgin extraction, million tons

Total cost



$950
billion **per year**

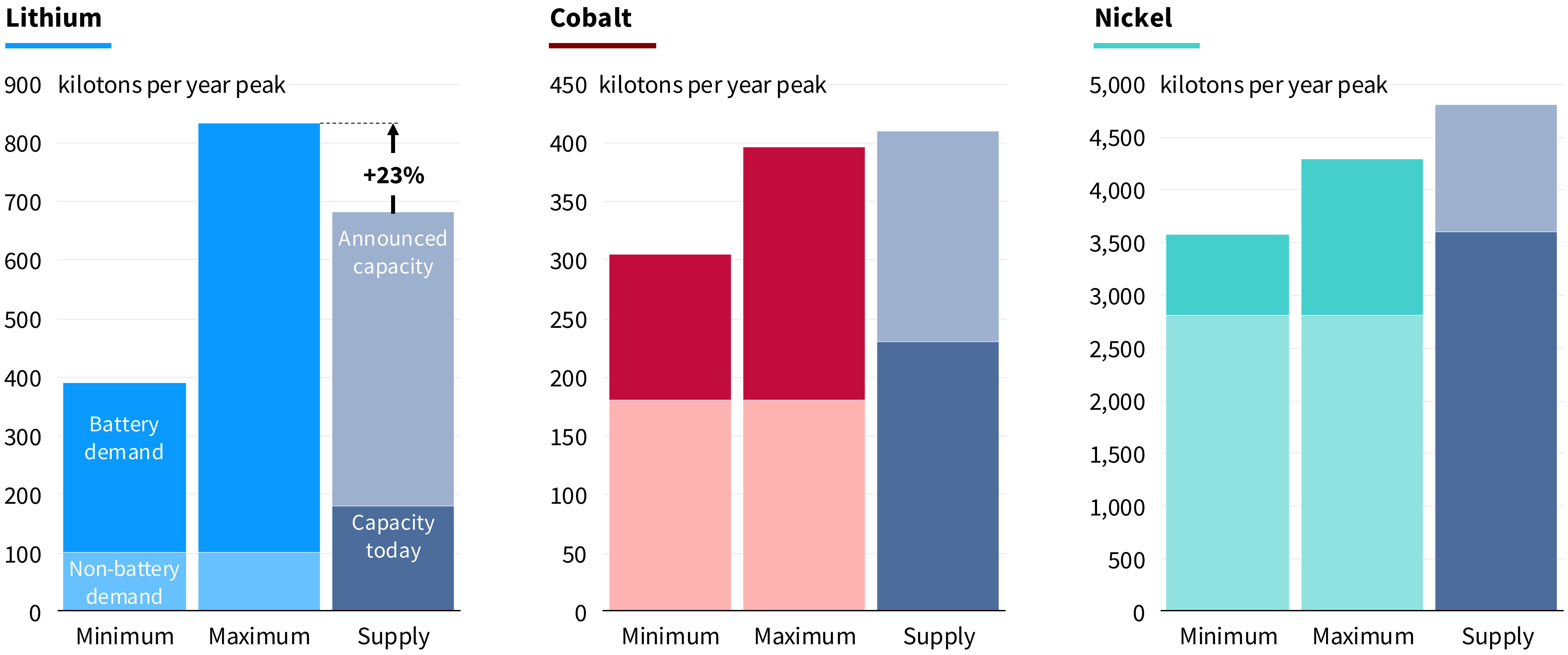
$1,025
billion **one-off**

Note: Accelerated scenario; faster uptake. Mass of other elements in transported ore are based on the typical mineral concentration of products leaving the mining site — i.e., after typical on-site concentration of natural ore. Cost is calculated based on current wholesale prices for extracted products; no refining or other costs are included.

Source: IEA Global Critical Minerals Outlook (2024), USGS National Minerals Information Center, RMI analysis.

We are tracking well on building the mining capacity

Under current announcement, there is only a (small) gap for lithium

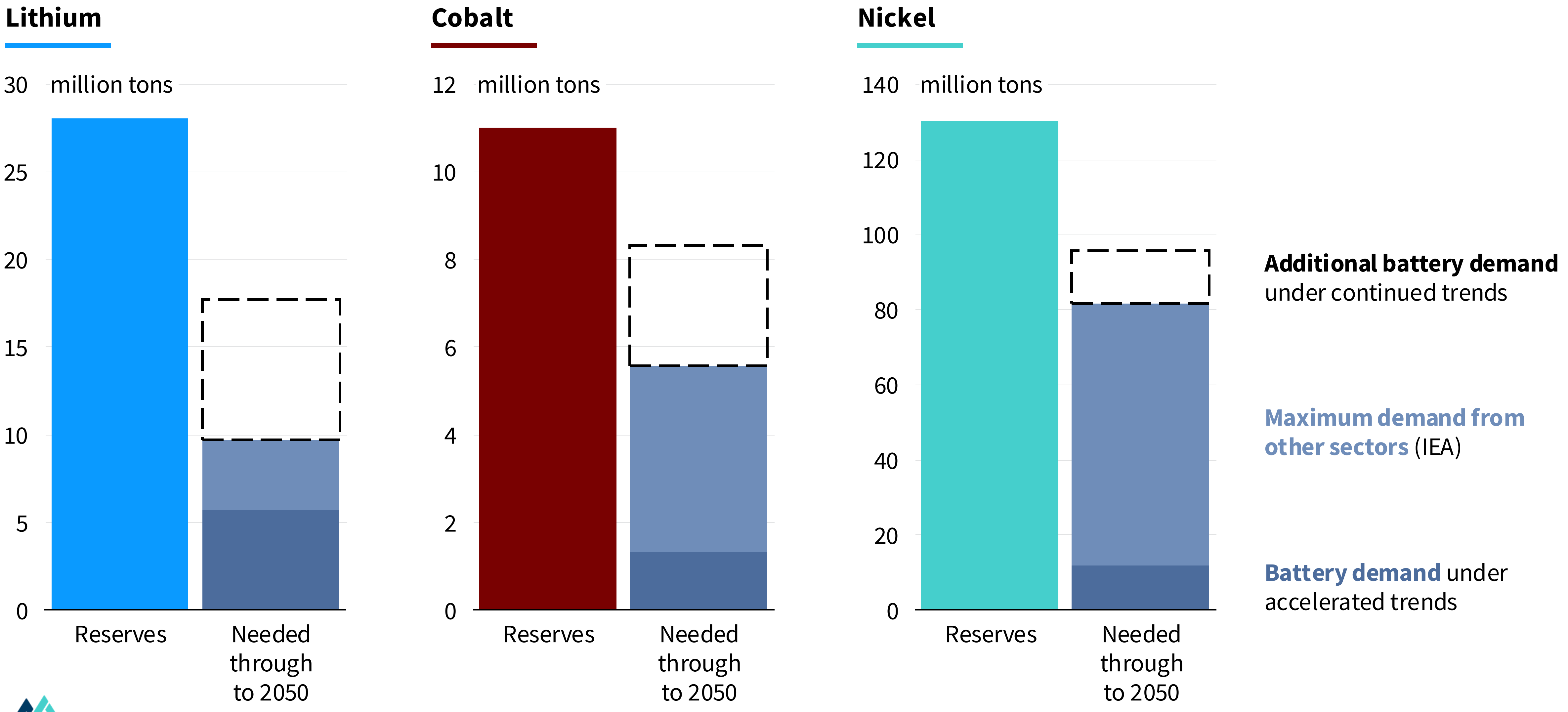


Note: Minimum represents the Fast scenario under accelerated trends; the maximum represents the Faster scenario under continued trends.

