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Energy Storage Academy - Session on Battery Recycling and Reuse

01 February 2020

08:00 - 09:30 EST

14:00 – 15:30 CET

The Circular Opportunity

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Importance of Circular Economy

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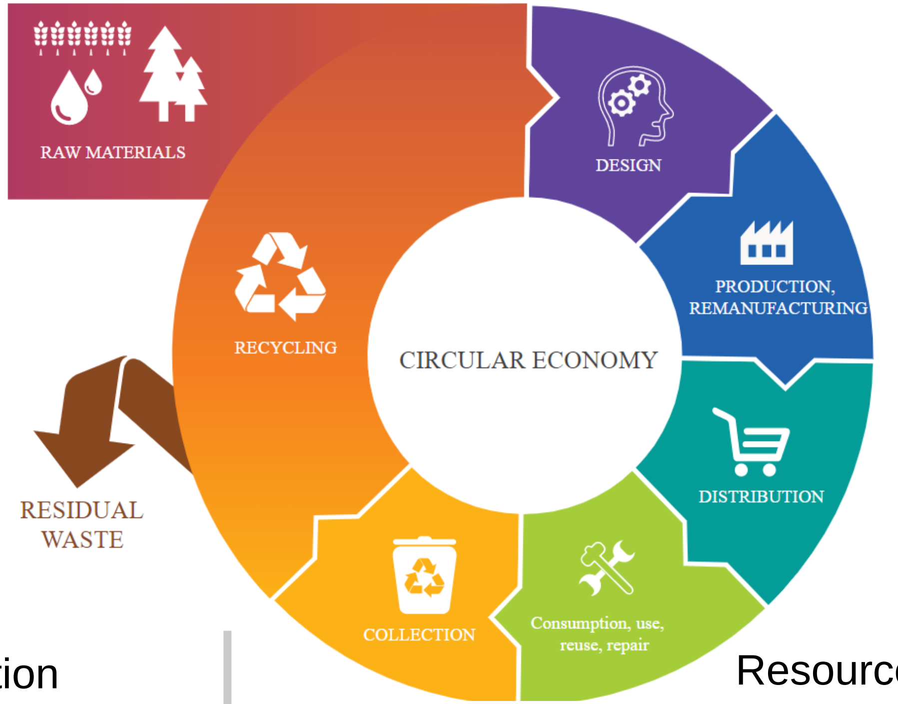
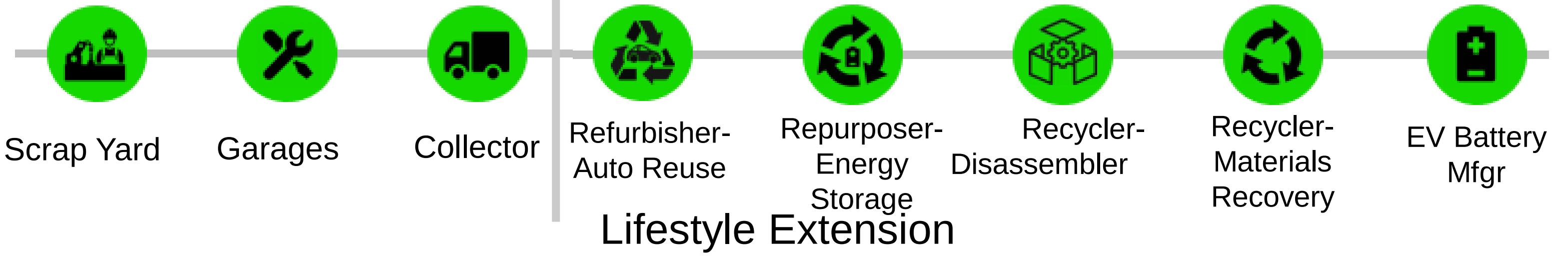
Establishing a circular battery value chain is a major driver for achieving the Paris Agreement

30% emission reduction in the transport and power sector

50% emission reduction in the battery value chain



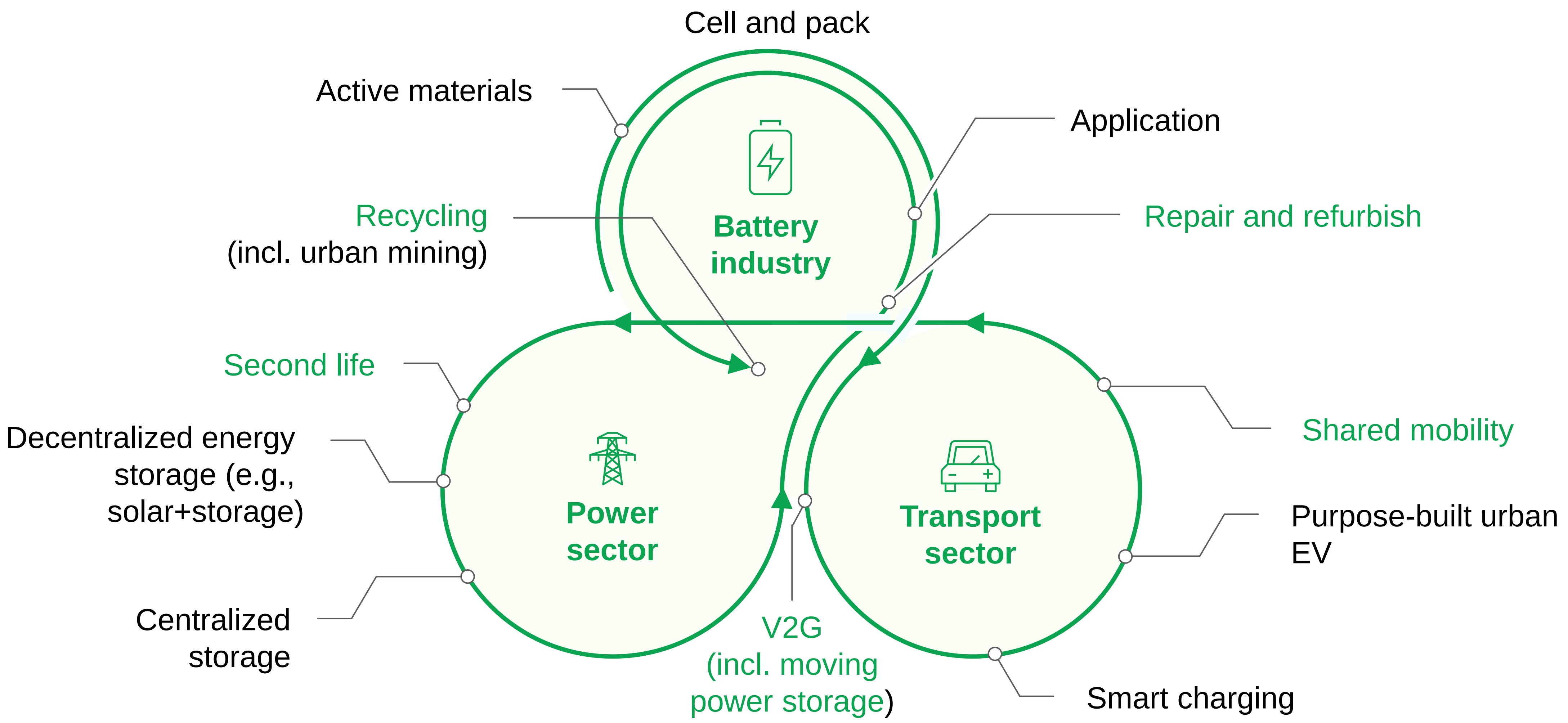


Impact of a sustainable value chain in 2030 – unattainable with business as usual

1 Sustainable Development Goals

SOURCE: World Economic Forum, Global Battery Alliance

Batteries enable **emission reductions** in transport and power – and help **couple the two sectors**



A circular battery value chain to couple transport and power sectors by 2030 globally, foundation for further sources of energy post 2030 (e.g., hydrogen, power to liquid) to stay below 2°C Paris Agreement target

SOURCE: GBA

GBA's circular battery vision shows batteries can deliver multiple SDGs beyond energy access, if recycling and repurposing markets scale up

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Outputs

- Reduced demand for primary raw materials
- Reduced hazardous waste
- Lower costs of energy storage
- New or expanded supply chains

