A Wood-to-Wood Cascade Upcycling Valorisation Approach

» Deliverable 16.2

Skills activities, trainings and lifelong learning programmes (version 1)

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PROJECT INFORMATION

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Dissemination Level		
PU	Public	X
RE	Restricted to a group specified by the consortium	
CO	Confidential, only for members of the consortium (including the European Commission Services)	

Legal Disclaimer

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GLOSSARY OF ACRONYMS

Acronym	Extended Definition
W2W	Wood2Wood
UML diagram	Unified Modeling Language diagram
CD	Construction and demolition
LCNF	Lignocellulosic nanofibers
NIPU	Non-isocyanate polyurethane
HTC	Hydrothermal Carbonization
LCA	Life cycle assessment
PLA	Polylactic Acid
LIDAR	Light Detection and Ranging
FDM	Fused Deposition Modeling
SLS	Selective Laser Sintering

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EXECUTIVE SUMMARY

The adoption of Industry 4.0 technologies, particularly within circular and digitalized manufacturing ecosystems, necessitates a structured and human-centered transformation approach. This deliverable, titled "Skills Activities, Trainings and Lifelong Learning Programmes," is part of WP16 and focuses specifically on the People dimension of the 6Ps methodology, aiming to enhance workforce capabilities in alignment with the evolving demands of digital transformation. Emphasis is placed on the identification of emerging job profiles, the mapping of critical competencies, and the formulation of targeted training interventions that support the upskilling and reskilling of professionals across multiple use cases.

This deliverable targets both internal stakeholders (use case partners) and external organizations. Internal users can follow a structured path from role profiles in Section 4 and project analyses in Sections 5 and 6 to relevant training courses in Section 7. External organizations can consult Section 7 for an overview of key roles and associated training opportunities, with detailed role descriptions available in Section 4.

This deliverable was originally intended to be published directly on the project website, as agreed with ISWA (website owner) and VTT (WP leader), to enhance accessibility and usability. Dedicated subpages were planned to allow different user groups—such as internal stakeholders and external organizations—to easily navigate to the most relevant sections. However, due to unforeseen technical issues with the website, this structure could not be implemented, and the content has been compiled in this document instead.

Research Background and Methodology: The research is grounded in a review of recent literature on digital transformation and sustainability in manufacturing sectors, with particular attention to the wood industry and adjacent circular value chains. The methodological foundation is provided by the 6Ps framework, originally developed under the MIDIH project[1], with this deliverable operationalizing its People dimension. The analysis involved systematic data collection through interviews, AS-IS / TO-BE assessments, and partner consultations across the Wood2Wood project use cases. This approach enabled a comparative analysis of current versus future workforce requirements and supported the development of a comprehensive roadmap for skill development.

New Roles, Professions, and Relevant Skills: As a first step, the project defined a range of new and evolving job roles, each aligned with the digital and sustainable transformation objectives of the participating organizations. These include roles such as AI/Robotics Integration Engineer, Bioreactor Technician, and Polymer Process Engineer, among others. Two structured surveys were administered to consortium partners to (i) prioritize critical skills for each role and (ii) assess the extent to which these skills are currently possessed within each organization. This dual-assessment revealed significant skill gaps—particularly in areas related to AI integration, process automation, and sustainable material processing—and provided a basis for structured training and workforce planning.

Workshop and Validation Activities: To complement the quantitative findings, a validation workshop was conducted with internal and external stakeholders. This session confirmed the relevance of the identified roles and emphasized ongoing difficulties in sourcing expertise in AI,

[1] https://midih.eu

data analytics, robotics, and sustainable engineering. Participants also highlighted structural barriers such as limited internal training resources and uncertainties around return on investment. The workshop reinforced the value of practical, immersive learning experiences, including joint pilot activities, partner exchanges, and modular online training, to foster applied skills and readiness for Industry 4.0 adoption.

Training Activities: In response to the identified gaps, the deliverable curated a set of over 36 training programs from reputable platforms, including POLIMI Open Knowledge, Coursera, Udemy, and Alison, each of them identified for the ten roles identified in support of the skills development of the project partners. These programs were evaluated and categorized according to a three-tiered framework: Awareness (introductory knowledge), Foundation (practical competencies), and Extended Know-How (advanced application). The classification was further aligned with organizational strata—Managerial, Professional, and Operational—ensuring that training content is tailored to the diverse learning needs of different workforce segments. This structured approach supports both immediate capacity-building and longer-term skills evolution across the consortium.

Next Steps: Building on these findings, the next phase of the People methodology will involve deeper analysis of use case-specific activities and the continuous expansion of the training catalogue. This includes the evaluation of additional learning resources and the development of a dedicated training webpage within the official project website.

1. INTRODUCTION

1.1. ABOUT THIS DELIVERABLE

Deliverable D16.2 titled "Skills Activities, Trainings and Lifelong Learning Programmes," in the context of task 16.2 navigates the future of skill development and this is the first version at M18 which has been purposefully designed as a clear and accessible, non-technical document, intended for readers with general familiarity with European research initiatives, without necessitating advanced domain-specific knowledge. Within the context of the Wood2Wood project, this report addresses two principal stakeholder groups.

The intended audience for this deliverable comprises both internal stakeholders (i.e., use case partners) and external (other) organizations. Internal stakeholders can easily locate information tailored to their specific needs, particularly the role profiles outlined in Section 4, which are structured according to each use case. By referring to the analyses presented in Sections 5 and 6—conducted during the initial phase of the project—partners can further navigate to Section 7 to identify the most relevant training courses aimed at addressing identified skill gaps.

For external organizations, Section 7 offers a consolidated overview of key roles and the corresponding training opportunities, allowing them to explore suitable capacity-building initiatives. Additional background and contextual details for each role can be found in Section 4.

1.2. STRUCTURE OF THE DELIVERABLE

The structure of this deliverable is organized into the following chapters. The introductory section (Chapter 1) outlines the general aim and structural organization of the document. The main analytical content is presented in Chapters 2 through 7, each addressing one of the central thematic areas under investigation. The concluding part, comprising Chapters 8 and 9, offers a synthesis of the primary findings, provides final reflections, and outlines proposed next steps. It concludes with a comprehensive list of referenced sources.

Chapter 2 – Research Background and Relevant Reports: This section presents a critical overview of recent literature and empirical contributions addressing the evolving nature of skill requirements and employment patterns in digitally transforming sectors. It also revisits the theoretical underpinnings of the 6Ps methodology, placing particular emphasis on the People dimension. This component serves as a key analytical lens for assessing workforce capacity and organizational preparedness in the context of digital and sustainable transition.

Chapter 3 – Initial Analysis: Interviews and Flow Charts: This section captures the preliminary qualitative analysis based on structured interviews conducted with partners across various use cases. Unified Modeling Language (UML) diagrams are employed to represent core workflows, operational roles, and skills, offering a visual synthesis of the insights gathered through the interviews.

Chapter 4 – New Roles, Professions, and Relevant Skills: In this section, a set of emerging job roles and their corresponding skill sets are introduced. These have been defined in direct relation to the technological activities and organizational needs identified within each use case. The identified roles reflect the broader transition towards digitalized and circular production models across the project domains.

Chapter 5 – Results of the Questionnaires: This chapter reports the outcomes of two structured surveys administered during the early stages of the project: the skills prioritization ("Voting") survey and the "Possessed vs. Needed" assessment. The findings offer a snapshot of current (AS-IS) competencies, enable the identification of critical skills for each role, and highlight skill gaps across different organizational contexts.

Chapter 6 – Workshop Findings: This section synthesizes the results of a participatory workshop conducted with both internal and external stakeholders in April 2025. The workshop served as a validation exercise to complement the survey data and provided additional qualitative insights into current challenges, capacity-building needs, and future workforce planning strategies.

Chapter 7 – Training Activities: Informed by the preceding interviews, surveys, and workshop insights, this section presents a curated set of training programmes tailored to the identified skills and organizational needs. The courses are categorized according to three proficiency levels—Awareness, Foundation, and Extended Know-How—and are further differentiated by role (managerial, professional, operational). The training resources and content of this deliverable are intended to be made accessible through the project's official website, thereby promoting open access and practical utility for a diverse group of stakeholders. This approach was agreed upon with ISWA (the website owner) and VTT (the WP leader); however, at the time of writing this deliverable, unforeseen technical issues with the website have prevented its implementation.

2. RESEARCH BACKGROUND AND RELEVANT REPORTS

2.1. An Overview of Digital Transformation

Transforming the Workforce in the Wood Sector

The global labor landscape is experiencing profound transformation, driven by the rapid integration of digital technologies and demographic shifts within the workforce. These changes are especially critical in the context of process and continuous manufacturing sectors, including the wood industry, where Industry 4.0 technologies—such as Artificial Intelligence (AI), advanced data management, and automation—are reshaping occupational roles and associated skillsets. Moreover, the shift towards circular economy principles has introduced an additional layer of complexity and opportunity, urging industries to redesign production systems with sustainability and resource efficiency in mind (Geissdoerfer et al., 2017). Addressing these concurrent shifts requires the restructuring of traditional work processes alongside the deployment of anticipatory education and training strategies aimed at equipping the workforce for a future-ready, circular-driven economy.

Industry 4.0, Human-Centered Transformation, and Circularity in Wood Manufacturing

Industry 4.0, often described as the Fourth Industrial Revolution, is defined by the fusion of cyber-physical systems, data-centric technologies, and intelligent manufacturing practices (Lasi et al., 2014). These innovations enable enhanced production efficiency, reduced development timelines, and higher degrees of product customization. Within the wood manufacturing sector, these technologies are increasingly aligned with circular economy objectives—such as minimizing waste, maximizing reuse of wood by-products, and extending product life cycles through digital tracking and predictive maintenance (Zhou et al., 2022). Consequently, new job profiles are emerging that demand expertise in systems thinking, abstraction, problem-solving, and cross-platform collaboration.

The concept of "Operator 4.0" (Romero et al., 2016) encapsulates the evolving role of industrial workers who are envisioned as proactive, digitally fluent contributors with enhanced autonomy and decision-making capabilities. In circular-oriented wood production systems, these operators are expected not only to manage technologically enhanced workflows but also to contribute to sustainability assessments and material recovery strategies, reinforcing the dual goals of efficiency and environmental stewardship.

Emerging Skill Demands and Educational Implications

The World Economic Forum's Future of Jobs Report (2023)[2] identifies technological adoption as the principal catalyst for transformation over the coming years, encompassing widespread integration of AI, big data analytics, and cloud-based platforms. These technologies both generate new employment avenues—particularly in data science, sustainability assessment, and cyber-physical integration—and displace conventional clerical and transactional roles.

[2] World Economic Forum, Future of Jobs Survey 2023:https://www.weforum.org/publications/the-future-of-jobs-report-2023/

Of particular concern is the finding that approximately 60% of the global workforce will require upskilling or reskilling by 2027, yet current access to training remains limited for nearly half of all workers. The competencies most in demand include:

i. Analytical and critical thinking

ii. Creativity and problem-solving

iii. AI and data analytics proficiency

iv. Leadership and influence skills

v. Adaptability, resilience, and curiosity

In circular wood manufacturing, such skills are essential not only for operational efficiency but also for understanding material flows, life cycle impacts, and eco-design principles. Notably, two-thirds of employers anticipate measurable returns on workforce training investments—such as improved productivity, increased cross-functional mobility, and enhanced job satisfaction—within a single year (WEF, 2023).

Online Learning and the Rise of Digital Training Ecosystems

Online and hybrid learning modalities have expanded considerably, particularly following the global shift in work patterns catalyzed by the COVID-19 pandemic. Enrollments in digital skill programs—focusing on areas such as information technology, data analytics, and sustainable production—have seen substantial growth (WEF, 2020)[3]. This reflects a broader demand for flexible, scalable educational models that serve both active professionals and job seekers.

Between 2020 and 2025, digital learning platforms have experienced substantial growth, solidifying their role in continuous professional development and addressing critical skill shortages. The global e-learning market is projected to reach $457.8 billion by 2026, reflecting a compound annual growth rate of 9.1% since 2018 . In the wood sector, such platforms are instrumental in disseminating circular economy knowledge, best practices in digitalized material tracking, and data-driven approaches to lifecycle thinking.[4]

2.2. People Dimension Analysis

The 6Ps methodology, implemented in the Wood2Wood project, was originally developed by Politecnico di Milano as part of the Horizon 2020 MIDIH project. This structured framework is designed to assist organizations in assessing their current digital maturity, establishing target maturity levels within a defined time horizon, and subsequently formulating a roadmap to guide their digital transformation (Spaltini et al., 2022).

[3] WEF 2020: https://www3.weforum.org/docs/WEF_Future_of_Jobs_2020.pdf
[4] https://upskillwise.com/online-learning-statistics/?utm_source=chatgpt.com

Figure 1 6Ps Digital transformation tool

As depicted in the accompanying figure, the methodology is built upon six core dimensions—collectively known as the 6Ps—which encompass three technical pillars (Product, Process, Platform) and three socio-organizational pillars (People, Partnership, Performance). The objective of this framework is to enable effective digital transformation strategies by evaluating each dimension and identifying the necessary tools, services, and competencies required to achieve the predefined objectives. Within WP16 (specifically Deliverable D16.2, Task 16.2), the methodology has been employed with particular emphasis on the People dimension. The main focus lies in evaluating and advancing education and skills development in the context of digitalization.

This dimension-specific analysis involves a detailed investigation of job functions and occupational profiles across different Use Cases within the project. Crucially, the approach goes beyond evaluating existing roles; it is also designed to identify and define new professional roles and emerging skillsets that may not yet be embedded within participating organizations but are projected to become essential in the near future. These new roles are indicative of the evolving demands brought about by digital transformation, where traditional positions may need to be restructured or supported through new competencies.

To operationalize the methodology, a systematic multi-step approach was adopted. Initially, interviews and qualitative assessments were conducted across all Use Cases, focusing on specific operational contexts and organizational needs. Drawing from this data, relevant roles and competencies were defined by mapping domain-specific activities and aligning them with established references, such as those from Politecnico di Milano's Osservatori Digital Innovation[5], the "Skills for Industry 4.0" framework (Pinzone et al., 2023), and other pertinent academic sources.

Subsequently, two targeted surveys were developed. The first survey aimed to prioritize the identified skills associated with each role, relying on the practical insights and experiences of project partners. The second survey sought to measure the current (AS-IS) and anticipated (TO-BE) status of these roles and skills within each organization. To enrich and validate the data collected, a dedicated workshop was conducted with both internal and external stakeholders. This

[5] https://eng.osservatori.net/

collaborative session facilitated the refinement of findings and offered a deeper understanding of emerging workforce needs.

Finally, relevant training courses were identified and examined in relation to the validated roles and skillsets. These courses were classified into three levels—Awareness, Foundation, and Extended Know-How—ensuring that they address diverse organizational contexts and training requirements. The subsequent sections provide a comprehensive overview of these implementation steps, demonstrating the methodological rigor and collaborative engagement that underpinned the process.

3. INITIAL ANALYSIS – INTERVIEWS AND FLOW CHARTS

As part of the methodology implementation, a series of structured interviews were conducted with key partners involved in each use case in the project. These interviews aimed to capture detailed insights into the specific operational contexts, digitalization needs, and workforce challenges unique to each use case. The qualitative data gathered through these engagements served as the foundation for the development of individualized UML charts, each reflecting the core processes, role dynamics, and skill requirements identified within the respective use case. These visual representations not only facilitated a clearer understanding of current workflows but also served as diagnostic tools to inform the identification of potential gaps and opportunities for digital transformation and skills development.

Use Case: Waste Stream Management

The Waste Stream Management use case, led by ICCS under WP5, focuses on the systematic handling of Construction and Demolition (CD) waste through advanced sorting, characterization, and separation processes. Based on interviews conducted with ICCS experts, the workflow begins with the classification of CD waste into two primary material streams: glass and wood. The process is initiated using robotic and intelligent systems to automate the preliminary sorting phase, followed by size modification procedures led jointly by ICCS and IRIS. For glass materials, the modified outputs are classified into four distinct categories—'Pure' and 'Impure' among them—before being redirected to appropriate W2W use cases.

