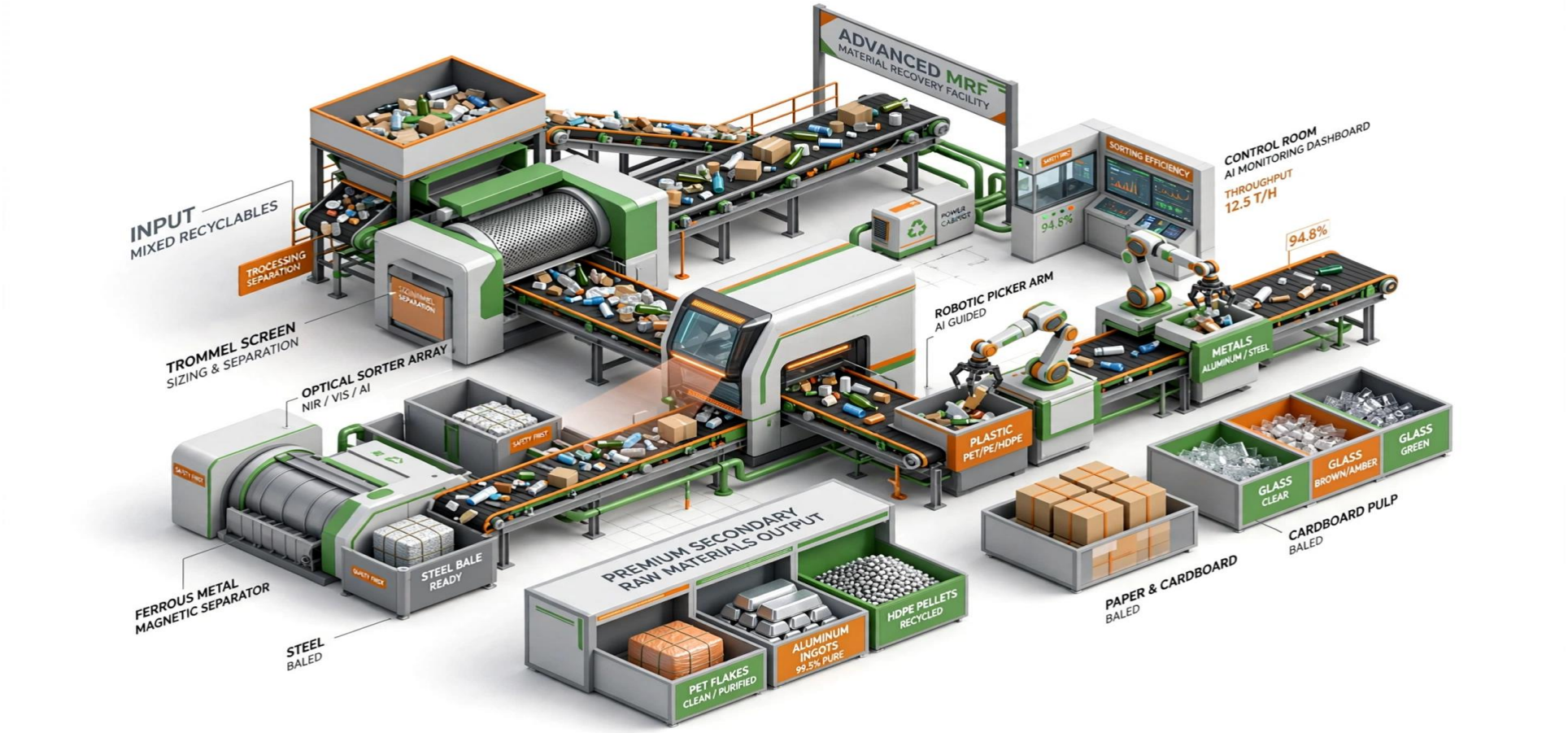
# HIGH-VALUE MATERIALS

# ADVANCED RESOURCE RECOVERY & CIRCULAR MANUFACTURING




High-Value Materials is a core value-creation platform within ADS ECO. It combines digital waste reception, advanced identification, automated separation, purification, quality assurance and market distribution to convert recovered resources into premium secondary raw materials. Operating model maximizes recovery, reduces dependence on virgin materials, lowers landfill disposal and creates diversified revenue streams.

