Final Report
EV Battery Anode for High-Speed Charging

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1. Executive Summary

Purpose

The Ohio State Arpa-E Fast Charge Anode Project is developing an innovative alloy-based anode material for EV batteries, enabling extreme fast charging in 10 minutes or less. This project focuses on commercializing a novel silicon-based anode material for lithium-ion batteries, with a particular target on the Battery Electric Vehicle (BEV) sector in the USA. The goal is to optimize the scalable production process to manufacture this innovative anode material at a competitive price. To evaluate the consumer value of this technology, we conducted a discrete choice experiment using Sawtooth Software, focusing on a representative EV product that integrates this anode into its battery system. We surveyed people to understand the demand and interest in BEVs and to evaluate how advancements in battery technology, like the silicon-based AAM, could influence consumer choices. The product category evaluated is compact to mid-size electric vehicles, in which we analyze how a hypothetical Tesla Model Y (referred to as Tesla Model Y+) with fast charging competes in the market against a traditional Tesla Model Y.

The purpose of this analysis is to assess the potential application and scalability of a silicon-based active anode material (AAM) for lithium-ion batteries used in electric vehicles (EVs). The decision variables of focus for this analysis include drying and heating equipment used in the process and the production location. These variables are critical in determining the optimal performance of the anode and, consequently, the battery. While the BEV itself is the product in focus, the silicon-ceramic-based novel active anode material (AAM) we are developing is not the product itself, but a technology(component) that can significantly enhance BEV performance, especially by reducing charging time.

Findings and Recommendations

Our core finding is that at an annual production of approximately **27,000 tonnes** [with a range of 25,000 to 30,000 tonnes] not only achieves economies of scale (EOS) but also **maximizes profit at around half a billion dollars**. The largest contributors to overall production cost are **raw materials**, **labor**, and **building costs**, while **equipment selection** and **energy use** are secondary but influential factors. Sensitivity analyses highlight raw material pricing and plant utilization rate as key levers for maintaining cost competitiveness.

From a demand-side perspective, our conjoint analysis revealed that price is the respondent's priority, and faster charging speed is valued more highly by consumers than improvements in driving range. The willingness to pay for 1 min decrease in charging time is about $400, and the willingness to pay for 1 mile increase in range is about $200. In our simulated market scenario, we assume compatibility of the silicon-based anode technology with all battery variants of the 2026 Tesla Model Y. Charging time is reduced from 16 minutes (Model Y) to 7 minutes (Model Y+), based on a linear charging assumption. Simulated choice share using the logit model shows a 97% preference for the Model Y+ versus 3% for the Model Y. Under pessimistic and optimistic scenarios (charging time of 10 and 5 minutes), the Model Y+

sees simulated choice shares of 74% and 100%, respectively. With 398,782 Model Y units sold in 2024, Model Y+ would capture over 373,000 units, requiring around 36,360 metric tons of active anode material. Segmentation analysis highlights that this preference is especially strong among urban male consumers aged 25–34. It could be because these users often face range anxiety and time constraints, making charging speed a critical differentiator. We estimate the unit cost of $21 at economies of scale, with a range of $16 in optimistic scenarios to $130 in pessimistic scenarios.

Overall, the technology demonstrates strong commercial viability. Our willingness-to-pay modeling shows that the market value of the technology's performance enhancements generally exceeds its projected cost, indicating a high likelihood of profitability under most realistic scenarios. This is supported by favorable market positioning, alignment with consumer needs, and the feasibility of scaling the production process without substantial technical risk. However, several uncertainties remain. Market willingness to adopt new anode chemistries depends on integration compatibility with existing battery manufacturing lines, potential long-term degradation behavior, and ongoing shifts in regulatory and supply chain dynamics. Additionally, our economic projections assume stable prices for key raw materials and relatively high plant utilization rates, both of which may fluctuate.

Based on these findings, we recommend proceeding with pilot-scale production to validate cost assumptions under continuous operation, while simultaneously engaging battery cell manufacturers and EV OEMs to assess integration pathways and co-development opportunities.

2. Introduction

Technology

The technology under analysis is a silicon-based active anode material (AAM) for lithium-ion batteries used in electric vehicles (EVs). The silicon-based anode enhances the performance of the battery by significantly reducing charging time while maintaining or improving the energy storage capacity of the battery. This technology addresses a key challenge in the EV market, reducing the time it takes to charge EV batteries to a level comparable to refueling internal combustion engine vehicles, which typically takes less than 10 minutes.

The active anode material consists of a blend of silicon, which offers superior electrochemical properties compared to the traditional graphite-based anodes. Silicon-based anodes have a higher theoretical capacity for energy storage, which increases the overall energy density of the battery. Additionally, the integration of an amorphous matrix helps mitigate mechanical stresses caused by expansion and contraction during battery cycling, thereby extending battery life and improving safety (CO et al., 2020).

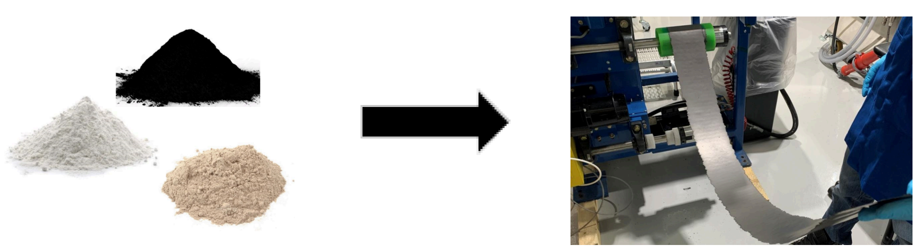

Figure 1. Left: graphite active anode material (Fuel Cell Store, 2025), which is used to create the anode on the right (Oak Ridge National Laboratory, 2023), which later goes inside a battery cell.

Production Process

The scope of this analysis will focus on scaling up the production of silicon-based anode material for lithium-ion batteries. The process flow diagram in Figure 2 outlines the major equipment used, the inputs and outputs flow, and the labor and energy required in the production process.

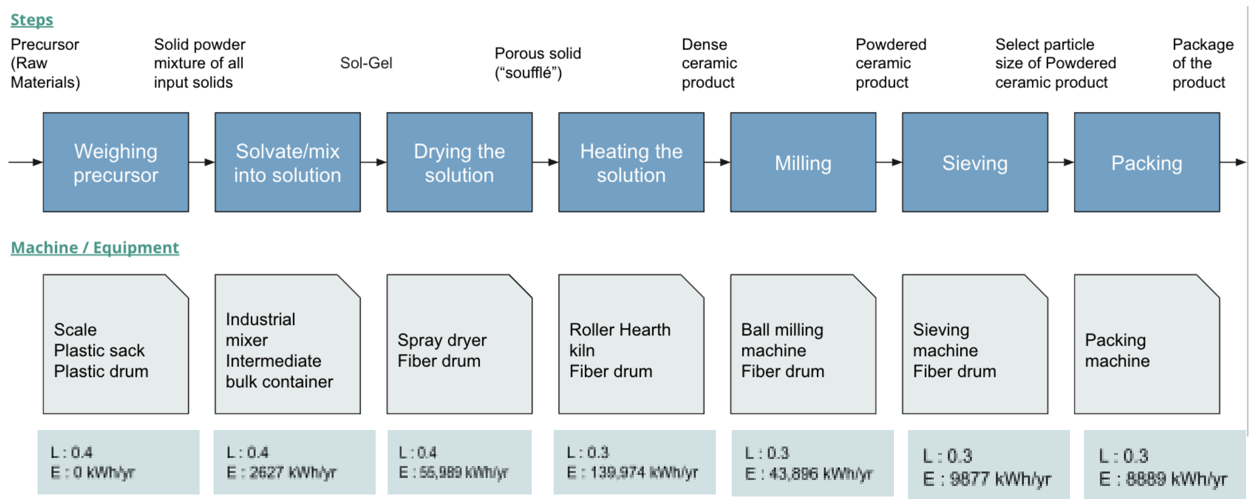

Figure 2. Process flow diagram of AAM production

The production process of AAM starts with weighing all the raw materials using industrial scales, where the solid material will be put in a plastic sack and liquid materials in plastic drums. This step will be followed by a mixing stage for 30 minutes in a stainless steel mixing vessel, where the reaction occurs, and the slurry output will be stored in an intermediate bulk container. Next, the sol-gel mixture was then fed into the spray dryer at a temperature of 150^0C to evaporate most of the water for an hour. The output of the spray dryer will be heated in a 700^0C roller hearth kiln for one hour to ensure the AAM contains suitable moisture content. The dense ceramic product is then crushed in a ball mill for 30 minutes into powdered AAM, which will then be sieved in a vibrating sieve to obtain the desired size needed. Fiber drums will be used to transport the material from the heating step to the packing step. Finally, the AAM is packaged to preserve the quality and the convenient shipping process. Auxiliary equipment, such as hand lifts and pallets, is used to move materials throughout the manufacturing area. The details of the equipment list are provided in Appendix A.

