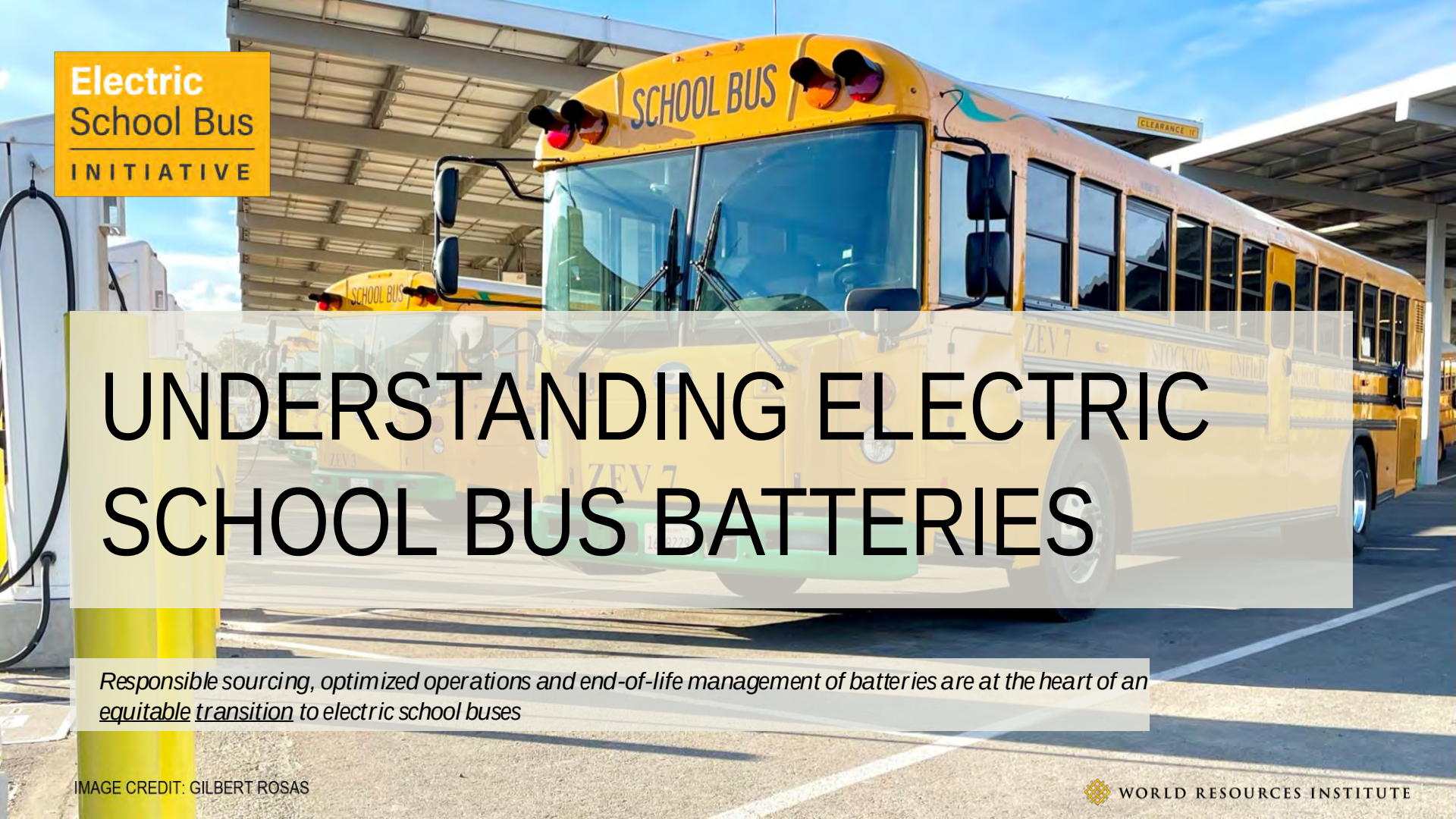

UNDERSTANDING ELECTRIC SCHOOL BUS BATTERIES

Responsible sourcing, optimized operations and end-of-life management of batteries are at the heart of an equitable transition to electric school buses

IMAGE CREDIT: GILBERT ROSAS

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MORE STUDENTS ARE RIDING ELECTRIC SCHOOL BUSES

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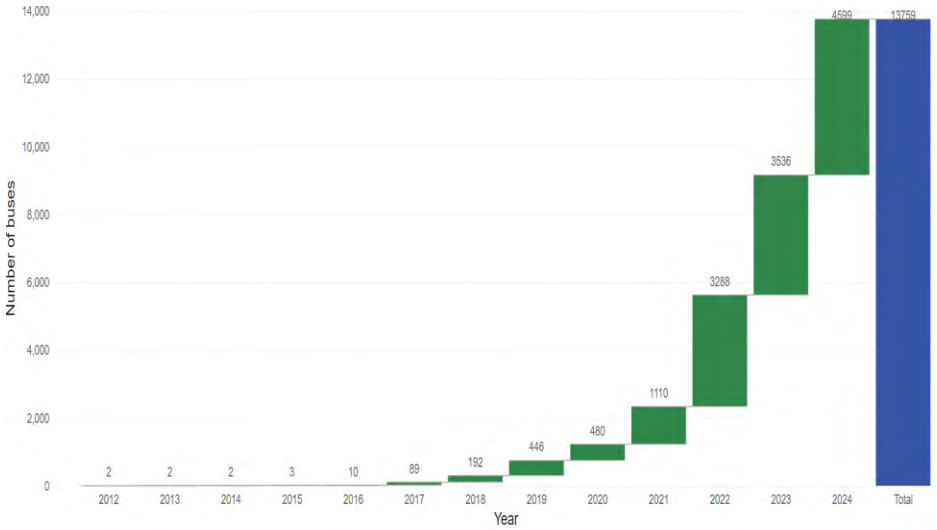

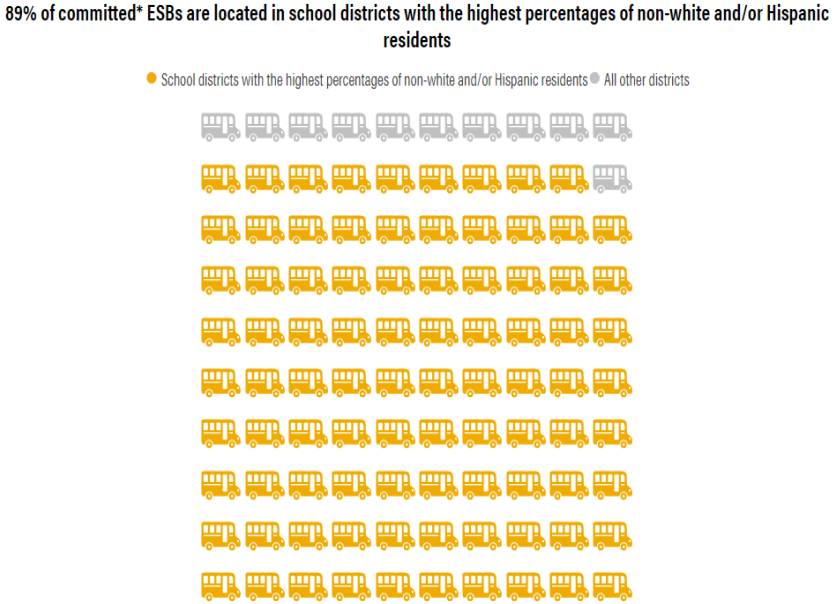

Nearly 14,000 bus batteries (Over 2.1 GWh*) already committed to be on the road, mostly in communities of colour

Source: [The State of Electric School Bus Adoption in the US | Electric School Bus Initiative](); *assuming 179 kWh as average ESB battery capacity

