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Chapter

Tesla’s Circular Economy Strategy to Recycle, Reduce, Reuse, Repurpose and Recover Batteries

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Abstract

The purpose of this research is to explore how Tesla is capable to materialize the circular economy futuristic vision. Specifically, it explains how batteries are recycled, reduced, reused, repurposed, and recovered in order to preserve raw materials and diminish toxic waste disposal. Tesla extends traveling distance by supercharging stations and repurpose degraded batteries for second-life applications to energize home appliances with its solar panels. Tesla intends to substantially diminish the costs of battery production while increasing range by developing an innovative 4680 tab-less cobalt-free battery. An insight emerging from the study is that the fundamental principles upon the operations management field was established such as the concept of focused factory and Goldratt’s theory of constraints stay valid and are applicable towards establishing sustainable manufacturing process at the 21st century.

Keywords: tesla, circular economy, recycle, reduce, reuse, repurpose, recover

1. Introduction

Circular economy (CE) is defined as an industrial revolution designed to be restorative in nature. It includes utilization of renewable energy sources with an emphasis on five pillars of sustainability: recycle, reduce, reuse, repurpose, and recover in order to preserve raw materials as much as possible. Consequently, it diminishes production of toxic materials and ensures safe disposal which in the case of Millions batteries for electric cars present an environmental hazard.

Major step taken in the 21st century to achieve an ambitious world-class progress towards materializing circular economy vision is by moving towards usage of fully electric vehicles. In order to institutionalize environmental protection by sustainable transportation [1], governments worldwide have been building a global momentum to strictly regulate CO₂ and greenhouse gases (GHG) emissions. In the Earth Summit (1992, 154 countries signed a treaty to voluntarily reduce emissions of GHG. One of the summit achievements was the establishment of a GHG pooled inventory shared between countries. Subsequently, over 187 countries have already signed the Kyoto protocol (1997) committing themselves to a reduction of GHG by 5.2% from the benchmark levels of 1990 in order to stabilize the depletion of the atmosphere ozone layer, and combat global warming [2]. More recently, the Copenhagen Summit in
2009 reached an accord that recognizes the necessity to maintain the temperature rise no more than 2 degrees Celsius above agreed threshold.

Tesla manifests a market encroachment attempt to meet the social principles mentioned above [3]. For example, it reached 92% battery cell material recovery in new recycling process of Nickel, Copper, and Cobalt. Furthermore, batteries at end-of-life cycle are reused at homes in conjunction with Tesla solar conglomerate. The companies’ executives embarked on a campaign to make the transition to electric vehicles not only in their regional areas but also in the global industrial economy. Specifically, at the end of 2018, Tesla sold its 500,000th car and the next half-million car deliveries will take about 15 months at the current production pace (Figure 1).

As of January 2019, Tesla surpassed GM, Ford and BMW to rank the world’s 4th most valuable car manufacturer in the stock market. According to Long et al. [4], Tesla is regarded by almost forty percent of customers as role model for future electric car manufacturers because of its elegant innovative attributes, innovation and artificial intelligence technology. It should be mentioned that the hype surrounding its CEO Elon Musk contributes to its stellar image too. In certain states such as California its sales have consistently surpassed over several quarters leading traditional combustion engine brands.

The purpose of this research study is to illustrate how Tesla developed a 21st century manifestation of Ford T mass-production philosophy to sustainable transportation [5]. The similarities between their founders’ (Ford and Elon Musk) entrepreneurship skills are stark and brings hope to revive American manufacturing

![Figure 1.](image)

*Tesla production rate based on VIN registration.*
global lead which seemed to be totally under control during last fifty years initially by Japan and more recently by China. Tesla follows an economy-of-scale mindset which is similar to Ford T mass-production line. It gains competitive advantage from capability to recycle, reduce, reuse, repurpose and recover battery materials, all in affordable expenses, which as will be elaborated in this article brings about the competitive manufacturing strategy of Tesla [6]. Tesla possesses vertically integrated supply chain built of Gigafactories producing approximately five thousand cars per week and thousands of batteries/cars [7]. Tesla reduces bullwhip effect phenomena associated with interruption in the supply chain by mining of battery raw materials instead of relying on external suppliers of battery ingredients [8]. Tesla manufacturers far more batteries in terms of kWh than the relevant contestants all together (approximately 15GWh/year, or 0.15TWh).