Outcomes

Sustainable consumption	*~60% cobalt sourced from DRC*
Decrease in environmental pollution	*1 in 3 children impacted by lead contamination globally*
Scale up of variable renewable energy & reduced GHG emissions	*Renewables capacity grows 2x as fast in a SDG7 scenario vs under Africa's stated policies*
Increased access to electricity, resulting in improved health and better education	*~25% lifecycle cost reduction in supply chain*
Boost to economic activity	*USD 150 billion added value globally*
Job creation and skills diversification	*5 million new jobs in emerging markets*

Results

Source: Globally Battery Alliance, 2019; S&P Global, 2020; Global Battery Alliance, 2019; IEA, 2020, World Energy Outlook

Battery Repurposing: Opportunities and Challenges

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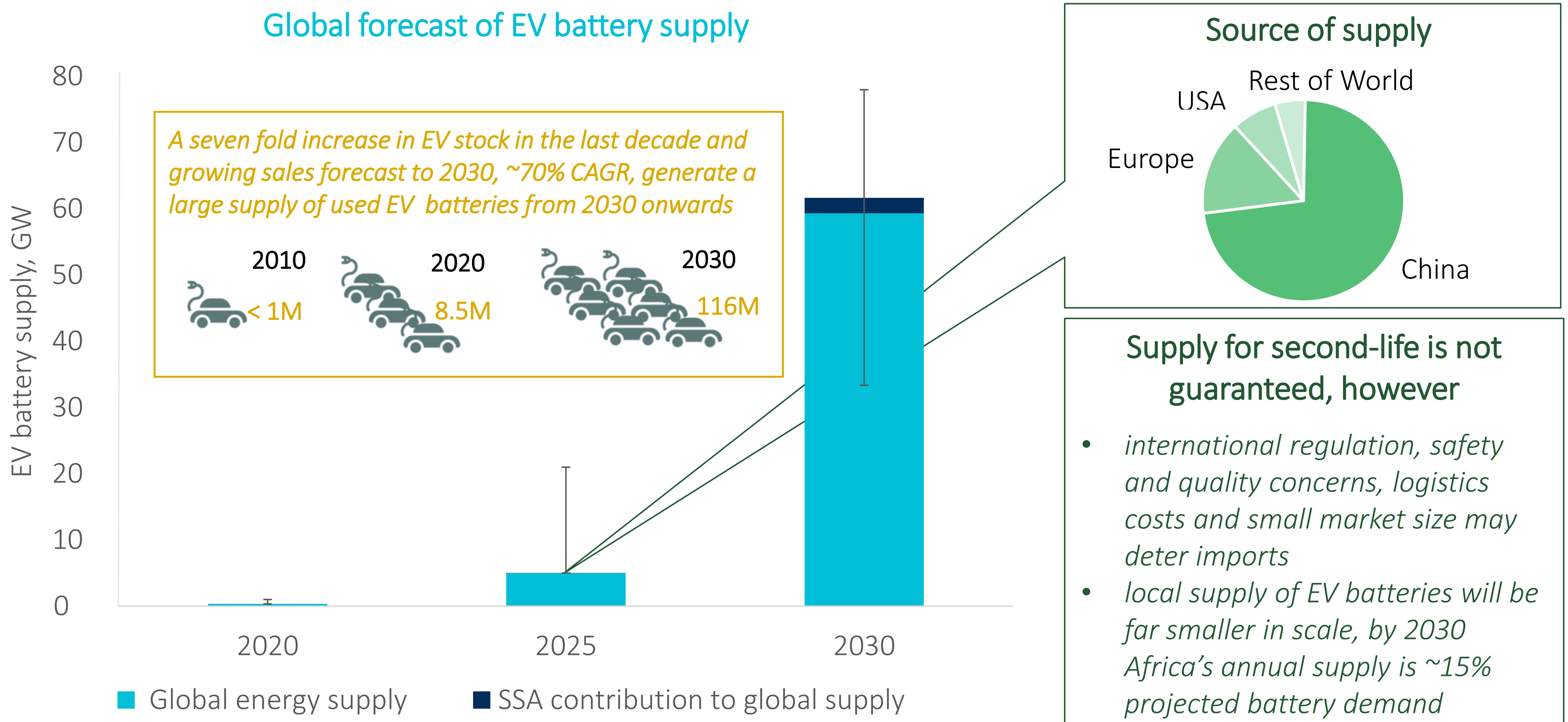
Globally, businesses are emerging within each stage of the EV battery repurposing supply chain

SUPPLY CHAIN:	FIRST LIFE BATTERY MANUFACTURING	REMANUFACTURING	SECOND LIFE APPLICATION
ACTIVITIES:	Design for second-life	Reducing costs & maximising performance	Testing new business models
EXAMPLES:	**4REnergy (Nissan and Sumitomo)** – closing the loop between Nissan EV batteries and utility-scale storage solutions	**RePurpose** – advanced battery management systems and real time state-of-health information **ReJoule** – battery diagnostic and management platform **SmartVille Energy –** harmonises refurbishing of different battery models.	**California** – BMW, EVGo and University of California San Diego **France** – United Technologies Research Centre Ireland and Nissan **UK** – Gateshead College, Nissan and University of Warwick **Germany** – RWTH Aachen Uni., City of Kempten, Daimler and Mobility House **Netherlands** – Nissan

Notes: *State of health refers to* information about the capacity, voltage, self-discharge… of a battery, relative to its ideal condition. *Battery diagnostic / management platform or system refers to an* online platform to monitor real-time state-of-health data produced by the battery.

Opportunities for repurposing emerge from the supply of retired EV batteries, ~60 GW per year in 2030 - almost 2x Africa's SDG 7 battery market



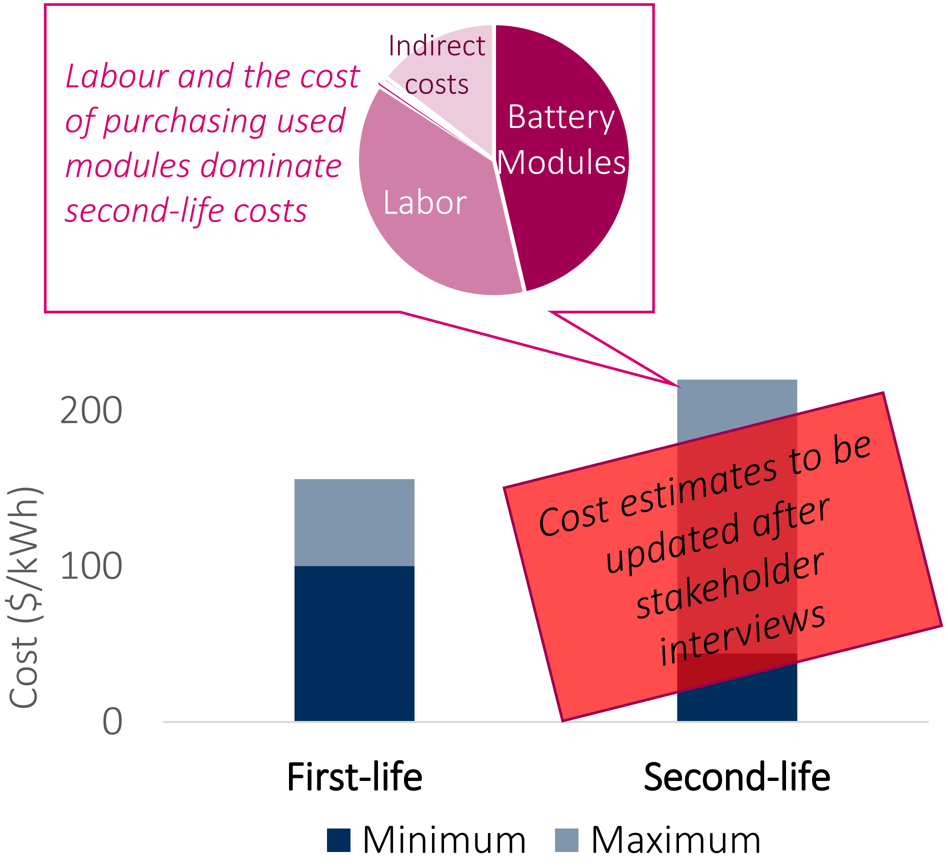
Supply for second-life is not guaranteed, however

- *international regulation, safety and quality concerns, logistics costs and small market size may deter imports*
- *local supply of EV batteries will be far smaller in scale, by 2030 Africa's annual supply is ~15% projected battery demand*

Notes: Sensitivity bars signify variance between McKinsey base case until 2025 & Circular Energy for 2030 and max. and min. of McKinsey, Circular Energy, Berylls Strategy Advisors and IEA SPS & SDS projections. Sub-Saharan Africa supply of batteries projected from DNV GL, 2020. CAGR = Compounded Annual Growth Rate. Sources: IEA, 2019, 2020; McKinsey, 2019; Circular Energy, 2019; Berylls Strategy Advisors, 2018; DNV GL, 2020; BNEF, 2020

Costs remain a key challenge to second-life markets, as most repurposing costs are highly uncertain and unreflective of energy access applications

Modelled estimates suggest second-life batteries could be cost-competitive with first-life batteries



Indirect costs includes taxes, insurance and administrative costs.