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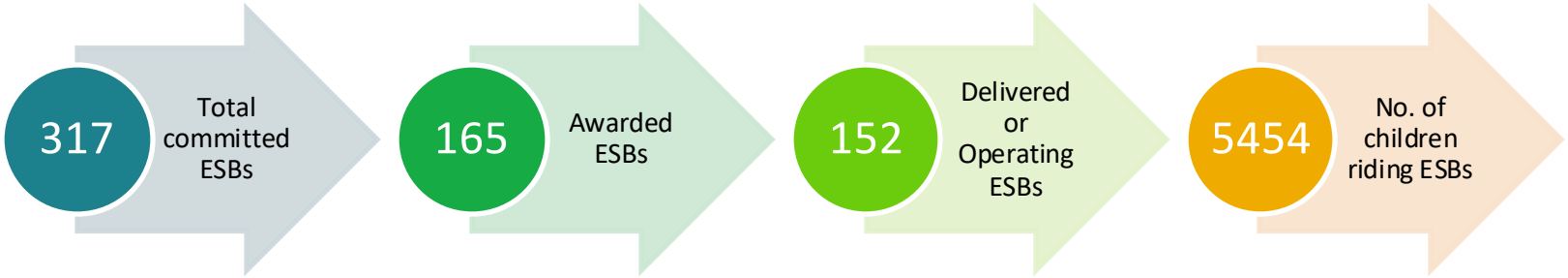
IN MICHIGAN – AS ON FEB 2024



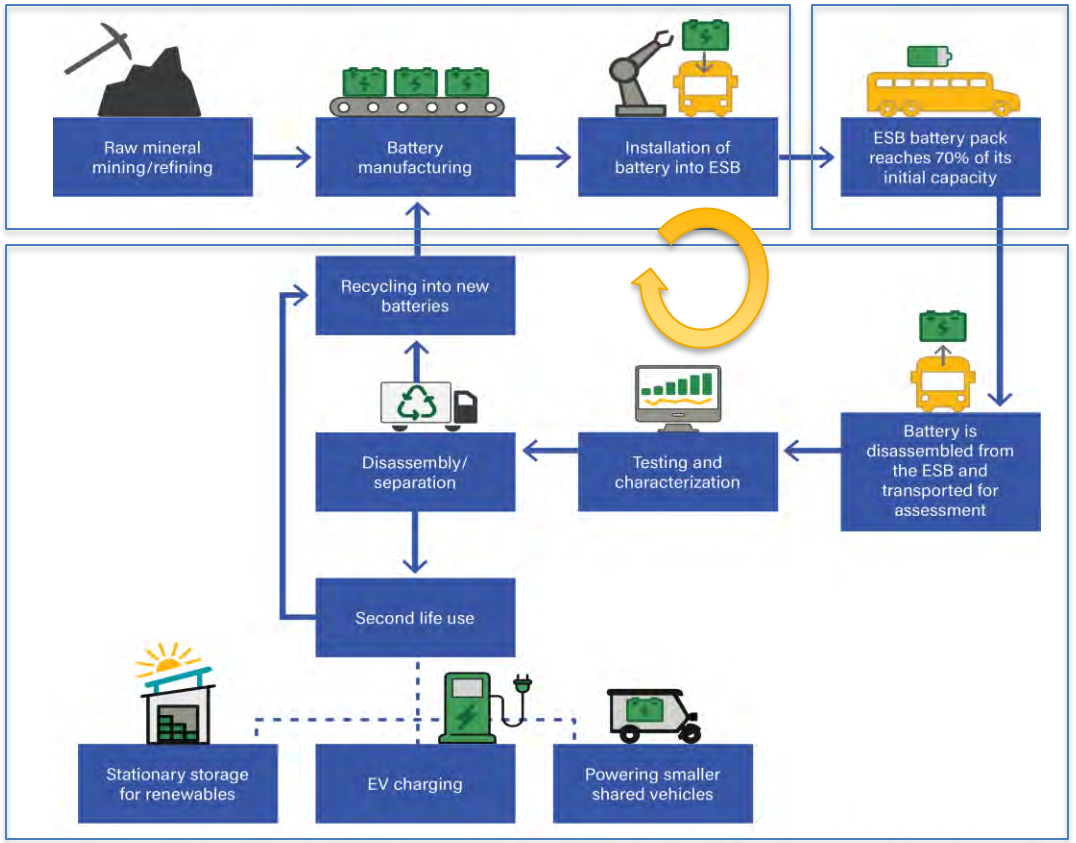
Source: Electric School Bus Data Dashboard | Electric School Bus Initiative

AGENDA

Supply chain

Operations

End-of-life (EOL) management



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CHEMISTRY

Foundational to understanding battery lifecycle

HOW DOES AN EV BATTERY CELL WORK?

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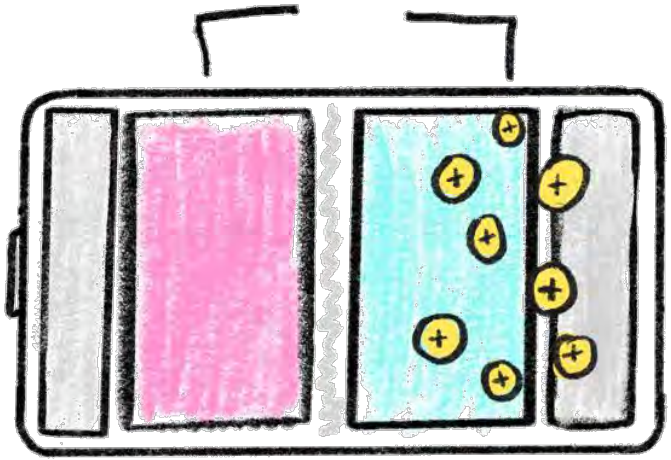
CATHODE
- Li-Metal oxides
  - Nickel
  - Cobalt
  - Manganese
  - Iron
  - Phosphorus
  - Aluminum
- Over 50% of cell cost
- Primary recyclable material of the cell



ANODE
- Graphite, Zinc

ELECTROLYTE
- Help move Li-ions
- Traditionally in liquid-form (water, acids, alkalis)

When a battery is charging, lithium ions flow from the cathode to the anode
When it's discharging, the ions reverse course and flow from anode to cathode

Source: Bloomberg; Univ of Washington

WHY DOES CATHODE MATERIAL MATTER?