Market Application

This technology is applied to the battery pack of Battery Electric Vehicles (BEVs). The integration of the silicon-based active anode material provides a competitive advantage by offering faster charging times, which is a key pain point for many consumers in the EV market. The target customers are EV battery or EV manufacturers for the AAM, and the consumers seeking an EV with superior charging performance. The key competitors in this market include other EV battery manufacturers and other EV battery technology manufacturers working to improve charging speeds and battery performance.

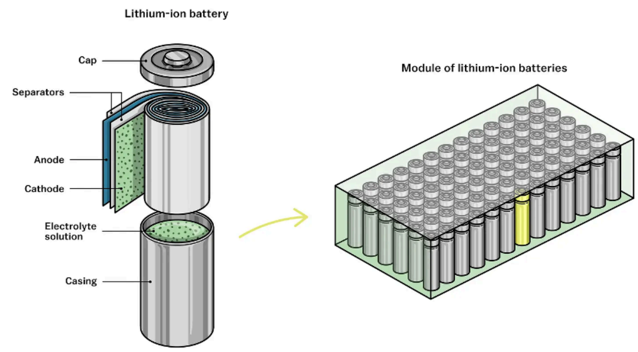

Figure 3. Battery electrodes in battery cell (Dallas, 2024)

Key Decisions

The finalized decision variables for this analysis are the heating machine, drying machine, and the manufacturing location price. These factors were selected for their direct influence on production costs, which in turn determine the final price of the electric vehicle (EV). The drying machine, utilized in the third stage of the production process, and the heating machine, used in the fourth stage, represent major cost drivers within the manufacturing workflow. Additionally, the choice of production location significantly affects expenses due to variations in labor, utility, and facility costs. As these variables do not alter the technical performance of the battery, their impact is isolated to product pricing, allowing for a focused cost optimization strategy.

The relationship between the decision variables and product attributes is highlighted in the model relationship table, as listed in Appendix B. The price of the EV is influenced by several process variables, including the drying machine, heating machine, and production location. All variables affect the cost of our active anode material. Although the charging time and driving range do not vary according to variations in decision variables.

3. Production Analysis

Production Model

We use a Process-Based Cost Model (PBCM) to estimate the unit cost (per kg) of active anode material. The model captures the full manufacturing process, incorporating step-specific and facility-wide inputs, including material, labor, equipment, energy, and tool costs. It calculates operational outputs such as production volume and line requirements, and financial outputs such as variable and fixed costs, which together determine the unit cost at a given production scale.

The scope of the model includes all major steps in the anode material production process as outlined previously, with details provided in the PBCM attachments. Key assumptions include baseline values for material composition, equipment specifications (e.g., yield, cycle time, capacity), and operational parameters provided by the sponsor and estimated based on limited manufacturer data. We conduct a sensitivity analysis across baseline, optimistic, and pessimistic scenarios to account for uncertainty in these inputs. Appendix E details the parameters and their justifications

Unit Cost Curve

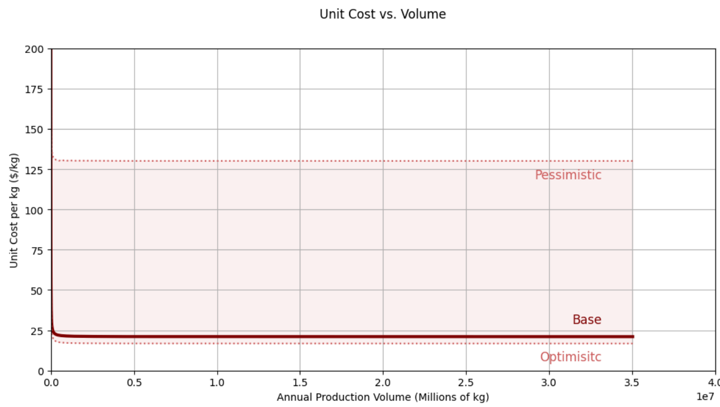

Figure 4. Unit cost curves for baseline, optimistic, and pessimistic scenarios.

Our base case unit cost curve, shown in Figure 4, indicates that the price drops significantly when annual production volume increases at the beginning of the incremental changes. The unit cost stays steady at around $21/kg at the production volume of 8,500 tonnes per year, as shown in Appendix C. While our projected production volume is 27,000 tonnes/year (to maximize profit), we conduct the production analysis at 8,500 tonnes/year since the trend stays the same even though the production volume increases. Uncertainty in the graph in Figure 3 reveals that the unit cost may vary significantly, up to 600% higher under pessimistic assumptions and 20% lower in optimistic scenarios. This asymmetry arises primarily from equipment cost, building cost, yield rate, setup time, and discount rate. Appendix D details the parameter ranges used.

Cost Breakdown

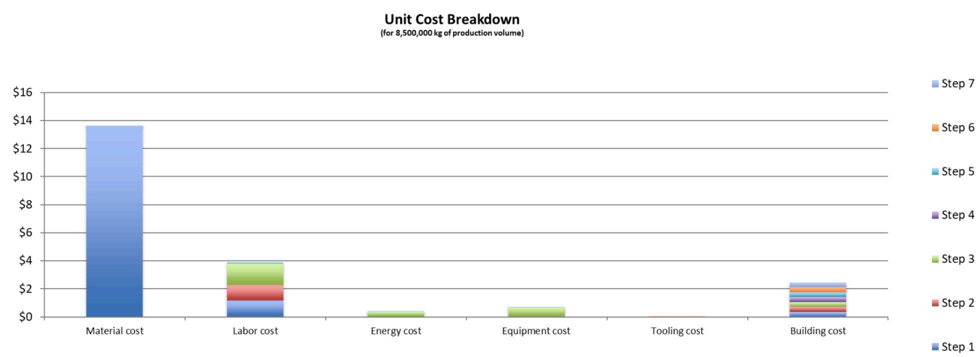

Figure 5. Unit cost breakdown by steps at 8,500,000 kg of annual production

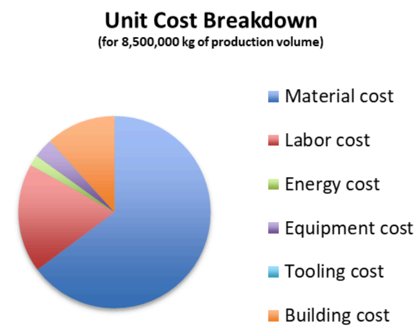

Figure 6. Unit cost breakdown at 8,500,000 kg of annual production

To better understand how cost components contribute to the overall unit cost, we present two visual breakdowns in Figures 5 and 6. Figure 5 disaggregates unit costs by both process step and cost element, while Figure 6 summarizes the contribution of each cost element independently. At the 8,500 tonnes/year production level, material costs emerge as the most substantial contributor, primarily concentrated in Step 1 of the process. Following this, labor costs account for a significant portion of the total unit cost, driven by the number of lines and labor required to run the production. The third major contribution of total unit cost is that building costs account for a significant share of the total cost, driven by facility construction and infrastructure expenses. Equipment and energy costs also contribute meaningfully, although to a lesser extent. Among all process steps, Step 3, the eating process, has the highest labor cost, energy cost, and equipment cost because this process requires a high number of lines due to high setup time, high cycle time, and small batch size. These breakdowns validate our identification of material costs, labor costs, and optimization in Step 4 as focal points for cost optimization and capital planning.

Cost Drivers and Cost Levers

To identify major cost drivers and actionable cost levers, we conducted several targeted sensitivity analyses and visualized the results using cost curves, scenario comparisons, and a tornado plot (Appendix F). One of the most impactful cost drivers is material price. As shown in Figure D, switching from a lower-cost to a higher-cost drying machine increased the unit cost by 188%, raising the unit cost from approximately \$21/kg to \$61/kg. Labor cost is the second-highest portion of total unit cost. However, while varying the proportion of chemists and production workers could potentially reduce overall wages from \$24.69 to \$19.95 (Appendix E), the unit cost only reduces by 3% from around \$21/kg to \$20/kg. Facility location also plays a key role; Figure F, in Appendix F, shows that choosing Dallas over Pittsburgh for production can reduce unit cost by more than \$0.05/kg due to lower construction costs in Dallas. From the tornado plot, we observe that other influential variables include drying machine, material price, wages, and setup time. To address these drivers, we propose several cost levers: optimizing equipment choices for cost-effectiveness, reducing material price by partnering or securing a long-term contract with raw material manufacturers, optimizing the right combinations of labor skills, reducing construction costs by selecting more affordable locations, and redesigning process workflow to minimize setup time and improve operational efficiency.