But, multiple sources of uncertainty affect real-world competitiveness to 2030:

Cost	*Sources of uncertainty*	*Likely pathways*
Purchasing used modules	Cost of alternative end-of life options	uncertain costs of recycling li-ion
	Cost of first-life batteries	declining costs of li-ion chemistries
Re-manufacturing process	First life battery information	state of health and use data improves
	Automation of disassembly and testing	standardisation of EV batteries
Transport and labour	Costs of certifying batteries (before and/or after re-manufacturing)	creation of certified quality standards
	Location of the remanufacturing process	scale of the EV market in Africa

Increases costs by 2030

Decreases costs by 2030

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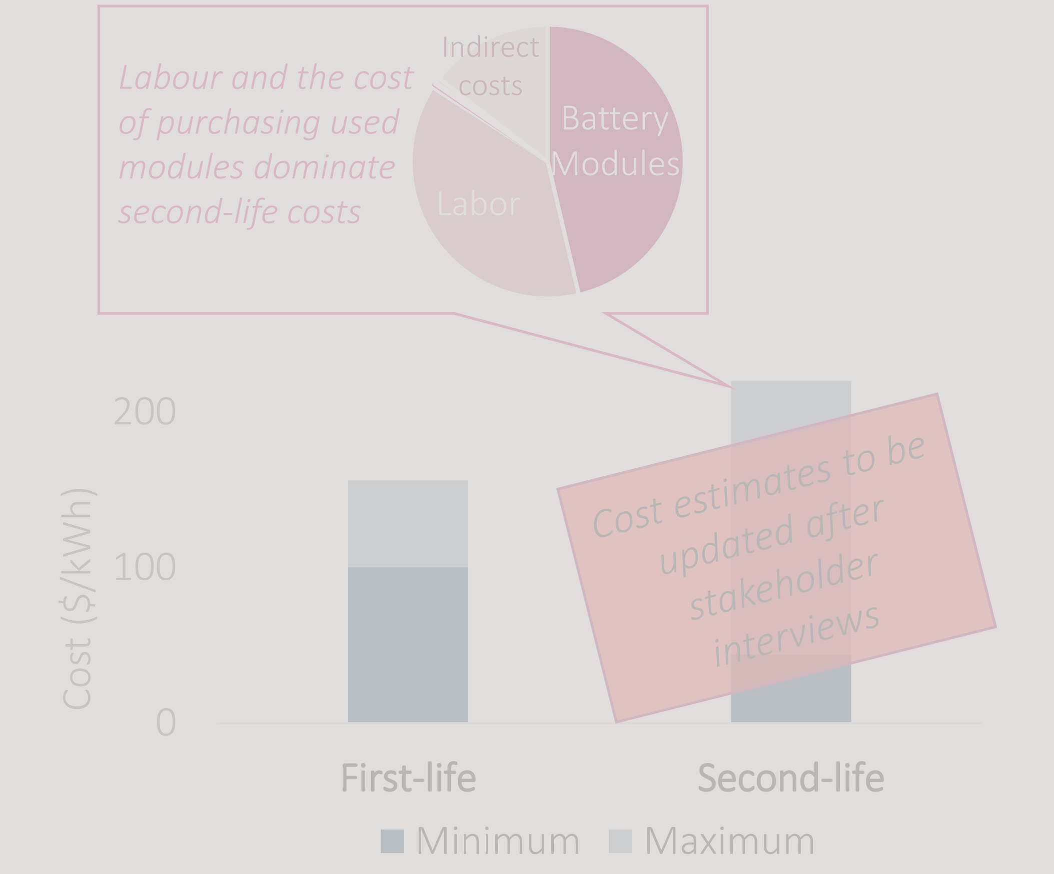

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Increases costs by 2030

Decreases costs by 2030

Under a model of EV industry coordination and investment, second-life battery costs could decrease by as much as [to be determined] % by 2030

We consider three potential cost pathways for second life batteries to 2030, each of which is affected by the key cost levers:

(1) First-life battery design and data sharing

will affect re-manufacturing costs

(2) Location of battery supply chain

will affect labour and transport costs

Scenario A: Coordinated & OECD-led

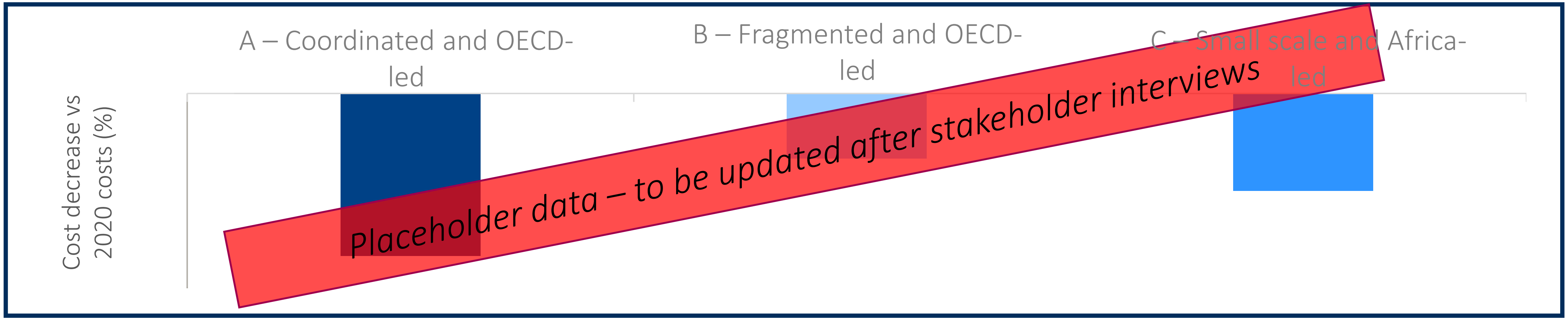
OEMS invest in BMS and design for second life. Modules are re-manufactured in OECD markets before export to Africa for assembly and use.*

Scenario B: Fragmented & OECD-led

OEMs fail to invest in BMS or design for re-purposing. Re-manufacturing occurs in OECD markets, as in Scenario A.

Scenario C: Small scale & Africa-led

Batteries from local EV and stationary applications meet small scale local battery demand. Low technology levels.



Notes: OEMS refers to Original equipment manufacturers (such as vehicle band battery manufacturers); BMS stands for battery management systems.

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Safety and performance concerns remain key challenges to market growth however, even as second life batteries become cost competitive

POOR MARKET OUTCOMES

- Low consumer appetite
- Strong political opposition
- Limited industrial activity

CHALLENGE

Safety & Performance remain critical barriers to market uptake

UNDERLYING CAUSES

Weak regulation

- no second-life certification
- unclear liabilities during repurposing & second-life
- no supplier warranties

Poor supporting evidence

- lack of performance data under local operating conditions

Negative past experiences

- first life battery failures*
- hazardous waste dumping
- accidents in battery handling facilities

Note: even amongst new batteries, ~50% top-selling products non-quality verified products failed battery storage durability tests and ~90% lacked warranties
Source: Lighting Global (2018)

Öko-Institut e.V. Institut für angewandte Ökologie Institute for Applied Ecology
:vivideconomics

Recycling

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Challenges

CHALLENGES

- Material recovery of certain technologies is not cost effective → Collection is not incentivised
- Low collection rates → Collection is not incentivised
- Recycling facilities non-existent or not up to standards → Recycling becomes costly due to transport
- Recycling facilities non-existent or not up to standards → Health and environmental implications
- Low Collection rates (e-waste)