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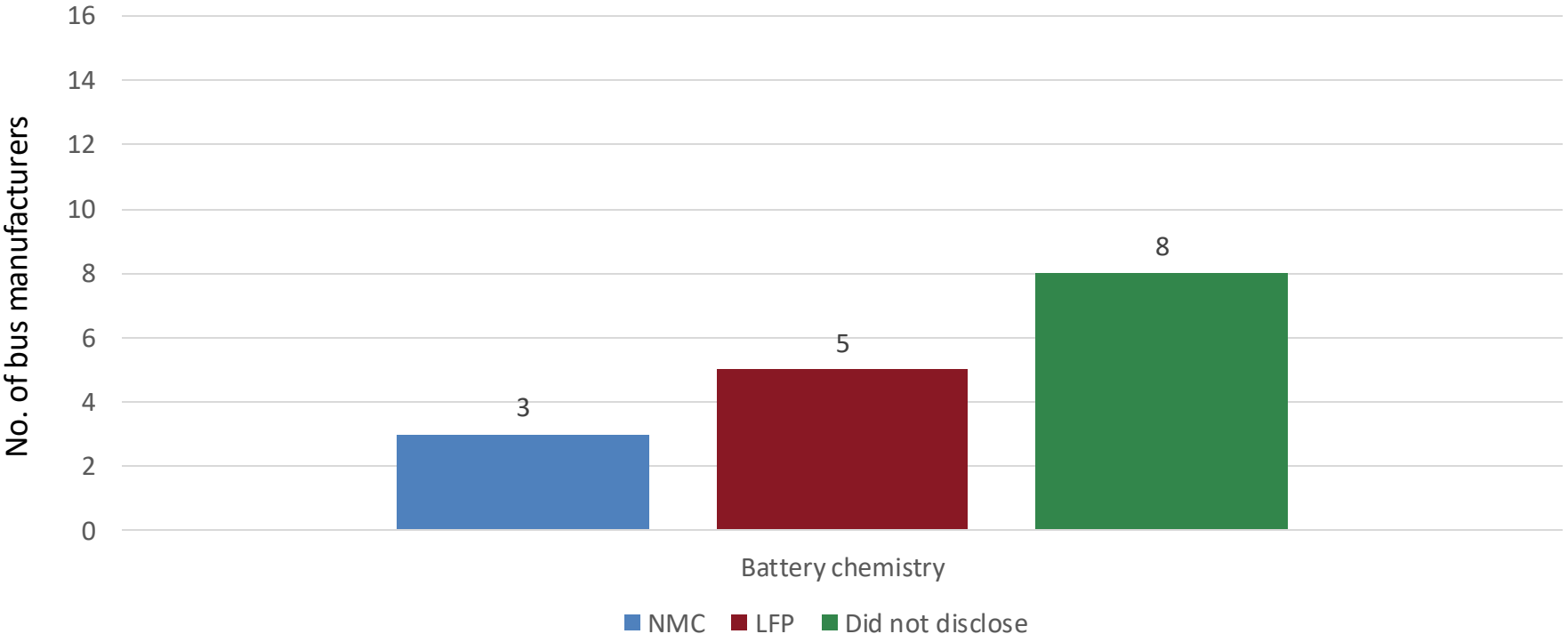
Cathode material	Nickel-Manganese-Cobalt (NMC/NMCA)	Lithium-Iron-Phosphate (LFP)
Availability/Cost	Concentrated in specific regions globally which can make it riskier and more expensive	Abundant raw materials which makes them more attractive where upfront cost is an issue
Safety	Safe due to extensive battery testing and compliance to international standards	More thermal stability, reducing the risk of overheating and runaway
Energy density	Higher energy density potentially allowing for longer driving range between charges	Most trip lengths can be met with current ESB models
Cycle and calendar life	Used in several EVs which have exceeded expectations of lifespan too	Typically, longer cycle life and better calendar life, meaning longer lifespan
Charging characteristics	Typically charge faster, which can lower downtime and improve efficiency	Charging time depends on a variety of factors including type of charger, bus capacity, etc.
Circularity	Better recycling economics due to higher commodity prices	Better suited for second life use applications like stationary storage for renewables, peak shaving, EV charging, etc.

The choice for fleet owners/operators would depend on operational needs, budget constraints and bus model availability

Source: LCA for electric buses; NMC and LFP safety; Second life storage; WRI research

ESB MANUFACTURERS BY CHEMISTRY TYPE



Source: WRI survey data

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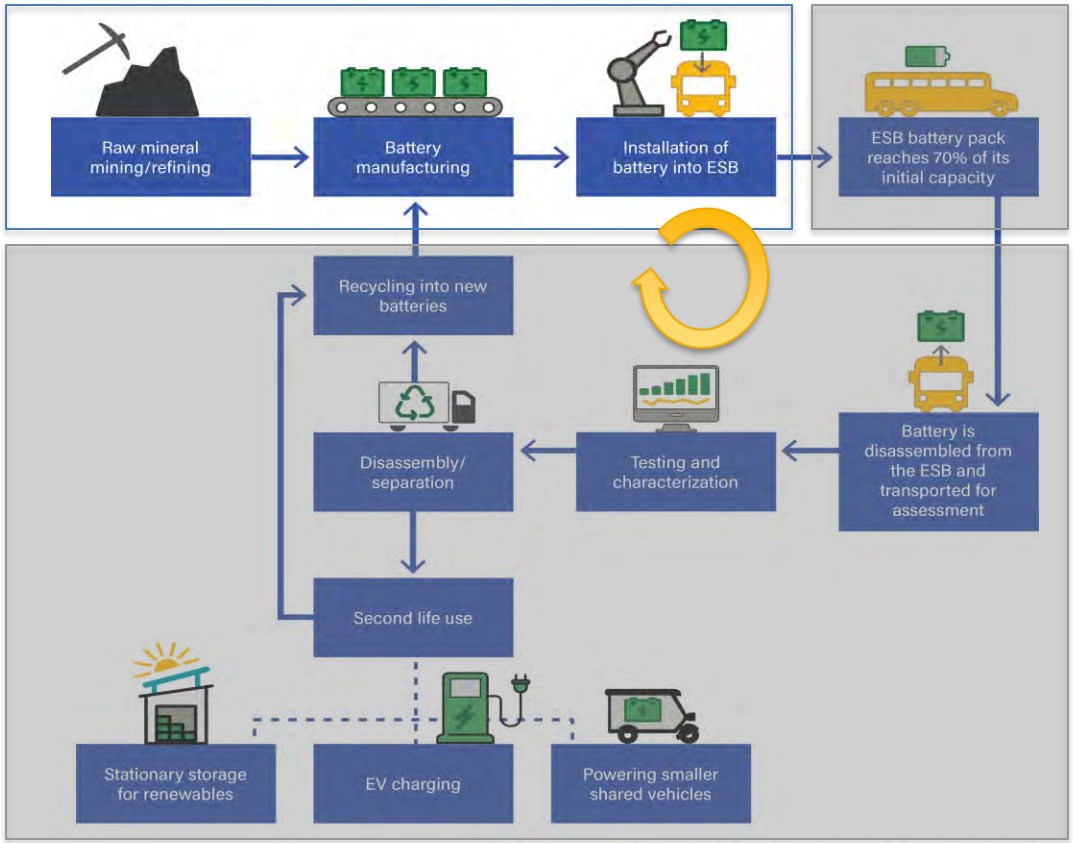
SUPPLY CHAIN

Transparency and disclosure of supply chains is critical to fleet owners

Electric school bus (ESB) battery value chain



Source: WRI.

