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Impact of U.S. DOE R&D on Potential Future Battery Material Demand

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Summary

The U.S. Department of Energy's (DOE) Vehicle Technologies Office (VTO) supports research, development (R&D), and deployment of efficient and sustainable transportation technologies that will improve energy efficiency, fuel economy, and enable America to use less petroleum. To accelerate the development and adoption of new technologies, VTO has developed specific targets for a wide range of powertrain components, including energy storage system. In this study, Autonomie, Argonne's vehicle system simulation is used to evaluate future energy storage requirements (i.e., power, energy, etc.) for different vehicle classes, powertrains, component technologies and timeframe. BatPaC, Argonne's tool dedicated to energy storage pack design and cost, is then used to quantify the materials required for each pack. Market penetrations are then used to estimate the overall material demand worldwide and in the US, with or without recycling. Results demonstrate the positive impact of VTO R&D leading to significant reduction in material due to new anode and cathode design.

Keywords: battery, demand, electric vehicle (EV), materials, simulation

1 Introduction

U.S. DOE-VTO relies on different market penetration tools to evaluate material demands of different materials in the United States and globally. However current method of evaluating the market demand for battery materials do not consist of applying individual VTO component targets such as battery energy density, lightweighting, etc., to estimate the overall impact of VTO R&D. Therefore the evolution of current and future battery material demand relies on data that does not reflect the VTO technology target goals.

A large scale study is being run as part of DOE Benefits and Scenario Analysis (BaSce). Using the vehicles modeled as part of this study, further analysis has been conducted to estimate the battery material demand for different analysis years and the impact of recycling. It provides the range of estimates for business-as-usual (low technology progress) and VTO target goal impacts (high technology progress) for vehicle component targets, battery chemistry and market penetration.

2 Process

The different vehicle technology targets (battery energy density, battery energy specific cost, lightweighting, etc.) set by DOE-VTO is used to build the assumptions that is evaluated over a range of time frames [2]. This paper will cover the results from 2015, 2020, 2025, 2030 and 2045 'lab years', which corresponds to 'model year - 5 years'. For example, a lab year 2015 vehicle would reflect a vehicle that is available in the market in 2020 and similarly a 2045 lab year vehicle would imply a vehicle that is available in the market in 2050.

The vehicle system simulation tool Autonomie [3] is used to perform simulation on vehicle models that incorporate these vehicle technology targets. The vehicle models used for the simulation include power-split hybrid (Split HEV), plug-in hybrid (Split PHEV20 & EREV PHEV50) and battery-electric vehicles (BEVs) of different all-electric ranges (AER) - BEV200, BEV300, and BEV400.

The Argonne battery performance and cost modeling tool, BatPaC [4] is used to estimate the active material content of the different chemistries across the different analysis years.

3 Study Assumptions

3.1 Vehicle and Component Assumptions

This section details the different vehicle classifications and some of the major vehicle attribute selection used in the study. Table 1 details the different vehicle classifications defined for various performance times (0-60 mph time) in seconds as well as corresponding vehicle attributes. The latest report from Argonne [5] details the assumptions and procedure involved behind the vehicle modeling and simulation efforts.

Table 1: Vehicle classification and characteristics

Vehicle Class	**0-60 mph time (s)**	**Frontal Area (m^2)**	**Drag Coefficient**	**Rolling Resistance**
Compact	10	2.3	0.31	0.009
Midsize	9	2.35	0.3	0.009
Small SUV	9	2.65	0.36	0.009
Midsize SUV	10	2.85	0.38	0.009
Pickup	7	3.25	0.42	0.009

Table 2 below summarizes the main DOE-VTO battery target assumptions associated with the different technologies over time. The different vehicles modeled in this study represent the "lab years" 2015, 2020, 2025, 2030, and 2045.

Table 2: Technology Assumptions

Lab Year	2015	2020		2025		2045	
Technology Progress	Low	Low	High	Low	High	Low	High
Specific Power @ 70% SOC – HEVs (*W/kg*)	2,750	3,000	4,000	4,000	5,000	5,000	6,000
Specific Energy (USABLE) - PHEV20 (*Wh/kg*)	60	80	100	105	125	115	170
Specific Energy (USABLE) - PHEV50 (*Wh/kg*)	70	95	105	105	125	115	170
Specific Energy (USABLE) - BEV (*Wh/kg*)	170	170	230	230	310	280	320

