**This case study was presented at the Laboratory for Machine Tools and Production Engineering (WZL) at RWTH Aachen.**

# Panasonic Battery Production Plant in India


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# II List of symbols and abbreviations

| symbol | unit | description |
|---|---|---|
| mAh | mAh | milliampere hour |
| GWh | GWh | Gigawatt hour |
| KWh | KWh | Kilowatt hour |
| Wh | Wh | Watt hour |
| Wh/L | Wh/L | Watt hour per Litre |
| Wh/kg | Wh/kg | Watt hour per kilogram |
| W/kg | W/kg | Watt per kilogram |
| Ha | Ha | Hectare |

| abbreviation | Description |
|---|---|
| e.g. | exempli gratia (for example) |
| i.e. | id est (that is) |
| NCM | Nickle Cobalt Manganese |
| NCA | Nickle Cobalt Aluminium |
| HPCL | Hindustan Petroleum Corporation Limited |
| sq | Square |

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# 1 Project plan

Authors of this chapter:

- Vishnu Vardhan Murugasamy

## 1.1 Plan

Factory Planning consist of range of task from a motive of the company to the complete installation of a new production unit. Planning is made regarding the Aachen factory planning procedure and milestone is created in Gantt Project Software by sorting them in chronological order with some interdependent Sub-task.

According to Tesla's objective for our factory, we formulated Strategic goals, influencing the factory and followed by risk analysis. Then Suitable location is selected for factory structure by considering our battery production chain with planned capacity. In end, building concepts for critical hazardous materials per production area and details on their influence on fire protection aspects are considered.

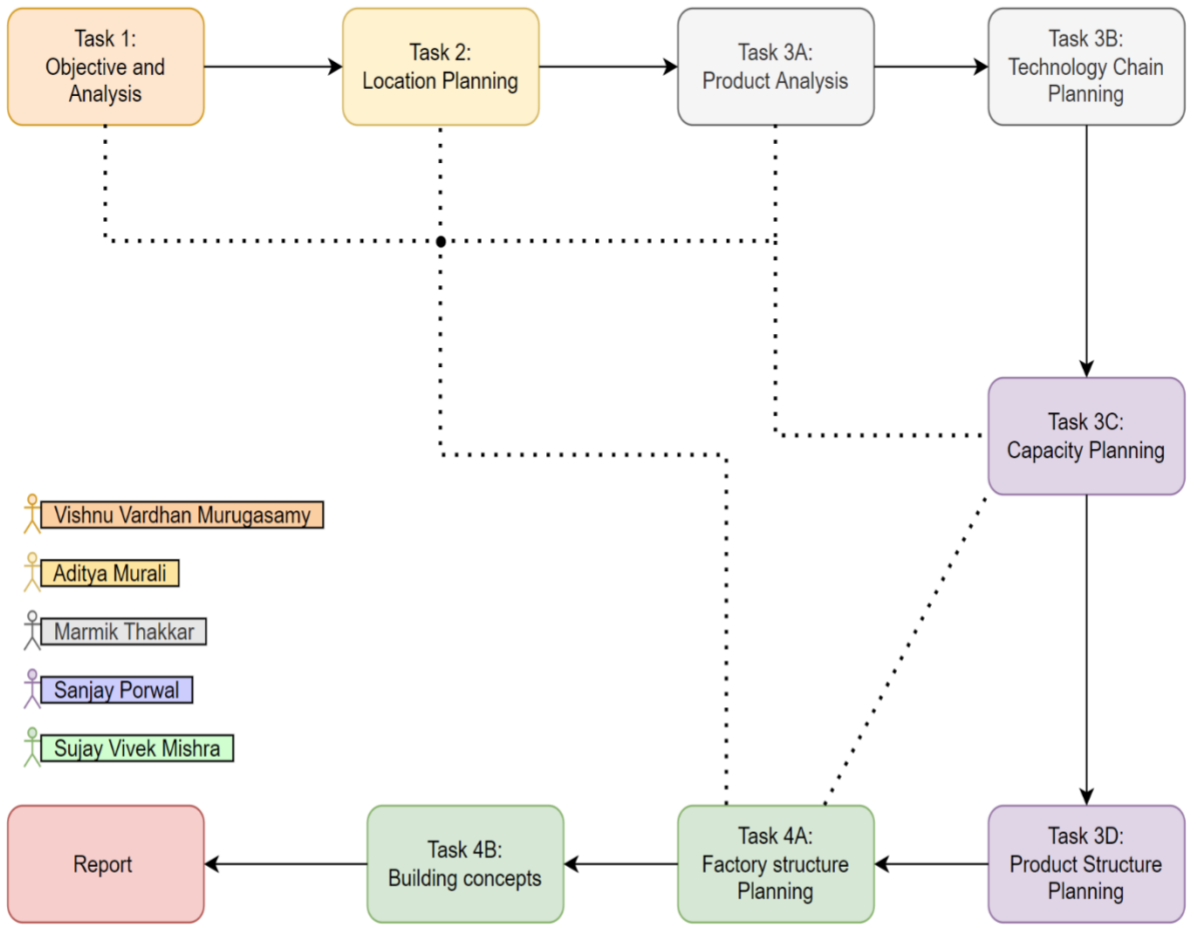



**Figure 1.1 Project Plan**

## 1.2 Gantt Chart

Gantt chart shows the amount of work done by people or the production timeline for pre-planned periods. In this, planning for over a week of 7 is considered and distributed among teammates indicating with different colours. A diamond's shape indicates the milestone to be accomplished before starting other tasks.

**Table 1.1 Key features**

| Symbols | Representation |
|---|---|
| | Milestone |
| | Sujay Vivek Mishra Timeline |
| | Sanjay Porwal Timeline |
| | Marmik Ajay Thakkar Timeline |
| | Aditya Murali Timeline |
| | Vishnu Vardhan Murugasamy Timeline |
| | Frame of one Complete task |

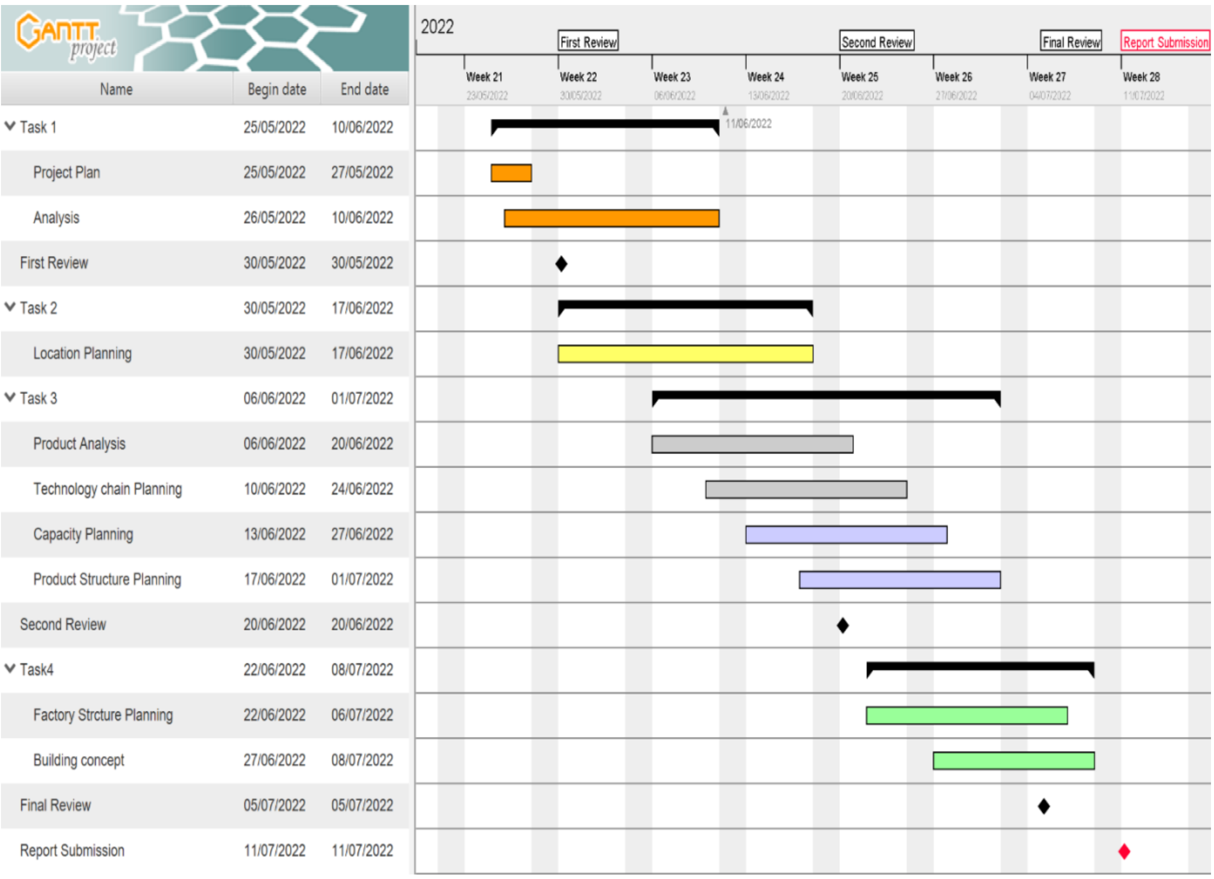



**Figure 1.2 Project Timeline**

# 2 As-Is analysis

Authors of this chapter:

- Vishnu Vardhan Murugasamy

## 2.1 Situation Analysis

Tesla, Inc. is a publicly-traded US car manufacturer that produces batteries as well as photovoltaic systems in addition to electric cars. The company was founded in 2003 by Martin Eberhard and Marc Tarpenning. In 2004, Elon Musk became chairman of the board and became the defining figure of Tesla. At the end of 2021, the company employed around 100,000 people. Tesla, to date, has 5 Gigafactory's in the operational mode or construction mode. They are located in Nevada, New York, Texas, Shanghai, and Berlin. Tesla's revenue grew to around 53.8 billion U.S. dollars in the 2021 fiscal year, a 71 percent increase from the previous year. The United States is Tesla's largest sales market.

Tesla is looking to enter the Indian automotive market which is one of the fastest-growing in the world. We will evaluate Tesla using the NOISE analysis. The **NOISE analysis** is a tool that allows us to examine the current state of a business and generate a strategic improvement plan. Needs, Opportunities, Improvements, Strengths, and Exceptions.

### 2.1.1 Needs:

- Resilient Supply chains for battery raw materials.
- Uninterrupted Supply of Semi-conductor chips in the face of geopolitical tensions and trade being used as a weapon.
- The trained workforce in a newly developing field.

### 2.1.2 Opportunities:

- **Alternative Battery chemistry:** Since Lithium mines are mostly located in Chile and Lithium processing capacity is mostly located in China, to build more resilient supply chains, it would be better if there are alternative and cheaper battery chemistries to explore to achieve the same result.
- **Room to Expand:** The EV Market-world is growing very fast and governments are also offering limited subsidies to manufacturers to sell their products. This is a market that Tesla is best positioned to tap since it is the largest EV manufacturer in the world by volume.
- **Wide product portfolio:** Tesla already has several platforms ready that it sells in markets like America, Europe, and China. This includes small cars, sedans, SUVs, pickup trucks, and long-haul trucks. There is a good opportunity for tesla to establish dominating market share in each of these product categories.

### 2.1.3 Improvements:

- **Financial Health:** Although Tesla products are in high demand, they are still a company that is still in debt (4.8 billion dollars). To break even, they need to scale up the production of affordable cars to achieve profitability in economies of scale.
- **Leadership unconventional:** Elon Musk is an unconventional CEO, and has been in the past fined by the SEC for some controversial tweets. Such behaviour leads to reduced investor confidence.
- **Liability claims:** There have been rare incidents of Tesla cars spontaneously catching fire. Also, there have been some rare autopilot accidents. Such failures can lead to legal suits and damage to brand value.
- **Product Quality:** Since Tesla is a relatively new automotive manufacturer, there have been reported issues with product quality that have even resulted in some recalls. Ironing out these defects is a necessary improvement for the OEM.

### 2.1.4 Strengths:

- **Workforce Attraction:** Tesla is arguably the most sought-after company to work for, both for fresh graduates and experienced professionals because of its prestige and innovation-encouraging culture.
- **Most Valued Automotive Company:** Tesla is the top valued automotive company in the world because of its innovative products and ability to push the envelope in new technologies.
- **Best Electric Cars:** Tesla is the only major automotive company that produces only electric cars. This allows them to focus on their specific product portfolio, unlike other competitors who also produce IC engine cars.

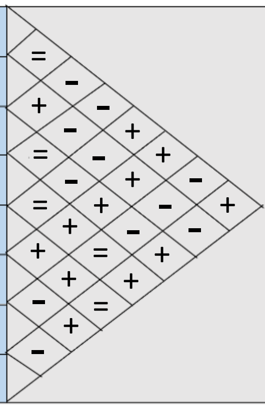
### 2.1.5 Exceptions:

- Elon Musk has a cult-like following and is rated by many as the smartest person in the world. This is because of his unique ability to juggle many tasks of critical importance to humanity such as making space travel affordable, accelerating the change to sustainable energy, as well as connecting humans to machines.
- Even during the pandemic nearly 20,000 employees joined because of Tesla's Work Culture and was expanding in some[i] markets, opening new stores and service centres. Both Gigafactory Berlin and Gigafactory Texas are planning to come online in the following year, which could reach a headcount of 100,000 employees.

## 2.2 Strategic Goals

The company aim for specific Financial or non-financial goals to be achieved over the period of time for establishing a company. Some of the main goals are identified and sorted according to their importance by using pair-wise Comparison from 1-5 Score.

**Table 2.1 Goal utility Analysis**



| | W | NS | AW | RW | NW |
|---|---|---|---|---|---|
| Production Volume | 3 | 4 | 7 | 18 | 5 |
| Delivery Time | -2 | 4 | 2 | 5 | 2 |
| Plant Location | 0 | 4 | 4 | 10 | 3 |
| Space utilization | 4 | 4 | 8 | 21 | 5 |
| Waste reduction | 3 | 4 | 7 | 18 | 5 |
| Profitability | -3 | 4 | 1 | 3 | 1 |
| Product Flexibilty | 0 | 4 | 4 | 10 | 3 |
| Investment & Inventory Cost | 2 | 4 | 6 | 15 | 4 |

**Table 2.2 Goal Prioritization**

| Priority | Goals |
|---|---|
| 1. | Profitability |
| 2. | Delivery time |
| 3. | Product Flexibility & Plant Location |
| 4. | Investment & Inventory Cost |
| 5. | Product Volume & Waste reduction |

## 2.3 Influencing Factor

Project has numerous internal and external factors to be a success. Such factors determine to Business analysis model which can help to understand our business strategy. These analysis strategy helps to improve organization in every sort of way by predicting the problems in forehand. Some of them are:

- **SWOT** analysis - **S**trengths, **W**eaknesses, **O**pportunities, **T**hreats
- **PESTEL** analysis- **P**olitical, **E**conomic, **S**ocial, **T**echnological, **L**egal and **E**nvironmental
- Scenario planning
- Porter's Five Forces framework

But, we will be choosing PESTEL for analysing as it has more perk than others and provides macro details in external factors.