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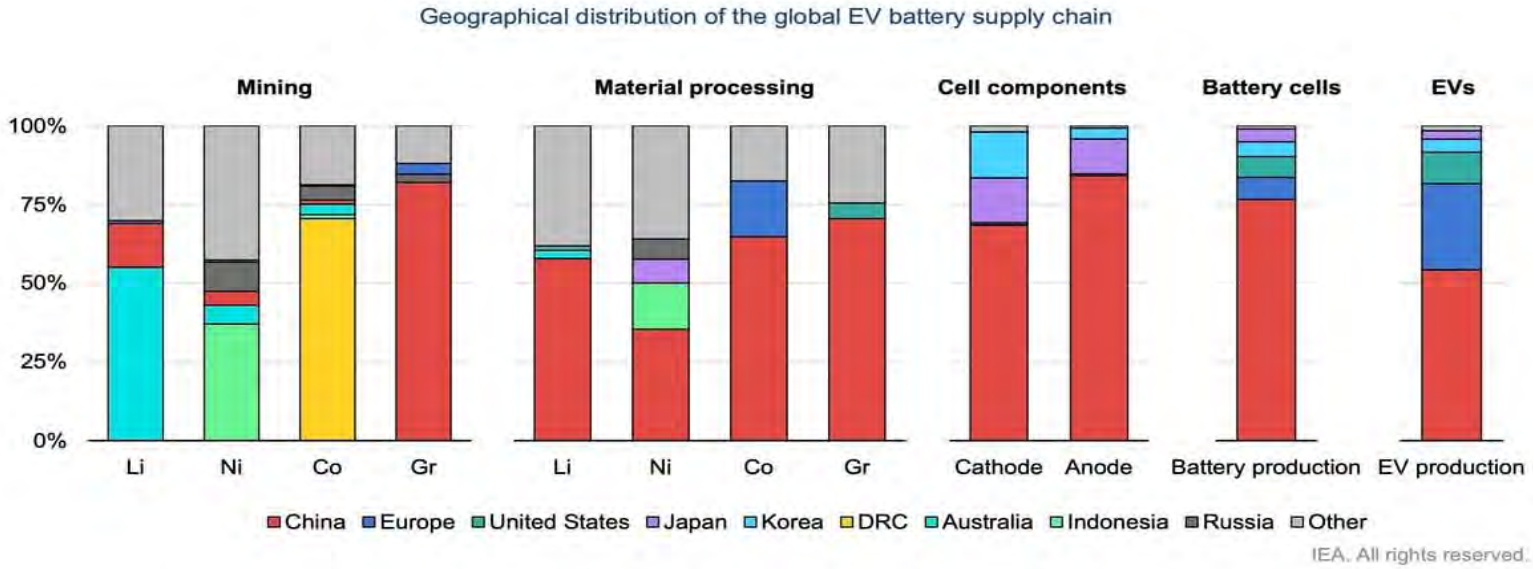
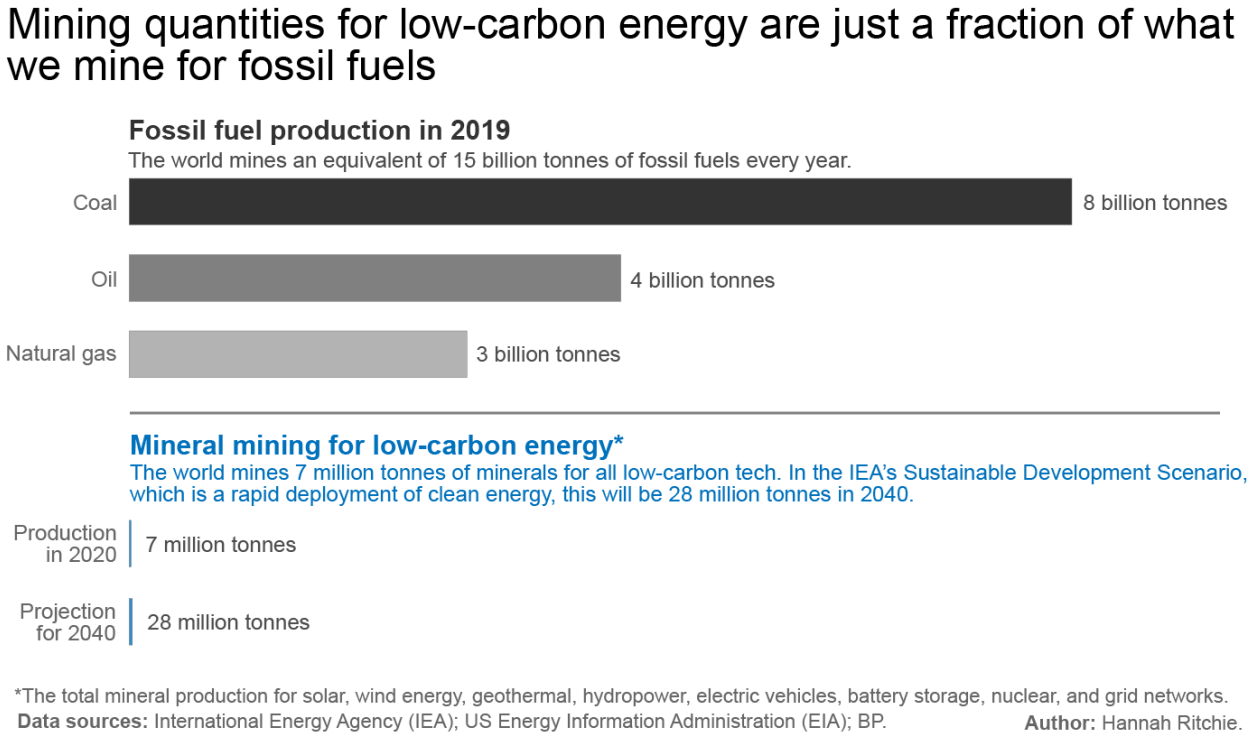
GLOBAL DISTRIBUTION OF SUPPLY CHAIN



This can create supply risk and increase costs from transport of battery materials

Source: IEA 2022

ELECTRIFICATION REDUCES OVERALL MINING IMPACTS



Source: Data; Clearing the air on propane

IMPACTS CAN BE FURTHER REDUCED

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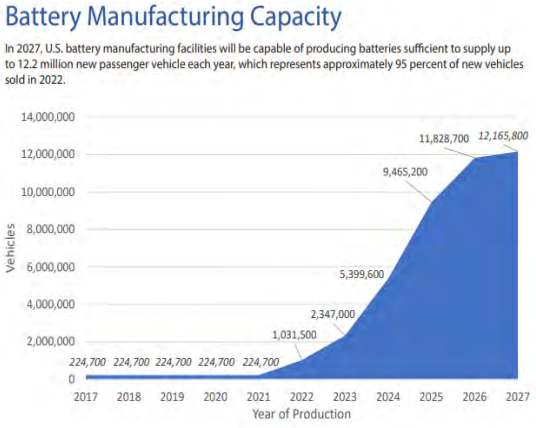
Traceability

Mining Standards



Domestic Sourcing

Source: GBA; IRMA Community Toolkit; DOE

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HOW TO ADVANCE RESPONSIBLE SOURCING?

School bus owner/operator:

Discuss battery chemistry with dealers/manufacturers to align with operational and budgetary needs.

Use consumer influence to ask about battery mineral source and verify through certifications where possible.

School bus OEMs:

Share battery chemistry on spec sheets.

Trace battery supply chains to the point of extraction.

Source minerals from audited mines. Use domestically manufactured batteries.

Policymakers:

Support legislation and stronger regulations on human rights and environmental due diligence

Improve data transparency by advancing use of digital battery passport
E.g. TRACE Act

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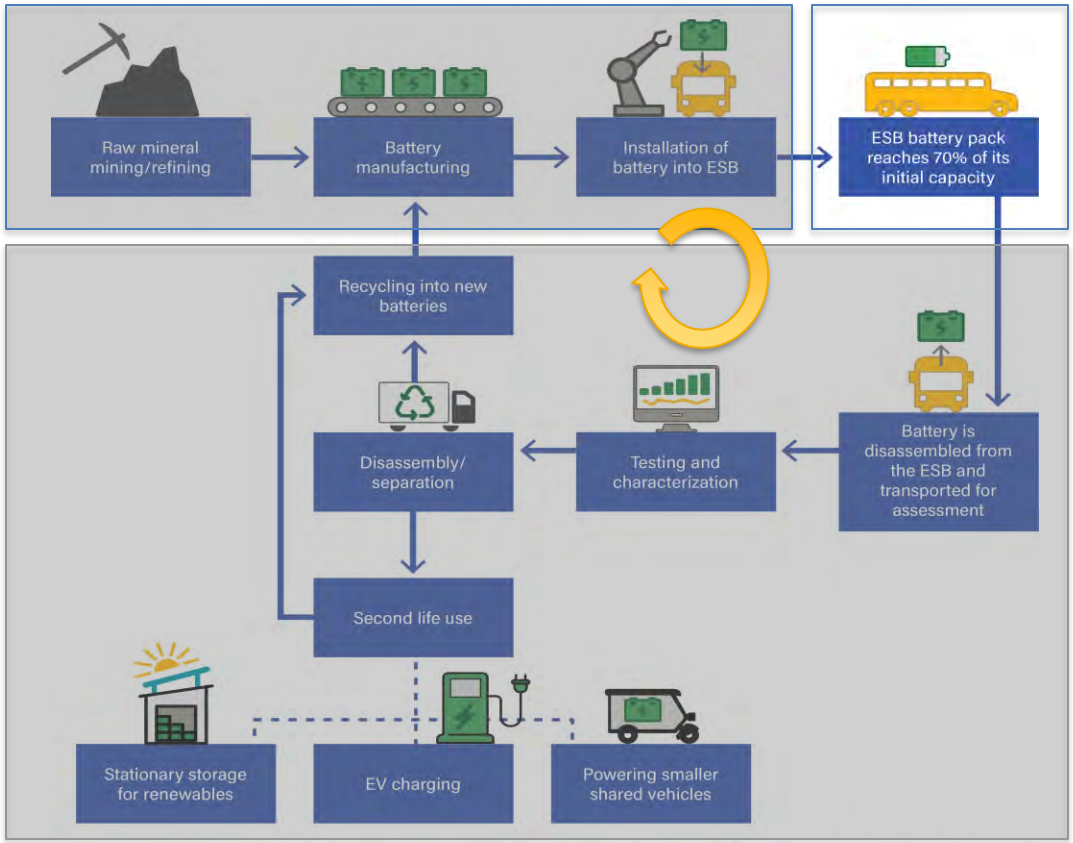
OPERATIONS

Best practices to optimize operations

Electric school bus (ESB) battery value chain



Source: WRI.