Source: IEA Global Critical Minerals Outlook (2024), USGS National Minerals Information Center, BNEF Battery Minerals Supply and Demand (2023), RMI analysis

And we already have found enough reserves to get there

We have more than enough mineral reserves to supply battery demand, and more



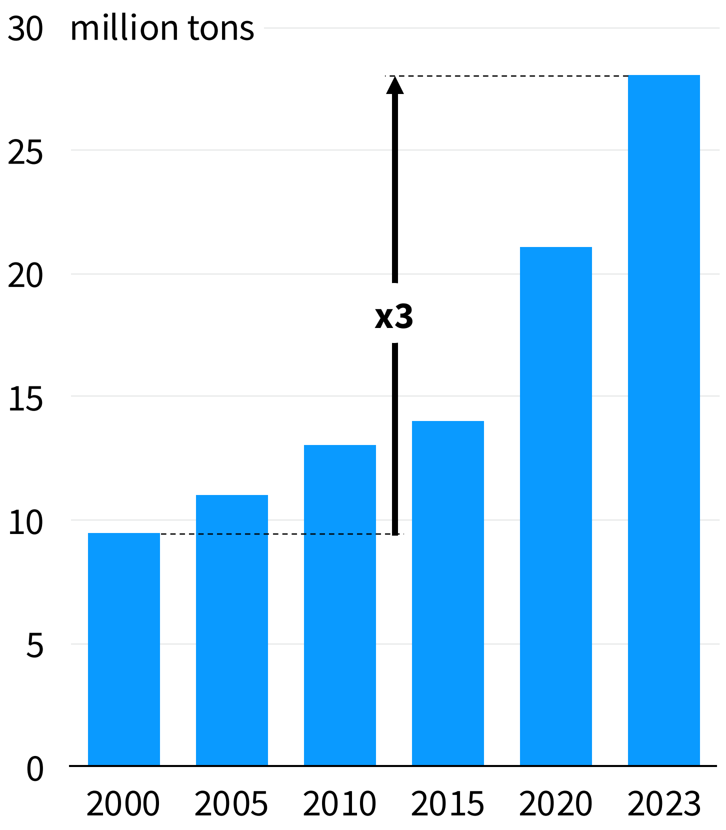
Source: IEA Global Critical Minerals Outlook (2024), USGS National Minerals Information Center, RMI analysis

The more we look, the more we find …

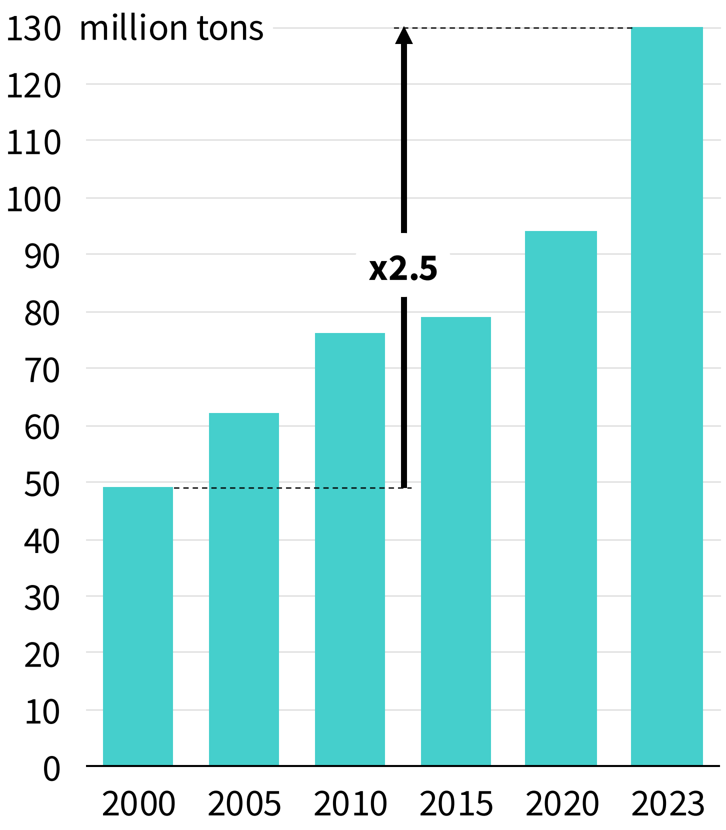
Reserve estimates keep rising

Global mineral reserves estimated in year

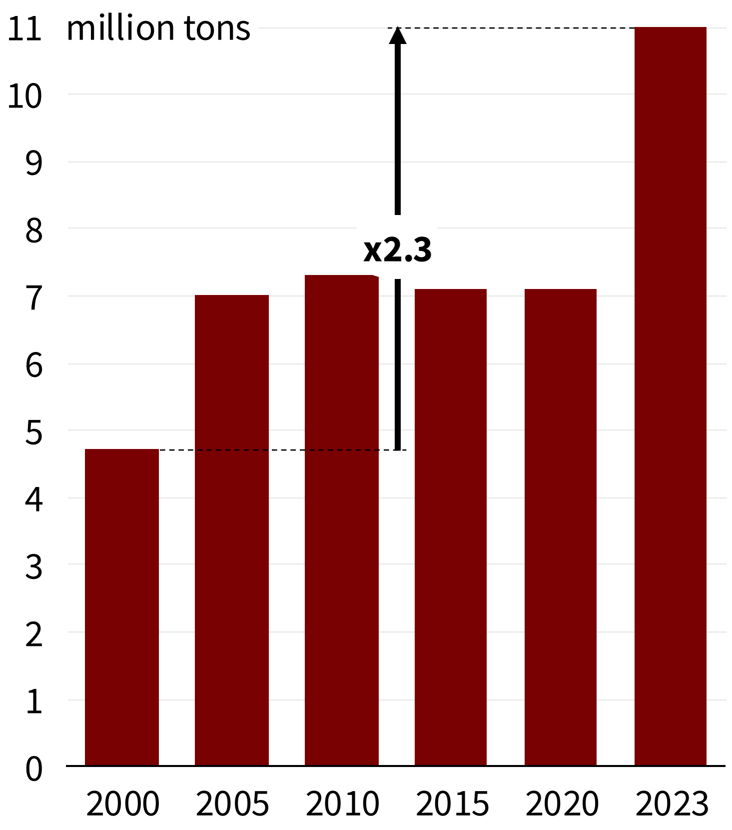
Lithium



Nickel



Cobalt



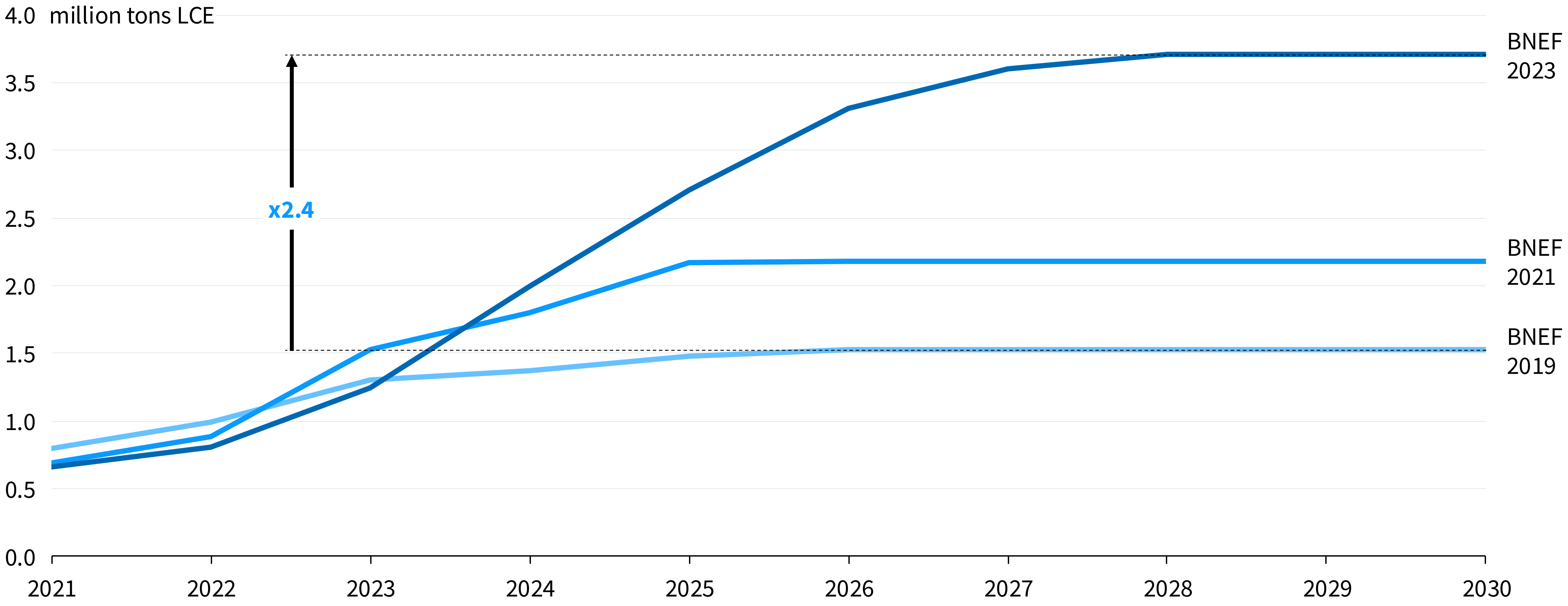
RMI

Source: BNEF 2019, 2021, 2023 Battery Supply and Demand Outlook; USGS Lithium, Cobalt, and Nickel Commodity Summaries; IEA Global Critical Minerals Outlook (2024)