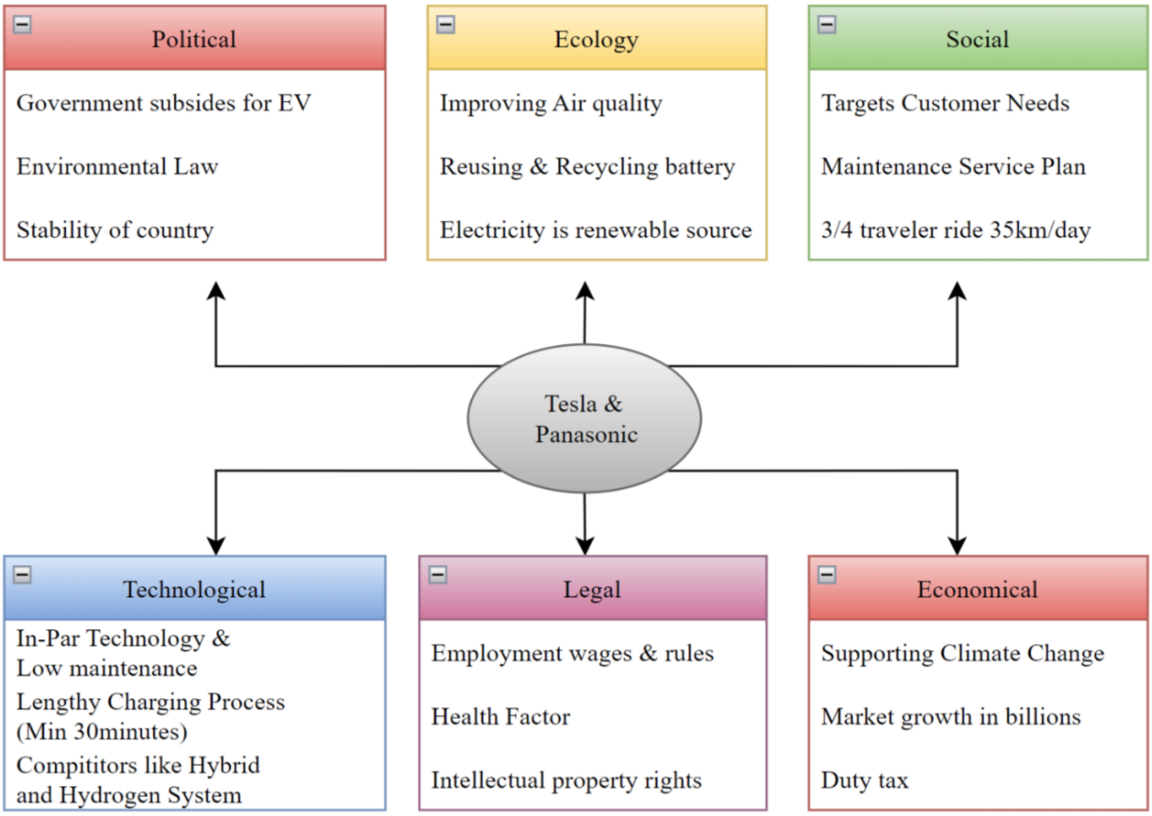



**Figure 2.1 Influencing Factor of Tesla & Panasonic**

## 2.4 Risk Analysis

Initiation of project can lead to potential issues that can negatively disturb the business. So, Risk analysis leads to mitigate or avoid those impact and risk analysis matrix are used to evaluate risk from 1-12. Where high value indicates the value of high-risk range.

**Table 2.3 Risk Analysis Matrix**

| Risk Evaluvation Matrix | Acceptable | Tolerable | Unacceptable | Intolerable |
|---|---|---|---|---|
| Improbable | 6,12 | 4,7 | 10,15 | |
| Possible | | 3,5 | 9,11,14 | 8,13 |
| Probable | | | 2 | 1 |

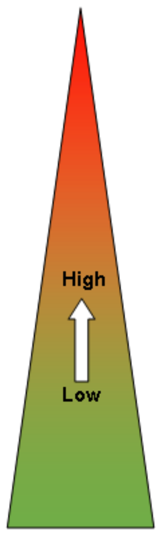


**Table 2.4 Risk and its causes**

| S.NO | Risks | Score | Causes |
|---|---|---|---|
| 1. | Unstable Electricity/water | 12 | Drought, Natural Disaster, State politics and Transformer outrage |
| 2. | Competitors | 9 | Government subsides welcome new competitors from all over in this Developing field |
| 3. | Machine malfunction | 5 | Interrupted Voltage/ Improper Maintenance |
| 4. | Plummeting market | 4 | Declining economy, inflation, deflation, tax increases, Cheaper Competitors pricing |
| 5. | Lifespan of Machine/battery | 5 | External factors like moisture and rust |
| 6. | Less trained Employee | 1 | Unseemly evaluation after Training |
| 7. | Political/Government Conflicts | 4 | Riots, strikes, coups, or politically motivated killings |
| 8. | Raw material depletion | 11 | High demand for raw materials and waste rate generation |
| 9. | Intellectual Property infringement | 8 | Free online platforms may sell less modified patented product or design without the consent of the patent owner |
| 10. | Employee issues | 7 | Interpersonal conflict, Improper Management and Communication problems |
| 11. | Technology Uprising | 8 | New innovations whose rapid application and diffusion typically leads to abrupt change in society. |
| 12. | Environment and Safety Norms | 1 | Excess industrialization and greenhouse gas emission |
| 13. | Waste Management | 11 | Non-proper actions undertaken from the initial creation to final disposal. |
| 14. | Transportation Facility | 8 | Long commutes, Parking issues and Sprawling Traffic |
| 15. | Financial crisis | 7 | Low interest rates, easy credit, insufficient regulation, and Improper repayment schedule |

## 2.5 Measures to cope up with potential risks

**1.Unstable Electricity/water:** Installing Backup generator, using renewable energy sources, and use of borewell water with proper underground treatment

**2.Competitors:** Providing customer satisfaction, cheap yearly plan schemes than competitors and providing high quality material for reasonable price.

**3.Machine malfunction:** Perform preventive maintenance and planned downtime to reduce the unplanned failure. Well-trained operators have insight into when machinery isn't working at optimal capacity.

**4.Plummeting market**: Tighten your financial belt for a while if you must. You might be able to recoup it with a little discipline if the loss is small enough.

**5.Lifespan of Machine/battery:** Members of operations team well-versed in how to run system and how to recognize problems and replace necessary parts

**6.Less trained Employee:** Well-planned training with intermediate evaluation test.

**7.Political/Government Conflicts:** Be first to act when there is a conflict, have a political risk insurance and purchase a policy that would compensate them if an adverse event occurred.

**8.Raw material depletion:** Reusing any waste you produce until it no longer has any value and then recycling the materials and use what is necessary.

**9.Intellectual Property infringement:** Pattern as soon as possible, keep it a Secret and defend if its infringed.

**10.Employee issues:** Work culture should be taught, find the root cause of the problem and executive should calmly hear through their problems.

**11.Technology Uprising:** Invest in R&D. New inventions should cope-up with trend and satisfy the end user.

**12.Environment and Safety Norms:** Follow the guidelines thoroughly from health and safety department according to the location of the factory.

**13.Waste Management:** Proper planning of hazardous waste disposal and implement 5'R- refuse, reduce, reuse, repurpose, and then recycle

**14.Transportation Facility:** Prior planning of Transportation schedule and Map Foreseen non-traffic route for supply chain.

**15.Financial crisis:** Monitor the cash flow, find the root cause of crisis and reduce the budget without compromising the quality of problem.

# 3 Location planning

Authors of this chapter:

- Aditya Murali

Location planning is the process of selecting the location for the setup of a facility. It consists of various procedures and factors which are taken into consideration for deciding the best suitable location. The task may include modification, restructuring or abandoning of the existing locations or the potential for exploring new locations for an expansion.

The location planning is generally done in two phases, the global footprint design and location selection.

## 3.1 Location Planning Phases

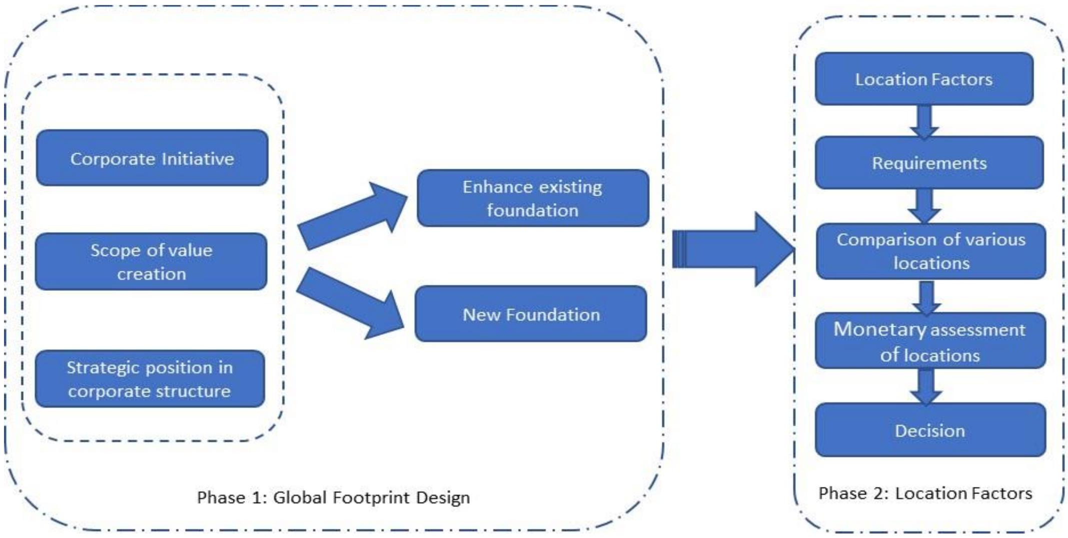



**Figure 3.1 Location planning phases representation**

As per the information, Tesla Inc.'s initiative to penetrate the Indian market is a huge step towards conquering majority of the share of electric vehicles in this large growing market. As per reports (IESA, 2020), the EV market in India expected to achieve over 63 million units per annum mark by 2027 which is a growth of 44% compounded annual growth rate. **Tesla has decided to achieve this by building a new foundation in the southern region of India near the technology metropolis of Karnataka, Bengaluru**. This along with the attractive schemes announced by the Government of India to support the new Tesla facility will ensure that the expansion and the manufacturing is cost efficient. Tesla also expects that its expansion by setting up a facility in India will not only help capture the Indian market but also will help cater other Asian markets.

## 3.2 Summary of Site Selection

Based on the requirements of Tesla’s operational plan in southern India around the region of Bengaluru in Karnataka, a preliminary analysis was conducted, and the following potential sites have been taken into consideration to set up Panasonic battery production plant in India.

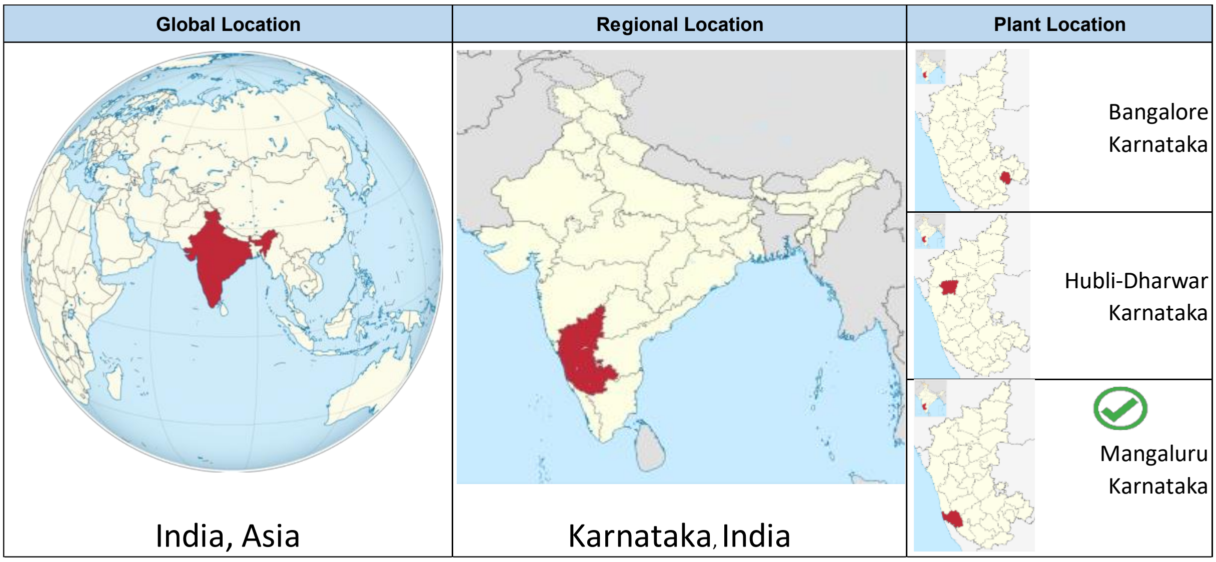
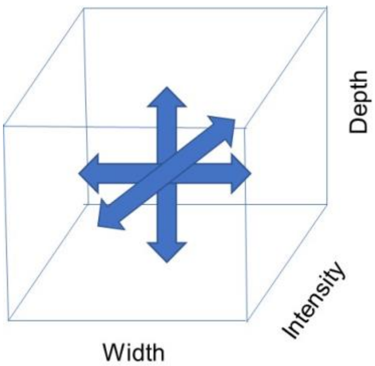



**Figure 3.2 Global, regional and local plant location**

## 3.3 Scope of Value Creation




The scope of value creation can be represented in three dimensions. The added value depth represents the value creation by the processes, the added value width describes the overall product portfolio, and the added value intensity represents the amount of goods and services being produced.

**Figure 3.3 Scope of value creation dimensions**

<u>Added Value Depth (Processes)</u>: All the processes required for battery manufacturing is performed in the facility. This ensures better control over the supply and demand. Also, the in-house manufacturing ensures that the products meet the highest quality standards. It is also required that the suppliers of the raw materials are nearby to keep procurement costs in check.

