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Technology Roadmap for Tesla Motors Sedan EV

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Technology Roadmap for Tesla Motors Sedan EV

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Abstract

In order for the United States, as well as other nations, to decrease their dependency and reliance on imported fossil fuel, to control and reduce the largest source of their carbon emission, and to secure their national transportation system, a faster transition from the Internal Combustion Engine to the Electric Vehicle has to be promoted. The public and private sectors will have to work hand in hand to ensure reaching such a national goal.

This paper lays out a technology roadmap for a private company 'Tesla Motors', proposing a balanced mixed basket of Technology Push and market Pull strategy in order to get closer and closer to the desired goal. Fossil fuel does not have to run out in order for the transition to take place. After all, the reason why humanity came out of the Stone Age was not due to the lack of stones, there still plenty out there.

Introduction

The ongoing increase in the fossil fuels' consumption, the uncontrollable rise in the price of crude oil, the natural and logical increase for energy demand due to global population growth which is expected to reach 10 billion by 2050 [1], and the general environmental awareness, added to the growing importance of sustainability and preserving natural resources and ecosystems in recent years have been major factors in product innovation. Efficiency has also been pursued by all energy related industries, and been promoted for its immediate and long term positive financial benefits. For the auto industry leading manufacturers, those were key business drivers to develop and produce vehicles that rely less on fossil fuel. The Electric Vehicles, whether being pure electric or hybrid (EV/HEVs) and that once were a dream, are becoming realities, commercially available and began gaining acceptance among the mainstream consumers. Toyota, Honda, Ford, Nissan, BMW, and Audi are among the leading automobile manufacturers that introduced hybrid and electric vehicle models. Tesla Motors decided to differentiate itself by solely manufacturing electric vehicles that will stand out in the market and survive the competition with the major well established brands in the market.

This paper will focus on the Tesla Motors, an American electric vehicle (EV) company. As it will be defined in a later section, the EV technology has a wide range of products, in this paper a technology roadmap for an affordable Tesla Sedan is the goal to be achieved. We will analyze the market to identify its drivers, define the market needs to fulfill the gaps with new products, suggest the technological capabilities needed to achieve the realization of the product gaps, and finally identify the necessary resources and link them to the suggested needed technologies. Figure 1 shows the flow to the final outcome; a Tesla Technology Road Map that will allow the newly established electric auto manufacturer to stand ground and gain more market share.

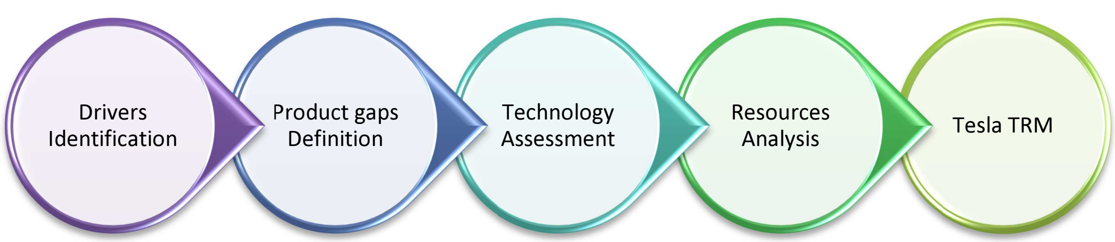


Figure 1: Flow of technology roadmapping (TRM) analysis

Background

A. The Electric Vehicle

1. Definition & history

The Electric vehicle (EV), as defined by the encyclopedia Britannica, is a motor vehicle powered by battery that originated in the late 1880s and that has been used for private as well as public transportation [2]. An electric vehicle can be a bicycle, a motorcycle or any type of four wheeled automobile, being private or commercial. The Electric automobiles competed very well with the petroleum-fuelled ones from the early days of the auto industry up until the 1920. They were preferred for their quietness and low maintenance costs. But with the highways system coming into use, automobile owners wanted to travel longer and faster; the Electric car fell short on fulfilling that desire. The fuel powered vehicle, with Internal Combustion Engine (ICE) that continued on improving, did [3]. Now a day, after almost a whole century of ICE vehicle dominance of the private transportation sector, it seems like the EVs are back in the picture with tremendous opportunities to revolutionize and reshape the transportation sector during this current decade [4].

2. Forecasted growth

Multiple service companies, Price Waterhouse Coopers, the international research consultancy firm Mckinsey, and Deloitte Consulting LLP to name a few, have reported promising forecasted growth figures for the Electric Vehicle market globally and in the U.S. Price Waterhouse Coopers forecast that the global market will continue to grow in a way that, by the year 2020 the EV market could be as large as almost 2.5 million or as low as 750 thousand but more realistically around 1.5 million vehicles [5]. Deloitte consulting LLC also provided three scenarios for the U.S. Electric Vehicle market penetration and trend. The aggressive, most probable and conservative vehicles forecasted figures for the year 2015 are 75000, 60000, &45000 respectively, and for the year 2020 the figures were 840000, 465000, & 285000 units [6].

The task is not an easy one, the success and survival of the EV require lots of efforts and collaboration among multiple players; the auto industry, the policies makers, the financial institutions, the energy sector, the media industry, and importantly the general public to name a few. Figure 2 graphically displays the relation or the nature of collaboration needed to the EV success. A later section of the paper will also identify the drivers for the Electric Vehicle positive trend which are rooted in various life aspects. Social, technological, economic, environmental, and Political factors are directly or indirectly linked to the success or failures of the Electric Vehicle completion survival.

Figure 2: Collaboration cycle needed for success

B. Tesla Motors [7,8]

Tesla Motors is a fairly new and ambitious American company that started operation in the year of 2003. Ever since, Tesla Motors differentiated itself by making it clear that the company will solely focus on the development, manufacturing, and delivery of nothing short than a high end performance electric vehicle; a pure electric vehicle (EV). The first vehicle, Tesla Roadster, was delivered to its new owners in 2008. The introduction of this first model was very important to the company. It was a showcase to the advanced technologies used, and a proof to Tesla Motors ability and willingness to lead the pure EV market. The advanced battery pack, along other sophisticated parts of the vehicle, allowed the newly delivered EV a longer range on a single charge, a decent 236 miles.

In 2010, the company secured a long term loan from the Department of Energy to finance further development of EVs, powertrains, and purchasing and retooling of manufacturing facilities. Tesla even negotiated with its suppliers an integrated manufacturing approach to manufacture parts on Tesla's sites to alleviate the dependency on the suppliers' performance. The positive indications to Tesla's success were noticeable and translated into actions by some of the automaker leaders. Daimler uses Tesla's battery pack in its a-class EV. Daimler also invests in the outstanding capital stock of Tesla by owning a good 8%. Furthermore, Toyota has a 3% equity investment in Tesla Motors in addition to the agreement of relying on the company (Tesla) as a source for major parts to the all-electric versions of RAV4. Such actions are strong assurances to the investors about the young Tesla's products and in the house designed and developed technologies. The following is part of a long innovations list backed by multiple patent applications.

- An advanced & efficient battery system.

- A sophisticated battery cooling, power, safety & management system.
- An exclusive alternating current 3-phase induction motor & its power electronics.
- An all-encompassing software system to manage safety, efficiency, as well as the overall vehicle control.

As mentioned in the previous section, the path of the EV or EV manufacturers is not free of obstacles. In case of tesla, the company has to focus on bringing the EV high tag price down a bid, a focusing point of this paper. Also, the company has to maintain its standards high in order to keep on gaining consumers appreciation and trust in an environment where the general public is lacking the awareness of EVs. As for the infrastructure, the slow, but steady rollout and development plans may hinder Tesla's and the EV industry ambitious expansion efforts.

Technology Roadmap Development

A. Electric Vehicles Market Drivers

In recent decade, car buyers have inclined using EVs due to several drivers in the USA environment. These drivers have been emerged from social (S), technological (T), economic (E), environment (E), and political (P) environments. To explain how these drivers affect the electric car market, STEEP analysis is used. Recognized factors are shown in Table 1.

Factor	Social/Market	Technological	Environmental	Economic	Political
Increasing Demand for Green Transportation	✓		✓		
Tax benefits and US government's incentives			✓	✓	✓
Increasing demand for lower cost transportation	✓			✓	
Smart Grid Implementation with relation to V2G technology		✓			
Emerging new technologies in EV's main parts (battery, electric motor,…)		✓			

Table 1- STEEP factors affecting EV market

1. Increasing demand for green transportation

According to increasing anxieties about environmental issues such as CO2 emissions and increasing GHGs, green transportation including public transportation like bus, walking, and bicycling have being noticed more and more. Electric vehicle as one of the green transportation has been noticed widely by societies and governments so that annual sales of different types of electric cars including EV's will have a remarkable growth by 2050, and the number of sold conventional gasoline and diesel cars will be decreased dramatically by that time [9]. International Energy Agency's studying shows that the number of EV and PHEV cars sold globally by 2050 would be around 106.4 million cars – Figure 3.