And the more we find, the more we plan to mine

BNEF mining outlooks keep getting adjusted upwards

Evolution of BNEF lithium mining supply outlook



RMI

Source: BNEF 2019, 2021, 2023 Battery Supply and Demand Outlook; USGS Lithium, Cobalt, and Nickel Commodity Summaries; IEA Global Critical Minerals Outlook (2024)

From oil dependency to circular independence

At risk in the immediate term | At risk in the long term | Not at risk

From oil dependency…

In an economy running on **oil imports**, **when imports stop…**

…the **entire economy comes to a halt** as engines run out of oil to power them

… to electric tech dependency…

In an economy running on **imported electric technology**, **when imports stop…**

…**only economic *growth* is inhibited** in the immediate term as no new technologies can get deployed

…while the **rest of the economy can keep running** on its current technology stock — only facing a long-term challenge as aging technologies need to get replaced eventually

… to full circular energy independence

In an economy running on **circular electric technology**, **when imports stop…**

…**most growth can continue** being powered with materials gained from old technologies at their end of life

…while the **rest of the economy can continue to run on its circular material loop**, even in the long term

Note: Bar sizes are illustrative.

Source: RMI analysis

Holistic efficiency compounds the benefits

Benefits go beyond only needing to mine less; but extend to emissions, equity, security and health

Measure	Emissions	Equity	Security	Health
Switching to EVs	**Avoided emissions from tailpipes and upstream oil** (~20% of global emissions)	**Fewer fossil fuel harms,** such as disproportionate impacts of pollution and climate disasters	**Lower dependency on oil and gas imports** for the 80% of countries that are net importers	**Cleaner air**, as roughly 5 of 8 million annual pollution deaths come from fossil fuels
Efficient vehicles and circular batteries	**Avoided emissions from battery production** and global transport of materials	**Reduced mining harms,** such as displacement and human rights violations	**Lower dependency on critical minerals,** which are highly concentrated in certain countries	**Safer vehicles**, as larger vehicles lead to more pedestrian deaths
Efficient mobility	**Avoided emissions from vehicle life cycle and system** (more efficient buildings and land use)	**Better mobility access,** as vulnerable populations are more likely to use alternative modes of transport	**Lower dependency on critical infrastructure**, as less of the economy depends on grids, roads, and other infrastructure	**Active mode benefits**, which can sometimes improve health even more than cleaner air

Further upstream; deeper efficiency intervention

Compounding benefits

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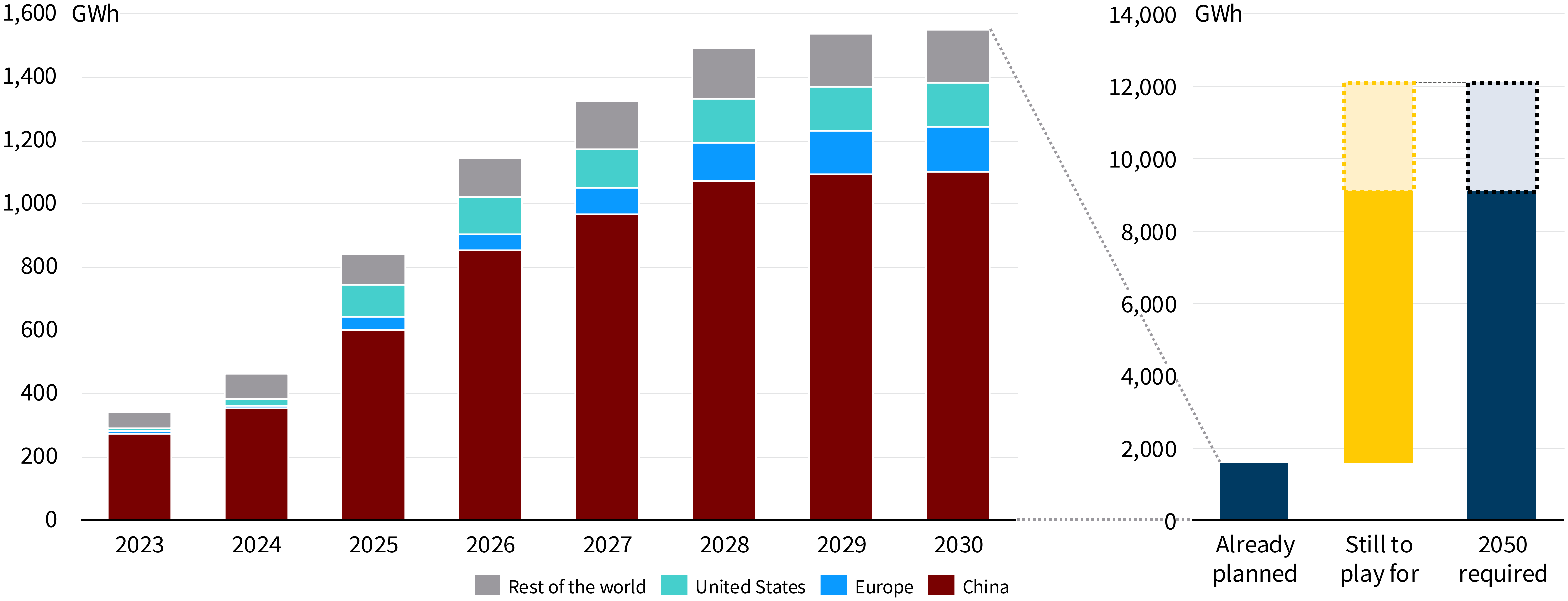
A circularity race to the top

China is ahead but there is more than enough still to play for

Expected battery recycling capacity by region based on current announcements

Required battery recycling capacity through 2050



Source: IEA Global EV Outlook (2024), RMI analysis

A unique role for the Global South

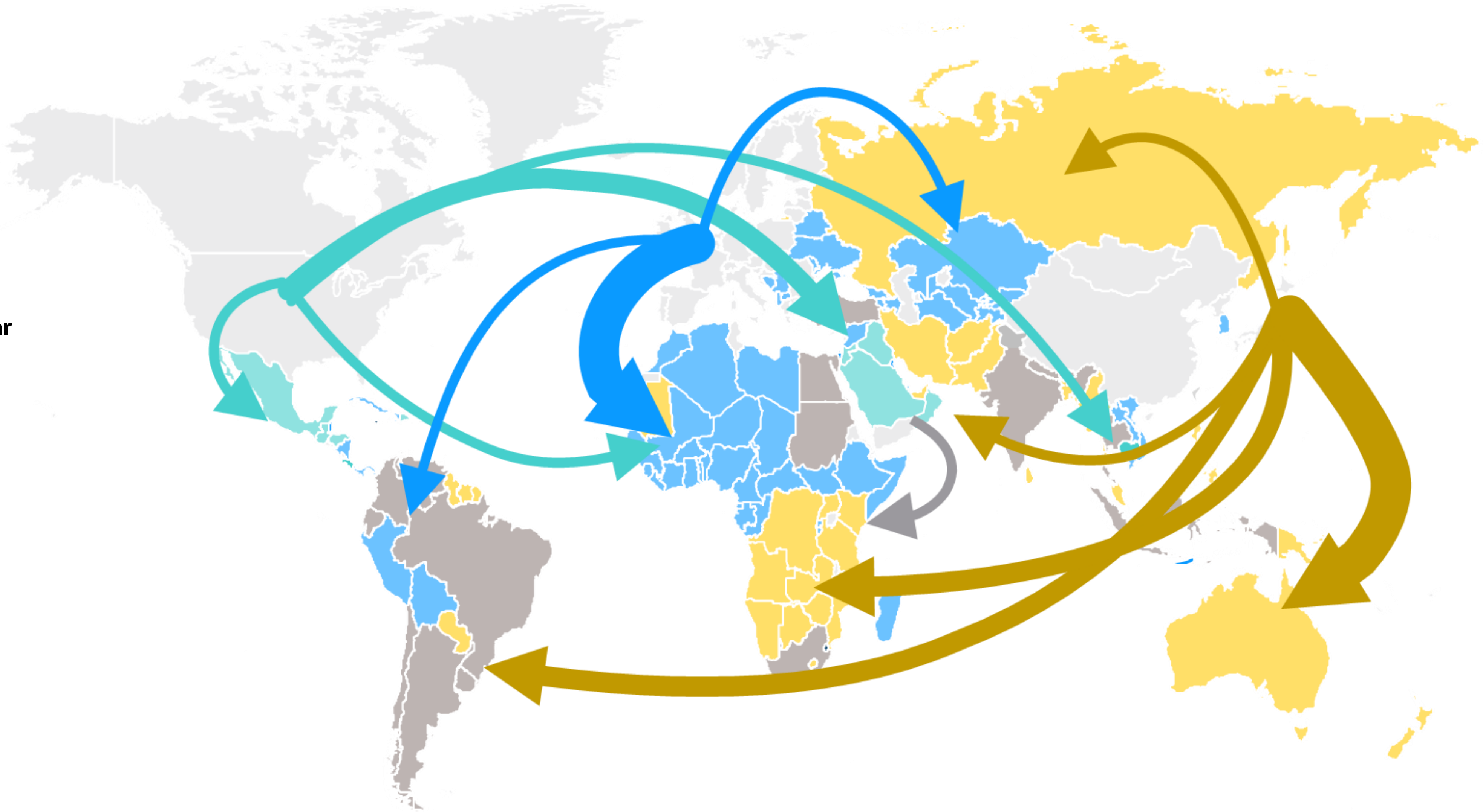
An outsized number of batteries may end up in the Global South in second- and third-hand vehicles