## 01 | VISION, OBJECTIVES & DESIGN PRINCIPLES

Vision: Transform waste into high-value industrial resources, create sustainable revenue streams through material recovery, establish ADS ECO as a regional platform for certified circular feedstocks. Objectives: Maximize material recovery rates, increase resource efficiency, reduce dependence on virgin raw materials, support circular manufacturing, generate long-term economic value, improve ESG performance and traceability.

| Strategic Pillar | Technical Meaning | Business Outcome |
|---|---|---|
| Maximum recovery | Multi-stage sorting, recovery and process control | Higher saleable yield and lower disposal cost |
| Premium quality | Purification, laboratory testing and specification control | Access to higher-value industrial markets |
| Digital traceability | RFID/QR, IoT, SCADA, historian and digital product records | Transparent chain of custody and ESG reporting |
| Circular manufacturing | Conversion into pellets, cullet, fibers, metals and components | Stable internal and external offtake |
| Low-carbon operations | Renewable power, energy-efficient equipment and avoided virgin production | Lower lifecycle emissions |

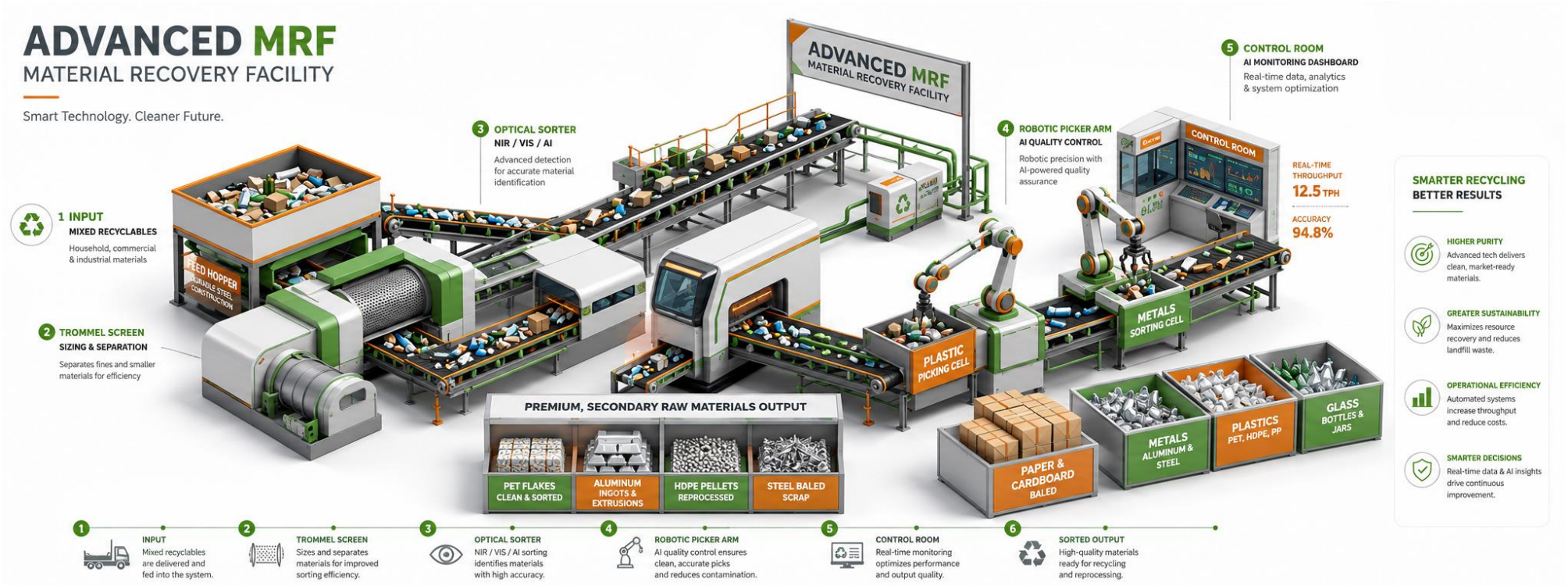
Engineering Design Principles: Design for flexible feedstock variability and seasonal changes; Use modular lines so capacity and product mix can be expanded in phases; Maintain physical separation between clean product areas, dirty reception zones and hazardous-material areas; Specify dust, fire, noise, wastewater and occupational-safety controls at equipment level; Build quality assurance into every stage rather than relying only on final inspection; Create redundant digital records linking incoming loads, process batches, laboratory results and outbound products.