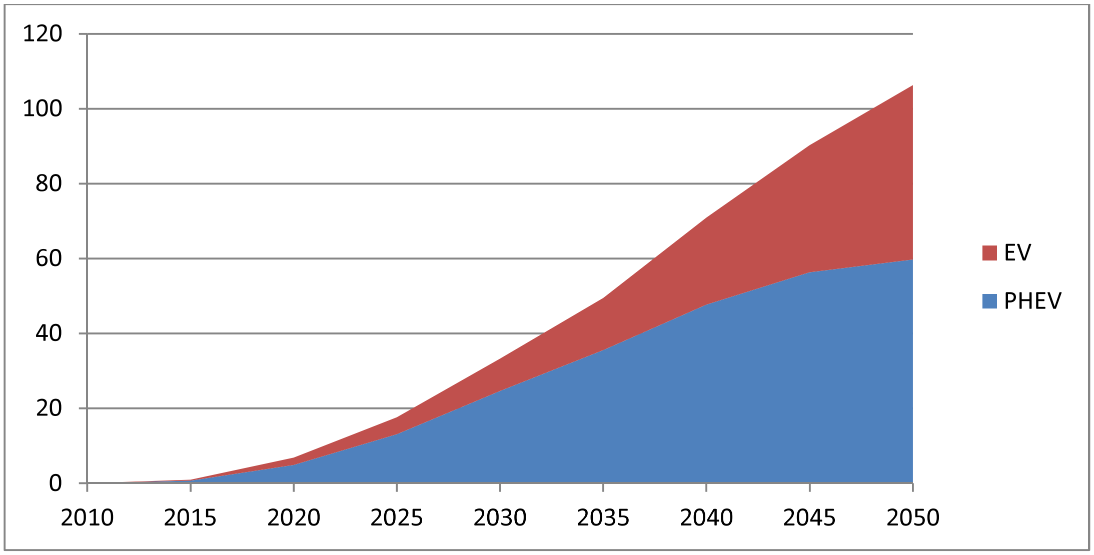


Figure 3 - Annual global EV and PHEV sales in BLUE Map scenario

2. Tax benefits and US government's incentives

Increasing gas prices in recent years made energy security as a one of federal and states governments' main concerns. Moreover, environmental issues and related international commitments led the governments to enact some incentives.

The most important incentive is the Recovery Act Funds. As part of DOE's $12 billion investment in advanced vehicles technologies, the Department is investing more than $5 billion $ to make the USA's transportation system electrified. These investments are supporting the development, manufacturing, and deployment of the batteries, components, vehicles and necessary charging infrastructure and facilities [10]. Other main incentives are shown in table 2

Table 2Table 2- Incentives deployed by federal and some state governments [11]

3. Increasing demand for lower cost transportation

Dramatic changes in gasoline, shown in figure 4, have been a big challenge for car drivers over recent years. Increasing gasoline price more than 200% between 2009 and 2012 indicates that fuel consumption cost is going to be a big problem in transportation cost. Also Kenny ham, vice president of Apocalyps EV, reported [12] that 70% of America's daily oil consumption relates to automotive transportation.

Despite of the high price of EVs, cost analysis on advanced EVs shows that they could be competitive with gasoline-powered vehicles over the time due to less maintenance cost, and energy cost reduction [13].

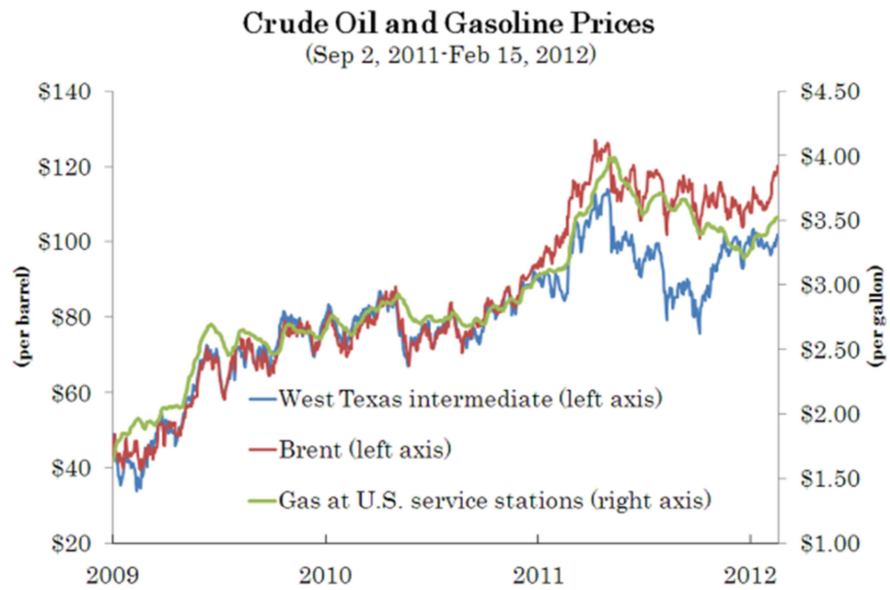


Figure 4- Changes in Crude oil and gasoline prices (2009-2012) [14]

4. Smart Grid Implementation with relation to V2G[1] technology

Smart grid implementation is a basic prerequisite to promote using EVs nationwide. Upgrading distribution level transformers to make a reliable service to homes and charging locations, investing in smart meters and smart charging software, investing in IT infrastructures to support applications including EVs are main parts of smart grid development that utilities have to follow. $3.4 billion were assigned in 2010 by the federal government as stimulus fund to develop smart grid and modernize the current one According to the U.S. Department of Energy's Alternative Fuels Data Center, there are currently around 4150 EV charging stations in the U.S. It's reported that the number of EV charging stations will be 4.1 million by 2017 [15].

5. Emerging new technologies in EV's main parts (battery, electric motor,…)

The technology of batteries has had a great progress after emerging lithium ion batteries in 1999. By emerging lithium batteries, the dream of riding electrical vehicles for long distances got more possible. As shown in figure 5, today's automotive Li-ion cells are capable of supporting higher mileage around 70 miles for a 200 kg pack. It's predicted that Li-ion batteries will reach 400 Wh/kg by using high-capacity cathode materials and alloy anode materials. Li-air batteries, which will be emerged in a close future, potentially surpass the battery technology used today. Li-air batteries may reach 400 Wh/kg. Theoretically, achieving 1000 Wh/kg is attainable if some technological obstacles would be overcome. This generation of batteries make possible to drive more than 380 miles on a single charge [16].

[1] - Vehicle to Grid

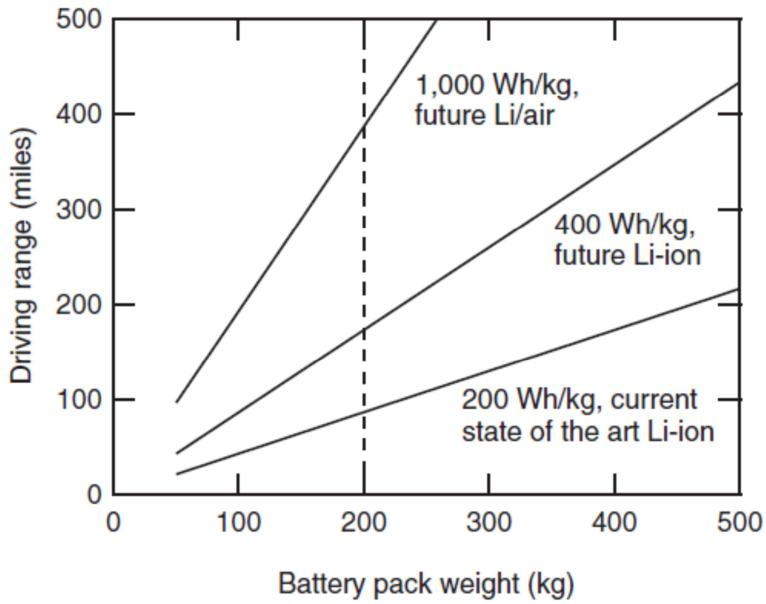


Figure 5- Driving range and battery weight for different cell-level specific values [16]

B. Product Roadmap & Gaps

Tesla Motors is well known for its premium cars. They maintained the top score features in all their products [17]. To understand what should be done for Tesla's product roadmap, we performed the gap analysis between the current features and features that are required for Tesla to make a difference in the market. We focused on identifying potential gaps and also tracking known gaps [20]. We are also focusing on Electric vehicles.

Current Position

Figure 6 shows the current features in the Tesla's model-S. It has features targeted for premium market.