Prominent scholars such as Harper et al. [9] and Siqi et al. [10] argue that discovery of advanced waste management techniques for batteries is essential for market domination of electric cars. These new technologies include pyrometallurgy usage of high temperature to extract materials. Hydrometallurgy is an innovative technology to recycle metals from ores with low reaction energy consumption. In a similar vein, Biometallurgy introduces a way to extract valuable metals by interaction with microorganisms. The major advantage of this technology is that it entitles lower expenses and render less pollution in comparison with pyrometallurgy and hydrometallurgy.

Substantial amount of saving in materials can be gained by repurposing battery packs towards second-life applications. Leading scholars in the field such as Hua et al. [11] and Yang et al. [12], corroborate that reuse and repurpose processes render less environmental signature in juxtaposition to recycling and recovery of ingredient materials composing batteries due to waste disposal residuals. Thus, Tesla, a solar panels mega-manufacturer, decided to repurpose batteries of old electric vehicles which are no longer capable to efficiently propel a car in order to electrify home appliances as manifestation of circular economy.

2. Applying Goldratt’s approach to Tesla’s needs

The theory of constraints [13] practical approach on generating profit from sales is useful for evaluating bottlenecks of large-scale projects such as the innovation of electric cars. It stands on three pillars: throughput, operational expenses, and inventory [14]. Previous similar electric car mega-projects such as Better Place in Israel were bankrupt because lack of sales rendered by poor marketing. The enormous amount of money required to establish country-wide charging infrastructure demands equally value assets secured in pre-sales format to ensure financial stability, a lesson carefully learned by Tesla from Better Place bankruptcy [15].

Goldratt’s principal idea is to locate bottleneck and utilize it efficiently to streamline the process. Traveling range on single full charge has been considered by scholars for over a century the prime bottleneck of electric transportation [16, 17]. Skippon and Garwood [18] empirically substantiate this claim by finding that consumers decision to procure an electric vehicle as a second car is dependent on its ability to travel a distance of 100 miles, and as their first priority vehicle if it has a traveling range exceeding 150 miles.

Tesla philosophy is based on imitating Fort T mass-production line (estimated to reach sales of 1 Million cars by 2021) by establishing advanced gigafactories.
Multi-purpose team is an essential part of this manufacturing paradigm consistent with Deming’s quality management philosophy [19].

Thomas and Maine [20], claim that Tesla production mindset did not follow a disruptive innovation route, instead its origin of commercialization success derives from an architectural model based on deploying supercharging stations countrywide which are meant to relieve customer’s traveling range anxiety. Importantly from a business perspective which has been Tesla strength from the outset because of Elon Musk’s sensemaking ability, the charging infrastructure is compatible with rival’s electric car design too, rendering an additional source of income from offering charging services to rivals which contributes to its image as green company with altruism motive, instead of greedy hidden agenda driven by ulterior motive to become a monopoly.

3. Methodology: case study description of mega-project

Shenhar and Holzmann [21] highlight that there is void in the literature in the subject of how to manage complex mega-projects. This is especially evident in pioneer megaprojects which require high degree of adaptation due to lack of experience. Tesla can be classified among this cluster of unprecedented projects both in its technological novelty and magnitude. As such, the method of case study is appropriate [22]. A longitudinal series of rigor interviews over a decade with Tesla employees as well as similar mega projects such as EV-1 in California and Better Place in Israel constituted the empirical approach in this case. It was validated with secondary data sources to juxtapose sources and verify information. Face-to-face interviews were conducted with Tesla’s marketing, procurement, and technical engineering in two headquarters located in McLean, Virginia and Washington, DC.

