**Gate 0: Opportunity Identification & Strategic Planning**

**Timeline:** Month 0 - Month 2

**Objectives:**

* Define product vision, target markets (2W/3W/ESS/4W/CV), and Chemistry (LFP/NMC) and form factors
* Assess customer requirements and market trends

**Deliverables:**

* Product Concept Document & Feasibility Report
* Top Down Business Case & ROI Estimation
* Competitor Benchmarking (Chemistry, Specs, Cost, Roadmap)
* Initial Risk Assessment (Technology, Market, IP) Based on current situation at site review the additional risk of **reliability, warranty, ppm, scrap etc...**
* High-level Budget Planning (CapEx & OpEx)
* Management approval for moving to concept stage

**Simulation Activities:**

* Initial simulation of cell electrochemical performance using software like COMSOL, AutoLion, or Battery Design Studio
* Electrode formulation feasibility (porosity, binder selection, loading)
* Energy density vs safety trade-off analysis
* Thermodynamic modeling of different chemistries
* Cycle life and degradation modeling
* High-level cost modeling (materials, process, infrastructure)

**Functions Involved:** Sales, Cell R&D, Finance, ME, Risk

**Gate 1: Cell Chemistry Validation (Coin & Half Cell Stage)**

**Timeline:** Month 3 - Month 6

**Objectives:**

* Down select chemistry based on performance, cost, safety
* Initial material compatibility check

**Activities:**

* Chemistry and materials screening (NMC 622, NMC 811, LFP, etc.) **Preliminary of bill of materials**
* Electrode formulation concepts (solid loading, thickness, coating approach) **Preliminary process flow diagram, DFM, DFA [ as applicable]**
* Selection of separator, electrolyte, binder, and conductive additives
* Electrochemical testing: CV, EIS, GCD, Cycle Life
* First cycle loss & irreversible capacity testing

**Coin Cell & Half Cell Prototyping (Optional physical validation during late Gate 1):**

* Lab-level coating, drying, calendaring
* Coin cell assembly under glovebox
* Initial performance testing (OCV, capacity, C-rate, cycle life up to 100 cycles)

**Procurement & Supply Chain Initiation:**

* Initiate sourcing of lab materials for prototype cells
* Engage with suppliers for raw material datasheets and MSDS
* Preliminary supplier audits for critical materials
* Budgeting for raw materials, lab consumables, and test setups

**Deliverables:**

* Preliminary cell design spec sheet – **Preliminary TDS / Drawings and test specifications release**
* Material BOM (Active/Inactive)
* Coin Cell Test Report (Target: 50-100 cycles)
* Simulation report with recommendation including **DFMEA, Preliminary Critical characteristics of product and process. Design verification, Design reviews**
* Chemistry Down selection Memo
* Go/No-Go decision for prototyping (Gate 2)

**Advanced Simulation Activities:**

* Coin cell modeling (open circuit voltage, capacity estimation, polarization analysis)
* Electrochemical impedance simulation (EIS)
* Abuse simulations: overcharge, short circuit, thermal runaway likelihood
* Thermal model under various C-rates
* 1D/2D modeling of electrode reaction kinetics and heat generation
* Voltage vs SOC mapping and optimization
* Cell swelling and mechanical stress simulations
* CFD modeling for thermal management feasibility
* Cost simulations vs different active materials
* Environmental impact/LCA modeling

**Functions:** Cell R&D, Procurement, EHS, ME, Sales, Risk

**Budget:** INR 20-30 Lakhs (Lab & testing consumables)

**Gate 2: Lab-Scale Prototype Cell Development & Validation**

**Timeline:** Month 7 - Month 10

**Objectives:**

* Develop the first physical prototypes based on finalized cell design
* Validate performance (electrochemical, thermal, safety, and mechanical) & reproducibility