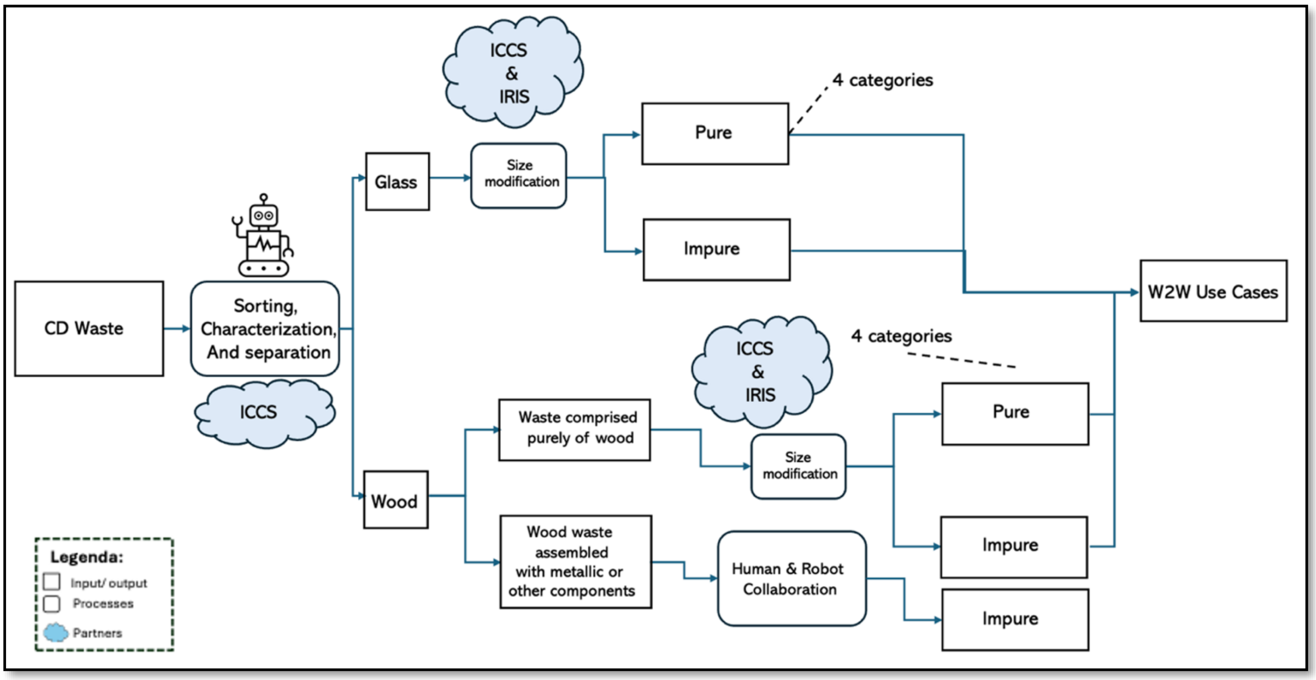

Figure 2 Waste Stream Management

Wood waste undergoes a more nuanced treatment depending on its composition. Waste comprised purely of wood is separated and sent through size modification processes, whereas wood waste combined with metallic or other composite materials requires human and robotic collaboration to manage the disassembly. Both streams—after their respective treatments—are subsequently evaluated and categorized into 'Pure' or 'Impure' classes, each grouped under four categories to align with downstream circularity objectives. This structured approach supports the broader goal of material recovery and reintegration into circular industrial applications, enabling optimized reuse, minimization of environmental impact, and operational efficiency in wood-based manufacturing ecosystems.

Use Case # 1 : CDW treatment via cascade bio refinement with separation lignin and cellulose

The Use case #1 process starts with the lignin production process, managed by UHE, that involves the recovery of lignin following the cooking and filtration of biomass. This is achieved through anti-solvent precipitation, whereby the liquor is diluted with water to induce lignin precipitation. The resulting solid is then separated via filtration and subsequently dried at 50°C to yield the final lignin product, intended for integration into biocomposite materials. Concurrently, UHE oversees the production of lignocellulosic nanofibers (LCNF) from the solid cellulose fraction obtained post-cooking. This material undergoes successive stages of water washing, dilution, and fiber size reduction using ultraturrax homogenization. Further refinement is achieved through multiple cycles of high-pressure homogenization, resulting in LCNFs with the characteristics required for biocomposite formulation.

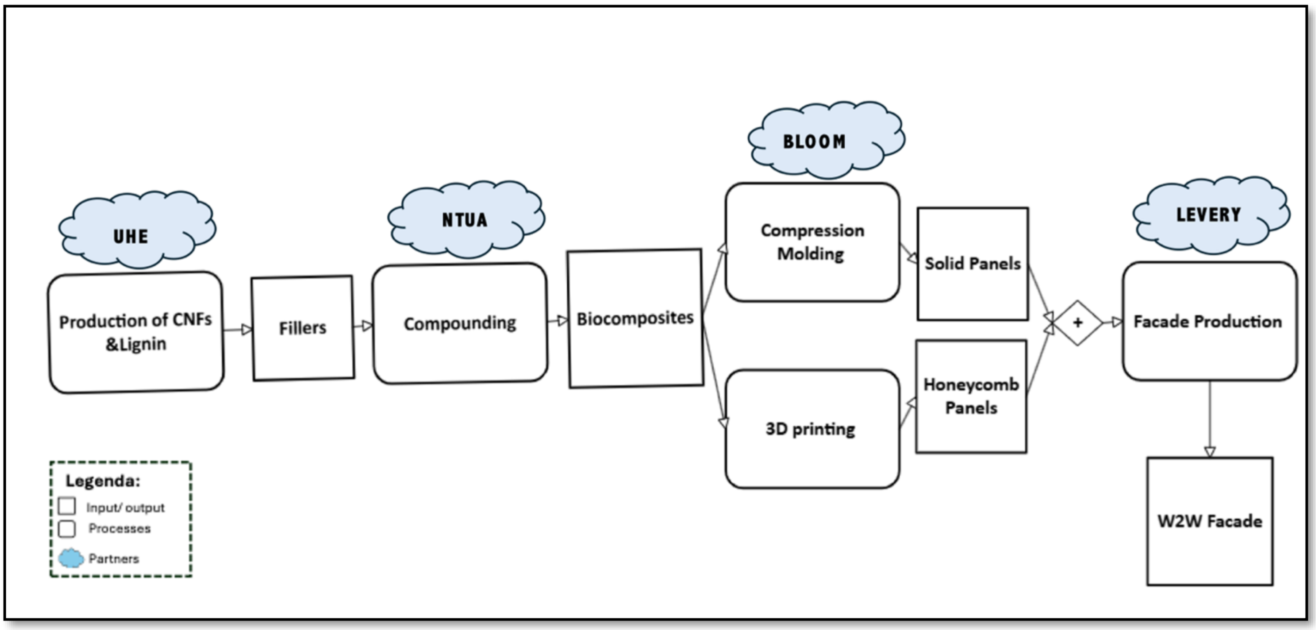

Figure 3 CDW treatment via cascade bio refinement with separation lignin and cellulose

The biocomposite compounding phase, conducted by NTUA, begins with the thermal pre-treatment of PLA polymer pellets, which are dried at 80°C for four hours. The dried pellets are then compounded with lignin and LCNFs using a twin-screw extrusion process operated at 190°C, with precise feeder and extruder speeds set at 3 rpm and 80 rpm, respectively. The extrudate is pelletized and subjected to an additional drying step. To ensure long-term material stability, anti-hydrolysis agents such as Carbodilite HMV-15CA and Stabaxol P110 are incorporated. Panel manufacturing is carried out by BLOOM and LEVERY. BLOOM employs two approaches: compression molding for solid panels—which includes drying, molding, heating/pressing, cooling, demolding, and cleaning—and 3D printing for honeycomb panels, involving filament preparation and printing. LEVERY performs the final assembly for facade systems, including profile and frame assembly, installation of insulation materials, and application of vapor and air sealing systems. This detailed process mapping has supported the definition of Life Cycle Assessment (LCA) system boundaries and has facilitated structured data collection across all sub-process stages.

Use Case # 2 : Waste management treatment by removing additives, via advanced chem and bio techs

A detailed UML model has been constructed to systematically illustrate the process flow, interdependencies, and transformation stages involved in Use Case 2. This model serves not only to represent the full operational logic of the use case but also to clarify the sequence of activities, material inputs and outputs, intermediate products, and the responsibilities of each project partner. It acts also as a functional reference for conducting Life Cycle Assessment (LCA), supporting the delineation of system boundaries and the organization of consistent data collection across stages. The visual framework enables a clear understanding of how raw wood feedstock is processed and transformed into final construction materials.

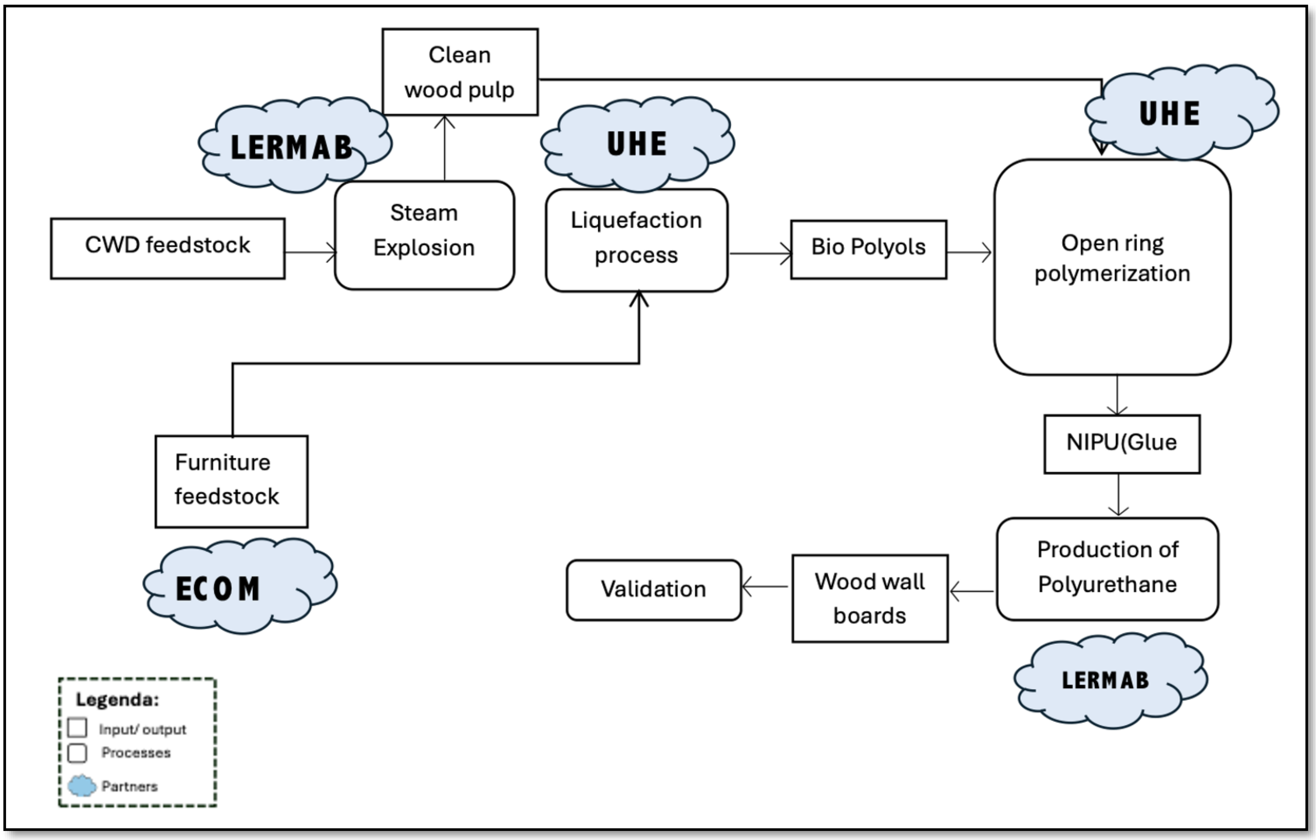

Figure 4 Waste management treatment by removing additives

The model outlines the primary processing stages as follows: Steam Explosion, carried out by LERMAB, involves the pre-treatment and purification of waste wood to generate clean wood pulp. Liquefaction, conducted by UHE, converts this wood feedstock into bio-polyols through the application of chemical reagents. These bio-polyols, together with the wood pulp, are then used in the Open Ring Polymerization stage—also managed by UHE—to synthesize non-isocyanate polyurethane (NIPU) adhesives. This stage, recently finalized and validated within the project, is a critical step in the material formulation process. Lastly, Final Wallboard Production, led by LERMAB, involves the polymerization of the components into the final wallboard product. Throughout the model, the functional roles of each partner and the associated data flows are explicitly defined, ensuring coherence between technical operations and LCA requirements.

Use Case # 3 : Integrated Waste Valorization Pathway for Bio-Based Detergent Production: A Multi-Stage Thermochemical and Biotechnological Process

Use Case 3 focuses on the valorization of both solid and liquid waste streams through a multi-stage biochemical and thermochemical conversion process aimed at producing sustainable detergent products. The process begins with the treatment of liquid and solid waste in a Hydrothermal Carbonization (HTC) reactor, operated by CIRCE, to produce hydrochar. This intermediate product is then subjected to gasification, also led by CIRCE, resulting in the release of H_2O and CO_2. These gaseous by-products serve as feedstock for a biotechnological conversion stage, managed by KIVERDI, where they are processed in a biotech reactor to synthesize dodecanol, a key carbon compound essential for detergent formulation.

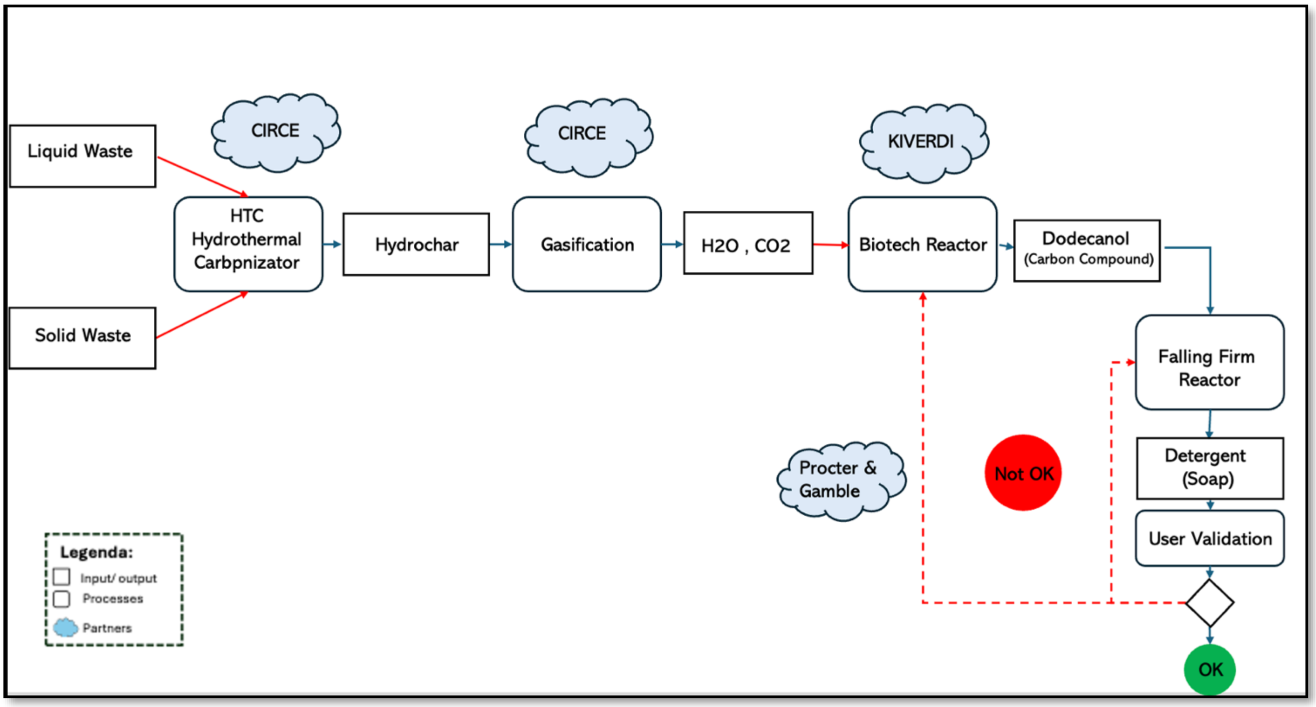

Figure 5 Integrated Waste Valorization Pathway for Bio-Based Detergent Production

Once dodecanol is produced, it is introduced into a falling film reactor to undergo the final transformation into detergent (soap). This product is then evaluated through user validation, with Procter & Gamble providing feedback on performance and suitability. In the event that the detergent does not meet functional or qualitative standards (as indicated by the "Not OK" feedback loop), the process reverts to the biotech stage for optimization. This structured, circular pathway integrates waste conversion, bio-based chemistry, and iterative product validation, contributing to sustainable consumer product innovation.