Conclusions

One of the major cost drivers in our production-based cost modelling is the material costs, followed by labor costs and building costs. However, the analysis includes a few key limitations that may affect the accuracy of our findings. Notably, we assume a constant yield rate of 90%, a machine lifetime of 20 years, and a 5% discount rate to calculate the Net Present Value (NPV) of equipment investments. Several important unknowns could also impact our results like unanticipated regulatory changes, shifts in energy costs, fluctuations in raw material prices due to supply chain disruptions, and global demand shifts.

4. Demand Analysis

Demand Model

To understand consumer preferences for battery electric vehicles (BEVs), we conducted a discrete choice experiment using Sawtooth Software. Our primary focus was on three key product attributes: Purchasing Cost, Charging Time, and Driving Range. These attributes were selected because they are core decision factors for EV customers, and they are influenced by the integration of our novel silicon-ceramic anode material. The levels for each attribute were chosen based on current market offerings and feasible performance benchmarks: Purchasing Cost ($32,000, $40,000, $48,000), Charging Time to add 180 miles of range (5 min, 10 min, 20 min), and Driving Range per full charge (250 mi, 300 mi, 350 mi).

The survey was designed with 10 choice tasks per respondent, alongside 2 attention-check questions and 4 segmentation questions for demographic insights. We collected 203 responses from a sample of respondents likely to show awareness or to be early adopters of BEV. Due to this specific sampling approach, an "outside good" was not included in the choice set. Additional demographic data were collected to allow for segmentation by age, gender, residency, and household income.

Our model assumes a linear utility function and follows a multinomial logit structure. We confirmed the appropriateness of the model through the beta coefficients obtained from Sawtooth Discover, which indicated that the assumed linearity was consistent. This suggests that the model accurately reflects the trade-offs consumers make between BEV price, charging time, and range.

Willingness to Pay

The willingness to pay (WTP) for improvements in product attributes was derived from the part-worth utilities estimated in our discrete choice model. As calculated in Appendix H from beta coefficients obtained, respondents are willing to pay approximately $400 for each minute reduction in charging time, and around $120 for each additional mile of driving range. This highlights a significant perceived value in faster charging, even more so than additional range, although both are clearly important.

Further interpretation of the model results shows that Purchasing Cost is the most influential attribute in consumer decision-making (see Figure I3), followed by Charging Time, with Driving Range having the lowest impact. However, this lower utility weight does not necessarily imply irrelevance; it is possible that charging speed becomes a decisive factor only when it reaches specific thresholds, such as below 10 minutes, which aligns with the behavior of early adopters valuing technological advancements. Overall, the data suggests consumers are highly sensitive to cost but will pay premiums for range and rapid charging, affirming the potential value proposition of our silicon-ceramic anode material.

Simulated Market Scenario

To assess the market potential of our technology, we constructed a simulated market scenario comparing two product configurations: the baseline Tesla Model Y and a modified version (Model Y+) incorporating our fast-charging silicon-ceramic anode. The baseline Model Y (2026) is priced at $41,490, offers a 327-mile range, and charges 180 miles in approximately 16 minutes. These metrics were standardized based on public specifications and adjusted to fit our defined attribute levels.

For the Model Y+, we estimated a slightly higher price of $43,417, accounting for the increased cost of silicon-based anode material relative to graphite ($21/kg vs. $9.50/kg, respectively). Battery composition estimates allowed us to project a **$1000** increase in vehicle cost due to the material switch. However, the key performance upgrade is a charging time of just 7 minutes to add 180 miles, assuming linearity up to 80% state-of-charge.

Using a multinomial logit model, we simulated choice shares under various conditions. Sensitivity testing with optimistic and pessimistic assumptions about maximum charge power (350 kW and 250 kW, respectively) shifts the Model Y+'s market share. These scenarios underscore the competitiveness of the fast-charging technology under a range of technical constraints.

Attribute	**Tesla Model Y+**	**Tesla Model Y**
Price	Varies	$41,490
Charging Time	7 mins	16 mins
Driving Range	327 mi	327 mi

Table 1: Summary of attributes for Tesla Model Y+ (our product) and Tesla Model Y (competitor).

Attribute	**Tesla Model Y+ (Base)**	**Tesla Model Y+ (Pessimistic)**	**Tesla Model Y+ (Optimistic)**
Price	$44,500	$44,500	$44,
Charging Time	7 mins	10 mins	5 mins
Range	327	311	350
Market Share	78%	1%	100%

Table 2: Summary of simulated choice share of the Model Y+ relative to the Model Y under different scenarios.

We also scaled our findings to estimate potential sales volume. Using 2024 Model Y sales data (373,613 units sold), we project that under the base scenario, our Model Y+ could capture over 347,000 units, translating to an annual demand of roughly 36,360 metric tons of anode material.

Opportunities to Increase Demand

To explore opportunities for increasing demand, we conducted a sensitivity analysis focused on our key attributes (price, driving range, and charging time). The results are presented as a tornado plot in Figure 7, showing the impact of optimistic and pessimistic assumptions on market share when the vehicle price is $44,500 (the price at which profit is maximized). We found that price sensitivity is especially strong: when the vehicle price exceeds $44,000, the market share of the Model Y+ declines, reaching 0% at $48,000 (Figure 8). This reveals a critical pricing threshold for the commercial success of the product.

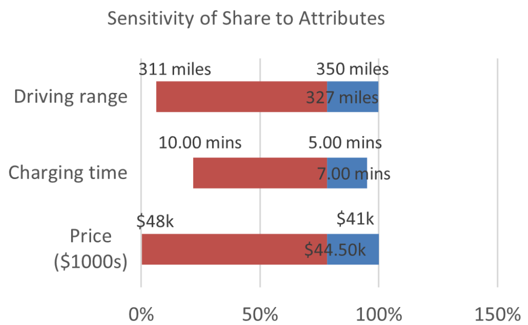

Figure 7. Sensitivity analysis shows how choice shares respond to changes in attributes under pessimistic and optimistic scenarios when the price of the vehicle is $44,500, which is where profit is maximized.

Figure 8. Sensitivity of shares of choice when the price changes

We perform a sensitivity analysis to determine the simulated market share under various prices and different scenarios (same as Table 2). Using 2025 EPA estimates (311 miles) for pessimistic range, the current Tesla Model Y driving range of 327 miles for the base case and our survey design maximum (350 miles) for the optimistic case, as well as 5 minute charging time for the optimistic scenario, 7 minutes for the baseline and 10 minutes for the pessimistic (see Appendix J for calculations).

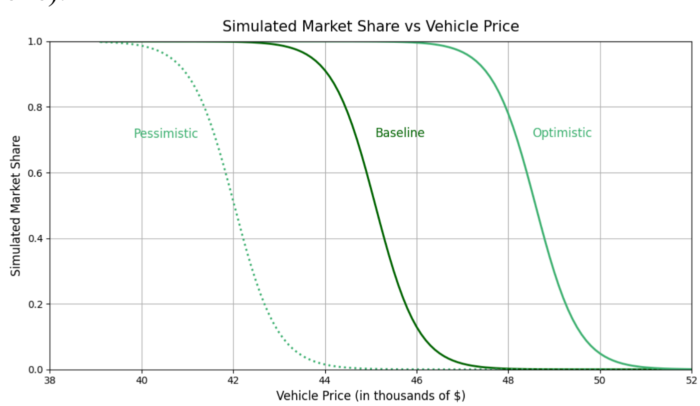

Figure 9. Sensitivity analysis of sales volume with varying price.

Conclusions

The demand analysis confirms that price and charging time are the most important attributes for consumers interested in buying an EV. While the market share may change depending on the price of the vehicle, people are willing to pay a premium for fast charging. Market share is attainable under all scenarios, but the profitability depends on the unit cost of the active anode material per kg. Important unknowns that could impact our results include access to charging stations and changes in regulations and policies for EVs. Additionally, our pool of respondents includes a large number of early adopters and not a broader market, which does not reflect the real-world scenario. Finally, our baseline scenario assumes that the rest of the vehicle components are compatible with the silicon anode, which allows charging speeds of 350 kW and higher.

5. Integrated Analysis

Value of Technology-Enabled Product Features

From the demand model, we estimated that people are willing to pay ~$400 per minute for reduced charging time. The difference in charging time between the two versions (Model Y+ and Model Y) is about 7 minutes. Therefore, we assert that **people would be willing to pay up to $3,600 more for a Tesla Model Y+**. Under an optimistic scenario in which charging time is 5 minutes, we estimate that people would be willing to pay up to $4,400 more for faster charging. Finally, under a pessimistic market scenario in which the charging time is 10 minutes (still faster than the Model Y's 16 minutes), we estimate that people would be willing to pay a premium of $2,400.