Dominant used car import country

- Europe
- Japan
- United States
- Imports banned

Used cars exported per year

- 20,000—145,000
- 145,000—270,000
- >270,000



Insights from RMI's Battery Circular Economy Initiative

E.J. Klock-McCook

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RMI

Barriers to Battery Circularity

Lack of infrastructure

Multiple stakeholders

Supply chain opacity & lack of data

Unclear ROI

RMI

RMI's Battery Circular Economy Initiative (BCEI)

Aggregate and analyze disparate data

- BCEI dashboard
- Thought leadership publications

Engage stakeholders for shared understanding

- Solicit peer review
- Make connections across the value chain

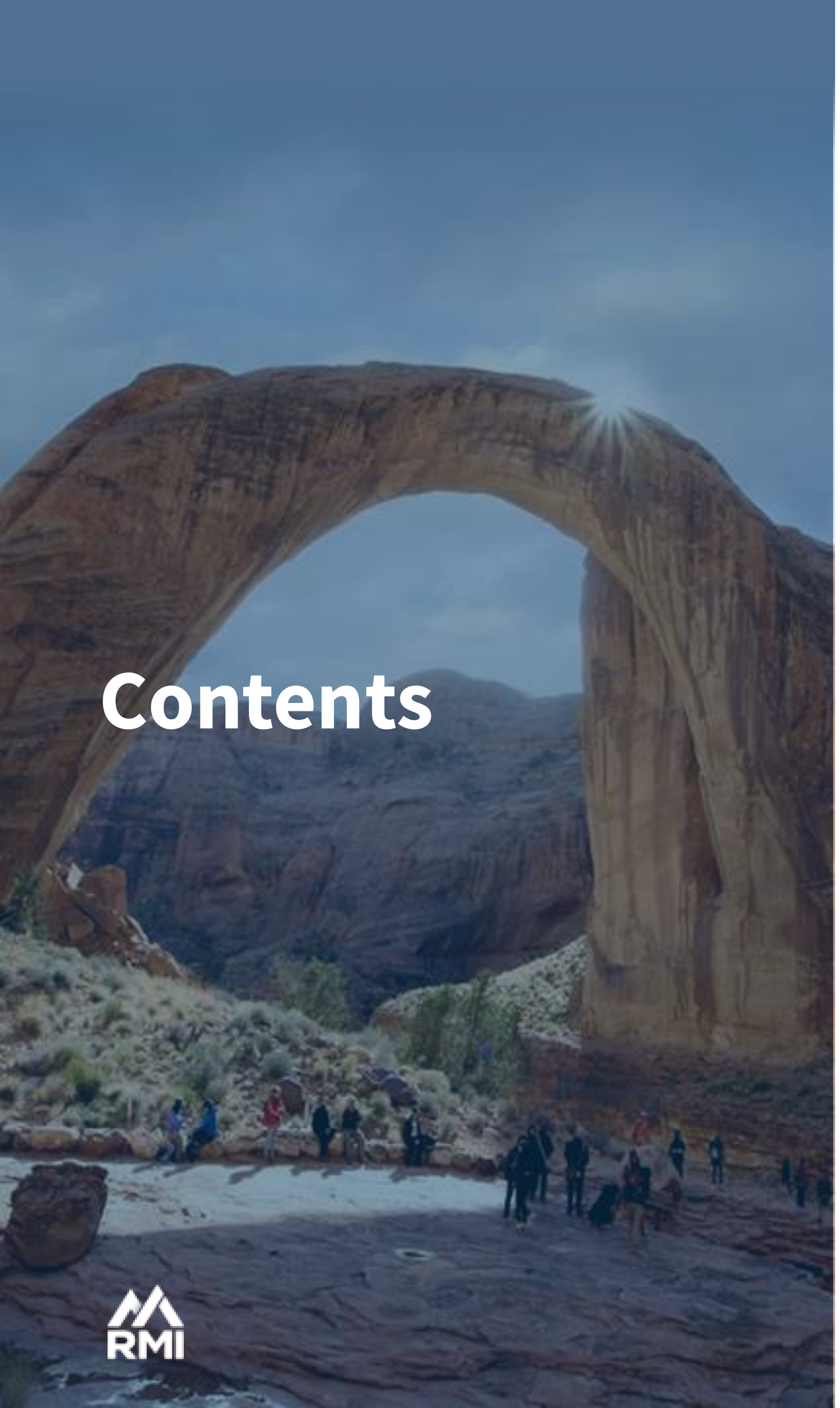
Support robust, data-driven policy

- Analysis of IRA implications
- 5 policies to advance a circular economy

Guide investment in circular infrastructure

- ROI analysis & investor roadmap

RMI



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A holistic perspective of recycling is needed

Financial returns

Jobs

Economic growth

Emissions

Land use

Water use

What does a holistic evaluation include?

Financial

Profit pools from EVB recycling

Social

Wages earned and GDP impact of jobs

Environmental

Reductions in: CO_2e emissions; water use; land use (all converted into dollar values)

How do we define financial and social ROI?

Profit Pools

1. Value and quantity of recovered metals from recycling feedstock
2. Feedstock acquisition costs
3. Operating expenses and capital expenses

Jobs & GDP

1. Number of shredding and refining jobs created over time
2. Average wages earned over time
3. Additional economic impact of wages earned

How do we define environmental ROI?