4. NEW ROLES, PROFESSIONS AND RELEVANT SKILLS

This section outlines the identification of a range of roles and corresponding skill sets (in the bullet points), derived from the specific activities undertaken by various organizations across different pilot implementations within the project's use cases. The following sections provide a structured classification of these roles, categorized according to their respective use case.

Use Case: Waste Stream Management

- **Waste Management and AI / Robotics Integration Engineer**

This role is responsible for designing and implementing machine learning algorithms that enhance the sorting, characterization, and separation processes in waste management. This role includes developing models for waste classification, optimizing robotic operations, and collaborating with other engineers to integrate AI solutions into existing systems.

i. Expertise in developing and implementing machine learning algorithms specifically tailored for waste classification, robotic sorting, and process optimization in waste management
ii. Proficiency in integrating AI with robotic systems, enabling collaboration between human operators and robotic arms for enhanced sorting efficiency and operational performance.
iii. Advanced programming skills in Python and R, with a focus on data-driven model development for real-time waste sorting and characterization tasks.
iv. Skilled in analyzing complex and heterogeneous waste datasets to uncover patterns, improve the precision of waste classification models, and optimize separation processes.

- **Robotics Automation Engineer**

This role is responsible for designing, developing, and maintaining robotic systems used in the sorting and separation of waste materials. This role involves working closely with AI developers to ensure seamless integration of robotics with machine learning algorithms, as well as conducting tests to optimize robotic performance.

i. Expertise in designing robotic systems tailored for specific waste management applications.
ii. Proficiency in programming languages such as C++ or ROS (Robot Operating System) for robot control and automation.
iii. Knowledge of control systems used in robotics for precise operation and automation.
iv. Familiarity with simulation tools (e.g., Gazebo, V-REP) for testing robotic designs virtually before physical implementation.
v. Experience with integrating sensors (e.g., cameras, LIDAR) that assist robots in identifying and sorting materials.

Use Case # 1 : CDW treatment via cascade bio refinement with separation lignin and cellulose

- **Polymer Process Engineer**

The Polymer Process Engineer is responsible for developing and optimizing polymer processing techniques to achieve specific material properties and efficiency in product quality. This role extends to the chemical and mechanical processing of waste wood, where the engineer will manage the separation of lignin from cellulose fibers and the subsequent production of cellulosic nanofibers. The engineer will also contribute to scaling processes from laboratory to industrial environments and exploring data-driven techniques like machine learning for enhanced efficiency.

i. Strong understanding of structure-property relationships in polymers.
ii. Knowledge of biodegradable polymer composites, particularly PLA-based materials, and their applications in construction.
iii. Experience in scaling processes from laboratory to industrial environments.
iv. Familiarity with machine learning techniques for process optimization and predictive modeling.
v. Effective collaboration and communication skills for interdisciplinary teams.
vi. General skills in root cause analysis, continual improvement, and quality assurance.

- **ML Process Optimization Engineer (Extrusion Systems)**

This role plays a pivotal role in the integration of ML/AI technologies into industrial material science processes such as polymer processing and extrusion. The engineer develops ML models to analyze operational parameters from extrusion processes and create predictive algorithms that can enhance material quality and process efficiency through real-time monitoring.

i. Expertise in machine learning and data-driven modeling for optimizing polymer extrusion processes.
ii. Experience applying ML techniques to manufacturing environments, particularly in polymer processing and extrusion.
iii. Proficiency in working with sensor data (e.g., pressure, temperature, torque) to enhance extrusion process efficiency and monitor operational parameters.
iv. Advanced data analysis and preprocessing skills for effective model development and integration into extrusion processes.

- **Research Engineer, Polymer Additive Manufacturing**

The Research Engineer, Polymer Additive Manufacturing focuses on the research and development of polymer-based materials and technologies for additive manufacturing (3D printing). This role involves the optimization of polymer formulations, printing processes, and post-processing techniques to achieve desired material properties and performance. The engineer works in collaboration with scientists, product developers, and manufacturing teams to push the boundaries of polymer-based 3D printing for both industrial and consumer applications.

i. Strong understanding of polymer chemistry and material science, particularly with thermoplastics and thermosetting polymers used in additive manufacturing.
ii. In-depth knowledge of additive manufacturing techniques (e.g., FDM, SLS, SLA), focusing on polymer-based printing processes.
iii. Familiarity with polymer-based 3D printing techniques and equipment.
iv. Ability to innovate new materials or technologies that improve the efficiency and performance of additive manufacturing.
v. Familiarity with CAD software (e.g., NX, SolidWorks, AutoCAD) and 3D printing slicer tools for preparing models and optimizing them for printing.

Use Case # 2 : Waste management treatment by removing additives, via advanced chem and bio techs

- **Chemical Analysis Specialist (PhD/Postdoc Level)**

The Chemical Analysis Specialist conducts chemical and physical tests on materials (e.g., green glue, polyurethane) to ensure they meet quality standards. This role involves analyzing data from material characterization tests, collaborating with production teams to improve material quality, maintaining detailed records of test results, and ensuring compliance with industry regulations.

i. Advanced chemical analysis of material properties (e.g., NIPU glue, polyurethane, wood fibers): Ability to conduct detailed chemical and physical tests to ensure material quality and performance in industrial applications, using advanced tools such as Molecular Dynamics Software (e.g., LAMMPS, Materials Studio) for material interaction modeling, Finite Element Analysis (FEA) for performance simulation, HPLC for chemical component analysis, and data analysis software like MATLAB, or Python libraries (e.g., SciPy, Pandas).
ii. Expertise in analytical techniques such as liquid chromatography, mass spectrometry, and high-performance thin-layer chromatography (HPTLC): These techniques are used to analyze the chemical composition of wood fibers, adhesives, and composite materials in both lab and industrial settings.
iii. Proficiency in operating laboratory instruments for chemical analysis: Familiarity with instruments for testing chemical and physical properties of materials like green glue and wood composites, ensuring the accuracy of data collected.
iv. Skilled in interpreting material test results using statistical methods: Ability to apply statistical tools (e.g., ANOVA, regression analysis) to evaluate material quality and improve processes based on test data, supporting material optimization and compliance with industry standards.

- **Production Data Analyst (with AI/ML Integration Potential)**

The Production Data Analyst is responsible for collecting, analyzing, and interpreting data from material testing, production processes, and operational performance, particularly in the context of steam explosion, polymerization, and wood fiber treatment. This role focuses on identifying inefficiencies and optimizing workflows by analyzing data patterns. Additionally, the analyst explores opportunities to integrate AI/ML models to predict outcomes and improve decision-making processes in material science and production activities.

i. Proficiency in analyzing large datasets related to production performance: Skilled in evaluating production data (e.g., steam pressure, material composition, and operational metrics) to identify trends that impact efficiency and material quality
ii. Expertise in statistical software (e.g., Python, R) for data analysis: Competence in using tools to process and analyze production and material testing data, generating actionable insights
iii. Ability to identify inefficiencies based on data patterns: Expertise in detecting inefficiencies or bottlenecks in the production workflow (e.g., material processing times, equipment usage), enabling process improvements.
iv. Proficiency in applying machine learning algorithms (e.g., regression, classification, clustering): Skilled in using AI/ML techniques to develop predictive models that can forecast production outcomes and material performance, facilitating data-driven decision-making.

Use Case # 3 : Integrated Waste Valorization Pathway for Bio-Based Detergent Production: A Multi-Stage Thermochemical and Biotechnological Process

- **Thermochemical Process Engineer (HTC and Gasification)**

The Thermochemical Process Engineer is responsible for designing, optimizing, and monitoring hydrothermal carbonization (HTC) and gasification processes. This role focuses on conducting experiments and simulations to validate process designs, integrating AI and machine learning models to enhance process efficiency, and collaborating with cross-functional teams to improve the production of biochar, syngas, and downstream products. The engineer ensures all processes comply with environmental regulations and safety standards relevant to high-pressure, high-temperature operations in waste processing.

i. Expertise in designing and optimizing thermochemical processes such as hydrothermal carbonization (HTC) and gasification: Ability to lead experiments and improve process designs based on data analysis.
ii. Proficiency in using simulation tools for modeling chemical processes: Skilled in running simulations to validate the performance of HTC and gasification systems under various operating conditions.
iii. Advanced analytical skills for interpreting complex datasets: Skilled in analyzing operational data to identify bottlenecks and enhance process efficiency.
iv. Familiarity with high-pressure and high-temperature sensor and control systems: Experienced in managing the instrumentation and control systems needed for safe and efficient operation of HTC and gasification reactors.
v. Understanding of environmental regulations and safety standards: Well-versed in ensuring all process designs and operations adhere to industry standards for waste processing and sustainable energy production
vi. Knowledge of integrating AI and machine learning models into process design: Ability to leverage AI/ML for optimizing thermochemical processes, improving automation, and enhancing predictive capabilities for biomass gasification.

- **Thermochemical Machinery Operator**

This role is responsible for operating machinery used in HTC and gasification processes. This role focuses on conducting routine maintenance, adhering to safety protocols during operations, documenting operational parameters, and ensuring optimal performance of equipment.

i. Expertise in operating machinery specific to HTC and gasification processes.
ii. Proficiency in performing routine maintenance and troubleshooting mechanical issues: Ability to perform routine maintenance and resolve mechanical issues effectively, with awareness of basic predictive models and tools to schedule predictive maintenance, ensuring timely interventions to enhance equipment reliability and reduce downtime.
iii. Awareness of basic AI tools that assist in monitoring equipment performance.
iv. Familiarity with recording operational data for performance analysis.
v. Understanding of safety standards for operating high-pressure systems.

- **Bioreactor Technician (Syngas-to-Detergent Process)**

This role is responsible for managing bioreactor setups for detergent production from syngas. This role focuses on monitoring bioprocess parameters, optimizing conditions for microbial growth, collaborating with research teams to validate product quality, and maintaining accurate records of experimental procedures.

i. Proficiency in managing bioreactors, incorporating statistical models and AI/ML tools for optimizing fermentation parameters and predicting system performance.
ii. Understanding of microbial cultures and their applications in detergent production.
iii. Competence in using advanced data analytics tools and machine learning algorithms for real-time monitoring, anomaly detection, and performance optimization in bioprocesses.
iv. Experience with laboratory equipment and procedures related to bioprocessing.
v. Skill in adjusting bioreactor conditions (e.g., pH, temperature), leveraging predictive models and AI tools to forecast optimal environmental parameters and maximize yields.
vi. Expertise in chromatography with integration of AI-enhanced data processing and statistical analysis to improve accuracy and streamline product characterization.

5. RESULT OF QUESTIONNAIRES

The aim of this chapter is to elucidate the fundamental components that define the skill-related surveys implemented within the framework of the project. It encompasses an overview of the survey objectives, the identification of the targeted respondent groups, and a synthesis of the principal findings obtained through the data collection process.

5.1. VOTING SURVEY

The primary objective of this survey[6] is to establish the prioritization of skills associated with each identified role and profession. It is designed to capture the perspectives of project partners by leveraging their practical experience and domain-specific insights. Moreover, the survey facilitates the re-evaluation of skill priorities and enables respondents to propose the inclusion or exclusion of particular skills based on their perceived relevance and necessity. The survey was principally directed toward all members of the project consortium, including both use case participants and non-use case partners. A total of 13 respondents from various organizations participated in the survey. The instrument consisted primarily of structured multiple-choice questions with ranking elements, where respondents were invited to select relevant skills for each role and prioritize them based on perceived importance. The results were analyzed quantitatively, using a simple rating method whereby each skill's percentage was calculated as the number of votes it received divided by the total number of responses. The survey covered all four use cases and allowed for cross-comparison of role-specific skill needs across different contexts. a link to the questionnaire is provided in the footnote. While the analysis was primarily quantitative, the percentage-based structure allowed for insight into the relative importance of each skill across roles and organizations.

Use Case: Waste Stream Management

- **Waste Management and AI / Robotics Integration Engineer**

The prioritization survey conducted among project partners aimed to assess the most critical competencies associated with the role of Waste Management and AI/Robotics Integration Engineer. Based on the feedback collected, there is a clear emphasis on the need for advanced technical capabilities that facilitate the integration of artificial intelligence within robotic systems. Partners particularly highlighted the importance of aligning AI and robotics to enhance real-time decision-making, automate waste classification, and improve operational efficiency across waste management processes. This suggests that cross-disciplinary expertise bridging AI, robotics, and environmental systems is regarded as a foundational requirement for this emerging role.

[6] https://polimi.eu.qualtrics.com/jfe/form/SV_6W0MuIv9niQiiz4

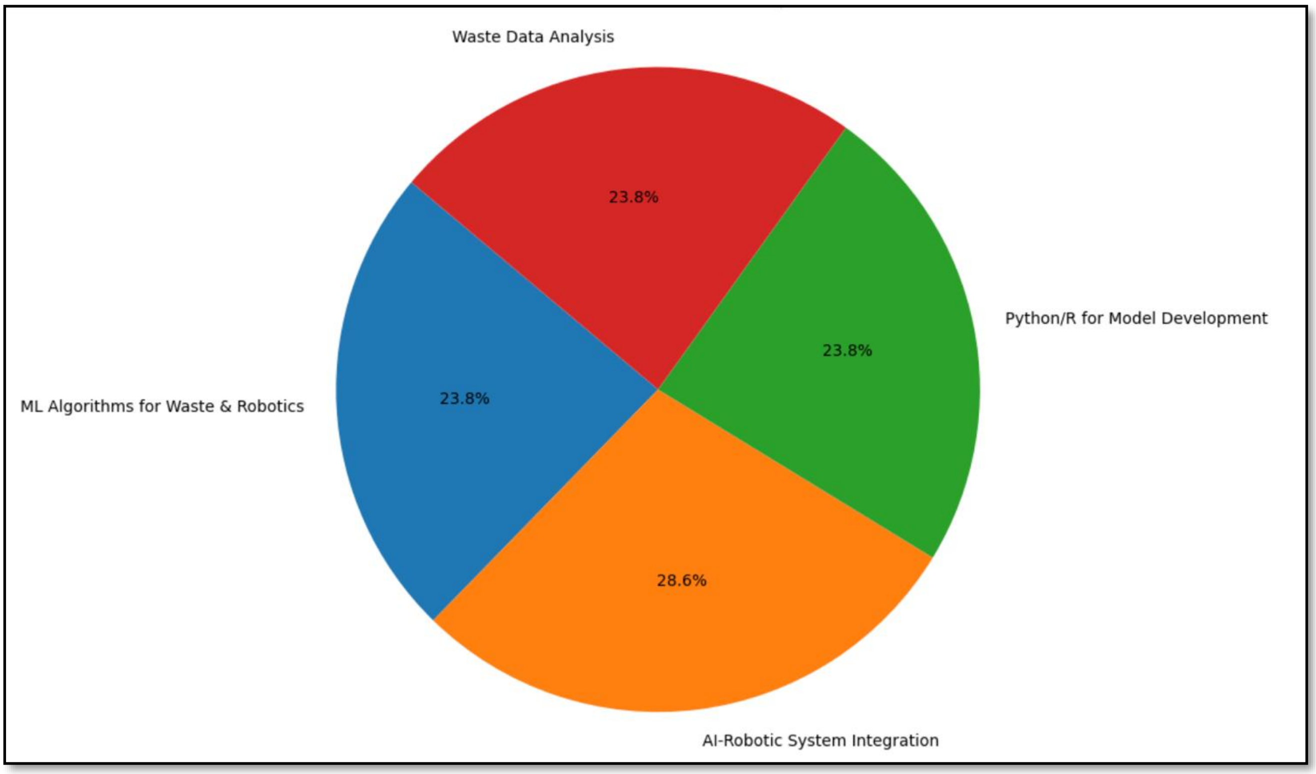

Figure 6 Voting survey: Waste Management and AI / Robotics Integration Engineer

Furthermore, the survey responses reflect a strong consensus on the relevance of data-centric skills, especially in the context of handling large-scale, heterogeneous waste datasets. Proficiency in programming languages such as Python and R is also recognized as essential, underpinning the development of machine learning models for real-time applications. The consistent prioritization of these skills across multiple partners underscores the necessity for engineers in this domain to possess both domain-specific environmental knowledge and technical fluency in AI-driven automation. These insights provide valuable guidance for the development of tailored training programs and curricula aligned with real-world industry demands.