Profitability

a) Unit Price and Cost

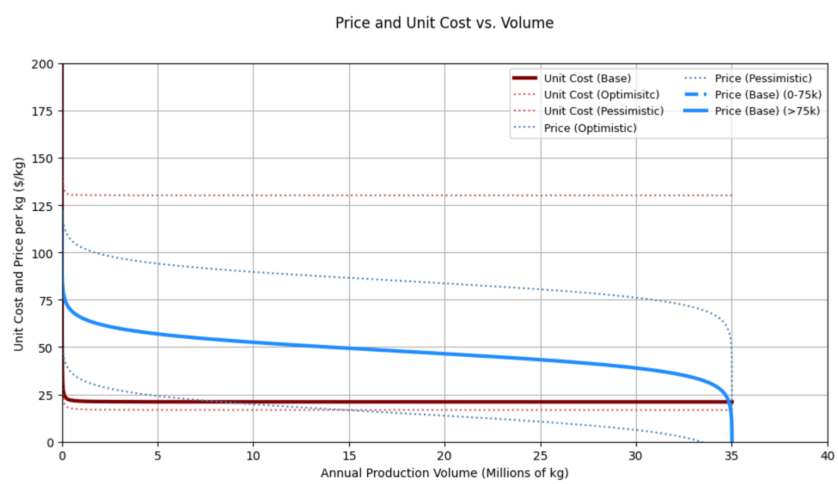

Figure 10. Annual production volume impact on price and unit cost of AAM

Figure 10 shows that in the base scenario, the prices that we would be able to sell based on the baseline attribute in Appendix J are around $10 - 50 per kg of active anode material, depending on the annual production volume. Even in the pessimistic market, we could still make a profit if the unit cost is not in the pessimistic condition. In the case of pessimistic production, we could not make any profit. It is important to optimize the production process and cost in order to avoid the pessimistic production scenario.

b) Profit

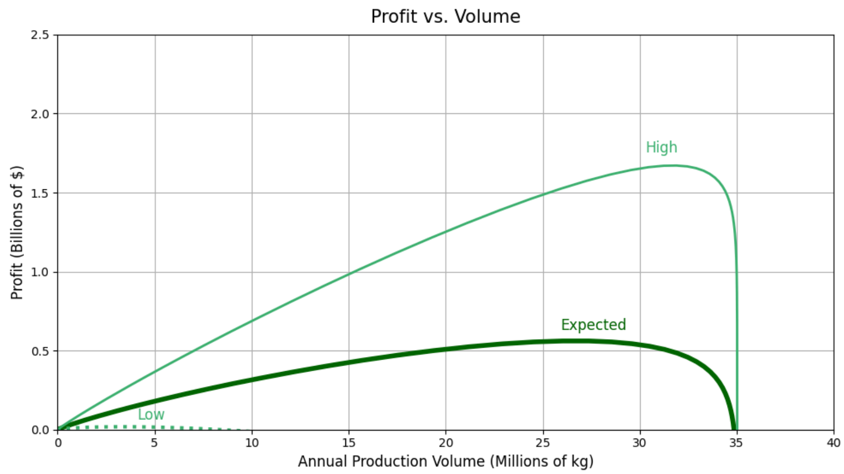

Figure 11. Profit as a function of annual AAM production volume

Figure 11 shows that profit varies at different annual production volumes in millions of kg with 3 scenarios, which are expected, low, and high. The expected scenario is where the production and the market are in the baseline condition. The low scenario is where production and market are in pessimistic conditions. The optimistic production with the optimistic market condition is where the high scenario is. The pessimistic, baseline, and optimistic scenarios of production are shown in Table D, while those of the market are shown in Table J2. In the expected scenario, the profit reaches the peak at around 27 million kg annual production volume. In the high scenario, the maximum profit is at around 34 million kg. However, if the production and market are both in a pessimistic condition, the venture would probably not be profitable.

c) Key Decisions

- **Price**: The most profitable price in the base scenario is \$50/kg AAM, which supports a production volume of 27 million kg per annum. Sensitivity analysis indicates that this price point maintains strong margins while preserving demand to justify scale up.
- **Design**: The enhanced battery charging time enabled by AAM delivers the highest user value. The analysis of the utility model used to evaluate the significant design attributes is presented in Appendix I.
- **Process**: The optimal process design to maximise profitability involves selecting cost-effective heating and drying machines and choosing a strategically located plant size. The sensitivity analysis of these variables is shown in Appendix F.

Limitations

The current model, developed using a linear logit framework, offers valuable insights into consumer preferences in electric vehicle (EV) selection. However, several limitations may affect the precision of projections and the overall robustness of strategic conclusions, thereby decisions based on this model should be interpreted with caution. First, the assumption of constant marginal utility across attribute levels oversimplifies consumer behavior that may lead to over-or underestimation of preference sensitivity for certain configurations. Additionally, the absence of interaction terms in the model may overlook important synergies or trade-offs between features despite the lack of statistically significant interactions observed in the current dataset.

The model also assumes a static competitive landscape and does not account for dynamic shifts in competitor pricing, product innovation, or regulatory changes, which are common in this sector. This limits the model's predictive validity in longer-term scenarios or under conditions of disruptive market entry. Moreover, while the survey sample segmentation may not fully capture the heterogeneity of the broader EV consumer base, especially across regional, cultural, and socio-economic subgroups. Critical contextual factors such as education, environmental attitudes, and local infrastructure access (e.g., proximity to charging stations) were excluded, despite their known influence on EV adoption (Rezvani et al., 2015; Sovacool et al., 2018).

From a cost perspective, the model does not integrate indirect cost components such as marketing expenditures, distribution logistics, financing costs, or policy-related compliance. These factors materially influence both the willingness-to-pay and operational viability, and their exclusion may lead to an overly optimistic estimation of commercial feasibility.

Conclusions

Customers are willing to pay ~$3600 more for a 9 min reduction in charging time for the Model Y+, which more than offsets the incremental increase in production cost of ~$1080 per vehicle. At an annual production volume of 27 million kg, the anode material achieves economies of scale. While profit is achievable in base and optimistic scenarios, it is highly sensitive to fluctuations in the cost of raw materials. The important unknowns include integration challenges with existing battery systems and resistance from OEMs to adopt silicon-based anodes.

6. Final Recommendations and Conclusions

This product has the potential to be economically viable. The analysis shows that it is profitable in most cases. The only case that it will not be profitable is in the pessimistic production condition. In order to tackle that situation, we recommend partnering with raw materials suppliers to secure the price of the material, which is the cost driver. Another recommendation is to choose the most suitable machines. It is not only about the cost of the machine, but the production capability also significantly affects the overall unit cost. The recommended price to maximize the profit is around $44,000 for the baseline case and around $48,000 for the optimistic case (See Figure K).

Top opportunities we identified for reducing cost and boosting demand include negotiating lower prices for the materials, relocating the manufacturing plant to a region with lower operational costs, and optimizing labor expenses by adjusting staffing strategies.

To strengthen the analysis and support decision-making, collecting more granular consumer preference data, especially across income levels and behavioral segments, would be essential to capture potential non-linearities and attribute interactions. Real production cost data, including indirect costs, would significantly refine unit cost estimates. Furthermore, detailed insights into competitor strategies, pricing, and features, and contextual factors such as policy incentives and infrastructure availability are critical for accurately assessing market potential and economic feasibility at scale.