Emissions Avoided

1. Emissions from recycling process
2. Emissions from mining virgin metals
3. Value of emissions avoided

Water Use Avoided

1. Freshwater required for recycling
2. Freshwater required to produce virgin material
3. Value of water use avoided

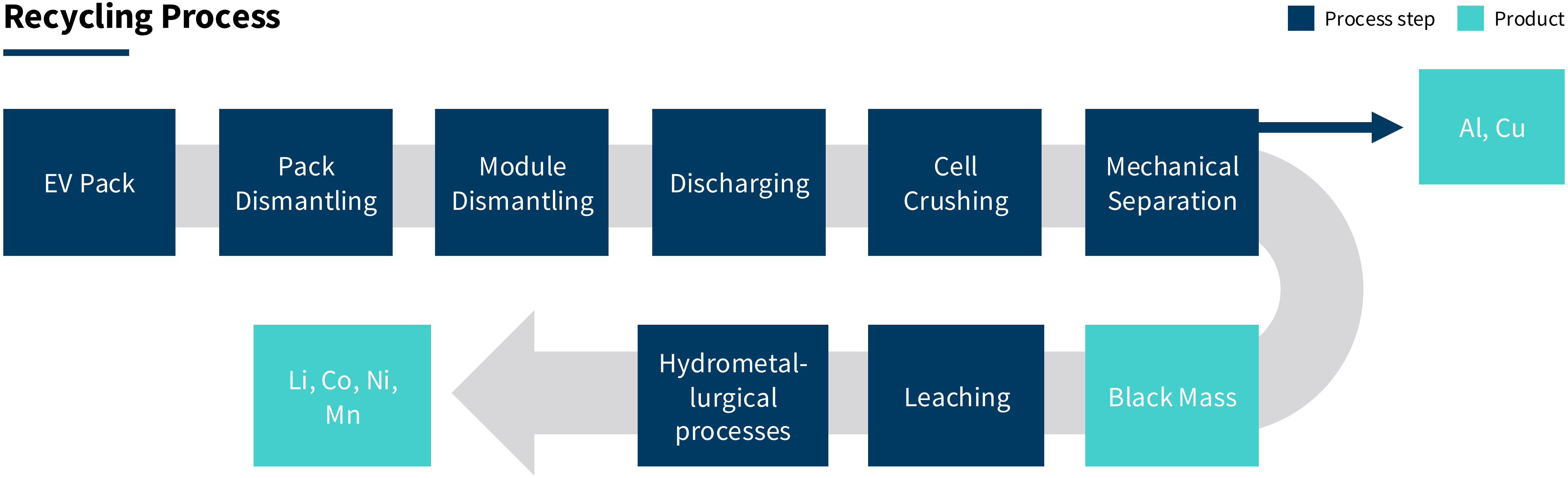
Land Use Avoided

1. Land required for recycling
2. Land required to produce virgin material
3. Value of land use avoided

RMI

Analysis compares holistic ROI of mined metals to that of recycled metals

Recycling Process

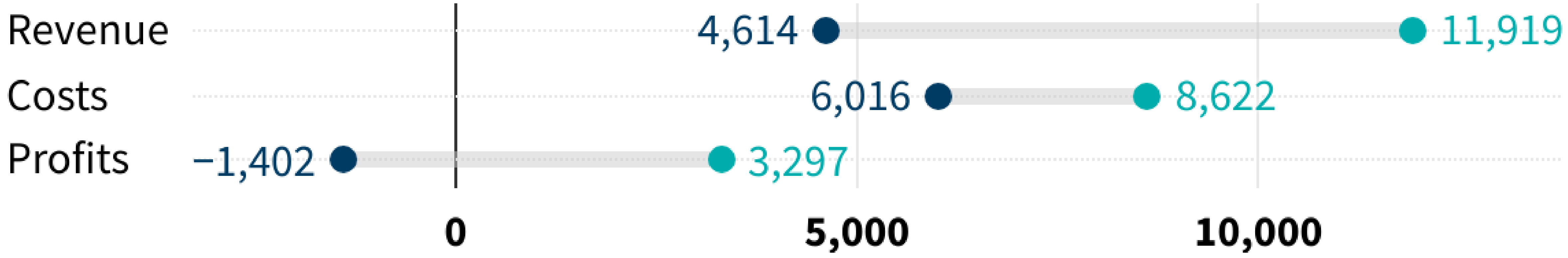


NMC532 | NMC811 | LFP | NCA

The financial profitability of recycling varies greatly

Value of social benefits remain unaccounted in traditional business models

Revenue and costs in $ per ton battery recycled

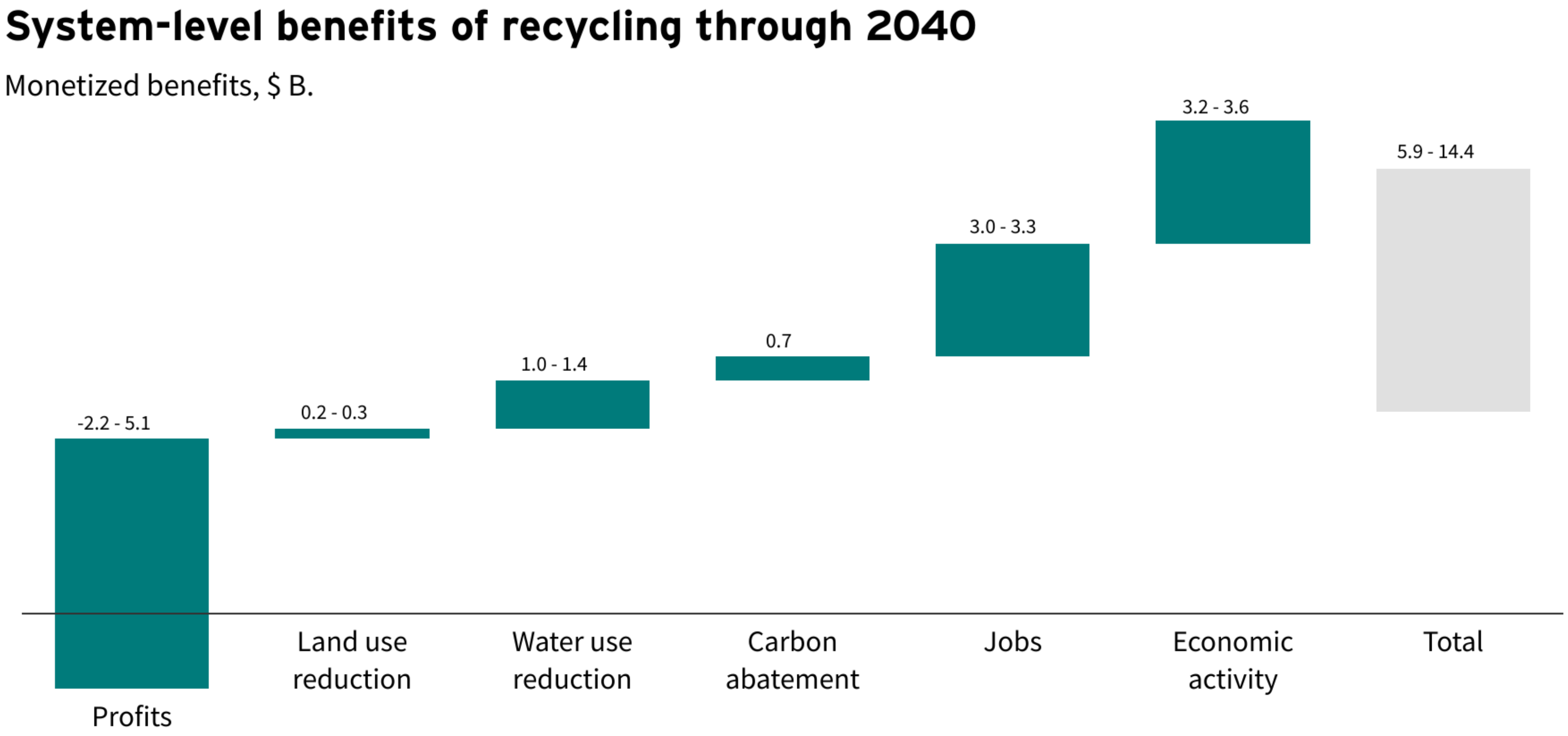


Recycling profits are driven by metal market prices and economies of scale

Source: RMI Battery recycling analysis

The holistic value of recycling is not reflected in P&L assessments

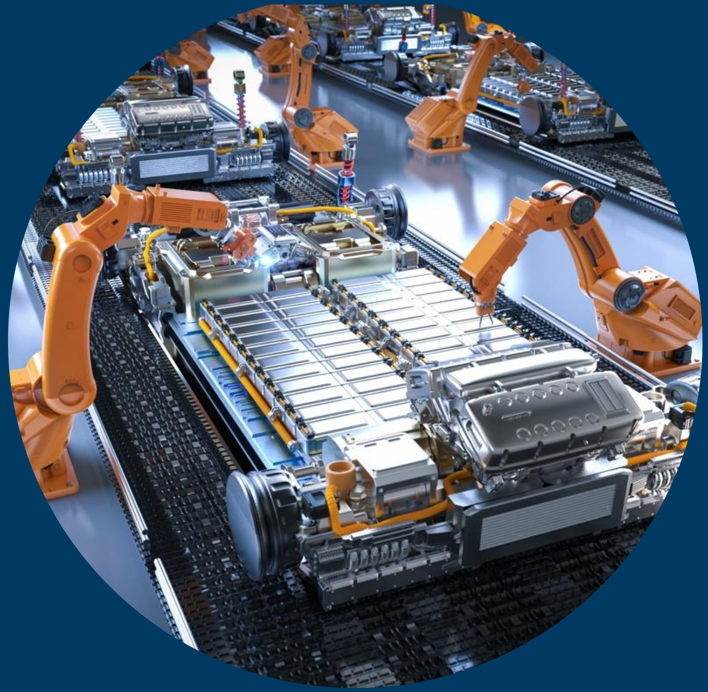
A triple bottom-line assessment determines the social value generated