Added Value Width (Products): The plan is to initially produce type 2170 battery starting in the year 2025, followed by the production of type 4680 batteries from the year 2027.

Added value intensity (Volume): The initial production volume stands at around 15 GWh which is 883 million units of type 2170 cells which is to be achieved by the year 2025. This will be followed by production of type 4680 batteries starting in the year 2027 with initial capacity of 1.3 GWh per annum. This will be followed by further expansion in production volume.

## 3.4 Overview of the requirements for the new site

The location selection for the plant setup is done based on certain location factors. Each of these factors are categorized in controllable factors, uncontrollable factors, and special location factors. These factors are taken into consideration, and it is ensured that the corresponding requirements are met by a certain threshold value to determine the most favourable location for the setup of the plant. If the location is unsuitable on the global or the regional levels as represented in the summary of site selection, no further evaluation is needed, and the location will be deemed to be unsuitable. The table below represents the general location factors and the corresponding requirements that are taken into consideration for selection of plant location:

**Table 3.1 Location factors and requirements**

| LOCATION FACTORS | | REQUIREMENTS DESCRIPTION |
|---|---|---|
| Controllable Factors | Land Availability | Required amount of land is available for plant set up |
| | Raw-Material Supply | Continuous supply of raw material like aluminium, graphite, plastics, steel etc. |
| | Availability of Labour | Appropriate amount of labour with required skill set |
| | Market Acess | Near to the customers and suppliers. |
| | Communication Facilities | Availability of strong telecommunication and internet facilities. |
| | Infrastructure Facility | Uninterrupted supply of water, electricity and arrangement for waste disposal. |
| | Transport | Fast and efficient delivery of raw materials and finished products. |
| | Economy of scale | More units of products produced with lower input costs |
| Uncontrollable factors | Government policies and support | Favourable laws, safety, building codes and incentive packages. |
| | Climate Conditions | Favourable temperatures, weather and humidity. |
| | Community | Availibility of educational institutions, hospitals, housing etc. in the vicinity |
| | Supporting services | Services like banking, consulting and communications |
| Special location factors | Labour Laws | Laws related to working hours, wages, training needs and strength of labour union |
| | Wages | Desired skills for affordable wages |
| | Quality of Life | Educational facilities, cultural events, modern lifestyle and recreational facilities. |
| | Closeness to resources and suppliers | Communication and coordination between organization and suppliers |
| | Utility costs | water, electricity, telecommunication network, relocation costs etc. |

## 3.5 Area Estimation

Tesla plans to establish manufacturing facility in India begins with the plan to manufacture the MODEL I specifically for the Indian market. The battery capacity for the car stands to be 75 KWh. The annual production volume for the year 2025 is 200,000 units before the upscaling of the manufacturing. To cater to the demand and the further expansion of the battery production, the initial production volume per year is set to 15 GWh which is equivalent to roughly 744 million units of type 2170 batteries. The optimal area required to establish the production plant is based on the current battery production plant setups around the world.

**Table 3.2 Various battery plant, capacity, and area**

| Manufacturer | Location | Capacity (GWh) | Area (m²) | Density (Gwh/m²) |
|---|---|---|---|---|
| LG Chem | Worclaw, Poland | 70 | 1,000,000 | 14,200 |
| BYD | Qinghai, China | 60 | 1,000,000 | 16,700 |
| Tesla Gigafactory | Nevada, USA | 35 | 177,000 | 5,060 |
| Northvolt | Skelleftea, Sweden | 32 | 500,000 | 15,625 |
| Samsung SDI | Hungary | 30 | 330,000 | 11,000 |
| CATL | Germany | 14 | 120,000 | 8,600 |

From the above table, the average density of the production plants across the world comes out to be approximately 12000 m² per GWh. For the current capacity of 15 GWh to be achieved in 2025, the minimum required area for the plant is 180000 m². The production area is estimated at 13000 m² ,the raw material storage approximately 4000 m² and final good storage to be 4500 m². Other areas would be covered by administrative area, parking, service area, expansion area etc.

Further, considering the huge expansion plan to cater higher variety and volume of the power plant, a requirement of 200,000 m² of area is set. Even though the above stated plants area includes the area required for the respective expansion plans, Tesla's requirement to introduce the manufacturing of battery type 4680 will require large area increase in the battery power plant. This would also potentially be important to cater other customers requiring battery for automobile manufacturing and other applications to begin with.

## 3.6 Target location proposal

The battery plant's location decision should be cohesive with the Tesla's plan to set up their production plant in India. India's large pool of engineers, a young and skilled labour force, competitive wages as well as strong geography qualifies it to be the most sensible location for the plant set up. The establishment of plant in India would also enable smooth operation of the supply chain without attracting strong import and export duties. Due to these reasons, the discussion on global target areas can be negated.

Based on Tesla's decision to establish the factory in southern India, precisely in the region around Bangalore and considering India's most attractive destinations for manufacturing industry set up (Invest India's report), certain regional locations can be short listed. The table below represents the regional location alternatives and the corresponding location.

**Table 3.3 Evaluation of regional locational factors**

| LOCATION FACTORS | | LOCATION ALTERNATIVES | | | | |
|---|---|---|---|---|---|---|
| | | **Karnataka** | **Tamil Nadu** | **Maharasthra** | **West-Bengal** | **New Delhi** |
| **General** | Population | 66.1 M | 76.4 M | 124.87 M | 100.8 M | 32.06 M |
| | Other Industries (% of total industries in the country) | 5.4 | 16.6 | 13.0 | 3.9 | 1.0 |
| | Score on Ease of doing business | 48.5 | 44.58 | 49.4 | 46.9 | 37.35 |
| | Literacy rate | 77.2 | 89.2 | 84.8 | 80.5 | 88.7 |
| | Distance from Tesla Factory** | Near | Nearer | Nearer | Far | Far |
| | Transportation modes | Roads, Rail, Water, Air | Roads, Rail, Water, Air | Roads, Rail, Water, Air | Roads, Rail, Water, Air | Roads, Rail, Air |
| **Labour Market** | Wages (Skilled Workers) | 264.0 | 438.2 | 239.7 | 291.0 | 325.0 |
| | Availability of skilled workers (Employability Index) | 2.93 | 1.9 | 2.6 | 0.2 | 3.26 |
| **Real Estate** | Land availability | 8189 Ha | 21456 Ha | 20609 Ha | 6000 Ha | 754 Ha |
| | Property prices | Low | Medium | Medium | Low | High |
| | Availability of commodities | Very Good | Very Good | Good | Poor | Good |

The above table clearly indicates Karnataka and Tamil Nadu to be the best alternatives for the plant set up. Further assessment shows Karnataka as the most suitable location due to its significantly lower wages, property prices and higher score on ease of doing business. The literacy rate, transportation modes and the availability of commodity like water, electricity etc. is found to be even in both these locations. The state's strong transportation systems through its rail, road, air and seaways ensure efficient logistics inside the state as well as nationally and internationally. The rich industrial establishment in the state also ensures strong raw materials supply. The state capital Bangalore also poses as the India's biggest technological hub which would help establish smart and connected industry for the battery manufacturing. The major factor of selection still stands to be the location of the customer Tesla. Due to the establishment of the plant in the same state, the laws, economic conditions, will remain the same which would ensure hassle free business between the customer and the supplier and the scope of coming together to improve any instability also exists.

### 3.6.1 Preselection of regional location alternatives

Based on evaluation of regional location factors, a clear decision needs to be made for the regional location of the plant set up. This is made considering K.O requirements & minimum requirements of the location. The K.O requirements represents the description that are a must have for the plant setup. The minimum requirements represent the threshold to the criteria which the regional location must surpass. To emerge as the ultimate location for plant location, it's mandatory that all K.O requirements & minimum requirements are fulfilled.

**Table 3.4 Regional location assessment**

| LOCATION FACTORS | | REGIONAL LOCATION ALTERNATIVES | | | | |
|---|---|---|---|---|---|---|
| | | Karnataka | Tamil Nadu | Maharasthra | West-Bengal | New Delhi |
| K.O Requirements | Steady political circumstances | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Free market economy | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Good waterway network | ✓ | ✓ | ✓ | ✓ | ✗ |
| | Cheap land costs | ✓ | ✗ | ✗ | ✓ | ✗ |
| | Other potential customers | ✓ | ✓ | ✓ | ✗ | ✓ |
| | Availability of skilled workers | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Near to the tesla factory | ✓ | ✓ | ✓ | ✗ | ✗ |
| Minimum Requirements | Labour cost < ₹300 per day | ✓ | ✗ | ✓ | ✓ | ✗ |
| | Literacy>75% | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Employability Index>2.5 | ✓ | ✗ | ✓ | ✗ | ✓ |
| | Subsidies >10% | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Working hour>2000 hours/year | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Electricity cost < ₹8 per unit | ✓ | ✓ | ✓ | ✗ | ✓ |
| | Inflation rate < 8% | ✓ | ✓ | ✗ | ✗ | ✓ |
| | Ease of doing business score>40 | ✓ | ✓ | ✓ | ✓ | ✗ |
| | Potential Location | ✓ | ✗ | ✗ | ✗ | ✗ |

The final assessment based on the requirements and location factors leads to selection of Karnataka, India as the best suited region for the Panasonic battery plant setup.

## Local Location evaluations

The selected regional locations is further evaluated to find the most suitable local locations for the plant set up. The preliminary search results in three locations in different part of the states.

**Location A**: Bangalore, Karnataka, India (200.000 $m^2$)

**Location B**: Hubli-Dharwar, Karnataka, India (245.000 $m^2$)

**Location C**: Mangaluru, Karnataka, India (300 $m^2$)

### Table 3.5 Evaluation of plant location factors

| LOCATION FACTORS | LOCATION ALTERNATIVES | | |
|---|---|---|---|
| | Bangalore | Hubli-Dharwar | Mangaluru |
| District Map |  |  |  |
| Plant Location |  |  |  |
| Land Size ($m^2$) | 200000 | 245000 | 300000 |
| Land Price (per $m^2$) | 180 | 118.3 | 93.3 |
| Distance to airport | 45 km | 30 km | 17 km |
| Distance to seaport | 330 km | 170 km | 9 km |
| Distance to Banglore (capital) | - | 440 km | 360 km |
| Distance to the nearest highway | 0.3 km | 2 km | 2 km |
| Main industries in the area | Aerospace, IT, Biotechnology | Machine tooling, Automotive, Rubber | Chemical, Textile, Electrical |

### Table 3.6 Plant location assessment

| LOCATION FACTORS | | LOCATION ALTERNATIVES | | |
|---|---|---|---|---|
| | | BANGLORE | HUBLI-DHANWAR | MANGALURU |
| K.O Requirements | Steady political circumstances | ✓ | ✓ | ✓ |
| | Government incentives | ✓ | ✓ | ✓ |
| | Skilled labour availability | ✓ | ✓ | ✓ |
| | Essential Infrastructure availability | ✓ | ✓ | ✓ |
| Minimum Requirements | Land size >200000 sq.m | ✗ | ✓ | ✓ |
| | distance to airport < 50 km | ✓ | ✓ | ✓ |
| | distance to seaport <200 km | ✓ | ✓ | ✓ |
| | Distance to highway <2 km | ✓ | ✓ | ✓ |
| | Land Price < $150 per sq.m | ✗ | ✓ | ✓ |
| | Working hours per week >40 hours | ✓ | ✓ | ✓ |
| | Labour wages per day <₹300 | ✓ | ✓ | ✓ |
| | Distance to the capital city Banglore <500 km | ✓ | ✓ | ✓ |

As per the evaluation shown in table 3, the K.O factors for the plant location is being fulfilled by all the three shortlisted locations. This is due to the roughly similar political situations, incentives and benefits and other conditions that different locations within the state shares. The further decision needs to be made based on the minimum requirements fulfilment. The table 4 clearly represents that the land size available in Bangalore is not suitable for the plant setup considering the future expansion plans. Also, the relatively high land prices is a major factor which plays against the decision of Bangalore as the chosen location.

The remaining two locations, Hubli-Dhanwar and Mangaluru needs to be further evaluated based on the pair-by-pair comparison of the location factors followed by cost-utility analysis.

### 3.6.2 Cost-Utility Analysis

For cost-utility analysis, an internal evaluation of qualitative factors needs to be performed via pair-by-pair comparisons of the identified criteria. These qualitative criteria have to be defined in such a way that it enables common perceptions. These criteria are difficult to quantify and are accessed by rating them against each other and further evaluating their characteristics on a scale. The qualitative criteria identified for the plant are as follows:

1) Availability of skilled workers
2) Availability of administrative workers
3) Road connections
4) Wages
5) Availability of land
6) Land prices
7) Distance from the capital city Bangalore
8) Essential Infrastructure availability
9) Airway connections
10) Waterways connection
11) Nearby industries
12) Ease of doing business

**Table 3.7 Pairwise Comparison of qualitative criteria**

| Pair-by-pair comparison<br>Evaluation criteria<br><br>-1 Row Less Important<br>0 Row Equally Important<br>1 Row More Important | Availability of skilled workers | Availability of administrative workers | Road connections | Wages | Availability of land | Land prices | Distance from Capital City Bangalore | Essential infrastructure availability | Airway connections | Waterway connections | Nearby industries | Ease of doing business | W | NS | AW | NW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability of skilled workers | X | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 7 | 6 | 13 | 5 |
| Availability of administrative workers | -1 | X | -1 | -1 | -1 | 0 | 1 | 0 | 0 | 1 | -1 | 0 | -1 | 6 | 5 | 3 |
| Road connections | 0 | 1 | X | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 7 | 6 | 13 | 5 |
| Wages | -1 | 1 | 0 | X | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 4 | 6 | 10 | 4 |
| Availability of land | -1 | 1 | -1 | 0 | X | 0 | 1 | 0 | 0 | 0 | -1 | 1 | -2 | 6 | 4 | 2 |
| Land prices | -1 | 0 | -1 | -1 | 0 | X | 1 | 0 | 1 | 1 | -1 | 0 | -4 | 6 | 2 | 2 |
| Distance from Capital City Bangalore | -1 | -1 | -1 | -1 | -1 | -1 | X | -1 | 0 | 0 | -1 | -1 | -3 | 6 | 3 | 2 |
| Essential infrastructure availability | 0 | 0 | -1 | 0 | 0 | 0 | 1 | X | 1 | 1 | 0 | 0 | -3 | 6 | 3 | 2 |
| Airway connections | -1 | 0 | -1 | -1 | 0 | -1 | 0 | -1 | X | 0 | -1 | 0 | -5 | 6 | 1 | 1 |
| Waterway connections | -1 | -1 | -1 | -1 | 0 | -1 | 0 | -1 | 0 | X | -1 | 0 | 5 | 6 | 11 | 4 |
| Nearby industries | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | X | 1 | -3 | 6 | 3 | 2 |
| Ease of doing business | -1 | 0 | -1 | -1 | -1 | 0 | 1 | 0 | 0 | 0 | -1 | X | 4 | 6 | 10 | 4 |

From the above pairwise comparison, the availability of skilled workers and the road connections has been evaluated to be the most important criterion for the plant location. Since the intended Tesla factory location lies in the same state, it is very vital to have the best roadway network to deliver achieve the the 7R's of logistics efficiently. It is also important to have the highly skilled workers required for the complex process of battery production. Hence, based on the location-wise qualitative evaluation based on these criteria, the final location of the plant will be determined.