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BEST PRACTICES

Safety

Ensure first responder training and access to emergency guides.

Battery weight is more evenly distributed between the front and rear wheels (v/s diesel), improving driving ability in the snow.

Charging

Charging an electric bus when it returns from its route is ideal as the battery will already be at optimal temperature.

Maintain a battery state of charge of at least 20% when possible.

Weather

When possible, keep batteries in their optimal temperature range: 59 – 95°F.

Use battery management software (BMS), electric heat pumps, pre-conditioning for cold weather operations.

Source: WRI Battery Resources; Cold Weather impacts

COLD WEATHER IMPACT

Inform

Temporary range reduction is typically around 15-35% of usable battery capacity.

Running HVAC has one of the highest impacts on battery

Plan

Plan routes and bus battery size for worst-case cold weather

Heat pumps can add 10% range. Aux heaters are an option too.

Heated seats for drivers require less energy than the entire cabin.

Perform

Drivers: Regen braking system typically improves battery efficiency by 16-25%

ESBs have improved driving ability in the snow

Cost savings: $0.24/mile v/s Diesel

Source: WRI Battery Resources; Cold Weather impacts: Recurrent Range

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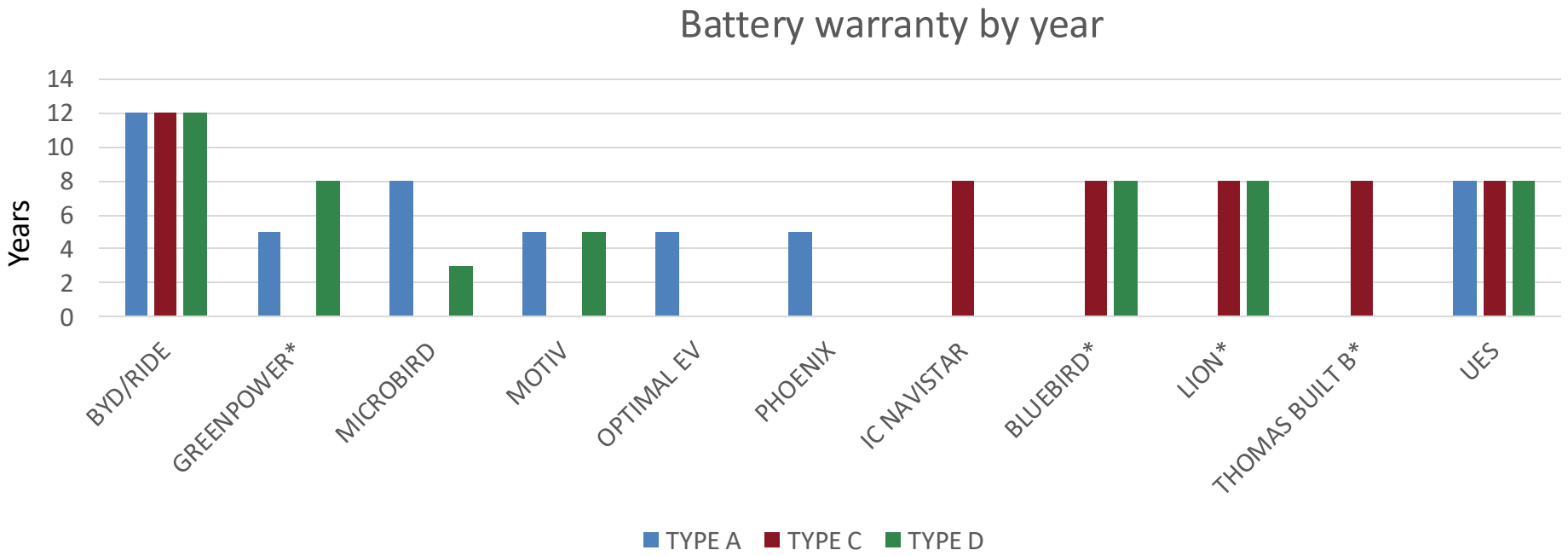
BATTERY WARRANTY CAN DIFFER



Notes: Buyers Guide * offer extended warranty

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BATTERY DEGRADATION

Why it happens

Continued chemical reactions cause barrier build-up inside cells over time. Also, mechanical stress.

Two types: cyclic life and calendar life

Difficult to estimate due to variables such as chemistry, charging habits, ambient temperature

When should it be replaced

When state of health significantly reduces (to ~70-80%) such that the drivers can no longer serve their routes.

Early indications from electric cars suggest vehicle batteries may last longer than initially expected.

Efforts must be taken to not landfill the used ESB battery.

Source: Limit battery aging. *self-reinforcing aging mechanisms that can result in rapid degradation and shortened battery life

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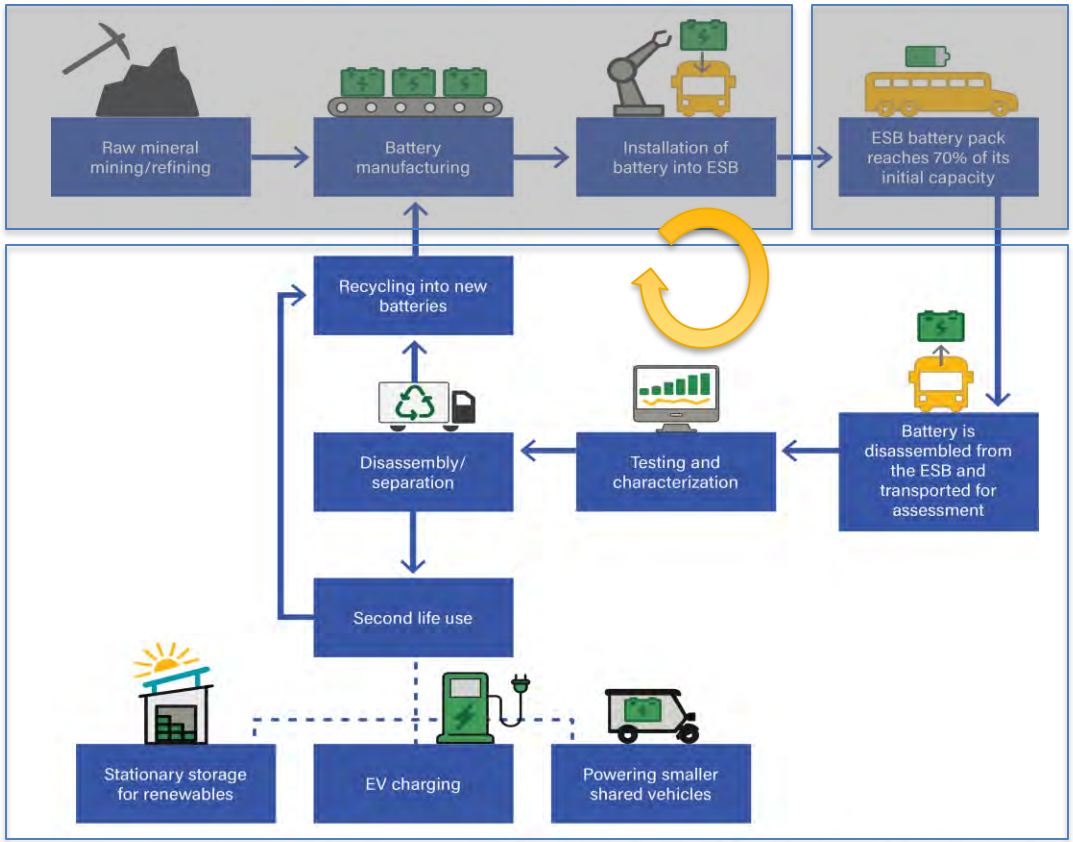
END OF LIFE BATTERIES

