Decarbonizing the Economy: The Role of Critical Materials

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Critical Materials Demand for U.S. Electric Vehicles to 2050

Plus Assessment Frameworks for
Environmental Impacts,
Supply Chains, & Energy Security

Webinar – September 20, 2023

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Corporate Overview

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KeyLogic: mid-tier firm offers deep domain expertise in our country's most critical undertakings within the energy, federal civilian, and defense sectors

Innovative Integration	**Large-scale data management**, advanced analytics, enterprise transformation, science & technology advisory services, R&D management, and systems engineering
Thought Leaders in Emerging Technologies	**Technology readiness scale:** Experience in modeling and assessing range of energy-relevant at low-technology-readiness levels
Critical Materials Expertise	**Material and resource analysis**, including LCA, across the supply chain in support of energy production, generation, and storage technologies

OnLocation: small firm with decades of experience in developing and applying innovative energy system and economic models to address key energy, climate, and environmental regulations and policies

Assess Role of New Energy Technologies	**Evaluate system and economic impacts** of new energy and climate mitigation technologies (unconventional natural gas, direct air capture, hydrogen, carbon capture & storage)
Explore Alternative Energy Futures	**Design "what-if" scenarios** and alternative energy futures for use in uncertainty analyses, including alternative energy prices and macroeconomic forecasts
Inform Energy & Environmental Policy	**Perform economic impact assessments** of proposed energy and environmental regulations and policies (Inflation Reduction Act, EPA proposed Standards for Light- and Medium-Duty Vehicles)

POINTS OF CONTACT

John Ramsey / SVP, Energy Programs / *John.Ramsey@KeyLogic.com*

Francisco de la Chesnaye / VP, OnLocation / *fdelachesnaye@onlocationinc.com*

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Research Team
- Hao Deng, Energy System
- Samaneh Babaee, Transportation
- Banafsheh Jabarivelisdeh, Materials
- Christina Ross, Environment
- Scott Matthews, Environment
- Less Goudarzi, Energy Security
- Francisco de la Chesnaye, Economics

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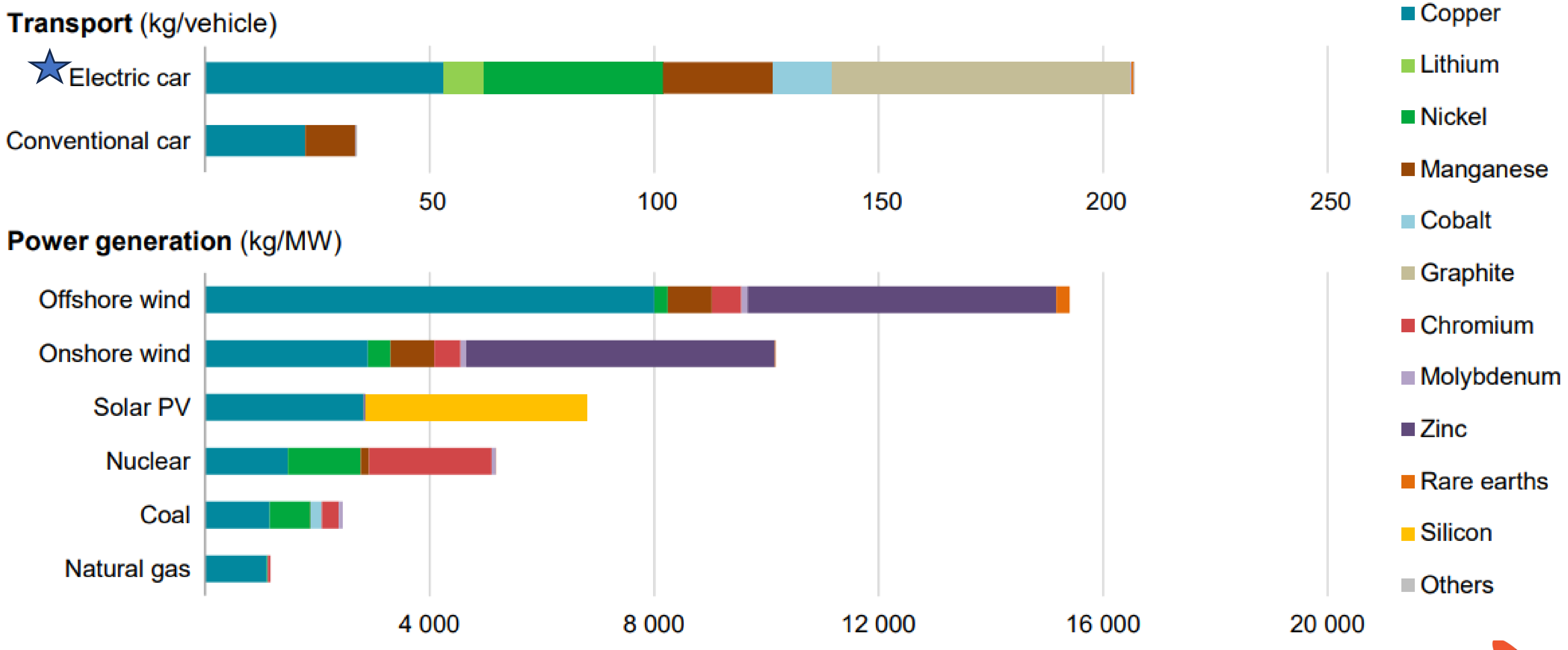
Why do Critical Materials Matter to the Global Energy Transition?