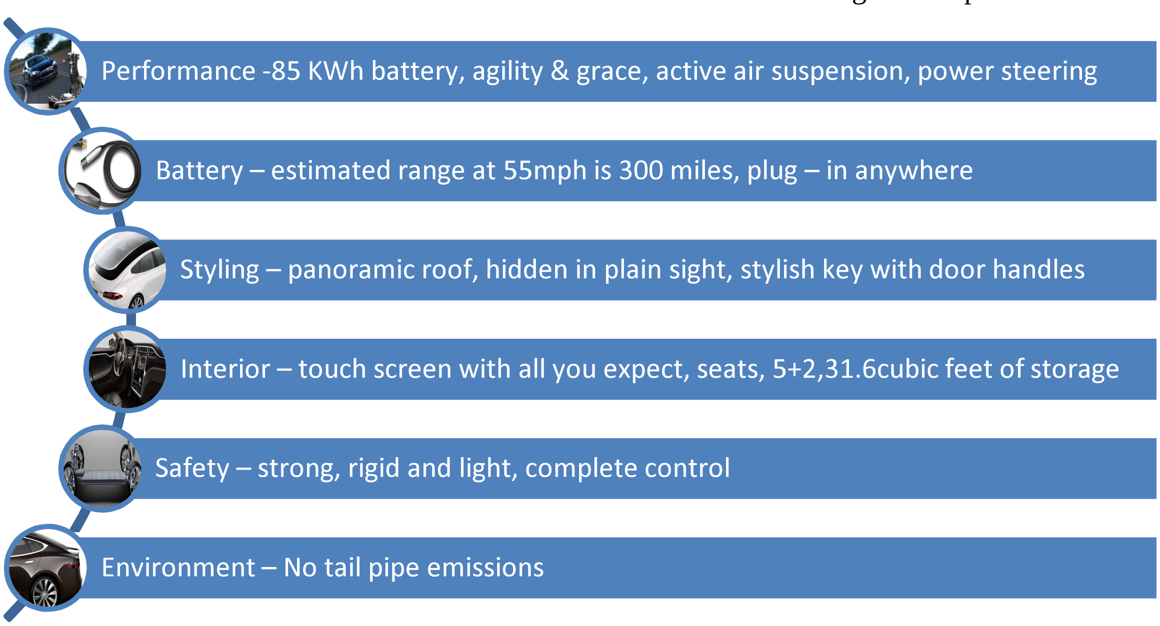


Figure 6- Present - Features of Tesla motors latest model-S [18].

1. Performance

It has one of the best performances in electric vehicle industry. It rises from 0 to 60 mph in just 5.6 seconds. 125 mph is the top speed with zero tail pipe emissions. Few of the important features include its 85 Kwh battery and its active air suspension [18].

2. Battery

Battery is the major part of the electric car. There is a lot of research going on to optimize the performance of the battery [21]. Understanding the issues with the battery and improving its performance is important for Electric vehicle's success. Currently Tesla is leading in this with 85 kWh batteries which enable the car to farther up to 130 mph [18].

3. Styling

Focusing on the premium; this car delivers all the features that most of the luxury cars deliver. Comparing with the competitors it has all the panoramic view with maximum efficiency. It has all the features that are expected in a premium car [18].

4. Interior

It has 5+2 seats with maximum capacity for the size of the car and also the touch screen with top most features in the present internal electronics. Few of them include integrated media, navigation, communications, and cabin controls [18].

5. Safety

This is one of the most important features. Tesla exceeds in the safety domain also with the rigid battery. The traction and stability also gives a complete control over the car. With high strength steel it provides maximum capacity for occupant safety [18].

6. Environment

Being an electric vehicle it is already favoring the environment. With zero tail pipe emission is more efficient than any of the gasoline or petroleum burned vehicles. The sources of electricity are also efficient technologies. Thus it is less harmful to the environment [18].

7. What will it cost?

With all of this we also looked into the price range for different performance levels as shown below.

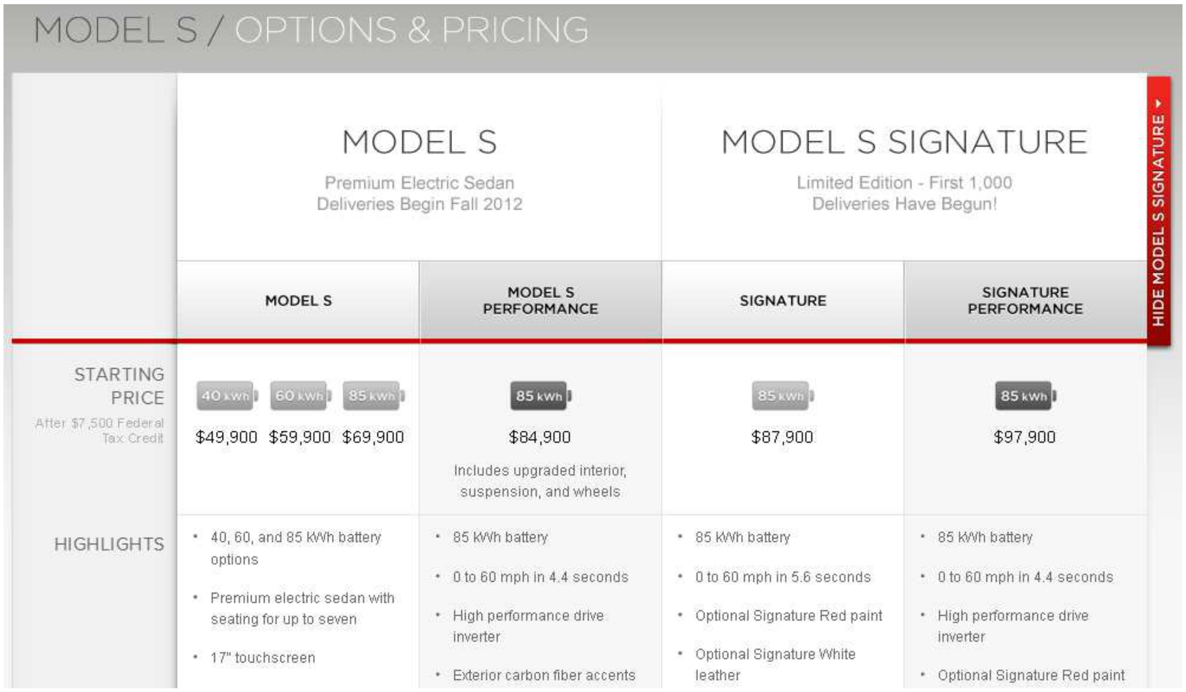


Figure 7- Current pricing structure for Tesla model-S [19].

Future of Tesla

Understanding the current features and also looking into future of EV, we identified the potential gaps and known gaps [20]. Surveys on the internet and literature review provided the information on what customers want to see in an electric vehicle. Figure 8 depicts our understanding on where Tesla should be in the future to become a market leader.

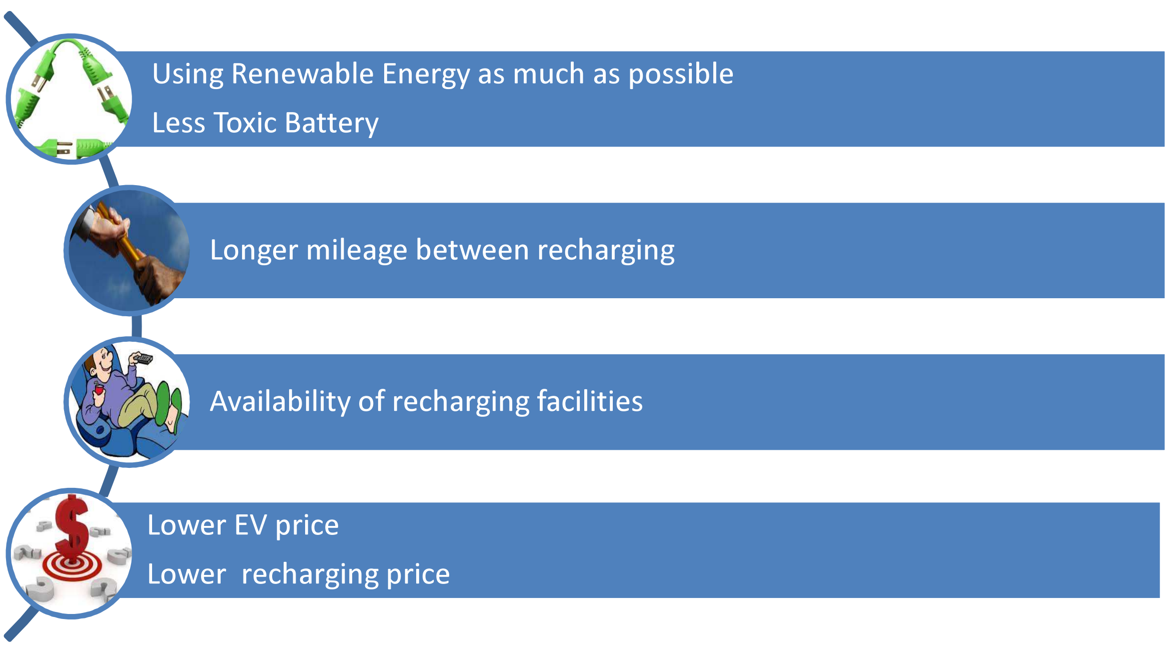


Figure 8- Features- Tesla market leader [22,23,24,25,26,27]

Known gaps

1. Lower Electric vehicle price

Electric vehicles are now not being purchased by regular salaried persons. They are mostly targeting the premium vehicle range. The most expensive part of the electric vehicle is the battery. We need to consider reducing the cost with reducing cost of battery [22, 23]. Understanding Tesla's design we came up with negative gaps like reducing the interior features and styling to make the car affordable.