Utilize the procurement opportunity to sustainably manage used batteries

Electric school bus (ESB) battery value chain

Supply chain

Operations



End-of-life (EOL) management

Source: WRI.

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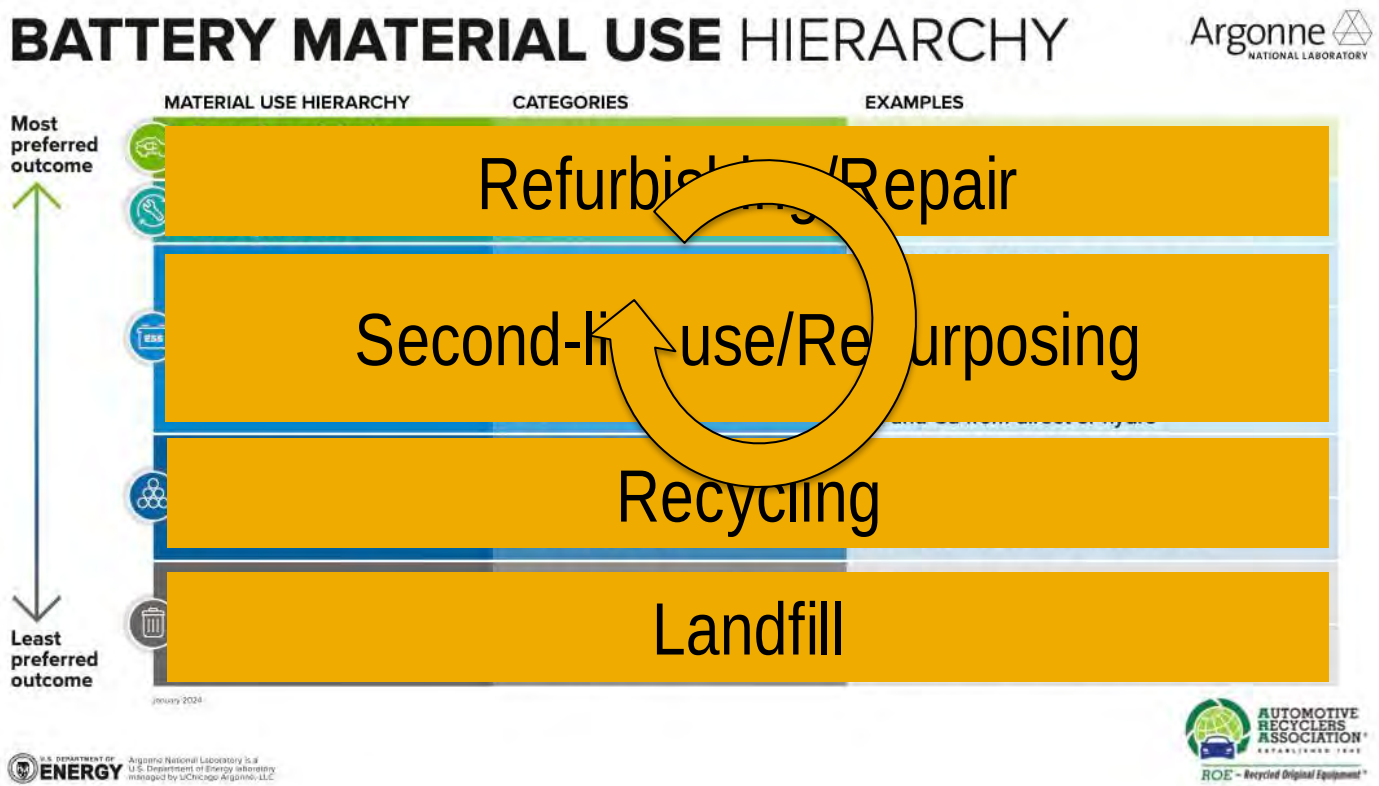
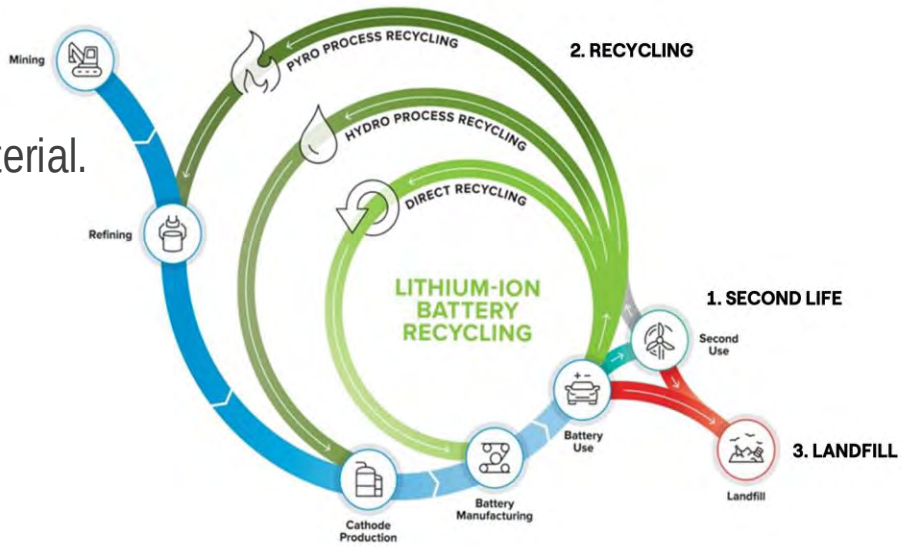
LANDFILLING IS NOT THE HIGHEST AND BEST USE



Source: ANL and ARA

BENEFITS OF BATTERY CIRCULARITY

- Reduce mining and landfilling.
- Strengthen domestic supply of battery material.
- Reduce electric vehicle prices.
- Create new green jobs.
- Enable the clean energy and transportation transition.