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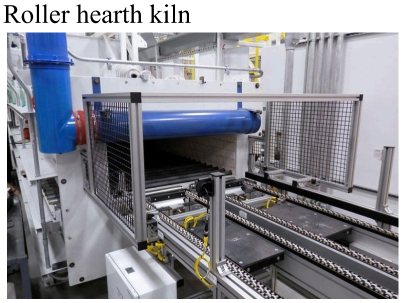
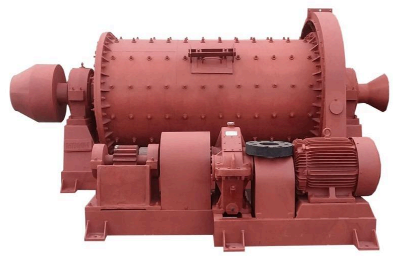
Appendix A. Detailed Equipment List

Table A. Equipment List

Production Step	Equipments	Specifications
Weighing precursor	Industrial scale  image source	Capacity: 1000 lb Dimensions: 1.22 m x 1.22 m
Mixing process	Mixing vessel  image source	Capacity: Materials: Stainless Steel 304/316 Working life: >10 years Mixer agitator: Included After-sales service: Yes
Drying	Spray dryer  image source	Capacity: 200kg/hour water evaporation, 95-98% Materials: Stainless Steel 304 for all contact part/ Stainless Steel 316 for structure and outer shell Input air <350℃ Output air outlet temperature range: 80℃ -100℃ Voltage: 380V Power: 45 kW Atomizer: rotary Tower dimension: Diameter 3.2m/Height 8m Atomizer speed: 16000rpm, centrifugal
Heating	Roller hearth kiln  image source	Output: 40.5-42 ton/hr Rotation speed: 0.6-3 r/min Motor power: 125 kW Floor dimensions: 3.2 m x 50 m
Milling	Ball mill	Average capacity: 1.6 tons/hr Floor dimensions: 1.5 m x 3 m Total weight with mill and drive, no balls: 38,500 lbs

Production Step	Equipments	Specifications
	 image source	Weight of balls: 20,900 lbs ZD motor: 100 HP
Sieving	Vibrating siever  image source	Voltage: 415 V Power: 1-5 HP Dimensions: 0.91 m x 1.83 m Speed: 1440 rpm
Packing	Packing machine  image source	Packing speed: 180-500 bags/hr Filling accuracy: +/-(0.1-0.2)%FS

Appendix B. Decision variables and product attributes

Technology: Novel anode material for EV battery
Product: EV Car

					Cost	Process		
					Cost	Drying machine	Heating machine	Production location
	Tesla Model Y+	Tesla Model Y	Units	Demand Effect	$21.04	M/C #1	M/C #3	Dallas
					$64.69	M/C #2	M/C #4	Pittsburgh
					US$/kg			
Price	$43.42	$41.49	US$ x 1000	-	+	+	+	+
Charging Time	7	16	minutes	-		+		
Driving Range	327	327	miles	+		+		
Product Attributes	**Benchmarking**				**Effects of Decisions on Attributes**			

Decision Variables (Cost, Process rows); Options (option rows); Relationships (Price, Charging Time, Driving Range rows)

Appendix C. Unit cost curve

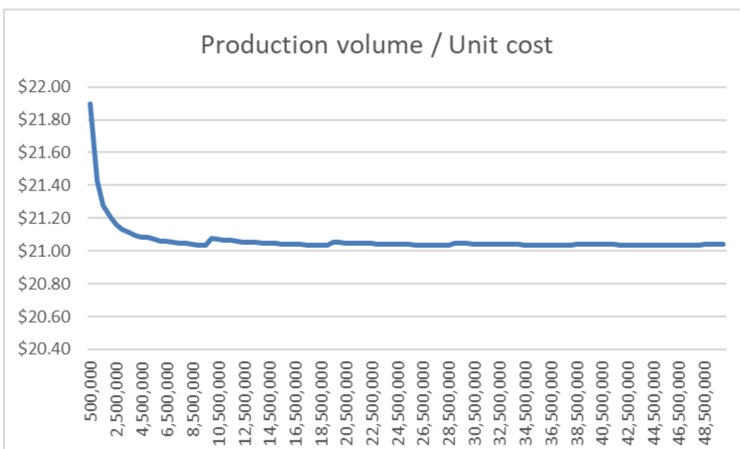


Figure C. Unit cost curve (highlighting small changes)

Appendix D. Value and range of the input parameters used for unit cost sensitivity analysis

Table D. Baseline, optimistic, and pessimistic scenarios model inputs

					Sources		
Conditions	**Pessimistic**	**Baseline**	**Optimistic**	**Unit**	**Pessimistic**	**Baseline**	**Optimistic**
Discount rate	10%	5%	3%	%	(Calhoun & Harkins, 2021)		(Statista, 2024)
Machine lifetime	15	15	20	years	Assumed		

Set up time #1 Weigh	40	35	30	minutes	Assumed
Set up time #2 Mix	45	40	35	minutes	Assumed
Set up time #3 Heat 1	35	30	25	minutes	Assumed
Set up time #4 Heat 2	35	30	25	minutes	Assumed
Set up time #5 Milling	35	30	25	minutes	Assumed
Set up time #6 Sieve	35	30	25	minutes	Assumed
Set up time #7 Package	35	30	25	minutes	Assumed
Yield rate	90	95	98	%	Assumed
Heating machine #1	Batch size 1.4 Price $167.5k Electricity consumption 45 kwh	Batch size 11.37 Price $80k Electricity consumption 40 kwh			(Col-Int Tech, 2025) (Alibaba, 2021)
Heating machine #2	Batch size 890 Price $260k Electricity consumption 267 kwh	Batch size 10185 Price $550k Electricity consumption 125 kwh			(Made-in-China, 2025)
City	Pittsburgh	Dallas			(Cushman & Wakefield, 2023)

Appendix E. Decision Variables Sensitivity Plot

When we compare different factors that affect unit cost, we vary the price of material, production location, heating machines, yield rate, setup time, machine lifetime, and discount rate.

We gathered material prices from online sources to get the baseline. For the pessimistic scenario, we assume that the overall material price goes up by 30%, while for the optimistic scenario, we assume the price decreases by 30%.

According to the U.S. Bureau of Labor Statistics, labor cost for chemists is $24.69 per hour, and for production workers it’s $18.76 per hour. For the baseline, we assume all our workers are chemists. For an optimistic case, we assume that we need 20% of our workers to be chemist,s and the other 80% can be production workers.

Table D.1. Material price for sensitivity analysis

Parameter	Pessimistic	Baseline	Optimistic	Unit
Overall material price	9.02	6.94	4.86	$ per kg of materials
Wages		24.69	19.95	$ per hour

Dallas was chosen to be one of the production locations since, according to Cushman and Wakefield (2024), it has the lowest price per SQFT. Future iterations of this work will incorporate different electricity prices and labor costs.

Table D.2. Cost per SQFT comparison of locations

Parameter	Value	Unit
Cost per SQFT in Pittsburgh	128.79	$
Cost per SQFT in Dallas	108.22	$

Appendix F. Tornado Plot

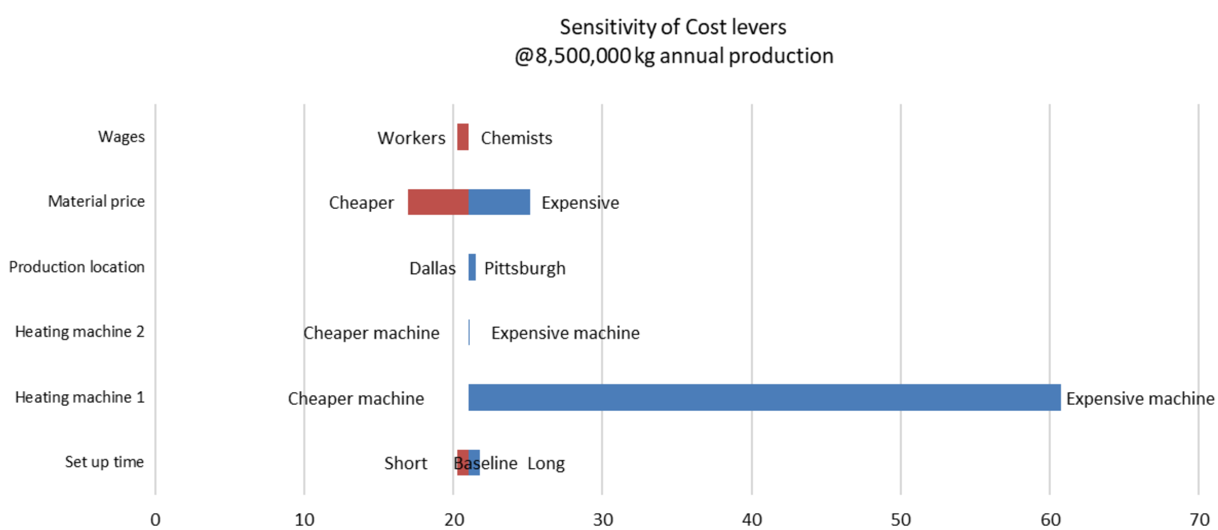


Figure F. Tornado plot of production volume 8,500,000 kg/year

Appendix G. Survey

Welcome!

Thank you for participating in our survey.
Your input will help us understand market preferences with regards to electric vehicles (EV).

Answer the following questions as if you were in the market for a new electric vehicle.

Next

Figure G1. Survey introduction

Suppose you are in the market for an electric vehicle (EV). If the options listed below were your only choices, which one would you be most likely to select? All four options would have the same design similar to the picture above.

Definitions
Purchasing cost: The price that you are willing to pay for the vehicle.
Charging time: The time required to add 180 miles of range to the vehicle using a public *hyper fast charger* when the battery level is below 25%
Driving range: The total distance a vehicle can travel on a full charge before the battery is fully depleted under normal driving conditions.