Materials used in selected clean energy technologies – global level 2020



IEA (2021), *The Role of Critical Minerals in Clean Energy Transitions*

Critical energy materials from overseas expose domestic manufacturers to geopolitical and supply chain risks

Major global applications with top global mining and U.S. import sources for Li, Ni, Co, and Mn

Material/ Element	Major Global Uses	Global Mining Sources (top three countries)[5]	U.S. Import Sources (2018-2021)
Lithium (Li)	Batteries (80%), Ceramics and glass (7%), Lubricating greases (4%)	Australia (46.9%), Chile (30%), China (14.6%)	Argentina (51%), Chile (40%), China (4%), Russia (3%)
Nickel (Ni)	Alloys and steel (85%), Electroplating, Catalysts, and chemicals	Indonesia (48.8%), Philippines (10%), Russia (6.7%)	Canada (45%), Norway (9%), Australia (8%), Finland (primary nickel) (7%)
Cobalt (Co)	Superalloys, mainly in aircraft gas turbine engines (40%), Chemical applications (35%), Metallic applications (15%)	Democratic Republic of Congo (70%), Indonesia (5.4%), Russia (4.8%)	Norway (22%), Canada (16%), Finland (12%), Japan (12%)
Manganese (Mn)	Steel production (90%), Non-metallurgical purposes (animal feed, brick colorant, dry cell batteries, and fertilizers)	South Africa (35.8%), Gabon (22.9%), Australia (16.4%)	Gabon (67%), South Africa (19%), Mexico (12%)

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IEA (2021), *The Role of Critical Minerals in Clean Energy Transitions*

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Critical materials in integrated energy models help us navigate the energy-economy nexus to achieve climate goals

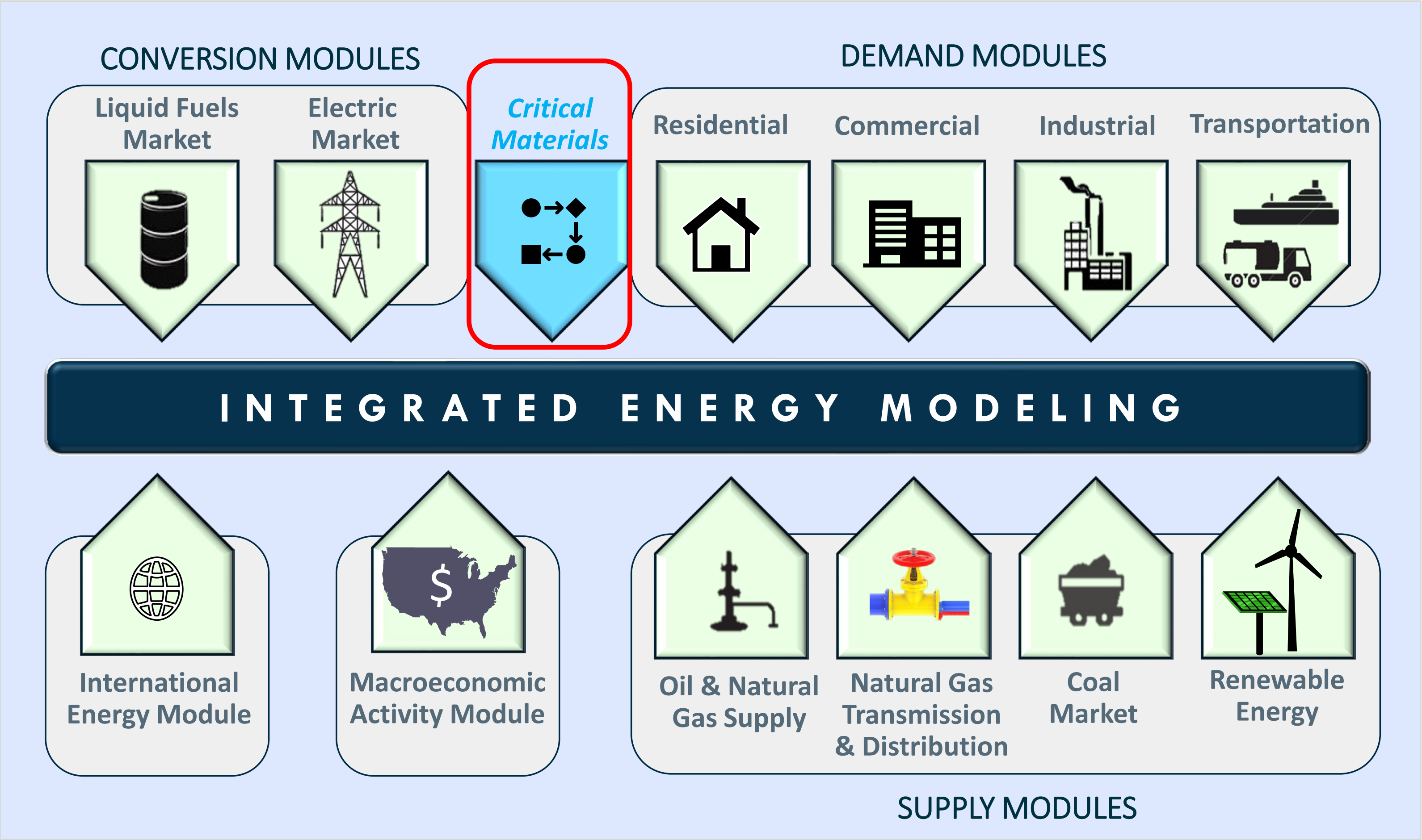
Customized Version of the National Energy Modeling System (CM-NEMS)

Development & Application of Energy System Models:

- Analyzing Energy and Climate Policy Impacts
- Assessing New Energy Technologies
- Informing Cost-effective Approaches and Policies

Customization & Analyses:

- Inflation Reduction Act
- Renewables and EV Expansion
- LNG Export Analysis
- **Critical Materials Analysis***



Official version of NEMS developed by the Energy Information Administration (EIA), U.S. DOE