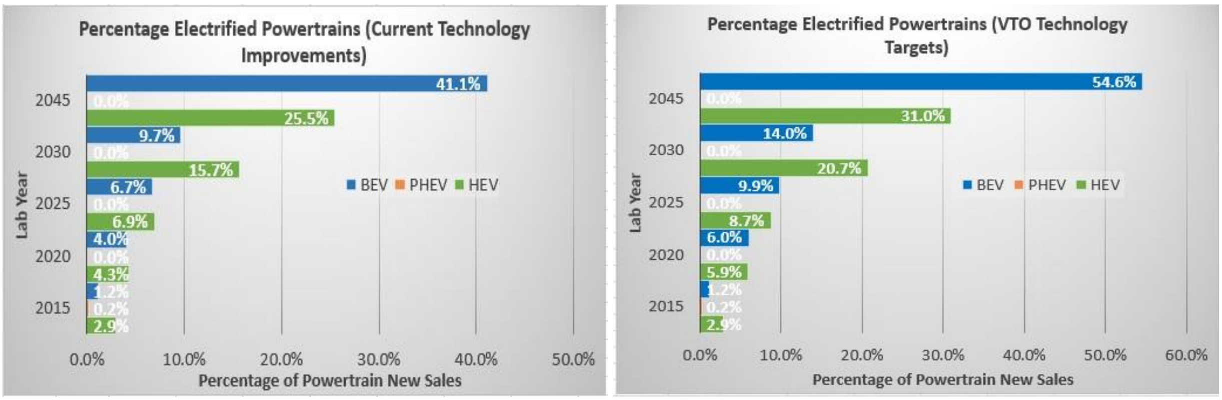
3.2 Market Penetration Assessment

Table 3 details the assumption of different battery chemistry penetrations across the fleet for different analysis years.

Table 3: Battery Chemistry Penetration Across Fleet

Lab Year	2015	2020		2025		2030		2045	
Technology Progress	Low	Low	High	Low	High	Low	High	Low	High
NCA-G	40	40	20	20	0	10	0	10	0
NMC622-G	48	48	24	37.5	0	16	0	16	0
NMC811-G	9	9	30	33.75	37.5	44	0	44	0
NMC955-G	3	3	6	3.75	37.5	20	100	20	100
NCA-G 10% Co	0	0	20	5	25	10	0	10	0

Figure 1 details the market penetration of different electrified powertrains for different lab years.



(a) Current technology improvements

(b) VTO technology targets

Figure 1: Market penetration of electrified powertrains

Figure 2 details the market penetration across the different electrified powertrains and vehicle classes for the different analysis years and technology progresses.

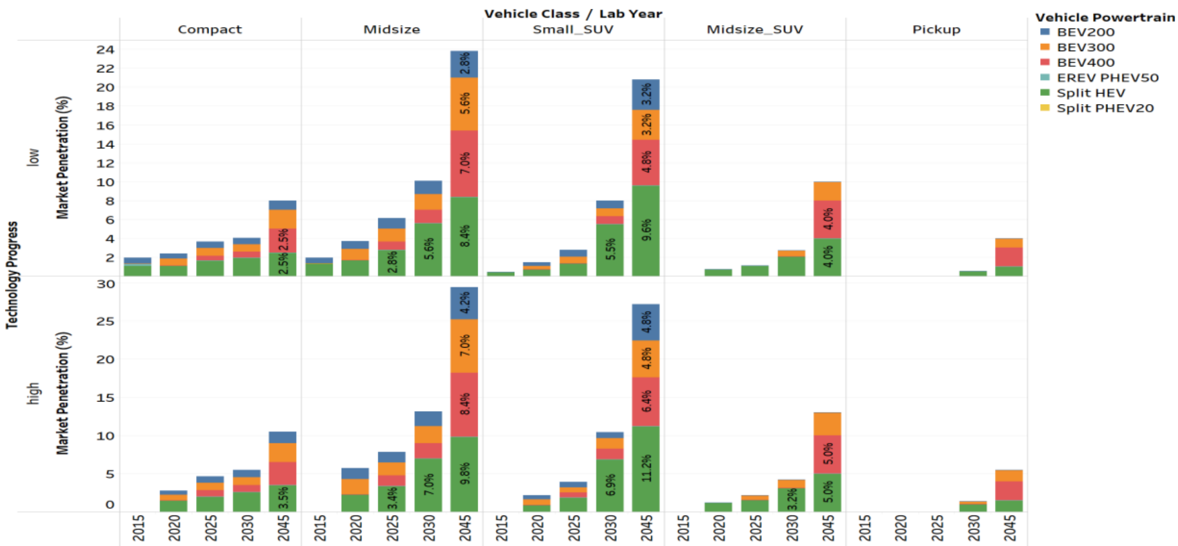


Figure 2: Market penetration of different powertrains and vehicle classes

3.3 Battery Material Recycling Assumptions

There are existing publications that evaluates different battery recycling methods. For this study, it is assumed that 100% of the available battery energy is recyclable assuming a 10 year end-of-life period for the batteries.

4 Results & Observation

Figure 3 shows the impact of the sum of the total battery energy for the different electrified powertrains and vehicle classes modeled for the different lab years and technology progresses. This is for the individual vehicle simulations, and do not represent the effect of market penetration.