2. Less Toxic battery

To improve battery as environment friendly, the toxic battery needs to be changed. There is research going on this subject and Lithium ion battery is an alternative that is being considered [22]. Considering this will make the vehicle greener to the environment.

Potential gaps

1. Using Renewable Energy as much as possible

Even though electric cars are considered environmental friendly, they are still ways to make it absolutely environmental friendly. One of which is using photo voltaic power to improve the efficiency and performance of electric vehicles. Power can be generated from the PV powered vehicle and PV powered charging stations [26].

2. Longer mileage between recharging

The major part of the EV is the battery. Increasing the performance of battery will increase the mileage and also other technologies that are covered in technology will increase the mileage between recharging [22,23,24]. This is one of the major gaps in the market. The target for mileage keeps on increasing with technological changes.

3. Availability of recharging facilities

This is considered to be gap for the entire EV market. Because the availability of charging stations is currently less, rolling out new facilities and improving these stations in collaboration with technology and electricity companies is essential. Measures have to be taken to standardize the availability by government and companies [23, 27]. Plugin station is also a priority from customer surveys [24, 25].

4. Lower recharging price

Lowering the recharging price is another gap that needs to be addressed. This is mostly related to technological changes that are coming up in the EV industry like smart grid and PV powered stations [26, 27]. This is a potential gap that is dependent on continuous improvements of the technologies.

The next step after identifying the product gaps is to map them to the market drivers. In the technology road mapping process understanding the market will give the insight to understand the product needs. This gives the opportunity to set the targets for the market. To map this product gaps with the market drivers we used a QFD (quality function deployment) tool. House of quality process will provide the relation between each of this gaps and helps to analyze the priorities. We can understand the immediate needs of the market and proceed with focusing on them [28, 29]. Table 3 shows the implementation of QFD matrix between the drivers vs. product gaps.

Drivers	Green transportation	Emerging technological changes	Tax benefits & US government's incentives	Lower cost of transportation	Performance
Using Renewable Energy as much as possible	✔ ✔	✔ ✔	✔		
Efficient Power electronics	✔ ✔	✔ ✔		✔	✔
Longer mileage between recharging	✔	✔ ✔		✔ ✔	✔ ✔
Charging Interface		✔ ✔		✔	✔
Lower EV price		✔ ✔	✔ ✔	✔ ✔	

Table 3 - QFD Matrix - Drivers vs. Product Gaps

All of them have equal importance. But considering the availability of technology and the top market drivers the prioritization for product features was selected. Understanding the prioritization and mapping them to the market needs helped to understand the implementation of the product and its lifecycle. We focused on the Sedan model for attracting the market as it drives towards satisfying the market needs.
Table 4 below represents the Products features delivered with each product and also gives on idea on the time line.

Time(years)	1	5	10
	B- Sedan	XY-Sedan	EV – Powered by PV
Efficient power electronic	✔	✔	
longer mileage		✔	✔
lower price	✔	✔	
charging interface	✔	✔	✔
Using renewable energy			✔

Table 4 - Product Gaps vs. Products

The products are designed for implementation for the roadmap only focused on the Sedans. This is planned for a time interval of 5 years. The first target is to make the Sedan affordable and add the technology changes that improve efficiency of the battery and charging interfaces. But lowering price is the main focus for the short term goal. The next step is to understand the technology gaps and mapping them to the product gaps.

C. Technology Roadmap & Gaps

Technology roadmapping is a process that can be applied to identify any existing technology gaps, critical system requirements, and milestones that are critical to the development of a product. It is a method by which one can assess the different pathways, if any, for meeting a requirement, and is especially useful when there are high risk elements in the product development process. In which case, one could pursue more than one path for fulfilling a specific requirement, and help in reducing the risk of execution. This sort of strategy management is ideally done before making any technological investments or starting the execution phase of the project or product. For a given set of needs and a timeframe, TRM provides a method to organize and analyze information about critical requirements, targets, performance metrics, etc. and the time frames by which they have to be accomplished so as to meet the needs of the product roll-out planned. It also helps in identifying alternative pathways, and making trade-offs among them to better mitigate the risks identified. [30]

In this first stage, typically the timelines are more or less defined, but not the means to achieve it. Within the scope of this project, the targets and timelines have been decided as shown below in table 5

	Current	~1 yrs	~ 5 yrs	~ 10 yrs
Model	Sedan	Sedan B	Sedan XY	PV Powered Sedan
Car Cost	≈ $50K	$40K	$50K	$60K
Battery RE-Charging Time	45mins	45 mins	30 mins	30 mins
Battery Range	≈160 miles	200 miles	500 miles	500 miles
Motor efficiency (KW)	≈245	≈275	≈500	≈500

Table 5 - EV product targets

These technology gaps and challenges have been identified based on market drivers and product gaps, and further technological assessment and adoption rates can help in multi stage product development. Following are some of the limitations with proposed solutions in the current state of the art EVs:

a) Battery Technology and Performance: Need for improved reliability, and capacity

Energy density in existing batteries is by far the biggest limitation in EV industry in terms of the amount of power that can be delivered per unit weight of the battery. It also plays a huge part in determining the overall price of the EV. So far, the only way to overcome this has been to use heavier batteries to improve the working range of a car for a single charge. However, this leads to a reduction in responsiveness of the car due to the extra weight, and slower acceleration in uphill climbs. One of the emerging technologies for improving energy density is to go for Lithium-air based batteries as demonstrated by the engineers at IBM [31].

In terms of reliability, while current estimates for Nickel metal-Hydride (NiMH) based batteries suggest that their life could be as high as 15 years based on regular usage of the EV, these estimates are based on projections based on extrapolated data, and higher reliabilities would be a welcome addition to the existing list of market drivers. [22] One way of ensuring higher reliability is to slow the rate of charge-discharge cycles, and in this context, the usage of ultra-capacitors [22] for short term booster power, or for storage of energy in regenerative braking would likely answer some of the above mentioned challenges. Another competing technology as demonstrated by scientists in Stanford University has been the usage of Nickel-Iron batteries for intermediate term storage supplementing the storage of the main batteries [32]. These batteries have a much larger life based on the charge-discharge cycles, and hence can definitely pave the way to improved reliabilities.

b) Safety – Thermal management of batteries

Storage of energy in a confined space whether it be liquids, gases (such as petrol, compressed natural gas) or batteries (fuel cells, lead-acid) could lead to safety hazards, and give rise to regulations by government or its agencies. One such example is the fire hazard in vehicles such as the Nano developed by Tata Motors [33]. The solution of this problem is an important step in addressing market and human concerns and is an important gap to be addressed. Interestingly, the temperature control of the battery is not only an important step in mitigating fire hazard, it is also a means to improve battery efficiency and usable-life. A team at Fraunhofer Institute in Germany devised a phase change material as a coolant to keep the battery temperature at an optimum level of between 20 and 35°C to improve the efficiency of the battery as well as reduce fire hazards [34].

c) Environmental issues: Battery recycling and re-purposing

Primary costs of the batteries come from the cost of Lithium and other scarce metals. Proper re-cycling and re-purposing of such metals is essential to ensure lower costs and also to ensure zero total emissions of EVs. Thus, development of a mechanism that allows end-users to trade-in their used batteries is essential to recover some cost and protect the environment, and as such adds to the appeal of owning a zero-emission vehicle. Possible usage models include re-purposing these batteries into indoor converters, or in utility vehicles for which the range may not have the same requirements as passenger vehicles. Existing companies such as Toxco already provide a range of services which could be tapped for closing the gap in this area. [35] Tesla currently ships the end of life batteries to Toxco for dismantling and reuse, recycling.

d) Use of renewable energy – Photovoltaic (PV)

Even though EVs have zero emissions, they are still reliant on electricity which is available from the grid, and more often than not, the electricity is produced by coal-fired plants, and hence the EVs are not truly zero-emissions. One of the readily available technologies is the use of solar PV panels which provide a truly zero-emission renewable energy based transport solution. Cost of electricity by PV means is expected to equal or drop below that of the coal-based electricity by 2025 [36], and this within the timeframe for using PV-based sources for the EVs. These could either be in the form of in-vehicle charging capabilities, or using roof-top PV panels (say in the garage) for providing charging and vehicle-to-grid technology.

Implementation Steps

The resources for these gaps could either be in-house R&D or existing commercial or emerging solutions. There could also be outsourcing and negotiations with partners or alliances with national labs and standards institutes such as NIST. Manufacturing concerns are not as important due to the already existing leadership role taken by Tesla in the EV/automobile manufacturing sector. Tesla already provides services to other auto giants and could even rely on the goodwill to develop partnerships in other areas as well.

In order to accomplish the timeline set for the product roll-out, Tesla would need to address the above gaps using the methods recommended so that the technology is available in a timely manner.