## 02 | MATERIAL STREAMS & PRODUCT PATHWAYS

| Material Stream | Primary Recovery Route | Typical Saleable Outputs | Main End Markets |
|---|---|---|---|
| Ferrous metals | Magnetic separation, shredding, cleaning | Steel scrap grades, iron-rich fractions | Steel mills, foundries, fabrication |
| Non-ferrous metals | Eddy-current, sensor sorting, LIBS/XRT | Aluminum, copper, brass concentrates | Smelters, cable and automotive supply |
| PET & HDPE | NIR sorting, washing, flake/pellet production | rPET flakes/pellets, rHDPE pellets | Packaging, pipes, molded products |
| Engineering plastics | NIR/XRT sorting, density separation, compounding | ABS, PP, PC/ABS specialty compounds | Electronics, automotive, durable goods |
| Glass | Color sorting, crushing, screening, decontamination | Clear/green/amber cullet, glass aggregate | Container glass, insulation, construction |
| Paper & fibers | Optical grading, screening, baling | OCC, mixed paper, recovered fiber pulp | Packaging, paperboard, molded fiber |
| E-waste / WEEE | Dismantling, shredding, magnetic/eddy/XRT | PCBs, copper, aluminum, plastics, critical fractions | Specialized refiners |
| Textiles / biomass | Fiber sorting, cleaning, shredding | Recycled fiber, insulation feedstock, biomass fuel | Textile, construction, energy |

## 03 | INTEGRATED RECOVERY PROCESS – FROM GATE TO MARKET

Digital and physical controls from gate entry to industrial market distribution. Stages: Reception → Identification → Separation → Purification → Conversion → Distribution, each with control parameters and quality gates.