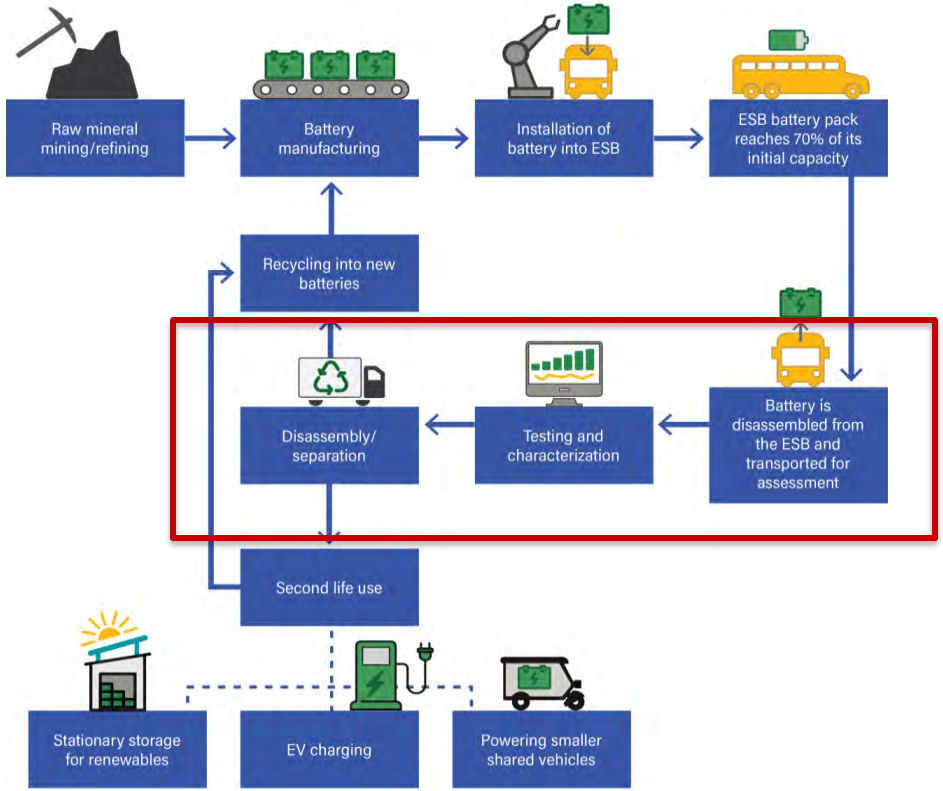


Source: DOE Recell Center

RESIDUAL VALUE DETERMINES PATHWAY

Residual value is the percentage of the original battery capacity that remains after a certain number of years of use.

Lowers total cost of ownership



CHALLENGES TO SELECTING PATHWAY

- Unstandardized battery testing creates uncertainty in resale value of batteries.
  - Role of dealerships and dismantlers is critical

- Battery collection process and responsibility is unclear
  - State regulation and industry partnerships can offer clarity

Source: ReJoule White Paper; How ESB batteries can avoid landfill

OWNERSHIP MODELS AND COSTS CAN INCREASE RISK OF LANDFILLING

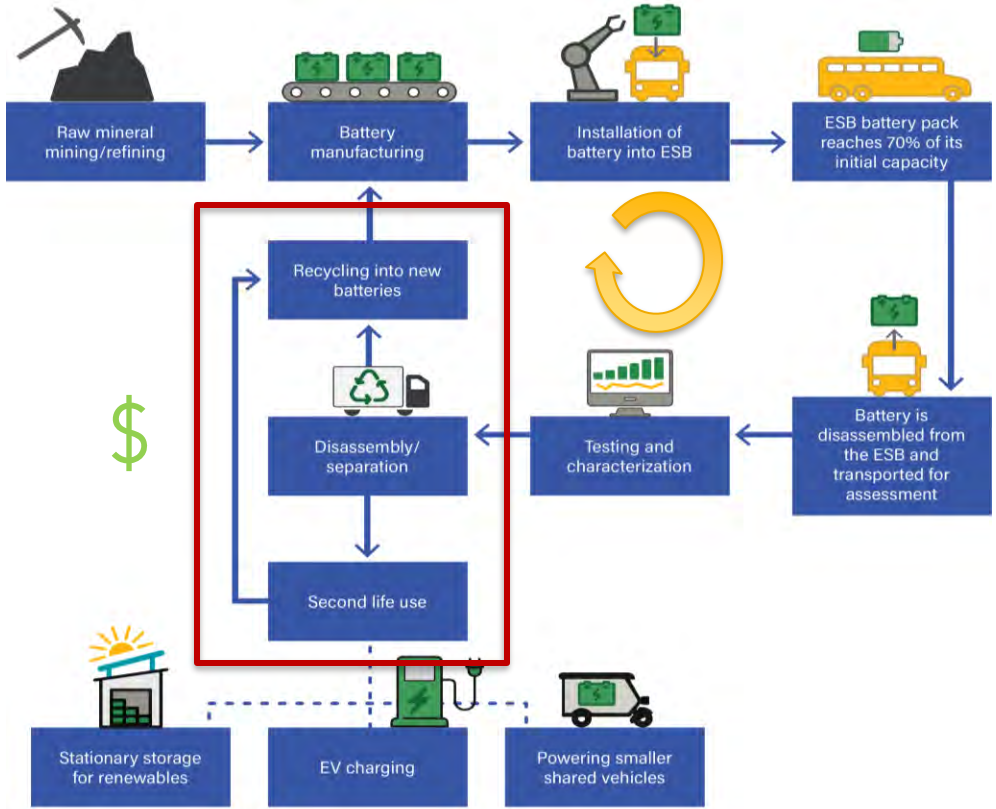
	Roles within all business models	
	Bus owner (& maintenance)	Bus operation
School ownership	SD	SD
Lease	3rd party	SD
Charging-as-a-Service	SD	SD
Turnkey asset management	3rd party	SD
Transportation-as-a-Service	3rd party	3rd party

Table 1: Price estimates for battery end of life processing

EOL Process	Cost	For a 150 kWh ESB battery
Transportation of Used Batteries	$0.06 / nameplate kWh / mile (a)	$900 (f)
Dismantling of Used Batteries	$1 - $5 / nameplate kWh (b)	$150 - $750
Testing of Used Batteries	$2 - $10 / nameplate kWh (c)	$300 - $1,500
Hazardous Waste Landfill Fee	$80 - $140 / ton (e)	$80 - $140 (g)

Source: Business models; How to avoid landfill

EXPLORE SECOND-LIFE USE BEFORE RECYCLING



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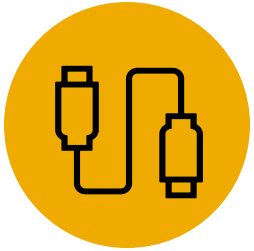
ESB BATTERIES ARE IDEAL FOR SECOND-LIFE USE

Average battery capacity is 179 kWh



Consistent charging schedule

Majorly LFP chemistry, some NMC

BATTERIES ARE IN SECOND LIFE USE TODAY

- Batteries must be considered for second-life before recycling
  - 70-80% capacity
  - 30-70% cheaper than new batteries
  - Reduces battery carbon lifecycle by ~17%

- Most widely used for stationary storage
  - EV charging
  - Low power EVs
  - Telecommunications and data center back up

Source: NSF; McKinsey; B2U

moment energy

Limit grid impact from DCFC

Client: Vancouver International Airport

Currently scaling a pilot initiative that yielded a Level 3 DC Fast Charger designed to charge two EVs, proving the second-life battery's ability to bolster EV-charging infrastructure.

smartville

Renewable energy integration

Working with Historically Black Colleges and Universities (HBCUs) in Los Angeles County, CA; Orangeburg, SC; Denmark, SC; Atlanta, GA; and New Orleans, LA

Installing 7 MWh of energy storage systems providing demand reduction, power resiliency, and improved renewable integration.

ZENOBĖ

Stationary storage for depot

Zenobe developed an end-to-end solution for National Express, UK

It includes using repurposed bus battery cells in an onsite battery energy storage system. Repurposed batteries are being used in a stationary battery storage system to provide power to electric vehicles and extend their useful life.