- **Robotics Automation Engineer**

The results of the skill prioritization survey for the role of Robotics Automation Engineer reveal a strong consensus on the importance of core competencies related to robotic system design for waste management contexts. Respondents emphasized the critical need for expertise in developing application-specific robotic solutions that address operational challenges within the waste processing environment. This prioritization suggests that partners view the ability to customize robotic hardware and workflow as fundamental to achieving efficiency and scalability in automation-driven waste systems.

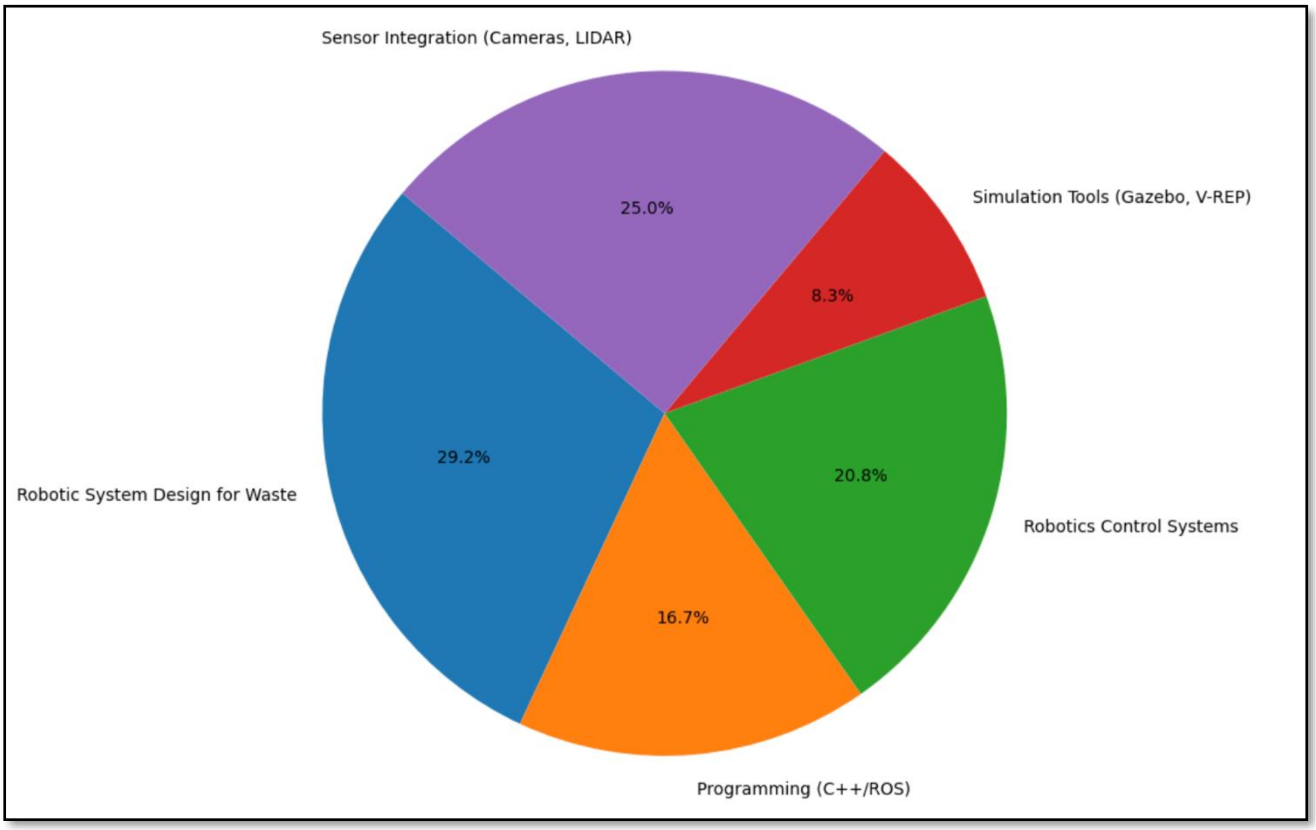

Figure 7 Voting survey: Robotics Automation Engineer

In addition, there is considerable recognition of complementary technical skills that support effective robotic deployment, including sensor integration, control system knowledge, and proficiency in robot programming. While simulation tools received relatively lower emphasis, familiarity with tools such as Gazebo or V-REP is still considered a useful, albeit secondary, skill for early-stage validation. The overall feedback underscores the importance of a well-rounded robotics engineer who can combine practical programming, mechanical design, and sensor-based automation for optimized material handling in circular economy applications.

Use Case # 1 : CDW treatment via cascade bio refinement with separation lignin and cellulose

- **Polymer Process Engineer**

The survey results for the Polymer Process Engineer role indicate a strong prioritization of domain-specific knowledge in polymer science, particularly regarding the structure-property relationships that govern material performance. Respondents also placed high importance on expertise in biodegradable polymer composites, with a specific emphasis on PLA-based materials used in construction applications. This emphasis reflects the increasing relevance of sustainable materials in industrial contexts and highlights the need for engineers to possess advanced technical understanding of both traditional and emerging polymer systems.

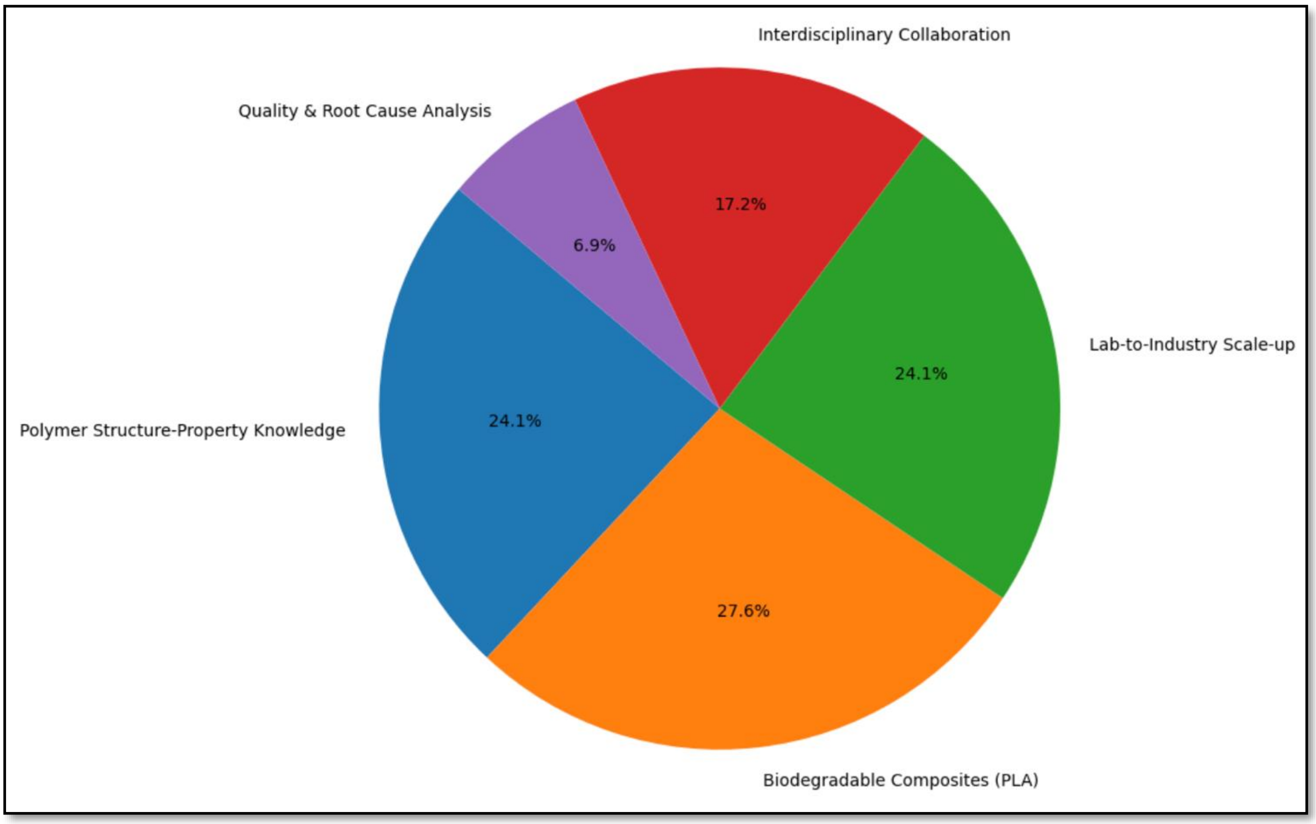

Figure 8 Voting survey: Polymer Process Engineer

Furthermore, partners highly valued experience in process scalability, signifying the importance of transitioning innovations from laboratory settings to full-scale industrial implementation. While competencies in communication and collaboration were moderately emphasized—especially in support of interdisciplinary project environments—skills related to machine learning for process optimization were not considered a priority at this stage. General quality assurance and root cause analysis received lower rankings, suggesting that domain expertise and scale-up capability are currently viewed as more critical for this role's impact within the project's objectives.

- **ML Process Optimization Engineer (Extrusion Systems)**

The survey responses for the Machine Learning (ML) Process Optimization Engineer – Extrusion Systems role reveal a strong emphasis on the practical application of machine learning within manufacturing environments. In particular, the ability to apply ML techniques specifically to polymer processing and extrusion is regarded as a top priority by project partners. This underscores the need for domain-specific ML expertise, where contextual knowledge of industrial workflows is integrated with algorithmic optimization to enhance material throughput, quality, and process stability.

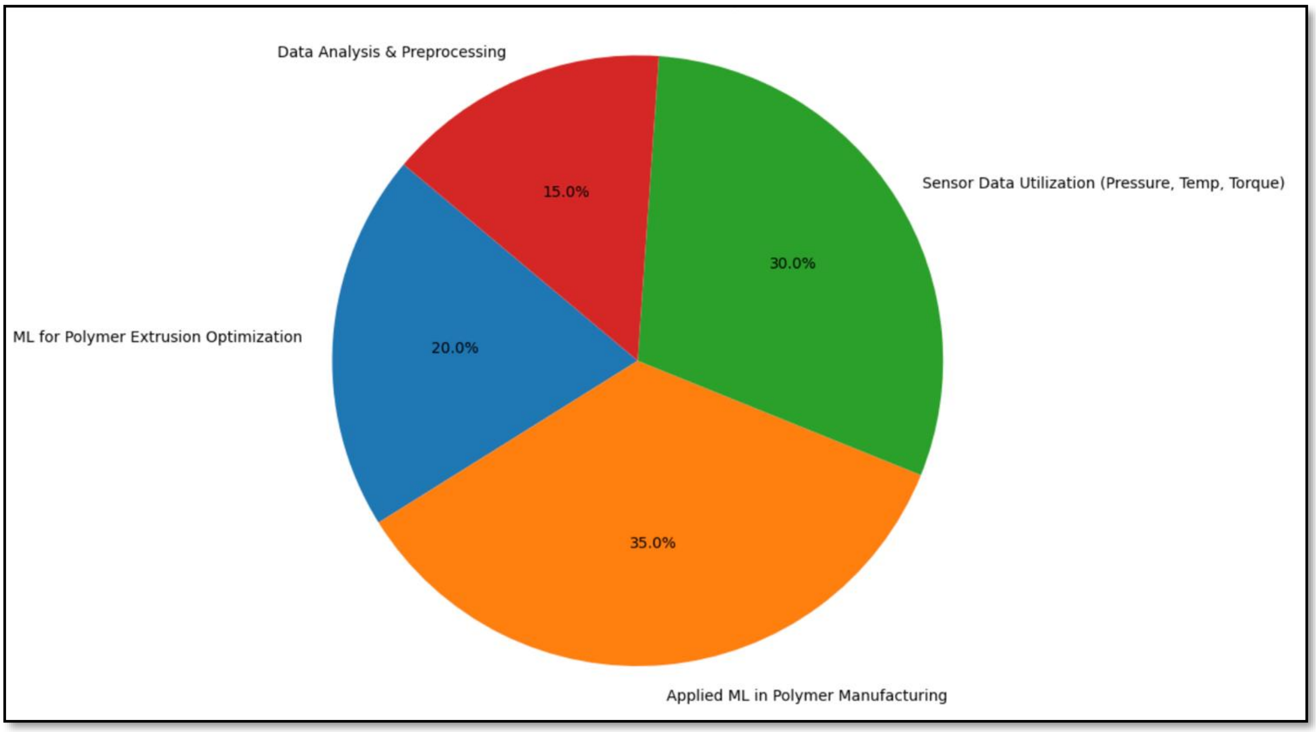

Figure 9 Voting survey: ML Process Optimization Engineer (Extrusion Systems)

Additionally, proficiency in handling sensor-based data—such as pressure, temperature, and torque readings—was identified as a critical skill, highlighting the role of real-time data acquisition in monitoring and refining extrusion systems. While foundational ML and data modeling competencies were valued, they were ranked slightly lower than applied, context-driven experience. Similarly, advanced data preprocessing skills were given moderate importance, suggesting that while data engineering is essential, the highest value is placed on deploying ML models in real-world extrusion systems for measurable process improvements.

- **Research Engineer, Polymer Additive Manufacturing**

The survey findings for the Research Engineer in Polymer Additive Manufacturing role indicate a high prioritization of fundamental expertise in polymer chemistry and additive manufacturing processes. Respondents emphasized that a deep understanding of both thermoplastics and thermosetting polymers, particularly within the context of additive manufacturing, is essential for effective performance in this role. Likewise, comprehensive knowledge of advanced 3D printing techniques—such as Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), and Stereolithography (SLA)—was rated as the most critical competency. This underscores the necessity for engineers to master process-specific material behavior and optimize print outcomes accordingly.