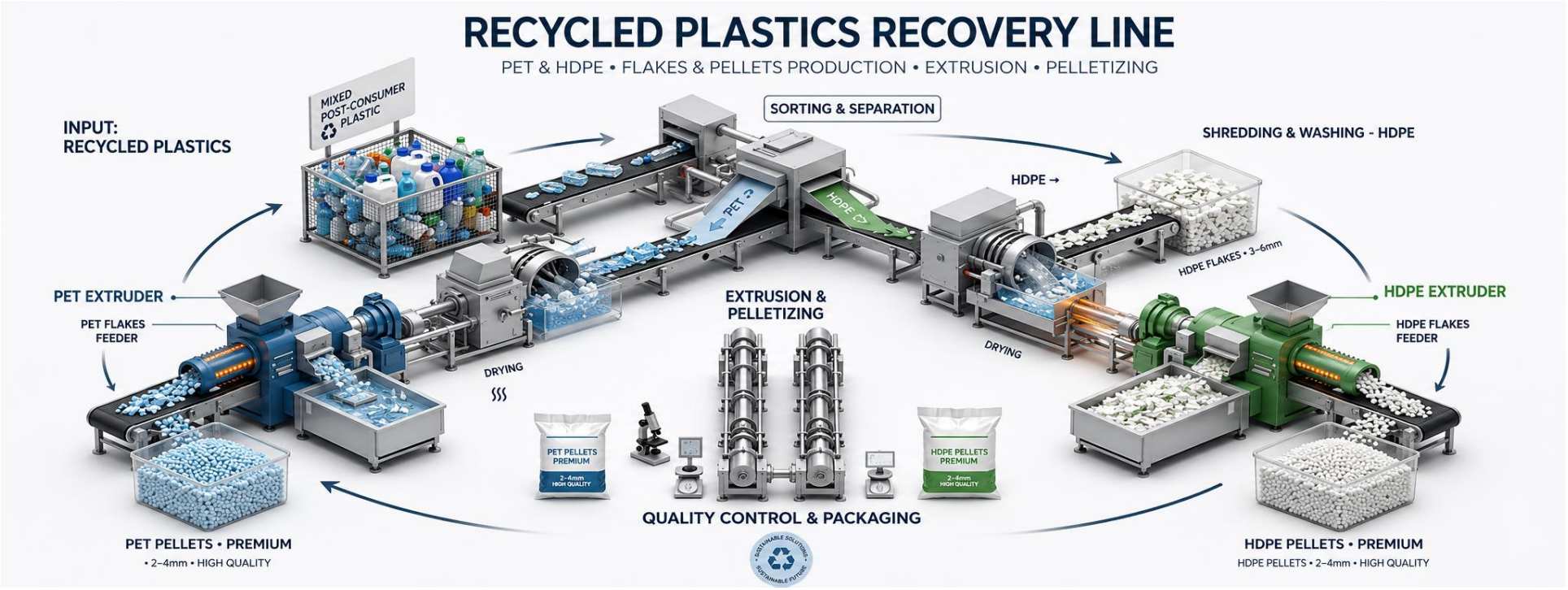

| Process Stage | Main Equipment | Control Parameters | Quality Gate |
|---|---|---|---|
| Reception | Weighbridge, radiation/gas screening, cameras, RFID | Gross/net weight, origin, load type, contamination | Load acceptance and routing decision |
| Identification | NIR/VIS, XRT, machine vision, AI classification | Polymer type, color, density, object recognition | Material class confidence threshold |
| Separation | Robots, magnets, eddy current, air classifiers, screens | Throughput, pick rate, belt speed, recovery efficiency | Recovered fraction purity % |
| Purification | Washing, friction cleaning, flotation, thermal drying | Moisture, residual labels/metals, wash-water quality | Product spec compliance |
| Conversion | Shredding, extrusion, pelletizing, briquetting, baling | Melt flow, particle size, bulk density, bale integrity | Batch release |
| Distribution | Covered storage, silos, WMS, loading systems | Inventory age, lot traceability, transport conditions | CoA and dispatch approval |

## 04 | AI IDENTIFICATION, ROBOTIC SORTING & SENSOR FUSION

Sorting architecture uses sensor fusion rather than single detector. NIR/VIS identifies polymer chemistry and color; XRT distinguishes materials by atomic-density response; LIBS provides rapid elemental composition; Machine vision detects shape, brand, contamination and object class; Magnetic and eddy-current systems recover ferrous and conductive non-ferrous metals. AI models combine signals to improve classification accuracy and adapt to changing feedstock.

| Technology | Primary Function | Typical Control Variables | Integration Requirement |
|---|---|---|---|
| NIR/VIS optical sorting | Polymer and color ID | Wavelength signature, confidence score, belt speed | Stable illumination, clean windows, calibration standards |
| XRT | Density and atomic-number differentiation | Transmission profile, thickness | Radiation shielding and certified safety |
| LIBS | Elemental composition | Laser pulse, spectral lines, alloy class | Fume extraction and reference-library maintenance |
| Robotic pickers | High-speed positive sorting | Pick rate, grip success, trajectory | Vision-to-robot latency and safe cell design |
| Machine vision AI | Object and contamination recognition | Image quality, model confidence, reject logic | Continuous dataset governance and validation |
| Magnetic / eddy current | Metal recovery | Field strength, rotor speed, splitter position | Feed presentation and particle-size control |