POSSIBLE SOLUTIONS / OPPORTUNITIES

Policies developed: EPR systems, take back systems etc

Working with distributors

Quota on recyclced content for new products

Declaration of % of recycled content from producers

Collection targets towards manufacturers

Technology: increased recycling efficiency

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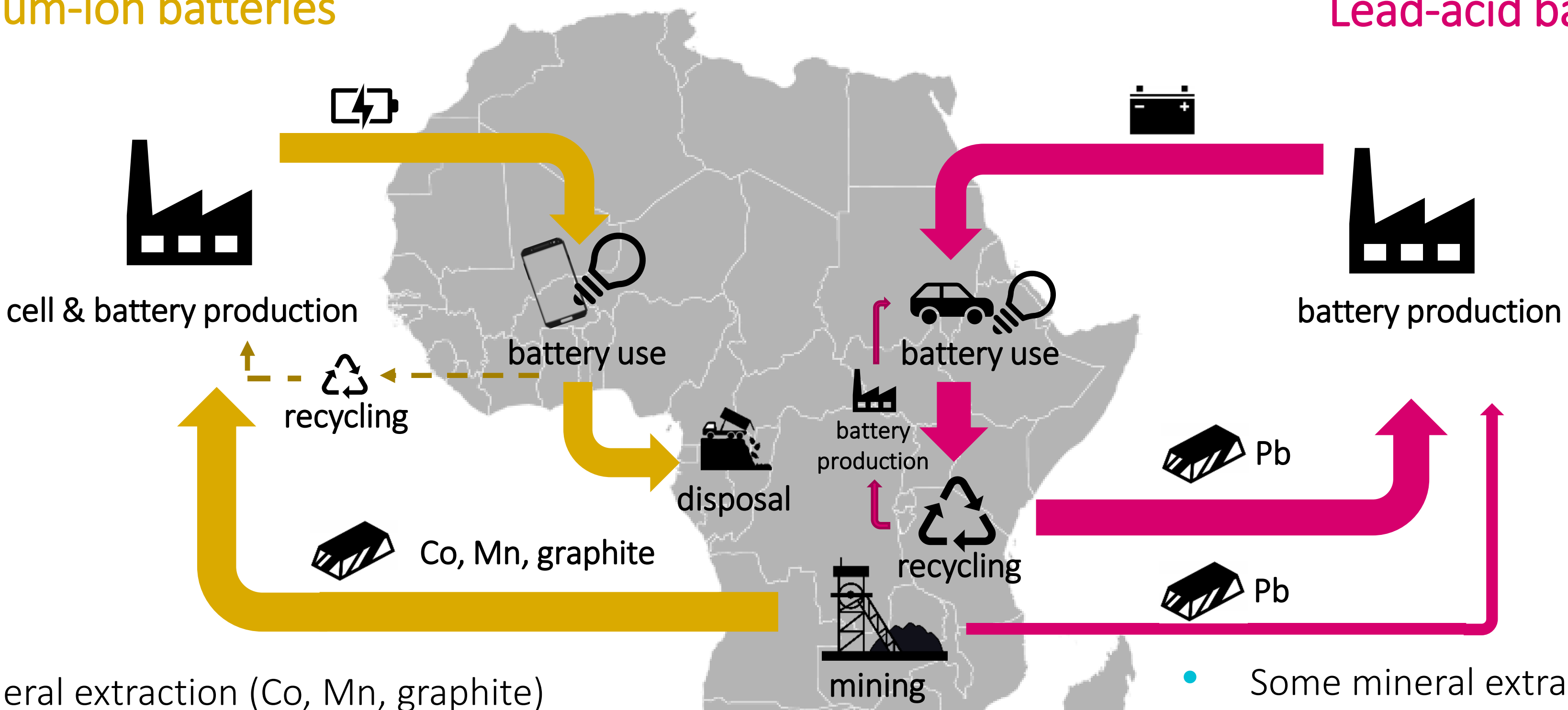
Africa's end-of-life management is dominated by lead acid recycling, with limited lithium-ion recycling or repurposing

Lithium-ion batteries

Lead-acid batteries



- Major mineral extraction (Co, Mn, graphite)
- Exclusively foreign production
- No established collection & recycling. Uncontrolled disposal
- Exports for recycling still in infant stage
- Some local re-use/repurposing supply chain

- Some mineral extraction (Pb)
- Mostly foreign production but some local producers
- Established collection & recycling (formal & informal)

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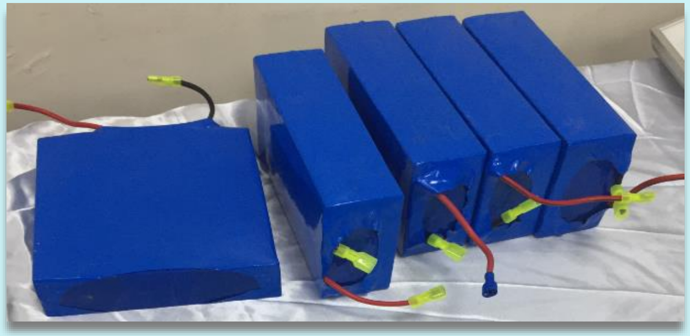
Collection and recycling of lithium-ion batteries is almost non-existent to date

Market status



Electronics applications

- Volumes of lithium-ion mostly from notebooks and mobile phones
- No established recycling in Africa
- Net material values ~ 0-1000 €/t depending on cobalt price
- Ambitious safety requirements for transport, storage and shipments
- Indicative shipment costs ~ 500 €/t

➡ Recycling is currently not economically viable

Energy access applications:

- EoL volumes are negligible
- Li-ion battery chemistries (mostly LFP) are unattractive for recyclers (treatment costs > revenues from material recovery)

➡ Recycling is even less viable

➡ A switch to repurposed EV batteries will not significantly change this dilemma

Issues & impact

➡ Without changed framework conditions, Li-ion batteries from energy access projects will not be collected and recycled.

➡ The most likely fate is dumping (either on existing landfills, on uncontrolled dumpsites, or openly burned together with other waste)

➡ Safety issues, pollution problems, loss of battery resources

Sources pictures 1-3: Oeko-Institut e.V.

Öko-Institut e.V. Institut für angewandte Ökologie Institute for Applied Ecology
:vivideconomics

Key challenges to lithium-ion battery recycling are low material values and high logistics costs

Recommended recycling option:

- Export to foreign recyclers
- Properly packaging (e.g. in UN-rated barrels and embedded in sand)
- Prior-informed-consent procedure (according to the Basel Convention)

Pilot exercise by Hinckley and Closing the Loop:

- 5t of batteries shipped from Nigeria to Belgium
- Initial cost: ~ 70,000 € (including start-up costs)
- Best case scenario costs: ~ 7,000 €
- Revenue from materials: ~ 2,500 €

Source picture 1: Oeko-Institut e.V.; source picture 2: Closing the Loop

Q&A

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Annex I – Market, Emissions and Costs

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Assumptions and data sources for the market sizing model

Scenario	Name	Description	Source	Notes
CD; F	Micro-level residential	Number of pico products and solar home systems	VE analysis for Lighting Global, *Off-grid Market Trends Report 2020*	• Impacts of COVID on sales are not taken into account • Sales in SSA are deduced from global sales • Storage capacity comes from previous VE analysis.
A				• Use the Global Electrification Platform (GEP) to calculate the number of people who will use pico lamps or SHSs for electricity in 2030. • Storage capacity comes from previous VE analysis.
CD; F; A	Micro-level productive use	Number of solar water pumps, small agricultural processing machinery, and coolers/freezers	Lighting Global, *PULSE Market Study*	• Storage requirements from expert analysis. • Storage demand is the same under the Market Forecast and Full Energy Access scenarios.
CD	Minigrids	Capacity used by consumers on mostly off-grid minigrids.	SE4All, *Mini-grids market report 2020*	• The storage to power ratio in minigrids is based on previous VE analysis.
F; A	Minigrids	Capacity used by consumers on mostly off-grid minigrids.	IEA, 2017, *Energy access outlook*	• The Market Forecast figure is based on the IEA's "Stated Policies" scenario • The Full Energy access figure is based on the IEA's "Energy Access" scenario. • The storage to power ratio in minigrids is based on previous VE analysis.
CD; F	Utility-scale	Point estimates of stationary utility-scale storage in 2020 and 2030	IEA, commentary on storage and flexibility	• One-off data points.
A	Utility-scale	Number of people connected to the grid in 2030 under least-cost electrification scenarios.	Global Electrification Platform; IEA data, 2018; IEA,2017, *Energy Access Outlook;* Carbon Tracker, 2018	• The number of people connected to the grid in 2030 is multiplied by a household's electricity consumption, multiplied by the share of electricity generation from VREs and a factor for storage per VRE generation.

CD: Current Demand. F: market Forecast. A: full energy Access. VE: Vivid Economics. SSA: Sub-Saharan Africa. VRE: Variable Renewable Energy.