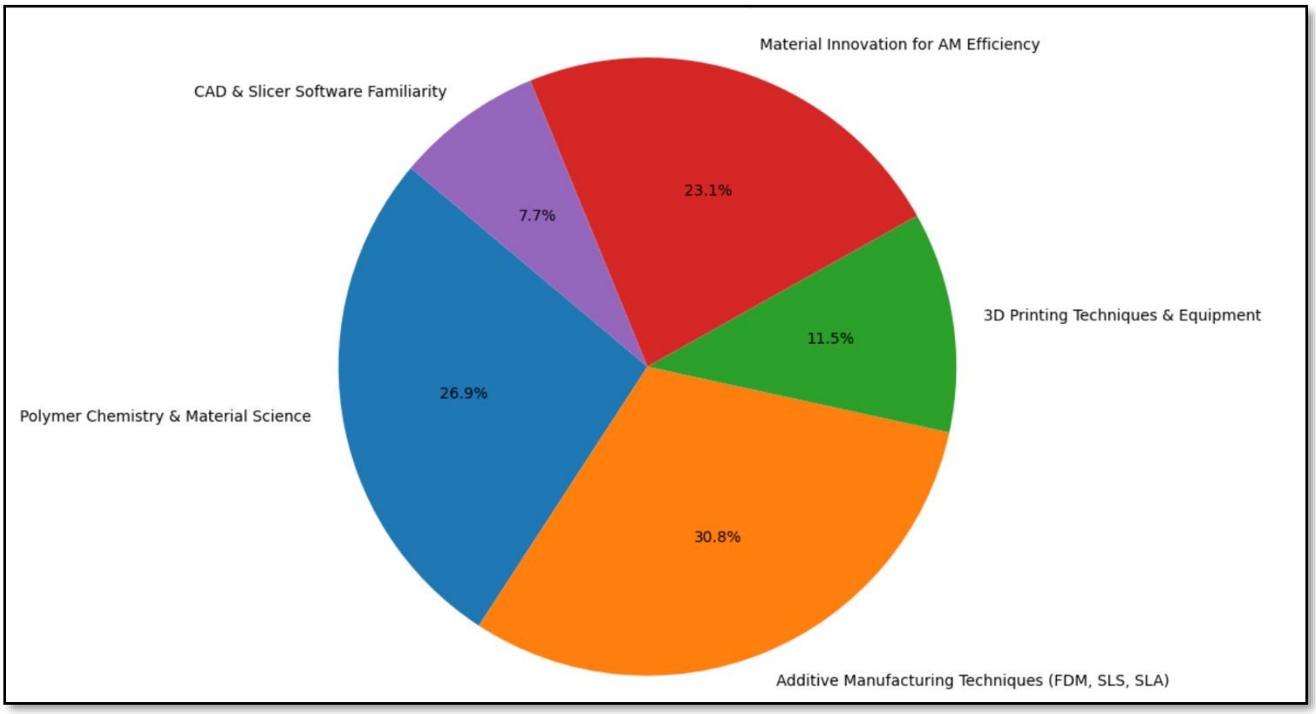

Figure 10 Voting survey: Research Engineer, Polymer Additive Manufacturing

Beyond foundational knowledge, partners also recognized the importance of innovation in materials and process improvement, reflecting a growing need to push the boundaries of existing polymer printing capabilities. However, familiarity with 3D printing hardware and software tools, including CAD programs and slicer utilities, was viewed as comparatively less important, potentially because these tasks may often be delegated to technical operators or supported by automated systems. Overall, the results highlight a preference for research engineers who can lead material innovation while maintaining a strong command of core additive manufacturing principles.

Use Case # 2 : Waste management treatment by removing additives, via advanced chem and bio techs

- **Chemical Analysis Specialist (PhD/Postdoc Level)**

The survey results for the role of Chemical Analysis Specialist (PhD/Postdoc Level) emphasize a strong need for hands-on expertise in laboratory instrumentation and experimental techniques for analyzing the chemical and physical properties of advanced materials, such as NIPU adhesives, wood fibers, and polymer composites. Among the highest-prioritized competencies is proficiency in operating laboratory equipment to ensure the accuracy and reliability of experimental results. This reflects the practical demands of both industrial and research settings, where material characterization must meet rigorous quality assurance standards.

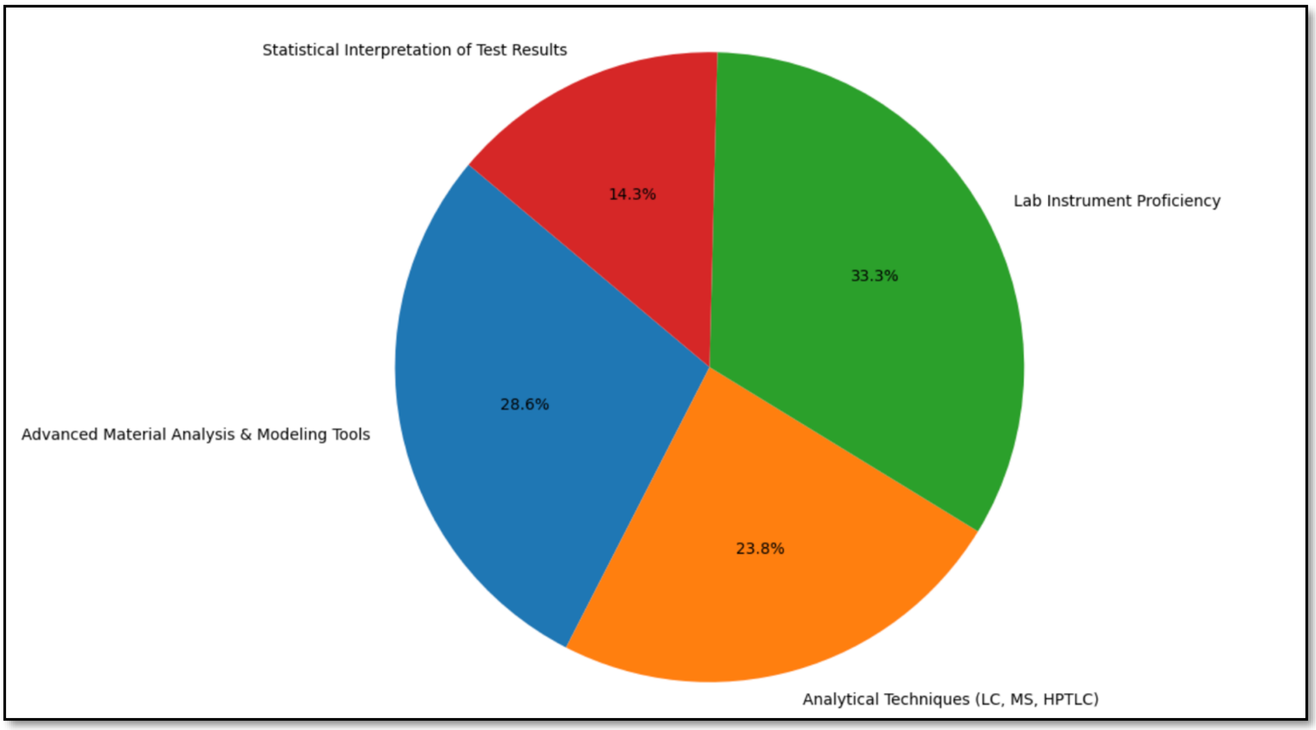

Figure 11 Voting survey: Chemical Analysis Specialist (PhD/Postdoc Level)

In addition to operational proficiency, respondents highlighted the value of experience with advanced chemical analysis techniques—including chromatography, mass spectrometry, and simulation software for modeling material behavior. While statistical interpretation skills were recognized as useful, they were rated as a lower priority relative to other, more hands-on competencies. Overall, the findings suggest that for this highly specialized research role, the emphasis lies on direct material testing capabilities, complemented by the use of digital modeling and analytical tools to support data-driven material development and validation.

- **Production Data Analyst (with AI/ML Integration Potential)**

The prioritization survey for the Production Data Analyst (with AI/ML Integration Potential) role highlights a clear emphasis on practical data analysis skills that support process efficiency and quality improvement in production environments. Respondents rated highly the ability to analyze large datasets capturing operational metrics—such as steam pressure, material composition, and equipment performance—to identify performance trends. Additionally, the capacity to detect inefficiencies or bottlenecks based on data patterns was also seen as a critical competency, reinforcing the need for analysts who can contribute directly to real-time process optimization and productivity enhancement.

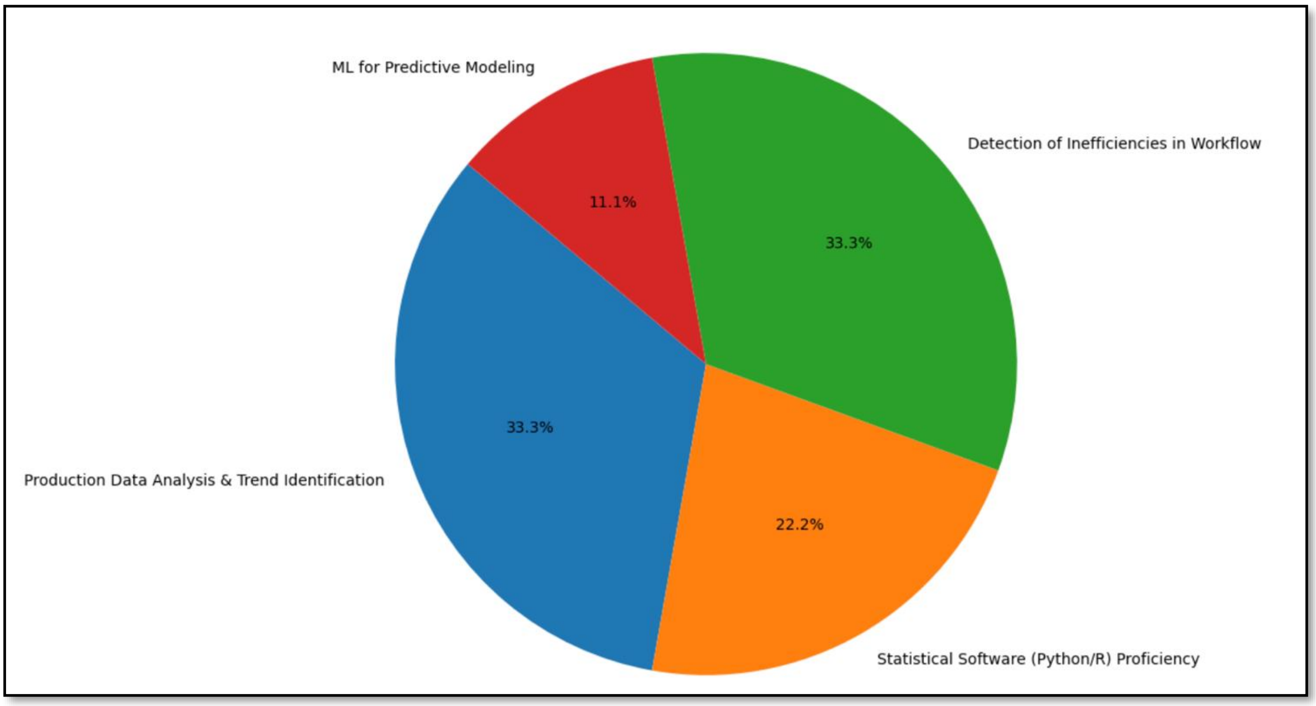

Figure 12 Voting Survey: Production Data Analyst (with AI/ML Integration Potential)

While statistical programming proficiency in tools such as Python and R is recognized as important for processing production-related datasets, the application of machine learning techniques received comparatively lower prioritization. This suggests that, at the current stage, partners may favor analysts with strong diagnostic and statistical capabilities over those focused on predictive modeling or algorithm development. Nevertheless, as AI/ML technologies continue to mature, this skill may become increasingly relevant for more advanced analytics integration within production systems.

Use Case # 3 : Integrated Waste Valorization Pathway for Bio-Based Detergent Production: A Multi-Stage Thermochemical and Biotechnological Process

- **Thermochemical Process Engineer (HTC and Gasification)**

The survey results for the Thermochemical Process Engineer (HTC and Gasification) role reveal a strong consensus among respondents regarding the critical importance of hands-on expertise in designing and optimizing thermochemical processes. The ability to lead experimental activities and iteratively enhance process designs—particularly in hydrothermal carbonization (HTC) and gasification systems—was ranked as the highest priority. This highlights the need for engineers who can drive process innovation through a combination of practical experience and data-informed decision-making, especially in circular and bioenergy applications.

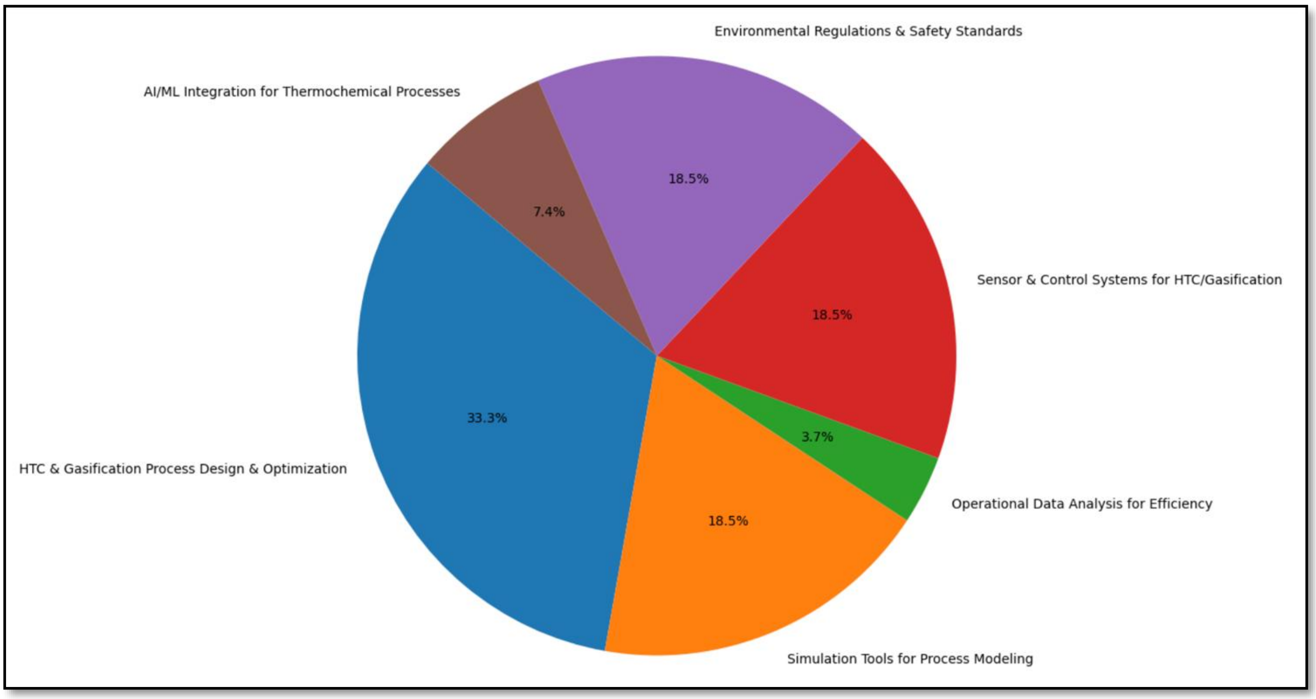

Figure 13 Voting survey: Thermochemical Process Engineer (HTC and Gasification)

Other key competencies include proficiency in simulation tools, knowledge of control systems, and familiarity with regulatory frameworks—all of which were rated with moderate to high importance. These skills support safe, compliant, and performance-optimized operation of complex thermochemical systems. In contrast, advanced data analytics and AI/ML integration were given lower priority, indicating that while these capabilities are emerging, they are not yet central to the core functional expectations for this role. Overall, the survey results suggest a preference for engineers with a strong foundation in process engineering, safety compliance, and simulation, with growing—but still secondary—interest in digitalization and AI-enhanced optimization.

- **Thermochemical Machinery Operator**

The survey responses for the role of Thermochemical Machinery Operator indicate a clear prioritization of practical, hands-on expertise in operating machinery associated with hydrothermal carbonization (HTC) and gasification processes. Respondents emphasized that direct operational knowledge of these systems is the most critical competency for ensuring smooth and effective daily functions in industrial settings. This reflects the high reliance on skilled technicians to manage thermochemical units that operate under demanding conditions, requiring precision and familiarity with specialized equipment.