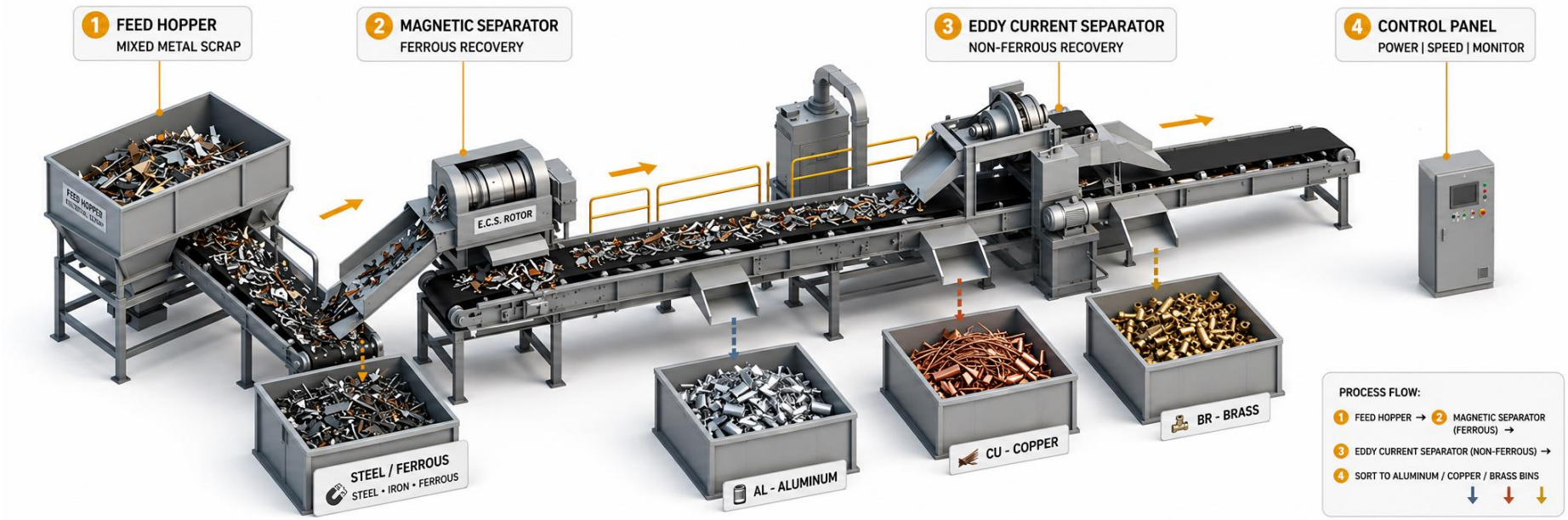
## 05 | PLASTICS & POLYMER RECOVERY




Configuration around polymer identification, contamination removal and conversion into stable, customer-specific grades. Sequence: Pre-sorting → size reduction → dry separation → hot or cold washing as required → friction cleaning → density separation → rinsing → dewatering → drying → optical re-sorting → melt filtration → extrusion and pelletizing. Engineering plastics require separate lines, lower-temperature handling, additive dosing and batch compounding. Key Utility Controls: Closed-loop wash-water clarification with screening, dissolved-air flotation and sludge management; Localized dust and VOC extraction at shredders, dryers and extrusion; Fire detection, spark monitoring and automatic suppression in storage and size-reduction areas; Noise enclosures and predictive maintenance for granulators, blowers and centrifuges.