4. Interpretation of results

In 2003, several engineers at Silicon Valley embarked on a journey to advance the world’s movement to green mobility [23]. To make this century-long dream come true, Tesla Motors was founded. As will be seen, Tesla always went bigger than industrial benchmark, appropriately setting its production quantities to yield sales of 1 million cars by 2021.

In the first step, on 2008, Tesla introduced the Roadster, a car with capability to drive 245 miles on single charge. Afterwards, Tesla introduced the Model S, with a traveling distance of 265 miles, which acclaimed Motor Trends’ 2013 car of the year prize. Next, it began manufacturing the Model X, a crossover type car with an additional third seating row. Tesla is currently building $5 billion worth battery factory that is estimated to produce more lithium-ion batteries in 2020 than all of the contestants’ yield.

Tesla owners are able to charge their batteries to 50% level in a short timeframe of 20 minutes. Tesla expanded rapidly in 2014, starting with charging stations in Norway, afterwards encroached 12 additional countries, and plans to enter into the market of almost every country in Europe [24]. In effort to extend international sales, Tesla began marketing its electric vehicles to the Chinese niche on August 2013. Although China’s market is larger than Europe, the regulatory environment in Europe makes it a favorable destination for electric cars in the next decade because European Parliament Transport Committee approved a resolution in November 2013 making it
compulsory that EU country members need to install network of at least one charging station per 100 km.

Tesla Motors portfolio is diversified to include both vehicle and battery components. The batteries manufactured by Tesla are compatible with other car brands extending their market worldwide. For example, Toyota and Mercedes utilize Tesla’s battery in the Rav4 and Mercedes B-Class.

In contrast to Better Place infrastructure which was based on the notion of swapping depleted batteries (Figure 2) of cars in short time period of 5 minutes but was limited to single car manufacturer (Renault), Tesla supercharging stations are capable to rapidly charge depleted battery in forty minutes. The super-charging stations are compatible with various car manufacturers rendering the infrastructure a servicing source of income for Tesla. As of April 2019, Tesla had a network of 12,000 supercharging stations across North America, Europe and Asia. According to Tesla, the funding needed to establish a supercharging station is $150,000 without solar panels, and $300,000 to construct a solar powered facility. A single station can charge multiple cars simultaneously (usually 2–4 spots are available). The decision where to build a super-charging station is determined based on actual electric car sales and strategically curated after rigor post-sales survey of consumers’ driving patterns.

On March 2019, Tesla debuted an innovative V3 supercharger architecture that is capable to reduce the charging time on average by approximately 50%. Furthermore, utilizing the V3 supercharger, the Model 3 car extends its traveling range by an additional 75 miles on a quick charge that consumes short duration of five minutes. To avoid over-usage of supercharging services which degrades the battery’s lifespan, the V3 supercharger can charge a battery up to 80% instead of its maximum capacity in 45 minutes because subject matter experts in university investigation found that charging a battery to its full extent had negative impact on its lifespan. Interestingly, Tesla is debuting a technology titled, on-route battery warmup, which heats the battery to an optimal temperature on the way to the supercharger station. The warmup technology diminishes the average charge time by an additional 25%. Overall, V3 supercharger network permits Tesla to double the amount of vehicles it servicizes in order to meet the needs of its exponentially increasing fleet.

Tesla portfolio has major differences from past mega-projects attempting to electrify transportation. The innovator’s dilemma is whether to focus on becoming solely

Figure 2. Renault Fluence swapping station better place.
an electric car manufacturer as Tesla have chosen or to diversify portfolio with blend of fuel combustion cars too such as done by other mainstream manufacturers such as Toyota [25]. Tesla pursues Skinner’s [26] seminal model called, focused factory, by creating array of Gigafactories which builds fully electric vehicles (not including hybrid or combustion engine type of cars inside it). Its Model X and S target different household incomes. The Model 3 represents an affordable family sedan with distance of 320 miles per charge, Model S large sedan with distance of 400 miles and Model X is a large SUV traveling 300 miles. Model Y is a mid-size SUV with 315 miles traveling distance. In future, the second-generation coupe Roadster is going to be designed in order to travel 650 miles per charge.