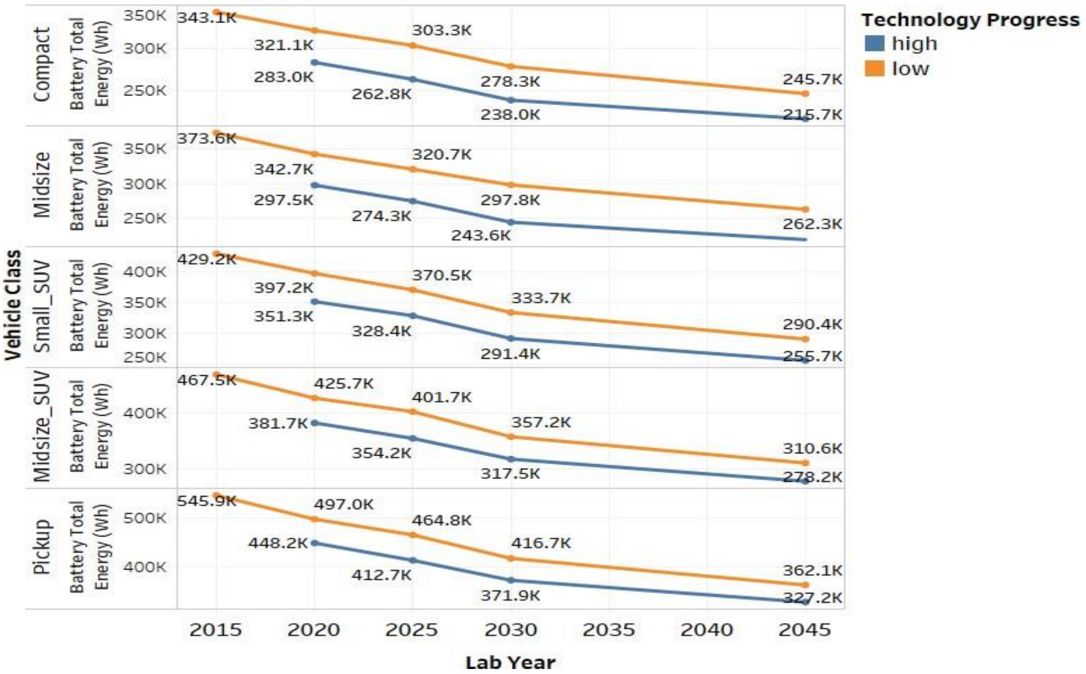
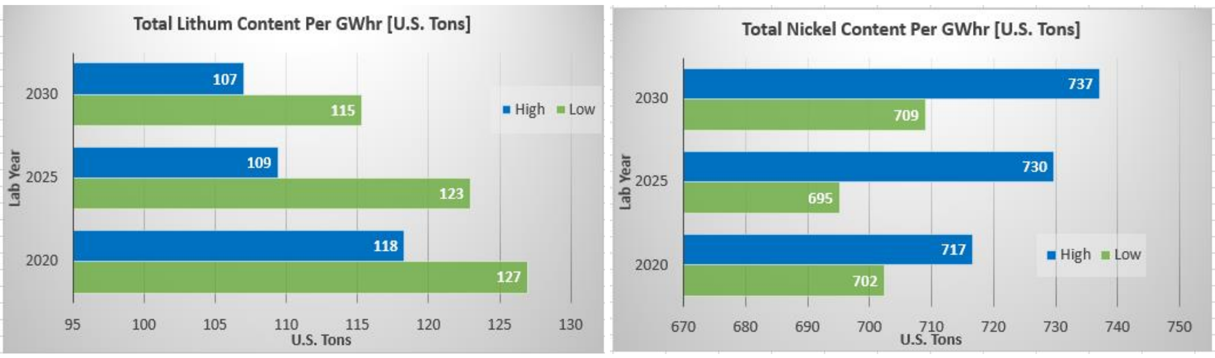
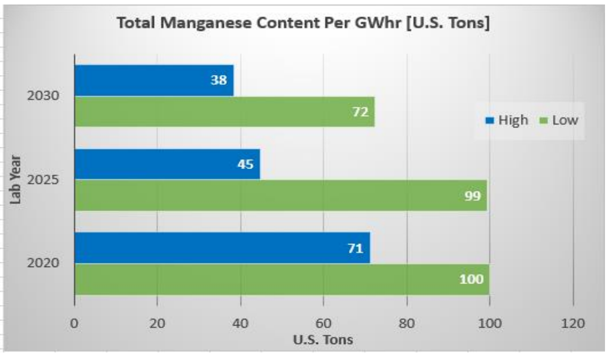


Figure 3: Total battery energy (Wh) for different vehicle classes

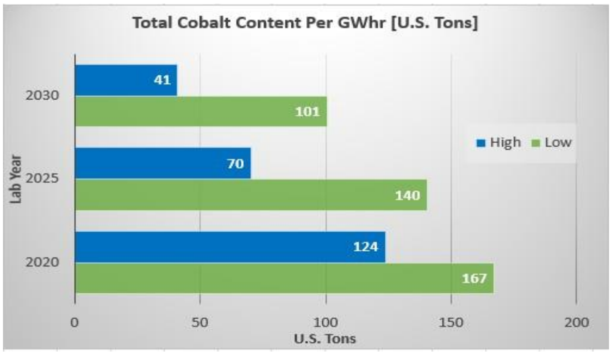
It shows the impact of advanced VTO targets on battery energy requirements. When scaled to a total energy requirement of per GWh, figure 4 shows the impact of VTO battery technology advancements for different materials demand per GWh.



(a) Total Lithium content (in U.S. tons) per GWhr (b) Total Nickel content (in U.S. tons) per GWhr



(c) Total Manganese content (in U.S. tons) per GWhr



(d) Total Cobalt content (in U.S. tons) per GWhr

Figure 4: Total battery materials content (in U.S. tons) Per GWhr

4.1 United States Demand

With the assumption of **17 million** new vehicle sales in the U.S. market every year, the appropriate market penetrations have been adopted for the different powertrains and classes. Figure 5 illustrates the total annual demand of different battery materials for U.S. split up across the vehicle powertrains modeled.