### 3.6.3 Formulas for utility analysis:

**Weighting (W)**

W = Sum (Main diagonal) – Sum (Secondary diagonal)

**Normalisation (NS)**

$$\mathrm{NS} = |\mathrm{W}_{\min}| + 1$$

**Absolute Weighting (AW)**

$$\mathrm{AW} = \mathrm{W} + \mathrm{NS}$$

**Normalised Weighting (NW)**

$$\mathrm{NW} = \mathrm{Rd}\left[1 + 4 * \frac{AW_i}{\max(AW_i)}\right]$$

**Relative Weighting (RW)**

$$\mathrm{RW} = \left(\sum_{i=1}^{n} AW_i\right)^{-1} * AW_i * 100$$

**Table 3.8 Location assessment by utility analysis**

| QUALITATIVE CRITERIA | Weighting | Hubli-Dharwar | | Mangaluru | |
|---|---|---|---|---|---|
| | | FF | Value | FF | Value |
| Availability of skilled workers | 5 | 4 | 20 | 3 | 15 |
| Availability of administrative workers | 3 | 3 | 9 | 3 | 9 |
| Road connections | 5 | 5 | 25 | 5 | 25 |
| Wages | 4 | 4 | 16 | 4 | 16 |
| Availability of land | 2 | 3 | 6 | 4 | 8 |
| Land prices | 2 | 3 | 6 | 4 | 8 |
| Distance from Capital City Bangalore | 2 | 1 | 2 | 2 | 4 |
| Essential infrastructure availability | 2 | 4 | 8 | 4 | 8 |
| Airway connections | 1 | 4 | 4 | 4 | 4 |
| Waterway connections | 4 | 3 | 12 | 4 | 16 |
| Nearby industries | 2 | 2 | 4 | 5 | 10 |
| Ease of doing business | 4 | 4 | 16 | 4 | 16 |
| Sum | | | 128 | | 139 |

On the comparison of the two locations, it can be observed the availability of skilled workers is comparatively higher in the Hubli-Dharwar region due to the higher population. In the area of availability of administrative workers, wages, essential infrastructure availability and ease of doing business, both the location scores the same due to the same government in control across the state which these locations are a part of. Both the locations also scores similar in road connectivity due to major highway connections in the plant proximity. Mangalore scores better in terms of availability of land and land prices due to a larger area of available land at comparatively cheaper prices. The distance from the capital city, even though far from both the locations is nearer to Mangaluru. The airport and seaport are accessible from both the locations with Mangalore being nearer to both their respective nearest airport and the seaport. Mangaluru scores high in terms of nearby industries due to the chemical and electrical industries neighbouring the plant. It is adjacent to the BASF and HPCL plants which can supply with the raw materials required for the battery manufacturing.

Overall, from the location assessment by utility analysis, Mangaluru is chosen to be the best plant location for the Panasonic battery production plant setup

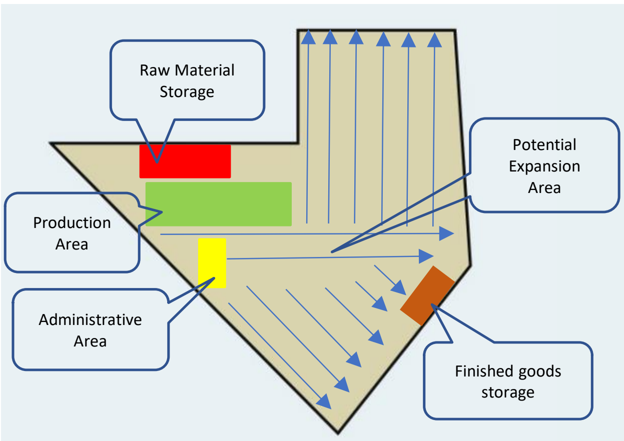



**Figure 3.4 Rough plant layout with expansion directions**

# 4 Product Analysis

Authors of this chapter:

- Marmik Thakkar

## 4.1 Overview

The projected requirement of the battery capacity is to be roughly 75 kWh for each car. Battery packs, which Tesla will manufacture from battery modules made up of individual battery cells, will eventually provide this power requirement.

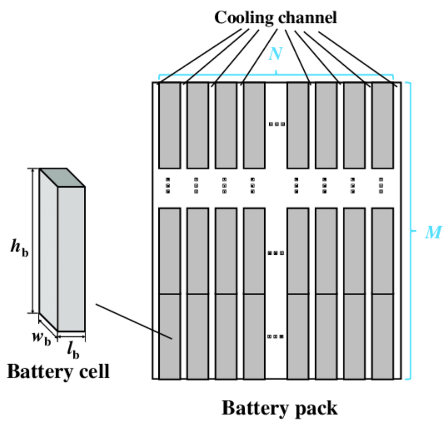



**Figure 4.1 Diagram of battery pack**

Individual cells differ in size, shape, life expectancy, material composition dimensions and are dependent on the proposed technology, size, and energy density. Battery packs are designed based on capacity, size, and heating factors after the individual cells have been designed. These modules are then assembled and put inside the vehicle to 18ulfil the power requirements, while cooling systems, BMS (battery management systems), and other considerations must be taken into account while designing the complete module.

Battery cells are mainly defined by the following properties:

- specific energy (Wh/kg)
- specific power (W/kg)
- cost
- safety
- lifespan
- performance

## 4.2 Cell Shapes

Battery cells come in a variety of forms, including pouch, prismatic, and cylindrical cells. The dimensions and manufacturing techniques of the inner structure, the electrode-separator-compound, vary.

### 4.2.1 Prismatic

Prismatic cells include huge sheets of anodes, cathodes, and separators sandwiched, rolled up, and pressed to match right into a metal or hard-plastic housing in cubic form. The electrodes can also be assembled via way of means of layer stacking. Lithium prismatic cells characteristic both single-row or two-row modules and the arresters are always on the same side of irrespective of the row.

### 4.2.2 Cylindrical

Cylindrical cells accommodate sheet-like battery anode, cathode, and separator that are sandwiched, rolled up, and packed into a cylinder-shaped can. This sort of cell is one of the primary to be mass-produced and remains very popular. Cells feature multiple rows with the arrester being on opposite sides.

### 4.2.3 Pouch

Unlike Cylindrical and Prismatic cells, Pouch cells do not have a hard case, it uses a sealed flexible foil as the cell container. The electrode and separator layers of a pouch cell are stacked. With pouch cells, enough space for possible swelling should be allocated by the designer. Modules with pouch cells show single-rowed cells, with the arresters being positioned either on the same or the opposite sides.

**Figure 4.2 Prismatic, Pouch and Cylindrical cells**

We will be planning for cylindrical cells as initial manufacturing because we would start manufacturing for Tesla and because of the benefits cylindrical cells hold.

**Table 4.1 Advantages and disadvantages of cell shapes**

| | Advantage | Disadvantage |
|---|---|---|
| **Cylindrical** | • Batteries are suited for automated manufacturing.<br>• Easier pack thermal management<br>• Mechanical stability | • Low packaging density of cylindrical cells.<br>• High-capacity batteries with a large number of cylindrical cells require excessive support and contactors system |
| **Pouch** | • The Lowest weight<br>• Flexible Cells | • Need to customize most pouch cells.<br>• Need to protect against external impacts or punctures |
| **Prismatic** | • Cells are not subject to swelling.<br>• Higher overall battery energy density.<br>• Lighter overall LIB weight compared to batteries with cylindrical cells | • More potential stress for parts<br>• Cells can be more expensive to manufacture. |

## 4.3 Type of Cylindrical Cells

The current standards of lithium-ion batteries is used to make cells in various configuration, size and energy density. Earlier types of cells utilized by Tesla include the **18650**, i.e. 18 mm in diameter and 65 mm in height, with a potential of 3500 mAh. The subsequent evolution cell was **2170**, i.e. slightly larger with a 21 mm diameter and a 65 mm height, which increase surface area for the anode and cathode which leads to a higher potential of 4800 mAh. Although it should be noted that the cell size of 2170 generates more heat during operation, and this must be managed by a well-designed cooling system for the battery pack/module. The cooling system can either be active or passive according to the requirement. Finally, the newly released **4680** cells has the highest capacity at 9000 mAh, without seeing any increase in resistance, leading to a lower heat load. Nevertheless, manufacturing methods for this cell type tend to vary from the smaller 1865 and 2170 types.


**Figure 4.3 Cylindrical cells sizes**

**Table 4.2 Cell specifications with sizes**

| | 18650 | 2170 | 4680 |
|---|---|---|---|
| Min Voltage (V) | 3 | 3 | 3 |
| Max Voltage (V) | 4.2 | 4.2 | 4.2 |
| Nominal Voltage (V) | 3.6 | 3.6 | 3.6 |
| Ampere Hour (Ah) | 3.5 | 4.8 | 26 |
| Power (Wh) | 14.7 | 20.16 | 109.2 |
| Weight (g) | 47 | 68 | 355 |
| Dimensions diameter x H (mm) | 18x65 | 21x70 | 46x80 |

## 4.4 Capacity Requirement

With each Model I equipped with a 75 kWh battery pack, Tesla presently projects its yearly demand at 200,000 vehicles, translating to a total annual battery demand of 15 GWh. This yields differing capacity figures for the 2170 and 4680 cells due to varied battery performance.

**Table 4.3 Cell Production estimate**

| Battery Pack | 2170 | 4680 |
|---|---:|---:|
| Cells | 4416 | 960 |
| Capacity (kWh) | 75 | 82 |
| Vehicles | 200000 | 200000 |
| Production Capacity Required | 883200000 | 192000000 |

## 4.5 Production Forecast

By the end of the decade, the Indian government predicted that the demand for li-ion batteries would be around 120 GWh (EVreporter, 2021). These estimates indicate overall demand, thus they also account for other uses, such the integration of renewable energy sources, in addition to electric car applications.

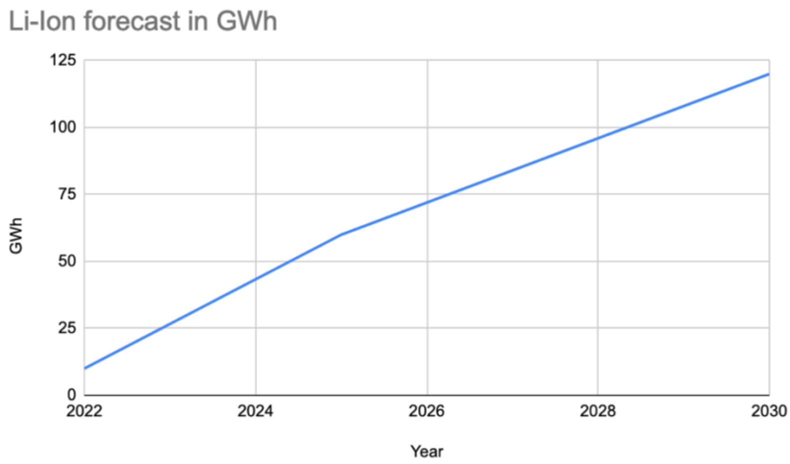



**Figure 4.4 Production forecast**

## 4.6 Product Structure

The cathode, anode, separator, electrolyte, and housing are the five main components that make up a battery's fundamental parts. Only cylindrical cells, like the one we will produce for Tesla, have metal housings. Other types of cells use different casing material. The other components can be further subdivided for each of the main components. Cathodes are made of Lithium and Nickel Cobalt Aluminium (NCA). There are other materials which can be used for producing cathode but because of the benefits of the NCA, we will produce NCA cathode. The anode is made up of a sheet of copper foil and graphite coating. Whereas, the Electrolyte are made up of all Volatile components and plastics.

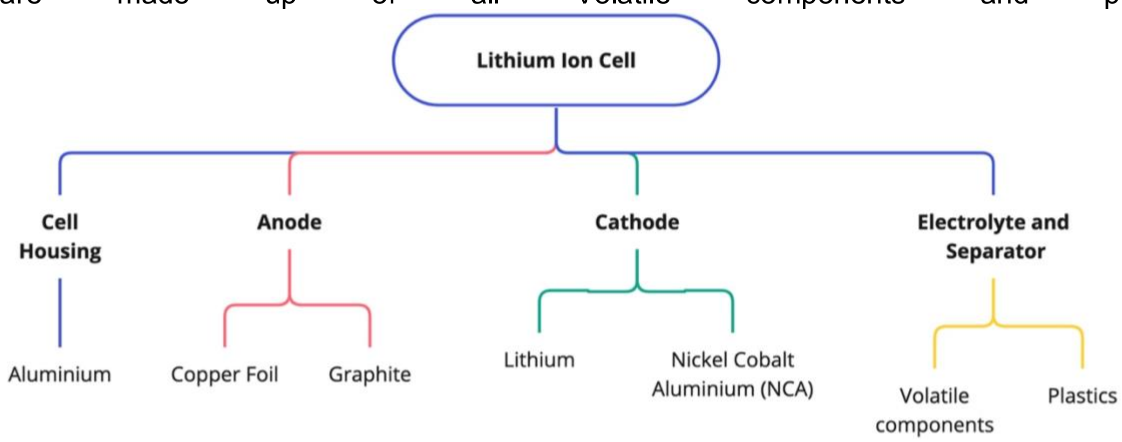



**Figure 4.5 Hierarchical product structure**

## 4.7 Product Attribute and Variant Tree

The basic parts and functions are outlined in the hierarchical structure. However, the process of assembling the cell and the modifications made at each stage result in numerous cell variations. Using an attribute tree and variant tree can help you better understand the cell variants.