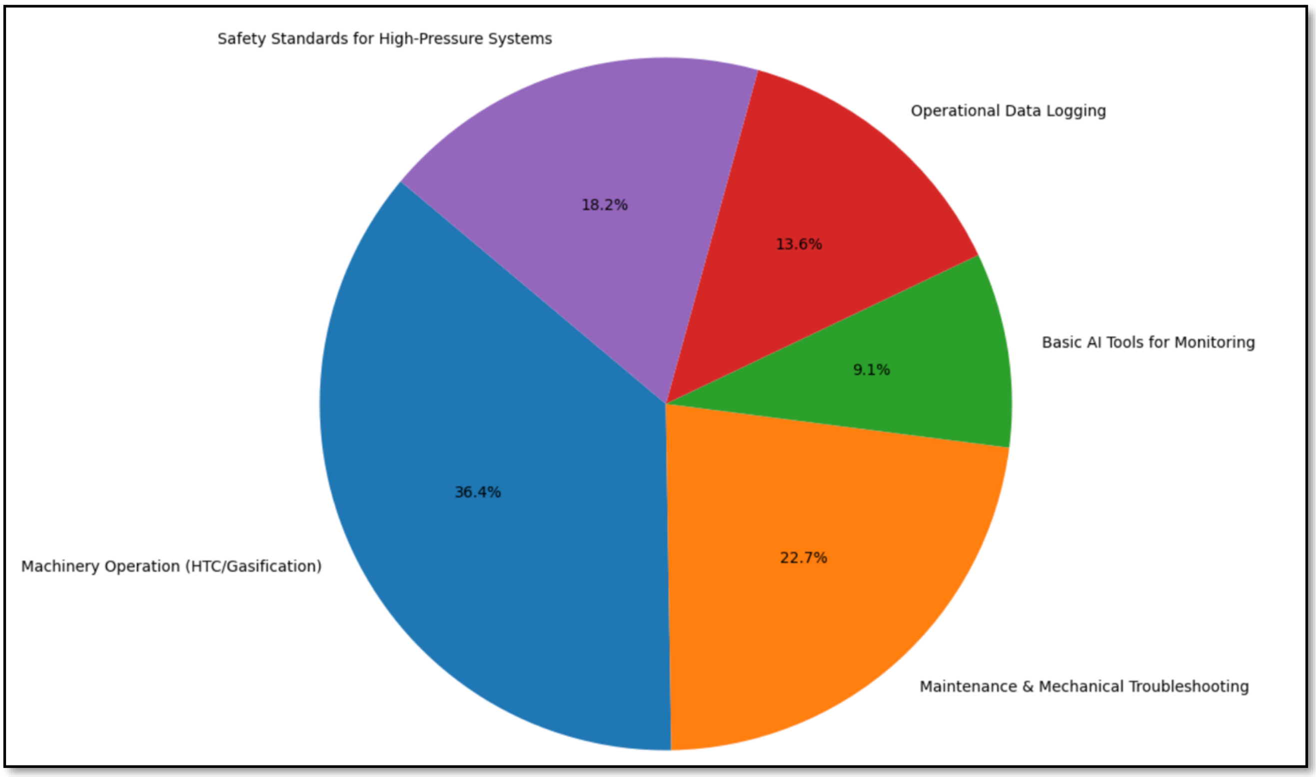

Figure 14 Voting survey: Thermochemical Machinery Operator

Routine maintenance capabilities and mechanical troubleshooting were also considered important, particularly when coupled with basic awareness of predictive maintenance tools that help reduce downtime and extend equipment lifespan. In contrast, familiarity with AI-assisted monitoring tools and operational data logging were viewed as secondary competencies, suggesting that while digital tools are becoming increasingly available, the core expectations for this role still revolve around manual operation and mechanical reliability. Compliance with safety standards for high-pressure systems was moderately prioritized, underscoring the importance of safe handling practices in potentially hazardous thermochemical environments.

- **Bioreactor Technician (Syngas-to-Detergent Process)**

The skill prioritization survey for the Bioreactor Technician (Syngas-to-Detergent Process) role highlights the critical importance of hands-on experience in bioprocessing operations. Respondents placed the highest value on the ability to operate and adjust bioreactor conditions—such as pH and temperature—particularly when supported by predictive modeling or AI-enhanced tools to optimize environmental parameters and improve yields. Additionally, practical experience with laboratory equipment and bioprocessing procedures was highly rated, reflecting the technician's direct role in managing fermentation systems and ensuring stable process performance.

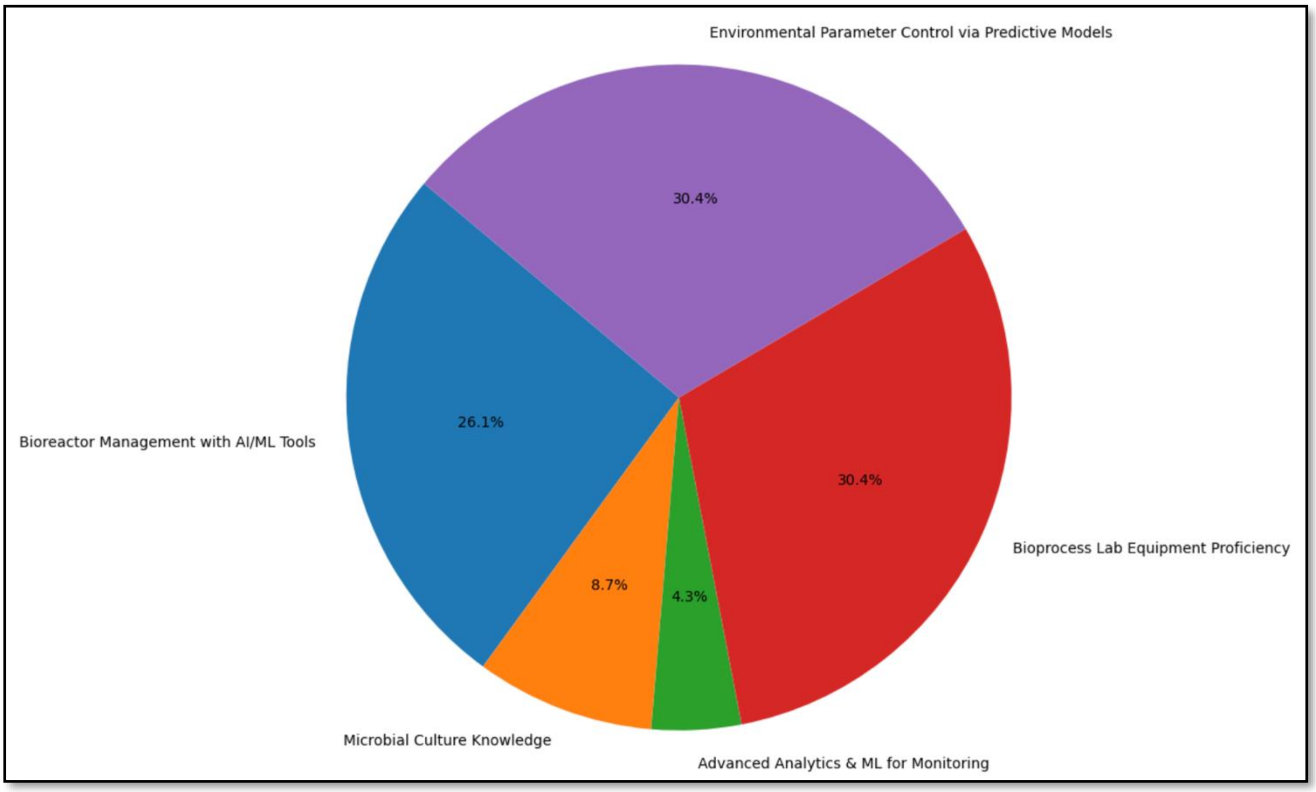

Figure 15 Voting Survey: Bioreactor Technician (Syngas-to-Detergent Process)

While the integration of statistical modeling and AI/ML tools for bioreactor management was also prioritized, competencies related specifically to microbial culture knowledge and advanced analytics for real-time monitoring were viewed as secondary. Skills in chromatography combined with AI-supported data analysis received the lowest priority, indicating that while digital tools are increasingly relevant, the current expectations for this role emphasize operational expertise over computational specialization. These findings suggest that successful performance in this position relies primarily on process control, equipment handling, and applied optimization supported by—but not dependent on—advanced digital systems.

5.2. Possessed and Needed Survey

The questionnaire employed a structured format in which respondents first indicated whether each role was currently possessed, needed, or not useful for their organization. For roles identified as relevant (possessed or needed), participants were then asked to assess the maturity level of each associated skill by selecting a single response from a predefined scale:

1. Novice
2. Proficient Beginner
3. Competent
4. Advanced
5. Expert

In addition, respondents were invited to provide complementary qualitative comments to explain their organizational strategies for addressing identified skill gaps.

To enhance the accuracy and representativeness of the findings, the survey was conducted with all actively engaged partners within each use case (Waste stream management: two partners, UC#1: four partners, UC#2: three partners, UC#3: three partners).This approach ensured that diverse perspectives were captured across the value chain. In order to determine the overall maturity level for each skill, the average score reported by all partners involved in a given use case was considered. (In the following analysis, decimal values may appear, indicating intermediate proficiency levels. For instance, a score of 2.5 represents a level between "Proficient Beginner" and "Competent.")

Nonetheless, the data collection process faced challenges related to the timely receipt of responses, as some partners were unable to meet the initially specified deadlines. Despite these constraints, the combination of structured ratings and open-ended responses enabled both quantitative analysis and qualitative interpretation. The survey link is included in the footnote to provide full transparency of the methodology.

Use Case: Waste Stream Management

The integration of AI and robotics within waste stream management presents substantial opportunities for optimizing sorting processes, enhancing operational efficiency, and advancing circularity objectives. However, the adoption of such roles often necessitates considerable investment in infrastructure, upskilling, and specialized expertise. Many organizations may still be operating within traditional or semi-automated frameworks, with digital transformation viewed as a longer-term objective, contingent upon the outcomes of pilot projects and the maturation of enabling technologies.

While this use case holds high strategic potential, it is important to note that not all relevant partners were able to provide the requested information through the survey during this reporting period. This limited the depth of insight into current role readiness and skill maturity levels. To address this, in the coming months of the project, we plan to organize more targeted and clarifying discussions with these partners to better understand their context, gather more accurate feedback, and collaboratively refine the analysis.

To support future adoption, it is essential to promote awareness of the strategic value of roles such as AI/Robotics Integration Engineers and Robotics Automation Engineers. Capacity-building initiatives, focused training programs, and the development of scalable, role-specific frameworks can prepare organizations for this transition. Furthermore, demonstrating tangible benefits—such as reduced operational costs, improved process reliability, and enhanced material recovery—through return-on-investment models will be key to fostering long-term commitment and accelerating the integration of intelligent systems into waste management practices.

Use Case # 1 : CDW treatment via cascade bio refinement with separation lignin and cellulose

- **Polymer Process Engineer**

The AS-IS / TO-BE survey results (Figure 16) for the role of Polymer Process Engineer indicate that partner organizations demonstrate high proficiency in several foundational skill areas. Notably, the highest average scores were recorded in polymer structure-property knowledge, interdisciplinary collaboration, and quality and root cause analysis. These results reflect a strong in-house capability, likely developed through structured research efforts, effective teamwork, and a clear internal focus on performance assurance and knowledge-sharing practices.

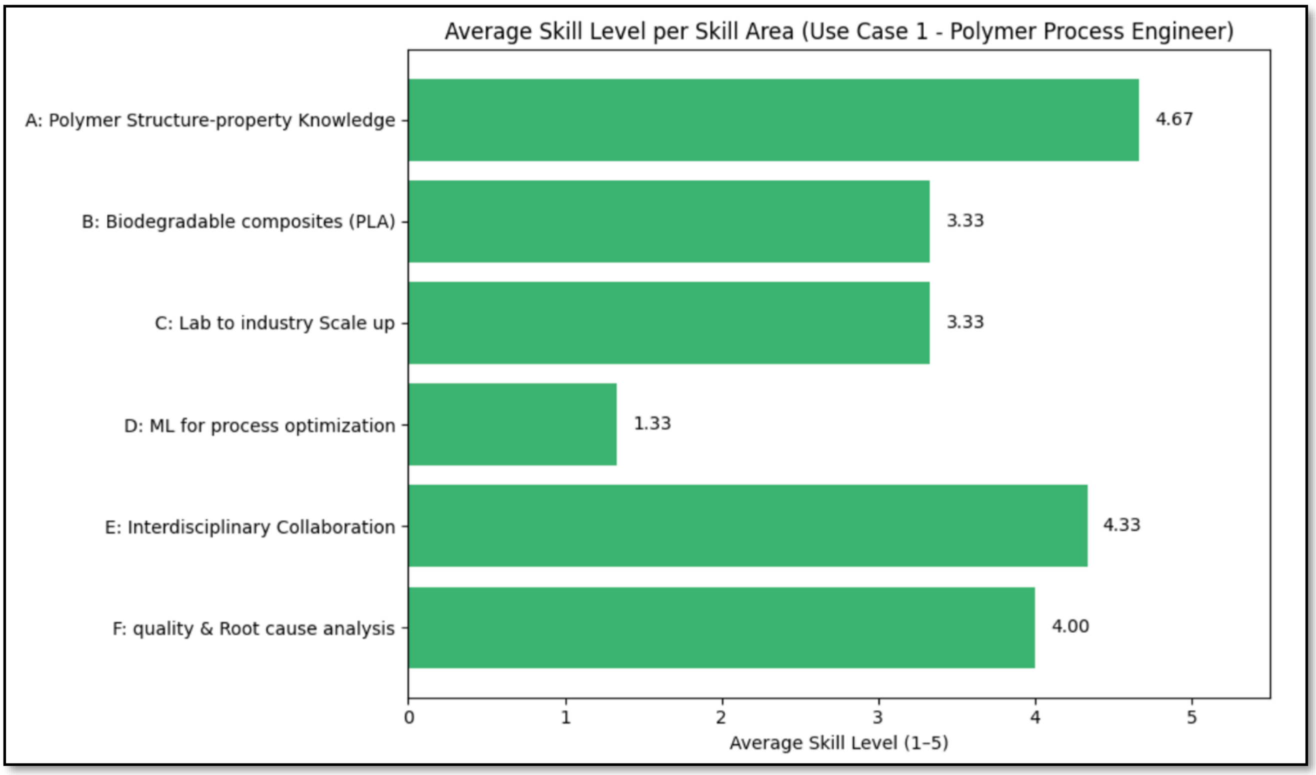

Figure 16 Possessed and Needed Survey - UC1 - Polymer Process Engineer

Moderate proficiency was reported in biodegradable composites (PLA) and lab-to-industry scale-up. While these areas are actively being addressed, further investment in applied training and resource alignment may enhance their scalability and integration into industrial practice.

The most significant skills gap was observed in machine learning for process optimization, signaling limited current capacity in digital and data-driven methodologies within the polymer processing context. This gap highlights an opportunity for upskilling through targeted initiatives such as training courses, specialized workshops, cross-disciplinary collaborations, or the strategic hiring of experts (e.g., data scientists or ML engineers) to build internal competence.

Overall, these insights reinforce the importance of aligning workforce development with evolving technical and digital demands. The findings suggest a need for structured learning pathways that not only consolidate current strengths but also bridge emerging skill gaps to support innovation, process efficiency, and sustainable material development in the future.

- **ML Process Optimization Engineer (Extrusion Systems)**

The AS-IS / TO-BE survey results (Figure 17) for the role of ML Process Optimization Engineer (Extrusion Systems) demonstrate a generally strong competency level in key machine learning applications. The highest average scores were observed in ML for polymer extrusion optimization and applied ML in manufacturing, indicating that most partner organizations have moved beyond foundational understanding and are actively implementing AI-driven strategies within specific production contexts.