D. Resources

1. The R&D Resources

Resource management is to manage the investment of the Company's R&D resources, which includes human resource, information resource, monetary resource, and material resource. There are concerns about the availability of skilled workforce, information and material resources when needed. The cost of securing these resources is usually determined by their usefulness and scarcity. The ability to get all the needed resource in a cost-efficient way is significant to the success of R&D programs, and hence to the success of the future of the company. Firms need to utilize strategic decision making during the acquisition of the R&D resources to maximize the utility and eliminate the risks in R&D process. The point of concern is to maximize R&D overall productivity of resources, which is beyond R&D job itself, and the purpose is to find the best balance between internal and external R&D productivity.

There are four ways to acquire the R&D resources, i.e., in-house R&D, alliances/partnerships, outsourcing, and acquisition. The definitions, pros and cons of all four ways of getting R&D resources are listed in table 6 below.

	Definition	Pros	Cons
In-house R&D	Do it by yourself, with your employees, your R&D facilities	1. Ownership of technology 2. Exclusiveness 3. Core competencies in the value chain 4. Strategic advantages	5. High fixed costs 6. Mobility of researchers 7. Risks of substituted by disruptive technological progress
Alliances/Partnership	Do it together with partners with knowledge share within alliances	1. help to get more resource at low prices 2. Complimentary in the vertical alliance	1. safety of exclusive technology 2. competition from partners usually in horizontal alliances 3. Knowledge and brain drain among alliances partners
Outsourcing	Pay the R&D suppliers to do it, get the outcome of R&D as the result.	1. Quick progress in R&D 2. Less cost of R&D team 3. Flexibility when disruptive technologies bring substitution	1. Dependency on the R&D suppliers. 2. Lack of control to the technology progress 3. Knowledge shared by the R&D suppliers
Tech Acquisition	Buying the technology in the form of patents, business secrets, etc.	Get the required technology fast, when a specific technology is need	Conducting a technology acquisition project every year would be very costly. (Therefore, you should do your best to select a vendor and a technology that can grow with your business for the next 2–3 years.)[37]

Table 6 - The Comparison of Four Ways to Acquire the R&D Resources

2. Strategic Decisions in Resources Acquisition

There has been research about the strategic decision of adopting in-house R&D, alliances or outsourcing. [37] Rajneesh Narula suggested when, and under what circumstances it is advantageous for firms to engage in R&D activity internally or externally, distinguishing between the use of in-house R&D activity, R&D outsourcing and R&D alliances.

Granstand et al viewed the competences of technology based firm as four types as demonstrated in Figure 9. Rajneesh Narula maps the four quadrants to in-house R&D, outsourcing and alliance as the oval circles show.

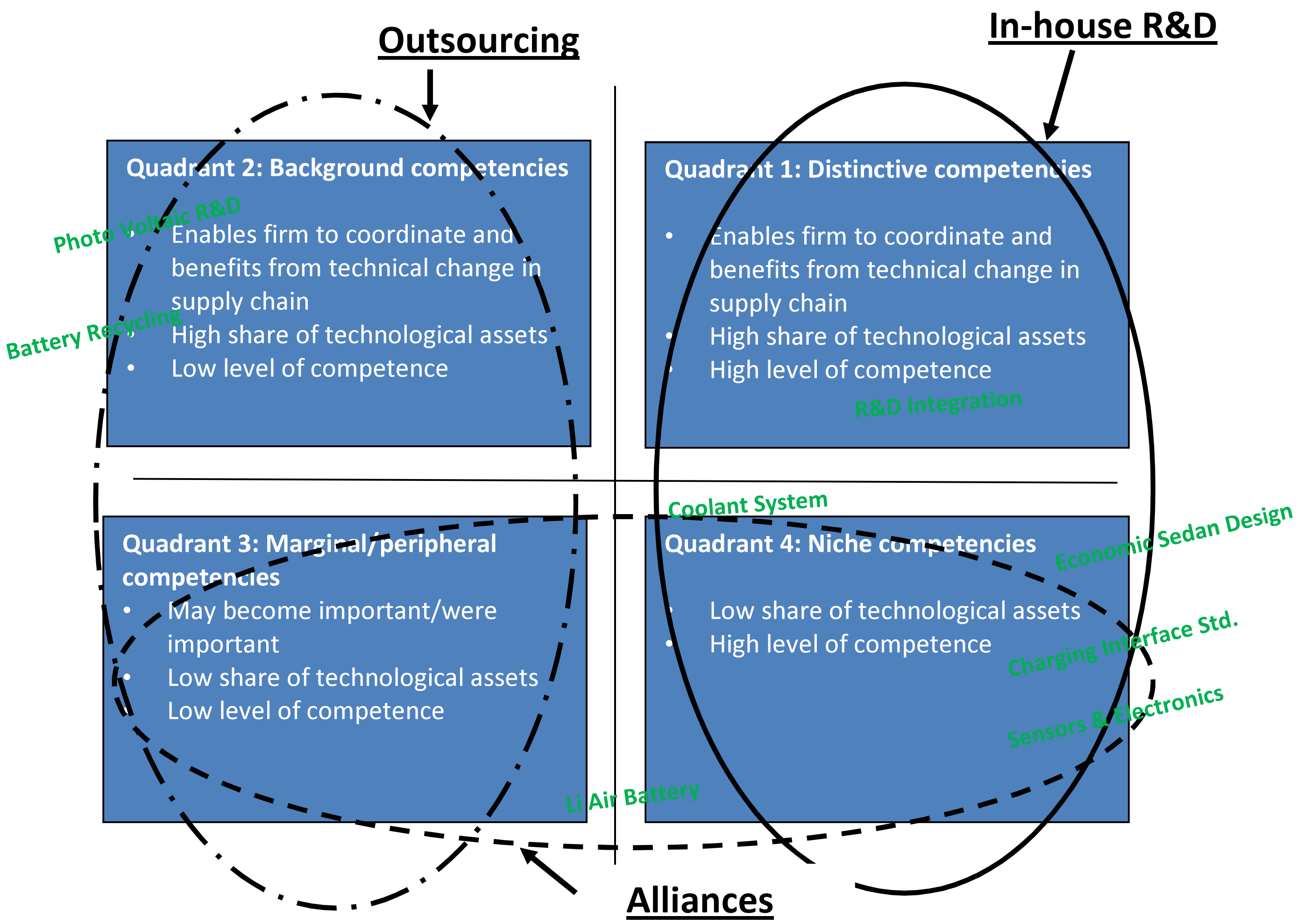


Figure 9 - The static view: relationship between distributed competencies and internal/non-internal R&D

Rajneesh Narula then looked into the dynamic view of the evolution of technological paradigms and came up with a decision tree for selecting mode of R&D for pre-paradigmatic technology shown in Appendix-A. Instead of using decision tree to express the decision model as in Rajneesh Narula's research, a decision table was used to express the decision modes as shown in Appendix-B.

3. Tesla's R&D Resources Decision

Several technological gaps were identified based on the earlier research performed above. Based on the R&D resource selection framework defined in the previous section, we will identify the appropriate R&D resource for each of these technological gaps. The technological gaps to be analyzed are:

- Economic Sedan Design
- Charging Interface Standard
- Coolant System
- Battery Recycling
- Li -Air Battery
- Photo Voltaic R&D
- Sensors & Electronic
- R&D for Integration

The appropriate R&D resource for each technological gap is derived by evaluating each of the gaps above against the selection model utilizing Tesla's strategy and current market status. Table 7 shows the recommended R&D resource outcome of each technology based on the selection model.

	Economic Sedan Design	Charging Interface Standard	Coolant System	Battery Recycling	Li Air Battery	Photo Voltaic R&D	Sensors & Electronic	R&D Integration
Slow/rapid technical change?	Rapid	Rapid	Slow	Slow	Slow	Rapid	Slow	Rapid
Systematic effect/marginal effect on existing technology?	Systematic	Systematic	Systematic	Marginal	Systematic	Marginal	Marginal	Systematic
Is Internal resource available?	Yes	Yes	Yes	No	No	No	Yes	Yes
Multiple substitutable sources available?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Is the entrance to the technology late?	No	No	No	No	No	No	No	No
Decision	In-house R&D Supported by alliance	In-house R&D Supported by alliance	In-house R&D Supported by alliance	Outsource	Alliance	Outsource	In-house R&D Supported by alliance	In-house R&D

Table 7 - Tesla's Decision among In-house R&D, Outsourcing or Alliances

4. Tesla's R&D Alliances

Based on the above analysis, we try to identify the potential external resources required for Tesla, as shown in Table 8.