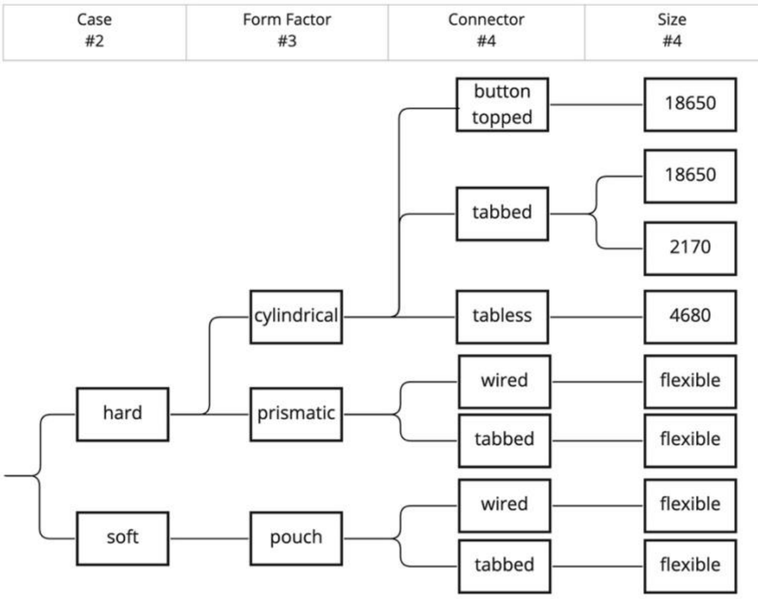



**Figure 4.6 Product attribute tree**

Below, we have constructed a Product variant tree which is has been divided by variants available in anode, cathode, form factor, connector, and size. As there is only variant for anode, we have all the variant derived from the same node. Cathode decides the capacity, voltage and the energy of the cell. We will be selecting 2,1 which refers to NCA (Nickle Cobalt Aluminium). For the form factor, we will be selecting 3,1 which refers to the cylindrical form factor. Tab-less and tab connector must be used to develop cells for tesla for 2170 and 4680 cells, respectively, hence we will select 4,2 and 4,3. Finally, for the sizes, as mentioned in the last statement, we would be selecting 2170 and 4680. Hence, we will select 5,2 and 5,3 which leaves us with 2 variants T3 and T4.

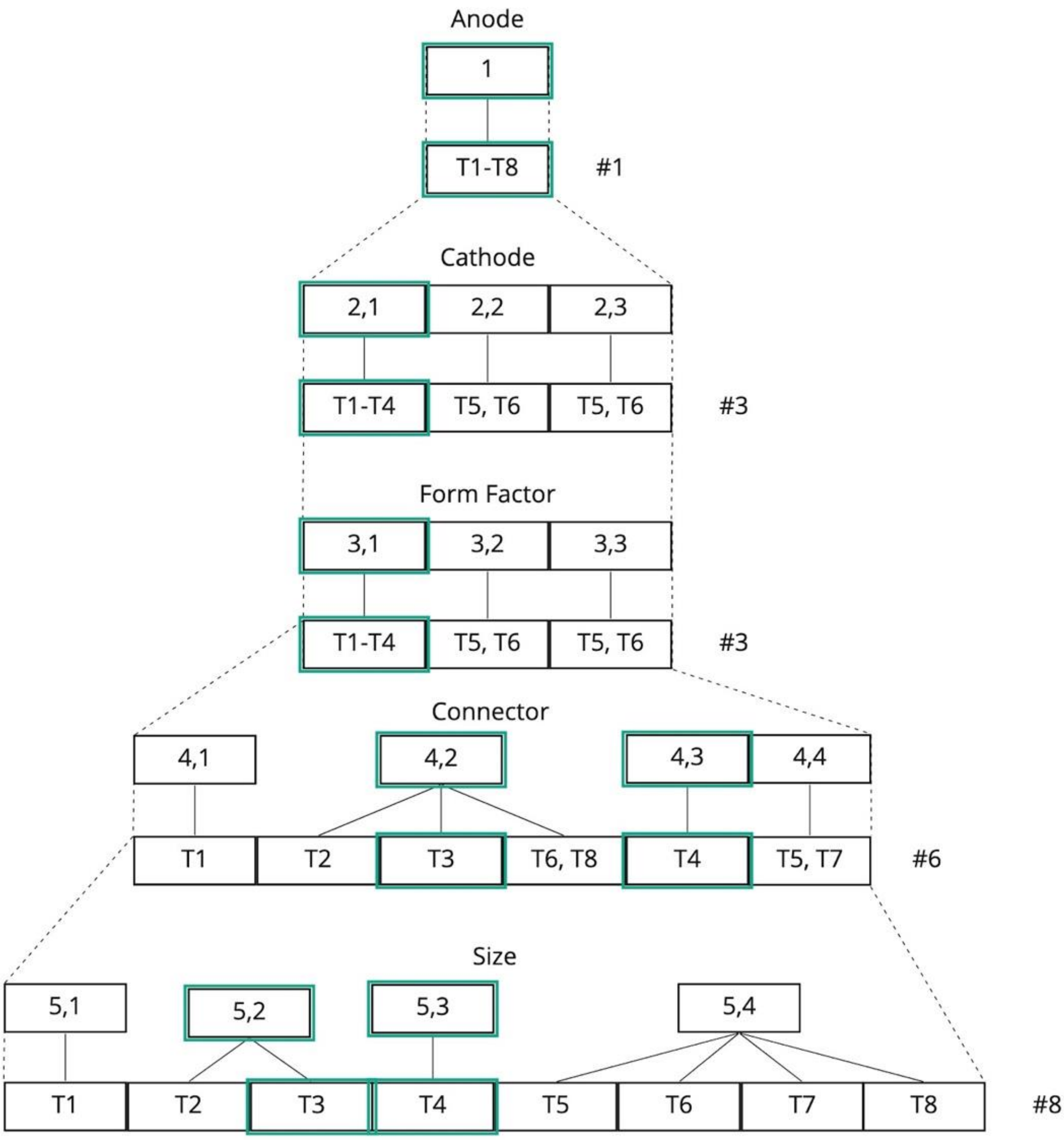



**Figure 4.7 Product variant tree**

# 5 Technology chain planning

Authors of this chapter:

- Marmik Thakkar

## 5.1 Production Sequence

The product analysis previously determined the product structure. There are 12 main production steps throughout the complete production process. Except for the battery casing and separator, every component is made on-site.

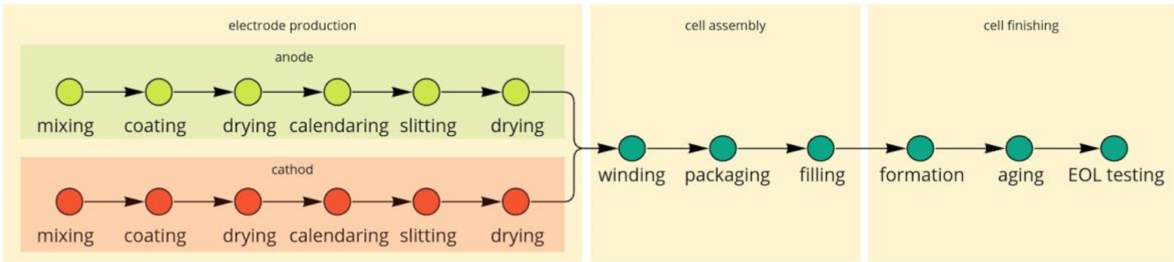



**Figure 5.1 Production priority sequence graph**

The process of making electrodes starts with slurry mixing and ends with the and vacuum drying processes. Both anode and cathode go through the same steps. This offers a chance for parallelization, allowing the cathode and anode electrode production processes to be carried out concurrently.

## 5.2 Production Form

To establish the organizational form of a production area (production method) there are different approaches available to support a systematic approach. We performed temporal and spatial synthesis of the work task by deriving some basic indications from the specifications of the processing task. As per Spatial structuring, since the Workstations are fixed in our case and the Product is would be moving to different Workstations, it is classified as Line production.

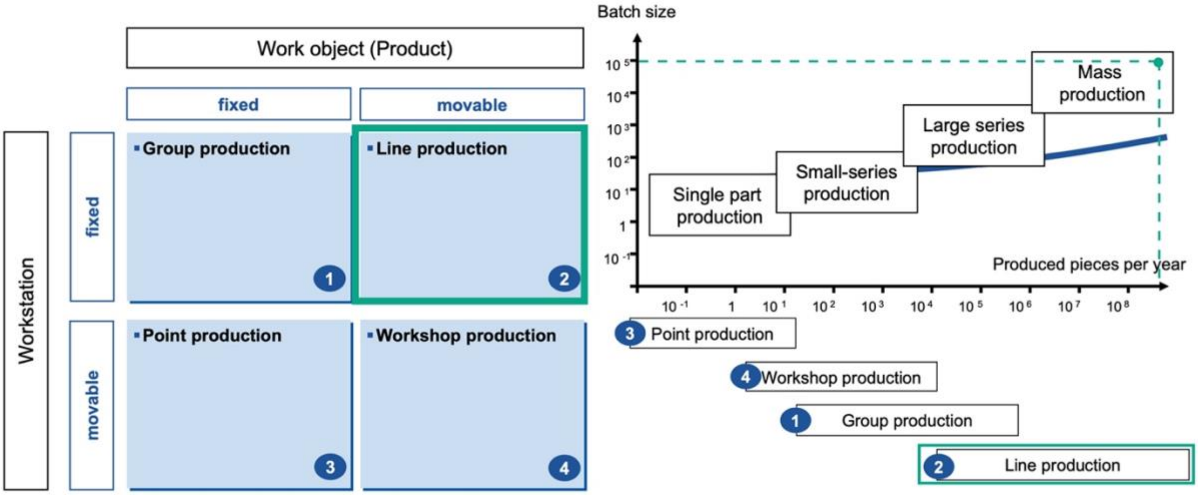



**Figure 5.2 Spatial Structuring and Temporal structuring**

Similarly, Temporal structuring also classifies it as Line production because annual production is $10^9$ (in pieces) and batch size is $10^5$ (in pieces), considering slurry mixing takes 20 mins to produce a batch and our planned capacity is roughly 141000 pieces per hour.

The production is in series flow in Line production, i.e., machines are positioned according to the sequence of a partial group as per the Technology Chain.

## 5.3 Production Process

As mentioned above, the production process is divided into 12 major steps. These steps can be broadly classified into electrode manufacturing, cell assembly and cell finishing. The electrode manufacturing and cell finishing processes remain independent of the cell type, except for certain distinctions in the cell assembly process. The current description focuses on the cylindrical cell type as per the requirement from Tesla.

### 5.3.1 Electrode Manufacturing

There are six steps in the production of an electrode: mixing, coating, drying, calendaring, slitting, and vacuum drying. After the fabrication of the electrodes, the electrodes are in the form of rolls.

#### 5.3.1.1 Mixing

The slurry necessary for coating electrodes is created during this procedure. A rotating tool is used to combine the active substance, conductive additives, solvents, and binders to generate the slurry. Wet mixing and dry mixing are two separate processes used in mixing. Active substance, additives, and binder are all added during dry mixing. After adding solvent, wet mixing begins.

For mixing, a variety of equipment are available, including planetary and intense mixers. Whether the process is batch-based or continuous can also be distinguished. The currently chosen approach uses a twin planetary vacuum mixing system to complete the process. Utilizing an ultrasonic mixing machine is an alternative.

#### 5.3.1.2 Coating

In this procedure, the slurry is applied to the appropriate copper and aluminum foils for the anode and cathode, respectively. The foil is successively coated using the existing process. It is continually fed to the dryer after the first side has been coated before being fed back into the coating machine for the second side.

The instruments include an anilox roller, comma bar, and slot die. The current procedure employs a slot die and a sequential coating approach. Dry coating and simultaneous coating are some alternative techniques.

#### 5.3.1.3 Drying

Before moving on to the next stage, the slurry that was coated the electrode needs to be dried. The electrode is dried and fed back into the coating machine for the single-sided coating process. The electrode is dried using the current technique by an air nozzle. Solvent evaporates during drying; this vapor is eventually collected and used again during mixing.

The currently used drying method makes use of air nozzles in a closed chamber with four temperature-controlled partitions. A different approach would involve adding a machine for infrared drying or using a laser drying technique.

#### 5.3.1.4 Calendaring

In this procedure, a roller applies a perfectly calibrated line pressure to the coated foils of copper and aluminum. The coated foils are statically ejected and cleaned by brushes or air flow before being fed to the roller.

The current process discharges the roll statically, cleans it using brushes, and then feeds it to a roller with carefully controlled pressure. Using heated rollers as an alternate addition can help get the ductility of the active material up to a specific level. Oil or water is the heating source for the rollers.

#### 5.3.1.5 Slitting

In this procedure, a mother roll, which is a wide electrode roll, is separated into smaller electrode rolls. With rolling knives or lasers, the smaller daughter rolls are produced.

Currently, slitting is done with a laser cutter.

#### 5.3.1.6 Vacuum Drying

A carrier containing the coated rollers is placed inside a vacuum oven for storage. The drying process takes between 12 and 30 hours. The electrodes' remaining solvent and moisture are removed during this procedure. The dry room utilized in the following method frequently uses the vacuum ovens as an air lock.

The drying procedure in the current technology takes place in a vacuum oven. Continuous dryers, which continually transfer the daughter rolls in a wound or unwound condition, offer an alternative approach. An infrared heating dryer can be used to augment either of the aforementioned processes.

### 5.3.2 Cell Assembly

The electrodes, separator, center pin, and battery case are assembled into a cylindrical form as part of the cell assembly. The procedure is as follows:

#### 5.3.2.1 Winding

To create prismatic or cylindrical cells, winding is utilized. The electrode foils and two separator foils are twisted around the center pin in a cylindrical cell. Jelly rolls are the type of coiled rolls that are fastened using sticky tape.

#### 5.3.2.2 Packaging

The jelly roll and a bottom insulting foil are placed into the metal container. The anode's current collector and cathode are welded to the housing's base and lid, respectively. The jelly roll is then placed between the lid and an insulation ring.

#### 5.3.2.3 Electrolyte Filling

Wetting and filling are the two subprocesses of electrolyte filling. Using a dosing needle, the electrolyte is injected into the cell during the filling process. By delivering a pressure profile to the cell during the wetting process, the capillary action in the cell is turned on. This pressure profile is applied by the alternately operating supply of inert gas and/or vacuum generation. Using crimping, beading, or welding, the cells are sealed after numerous iterations of evacuation and filling.

### 5.3.3 Cell Finishing

#### 5.3.3.1 Formation

A carefully specified current and voltage are used to charge and discharge the cells. Cell formation refers to this initial charge and discharge cycle. The Solid Electrolyte Interface, which forms an interface between the electrode and electrolyte, depends on cell formation.