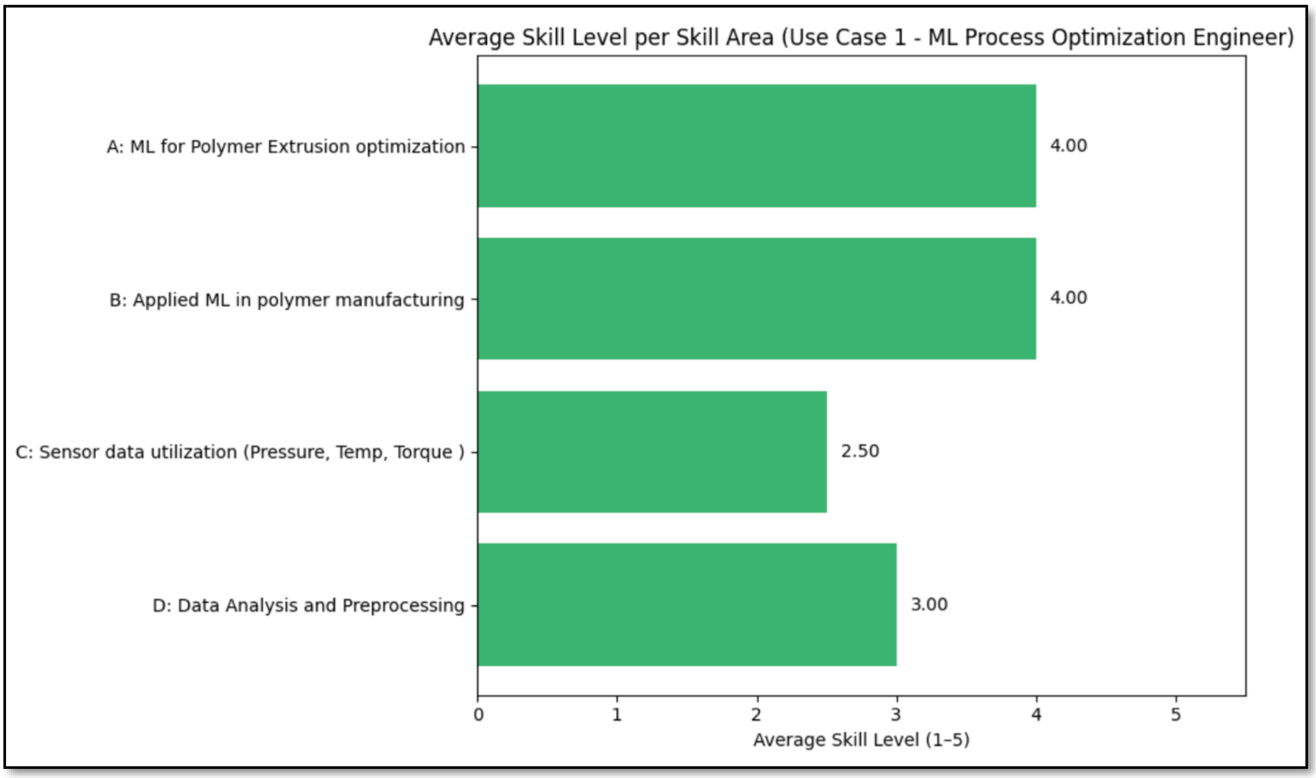

Figure 17 Possessed and Needed Survey - UC1 - ML Process Optimization Engineer

Moderate capability was identified in data analysis and preprocessing, suggesting that while the foundational skills exist, there is still room for refinement in areas such as feature engineering, noise reduction, and data normalization for model readiness.

By contrast, the lowest score was reported for sensor data utilization —highlighting a limited ability to effectively gather, interpret, and apply real-time process signals (e.g., pressure, temperature, torque) for optimization. This area remains underdeveloped and presents a critical bottleneck for integrating smart monitoring systems into extrusion workflows.

To address these gaps, respondents emphasized the need for targeted training initiatives focused on advanced data handling and sensor integration. Additionally, collaboration with domain-specific experts and AI practitioners was seen as an effective way to fast-track learning and ensure relevant, scalable deployment of ML systems.

Overall, the findings underscore the importance of investing in both internal upskilling and external knowledge partnerships to build robust AI-driven process optimization capabilities.

- **Research Engineer, Polymer Additive Manufacturing**

The AS-IS / TO-BE survey results (Figure 18) for the Research Engineer in Polymer Additive Manufacturing highlight an uneven maturity level across the skill areas assessed. Participating organizations generally exhibit solid internal capabilities in polymer chemistry and material science, along with an emerging focus on material innovation to enhance additive manufacturing efficiency. These strengths are often supported by postdoctoral recruitment, specialized internal roles, and a broader organizational commitment to research and innovation.

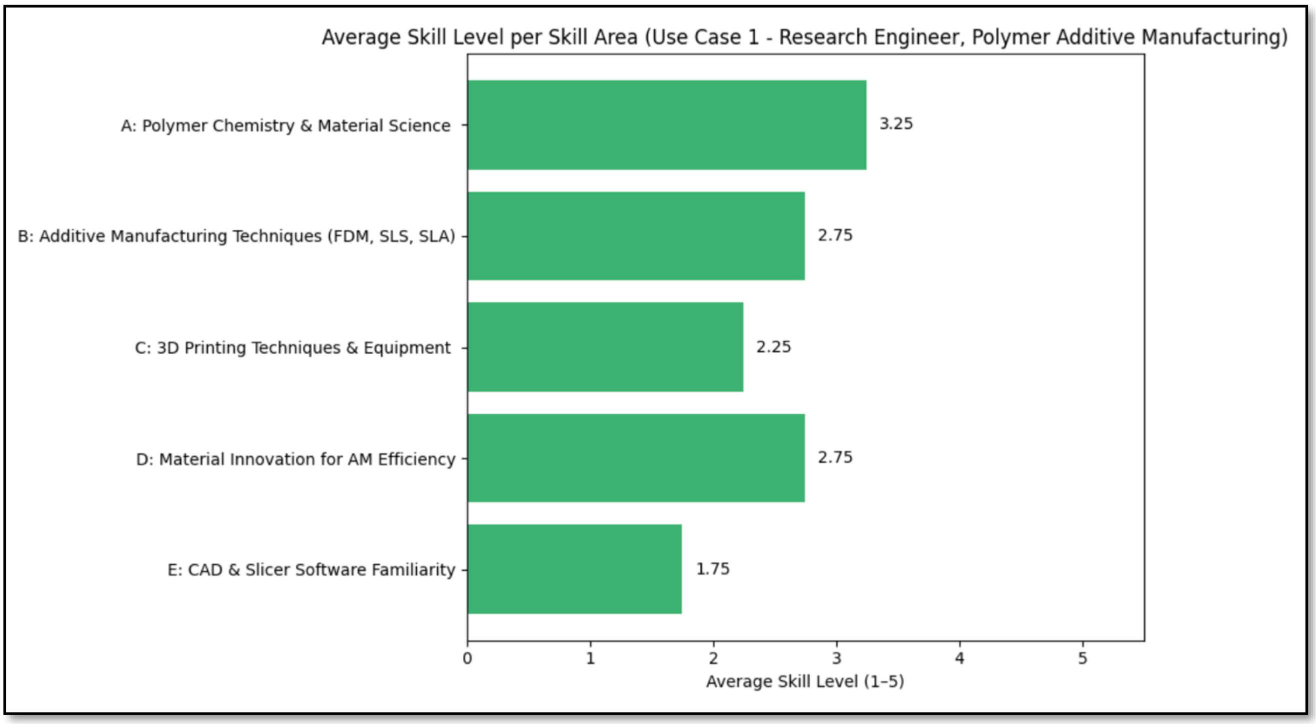

Figure 18 Possessed and Needed Survey - UC1 - Research Engineer, Polymer Additive Manufacturing

However, the survey also revealed limited capacity in more operational and technical aspects of additive manufacturing. Areas such as familiarity with 3D printing techniques and equipment, specific AM processes (e.g., FDM, SLS, SLA), and CAD/slicer software tools are less developed across several partners. These gaps suggest a disconnect between material development expertise and the hands-on implementation skills needed for efficient prototyping and process integration.

To strengthen this role, organizations emphasized the value of structured training courses, practical workshops, and greater exposure to real-world AM environments. Collaborations with specialized service providers and cross-institutional knowledge exchanges were also identified as important enablers for capacity building.

Overall, the findings reinforce the need for targeted upskilling strategies that can bridge the gap between conceptual R&D and the operational demands of polymer-based additive manufacturing workflows.

Use Case # 2 : Waste management treatment by removing additives, via advanced chem and bio techs

- **Chemical Analysis Specialist (PhD/Postdoc Level)**

The AS-IS / TO-BE survey results (Figure 19) for the role of Chemical Analysis Specialist reflect a balanced yet evolving competency profile across partner organizations. Participants generally reported solid hands-on experience in the use of standard laboratory instrumentation and routine analytical techniques, particularly those applied in the evaluation of composite materials, adhesives, and bio-based formulations. Proficiency in techniques such as liquid chromatography and HPTLC appears to be well integrated into daily workflows, along with consistent use of statistical tools for interpreting test results in applied settings.

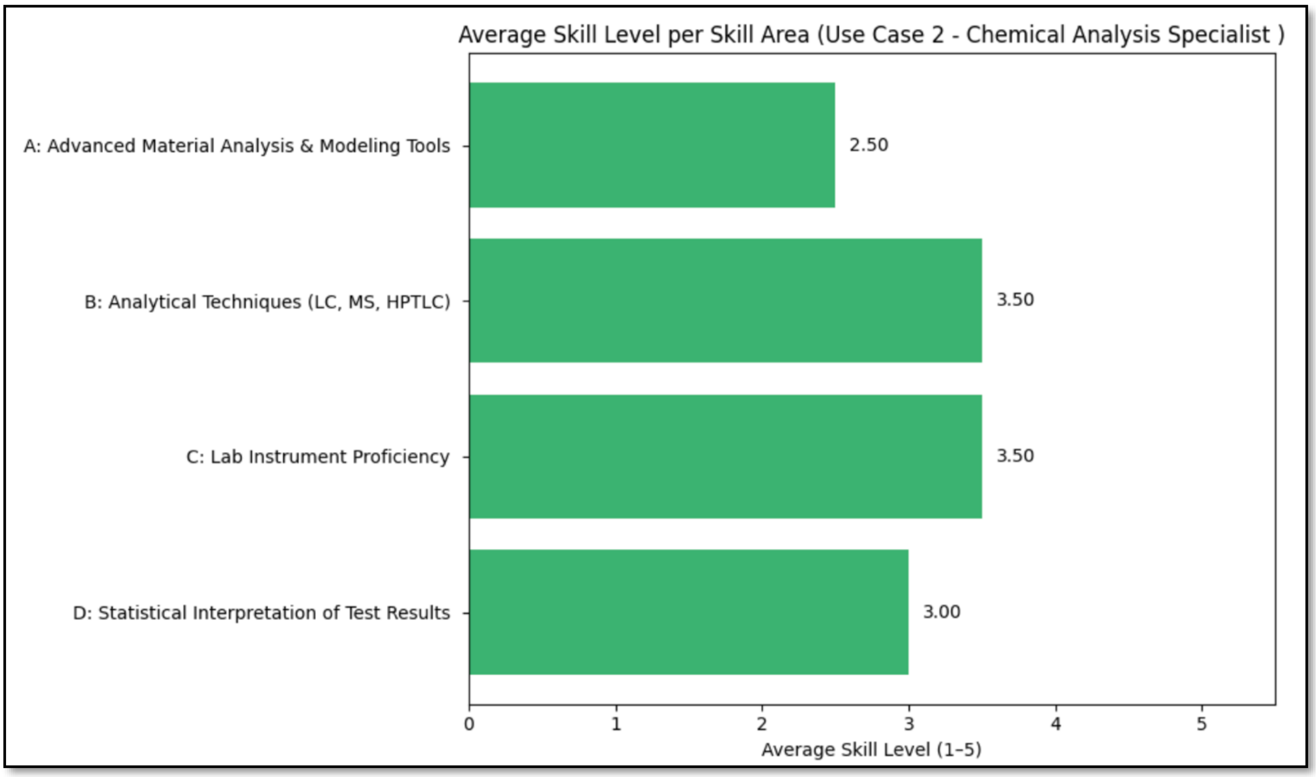

Figure 19 Possessed and Needed Survey – UC2 - Chemical Analysis Specialist

However, capabilities related to advanced modeling tools and material simulation methods were reported to be less developed. Organizations highlighted limitations in areas such as chemical system modeling, computational analysis, and high-level material characterization—pointing to a gap in more specialized analytical capacity.

To address these challenges, partners emphasized the importance of structured training programs focused on modern analytical methodologies and modeling environments. In addition to upskilling existing staff, some organizations also expressed intent to recruit specialized chemists or establish collaborative ties with external experts to support complex chemical evaluations. These findings underline the critical need to invest in expert development and enhanced analytical infrastructure to support innovation and ensure regulatory and performance standards are met in next-generation material development.

- **Production Data Analyst (with AI/ML Integration Potential)**

The AS-IS / TO-BE survey results (Figure 20) for the Production Data Analyst role suggest that partner organizations have developed baseline competencies in analyzing production-related data and using statistical tools to uncover trends and performance patterns. Respondents reported practical familiarity with platforms such as Python and R, which are commonly used to evaluate operational parameters, identify recurring bottlenecks, and support quality monitoring activities across manufacturing lines.

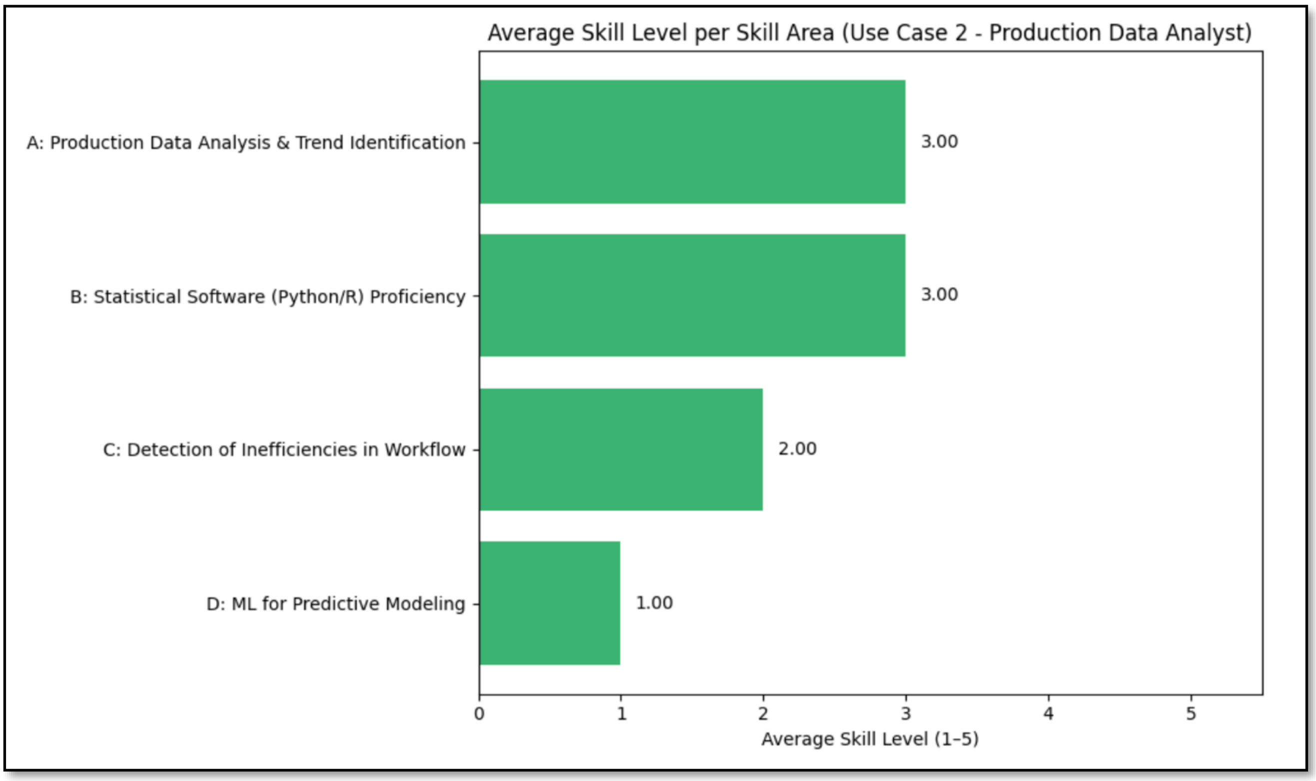

Figure 20 Possessed and Needed Survey - UC2 - Production Data Analyst

However, the survey also highlighted limited expertise in more advanced analytical functions, particularly in the use of machine learning techniques for predictive modeling. The ability to proactively detect inefficiencies within workflows and automate data-driven insights remains underdeveloped, presenting a key area for improvement as organizations transition toward more intelligent, adaptive production systems.