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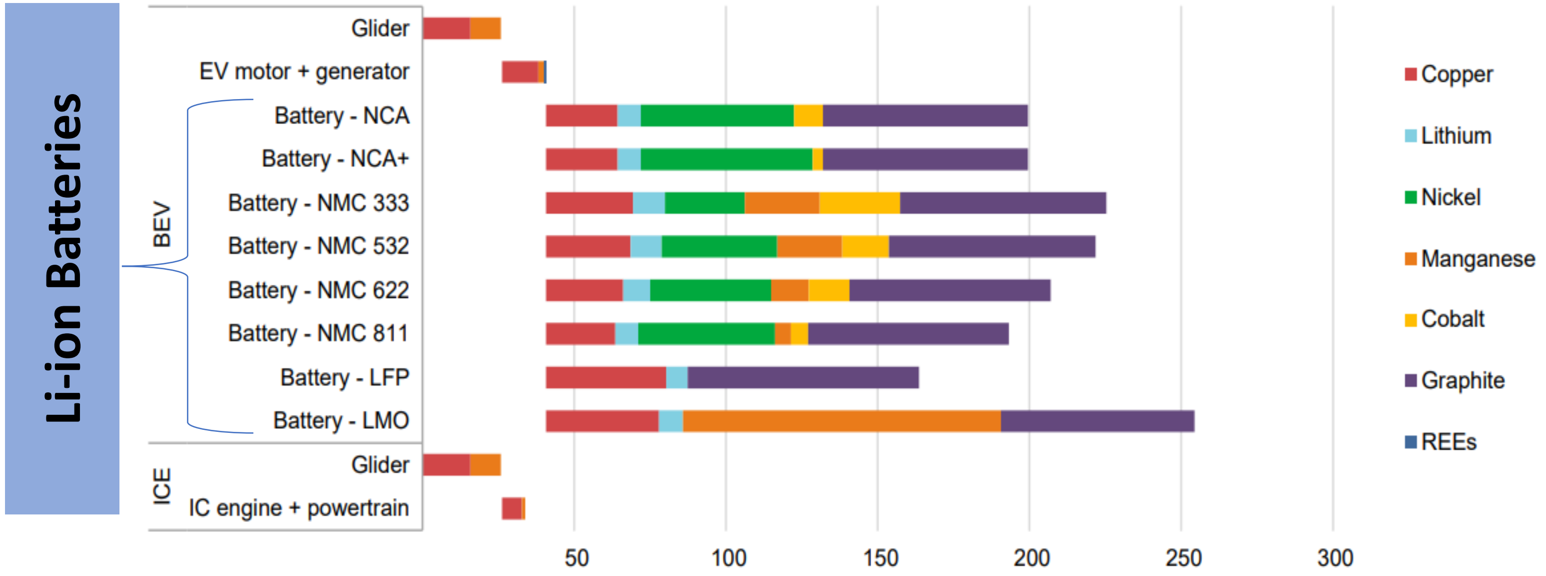
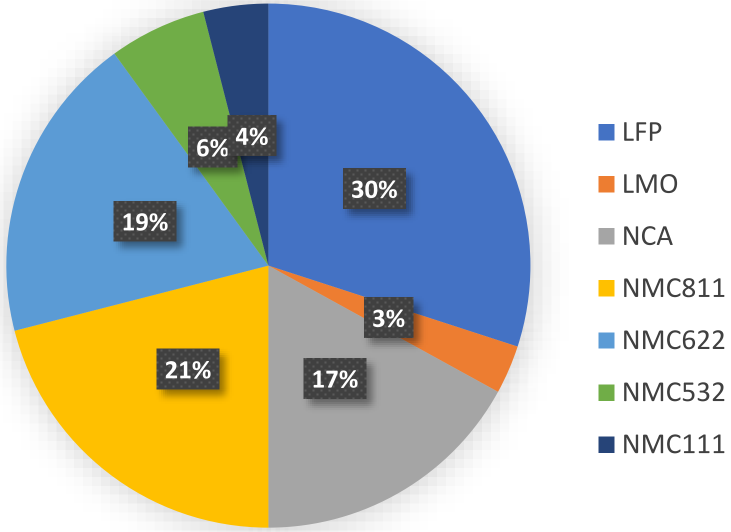
EVs & Battery Chemistry Types

Most of the critical materials in EVs are in two components: batteries & electric motors



kg per Vehicle



2022 Market Share Sales by Battery Chemistry

IEA (2021), *The Role of Critical Minerals in Clean Energy Transitions*

Scenarios to capture the potential impact of alternative battery chemistry adoption

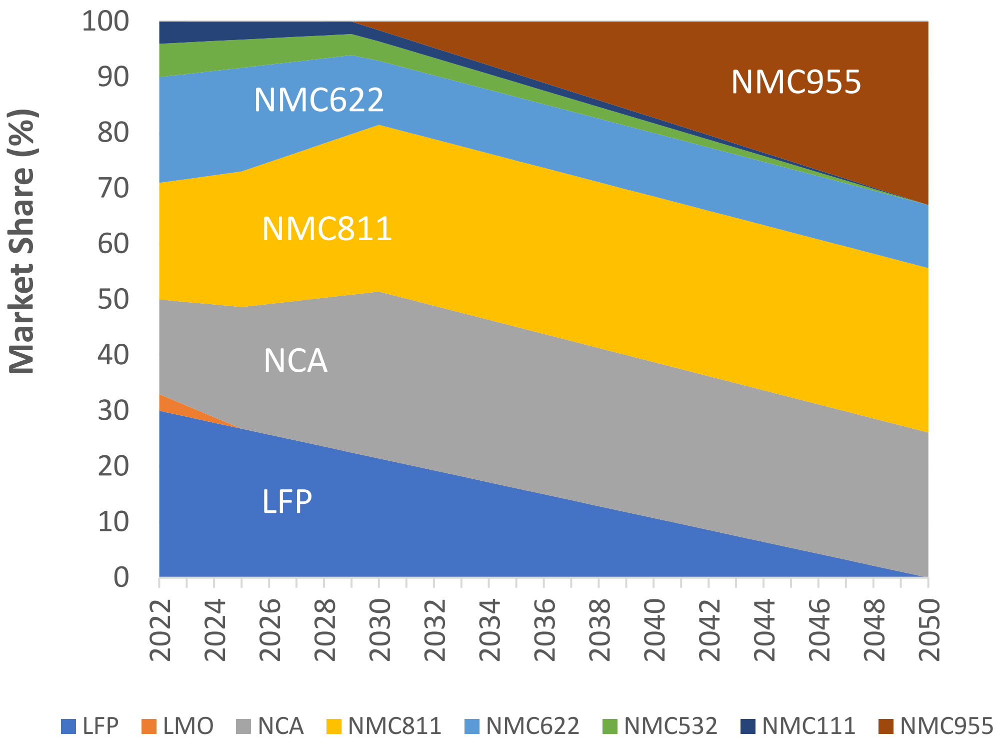
Battery Materials Requirement Variables:

- Cathode and anode chemistries (diverse material intensity)
- Evolution of cathode and anode chemistries could drive material use for batteries in varying directions
  - Energy density & cost
  - Thermal stability/safety
  - Potential supply chain, env concerns with mineral used

Battery Chemistry Evolution Trajectories:

1 High-Nickel Cathode:

- Widespread usage of NCA and NMC (high specific energy)
- Shifting towards more Ni-rich chemistries (e.g., NMC811 & NMC955)
- Increasing Ni content for higher energy density
- Reducing required amount of expensive Co
- NMC955 (to be introduced in 2030): market share of one third by 2050



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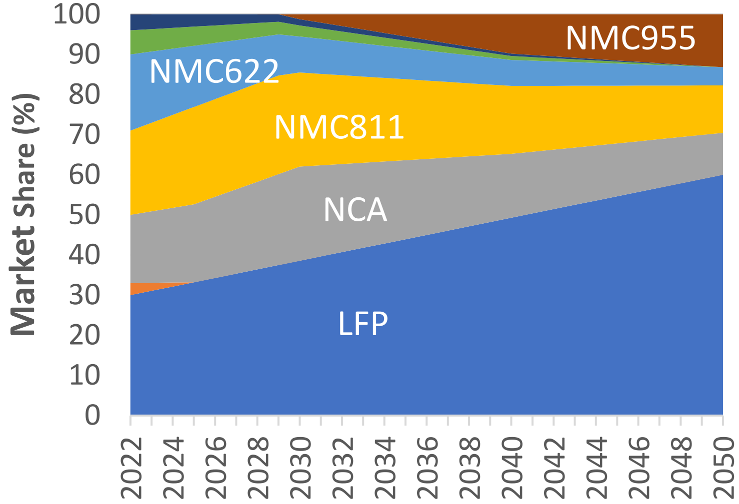
Scenarios to capture the potential impact of alternative battery chemistry adoption

Battery Chemistry Evolution Trajectories

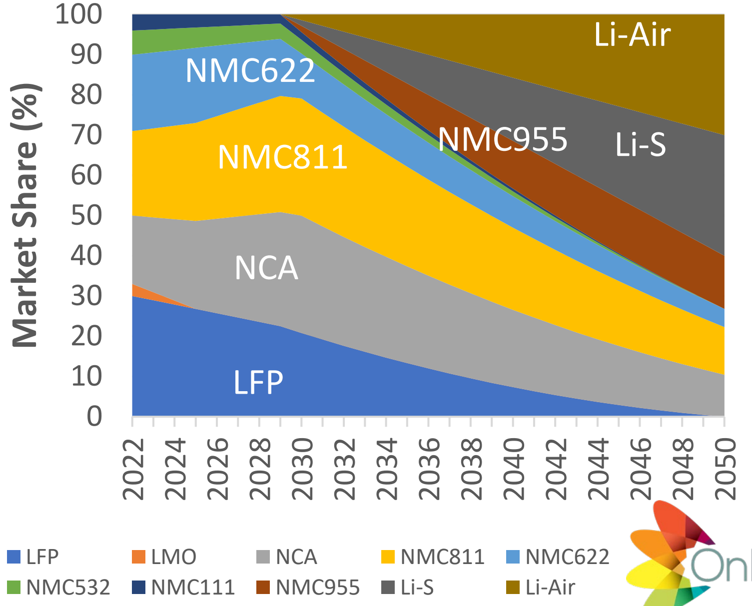
2 Low-Ni and Low-Co Fe-based Cathode:

- gradually increased market share of LFP
  - A more resource-friendly option (no Ni and Co), but offering lower energy density
  - lower production costs and better thermal stability
- market share of 60% by 2050



3 Lithium-Metal Solid State Battery:

- based on emerging Li-metal solid state batteries: Li-Sulphur (Li-S) and Li-Air
- provide two to three times the specific energy of the current Li-ion batteries
  leading to longer EV ranges and lower production costs
- to be available in 2030 with increasing market share of 60% by 2050



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OnLocation Scenario Includes Expanded Electric Vehicle Incentive Policies

Policy and Regulations	Reference Scenario	OnLocation Scenario
Advanced Clean Truck (ACT) Rule for Medium- and Heavy-Duty Vehicles	None	Included for CA, NY, MA, NJ, OR, and WA, based on Zero-Emission Vehicle (ZEV) sales shares from California Air Resource Board (CARB)
EPA Proposed GHG Standard for Light-, Medium-, and Heavy-Duty Vehicles for Model Year 2027 and later	None	Proposed GHG standards are included for light-duty vehicles and class 2b-8 freight trucks for model years 2027 and later
Inflation Reduction Act (IRA) Tax Credits for Light-Duty Vehicles: Clean Vehicle Credit (30D and 45X)	30D: $116 to $800 average weighted credit	30D and 45X based on the International Council on Clean Transportation (ICCT) Moderate Case 30D: $4,100 to $4,500 average weighted credit
IRA Tax Credits for Medium- and Heavy-Duty Vehicles: Commercial Clean Vehicle Credits (45W and 45X)	None	45W and 45X based on section 13403, part 4

ACT rule: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/fro2.pdf
EPA proposed GHG standard for LMDVs: https://www.epa.gov/regulations-emissions-vehicles-and-engines/proposed-rule-multi-pollutant-emissions-standards-model#rule-summary
EPA proposed GHG standard for HDVs: https://www.epa.gov/regulations-emissions-vehicles-and-engines/proposed-rule-greenhouse-gas-emissions-standards-heavy
ICCT Energy Innovation: https://energyinnovation.org/wp-content/uploads/2023/01/Analyzing-the-Impact-of-the-Inflation-Reduction-Act-on-EV-Uptake-in-the-U.S..pdf