Purchasing cost	$48,000	$32,000	$40,000
Charging Time	20 minutes	5 minutes	10 minutes
Driving Range	250 miles	350 miles	300 miles

	Car A	Car B	Car C
Select	○	○	○

Back

Next

Figure G2. Survey attention check question

Suppose you are in the market for an electric vehicle (EV). If the options listed below were your only choices, which one would you be most likely to select? All four options would have the same design similar to the picture above.

Definitions
Purchasing cost: The price that you are willing to pay for the vehicle.
Charging time: The time required to add 180 miles of range to the vehicle using a public *hyper fast charger* when the battery level is below 25%
Driving range: The total distance a vehicle can travel on a full charge before the battery is fully depleted under normal driving conditions.

TASK 1/10

Purchasing cost	$32,000	$40,000	$48,000
Charging Time	20 minutes	5 minutes	10 minutes
Driving Range	350 miles	250 miles	300 miles
	Select	Select	Select

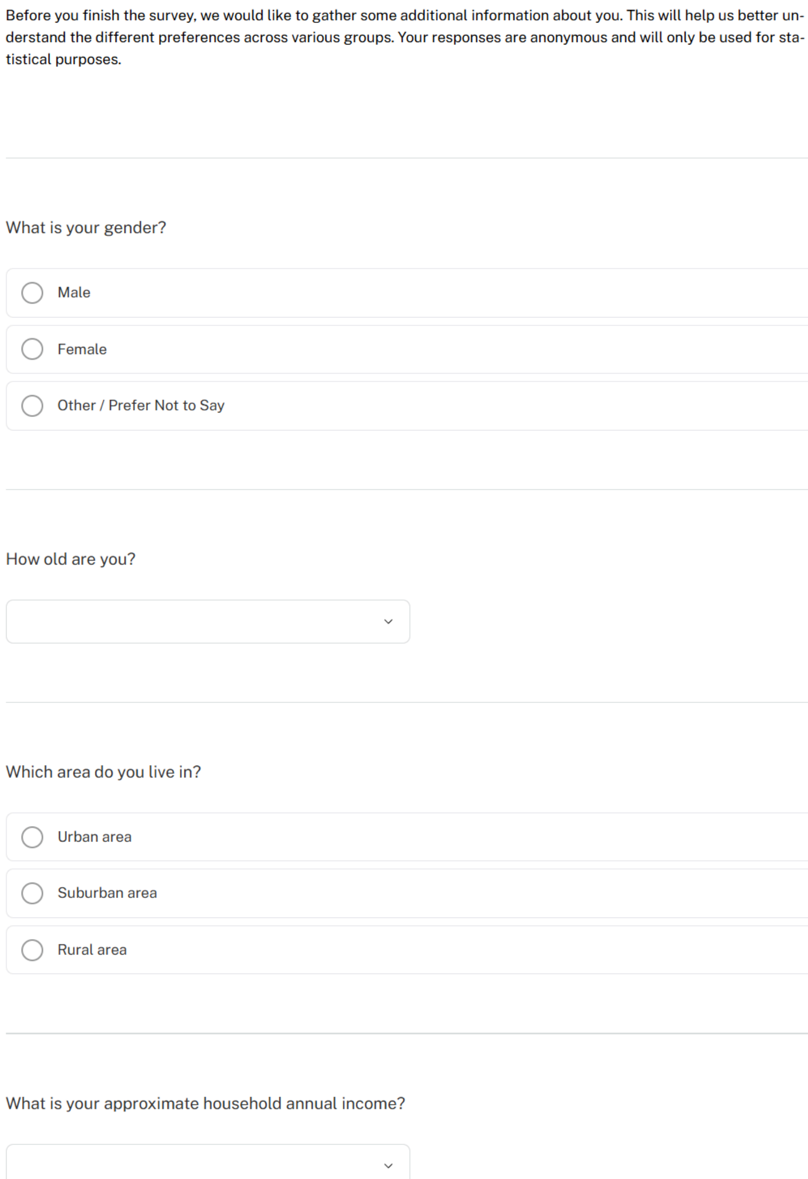
Back Next

Figure G3. Survey conjoint question

What other factors are important to you when purchasing a vehicle that we did not discuss in this survey?

Back Next

Figure G4. Survey second attention check question



Before you finish the survey, we would like to gather some additional information about you. This will help us better understand the different preferences across various groups. Your responses are anonymous and will only be used for statistical purposes.

What is your gender?

- Male
- Female
- Other / Prefer Not to Say

How old are you?

Which area do you live in?

- Urban area
- Suburban area
- Rural area

What is your approximate household annual income?

Figure G5. Survey demographic question

Appendix H. Model parameters and standard errors

The function of the utility function we used is as follows:

$$v_j = \beta_0 p_j + \beta_1 x_{1j} + \beta_2 x_{2j} + \epsilon$$

So, the probability of choosing choice j is

$$P_j = \frac{exp(\beta_0 p_j + \beta_1 x_{1j} + \beta_2 x_{2j})}{\sum_k exp(\beta_0 p_j + \beta_1 x_{1j} + \beta_2 x_{2j})}$$

From the survey result, we get the parameters as follows:

$$\beta_0 = -2.11932$$

$$\beta_1 = -0.85041$$

$$\beta_2 = 0.24796$$

The standard errors, which represents by estimated covariances are:

1.58833	-0.21091	0.07709	0.13382	-0.01492
-0.21091	1.55821	-0.62077	-0.93744	0.01638
0.07709	-0.62077	1.30498	-0.68421	-0.01906
0.13382	-0.93744	-0.68421	1.62165	0.00268
-0.01492	0.01638	-0.01906	0.00268	1.11604