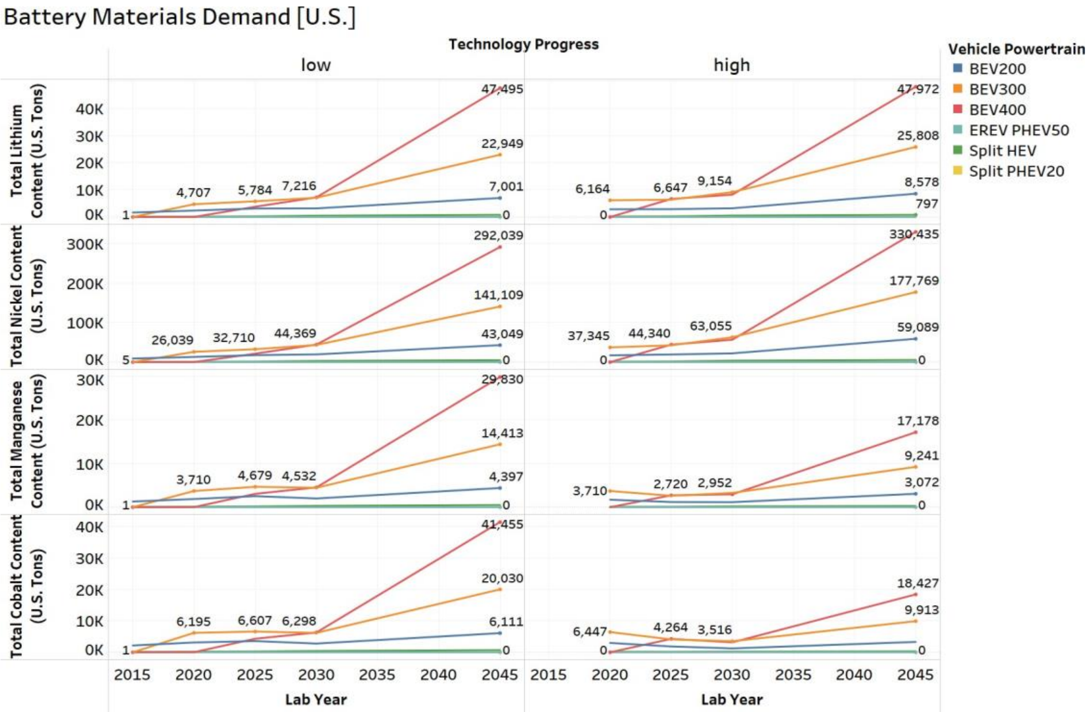


Figure 5: Total battery materials demand for different vehicle classes

Figure 6 illustrates the total annual demand of different battery materials for U.S. split up across the vehicle classes modeled.

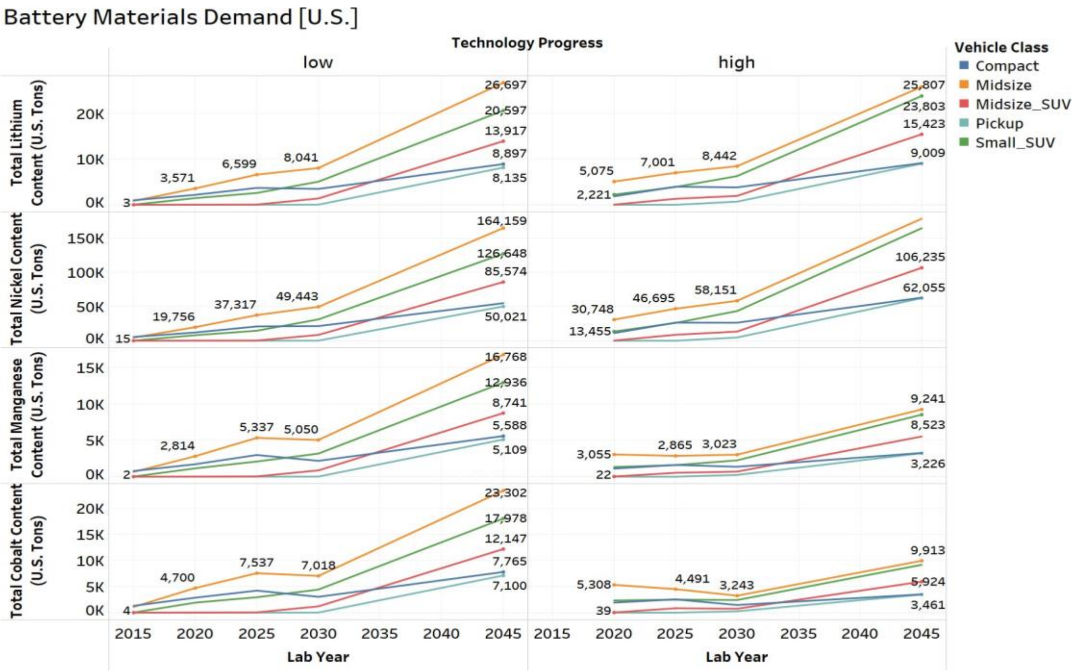


Figure 6: Total battery materials demand for different vehicle classes

Figure 7 illustrates the total annual demand of different battery materials for U.S.