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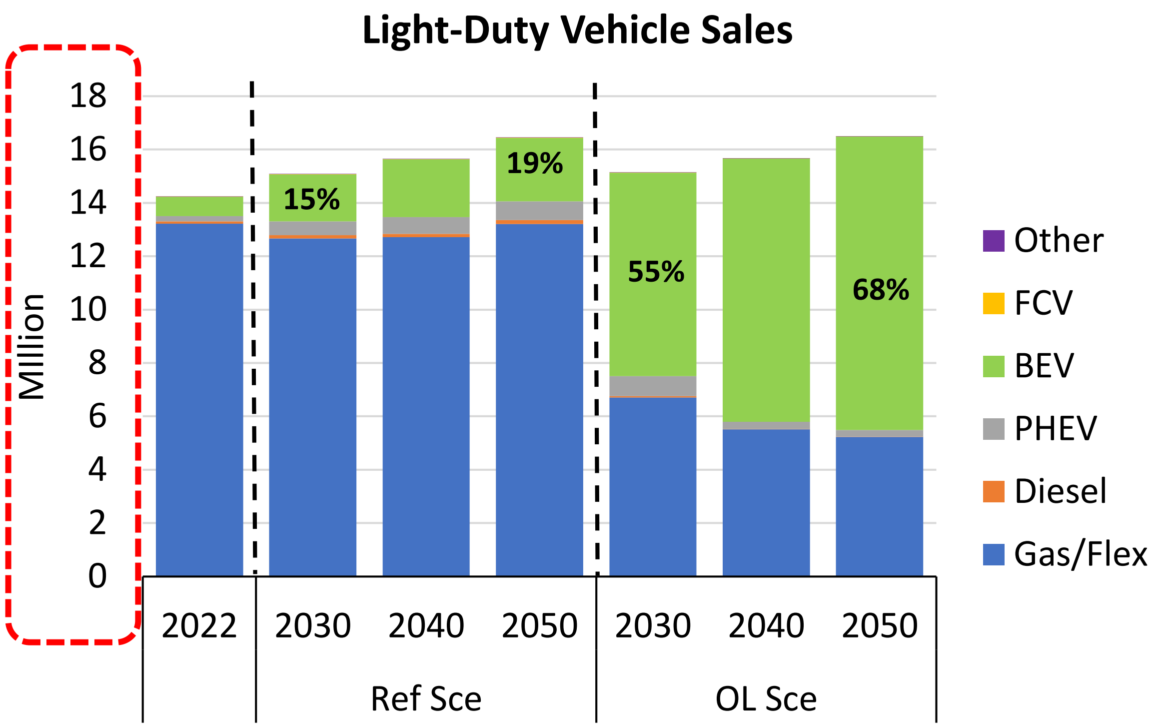
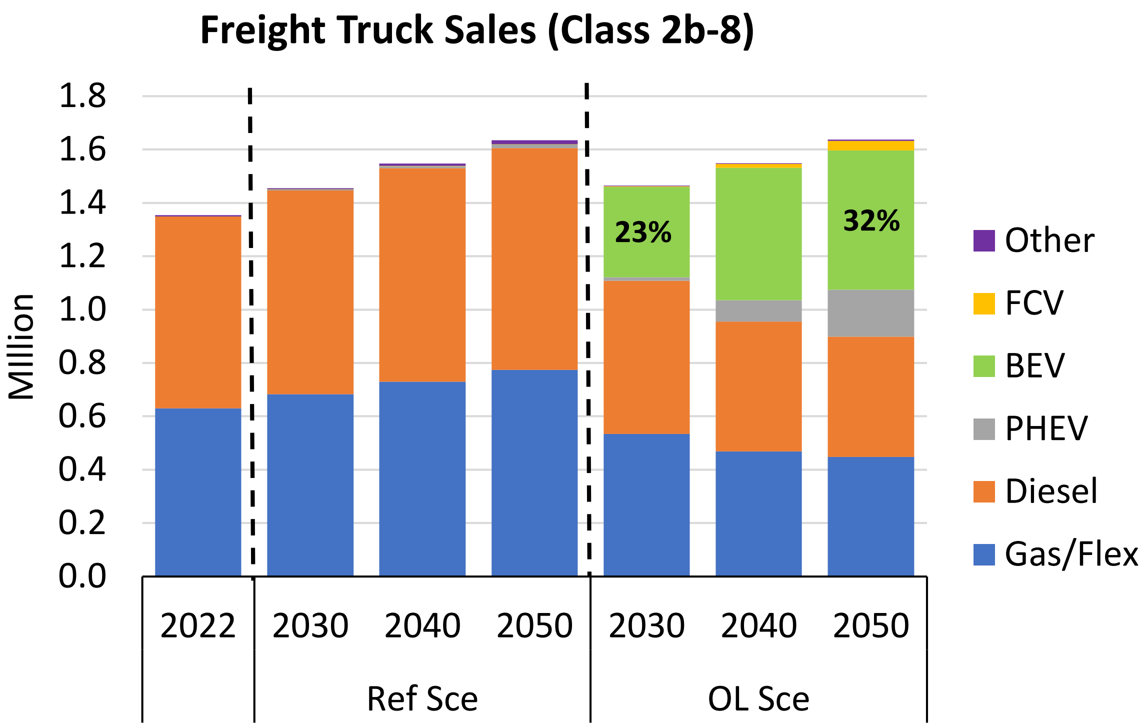
Expanded policies could stimulate BEV sales of 8 million vehicles in 2030, an 11x increase from 2022