Appendix I. Model parameters and standard errors

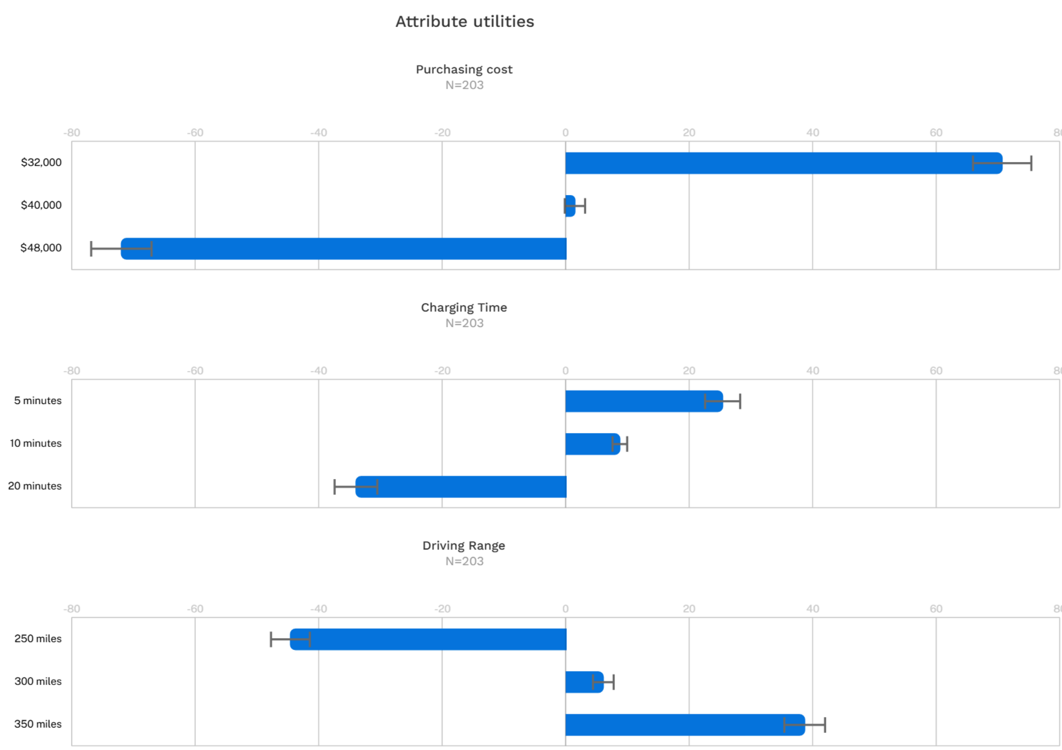


Figure I1. Betas of attributes generated by Sawtooth Discover

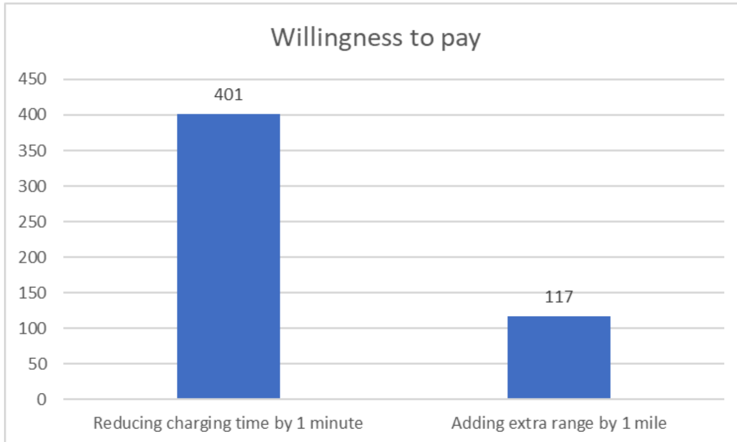


Figure I2. Willingness to pay for faster charge and longer driving range

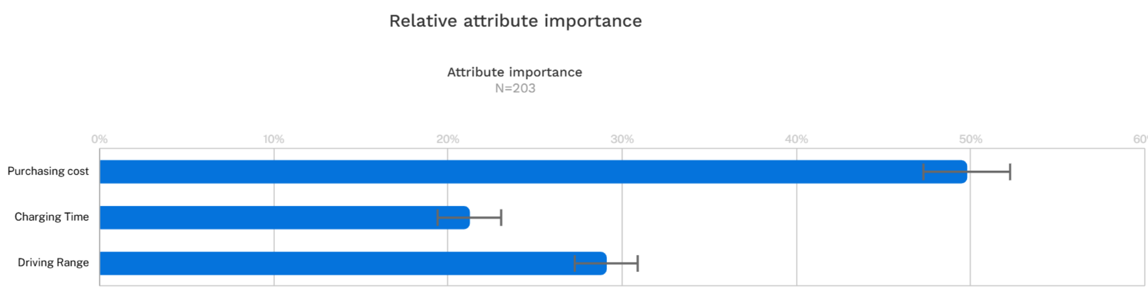


Figure I3. Relative importance of attributes used in the choice model

Appendix J. Estimating Battery Anode Composition and Charging Time

In this section, we estimate the cost of anode material going into a Tesla Model Y with our new silicon-based anode material and with the traditional graphite anode material. This will allow us to estimate the cost difference between a Tesla Model Y with fast charging capabilities, enabled by our silicon-based battery anode, and one with a graphite anode. We will be doing this for the New 2026 Tesla Model Y. Hereafter, we will refer to the Tesla Model Y+ as the Tesla with the silicon-based anode material and Tesla Model Y (no "plus" sign) to the one with traditional graphite anode material.

Additionally, in this section, we calculate the amount of time it would take to add 180 miles of range to the battery of the Tesla Model Y+ we study. These calculations are made on the assumption that both versions have a battery capacity of 75 kWh (Motortrend, 2025; Tesla, 2025)

We estimate the charging time for a 75 kWh battery and the battery mass using the information the client provided from experiments on coin cells:

- Charge Power per kg: 1.9 kW/kg
- Energy Density: 200 Wh/kg

Assuming we use the same 75 kWh battery used in the New 2026 Tesla Model Y, we determine the battery mass by dividing our battery capacity by the charge power per kg.

$$Battery\ Mass = \frac{Battery\ Capacity\ (Wh)}{Energy\ Density\ (Wh/kg)} = \frac{75000}{200} = 375\ (kg)$$

Knowing that the entire cell array (not pack) has a mass of about 375 kg, we can estimate the mass of the anode material in the battery cells. We estimate that the amount of anode material in the 75 kWh battery is 25% of the total battery cell mass, which would be equivalent to 94 kg (Bhutada, 2022; Thunder Said Energy, nd).

Since we estimated that the cost per kg of silicon-based active anode material (AAM) is about \$30 per kg from our process-based cost model (PBCM), we calculate that the cost of the active anode material going into the 75 kWh battery would be:

$$Anode\ Material\ Cost\ =\ 94\ kg\ of Anode\ *\ \$21\ per\ kg\ of\ Anode(New)\ =\ \$1974$$

This assumption holds if there is no mass loss in converting active anode material (i.e., the dry powder used to make the anode electrolyte) into anode material inside a battery, which we assume is the case.

We assume that the amount of anode material used in a traditional graphite battery pack for a Tesla Model Y with a 75 kWh battery would also be 94 kg. Considering that graphite anode material has a price of \$9.5 per kg (Kneher, 2024), the total cost would be:

$$Anode\ Material\ Cost\ =\ 94\ kg\ of Anode\ *\ \$9.5\ per\ kg\ of\ Anode(New)\ =\ \$893$$

	Tesla Model Y+ (Silicon-Based Anode)	Tesla Model Y (Graphite-Based Anode)
Amount of Anode Material	94 kg	94 kg
Cost per kg of Anode	$30 $/kg	$9.5 $/kg
Cost	$1,974	$893

Table J1. Cost estimate summary of anode material going into a Tesla Model Y+ and Y.

We find that the difference in cost between using one anode material (silicon-based) versus the other (graphite-based) is about $1,927. We will use the assumption that costs are passed down to the consumer and that no extra profit is made from selling a Tesla Model Y+, and thus, the difference in retail price between the Tesla Model Y+ and Tesla Model Y would be $1,081.

To estimate the amount of time it would take to add 180 miles, we first calculate the total charge power of the Tesla Model Y+. This is the maximum amount of charge power the battery would handle if all the other components (e.g., thermal system and battery charger) were compatible with the gains from using the silicon-based

Total Charge Power (kW) = Charge Power per Kg (kW/kg) x Battery Mass (kg) =

$$1.9 \, x \, 375 \, = \, 712.5 \, kW$$

Finally, we can calculate the time to charge the battery:

$$Time \ to \ Charge \ = \frac{Battery \ Capacity \ (kWh)}{Total \ Charge \ Power (kW)} = \frac{75}{712.5} = \ \sim 0.105 \ hrs/6.3 \ mins$$

A 6.3-minute charging time sounds unrealistic, but it is not. The Chinese EV manufacturer BYD is expected to release a vehicle that can add 250 miles in 5 mins (Marshall, 2025). However, it is important to consider other elements that affect charging time, such as charger charge power and efficiency, battery temperature, and battery deterioration, to name a few (Whaling, 2022). Additionally, it is known that charging times in batteries are nonlinear. Therefore, the charging time to fully charge the battery of a Tesla Model Y with a 75 kWh battery would be more than the 6.3 minutes estimated. However, we can assume that the charging speed is linear up to 80% battery capacity (Cole, 2024). This means that we could charge from 0 to 60 kWh of the 75 kWh battery (80%) in about 5 minutes if the charge power from a charger is 712.5 kW.

To ground this on a more realistic scenario, we assume that the Tesla Model Y+ is capable of charging at a 350 kW charger as offered by Electrify America (nd), while the Tesla Model Y is capped at 250 kW (Tesla, 2024). Knowing the battery capacity of these models, the assumed maximum charger power they can accept, and the estimated range (Tesla, 2025), we can calculate a theoretical charging time for the battery from 0-100%, and a theoretical charging time to add 180 miles of range based on driving mileage per kWh of the Tesla Model Y+.

$$Theoretical \ Time \ to \ Charge \ = \frac{Battery \ Capacity \ (kWh)}{Total \ Maximum \ Charge \ Power (kW)} = \frac{75}{350} = \ \sim 0.214 \ hrs/12.9 \ mins$$

In addition, we calculate the MPGe[1] (miles per kWh) by dividing driving range by battery capacity. We calculate MPGe to determine the battery capacity needed (in kWh and as a percentage) to drive 180 miles at the calculated MPGe. Using this and the theoretical time to fully charge the battery, we can estimate the time required to add 180 miles of range.

[1] While DOE reports fuel economy in kWh per miles, we do not use those estimates since they base their calculations on power drawn from a charger and its associated inefficiencies.

$$MPGe = \frac{327\ miles}{75\ kWh} = 4.36\ miles\ per\ kWh$$

$$Battery\ Capacity\ Needed\ for\ 180\ Miles = \frac{180\ miles}{MPGe} = \frac{180}{4.23} = \sim 41.3\ kWh$$

$$Time\ Needed\ for\ 180\ Miles = \frac{41.3\ kWh}{75\ kWh} * 12.9\ mins = 7.1\ mins$$

For the Tesla Model Y (with the graphite anode), we scale up their reported 169 mi charge in 15 mins:

$$\frac{169\ miles}{15\ minutes} = \frac{180\ miles}{x\ minutes} \ -> x = \sim 16\ mins$$

Attribute	**Tesla Model Y+**	**Tesla Model Y**
Price	Vary	$41,490
Battery Capacity (kWh)	75	75
Driving Range (mi)	327	327
Calculated MPGe (mi/kWh)	4.36	4.36
Maximum Battery Charge (kW)	350	250
Theoretical Time to Fully Charge Battery[2] at Maximum Battery Charger (mins)	12.9	N/A
Battery Capacity Needed to Drive 180 Miles (kWh)	41.3 kWh	N/A
Battery Capacity Needed to Drive 180 Miles (%)	55	N/A
Time to Add 180 miles (mins)	7.1	16

Table J2. Summary of Tesla Model Y+ and Y attributes.