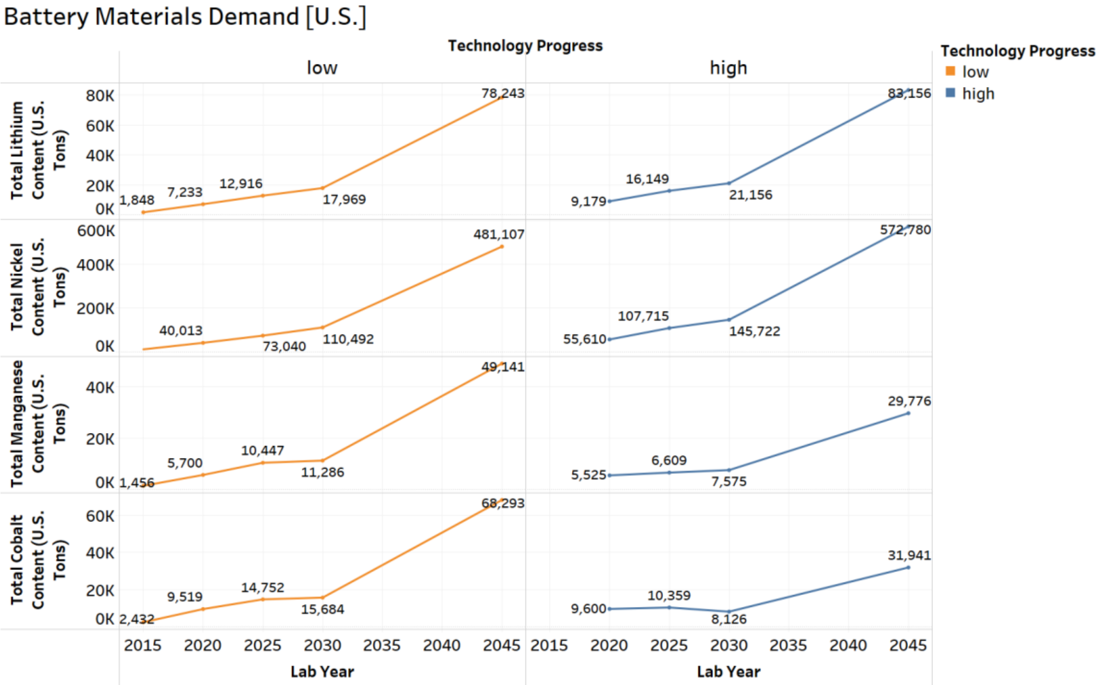


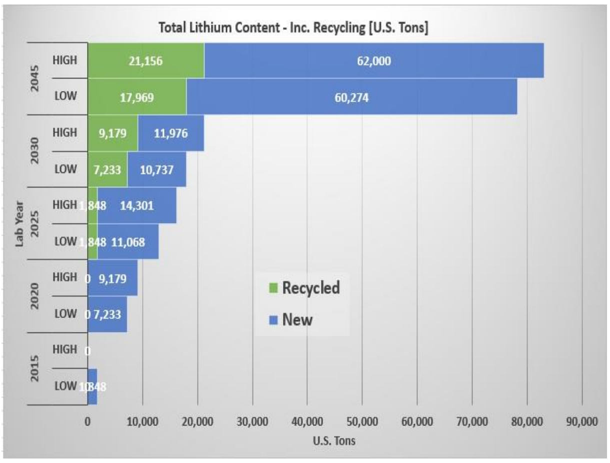
Figure 7: Total battery materials demand for different vehicle classes

The findings are summarized below:

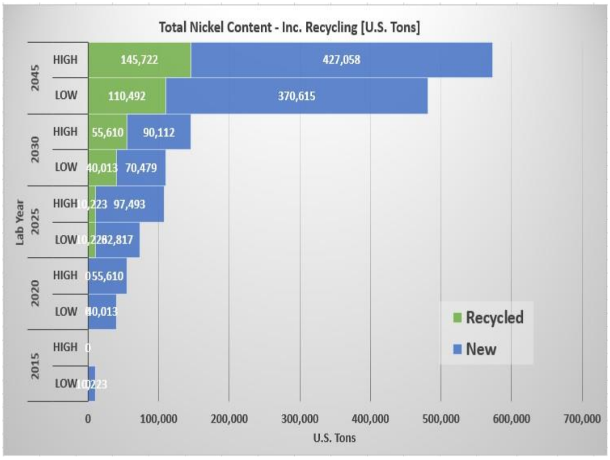
- For total lithium content demand, it increases from 1,848 tons to 78,243 tons by 2045 Lab Year for current technology improvements (low progress), and it increases to 83,156 tons for VTO technology improvements (high progress).

- For total nickel content demand, it increases from 10,223 tons to 481,107 tons by 2045 Lab Year for current technology improvements (low progress), and it increases to 572,780 tons for VTO technology improvements (high progress).
- For total manganese content, the demand increases from 1,456 tons to 49,141 tons by 2045 Lab Year for current technology improvements (low progress), and it increases to 29,776 tons for VTO technology improvements (high progress).
- For total cobalt content, the demand increases from 2,432 tons to 68,293 tons by 2045 Lab Year for current technology improvements (low progress), and it increases to 31,941 tons for VTO technology improvements (high progress).