Even in volatile markets, holistic ROI is overwhelmingly positive

Source: RMI Battery recycling analysis

Metal Focus: Lithium



Process: Traditional ore mining

Purpose: Baseline

Process: Direct lithium extraction with geothermal

Purpose: Assess impact of technological innovation

Process: Recycling

Purpose: Assess impact of circular approaches

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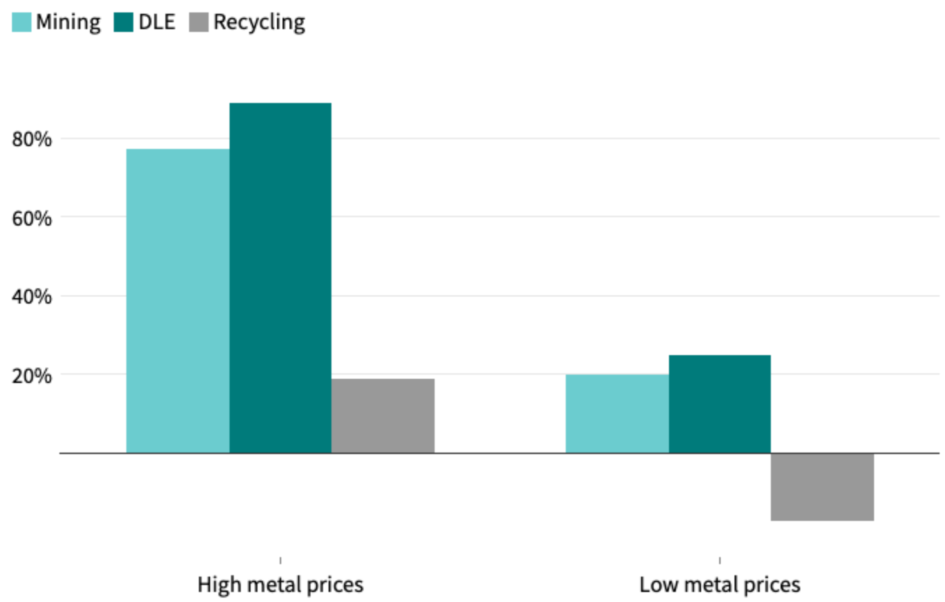
The case for policy interventions and incentives

Unlocking the social value requires de-risking recycling business models

Recycling of LFP chemistries is challenging ...

Profit margins sensitivity to metal prices

Profits per ton of Lithium Carbonate Equivalent (LCE) produced.



... but incentives can help de-risk

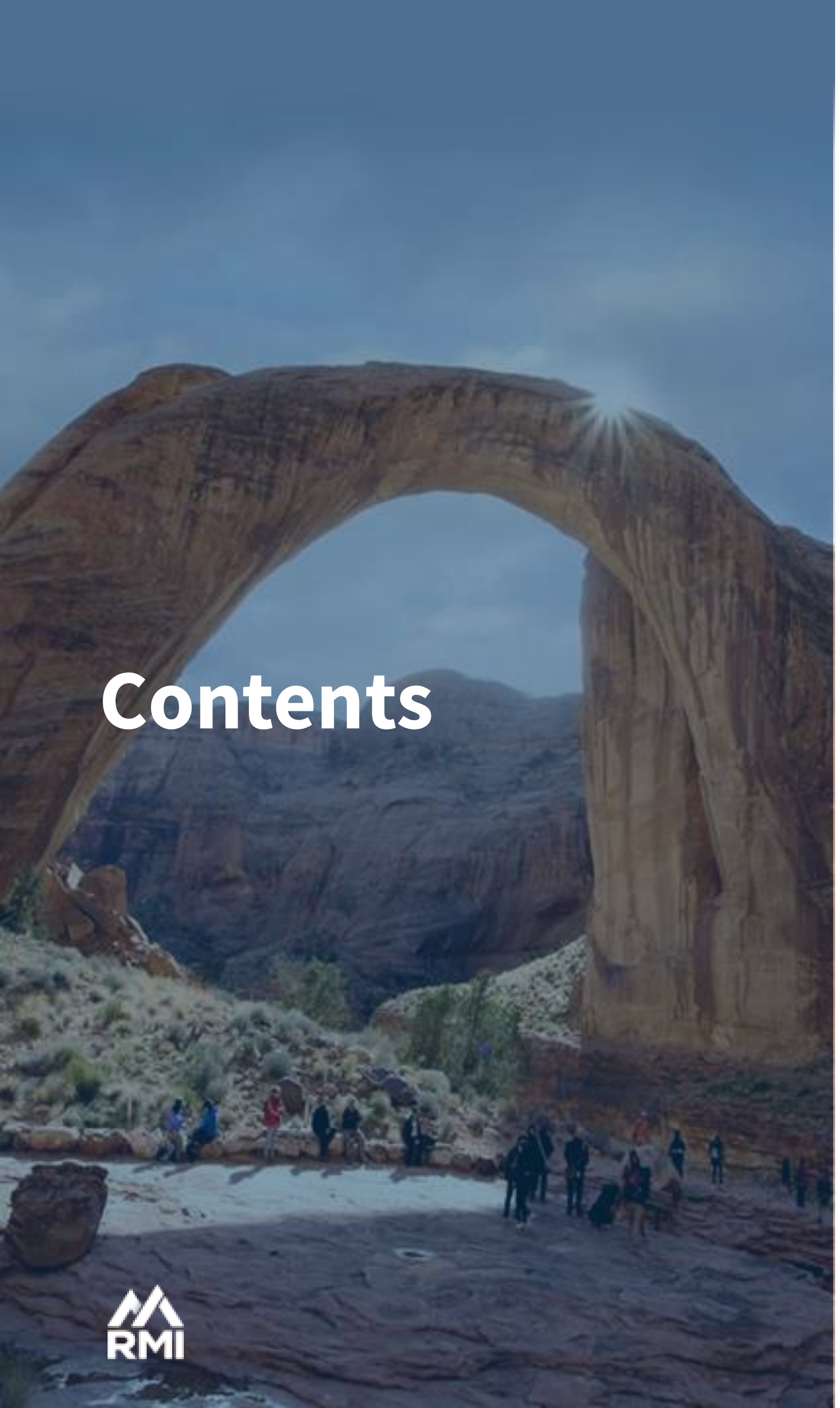
Indicative effect of incentives on the profit margin

The sensitivity of profit margins to the allocation of incentives to recyclers.

−17.0% 6.0%

Incentive allocated ($/ton)	**0**	**750**	**825**	**900**	**975**	**1050**
Profit Margin	**−17%**	**−1%**	**1%**	**2%**	**4%**	6%

Source: RMI Battery recycling analysis



Contents

System level interventions can support circularity

And it is easier to deploy solutions at the start of the transition

Clear requirements for proper handling of retired batteries

Traceability and due diligence requirements to inform decisions

De-risk repurposing and recycling business models through policy and market measures

Continued R&D investments and pilots for further innovation

Six Ways to Eliminate the Need for Newly Mined Battery Minerals

Moderated Q&A

QR code to event page (recording, link to resources)

Thank you for attending!

Daan Walter
daan.walter@rmi.org

E.J. Klock McCook
ekmccook@rmi.org

rmi.org/subscribe/

https://renewablerevolution.substack.com/

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Executive summary

Battery minerals are *not* the new oil — they are a gateway to a leaner, cheaper, circular economy.