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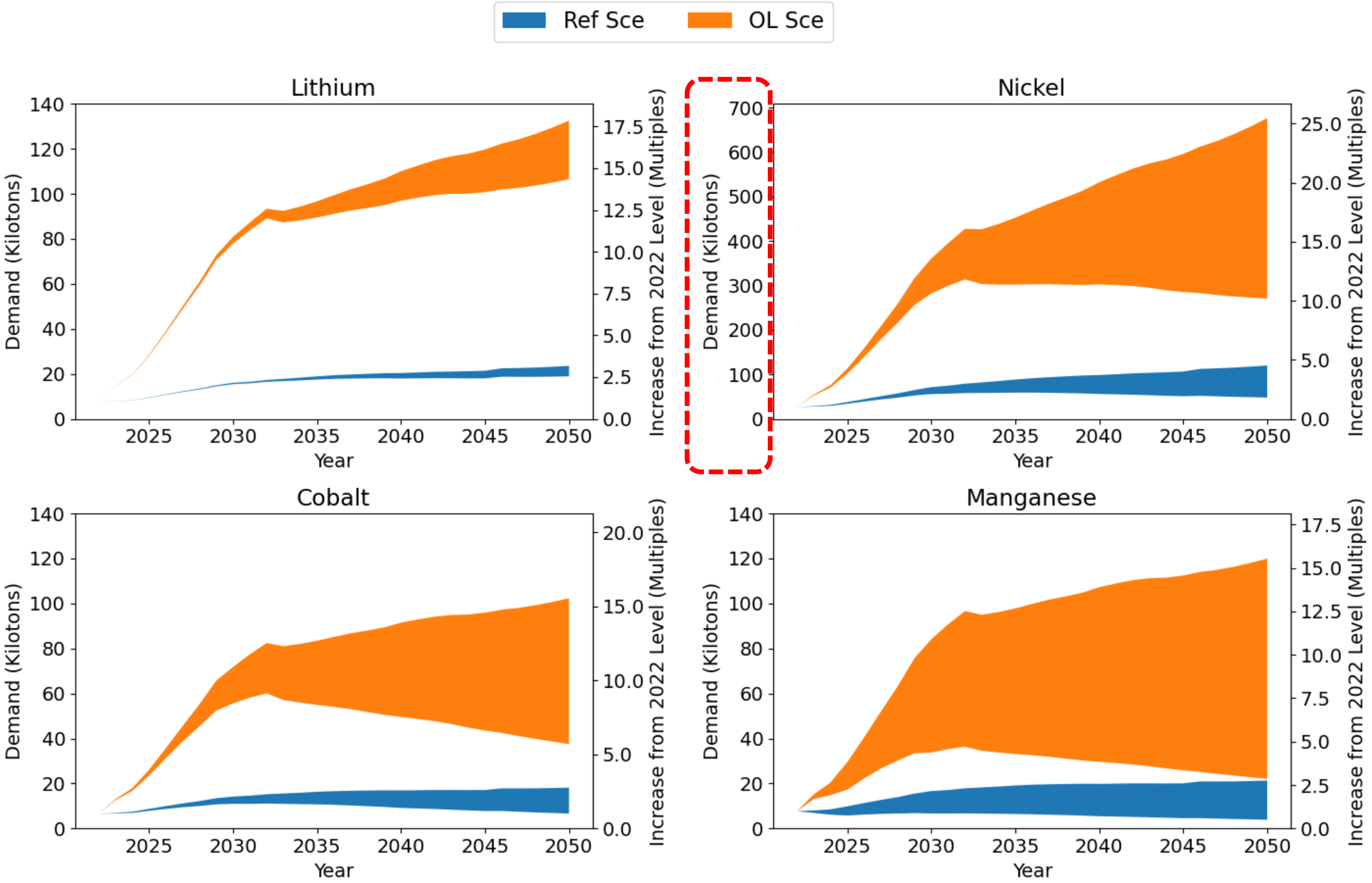
Policies can drive a significant **Demand for Critical Materials**

Alternative battery chemistries can create a band of uncertainty



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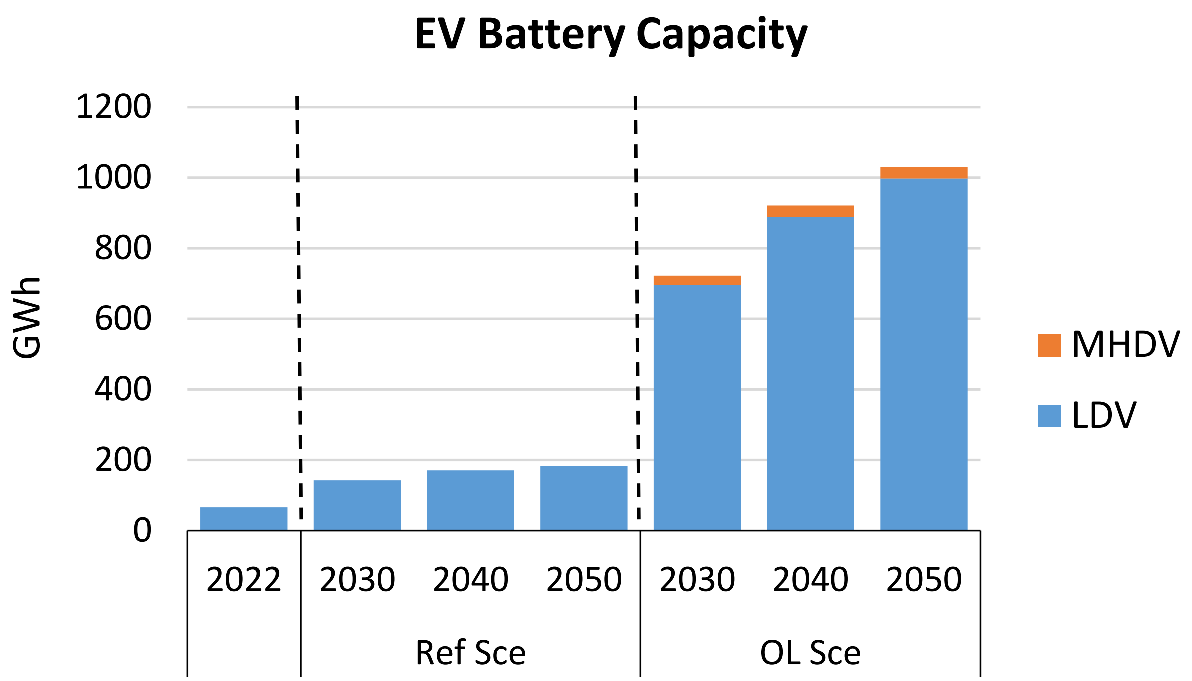
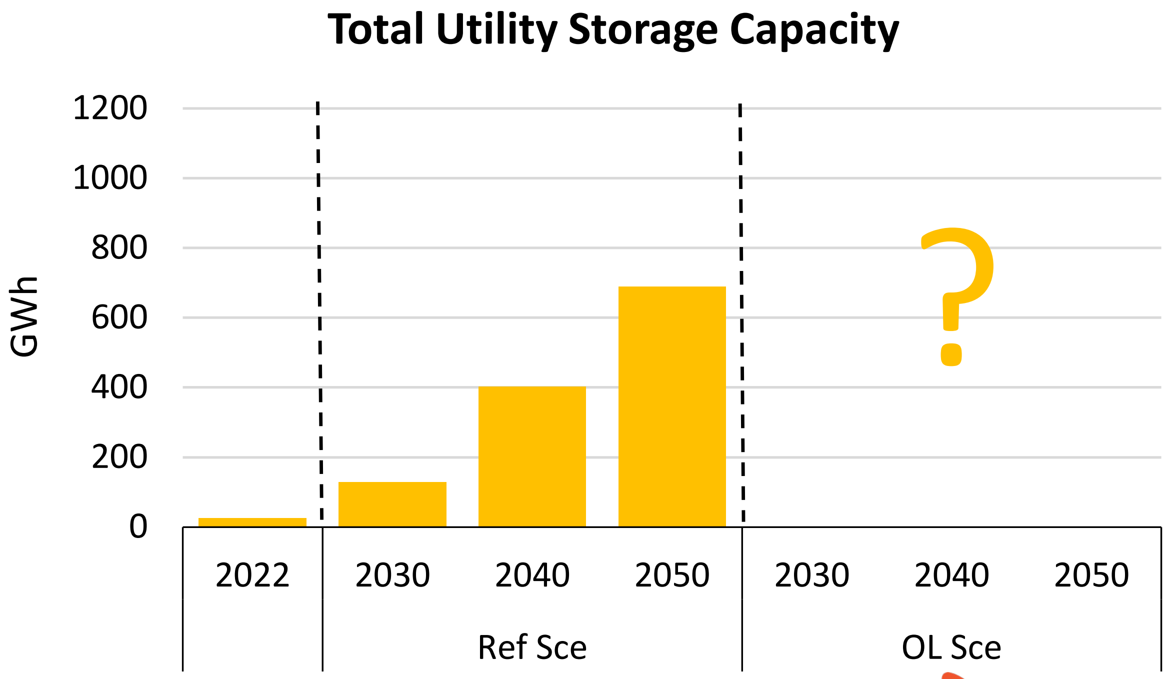
EV vs Utility Storage Energy Capacity to 2050