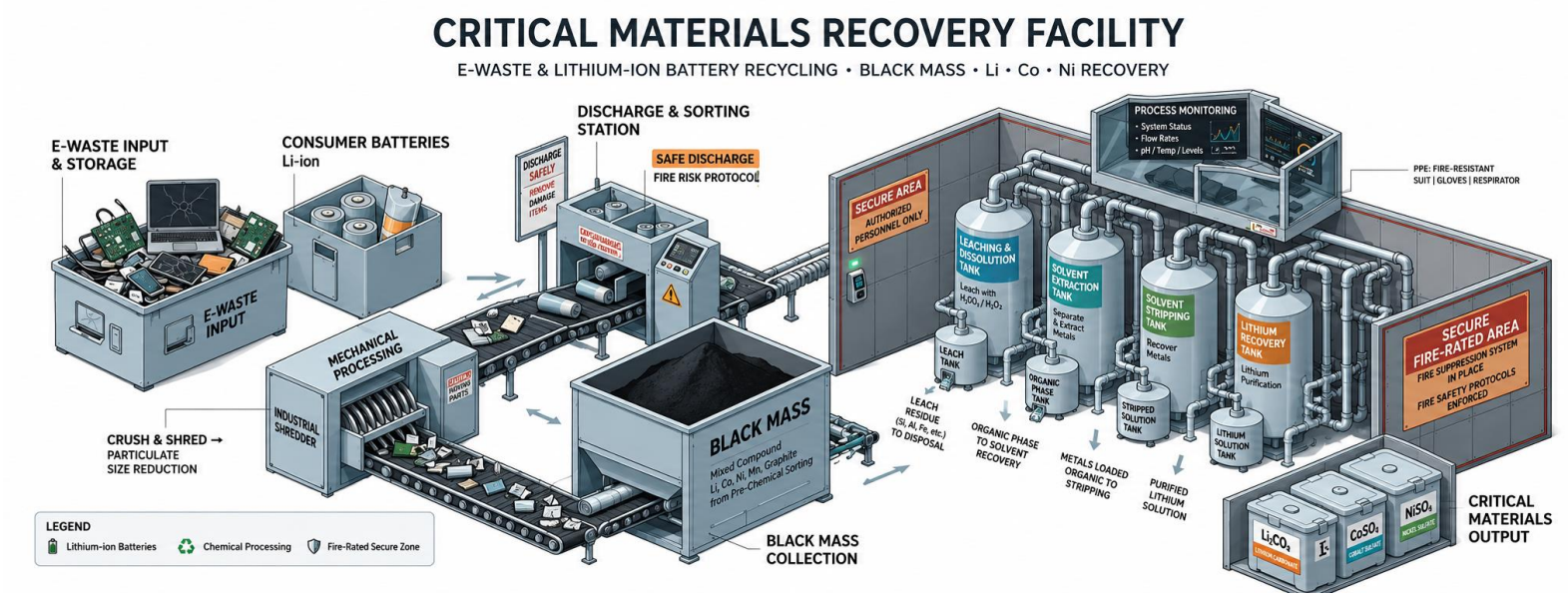
| Parameter | PET / HDPE Target | Engineering Plastics Target | Verification Method |
|---|---|---|---|
| Polymer purity | ≥95% | ≥92-95% by grade | NIR verification and lab composition test |
| Moisture | Typically ≤1% before extrusion | Application-specific, controlled before compounding | Moisture analyzer |
| Metal contamination | Near-zero at extruder inlet | Near-zero at compounder inlet | Metal detector / magnetic trap |
| Melt quality | Stable IV/MFI within customer spec | Stable MFI and mechanical-property profile | Melt-flow, tensile and impact testing |
| Traceability | Lot-linked incoming and outgoing batch records | Recipe and additive traceability | MES / WMS batch record |

## 06 | METALS, GLASS, PAPER, FIBERS & BIOMASS




| Stream | Processing Train | Critical Risks | Premium Product Strategy |
|---|---|---|---|
| Ferrous metals | Magnet → sizing → cleaning → grade separation | Tramp materials, oils, mixed alloys | Consistent scrap grades with low residual contamination |
| Aluminum/copper/brass | Eddy current → XRT/LIBS → robot verification | Mixed alloy chemistry, battery contamination | Alloy-class concentrates and clean copper fractions |
| Glass | Color sort → crush → screen → ceramic/metal removal | Ceramics, stones, heat-resistant glass | Color-controlled cullet and graded aggregate |
| Paper/cardboard | Optical grade sort → screen → bale → moisture control | Wet loads, plastics, waxed fiber | High-density bales with grade and moisture certificates |
| Textiles | Fiber recognition → remove hard parts → shred → clean | Mixed fiber chemistry, chemicals, hygiene | Sorted fiber classes, insulation and composites |
| Wood/biomass | Manual/AI sort → metal removal → chip → dry/grade | Treated wood, nails, excessive moisture | Clean chips, panels feedstock or controlled biomass fuel |

## 07 | E-WASTE, LI-ION BATTERIES & CRITICAL MATERIALS




E-waste and battery streams require dedicated secure areas, trained personnel, specialized fire protection and strict chain-of-custody controls. Incoming units classified before dismantling. Batteries isolated from general shredding, state-of-charge managed, damaged units placed in fire-resistant quarantine. Mechanical treatment can produce black mass and separated copper, aluminum, steel and plastics, while downstream hydrometallurgical or approved specialist refining recovers lithium, nickel, cobalt, manganese and graphite. Note: exact battery-processing technology and permitted scope must be finalized through process safety studies, environmental permitting, fire authority review and specialist licensor design.