	Decision	Available partners/vendors	Negotiation Result
Economic Sedan Design	In-house R&D Supported by alliance	Daimler and Toyota Fresno Design Alliance	TBA
Charging Interface Standard	In-house R&D Supported by alliance	SAE International China Enterprise Confederation and China Electric Power Research Institute International Electrotechnical Commission	TBA
Coolant System	In-house R&D Supported by alliance	Fraunhufer Inst. DENSO Corporation Alliances with SAE (Society of Automotive Engineers)	TBA
Battery Recycling	Outsource	Interstate Batteries, Inc. Toxco Battery Solutions, Inc.	TBA
Li Air Battery	In-house R&D Supported by alliance	IBM Chengdu Jianzhong Lithium Battery	TBA
Photo Voltaic R&D	Outsource	Kyoecera Mitsubishi SunPower Corporation, CleanTech Institute Toyota	TBA
Sensors & Electronic	In-house R&D Supported by alliance	Large Number of Providers (634)	TBA
R&D integration	In-house R&D Supported by alliance		TBA

Table 8 - The External Resources pool for Tesla

After Tesla has got the decisions of selection between in-house R&D, outsourcing and alliances, it still needs to set up the outsourcing provider and the alliance partnership. There are 5 steps to do this:

- Step1: to find out the available providers/partners
- Step2: to do technology assessment, make sure that the technology is what Tesla need
- Step3: to select some of the providers to negotiate with according to the result of Step 2
- Step 4: to negotiate with the candidates
- Step 5: to make decisions about the selection of providers/partner

Proposed Sedan EV Roadmap

Roadmap is an integrated plan linking all factors in market, product, technology, and resources parts, so three main tasks must be accomplished to make an integrated roadmap: timing, prioritization, and naming product generations. To make a reasonable foresight and adjust our timing to the realities of the business, we divided our timing to:

- Short range: one year, to make more economic current product
- Medium range: five years, to make more improvements in the main parts of the product and its performance
- Long range: ten years, to apply new technologies, particularly Photo Voltaic, to make new generation of EVs

To make priority among all factors and anticipated activities, each was discussed and its relationship with others was determined. Timing was another point considered in making prioritization. The roadmap focuses on three main product generations offerings to support the described market drivers discussed earlier. The product offering will be derived by R&D programs that are precisely linked to the technology and product requirements. The three product generations in the roadmap are:

- Basic (B): introducing the product with some minor design changes to the current product in order to make it more affordable.
- XY: introducing the product with significant environmental, performance, and operational enhancements at an affordable price.
- PV Powered. Explaining next generation of Tesla's products which will be powered by Photo Voltaic technology

The integrated roadmap of Tesla's Sedan EV is shown in figure 9 below and Appendix C.

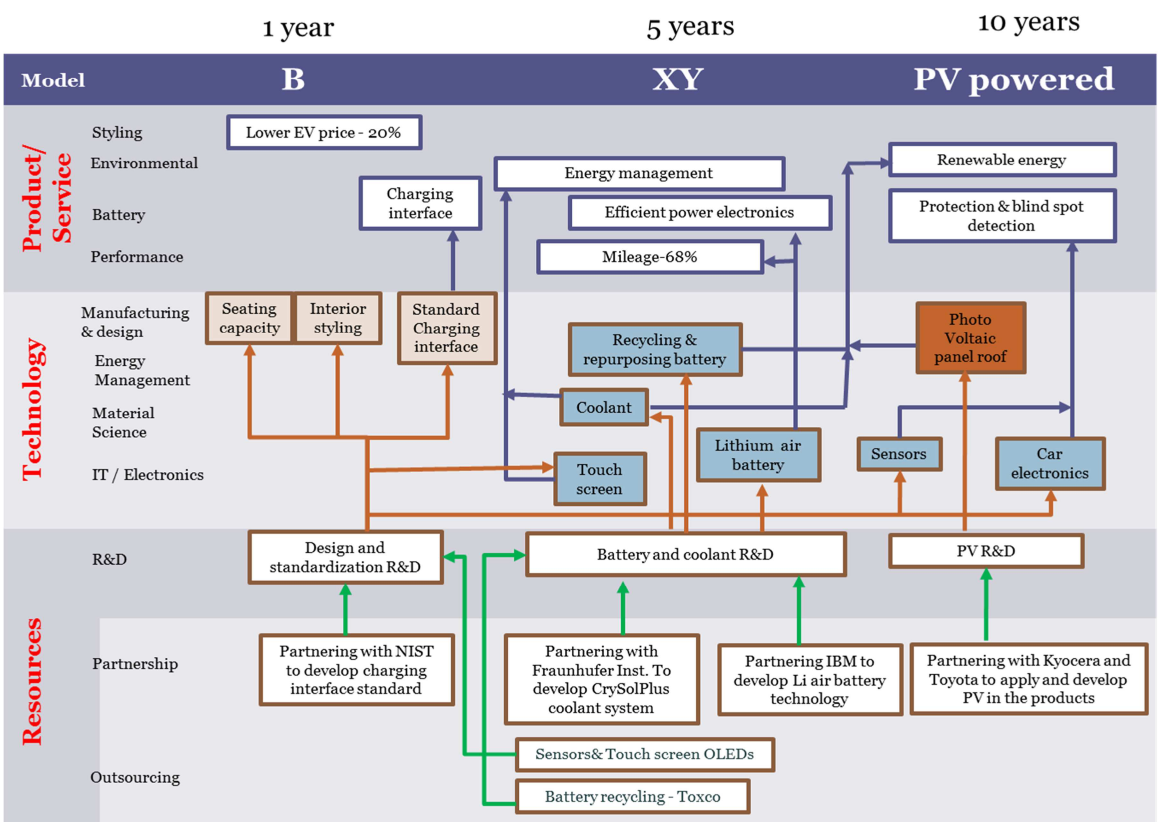


Figure 9 – Proposed Tesla Sedan EV Roadmap

Conclusion

In order to maintain sustainability in today's diverse and competitive automobile market, it's imperative for Tesla Motors to design, develop, and integrate TRM as a strategic planning tool to align their technology strategies with business strategies.

A preliminarily technology roadmap was created to address the short and long term business strategy and market penetration for Tesla sedan EVs. A typical TRM development model was adopted throughout this study which focuses on analyzing the market to identify its drivers, defining the market needs to fulfill the gaps with new products, suggesting the technological capabilities needed to achieve the realization of the product gaps, and finally identifying the necessary resources and linking them to the suggested needed technologies. Throughout the study some specific tools and/or frameworks were utilized during each stage of the roadmapping development process. As an example, STEEP analysis was used during the market driver's definition stage. To map product gaps with the market drivers QFD technique was used during the technology analysis stage. At the resource analysis stage a combination of decision tree and decision tables were used to determine the best and most effective method of securing the required resources for each technology defined.

The study focused on creating a high-level roadmap for one product segment which is the Sedan EV. Additional research can focus on expanding this roadmap to include other segments such as compact and SUV vehicles. This might entail using addition or new tools, models, and/or frameworks during the roadmap development stage.
This study was done based on the current market and technology status and taking into the consideration Tesla's current positioning in the market. Additional research can be performed in the areas of providing a continuous maintenance to the roadmap and adapting to future market and technology changes.

Finally, Tesla should plan for the after technology roadmap development stage, which is the continuous integration and implementation of TRM into an ongoing strategic planning process. TRM integration and implementation will require adopting change in some business process, organizational structure, or even working culture. Additional research can be conducted on how Tesla can effectively integrate this roadmap into its business process and organizational changes are required.

References

[1] C.C. Chan and Y.S. Wong, "Electric Vehicles Charge Forward," IEEE Power & Energy Magazine, vol. 2, no. 6, pp. 24-33, 2004.

[2] Encyclopedia Britannica, viewed on line at http://www.britannica.com/ on July 31, 2012

[3] C. Chan, "Present status and future trends of electric vehicles," in Advances in Power System Control, Operation and Management, 1993. APSCOM-93., 2nd International Conference, Hong Kong, 1993.

[4] S. Brown, D. Pyke and P. Steenhof, "Electric vehicles:The role and importance of standards in an emerging market," Energy Policy, vol. 38, no. 7, p. 3797–3806, 2010.

[5] C. Macrae and M. Mckenzie, "Price Water House Coopers Automotive Institute Analyst Report" Price Water House Coopers, January 9, 2009.

[6] C. Giffi et al, "Gaining Traction – A customer view of electric vehicle mass adoption in the U.S. automotive market," Deloitte Consulting LLC, 2010.

[7] Tesla Motors, Inc., "Annual report", filed 03/03/2011 for the period ending 12/31/2010

[8] E. Loanzon, M. Mansour, and T. Torres , "No Gas Required: A Marketing Plan for Tesla Motors' Model S Electric Car", Portland State University, Spring term of 2011.