The EV Capacity is a new feature in CM-NEMS

NEMS development needed to deal with new reality of increased EVs and energy capacity:

- Current load shapes for EV assumes charging mostly in evening/nighttime hours
- New tax credits & incentives for renewables and storage
- Vehicle to Grid Dynamics





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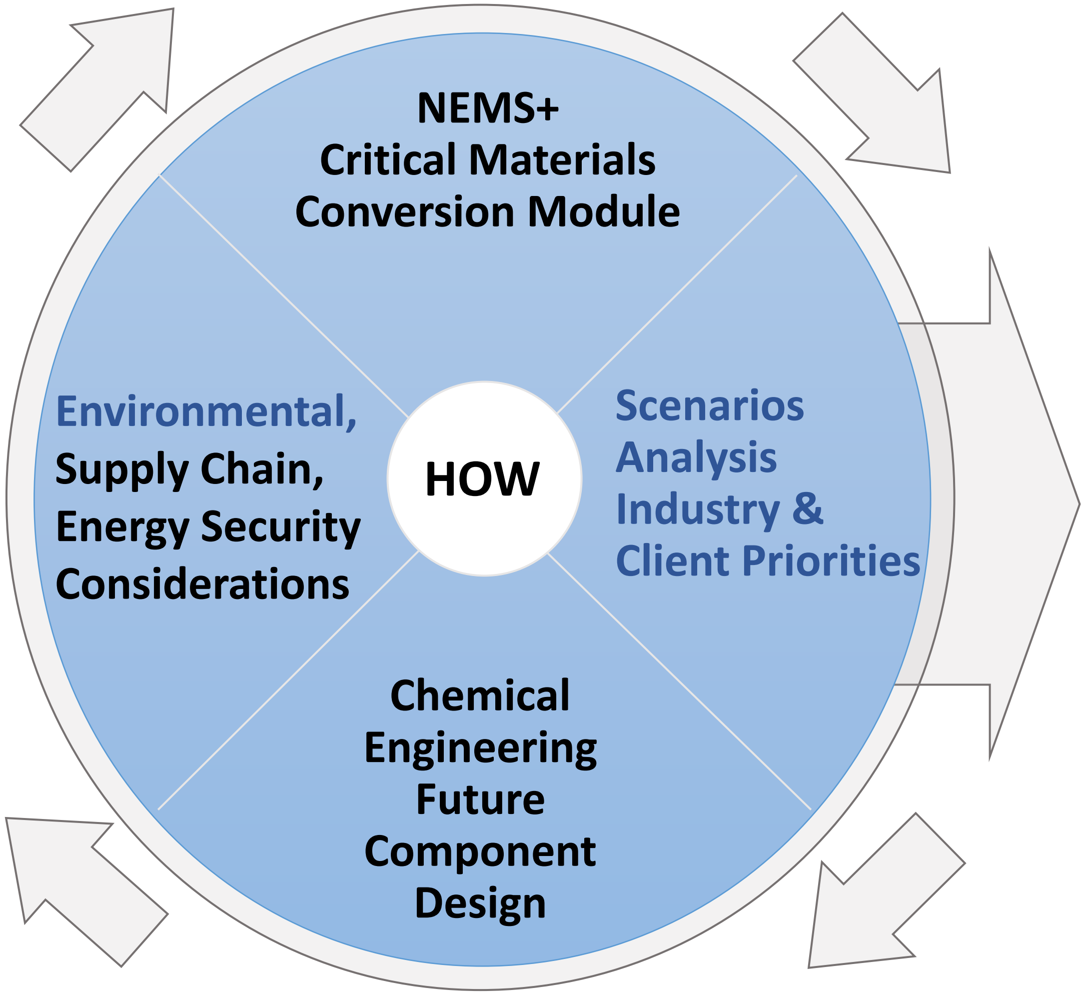
Environmental Assessment