#### 5.3.3.2 Aging

Aging is a technique used to guarantee a product's quality. Over the course of three weeks, the cell's properties and performance are tested and tracked using open circuit voltage. Throughout the aging process, cells experience aging at both high and low temperatures. The cell is regarded as completely functioning if there is no discernible performance loss.

#### 5.3.3.3 EOL Testing

This completes the cell-finishing process. From the aging rack, the cells are taken out and put into the testing station. They are released to the state of charge for shipping. Numerous methods, including as the pulse test, internal resistance measurements, optical inspections, OCV test, and leakage tests are used to evaluate the cells. The requirements may dictate different tests. After the testing, the cells are rated based on performance information, packed, and sent.

# 6 Capacity planning

Authors of this chapter:

- Sanjay Porwal

## 6.1 Capacity Calculations

Keeping in mind the initial production capacity of 200000 vehicles forecasted by Tesla CEO, and our conclusion of producing 2170 type cells initially and gradually moving towards 4680 with the time, a production facility with effective output of 15GWh or approximately 744 million 2170 cells is to be designed. Upon calculating the Overall Equipment Effectiveness, we concluded to design the facility with an output little less than 20 GWh or approximately 987 million cells of type 2170. Below table contains the required no. of all types of machines for first year of production.

**Table 6.1 Required Machine Quantity**

| S. No. | Machine Type | Required Quantity |
|---|---|---|
| 1 | Battery Slurry Mixing Machine | 44 |
| 2 | Electrode Coating Machine | 8 |
| 3 | Drying Machine | 8 |
| 4 | Calendaring Machine | 4 |
| 5 | Laser Cutting Machine | 2 |
| 6 | Vacuum Drying Machine | 120 |
| 7 | Cell Assembly – Winding, Packaging, Electrolyte Filling & Sealing | 1 |
| 8 | Cell Finishing – Formation, Aging and EOL Testing | 1 |

Required quantity of machines in above table are calculated using Capacity Requirements, Available Capacity and Overall Equipment Effectiveness formulae below and the input required for these formulae are described in table 6.2.

$$Required\ no.of\ machines = \frac{corrected\ required\ machine\ capacity}{available\ machine\ capacity}$$

$$Corrected\ required\ machine\ capacity = \frac{required\ machine\ capcity}{performance\ efficiency \times degree\ of\ efficiency}$$

$$Required\ machine\ capacity = \ quantity\ per\ year \times \left(\frac{setup\ time\ per\ batch}{minimum\ batch\ size} + part\ production\ time\right)$$

$$Available\ machine\ capacity = Working\ hours\ per\ shift \times shifts\ per\ day \times working\ days\ per\ year$$

$$Overall\ Equipment\ Effectiveness = Availablity \times Level\ of\ performance \times \ Quality\ rateAvailability$$

$$Availability = \frac{Run\ time}{Run\ Time + Unplanned\ downtime}$$

$$Level\ of\ performance = \frac{Current\ output\ in\ pieces}{Potential\ output\ in\ pieces}$$

$$Quality\ rate = \frac{Produced\ parts - Reworked\ parts - Scraped\ parts}{Produced\ parts}$$

**Table 6.2 Inputs based on Research and Planning**

| Factor | Value | Remarks |
|---|---|---|
| Working Days | 270 per year in Karnataka State | 6 working days in week. Including major maintenance / upgradation shutdown. Data for Karnataka state. |
| Shift per day | 3 per day | |
| Effective working hours per shift | 7 hr 10 min per shift | Includes meal, coffee, and shift change-over breaks |
| Working hours per year | 5800 hours | From calculations |
| Annual unplanned downtime | 8% of total run time | Average industry downtime |
| Scraped products | 10% of total production | Data from similar facilities |
| Reworked products | 2% of total production | Data from similar facilities |
| Performance efficiency | 1.05 | Based on research |
| OEE | 75.4% | From calculations for 2170 |
| Cycle time | 141113 cells per hour | From calculations for 2170 |

The selected machines are compatible to produce both 2170 and 4680 type of cells. Any regular maintenance work can be carried out during various breaks in the shifts or on the Sunday. Any specific points related to each machine from internal technology research is described below:

**Slurry Mixing Machine** – The Double Planetary Vacuum Mixer has a production output of 0.4GWh/unit/year with an OEE of 80%. It has a capacity of 200 litres in 20 minutes which, as per our calculations, gives a minimum batch size of around 1300 pieces. Each machine occupies 10 sqm space.

**Electrode Coating Machine** – The Pilot production equipment has achieved production output of 1 GWh/unit/year and occupies 60 sqm of space. Based on feedback from development engineers, the production version expected to achieve an output of 250 – 300% than the current pilot version and the size will be almost doubled in length with an area of 120 sqm. We considered the production output of 2.5GWh for our calculations.

**Drying, Calendaring, Slitting & Vacuum Drying** – To process the output of every ECM, there is a requirement of 1 Drying Machine, 0.33 Calendaring Machine, 0.2 Laser Cutting Machine and around 15 Vacuum Drying Machines and each of these machines occupy an area of 225sqm, 116sqm, 35 sqm and 9 sqm respectively

**Cell Assembly** – The recently developed cell assembly unit for Winding, Packaging, Electrolyte Filling and Sealing is entirely automatic. It can produce 150000 cells per hour of 2170 type cells and 50000 cells per hour of 4680 type cells. Area occupied by this system is around 1500 sqm and it can be scaled up on the longer axis to increase production.

## 6.2 Personnel Planning

Personnel requirement is forecasted based on various criteria like the production structure, number of shifts and machines. For this purpose, production teams are majorly categorized into three shops (Electrode Manufacturing, Cell Assembly & Cell Finishing) and then the process lines under those shops. Personnel requirement grouped as per department. Refer to table 6-3 for further description.

**Table 6.3 Personnel Planning**

| Department | Position | Head Count | Min Qualification |
|---|---|---|---|
| | Plant Head | 1 | MBA |
| Production | Shop/Area Head | 3 | MBA |
| | Shift Leader | 9 | BE / BTech |
| | Line Supervisor | 36 | Diploma |
| | Operators | 132 | Diploma |
| Maintenance | Shop Manager | 3 | BE / BTech & MBA |
| | Shift Super Visor | 9 | BE / BTech |
| | Technician | 36 | Diploma |
| Quality | Manager | 1 | MBA |
| | Inspector | 3 | BE / BTech |
| Logistics | Manager | 1 | MBA |
| | Planners | 2 | MBA |
| | Operator | 24 | High School |
| Safety | Inspector | 3 | BE / BTech |
| Manufacturing Engineering | Technical Project Manager | 1 | BE / BTech + MBA |
| | Project Engineers | 6 | BE / BTech |
| Operations | Senior Manager | 1 | MBA |
| | Administrator | 1 | BBA |
| Human Resources | Head of Department | 1 | MBA |
| | Associates | 9 | MBA |
| Finance | Head of Department | 1 | MBA |
| | Associates | 6 | MBA |
| Legal | Consultant | 2 | LLB |
| IT | Manager | 1 | BE / BTech |
| | Service Desk Admin | 3 | Diploma |
| Purchasing & Inventory | Manager | 1 | MBA |
| | Procurement Officer | 3 | MBA |
| | Inventory Manager | 3 | MBA |
| Security | Chief Security Officer | 1 | Masters in Safety Management |
| | Supervisor | 3 | Prior Experience |
| | Guards | 24 | Prior Experience |
| House Keeping | Supervisor | 1 | Diploma |

| | | | |
|---|---|---|---|
| | Housekeeper | 40 | None |
| Medical | Doctor | 1 | MD |
| | Nurse | 4 | ANM / BSc |
| Canteen | Supervisor | 1 | High School |
| | Chef | 2 | BA (Culinary Arts) |
| | Helper/Server | 24 | None |
| Total | | 403 | |

## 6.3 Capacity Fluctuations

Capacity Fluctuations can be accommodated majorly through four strategies:

1. Investments
   Investments for additional machines could be done to meet the higher demands. Few additional machines alone at the bottlenecks can help improve the entire cycle time. Apart from this, increasing the inventory of finished product to meet near future demands can also be done.

2. Additional shifts
   The current facility is already designed for maximum utilisation. So, the only possible additional shifts are on Sundays and Holidays where 2 shifts can be operated considering another shift time for regular equipment maintenance. Though if the demand decreases, either the frequency of night shifts can be reduced, or they can be eliminated. Temporary contract workers can be hired for such fluctuating demands to keep a check on cost.

3. Overtime/Short working time
   To accommodate increase in temporary demands, it is possible to carry out the production task that does not require active involvement during breaks under the observation of few operators (who can have breaks once rest of the operators are back). Whereas shift timings can be reduced from 8 hours if demand decreases.

4. External production
   Because of the exponential increment in production forecast for next 10 years, it seems to be a good option to train other local players gradually while observing the demand and capacity fluctuations.

# 7 Production structure planning

Authors of this chapter:

- Sanjay Porwal

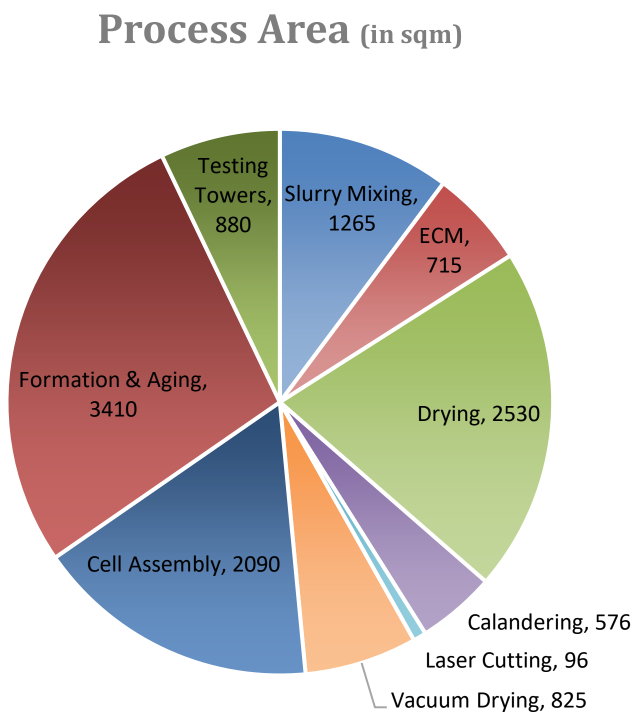



**Figure 7.1 Process Area Breakdown**

The above chart shows the area occupied by various process machines with clearance (roughly 12400 sqm). Clearance of 1m between machines and 3m at places to operate Forklifts is taken into account. The Vacuum Dryers are stacked on top of each other, thus reducing the floor space to half. Floor space for Aging is calculated considering 2m high shelves to store cells for 3 days, i.e., equivalent to 3 days of planned production capacity. Our internal research shows that Testing towers, for Formation and EOL Testing, occupies generally 30% of floor space in relation to the aging shelves

A raw material storage to fulfil daily requirements is considered in the beginning of production structure. For Electrode Manufacturing shop, Cell Assembly shop and Cell Finishing shop separate office spaces, break spaces for operators, quality testing rooms and washrooms are planned whereas a common forklift parking station, spare parts room and 2 tool rooms are planned. Total area occupied by entire production structure is 13800 sqm with a length of 260m and width 60m which includes everything mentioned above.

The raw material to the production storage will be loaded from central raw material storage facility regularly. The final product after EOL testing will be moved to the central inventory.

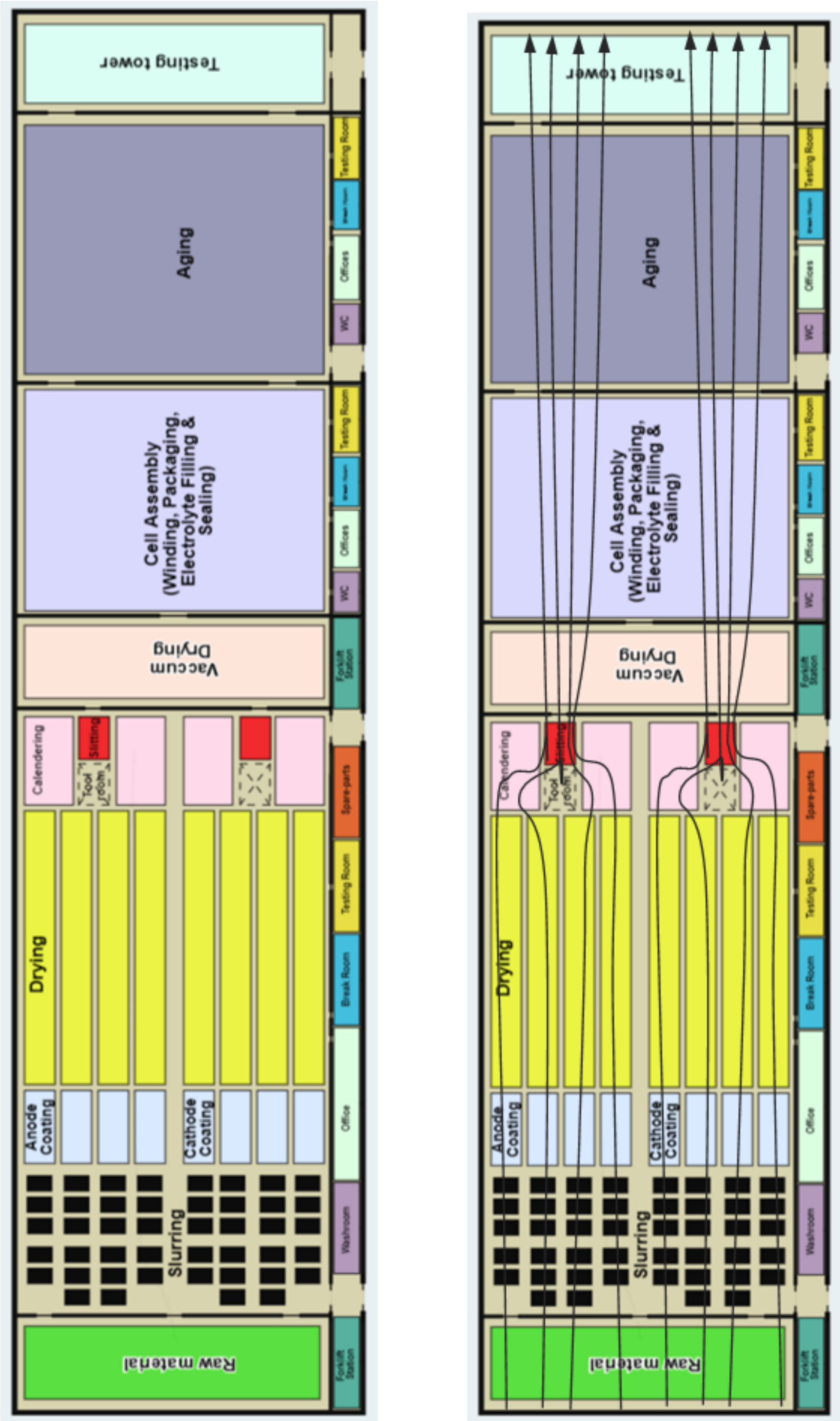



**Figure 7.2 Production Layout and Material Flow**

# 8 Factory structure planning

Authors of this chapter:

- Sujay Mishra

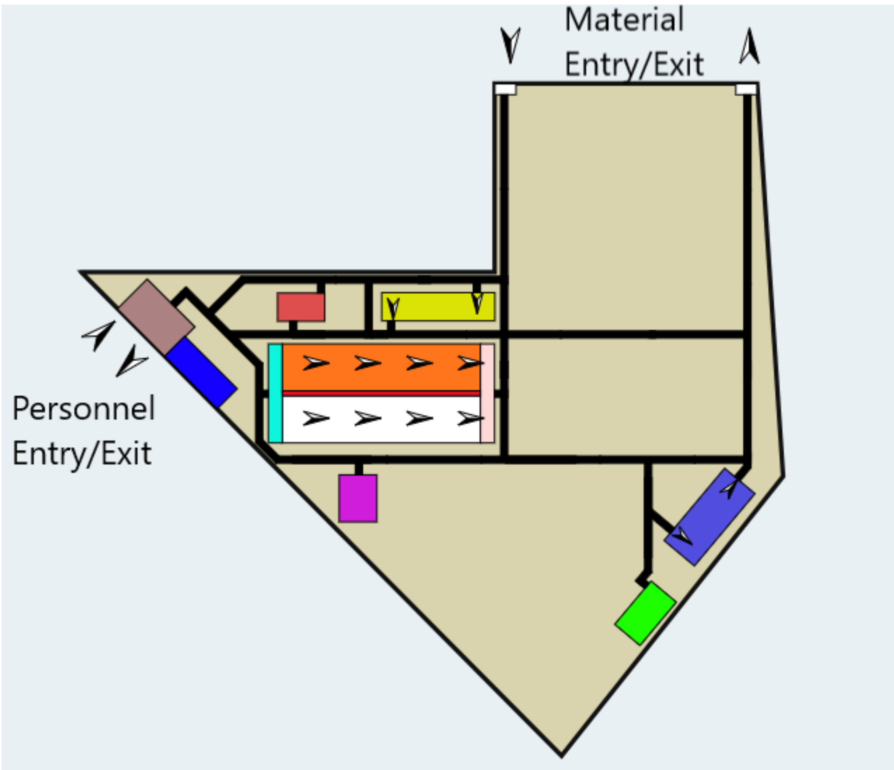
- 


**Figure 8.1 Initial plant layout**

## 8.1 Areas

Legend of the above diagram can be found at the end of this section

**Temporary Raw Material Storage**

The temporary raw material storage is placed before the production starts. The temporary storage is assumed to have the storage capacity for one entire day so that there is enough material as a buffer even in case of sudden surges of demand at the start of the production. For this the weights of all the materials required for the production per day are calculated from previous tasks. Then, based on their densities, we get their required volume. After that we assume a maximum storage height of 1.5 meters so as to not put too much load on the floor structure for heavy materials and we get the required minimum floor area for storage.

### Table 8.1 Calculation of temporary storage area

| Battery Component | Daily Weight Requirement (kg) | Density of Material (kg/m^3) | Volume Required per day (m^3) | Floor Area Required for Storage (m^2) |
|---|---|---|---|---|
| Aluminium | 71,800 | 2710 | 26.5 | 17.66 |
| Steel | 17,324 | 7750 | 2.2 | 1.49 |
| Electronics | 5,197 | 2330 | 2.2 | 1.49 |
| Cables | 4,427 | 8960 | 0.5 | 0.33 |
| Plastics | 21,174 | 940 | 22.5 | 15.02 |
| Oxygen | 9,240 | 1141 | 8.1 | 5.40 |
| Nickel | 5,967 | 8908 | 0.7 | 0.45 |
| Cobalt | 5,967 | 8900 | 0.7 | 0.45 |
| Lithium | 1,925 | 530 | 3.6 | 2.42 |
| Copper | 17,709 | 8500 | 2.1 | 1.39 |
| Graphite | 15,784 | 2260 | 7.0 | 4.66 |
| Voltable components | 15,977 | 1200 | 13.3 | 8.88 |
| | | | | 59.62 |

We get required floor area for material storage as approx. 60 sq. meters. Taking clearance and area for forklifts, overhead cranes and walking pathways, pipelines and tanks for oxygen, area is multiplied by 5, so we assume a required temporary storage area of 300 sq. meters.

Since production line we already has a width of 50 meters, required length of the temporary storage should be 6 meters. For convenience and expansion in mind we take it as 15 meters.

### Main Raw Material Storage

Apart from temporary storage, it is assumed to have a main raw material storage of 6 days at the plant. This is necessary because it is important to have a buffer stock at the plant in case of emergency stoppages to raw material. It may be a natural disaster or sudden disruption in supply chains, in such cases there cannot be a scenario where production halts immediately if the raw material supply is interrupted. The area for this is calculated similar to the temporary raw material storage, except it is done for 6 days, as opposed to 1 day.

### Table 8.2 Calculation of main storage area

| Battery Component | Weekly Weight Requirement (kg) | Density of Material (kg/m^3) | Volume Required per day (m^3) | Floor Area Required for Storage (m^2) |
|---|---|---|---|---|
| Aluminium | 430,798 | 2710 | 159.0 | 105.98 |
| Steel | 103,946 | 7750 | 13.4 | 8.94 |
| Electronics | 31,184 | 2330 | 13.4 | 8.92 |
| Cables | 26,564 | 8960 | 3.0 | 1.98 |
| Plastics | 127,045 | 940 | 135.2 | 90.10 |
| Oxygen | 55,438 | 1141 | 48.6 | 32.39 |
| Nickel | 35,804 | 8908 | 4.0 | 2.68 |
| Cobalt | 35,804 | 8900 | 4.0 | 2.68 |
| Lithium | 11,550 | 530 | 21.8 | 14.53 |
| Copper | 106,256 | 8500 | 12.5 | 8.33 |
| Graphite | 94,706 | 2260 | 41.9 | 27.94 |
| Voltable components | 95,861 | 1200 | 79.9 | 53.26 |
| | | | | 357.73 |

The result from the calculations is an area of approx. 360 sq meters. Again like before, this is multiplied by 5 to get 1800 sq meters. Keeping in mind future expansion in and loading and unloading areas for internal logistics of the plant, we assume an area of 3600 sq meters.

### Temporary Finished Product storage

The Formation and Ageing process area is 2004 sq meters. This includes storage for 3 days in the process. So storage space per day in 2025 is 2004/3 = 668 sq meters. We will keep a storage of one day at the end of the line. Since our width is fixed at 50 meters, the length of storage is 700 (rounded) divided by 50 which is 14 ~ 15 meters including safety margin.

### Main Finished Product Storage

Apart from temporary storage, it is assumed to have a main storage of 6 days at the plant. So the total area of the main storage of the plant is calculated as 668 * 6 = 4008 sq meters ~ 4200 including safety margin. As the production increases, this will be expanded vertically as well to accommodate the increased volume. This ensures a storage area for the finished products for

6 days to ensure uninterrupted supply to the end customer even in case of temporary set backs in production. It also acts like a buffer in case of increasing demand.

**Production Office Areas/Washrooms/Break Rooms**

The red area denotes the offices of the production managers. The width is assumed to be as 5 meters as that is more than sufficient and the offices stretch along the production lines so that each manager is located precisely at his/her area of responsibility Also included in this area are toilets and a break area for the production workers.

**Compressor & Tool Room**

A separate room is kept as the compressor room and for storage of the tools, lubricants etc. The area allocated for this is 2100 sq meters. (Half of the finished products area storage).

**Main Office**

The main office is where the administration, HR, top management, Finance, as well as other production related departments like procurement, quality assurance etc sit. It is assumed that the corporate head office (Sales and Marketing) is an external office at a separate location. The area of office per person is taken as 5 sq meter on average. Since the offices for production managers are located in near to the production lines, as far as the non-production staff goes, their strength is approx. 93. Based on future expansion, we pen this number as 200. So based on the bigger offices of top management, conference rooms, seating hall, in house training center for employees etc. the total area required is taken as 2000 sq meters.

**Canteen**

The total number of employees in the plant are 407. Hence for their food arrangements, some safety factor for any visiting vendors or business partners etc a canteen is selected with an area of 2 sq meter per person so a total area of 407 * 2 * 1.5 = 1221 sq meters. Including serving and washing dish washing areas, a total area of 1500 sq meters is taken.

**Parking Area**

1 car is assumed to be of 6 sq meters. We have assumed a bus service for regular employees as well as a limited parking space. Considering 200 car parking spaces in total for employees as well as vendors and partners, the total parking space is assumed to be 1200 sq meters. Including some gaps and roads to navigate, it is taken as 1800 sq meters.

## 8.2 Capacity Expansion Strategy

In the first year of production, we must produce 200000 cars as per the given requirement. We have assumed this to be cars of the Model I which contains 2170 cells. Our strategy for the plant is to produce 2170 cells for both variants of the Model I and 4680 type cells for the other models. Hence as per the product life cycle of a car, the demand for 2170 cells will rise, peak and then begin to reduce while the demand for 4680 type cells which will be introduced in all later models will begin to pick up in the upcoming years. This assumption has been based on the given data since the EV industry is gradually trending towards the 4680 type cells, however presently the 2170 cells are the most in use.

Our approach is to make linear production lines since it fits best with the layout of the plot in terms of efficiency of land usage. Our strategy to increase production capacity year on year is to construct the first factory line for 2170 cells as shown in the orange color at the start of the factory itself. This is capable of meeting the demand of the 1$^{st}$ year, that is 15 GWh. Simultaneously, while the production begins, the phase 2 of the building that produces 2170 cells will be completed as shown in white. We will then go on adding machines in this building to cater to the increasing demand year after year. The entire building consisting of both the lines is capable of meeting the peak demand of 2170 cells. This ensures that we are able to scale up fast and we do not need long down time in order to scale up our capacity.

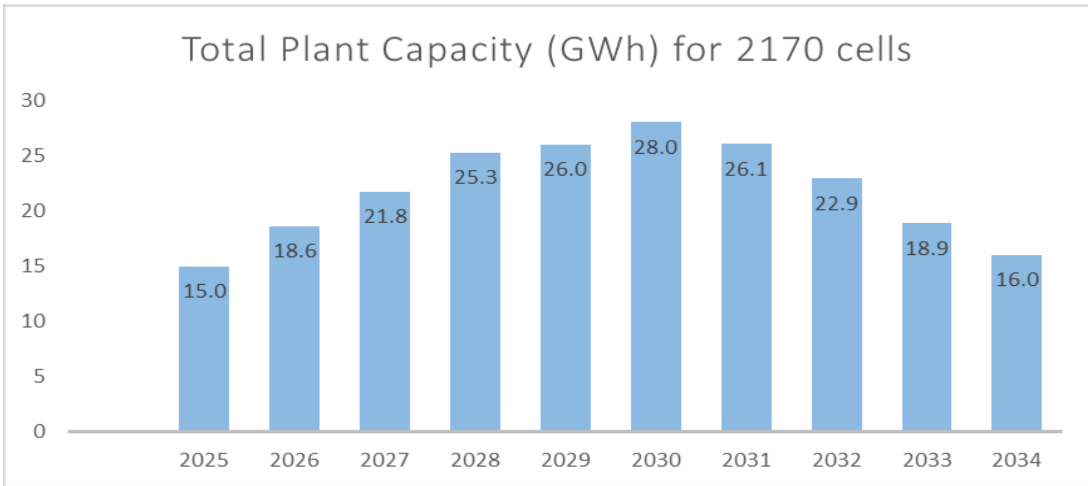



**Figure 8.2 Demand projection for type 2170 cells**

The same strategy will be followed as far as the 4680 cells are concerned. The production lines for 4680 cells are shown in light green color and will be constructed as per the rising demand with the first line being operational by 2027. The demand figures have been obtained via detailed calculations which are not shown in detail due to lack of space, however they can be submitted in detail if required. The demand figures are calculated for the Indian as well as the export market.