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Source: B2U

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RECYCLING CAPACITY IS GROWING

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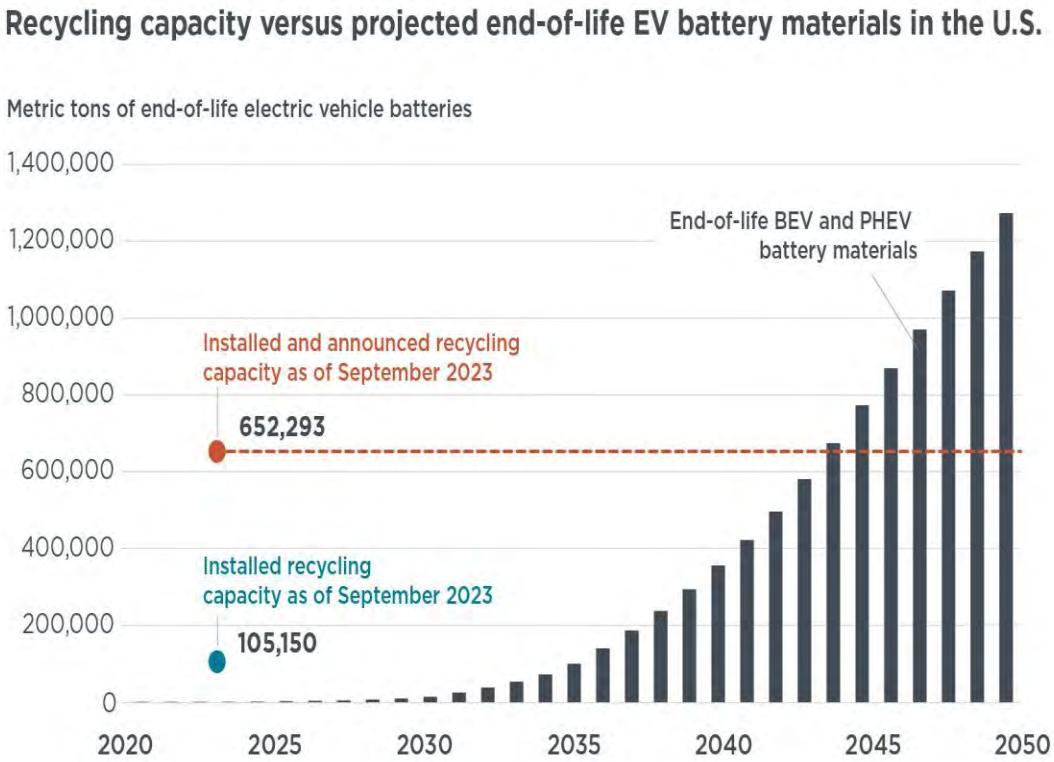

Source: The International Council on Clean Transportation

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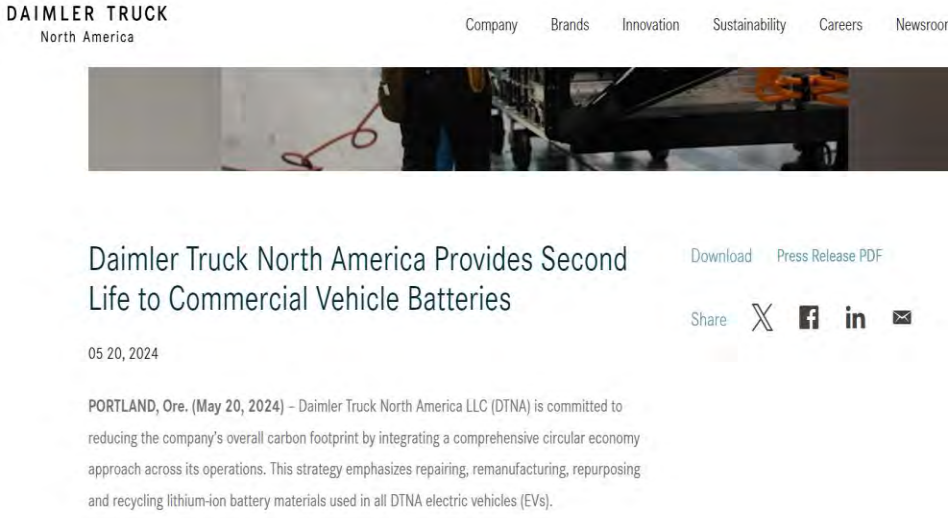
LFP RECYCLING IS NOT YET ECONOMICALLY VIABLE

- Economic viability depends on high-value materials
  - LFP recycling not yet commercialized
  - Tech progress improving economics
- Open and closed loop contracts with vehicle OEMs
- New processes and business models – like Cirba Solutions, Nth cycle - reduce adverse impacts

VEHICLE OEMS ARE SETTING UP CIRCULARITY PROGRAMS

- Remanufacture
  - "Enters the remanufacturing process at existing Detroit Diesel Remanufacturing locations across the U.S. like the recently expanded Hibbing facility with intended reuse in vehicles"
- Repurpose/Second-life use
  - "DTNA has partnered with Nuvation Energy"
  - "Designed to assist in charging, peak shaving, backup storage and microgrid scenarios"
- Recycle
  - "DTNA has created a process in partnership with Li-Cycle"



Source: Daimler Trucks

U.S. POLICY ADVANCING BATTERY CIRCULARITY

TRACE Act

Encourages voluntary use of battery passport to disclose data

NJ Batt. Mgmt. Law

Places responsibility of battery end-of-life on manufacturers

CA SB615

Outlines standards for chain of custody, second life use and recycling

Note: TRACE Act, NJ law, CA bill

HOW TO ADVANCE BATTERY CIRCULARITY

School bus owner/operator:

Ask for an end-of-life plan from the school bus manufacturer at the RFP phase. See WRI's RFP template for language.

Large fleet owners/contractors can explore partnerships and pilots.

Consider second life use prior to recycling

School bus OEMs:

Create battery circularity programs that encourages second life use.

Create partnerships with second-life use and recycling companies that school districts can leverage.

Design batteries with its end-of-life use in mind

Policymakers:

Invest and support standards development for residual value

Design federal and state incentive programs that require an EOL plan, ideally from the bus OEMs.

Advance legislation that can bring certainty to the chain of custody of the used battery E.g. NJ, CA

Source: RFP Template

TAKEAWAYS

1

Battery chemistry is foundational to understanding electric school bus battery lifecycle

2

Transparency and disclosure of supply chains is critical to fleet owners

3

Adopt best practices to optimize operations

4

Utilize the procurement opportunity to sustainably manage used batteries

ESBs can play a leadership role

WHATS NEXT AT WRI

Battery FAQs – spring 2025

Connect vehicle OEMs with potential partners – pilots on battery passport, second life use and recycling

Support equitable policies for battery circularity – federal and state

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RESOURCES

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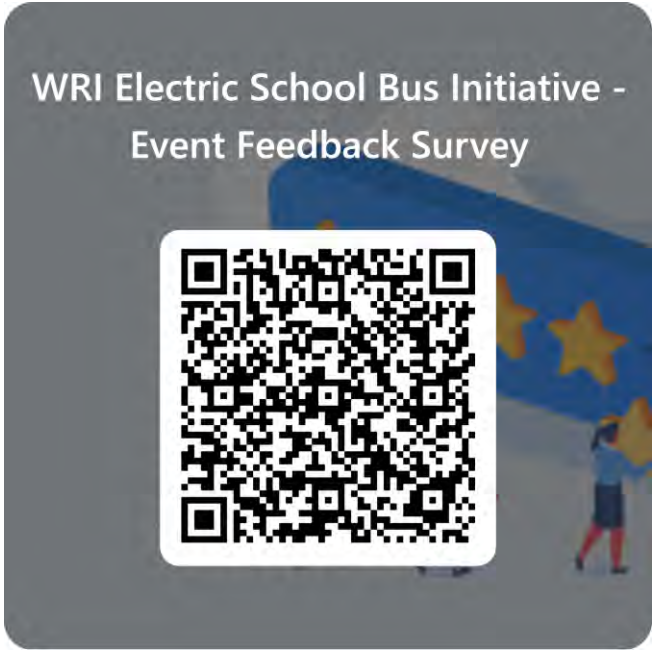
- Electric School Bus Battery Resources
- All About Operating Electric School Buses in Cold Weather | Electric School Bus Initiative
- EPA Joint Office Resource on Cold Weather
- Recurrent Auto – EV Range in Winter
- NREL Battery Supply Chain Database



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