**Key Activities:**

1. **Prototype Cell (Lab Scale): Proto control plan**
   * Develop multiple batches of prototype cylindrical/prismatic cells using pilot line.
   * Document the manufacturing recipe and parameter window.
   * Output: 5-10 prototype cells for testing.
2. Process Development and Optimization: **Facilities requirements [ Line, Machines, Equipment’s, Instruments, Gauges etc...,]** **… Team Feasibility Commitment**
   * Refine mixing, coating, calendaring, slitting, stacking/winding, formation, and aging processes.
   * Track OEE, yield rate, process repeatability.
   * Ensure scale-down version mimics gigafactory setup.
3. **Initial Electrochemical Testing:**
   * Capacity, IR, cycle life (up to 200 cycles), charge/discharge rates.
   * Establish baseline data vs. design targets.
4. **Thermal and Mechanical Validation:**
   * Conduct thermal runaway, nail penetration, drop, crush, vibration tests.
   * Ensure mechanical stability of cell casing and internal layers.
5. **Safety Testing (Internal):**
   * Overcharge, short-circuit, forced discharge.
   * Simulate misuse cases and evaluate mitigation.
6. **Quality and Metrology: Special characteristics of product and process**
   * Define cell inspection protocols.
   * Ensure consistency across batches.
7. **Packaging and Logistics Plan:**
   * Define packaging requirements for handling and transportation.
   * Evaluate cost and regulatory aspects.
8. **Supplier Trials for Key Raw Materials:**
   * Raw materials sourced from shortlisted suppliers used in prototypes.
   * Identify material variance and quality impact.
9. **Cost Evaluation Update:**
   * Update BOM and cost estimates based on pilot runs.

**Deliverables:**

* Prototype Cell Test Report
* Thermal & Electrical Models
* Cell Design V1, Electrode Design
* Material qualification progress - **Test plan and results, Supplier inspection reports.**
* Process optimization results
  + **Process flow diagram**
  + **Proto control plan**
  + **Things Gone right and Things Gone Wrong**
* Safety test summary
* Procurement cost update

**Functions:** Cell R&D, Procurement, ME, EHS, Quality, **Process Engineering, Cell Manufacturing**

**Budget:** INR 1–1.5 Cr (Electrode coating, cell fixtures)

**Gate 3: Pre-Pilot Development (Pilot Line V0 Setup)**

**Timeline:** Month 11 - Month 15

**Objectives:**

* Build pre-pilot infrastructure for A Sample cells (500 ~ 250 Nos)
* Validate product design and processes under conditions simulating gigafactory production
* Readiness for homologation and regulatory certification

**Key Activities:**

1. **Pre-Pilot Batch Production (500–25000 cells):**
   * Use pilot line to simulate near-production-scale runs.
   * Assess consistency and stability across large batches.
2. **Advanced Electrochemical Testing:**
   * Full cycle life tests (500–1000+ cycles).
   * C-rate capability and calendar aging.
   * Abnormal temperature and fast charging tests.
3. **Regulatory Certification Preparation:**
   * Initiate certification protocols: BIS, AIS-156, UN38.3, UL1642, IEC62133, etc.
   * Engage 3rd party labs and schedule audits.
4. **Safety & Abuse Testing (External and Internal):**
   * Functional Testing: Thermal, Cycle, Calendar Life
   * Full Abuse Testing: Nail Penetration, Crush, Thermal Runaway, Drop Tests etc.
5. **Supply Chain Finalization:**
   * Final approval of raw material vendors (Foil, Electrolyte, Separator, Binders etc).
   * Contracts for long-term sourcing.
6. **Cost & BOM Finalization:**
   * Lock cost with procurement.
   * Freeze pricing strategy for SOP.
7. **Design FMEA and Process FMEA Updates:**
   * Close all open risks.
   * Validate control plans.
8. **ESG and Sustainability Checkpoints:**
   * Ensure responsible sourcing.
   * Lifecycle impact analysis and recycling strategy draft.
9. **Gigafactory Transition Plan – Change Scope Finalization**
   * **Gap Assessment**: Compare Pilot line processes with Gigafactory capability.
     1. Electrode coating line suitability (e.g., drying speed, slot die/gravure).
     2. Cell assembly equipment compatibility (winding/staking, welding tools, etc.).
     3. Formation & aging system capacity and modification needs.
   * **Utility & Facility Scope Definition**
     1. Cooling systems, compressed air, dry rooms, cell storage, fire protection.
     2. Modification needs in dry room humidity, layout, material handling systems.
10. **Capex & Timeline Plan**
    * Initial Capex estimates for equipment upgrades or additions.
    * Detailed transition timeline, including production stoppage windows (if any).