Tesla marketing is using social media word of mouth as its main networking tool to reach audience. Surprisingly, this low budget method achieves record high pre-orders which paces the production line capacity.

Trying to stay head of the curve, Tesla vehicles come equipped with autonomous capability based on variety of technologies such as radar, sonar, acoustic sensors and a network of cameras to identify pedestrians, cars and other potential obstacles on the route. The United States Department of Transportation categorizes Tesla as Stage 2 level self-drive capability, meaning that a driver must be seated behind the wheel at all times. Tesla self-driving parallel parking capability has been appealing for wide segments of population. The capability for stage 3 autonomous driving without driver behind the wheel is built-in by Tesla vehicles too, but its pending approval of regulatory agencies.

To meet weekly pre-sale, Tesla emulates Ford T mass-production mindset by building Gigafactories. Historically, the Ford T used the stationary construction methods available in the 20th century, assembly by hand, to manufacture small batches. The original Ford Piquette Avenue Plant could not meet demand for the Model T because 11 cars were built there during the first month of production. Consequently, in 1910, in order to create mass-production line, Henry Ford moved the factory to the new Highland Park facility. The Model T production line shifted into an innovative modular format where Ford’s cars were constructed rapidly, diminishing production time from 12.5 hours beforehand to 93 minutes by 1914. It was accomplished by conveyor belts, a technology which standardized the process. This allowed Ford to decrease the cost of cars by gaining economies of scale [27, 28]. Fredrick Taylor rendered consulting services to diminish the assembly line into 84 discrete steps (an unprecedented accomplishment last century). Subsequently, Ford built machines that could stamp-out large car components automatically for engine and transmission.

After the Model T reached a remarkable threshold of 10 million vehicles, it accounted for 50% of all cars globally. Similar to Tesla marketing method, Ford brand was notably famous among consumers so it did not require extra advertisement. By 1925, Ford plant reached a production milestone of 15 million vehicles, with a manufacturing pace of 10,000 cars per day (2 million annually).

Following Ford’s footsteps, Tesla established hubs (Gigafactories) around the world to mass-produce electric cars. These green plants are energized by solar power. Gigafactory 1 located at Nevada is a large size, 10 million square feet plant, which is forecasted to yield 500,000 batteries for the Models S, X and 3 cars per year. The facility also produces Tesla Powerwall, Powerpack, and Megapack devices. It is expected to build the Tesla Semitruck in future. Battery production at Gigafactory 1 passed an annualized pace of about 20 GWh (3.5 Million cells per day), ranking it the highest-volume battery plant globally. Tesla has been innovating Tab-less cobalt-free lithium battery cell measuring 46 by 80 millimeters (hence called 4680), utilizing nickel-manganese structure, which extends by 16% the car range and multiply six times the
amount of energy, while decreasing expenses to produce the cell by 14% compared to existing cells which are powering the model 3 and Y. Its anode uses raw metallurgical silicon which does not crack. The new cylindrical architecture shape batteries will utilize Maxwell's dry electrode technology which is lowers cost and is purer than lithium-ion batteries. The rolled-up copper material cuts the distance for electrons to travel rendering a decrease in internal resistance and heat dissipation. The state of Nevada, where Tesla Gigafactory is located has plenty deposits of lithium embedded in clay which Tesla plans to mine. Overall, Tesla plans to diminish the price per kilowatt hour (kWh) of its cells by 56%. After the Model 3 production had reached the pace of 5000 cars a week, the manufacturing quota of battery cells in the Gigafactory had reached 3.5 million cells per day. As of 2019, the plant employs about 8000 workers.