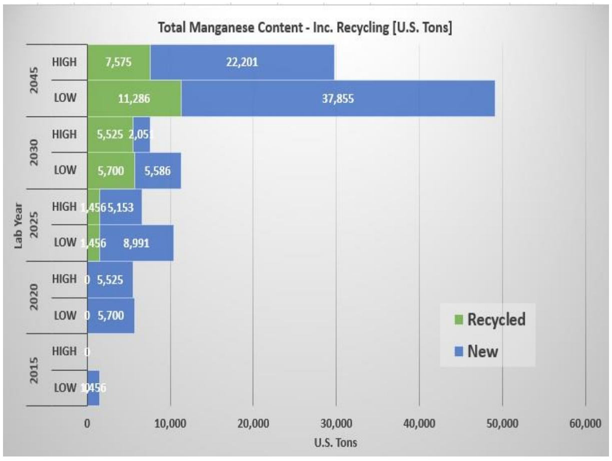
Accounting for the recycling assumptions mentioned earlier, appropriate analysis is conducted to evaluate the impact of recycling on the different battery material demands. Figure 8 illustrates the annual demand of different raw materials for U.S. to satisfy the market penetration of 17 million new vehicle sales per year, accounting for battery recycling.



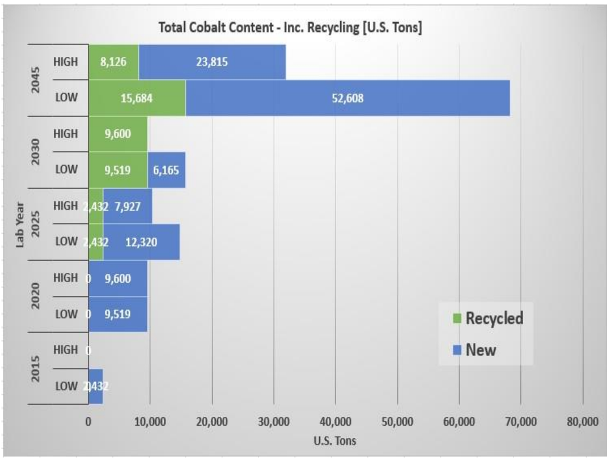
(a) Total lithium content



(b) Total nickel content



(c) Total manganese content



(d) Total cobalt content

Figure 8: United States battery materials demand (in U.S. tons) for different lab years (including recycling)

The impact of recycling estimations is summarized below:

- For total lithium content demand, it can be seen that 11%-14% of the demand can be met through recycling in 2025 lab year, 40%-43% in 2030 lab year and 23%-25% in 2045 lab year.

- For total nickel content demand, it can be seen that 9%-14% of the demand can be met through recycling in 2025 lab year, 36%-38% in 2030 lab year and 23%-25% in 2045 lab year.
- For total manganese content demand, it can be seen that 14%-22% of the demand can be met through recycling in 2025 lab year, 51%-73% in 2030 lab year and 23%-25% in 2045 lab year.
- For total cobalt content demand, it can be seen that 16%-23% of the demand can be met through recycling in 2025 lab year, 61%-118% in 2030 lab year and 23%-25% in 2045 lab year.

It can be seen that the assumed recycling estimations reduces the materials content demand significantly higher with the advancements of DOE-VTO target aggressiveness.

4.2 Global Demand

With the assumption of **80 million** new vehicle sales in the global market every year, the appropriate market penetrations have been adopted for the different powertrains and classes. Accounting for scalability of the total energy requirements, the materials demand has been evaluated for the global scale.

Figure 9 illustrates the total annual demand of different battery materials for world demand split up across the vehicle powertrains modeled.