Annex II - Background

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GBA vision: the potential of a sustainable battery value chain in 2030

Establishing a circular battery value chain is a major driver for achieving the Paris Agreement

30% emission reduction in the transport and power sector

50% emission reduction in the battery value chain

Transforming the economy in the value chain creates new jobs and economic value

10 m additional jobs

150 bn in economic value generated in a responsible and just value chain

35% increase in battery demand

Safeguarding human rights and economic development is in line with the UN SDGs[1]

600 m additional people with access to electricity, reducing the gap of people without electricity by 70%

Ensuring safe working conditions, fostering anti-corruption practice and eliminating child/forced labor

Additional impact of a sustainable value chain in 2030 compared to business as usual – unattainable with business as usual

1 Sustainable Development Goals

SOURCE: World Economic Forum, Global Battery Alliance

The impact of the global battery industry spans across all United Nation Sustainable Development Goals

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… and provide access to clean energy, create economic value, and jobs

~850M people of which lack access to electricity world wide, 67% in Sub- Saharan Africa (2017)

Batteries, in battery-solar systems and as part of microgrids and off-grid solutions, enable affordable energy access for around 600 million people, reducing the gap of households without electricity by **70%.**

Batteries contribute to the UN SDGs directly and indirectly. They enable decentralized and off-grid energy solutions. Bringing energy ton people without access to electricity today can increase productivity, improve livelihoods and improve health on a large scale.

Battery industry created **~$40B** economic value in 2018, and grew annually at ~15% last decade

We estimate that **~2M** people are employed in the battery value chain, of which >1.6M work in developing countries (2018)

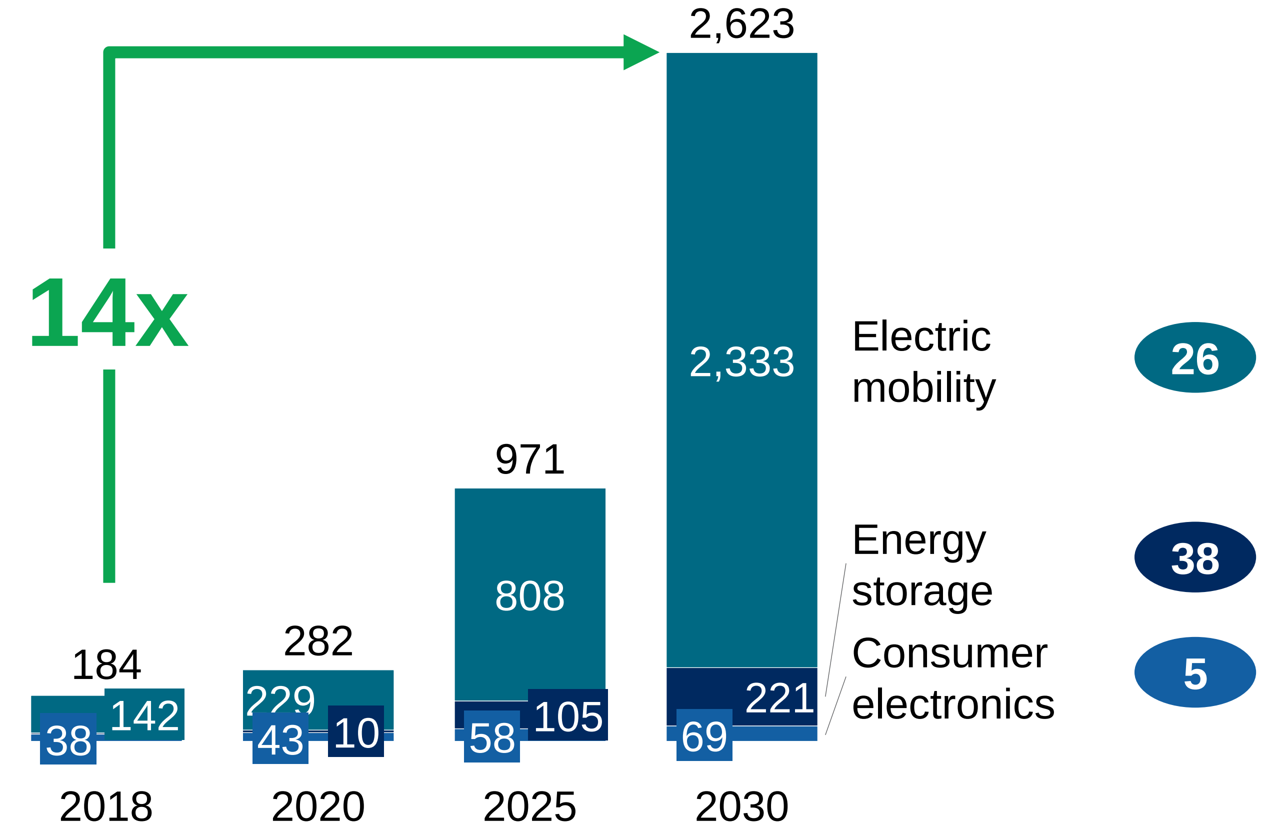
Addressable United Nations Sustainable Development Goals

SOURCE: World Bank; United Nations Sustainable Development Goals; McKinsey

1 Compared to today, global battery demand is expected to grow by a factor of ~14 to reach ~2,600 in 2030

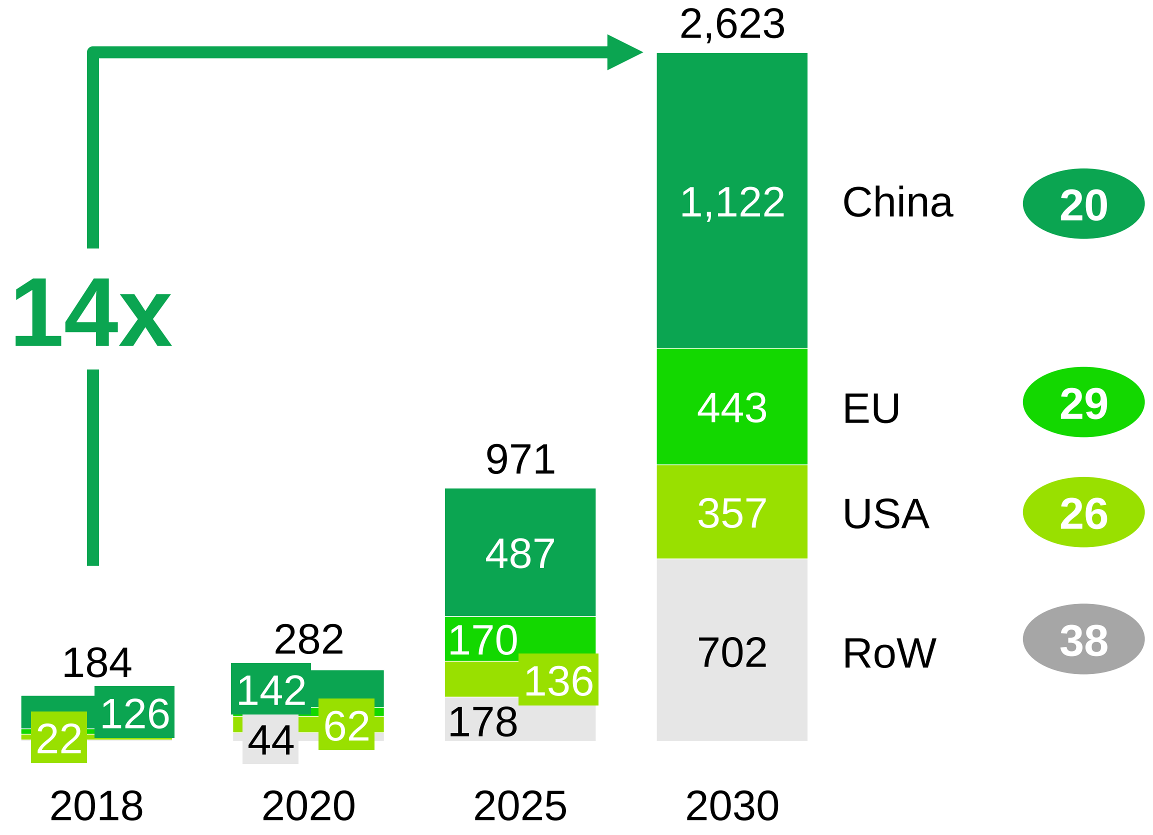
Global battery demand by application
GWh in 2030, base case

CAGR
% p.a.