| Stage | Technical Requirements | Safety / Compliance Controls | Output |
|---|---|---|---|
| Receiving and quarantine | Battery chemistry identification, visual inspection, insulated handling | Thermal monitoring, fire-rated compartments, spill kits | Accepted lots and segregated risk classes |
| Discharge / preparation | Controlled electrical discharge where applicable | Interlocks, grounding, trained operators | Safe modules/cells for treatment |
| Dismantling | Manual and robotic disassembly, component depollution | ESD control, ventilation, hazardous-part tracking | PCBs, motors, cables, displays, batteries |
| Mechanical separation | Inert or controlled-atmosphere shredding as required | Gas monitoring, explosion prevention, dust capture | Black mass, copper, aluminum, steel, plastics |
| Refining interface | Sampling, assay, packaging and shipment | Dangerous-goods packaging and licensed transport | Certified critical-material concentrate |

## 08 | DIGITAL TWIN, SCADA, IoT & AI QUALITY CONTROL


| Digital Layer | Core Functions | Data Examples | Primary Users |
|---|---|---|---|
| Field and edge | Measurement, machine protection, local control | Speed, vibration, temp, pressure, power, moisture | Operators and maintenance |
| SCADA / historian | Real-time visualization, alarms, trends, audit trail | Equipment status, alarms, downtime, utilities | Control room and engineering |
| MES / production | Batch execution, genealogy, recipes, OEE | Feed lot, process settings, output lot, yield | Production and quality teams |
| Digital twin | Simulation, bottleneck analysis, predictive scenarios | Mass balance, energy balance, equipment degradation | Process engineers and management |
| AI analytics | Classification, anomaly detection, quality prediction | Sensor spectra, camera images, lab results | Sorting and quality teams |
| ESG / reporting | Material traceability, avoided disposal and emissions metrics | Recovered tonnes, diversion, energy use, CO2e | ESG, investors and regulators |

## 09 | QUALITY ASSURANCE & PRODUCT CERTIFICATION

| Product Family | Key Tests | Release Criteria | Typical Record |
|---|---|---|---|
| Recycled polymers | Polymer identity, moisture, MFI/IV, ash, color, contamination | Customer spec and regulatory | Certificate of Analysis (CoA) |
| Metals | Composition, residual contamination, bulk density | Declared grade / alloy class | Weight ticket and assay report |
| Glass cullet | Color, particle size, ceramics/stones/metals, moisture | Furnace or aggregate spec | Cullet quality certificate |
| Paper/fiber | Grade, moisture, prohibited materials, bale density | Buyer grade spec | Bale inspection and moisture record |
| Black mass / critical fractions | Ni/Co/Li/Mn/graphite assay, moisture, impurities | Refiner acceptance spec | Lab assay and chain-of-custody |
| Wood / biomass | Moisture, size, treated-wood exclusion, calorific value | Product or fuel spec | Inspection and test report |

## 10 | INDUSTRIAL APPLICATIONS & OFFTAKE STRATEGY

| Recovered Product | Priority Applications | Commercial Requirement |
|---|---|---|
| rPET / rHDPE / PP compounds | Packaging, pipe, profiles, molded components | Stable color, MFI/IV, contamination and recycled-content evidence |
| Steel and aluminum grades | Foundry, rolling, automotive and fabrication | Grade consistency, traceability and transport density |
| Glass cullet | Container glass, fiberglass, insulation, aggregate | Low ceramic contamination and controlled color |
| Recovered fiber | Paperboard, molded fiber, protective packaging | Moisture, bale density and prohibited-material limits |
| Critical-material concentrates | Battery and metal refiners | Assay accuracy, safe packaging and chain of custody |
| Recycled textile fibers | Insulation, nonwovens, composites | Fiber composition, cleanliness and consistent cut length |

Offtake Contract Principles: Define product specifications, testing methods and rejection limits; Use formula-based pricing linked to recognized commodity or polymer benchmarks where appropriate; Include minimum-volume commitments, delivery windows and quality claims procedures; Establish traceability and recycled-content documentation requirements.