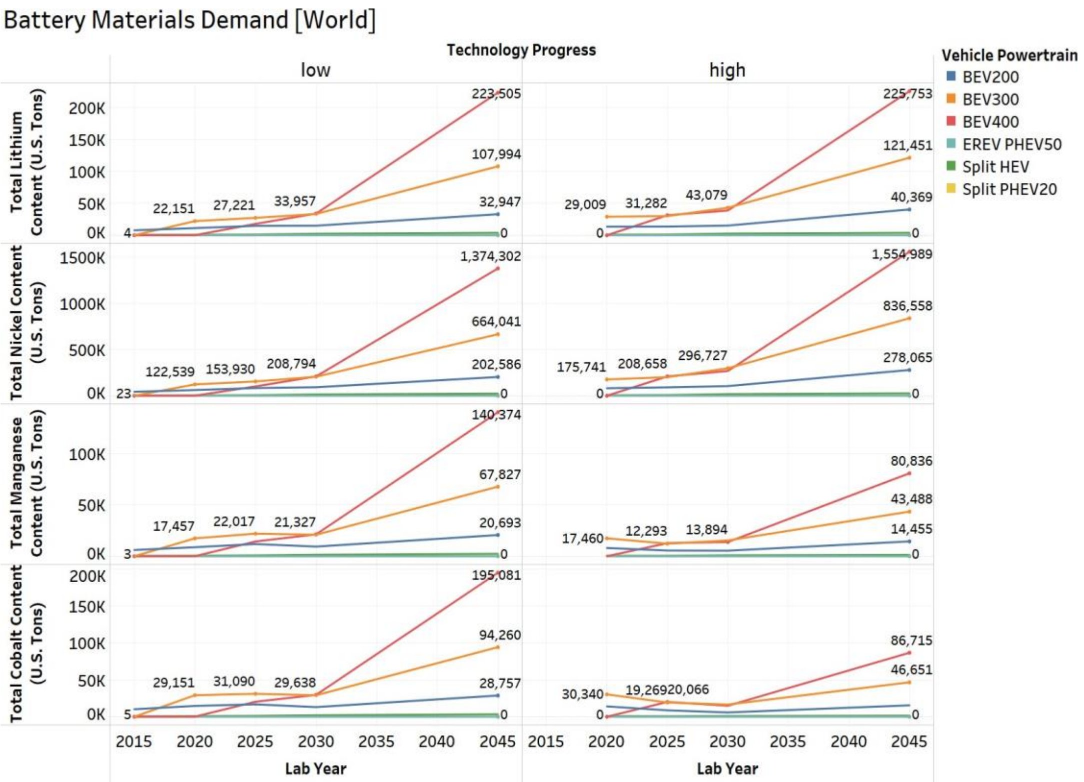


Figure 9: Total battery materials demand for different vehicle powertrains

Figure 10 illustrates the total annual demand of different battery materials for global demand split up across the vehicle classes modeled.

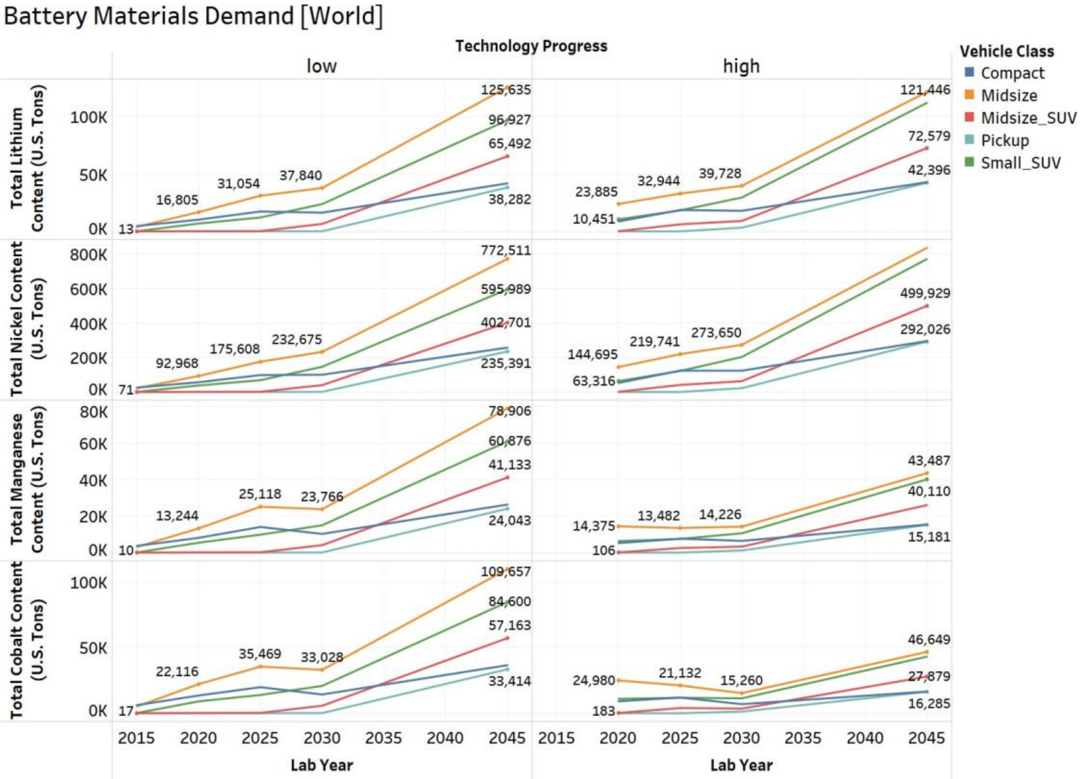
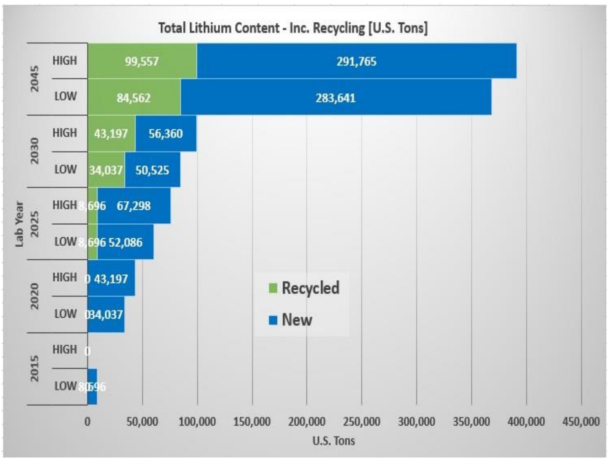
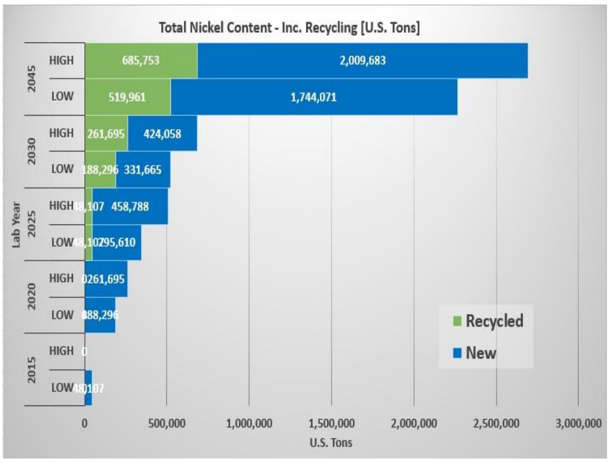