Following the steps above we can calculate a pessimistic case in which the Tesla Model Y+ is only able to charge at consistent 250 kW for the first 80% of the battery, which the Tesla

[2] We refer to this as the theoretical time to fully charge a battery because charging times are not linear. However, we assume that the charging time will be linear from 0% to 80% of the battery pack. We assume that the battery is charged to add 180 miles of range when the capacity is below 25%. The 180 miles of extra range should

Model Y (without fast charging) seems to not be able to do based on the reported 169 miles in 15 mins, and an optimistic case in which the Tesla Model Y+ can charge at a consistent 500 kW for the first 80% of battery capacity.

Attribute	**Tesla Model Y+ (Base)**	**Tesla Model Y+ (Pessimistic)**	**Tesla Model Y+ (Optimistic)**
Price	Vary	Vary	Vary
Battery Capacity (kWh)	75	75	75
Driving Range (mi)	**327**	**311**	**350**
Calculated MPGe (mi/kWh)	4.36	4.36	4.36
Maximum Battery Charge (kW)	350	250	500
Theoretical Time to Fully Charge Battery[3] at Maximum Battery Charger (mins)	12.9	18	9
Battery Capacity Needed to Drive 180 Miles (kWh)	41.3 kWh	41.3 kWh	41.3 kWh
Battery Capacity Needed to Drive 180 Miles (%)	55	55	55
Time to Add 180 miles (mins)	**7.1**	**9.9**	**4.95**

Table J3. Summary of Tesla Model Y+ attributes under base, pessimistic, and optimistic scenarios.

[3] We refer to this as the theoretical time to fully charge a battery because charging times are not linear. However, we assume that the charging time will be linear from 0% to 80% of the battery pack. We assume that the battery is charged to add 180 miles of range when the capacity is below 25%. The 180 miles of extra range should

Appendix K. Total profit when varying the selling price

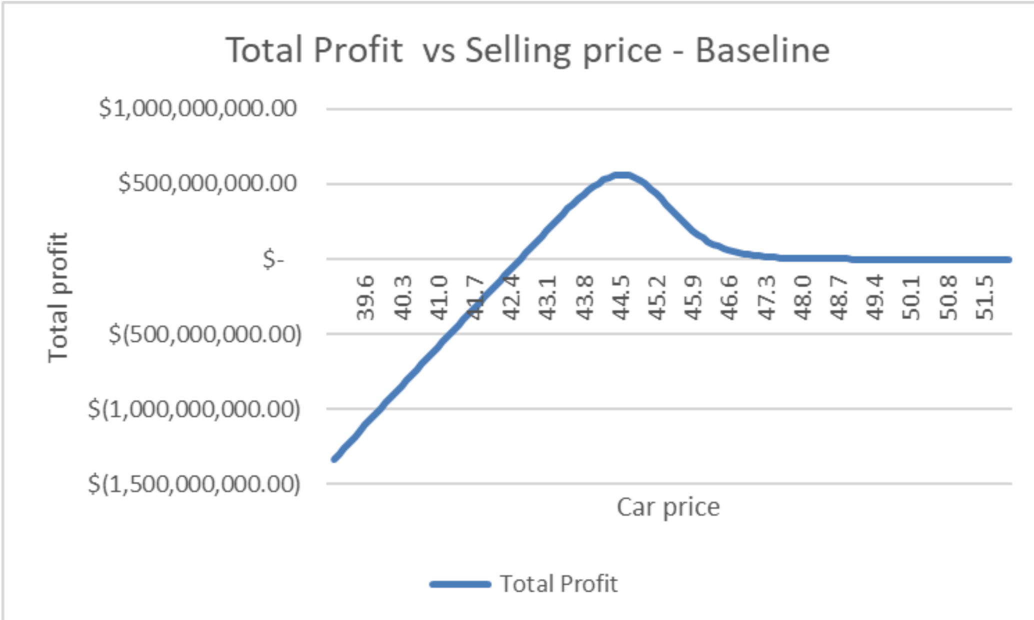


Figure K1. Total profit when the selling price varies for the baseline case

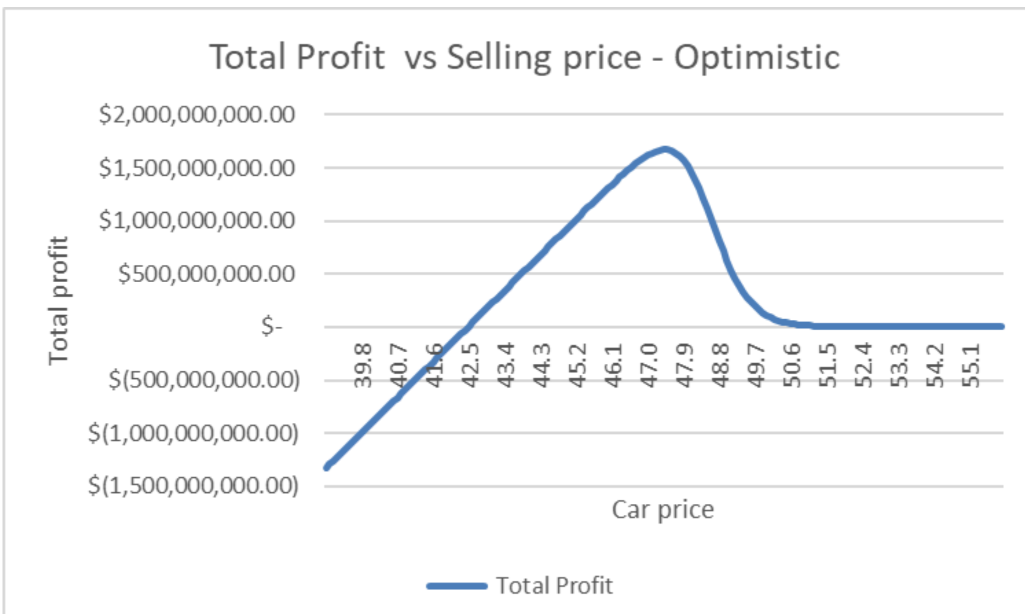


Figure K2. Total profit when the selling price varies for the optimistic case

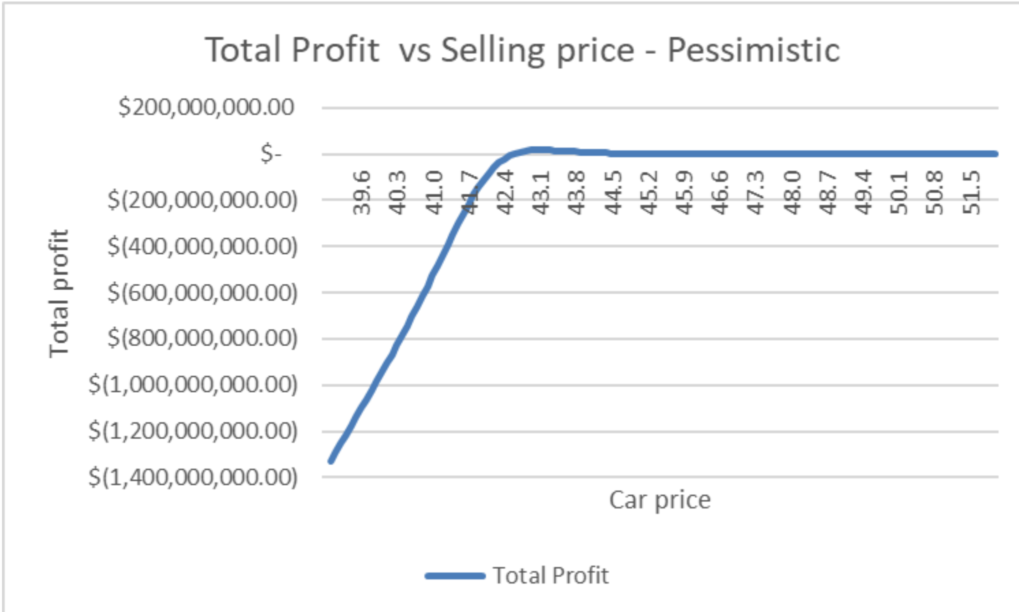


Figure K3. Total profit when the selling price varies for the pessimistic case