- **There are six alternatives to mineral mining.** These include deploying new battery chemistries, making batteries more energy-dense, recycling their mineral content, extending their lifetime, improving vehicle efficiency, and improving mobility efficiency.
- **Change is already underway.** Without the past decade of improvements, today's lithium, nickel, and cobalt demand would be 60%–140% higher.
- **Peak mineral demand is only a decade away.** Continuing the current trend means we will see peak virgin battery mineral demand in the 2030s.
- **Net-zero mineral demand before 2050 is within reach.** Accelerating the trend— using all six solutions above — means we can reach (near) zero mineral mining demand before 2050, when virtually all battery demand can be met through recycling.
- **So mineral mining will be a one-off effort.** End-of-life batteries will become the new mineral ore, limiting the need for battery mineral mining in the long term.
- **We won't have to move mountains.** Accelerated progress means we only need to mine a cumulative 125 million tons of battery minerals. This quantity alone can get us to circular battery self-sufficiency. That is 17 times smaller than the amount of oil used in road transport *every year*.
- **We have enough minerals.** Our known reserves of lithium, cobalt and nickel are twice the level of total virgin demand we may require. And announced mining projects are already sufficient to extract almost all the minerals we need.
- **Countries can move from oil dependence to circular independence.** Most economies would grind to a halt if oil imports were to stop. Electric vehicles powered by renewables face no such short-term risk, especially when paired with battery recycling and (re)manufacturing.
- **China leads the battery circularity race to the top.** China's largest battery manufacturer, CATL, expects battery recycling to lead to mineral independence in China by 2042. The West is trying to catch up, while the Global South can benefit from the batteries in their used vehicle imports.
- **Systemic solutions will broaden the benefits.** The more holistically we approach demand through efficient batteries, vehicles, and mobility, the broader the benefits for the climate, human rights, security, health, and wealth.
- **To accelerate action, we need all stakeholders to lean in.** From governments to corporate innovators, all can help capture the opportunity.

RMI

Accelerating means the whole value chain needs to lean in

The opportunity is there — now it it up to policy makers and the market to seize it

Value chain	**Mining and processing**	**Battery manufacturing**	**Vehicle manufacturing**	**Mobility applications**	**Second-life battery use**	**Battery recycling**
The six solutions		Changing chemistries; Higher energy density batteries	Efficient vehicles	Efficient mobility	Reuse and extend lifetime	Recycling
Key actions	**Markets:** transition business models from mining to recycling **Policy:** incorporate cost of externalities into policy reforms	**Markets:** Incorporate traceability software and design for circularity **R&D:** accelerate battery innovation on cost, performance, and environmental footprint **Funders:** support R&D efforts to improve technology and economics	**Markets:** unlock lower cost EVs by right-sizing and designing for circularity **Policy:** incentivize right-sizing by setting ambitious efficiency standards across vehicle types	**Markets:** scale efficient freight practices and electric micro-mobility **Policy:** reform land use and scale infrastructure to enable mode shift, particularly for new development	**Markets:** innovate on diagnostics, insurance and warranty frameworks, and battery management systems **Policy:** incentivize re-use or set longer lifetime standards	**Markets:** scale new technologies and improve economics; co-locate recycling infrastructure with battery processing **Policy:** incentivize or set standards for collection, recovery rate, traceability, and recycled content

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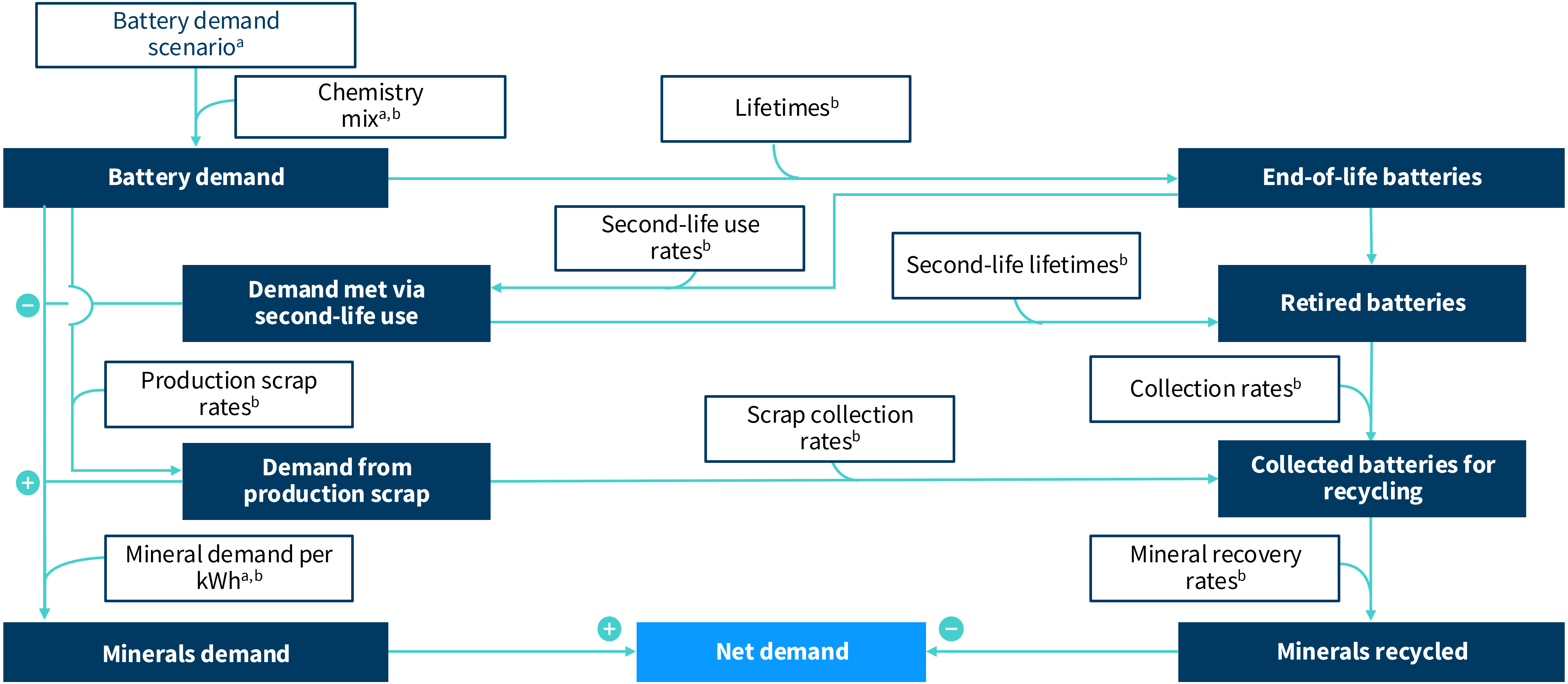
Our model

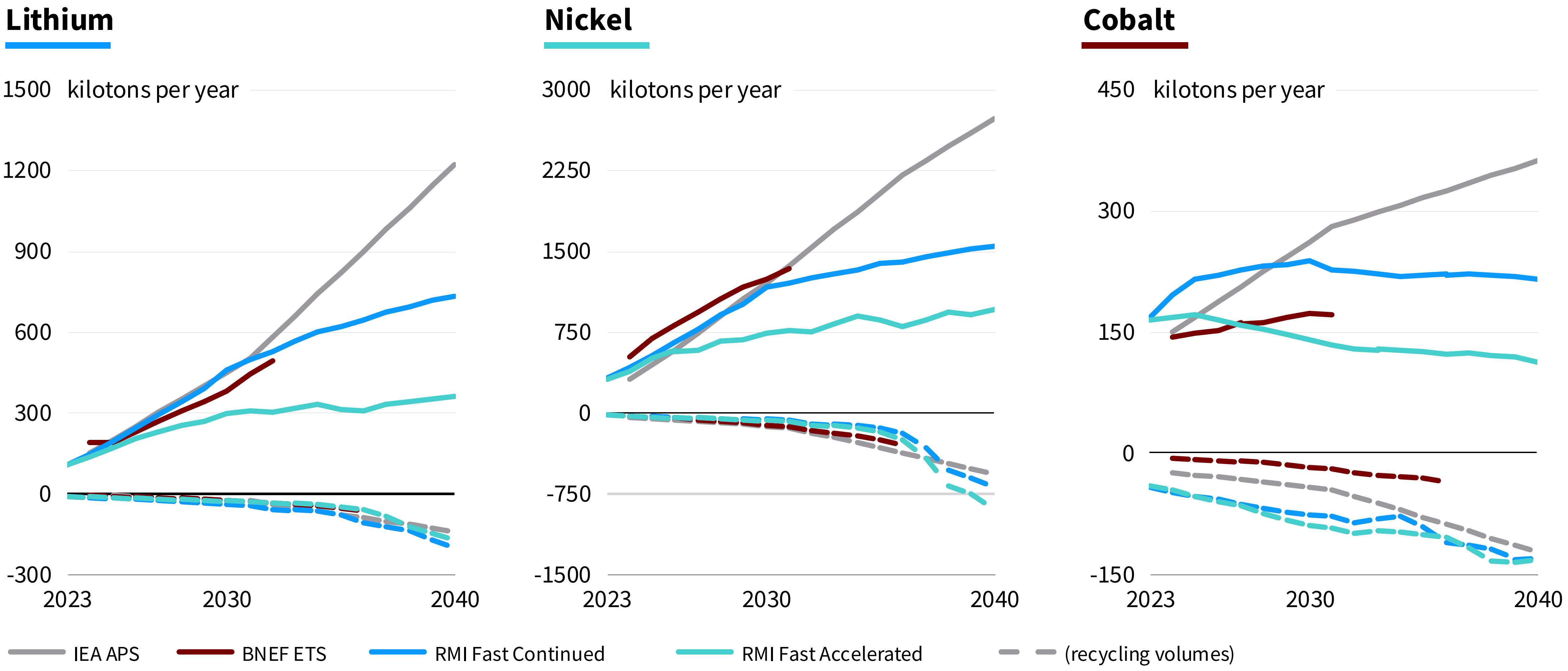
We model battery mineral stock and flows in detail