## 11 | ENVIRONMENTAL, HEALTH, SAFETY & FIRE PROTECTION

| Risk Area | Main Hazard | Required Engineering Controls | Management Controls |
|---|---|---|---|
| Shredding and conveying | Dust, entanglement, noise, sparks | Guards, extraction, spark detection, suppression, acoustic enclosure | LOTO, inspections, housekeeping |
| Plastic washing/extrusion | Hot surfaces, chemicals, VOCs, wastewater | Ventilation, bunding, temp interlocks, water treatment | SDS, training, process monitoring |
| Battery handling | Thermal runaway, toxic gases, fire | Quarantine, thermal cameras, gas detection, fire-rated zones | Chemistry ID and emergency plan |
| Metal separation | Sharp materials, projectiles, magnetic fields | Enclosures, guarding, exclusion zones | PPE and maintenance procedures |
| Storage | Combustible inventory and pile fires | Compartmentation, hydrants/sprinklers, pile-size limits | Inventory rotation and fire watch |
| Traffic and logistics | Vehicle-person interaction | Segregated routes, barriers, smart gates, speed control | Traffic plan and driver induction |

## 12 | UTILITIES, INFRASTRUCTURE & LAYOUT

| System | Design Considerations | Monitoring |
|---|---|---|
| Electrical power | Dedicated feeders, harmonics control, high-efficiency motors, backup for critical controls | Power quality, demand, specific kWh/t |
| Compressed air | Dry, filtered air sized for optical ejectors and instruments | Pressure, dew point, leakage |
| Process water | Segregated clean/process loops and maximum recirculation | Flow, turbidity, pH, conductivity |
| Wastewater | Screening, equalization, oil separation, DAF/biological as needed | COD, TSS, pH, discharge/reuse volume |
| Dust extraction | Source capture at shredders, transfer points and screens | Differential pressure, particulate level, filter condition |
| Fire water | Ring main, hydrants, sprinklers/foam or specialist systems | Tank level, pump status, pressure |
| Roads and yards | One-way flows where possible, separate pedestrians, covered loading | Traffic counts, dwell time, incidents |
| Product storage | Covered, dry, segregated lots with WMS location control | Inventory, age, lot status, temperature |

## 13 | KPIs, DATA GOVERNANCE & IMPLEMENTATION ROADMAP

| KPI | Definition / Formula | Indicative Target | Frequency |
|---|---|---|---|
| Material recovery rate | Saleable recovered ÷ eligible incoming | 90%+ where feasible | Daily / monthly |
| Material purity | Target material mass ÷ total batch | 95%+ for premium grades | Per batch |
| Yield by stream | Released product tonnes ÷ feed tonnes per line | Line-specific baseline | Shift / daily |
| OEE | Availability × performance × quality | Progressive ramp-up to world-class | Shift / monthly |
| Specific energy use | Electricity and fuel ÷ processed tonnes | Continuous reduction vs baseline | Daily / monthly |
| Water recirculation rate | Reused process water ÷ total demand | Maximize subject to quality | Monthly |
| CO2e benefit | Avoided disposal + avoided virgin − operating | Verified methodology and annual assurance | Quarterly / annual |

| | | | |
|---|---|---|---|
| | emissions | | |
| Traceability completeness | Batches with complete genealogy ÷ all dispatched | 100% | Weekly / monthly |

| Phase | Key Activities | Primary Deliverables |
|---|---|---|
| 1. Concept validation | Feedstock characterization, market study, options analysis, preliminary mass balance | Basis of Design and preferred process configuration |
| 2. Basic engineering | PFDs, equipment sizing, layout, utility loads, HAZID | Basic engineering package and CAPEX/OPEX estimate |
| 3. Permitting and procurement | ESIA, permits, performance specs, tendering, contracts | Approved permits and supplier packages |
| 4. Detailed design and construction | Civil, mechanical, electrical, automation, lab and fire systems | Installed and inspected facilities |
| 5. Cold and hot commissioning | I/O tests, dry runs, feed trials, calibration, performance testing | Commissioning records and acceptance tests |
| 6. Ramp-up and optimization | AI model tuning, operator training, customer qualification, debottlenecking | Stable product grades, target throughput and quality |
| 7. Continuous improvement | Digital twin optimization, predictive maintenance, new-product development | Higher yield, lower unit cost and expanded markets |