Balancing the critical materials need of net zero with environmental stewardship will require a complex framework

Environmental Framework

- Existing Sector / Manufacturing Resources
- Product Planning
- Critical Materials
- Environmental Variables & Impact
- Sustainable Practices
- Evaluate Environmental Mitigation against Policy & Economic Considerations

Research Integration



Analysis

1. Project Future CM Demand
2. Assess Potential Ecological Effects through CM Life Cycle
3. Evaluate CM Sourcing Option Implications
4. Provide Real World Calibration of Policy Implementation
5. Advance Future CM Projections & Policy

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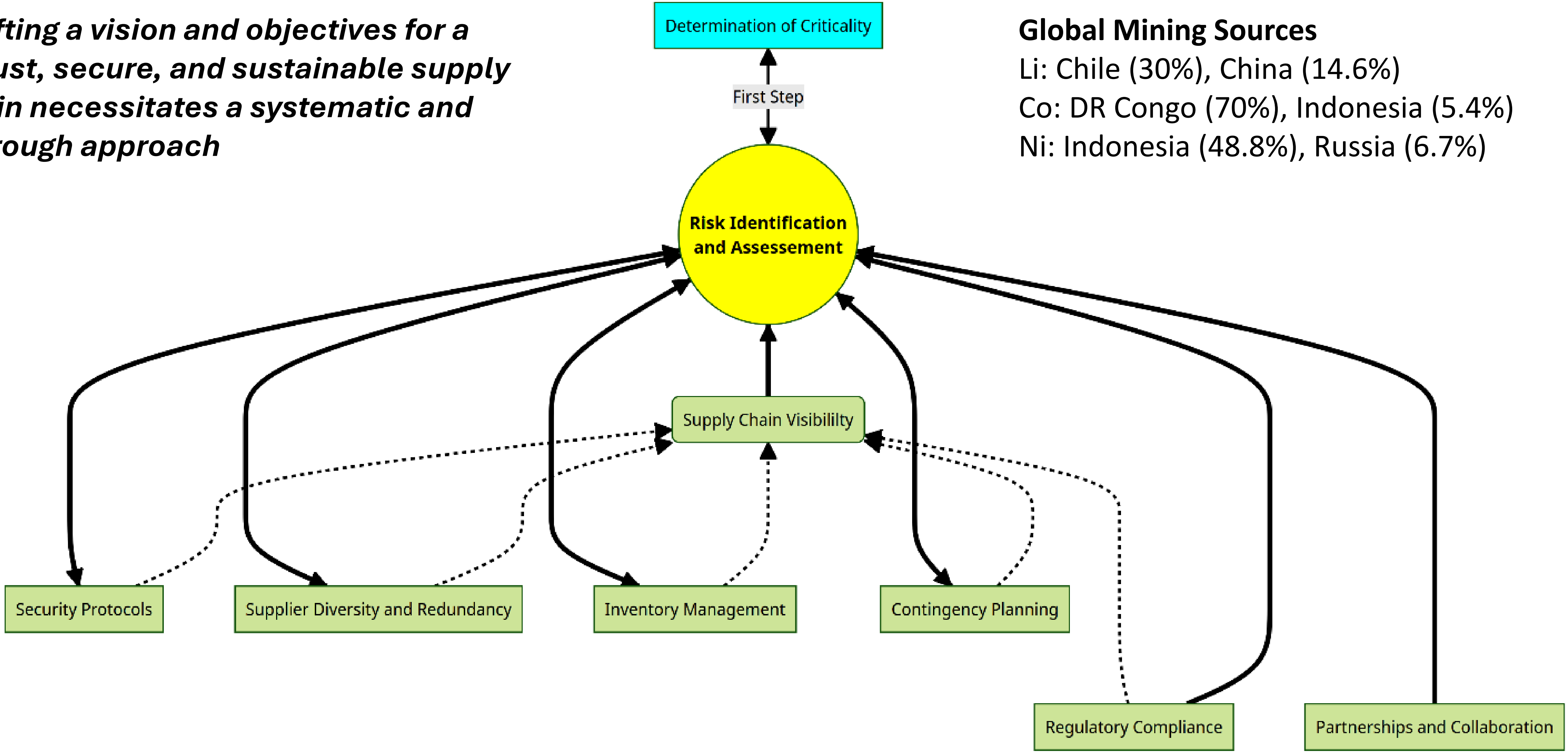
Supply Chain & Energy Security

Crafting a vision and objectives for a robust, secure, and sustainable supply chain necessitates a systematic and thorough approach



Global Mining Sources

Li: Chile (30%), China (14.6%)

Co: DR Congo (70%), Indonesia (5.4%)

Ni: Indonesia (48.8%), Russia (6.7%)

Next Steps for Critical Materials & Related Analyses

Next Webinar: Oct 18 at 2pm ET

- Environmental Assessment
- Supply Chain & Energy Security

Expanded Modeling & Analysis - Full Energy System

- Additional materials (e.g., gallium, niobium, neodymium, graphite, rhodium) and rare-earth elements
- Additional transportation modes
- Power sector energy storage and renewables, including system integration and coordination of vehicle energy storage with electric grid reliability
- Vehicle to Grid assessment
- H_2 production and use
- Critical materials from fossil fuels (coal, petroleum)
- U.S. Net-Zero GHG Target

Expanded Environmental, Supply Chain and Energy Security Assessments

- Understanding Resource Extraction Challenges to Mitigate Environmental Impacts
- Colocation
- Co-production
- Water Quality and Quantity
- U.S. Primary / Secondary Resources

- Supply chain implications of mining and production delays
- Foreign competition / market manipulation

Question & Answer Session

How can we help *you* prepare for the evolving climate and energy transition?

fdelachesnaye@onlocationinc.com

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