**Deliverables:**

* Pre-Pilot Process SOPs & Batch Records **with targets for Capability and OEE**
* Detailed test report (all specs, abuse testing, certifications).
* BOM and cost lock
* Supplier approval status
* Certification Planning
* DFMEA, PFMEA, Control Plan V2
* Go/No-Go decision for Gate 4
* **Product Launch Document with a plan and target, including the below**
  + **Final Process flow diagram Version 0**
  + **PFMEA Version 0**
  + **Pre-launch control plan**
  + **Measurement system analysis plan**
  + **Preliminary process capability plan and studies – SPC**
  + **Preliminary - Work instructions**
  + **Packaging and handling methods if any.**
  + **Third party labs Certification decisions [ ARAI, GARC, Natrax etc.., ]**
  + **Things Gone right and Things Gone Wrong until now with care info.**

**Functions:** Cell R&D, Procurement, ME, EHS, Quality, Project, IT, **Process Engineering, Cell Manufacturing**

**Budget:** INR 10–15 Cr (Pilot Line Equipment) & INR 2–3 Cr (Testing, third-party validation)

**Gate 4: Pilot Production & Customer Sampling**

**Timeline:** Month 16 - Month 18

**Objectives:**

* Build B Sample cells in volumes for customers
* validate manufacturing feasibility, process stability, quality, and initiate customer sampling.
* Validate pack-level integration, if required

**Key Activities:**

1. **Pilot Line Setup & Qualification**
   * Calibration and setup of pilot equipment
   * Safety and process SOPs deployment
   * Trial runs for consistency in quality, yield, and throughput
2. **Raw Material Procurement & Quality Validation**
   * Secure pilot-scale raw materials with supplier CoA
   * Conduct incoming raw material checks (purity, morphology, specs)
   * Approve materials via lab-scale validation on coin/half/full cells
3. **Process Engineering & DOE**
   * Finalize process parameters via DOE (Design of Experiments)
   * Run 3–5 pilot batches for process consistency
   * Freeze electrode design, coatings, assembly recipe, and formation profiles.
   * Document Process Flow Diagram (PFD) and PFMEA.
   * Record yield, scrap rate, energy consumption, process control metrics
4. **Cell Assembly & Testing**
   * Produce 1000–5000 pilot cells (as per form factor)
   * Conduct 0–100% charge-discharge cycles (cycle life testing)
   * Run safety testing (overcharge, nail penetration, thermal runaway, etc.)
5. **Customer Sampling & Feedback**
   * Share cell samples with 3–5 prospective OEMs/partners
   * Collect application-specific feedback (performance, fitment, safety)
   * Adjust chemistry or packaging as per use-case (if required)
6. **Certification Testing (Start)**
   * Submit samples for BIS/UN38.3/IEC 62133 or relevant certifications
   * Safety lab collaboration for abuse and transport certification
7. **Detailed Engineering & Facility Upgrade**
   * Final layout drawing with equipment modifications.
   * Construction/facility readiness checklists.
8. **Equipment Procurement & Modification**
   * PO release and equipment change kits ordered (for coating line, stacking/winding, etc.).
   * Equipment modification/upgradation and FAT (if applicable).
9. **Quality & Safety Planning**
   * Freeze control plan, CTQ parameters, in-process and final QC checklist.
   * Define incoming raw material inspection plan.
   * Review Hazard Analysis (FMEA, HIRA, EHS).