[9] Technology Roadmap: Electric and plug in hybrid electric vehicles. International Energy Agency. 2011.
[10] The Recovery Act: Transforming America's Transportation Sector s.l. : Department of Energy, 2010.
[11] Ciarcia, Daniel. Charging ahead GE EV Solutions. General Electric. 2011.
[12] Ham, Kenny. Why the USA needs small electric vehicles. Vice President, Appocalyps EV. 2011.
[13] Saving Energy in U.S. Transportation. Office of Technology Assessment, Congress of the United States. 1994.
[14] Economic Briefing: Economics & Statistics Administration. Economics & Statistics Administration Web Site. [Online] United States Department of Commerce, February 22, 2012. http://www.esa.doc.gov.
[15] Strategic Technology and Market Analysis of Electric Vehicle Charging Infrastructure in North America. Frost & Sullivan. 2012.
[16] A Critical Review of Li/Air Batteries. Christensen, J, et al. 2012, Journal of The Electrochemical Society.
[17] Tesla Motors Company Overview Summer 2011, Internet: http://files.shareholder.com/downloads/ABEA-4CW8X0/1404747030x0x494001/dd297293-ec2d-4dc5-8db4-63d491fb6bd0/Company_Overview_Q3_2011.pdf
[18] Tesla Motors website, Internet: http://www.teslamotors.com/models/features, Viewed on: 8/11/2012
[19] Tesla Motors website, Internet: http://www.teslamotors.com/models/options, Viewed on: 8/11/2012
[20] White Paper: 5 steps for gap analysis, Internet: http://jthawes.com/pdf/5StepsforGapAnalysis.pdf
[21] Battery Manufacturing for Hybrid and Electric Vehicles: Policy Issues, Bill Canis Specialist in Industrial Organization and Business March 22, 2011, Congressional research service, Internet: http://www.fas.org/sgp/crs/misc/R41709.pdf
[22] Mike Elwood. "Electric Vehicle Technology Roadmap for Canada 2010". Internet: http://canmetenergy.nrcan.gc.ca/transportation/hybrid-electric/329 , Viewed on: 8/11/2012.
[23] Electric Vehicles (EVs), Internet: http://www.fueleconomy.gov/feg/evtech.shtml/, viewed on 8/11/2012
[24] Electric vehicle survey reveals consumer preferences, Internet:http://www.gizmag.com/electric-vehicle-survey-reveals-consumer-preferences/17418/ , Viewed on 8/11/2012
[25] Survey: Consumers express concerns about electric, plug-in hybrid cars, Internet: http://news.consumerreports.org/cars/2012/01/survey-consumers-express-concerns-about-electric-plug-in-hybrid-cars.html, Viewed 8/11/2012
[26] Performance of a PV powered charging station for electric cars, Internet: http://www.cede.psu.edu/users/alau/ASESPVChrgingStation95.pdf, Viewed on 8/11/2012
[27] Electric Vehicle Charging Infrastructure, Internet: http://www.mpoweruk.com/infrastructure.htm , Viewed on 8/11/2012
[28] House of quality- Steps in understanding house of quality, Internet: http://www.public.iastate.edu/~vardeman/IE361/f01mini/johnson.pdf
[29] The House of Quality , by John R.Hauser and Don Clausing, Harvard Business review Reprint 88307, Internet: http://www.csuchico.edu/~jtrailer/HOQ.pdf
[30] Garcia, M.L. and Bray, O.H. "Fundamentals of Technology Roadmapping. Strategic Business Development Department Sandia National Laboratories".Internet: www.sandia.gov/PHMCOE/pdf/Sandia%27sFundamentalsofTech.pdf, 1997
[31] Winfried Wilcke. "The Battery 500 Project". Internet: http://www.ibm.com/smarterplanet/us/en/smart_grid/article/battery500.html, [Aug 8 2012]
[32] H. Wang, et al, "An ultrafast nickel–iron battery from strongly coupled inorganic nanoparticle/nanocarbon hybrid materials", Nature Communications, vol. 3, 2012
[33] Ashish Kumar Mishra "Tata's Nano: Fire!" Internet: http://www.forbes.com/2010/05/20/forbes-india-wheels-of-fire-tata-moters.html, May 21 2010

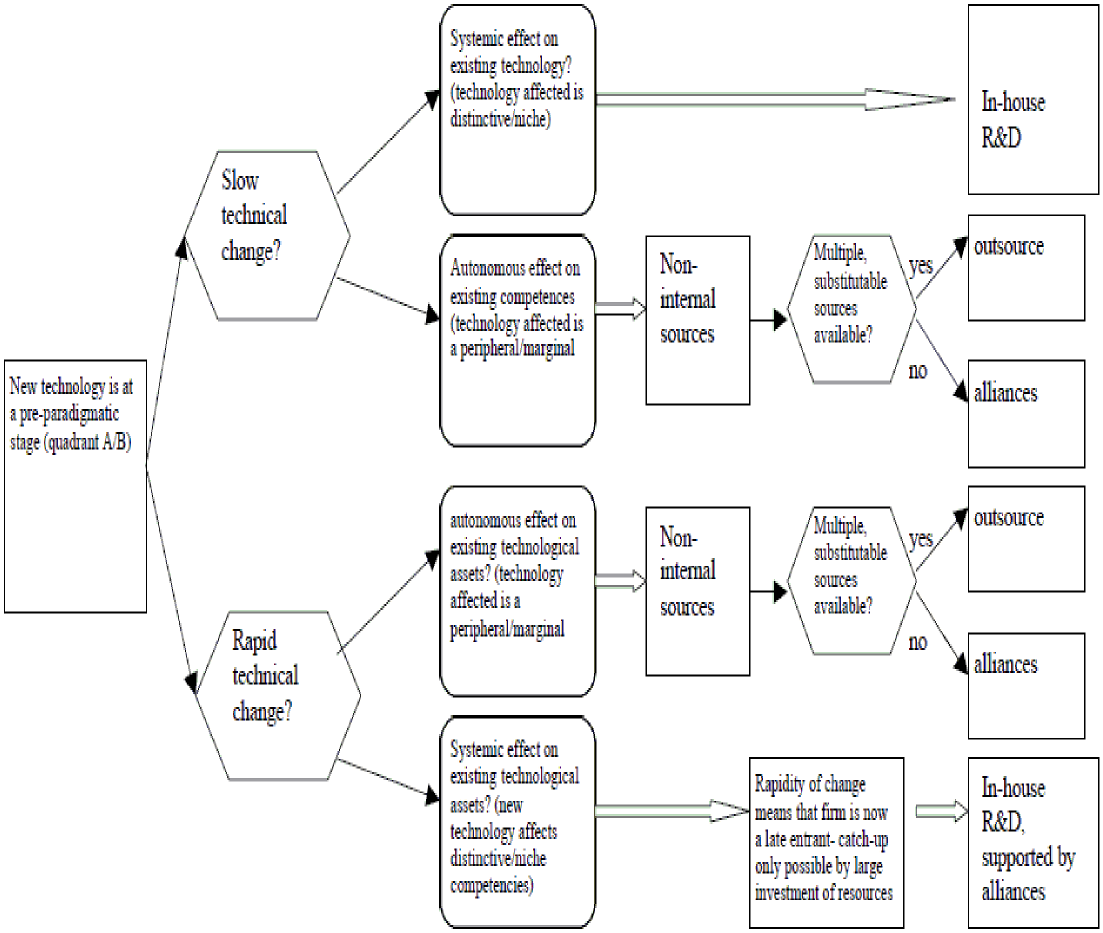
[34] Andrew Czyzewski, ”EV battery coolant offers better temperature buffering”, Internet: http://www.theengineer.co.uk/sectors/automotive/news/ev-battery-coolant-offers-better-temperature-buffering/1013127.article,[13 July 2012]

[35] DON SHERMAN ” When Electric-Car Batteries Die, Where Will They End Up? “, Internet: http://www.nytimes.com/2010/06/13/automobiles/13RECYCLE.html?_r=1&pagewanted=all, June 11, 2010

[36] K. R. Cowan and T. Daim,” Comparative technological road-mapping for renewable energy.” Technology in Society, vol 31, pp 333-341, 2009

[37] R. Narula, " Choosing between internal and non-internal R&D activities: some technological and economic factors" viewed on line at http://arno.unimaas.nl/show.cgi?fid=306 on August 7, 2012