Gigafactory 2, Tesla's plant for Model 3 cars in Fremont, California, was in the beginning constructed on 5.3 million square feet but latter expanded after the City of Fremont's granted permission for Tesla, in 2016, to double the plant's area to 10 million square feet, employing over 10,000 people in the Feront's municipality. It is connected to rail network which transports batteries and parts between Tesla Gigafactories. The production line uses more than 160 robots, including 10 of the biggest robots globally. The assembly process takes between three to five days. The battery pack which is put inside car weighs approximately 1200 pounds. Tesla built a mega casting machine in the Fremont factory in order to produce large car parts in a single piece. The one-of-a-kind machine called, Giga Press, made of aluminum die casting, produced by Idra Group in Italy, has a clamping force of about 60,000 Kilonewtons. It reduced casting from 70 parts to four parts, with future goal to produce most of the Model Y frame in one piece.

Gigafactory 3, is located in Shanghai, China. The plant was built in a minimal time period of one year. Tesla targets this plant to produce a quota record of 250,000 cars per year (starting with a weekly production quota of 3000 units). Tesla introduced the Model Y crossover for the Chinese market, postulating on the assumption that sales for this car model are going to exceed that of Tesla's other models altogether. The president of Tesla's location in China, proclaimed that it is designing a cheaper Tesla for the low-income customer niche which is expected to be priced at an affordable $25,000. It is called Model 2 and will be a hatchback.

Gigafactory 4, is at Austin, Texas. This plant is going to manufacture the cybertruck (Figure 3) which has over 500,000 preorders. Tesla is developing three models of cybertruck: single, dual and tri motor) to conquer the vast market of electric pickup trucks which is very popular in North America rural landscape. The cybertruck is built with an exterior shell called exoskeleton for extra strength, and equipped with a passenger protection armor glass.

Gigafactory 5, is taking ground at Berlin, Germany. The plant is going to produce Model Y (500,000 car annually) and associated battery packs. Tesla ordered eight new casting equipment devices that are planned to be assembled in the Berlin Gigafactory which encroaches into the European market.

There is a plan in blueprint to establish Gigafactory 6, at India. Specifically, on January, 2021, Tesla stepped into the Indian market by officiating a subsidiary, Tesla India Motors and Energy Private Limited. Tesla's Indian branch is considered to be built in the Karnataka state which encompasses research and development infrastructure hubs. Since India has demand for small size and cheaper price vehicles, the low-cost Model 2 is primary designated for production in this GigaFactory. Importantly, India's interest in the worldwide growing trend of sustainability fits with Tesla solar panels branch.
5. Discussion of Tesla business model limitations and future challenges

Tesla exponential sales' growth is notable, but it faces numerous impediments in the near future. First, the battery production is composed of three components: cell manufacturing, module manufacturing, and pack assembly. Tesla manufactures battery modules and packs at both its Gigafactory in Nevada, and at its vehicle assembly plant in Fremont, California. Tesla's battery packs for the Model 3 utilize cells from the Gigafactory, while cells for the Model S and Model X are still manufactured by Panasonic in Japan, which should be brought back home for manufacturing instead of outsourced because pack assembly needs to be near the vehicle assembly location for logistic reasons to reduce cost of transporting battery packs, which are larger and heavier than cells or modules. Thus, Tesla is aiming to achieve cell manufacturing capacity of 100 GWh per year by 2022 and 3 TWh per year by 2030. Through usage of nickel and lithium resources available within North America, and manufacturing cells in-house at Nevada, Tesla may substantially lower the cost of lithium production by 33% and decrease the miles traveled for the battery packs assembly by 80%. Following this mindset, Tesla vertical supply chain should extend into the mining industry coupled with investment in developing frontier material science in collaboration with prime universities which are leading the field. Tesla plans to reduce by 50% the price of its batteries in an effort to sell its flagship Model 2 car in a low-cost price of $25,000. Towards this goal, Tesla signed a contract with North Carolina-focused mining group Piedmont Lithium to purchase five years of their yield starting in 2022 and Tesla is also looking at creative ways to mine lithium from clay deposits in Nevada. These actions are going to render a fraction of Tesla lithium consumption, while the rest can be procured from Chile, Australia, China, etc. Tesla needs 25,000 tons of lithium per year to produce 35 GWh. It is a source of discrepancy because a future Tera-factory can consume up to 800,000 tons of lithium per year. Currently, there is no shortage of lithium worldwide. Which has decreased lithium cost (at 2020's global lithium production output is at 300,000 tons per year), but this situation is going to dramatically change due to disruption in worldwide supply chain rendered by COVID-19 crisis starting 2021 until at least 2024.