**Deliverables:**

* Pilot batch summary report (yield, cycle life, process data)
* Customer feedback report
* Production Quality Audit Report
* Procurement Contracts with Approved Suppliers
* DVP Test Report
* PFMEA, Control Plan V3, Line Capability Data (Cp/Cpk)
* Go/No-Go decision for Gate 4
* To also include the following
  + **Safe-launch control plan**
  + **Measurement system analysis**
  + **Process capability studies – SPC**
  + **Work instructions**
  + **Production trial run [ Low volume / high volume]**
  + **Suppliers PPAP**
  + **Customer PPAP approvals plan**

**Functions:** Cell R&D, Procurement, ME, EHS, Quality, Project, IT, Production, Sales

**Budget:** INR 3–5 Cr (Raw materials, samples, logistics)

**Gate 5: Gigafactory Readiness & SOP Transition**

**Timeline:** Month 19 - Month 22

**Objectives:**

* Transfer learnings and validated processes to Gigafactory
* Implement all the equipment, facility, process, and supply chain changes at Gigaline

**Key Deliverables:**

1. **Facility Upgrade**
   * Utility upgrade execution (dry room upgrades, HVAC, ESD protection, safety systems).
2. **Equipment Modification**
   * Install and commission new jigs, tools, or add-ons.
3. **Process Validation in Gigafactory Environment**
   * Golden Batch production for line tuning.
   * Full process validation on modified equipment.
   * Run >3 PQ batches to demonstrate repeatability.
4. **Raw Material Procurement & Vendor Qualification**
   * Bulk orders initiated with qualified vendors.
   * Monitor incoming quality consistency and vendor NCRs.
   * Supplier audits (if required).
5. **Training & SOP Development**
   * Operator and QA team training.
   * SOPs and work instructions for manufacturing, testing, safety.
6. **Homologation / Certification Finalization**
   * Final certification with cells from Gigafactory (if required by customer).
   * Documentation and test report submission.
7. **Quality Control & Traceability Systems**
   * Implementation of traceability (MES/barcode system).
   * Set up end-of-line testers and in-process checkpoints.
8. **Pre-SOP Audit**
   * Internal & external (customer) audits to validate readiness.
   * Final risk review (PFMEA, HIRA) and approval.

**Activities:**

* Final Process Freeze
* Line Simulation & Capacity Planning
* Training for Gigafactory Staff
* MES/ERP Integration
* Run@Rate Trial @ Gigafactory

**Deliverables:**

* **Customer PPAP Approval**
* **Safe** Launch Approval & Ramp-up Plan
* Training SOPs & Work Instructions
* **Final Production control plan**
* **Customer performances for the initial 3 months and actions**
* SOP Readiness Sign-off

**Functions:** Procurement, ME, EHS, Quality, Project, IT, Production

**Budget:** INR 50–100 Cr (Plant, CapEx, Training, Infrastructure)

**Gate 6: Start of Production (SOP) & Continuous Improvement**

**Timeline:** Month 23 onward

**Objectives:**

* Launch full-scale manufacturing at Gigafactory
* Monitor quality & scale

**Key Activities:**

1. **SOP Launch**
   * First commercial lot delivery
   * Daily/weekly tracking of production metrics
   * Post-SOP review meetings with cross-functional teams
2. **Quality Assurance & Customer Feedback Loop**
   * Monitor in-line quality, customer complaints, failure analysis
   * Use feedback for ongoing improvements
   * Start Reliability Run (e.g. 5000 cells/month tracked for 12 months)
3. **Cost Reduction & Yield Improvement**
   * Identify top 5 cost contributors (material, energy, manpower)
   * Initiate VAVE (Value Analysis/Value Engineering) projects
   * Improve yield from >85% to >95% within first year
   * Based on customer demand/market feedback, initiate variant design
4. **Supply Chain Scale-Up**
   * Optimize supplier contracts for volume scale-up
   * Finalize alternate sources for critical materials

**Activities:**

* Mass production
* Warranty return monitoring
* Performance tracking
* Design optimization for Gen-2/3 variants

**Deliverables:**

* SOP Sign Off
* Monthly Yield & OEE Dashboard
* Warranty & Return Report
* Cost Optimization Plan

**Functions:** Procurement, Quality, Production, Sales