Global battery demand by region
GWh in 2030, base case

CAGR
% p.a.



1 2018 and 2030 battery demand varies by region and application – China and electric mobility expected to be the largest markets in 2030

2030 / 2018 ##x growth factor '18 to '30
250 GWh/year

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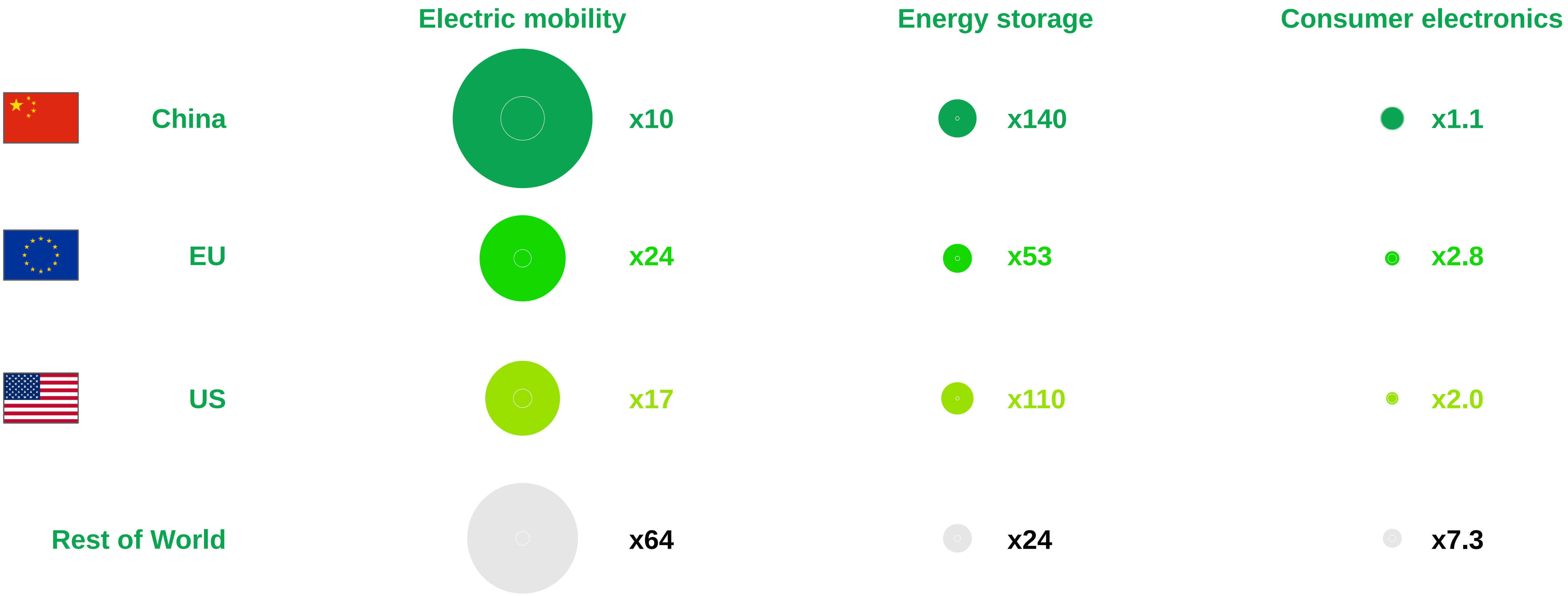
Global battery demand by application and region

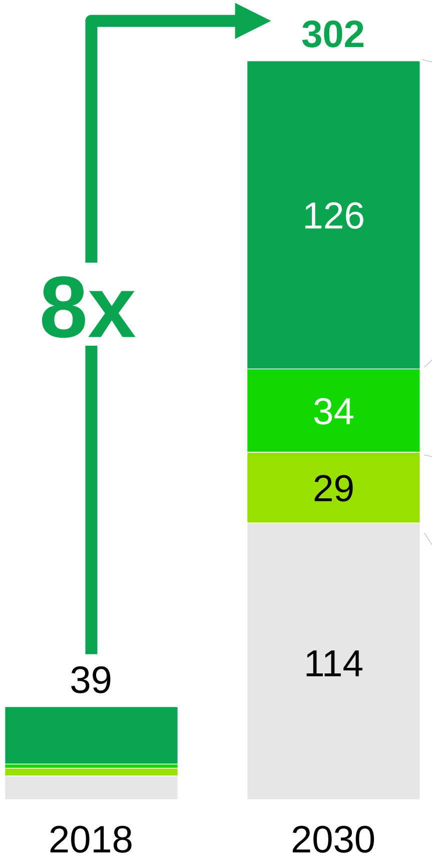
GWh in 2030, base case



SOURCE: McKinsey

2 The Li-ion battery value chain provides **revenue opportunities** of $300 billion by 2030 – cell manufacturing comprises the largest share

Revenues, base case 2030, $ billion

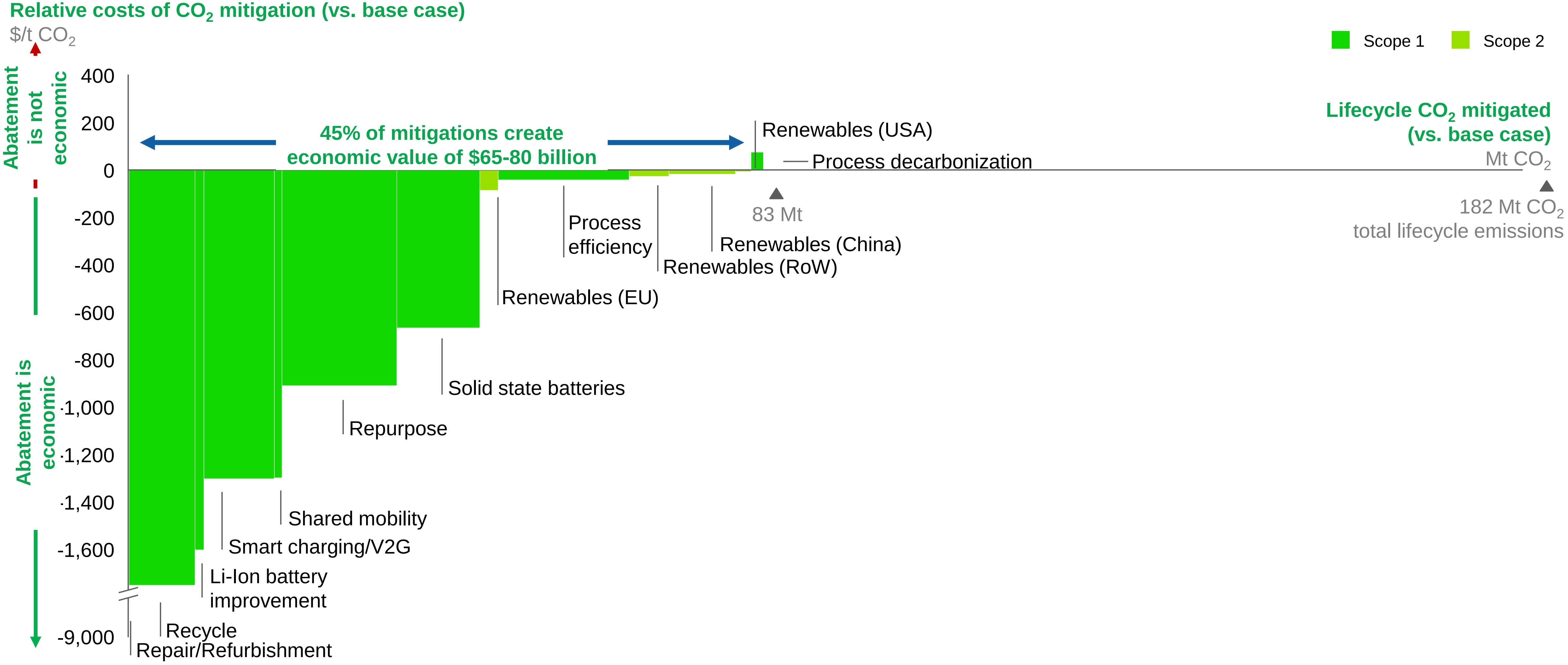


	Mining	Refining	Active materials	Cell	Pack	Reuse & recycle
Total	**8** (3%)	**74** (25%)	**25** (8%)	**137** (46%)	**47** (16%)	**11** (4%)
	2	17	15	64	20	8
	0	1	2	21	8	1
	0	1	2	17	6	1
Rest of world	6	55	5	34	13	1