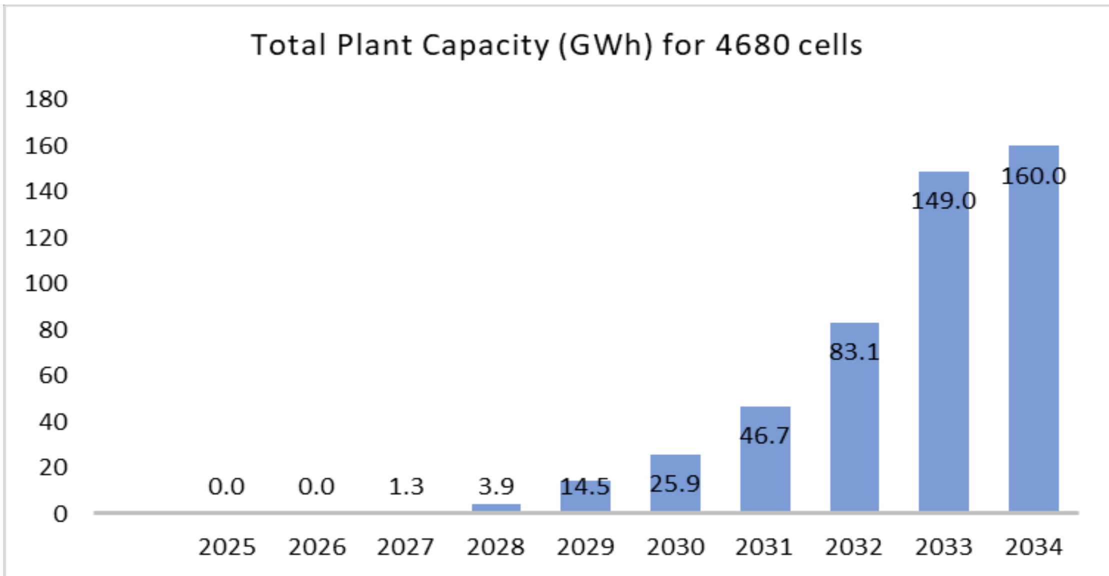
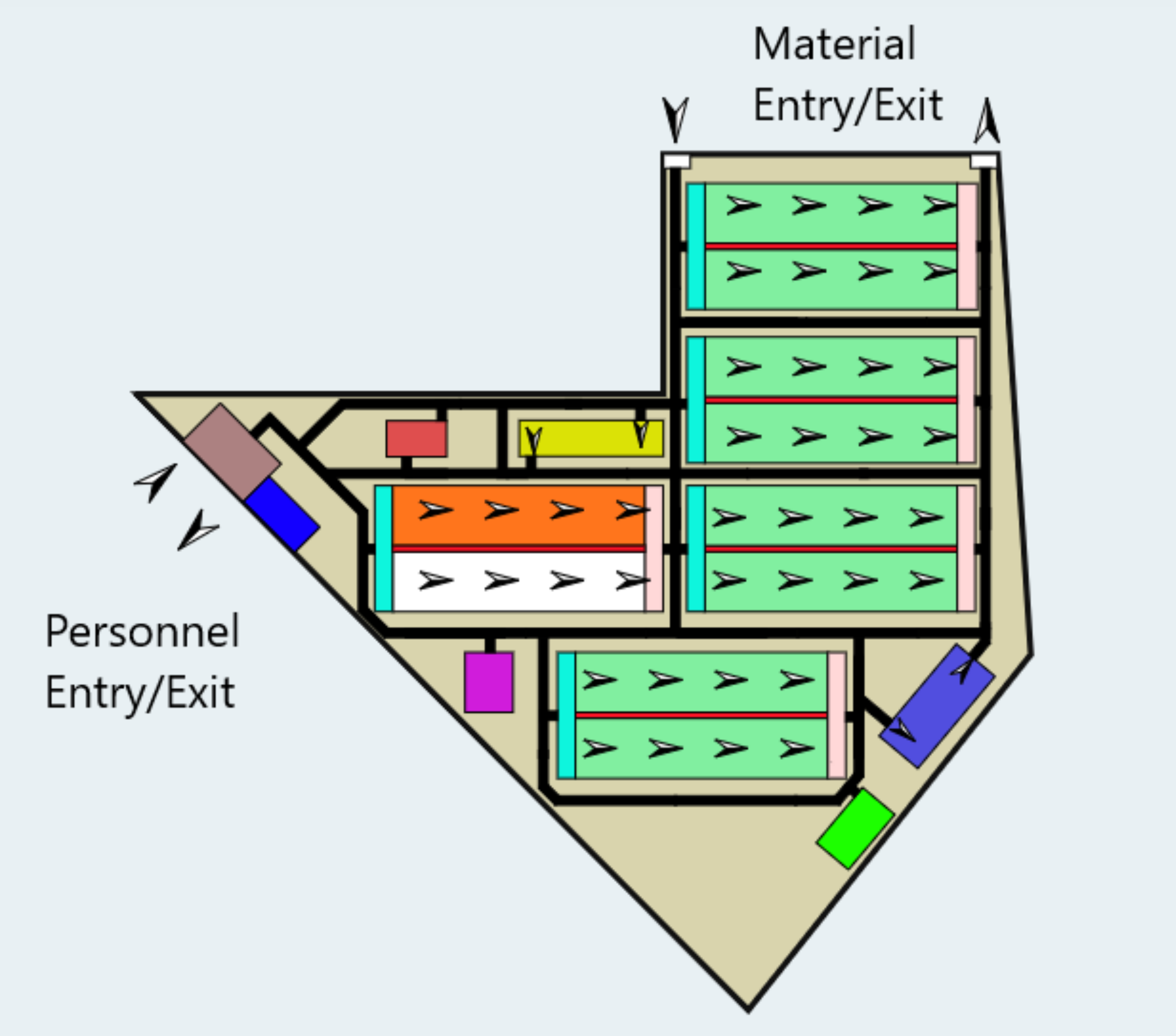



**Figure 8.3 Demand projection for type 4680 cells**

Once the plant is fully equipped, the plant will look as shown below. The arrows show the direction of material flow in the production lines. The plant is built so that all demand can be met by producing on site so as to reduce costs and ensure quality. However, as the demand picks up particularly in 2033 and 2034, some amounts may have to be manufactured externally due to space constraints.




| Color | Building Name | Size (m) |
|---|---|---|
| | Main Raw Material Storage | 120 x 30 |
| | Canteen | 50 x 30 |
| | Production Line for 2170 cell - Phase 1 | 230 x 55 |
| | Production Line for 2170 cell - Phase 2 | 230 x 55 |
| | Production Line for 4860 cell | 230 x 55 |
| | Main Finished Product Storage | 100 x 42 |
| | Temporary storage for Raw Material | 105 x 15 |
| | Temporary Finished Product Storage | 105 x 15 |
| | Production Office Area | 230 x 5 |
| | Main Office Building | 50 x 40 |
| | Roads | 7.5 m width |
| | Compressor and Tool Room | 35 x 60 |
| | Parking Space | 30 x 60 |

**Figure 8.4 Plant structure with expansion visualization and legend**

# 9 Building concept

Authors of this chapter:

- Sujay Mishra

## 9.1 Structural Systems

### 9.1.1 Building Shape

The building concept plays a pivotal role in the overall look, and structure of the plant. The structural shape is something that's defined for the lifetime of the plant and it's very important to choose it carefully since it can't be changed or modified easily. Factory shapes are classified under four typologies: Campus/Courtyard, Compact/Block Structure and Axis/Comb/Linear Structure and Amorphous Structure. We need to evaluate which one is suitable for our needs based on defined criteria which are important to us as shown and weighted below. Since we have a high-capacity plant, logistical capacity has been given the highest weightage and since we have to freeze the building shape & incorporate any expansion in the selected concept, expandability has also been given a high weightage.

**Table 9.1 Building shape selection parameters**

| Building Shape/ Evaluation Parameter | Weighting Factor | Courtyard | Block | Comb | Amorphous |
|---|---|---|---|---|---|
| Logistical Capacity | 5 | 5 | 4 | 8 | 6 |
| Expansion Ease | 4 | 7 | 5 | 7 | 7 |
| Efficiency of Land Utilization | 3 | 3 | 7 | 5 | 5 |
| Flexibility | 3 | 7 | 2 | 4 | 7 |
| Total Score | NA | 83 | 67 | 95 | 94 |

Based on the evaluation, we finalize a comb/linear shape since it gets the highest score.

### 9.1.2 Bearing structure

The main aim of the bearing structure is to absorb the structural load. There are two types of bearing structures: Hierarchical and Non-Hierarchical. Since the non-hierarchical structure is expandable in two directions and the hierarchical structure is expandable in only one, we choose the non-hierarchical structure considering future expandability and flexibility.

**Table 9.2 Bearing structure selection parameters**

| Typology of Bearing Structure / Evaluation Parameter | Weighting Factor | Heirarchical | Non - Hierarchical |
|---|---|---|---|
| Efficiency of Land Utilization | 3 | 5 | 7 |
| Expansion Ease | 5 | 3 | 8 |
| Flexibility | 5 | 3 | 8 |
| Total Score | NA | 45 | 101 |

Among the non-hierarchical bearing structures, the girder grid structure has been selected.

**Table 9.3 Type of non-hierarchical bearing structure selection parameters**

| Type of Non Heirarchical Bearing Structure / Evaluation Parameter | Weighting Factor | Girder Grid | Space Truss | Cable Constraint Beams |
|---|---|---|---|---|
| Cost | 4 | 5 | 5 | 6 |
| Expansion Ease | 5 | 7 | 7 | 3 |
| Flexibility | 5 | 7 | 6 | 3 |
| Total Score | NA | 90 | 85 | 54 |

### 9.1.3 Disposition of Office Space

Location of the office in the plant area is a crucial decision in the functioning of the company. There are four types of typologies: Dethatched, Attached, Integrated and Mixed. We evaluate which one is suitable for our needs based on parameters such as communication ease, disturbance to the office, ease of expansion of the factory, & flexibility of the plant.

**Table 9.4 Disposition of the office space selection parameters**

| Typology of Office Space / Evaluation Parameter | Weighting Factor | Detachted | Attached | Integrated | Mixed |
|---|---|---|---|---|---|
| Communication Ease | 2 | 3 | 6 | 8 | 9 |
| Lesser Disturbance | 4 | 8 | 5 | 4 | 2 |
| Expansion Ease | 5 | 8 | 5 | 5 | 5 |
| Flexibility | 4 | 7 | 4 | 3 | 3 |
| Total Score | NA | 106 | 73 | 69 | 63 |

Based on our evaluation for weighted parameters, we have chosen the detached structure. However, certain offices will be integrated as their function is related to production.

### 9.1.4 Construction Material

Construction material not only serves a functional purpose of carrying the load of the structure, but also provides an aetheric look to the factory. The different types of construction material that are generally used are Concrete, steel or timber. Based on our evaluation, we chose steel as our construction material.

**Table 9.5 Construction material selection parameters**

| Type of Construction Material / Evaluation Parameter | Weighting Factor | Concrete | Steel | Timber |
|---|---|---|---|---|
| Cost | 4 | 5 | 7 | 6 |
| Corrosion/Fire Protection ability | 5 | 8 | 5 | 6 |
| Flexibility | 5 | 3 | 5 | 3 |
| Total Score | NA | 75 | 78 | 69 |

### 9.1.5 Bracing

Mangalore faces cyclones & our bracing structure must be strong enough to withstand heavy rains as well as cyclones. The highest wind speed in a cyclone ever recorded in the Western Indian Coast was 220 kmph. Our bracing must be able to withstand that with a FOS of 3.

**Table 9.6 Bracing selection parameters**

| Type of Bracing / Evaluation Parameter | Weighting Factor | 4 Walls | 3 Walls + 1 Ceiling | Fixed Columns |
|---|---|---|---|---|
| Protection Against extreme weather | 5 | 7 | 7 | 6 |
| Ease of Expansion | 5 | 3 | 3 | 7 |
| Total Score | NA | 50 | 50 | 65 |

Based on our evaluation for weighted parameters, we chose fixed columns as our bracing.

## 9.2 Building Envelope

The concept of a building envelope relates to design and construction of the exterior of the building. A good building envelope involves using exterior wall materials and designs that are climate-appropriate, structurally sound and aesthetically pleasing. These three elements are the key factors in constructing an optimal building envelope. The benefits of a good building envelope include reduced stress, wear and tear. This results in turn to reduce energy bills.

**Table 9.7 Building envelope selection parameters**

| Building Envelope / Evaluation Parameter | Weighting Factor | Steel | Timber | Glass | Synthetic |
|---|---|---|---|---|---|
| Climatic Protection | 5 | 8 | 4 | 4 | 7 |
| Structural Capacity | 5 | 7 | 4 | 4 | 6 |
| Aesthetics | 3 | 7 | 8 | 8 | 6 |
| Cost | 4 | 5 | 7 | 7 | 5 |
| Ease of expansion | 5 | 6 | 4 | 4 | 6 |
| Total Score | NA | 146 | 112 | 112 | 133 |

Based on our evaluation, we have chosen thin steel façade as the material for our building envelope. Not only is this functionally useful, but it is also aesthetically sound.

## 9.3 Fire Safety

### 9.3.1 Identification of Hazardous Materials

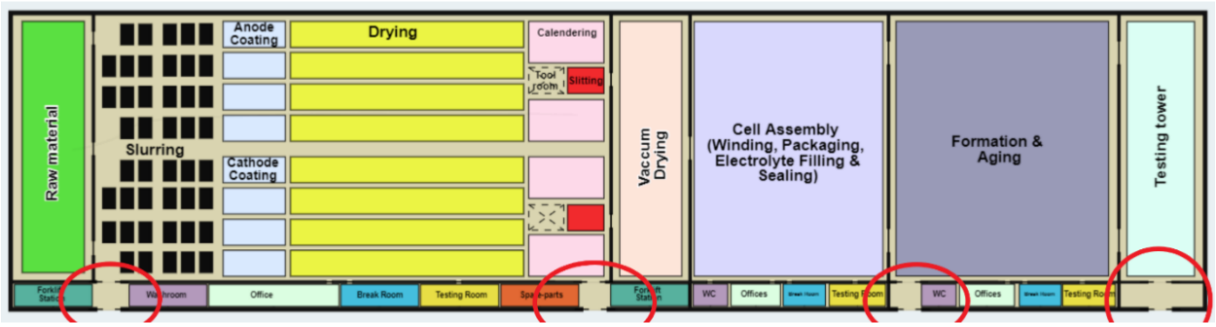
In order to correctly classify the chemicals used in our process, we will use the HMIS classification system. The Hazardous Materials Identification System (HMIS) is a hazard rating system that provides information about chemicals regarding how dangerous they are. It was developed by, the National Paint Coatings Association (NPCA).

**Table 9.8 HMIS Rating of materials**

| Process | Material | HMIS Rating | | |
|---|---|---|---|---|
| | | Health | Flammability | Physical Hazard |
| Slurrying (Mixing) | Graphite | 0 | 0 | 0 |
| | Li(NiAlCo)O2 | 2 | 0 | 0 |
| | Carboxymethyl cellulose (CMC) | 0 | 0 | 0 |
| | Deionized Water | 0 | 0 | 0 |
| | Styrene-butadiene (SBR) | 0 | 0 | 0 |
| | N-Methyl-2-Pyrrolidone (NMP) | 1 | 2 | 1 |
| | Polyvinylidene Fluoride (PVDF) | 0 | 1 | 0 |
| Coating | Copper Roll | 2 | 2 | 0 |
| | Aluminium Roll | 1 | 1 | 0 |
| Vacum Drying | Inert Gas | 0 | 0 | 3 |
| Winding | Adhesive Tape | 2 | 0 | 0 |
| Electrolyte Filling | Lithium hexafluorophosphate (LiPF6) | 3 | 0 | 1 |

### 9.3.2 Structural/Plant Specific Fire Protection

In our production line, we have ensured there are 4 fire exits highlighted in red through which people can exit in case of an emergency. Also a fire alarm system with loud speakers in every room along with a ventilation system will be incorporated. Once in the main passage, employees can evacuate to the front or rear of the production building from either side.




### 9.3.3 Organizational Fire Protection

There will be routine mock drills that will be conducted periodically to ensure that everyone is aware of SOP during a fire emergency. Exit Signs will be put up in all places for people's convenience and floors will be marked with glow in the dark arrows to ensure that people can see the exit route path even during power cuts. Apart from fire extinguishers of appropriate types will be placed in production areas & trainings will be organized for employees.

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