Also, the Tesla’s Model 3, which is relatively affordable electric car, suffered from production delays. It has recently met the monthly production quota needed to satisfy customers’ backlog of reservations and the demand forecasted. Although, Tesla has fulfilled a goal of producing 5000 Model 3s each week and delivering over 500,000...
cars, its ability to meet increasingly high pre-orders rendered by spiking oil prices is doubtful [29]. Consequently, Tesla ended its customer referral program, cut its workforce by 7% and reduced the prices of the Models 3, S and X by $2000 because its sales in the fourth quarter of 2018 fell behind estimates. Tesla has yet to fulfill its major promise to market its flagship Model 3 car at a price of $35,000 and has reduced its production of the Models S and X that are in less demand to 2000 cars per week.

Another source of concern is the quota limit on tax credits [30]. Electric car buyers are granted a $7500 break on their federal taxes. These perks are intended to put more green vehicles on the road. However, each electric car brand has a quota limit: 200,000 units. After passing this threshold, the incentives halt. As of 2019, more than 370,000 consumers have secured deposits for a Model 3 but not all of them will be able to receive the tax exemption, rendering risk of abolishing pre-orders.

A bigger source of concern for Tesla future prospects is that it falls behind rivals in offering car-sharing services. For instance, the Waymo originally developed by Google which pioneered the ride-sharing market, Zoox a self-driving car company that Amazon bought, and AutoX a Chinese self-driving startup funded by Alibaba. BMW group and Daimler AG are pooling resources to invest 1 Billion Dollars in total to develop ride-hailing services. In the future, Tesla plans to further expand its supply chain network by creating a ride-hailing platform titled Robotaxi. According to ARK invest report, this market has the potential to generate 1 Trillion Dollars in annual operating earnings by 2030 [31]. Essentially, the Robotaxi service aims to repurpose the car by allowing Tesla customers whenever not driving their vehicle, to use it as an autonomous taxi.

Finally, one should not ignore that the electric grid can become overloaded on peak-hours of consumption. It requires collaboration between all electric car manufacturing and their affiliated charging stations for development of a smart grid.

6. Conclusion

Despite concerns mentioned above, a report by UBS [32] asserts Tesla’s future is promising. The bank highlights Tesla’s record-high order backlog, growing margins, and an advantage in critical supply chains components. The analysts of the bank corroborated their arguments based on Tesla’s two new plants in Germany and Texas, which are ramping up manufacturing and should roughly double the company’s production capacity over time. They forecast the new factories with Tesla’s pricing is going to keep the company’s automotive margins above 30% for quarters to come. Tesla postulates sales grow by approximately 50% on average year over year, a goal UBS confirm it will meet in 2022. Despite lost sales due to the COVID-19 lockdown in Shanghai which restricted employees from attending work for a while, Tesla should be capable to manufacture 1.4 million vehicles on 2022 and reach 2.9 million by 2025. Finally, Tesla’s capability to retain competitive advantage stems from software’s scalability, which can gain substantial revenue beyond 2025 because Tesla is yet again head of the curve by investing in lidar and machine learning technologies for self-driving cars.
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Recycling Strategy and Challenges Associated with Waste Management towards Sustaining the World


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