NOTE: Calculated based on demand from mobility, energy storage, and consumer electronics applications as well as battery pack prices for 2030 (not including lead-acid batteries)

SOURCE: McKinsey

3 CO2 abatement curve shows potential of economic levers to reduce battery value chain emissions



3 Target case lifecycle EV emissions can improve significantly due to circular levers and more renewable energy deployment across the value chain

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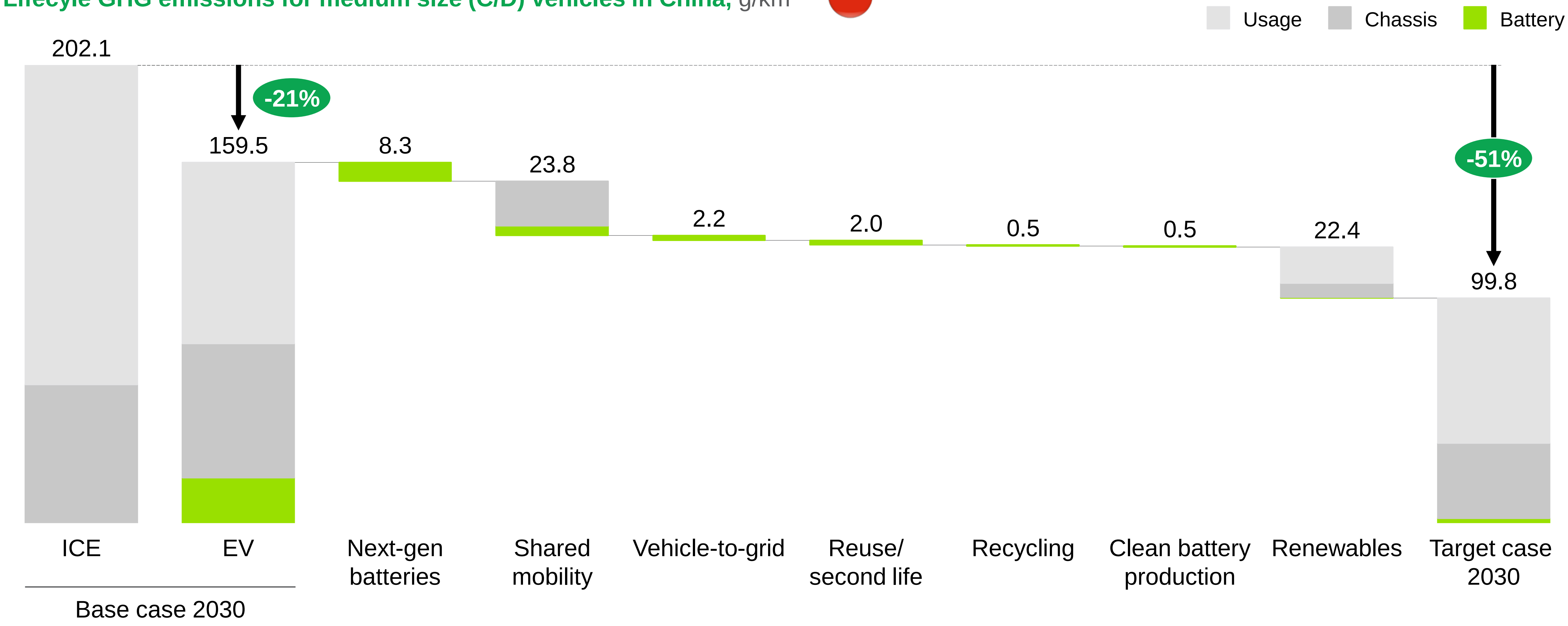
Lifecyle GHG emissions for medium size (C/D) vehicles in China, g/km[1]

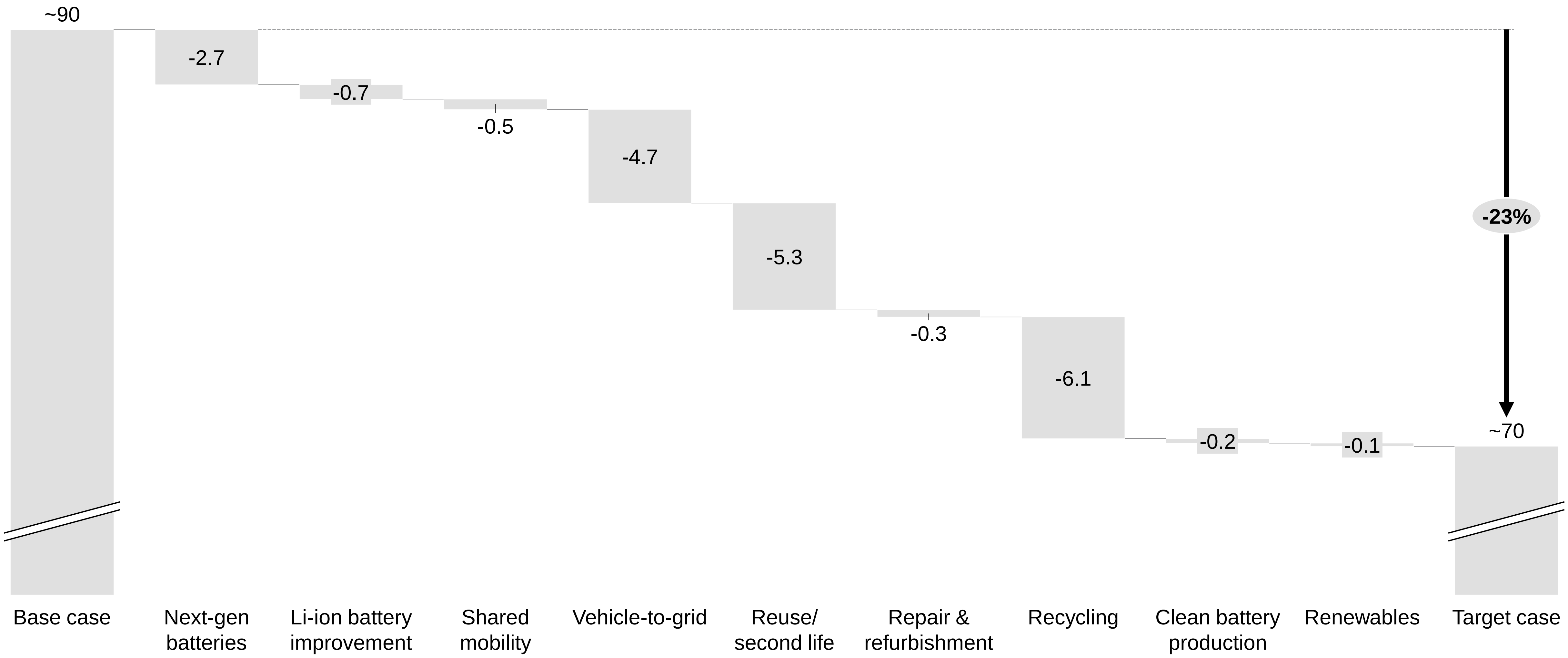


1 Key assumptions - vehicle lifetime: 200,000 km = 13 years x 15,000 km p.a.; BEV energy consumption (kWh/km): 0.18 (2018), 0.16 (2030); battery sizes: 50 (2018), 60 (2030); battery production emissions (kgCO2e/kWh): 138 (2018), 71 (2030); electricity carbon intensity (gCO2e/kWh): 655 (2018), 411 (2030); ICE use emissions (gCO2e/km): 146 (2018), 116 (2030); emission factor of fuel production: 21%