Sources: (a) RMI, (b) BNEF Lithium-Ion Battery Recycling Availability Model (2024) & Gaines et al. (2023)

Our outlooks benchmarked

Our outlooks are in line with short-term outlooks of IEA and BNEF, but divert in the long term



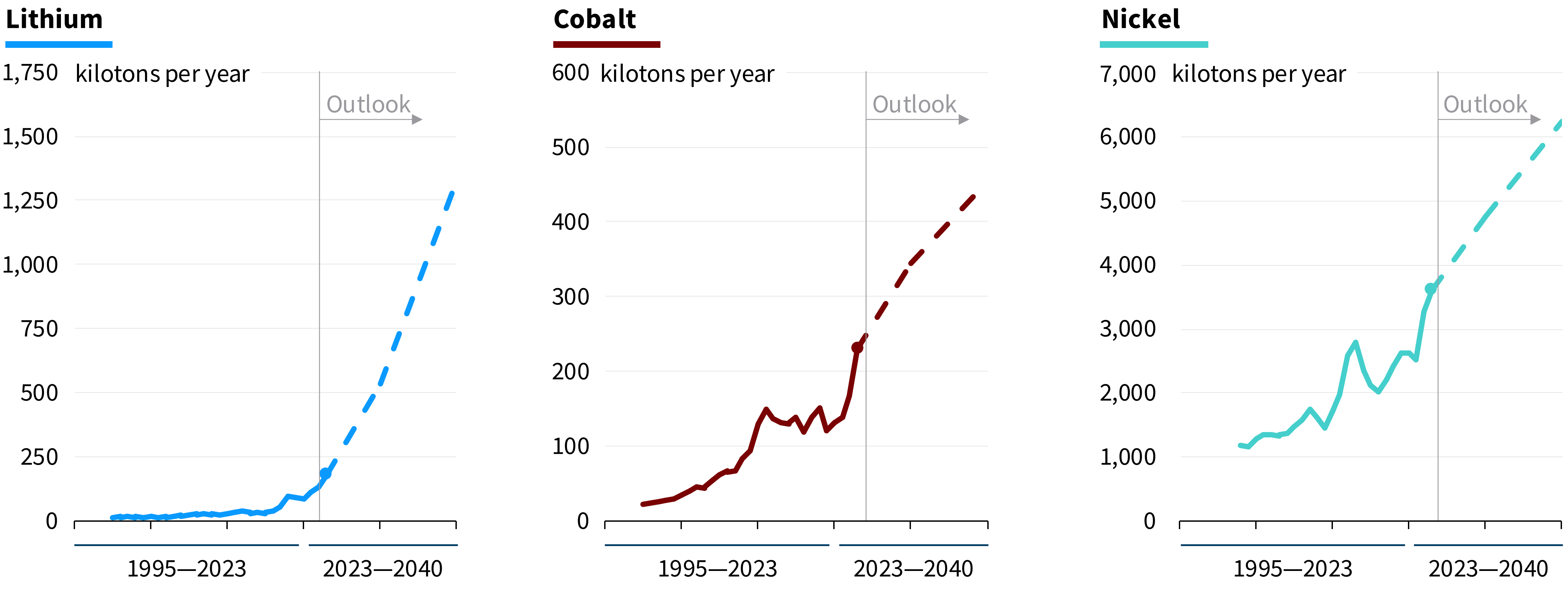
Note: APS = Announced Pledges Scenario; ETS = Economic Transition Scenario

Source: IEA Global Critical Minerals Outlook (2024), BNEF Battery Metals Supply and Demand (2023), BNEF Lithium-Ion Battery Recycling Availability Model (2024), RMI analysis

Mineral demand growth in context

IEA's projections on mining demand are in line with historical growth rates

Historical mineral demand and IEA outlook



	Lithium 1995—2023	Lithium 2023—2040	Cobalt 1995—2023	Cobalt 2023—2040	Nickel 1995—2023	Nickel 2023—2040
CAGR	11%	12%	9%	4%	5%	3%

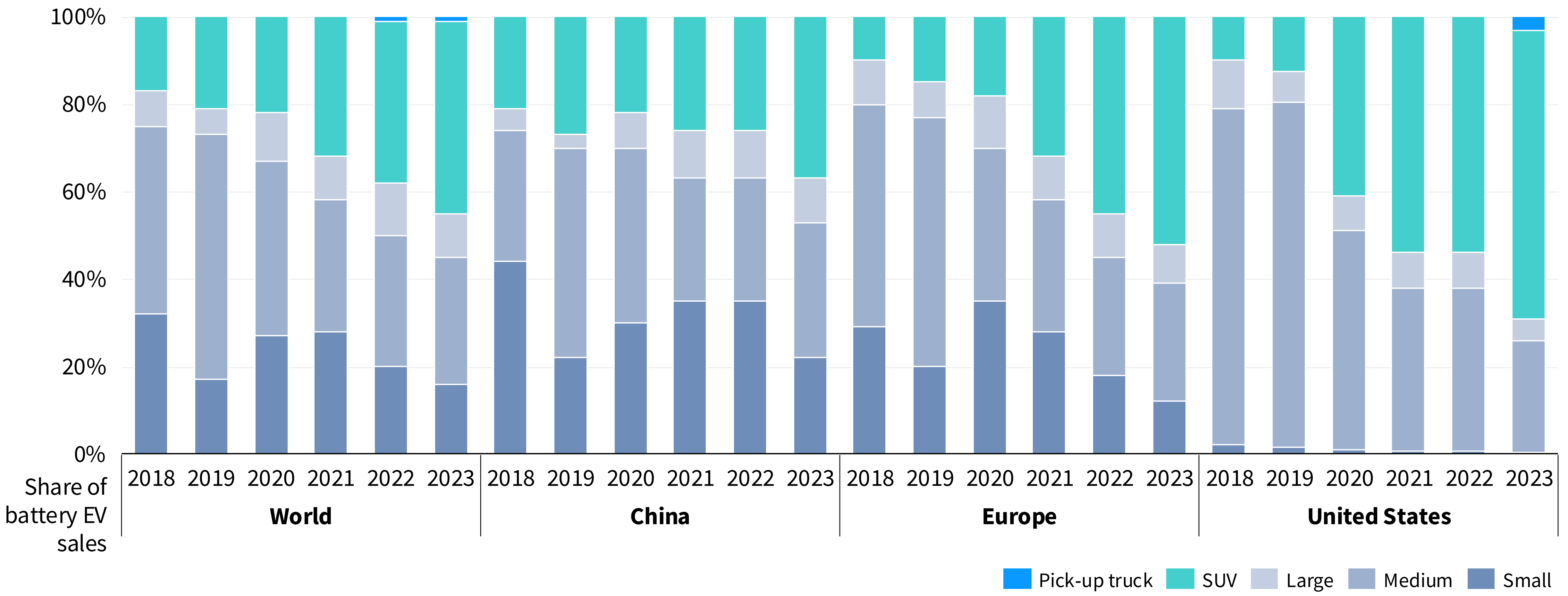
RMI

Source: USGS Lithium, Cobalt, and Nickel Commodity Summaries; IEA Global Critical Minerals Outlook (2024)

Automotive obesity in EVs

EV sales are skewing towards heavier vehicles — this can and should be reverted

Share of EV sales by car size



Source: IEA Global EV Outlook (2024)