Figure 10: Total battery materials demand for different vehicle classes

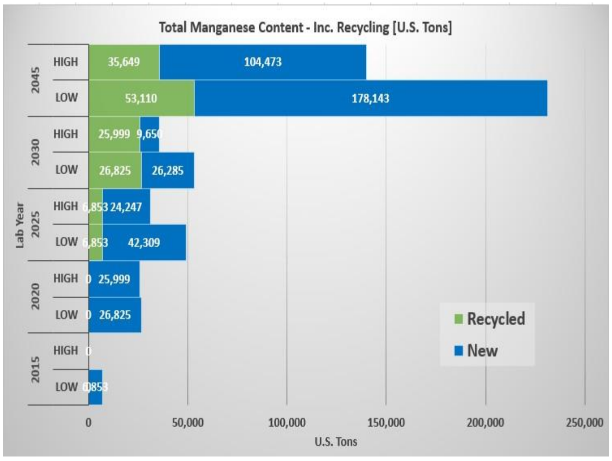
Figure 11 illustrates the annual supply of different raw materials for global to satisfy the market penetration of 80 million new vehicle sales per year, accounting for the same recycling assumption.



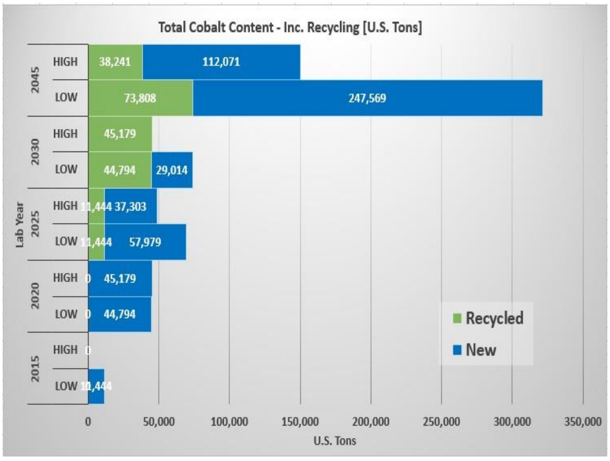
(a) Total lithium content



(b) Total nickel content



(c) Total manganese content



(d) Total cobalt content

Figure 11: Global battery materials demand (in U.S. tons) for different lab years (including recycling)

5 Summary and Conclusion

The paper demonstrates an in-depth analysis and study of different raw materials demand for EV batteries. It shows the impact of DOE-VTO goals for battery energy densities on reducing the total energy demand, and the subsequent impacts on different raw materials demand. The impact of different raw materials demand is influenced by the market penetration assumptions for vehicles along with the different battery chemistries. The main conclusions drawn from the study are outlined below:

- The DOE-VTO goals is expected to decrease the total battery energy requirement by 31% by 2045 lab year for low technology progress and 40% for high technology progress.
- The market penetration of electrified vehicles is assumed to increase by 62% by 2045 lab year for low technology progress and by 81% for high technology progress.
- The DOE-VTO goals impact the total materials demand per GWh for different materials. By 2045 lab year, it is expected for the total lithium content to decrease by 16%, total nickel content by 62%, total cobalt content by 75% and increase the total nickel content by 5%.
- Accounting for the market penetration of battery chemistry and electrified vehicles, the total lithium content requirement is expected to increase by 42 times by 2045 for low technology progress and 45 times for high technology progress. The total nickel content requirement is expected to increase by 47 times for low technology progress and 56 times for high technology progress. The total manganese content requirement is expected to increase by 34 times for low technology progress and by 20 times for high technology progress. The total cobalt content requirement is expected to increase by 28 times for low technology progress and by 13 times for high technology progress for both U.S. and global market.

For the purpose of this study, there are certain assumptions made for the market penetration of vehicles as well as the different battery chemistries. Although these assumptions could influence the values, this approach lets us evaluate the impact of DOE-VTO goals on the impact of the demands for different battery materials.

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Presenter Biography

Ehsan Sabri Islam completed his M. Sc. in Interdisciplinary Engineering from Purdue University, USA in 2019 and B.A.Sc in Mechatronics Engineering from University of Waterloo, Canada in 2016. His skills set and interests focus on applying Mechatronics principles to innovate systems and processes in advanced vehicle technologies and controls systems. At Argonne, he focuses his research on vehicle energy consumption analyses and inputs for U.S. DOE-VTO and NHTSA/U.S. DOT SAFE regulations using innovative large scale simulation processes and applications of AI.