SOURCE: McKinsey, SYSTEMIQ

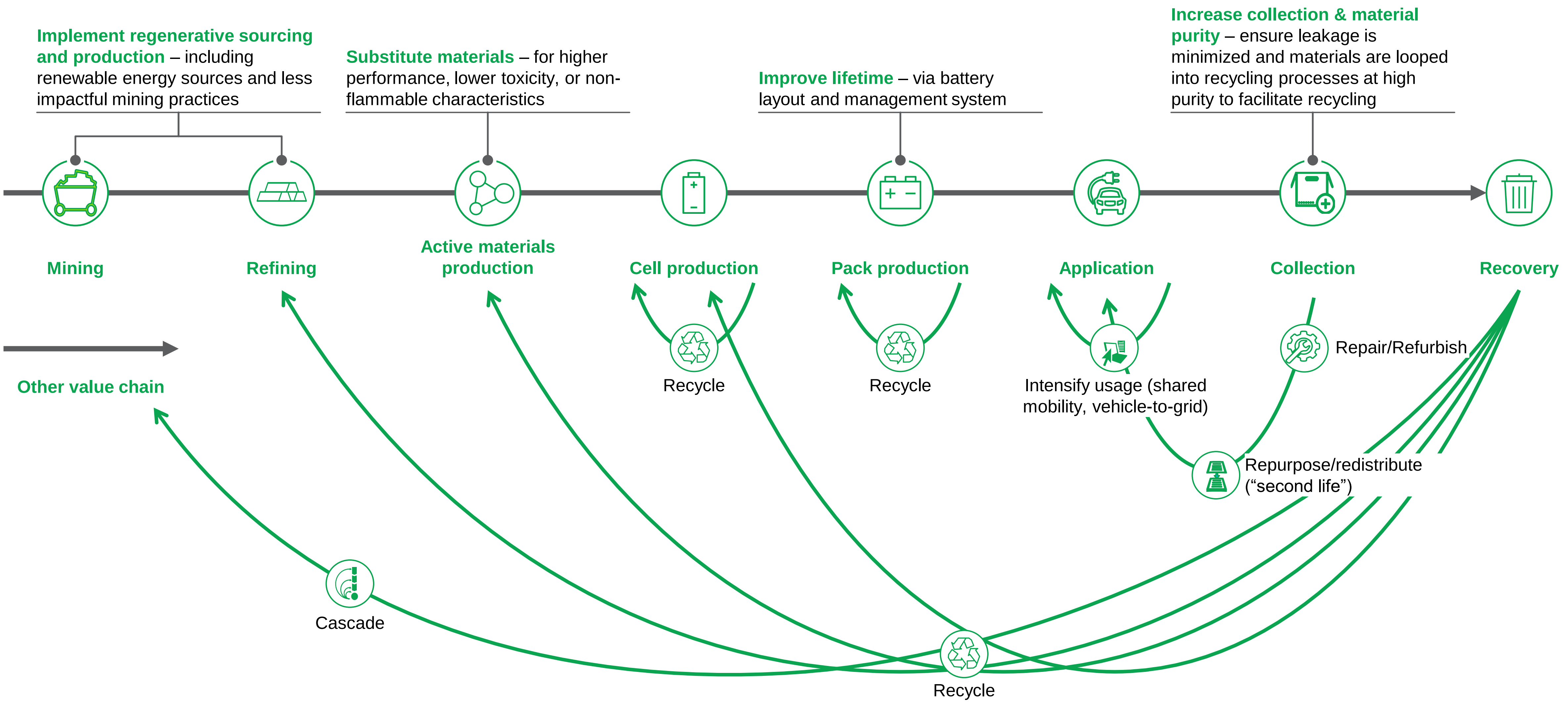
3 The target case levers contribute to further battery cost reductions 23% in 2030 and, therefore, drive adoption even further

Example passenger car, average cost, in USD/kWh



SOURCE: McKinsey, SYSTEMIQ

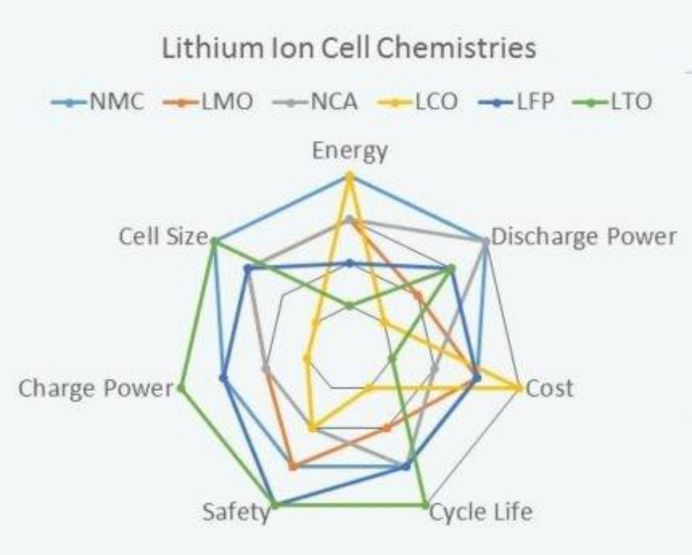
3 A variety of levers address challenges and support achievement of the target state – Overview of circular economy levers for batteries



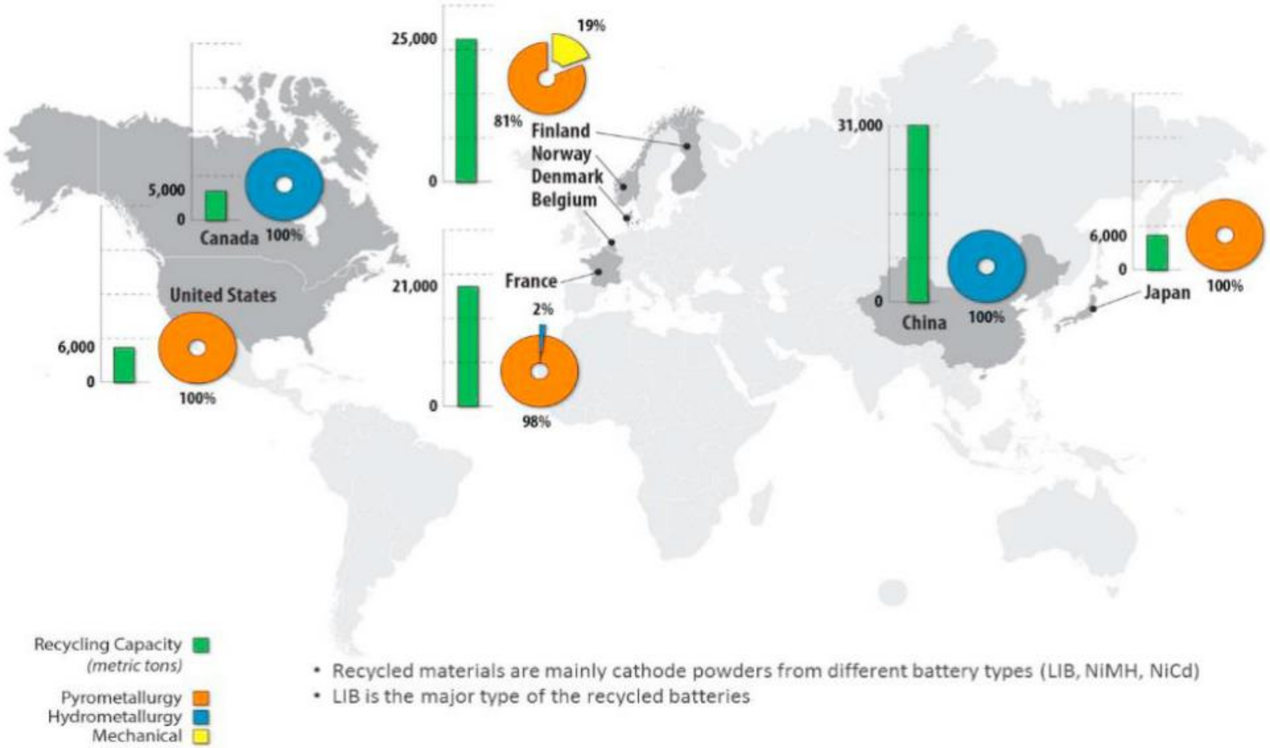
SOURCE: McKinsey, SYSTEMIQ

Li-Ion technologies and applications

Acronym	Cathode (+)	Anode (-)	Examples of Evs using this technology	Utility Storage
NMC	nickel manganese cobalt	Graphite	Renault, VW, Honda, Chevrolet	Yes
LFP	lithium iron phosphate	Graphite	BYD, Tesla	Yes
LMO	lithium ion manganese oxide	Graphite		
NCA	nickel cobalt aluminum	Graphite	Tesla	
LCO	lithium cobalt oxide	Graphite		
Blended chemistries			Nissa, Ford, Mitsubishi	



Global Recycling Capacity



SOURCE: Chen, Mengyuan & Ma, Xiaotu & Chen, Bin & Arsenault, Renata & Karlson, Peter & Simon, Nakia & Wang, Yan. (2019). Recycling End-of-Life Electric Vehicle Lithium-Ion Batteries. Joule. 3. 10.1016/j.joule.2019.09.014.
Economics and Challenges of Li-Ion Battery Recycling from Endof-Life Vehicles, Darlene Steward*, Ahmad Mayyas, Margaret Mann, NREL, 2019

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