Appendix A: R&D Decision Tree

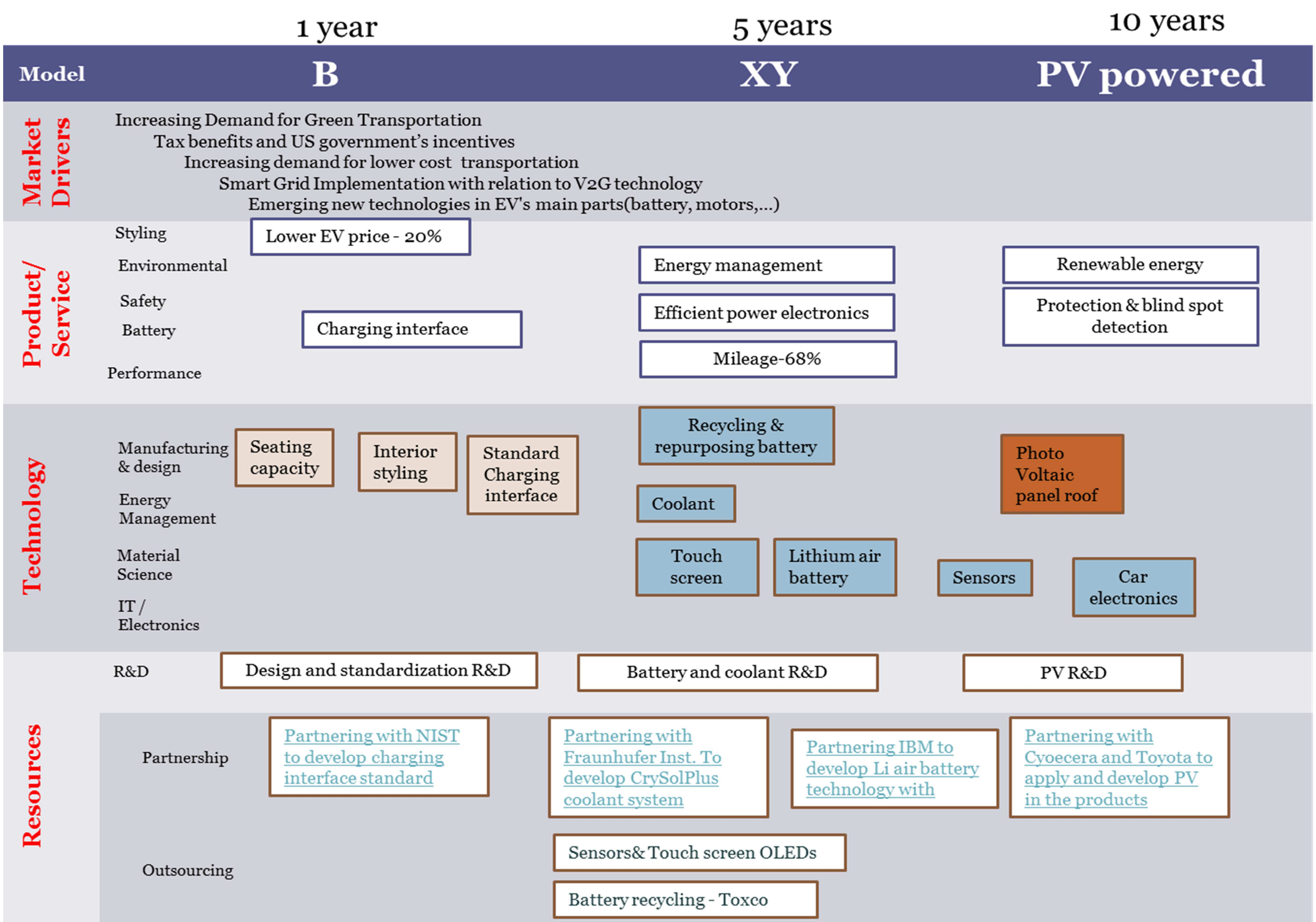


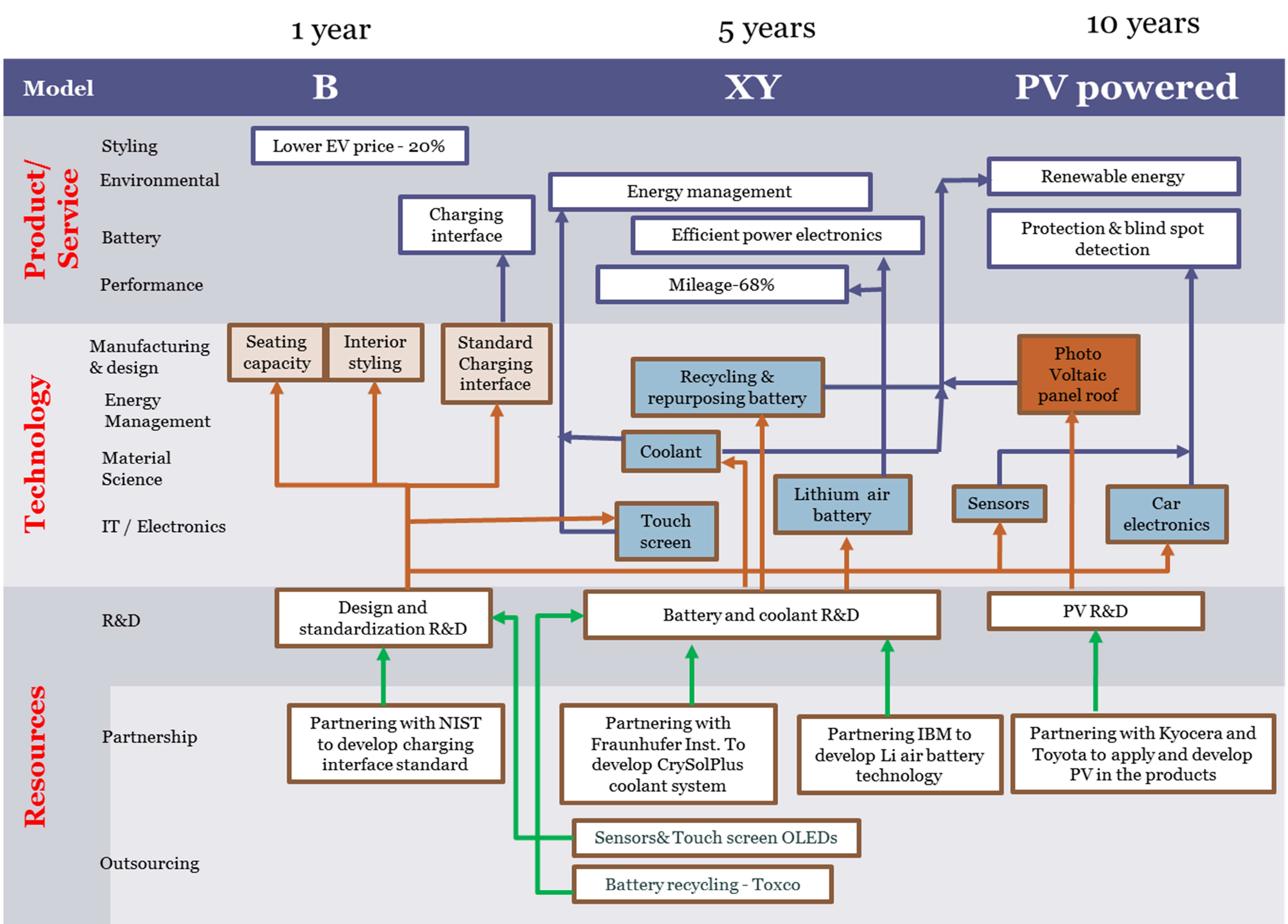
Appendix B: R&D Decision Table Analysis

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Slow/rapid technical change?	Rapid	Rapid	Rapid	Rapid	Rapid	Rapid	Rapid	Rapid	Slow	Slow	Slow	Slow	Slow	Slow	Slow	Slow
Systematic effect/marginal effect on existing technology?	Systematic	Systematic	Systematic	Systematic	Marginal	Marginal	Marginal	Marginal	Systematic	Systematic	Systematic	Systematic	Marginal	Marginal	Marginal	Marginal
Are Internal resources available?	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Multiple substitutable sources available?	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Is the entrance to the technology late?	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Decision	In-house R&D Supported by alliances	In-house R&D Supported by alliances	In-house R&D Supported by alliances	In-house R&D Supported by alliances	In-house R&D with support from alliances	In-house R&D	Outsource	Alliance	In-house R&D	In-house R&D	In-house R&D	In-house R&D	In-house R&D with support from alliances	In-house R&D	Outsource	Alliance

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Slow/rapid technical change?	Rapid	Rapid	Rapid	Rapid	Rapid	Rapid	Rapid	Rapid	Slow	Slow	Slow	Slow	Slow	Slow	Slow	Slow
Systematic effect/marginal effect on existing technology?	Systematic	Systematic	Systematic	Systematic	Marginal	Marginal	Marginal	Marginal	Systematic	Systematic	Systematic	Systematic	Marginal	Marginal	Marginal	Marginal
Are Internal resources available?	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Multiple substitutable sources available?	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Is the entrance to the technology late?	Yes	Yes	Yes	Yes	Yes	--------	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Decision	In-house R&D Supported by alliance	In-house R&D Supported by alliance	In-house R&D Supported by alliance	In-house R&D Supported by alliance	In-house R&D Supported by alliance	In-house R&D	Outsource supported by alliance	Alliance	In-house R&D Supported by alliance	In-house R&D Supported by alliance	In-house R&D Supported by alliance	In-house R&D Supported by alliance	In-house R&D Supported by alliance	In-house R&D Supported by alliance	Outsource supported by alliance	Alliance

Appendix C: Technology Roadmap for Tesla EV Vehicle – Sedan




1 year
5 years
10 years
Model
B
XY
PV powered
Product/ Service
Styling
Environmental
Battery
Performance
Lower EV price - 20%
Charging interface
Energy management
Efficient power electronics
Mileage-68%
Renewable energy
Protection & blind spot detection
Technology
Manufacturing & design
Energy Management
Material Science
IT / Electronics
Seating capacity
Interior styling
Standard Charging interface
Recycling & repurposing battery
Photo Voltaic panel roof
Coolant
Touch screen
Lithium air battery
Sensors
Car electronics
Resources
R&D
Partnership
Outsourcing
Design and standardization R&D
Battery and coolant R&D
PV R&D
Partnering with NIST to develop charging interface standard
Partnering with Fraunhufer Inst. To develop CrySolPlus coolant system
Partnering IBM to develop Li air battery technology
Partnering with Kyocera and Toyota to apply and develop PV in the products
Sensors& Touch screen OLEDs
Battery recycling - Toxco