To support this transition, respondents emphasized the need for structured upskilling programs targeting the integration of AI into routine data operations. Training initiatives focused on applied machine learning, workflow optimization, and real-time data analytics were seen as critical enablers for building capacity in predictive and prescriptive analysis. Such capability development is essential not only for enhancing operational efficiency but also for aligning production processes with broader digital transformation goals and circular economy ambitions.

Use Case # 3 : Integrated Waste Valorization Pathway for Bio-Based Detergent Production: A Multi-Stage Thermochemical and Biotechnological Process

- **Thermochemical Process Engineer (HTC and Gasification)**

The AS-IS / TO-BE survey results (Figure 21) for the role of Thermochemical Process Engineer demonstrate a strong foundation of expertise across participating organizations. Respondents highlighted robust capabilities in process simulation, sensor integration, and operational data analysis—core elements essential for the development and optimization of hydrothermal carbonization (HTC) and gasification systems. Teams also reported well-established practices for managing environmental compliance and adhering to relevant safety regulations, indicating a high degree of technical maturity in both experimental execution and system oversight.

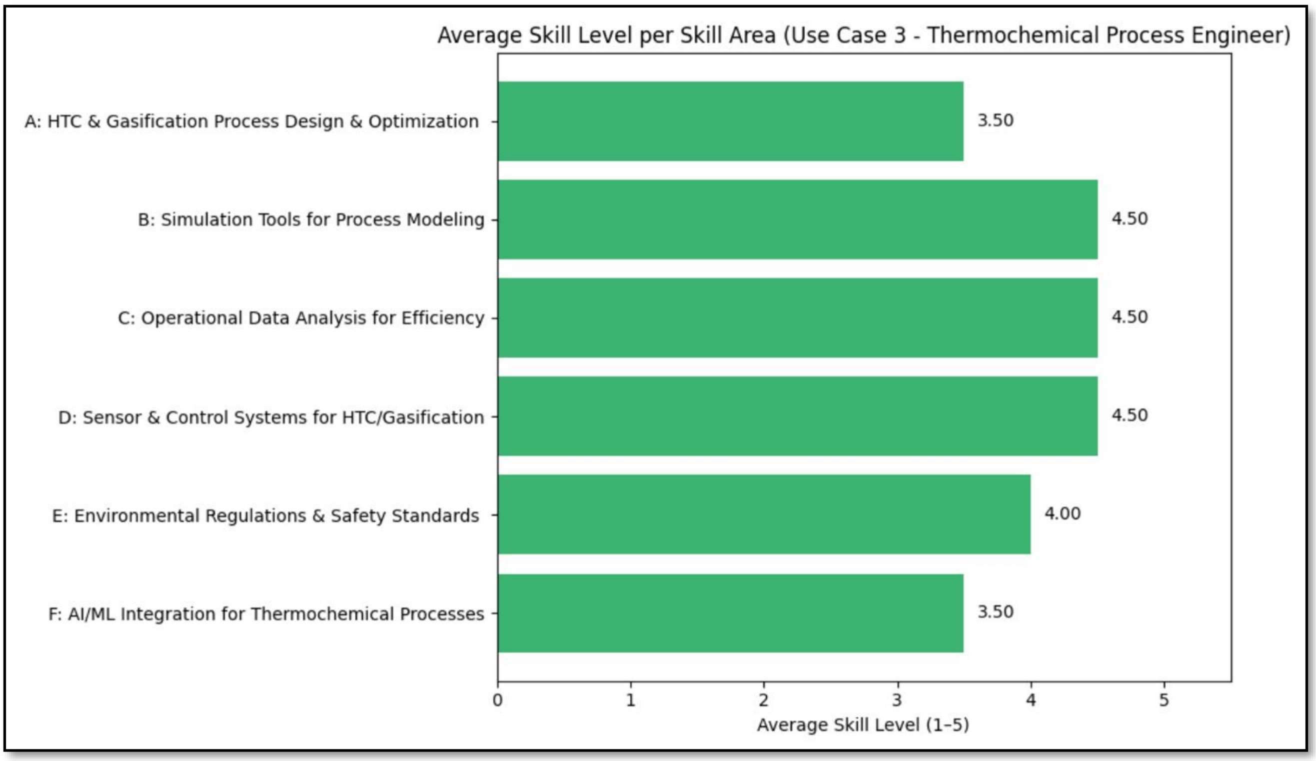

Figure 21 Possessed and Needed Survey - UC3 - Thermochemical Process Engineer

While these strengths create a solid platform for innovation, the integration of artificial intelligence and machine learning techniques into thermochemical workflows is still developing. Although there is growing awareness of the potential of AI/ML to enhance predictive modeling and dynamic process optimization, its widespread application remains limited within current practices.

To build on this momentum, respondents emphasized the importance of structured training and upskilling initiatives specifically focused on the digital transformation of thermochemical systems. Such programs would enhance current strengths by introducing advanced capabilities in automation, machine learning integration, and real-time analytics—key enablers for achieving more efficient, responsive, and sustainable waste-to-energy processes.

- **Thermochemical Machinery Operator**

The AS-IS / TO-BE survey responses (Figure 22) for the Thermochemical Machinery Operator role reflect a high level of practical expertise across partner organizations. Operators are reported to be well-versed in the daily operation of hydrothermal carbonization and gasification machinery, with strong proficiency in system handling, equipment maintenance, and mechanical troubleshooting. A robust understanding of safety procedures—especially those related to high-pressure systems—further reinforces the maturity of operational practices and alignment with industrial safety protocols.

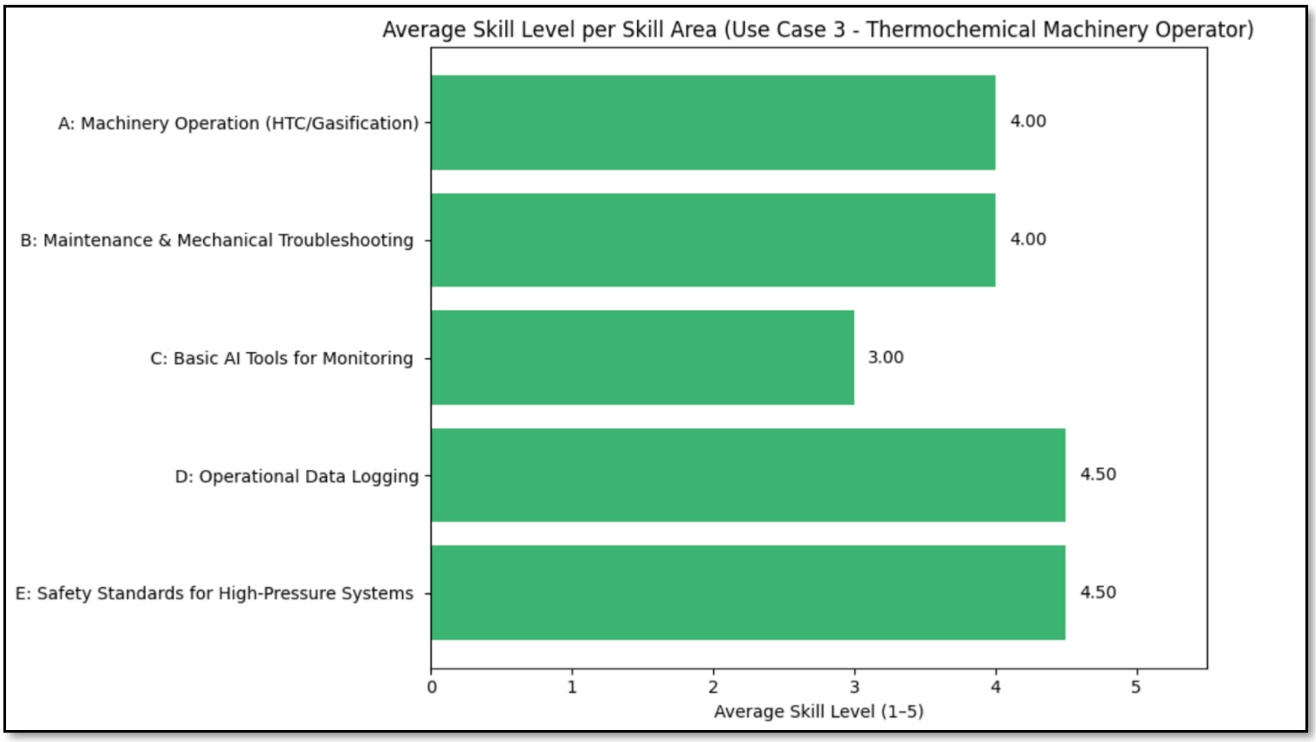

Figure 22 Possessed and Needed Survey - UC3 - Thermochemical Machinery Operator

In addition, the capacity to accurately log operational data and monitor system performance is widely integrated into existing workflows, enabling consistent oversight and traceability within the production environment.

Despite these strengths, the application of AI-assisted monitoring tools remains a developing area. While some organizations have started to explore the benefits of predictive technologies, broader implementation of digital monitoring solutions is still at an early stage.

To support this transition, partners emphasized the value of targeted training programs focused on digital tools, with a particular focus on predictive diagnostics, anomaly detection, and AI-supported maintenance strategies. These initiatives would enable machinery operators to shift from reactive to proactive decision-making, reducing unplanned downtimes and strengthening overall equipment reliability in thermochemical processing.

- **Bioreactor Technician (Syngas-to-Detergent Process)**

The AS-IS / TO-BE survey results (Figure 23) for the Bioreactor Technician role reveal a varied skill landscape across partner organizations. Some teams have developed core competencies in managing bioreactor systems, controlling environmental conditions, and operating bioprocess lab equipment—typically gained through experience with lab-scale and pilot-scale fermentation setups. This includes routine handling of parameters such as pH, temperature, and agitation, alongside a growing interest in integrating predictive approaches for improving process outcomes.

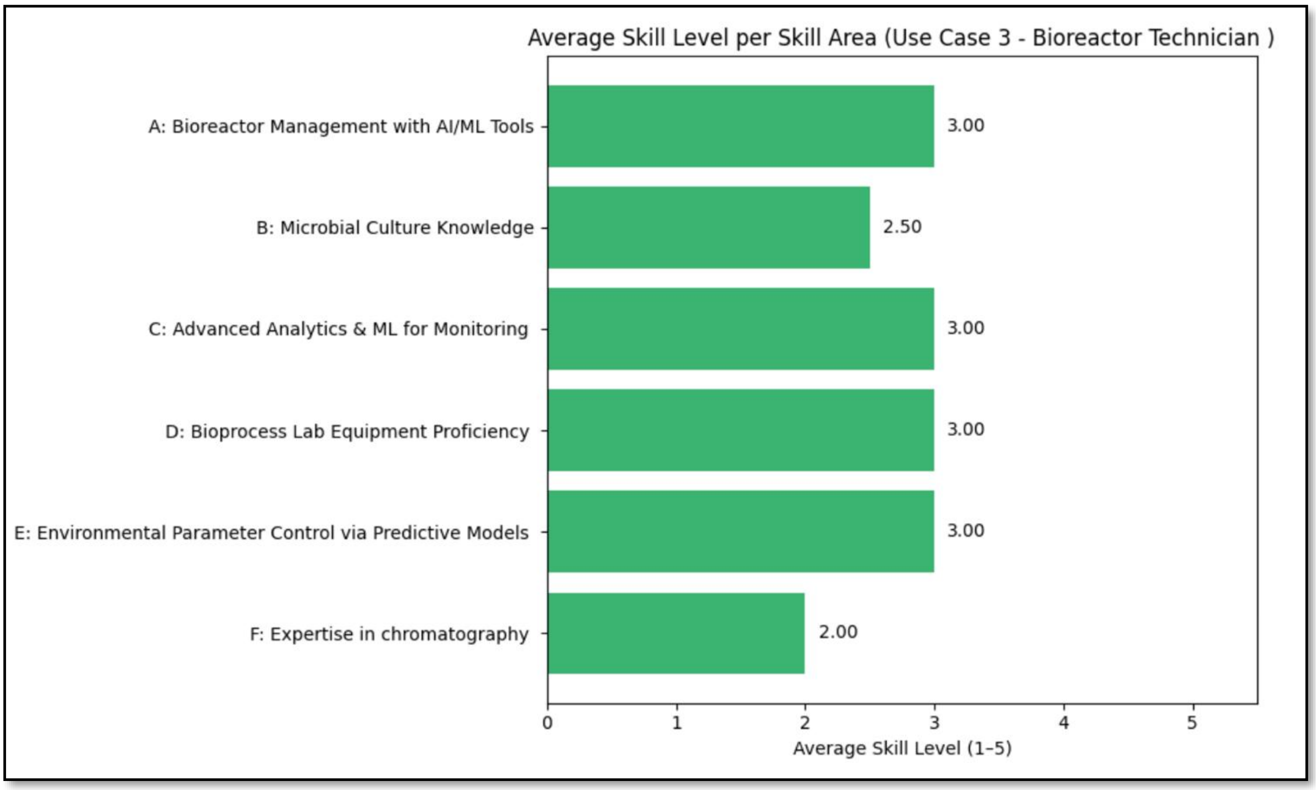

Figure 23 Possessed and Needed Survey - UC3 - Bioreactor Technician

However, other organizations reported more limited readiness in areas such as microbial culture knowledge, chromatographic techniques, and the use of advanced analytics for monitoring and control. These gaps indicate a divergence in operational maturity and highlight the need for harmonized capacity-building efforts.

Respondents emphasized the growing importance of AI- and ML-enabled monitoring tools for real-time decision-making, anomaly detection, and process optimization in biotechnological workflows. While such technologies are increasingly recognized as valuable, practical implementation remains limited and underexplored in many teams.

To bridge these gaps, partners pointed to the value of targeted training programs focused on smart bioprocess control, microbial cultivation, and digital monitoring systems. These upskilling efforts would reinforce technical consistency, support greater cross-team collaboration, and enable the effective scale-up of syngas-to-detergent production processes—especially in coordination with downstream stakeholders focused on product refinement and application.

6. WORKSHOP

As a follow-up to the AS-IS / TO-BE surveys conducted across partner organizations, a collaborative workshop was implemented to validate the initial findings and further explore the practical challenges and opportunities related to digital upskilling. This workshop brought together internal and external partners in April 2025 with 25 participants consist of 12 internal and 13 external stakeholders, and served as an interactive forum to complement the data previously collected. Its main objective was to identify critical technical roles, understand barriers to adoption of emerging technologies, and outline strategies for skill development that align with the project's broader digital and sustainable transformation goals.

One of the clearest outcomes from the workshop was the repeated mention of AI and Machine Learning experts as the most difficult roles to recruit or develop across the industry. This was followed by persistent challenges in sourcing data analysts and robotics engineers, indicating a high demand for professionals who can bridge data-driven decision-making and intelligent automation. Some participants also expressed difficulty in finding process engineers with expertise in energy and material systems, as well as sustainability experts—highlighting the growing importance of hybrid roles that combine technical and environmental competencies. These findings directly reinforce the prioritizations observed in the earlier surveys, particularly for roles like the ML Process Optimization Engineer and AI/Robotics Integration Engineer, which were identified as lacking internal capacity.

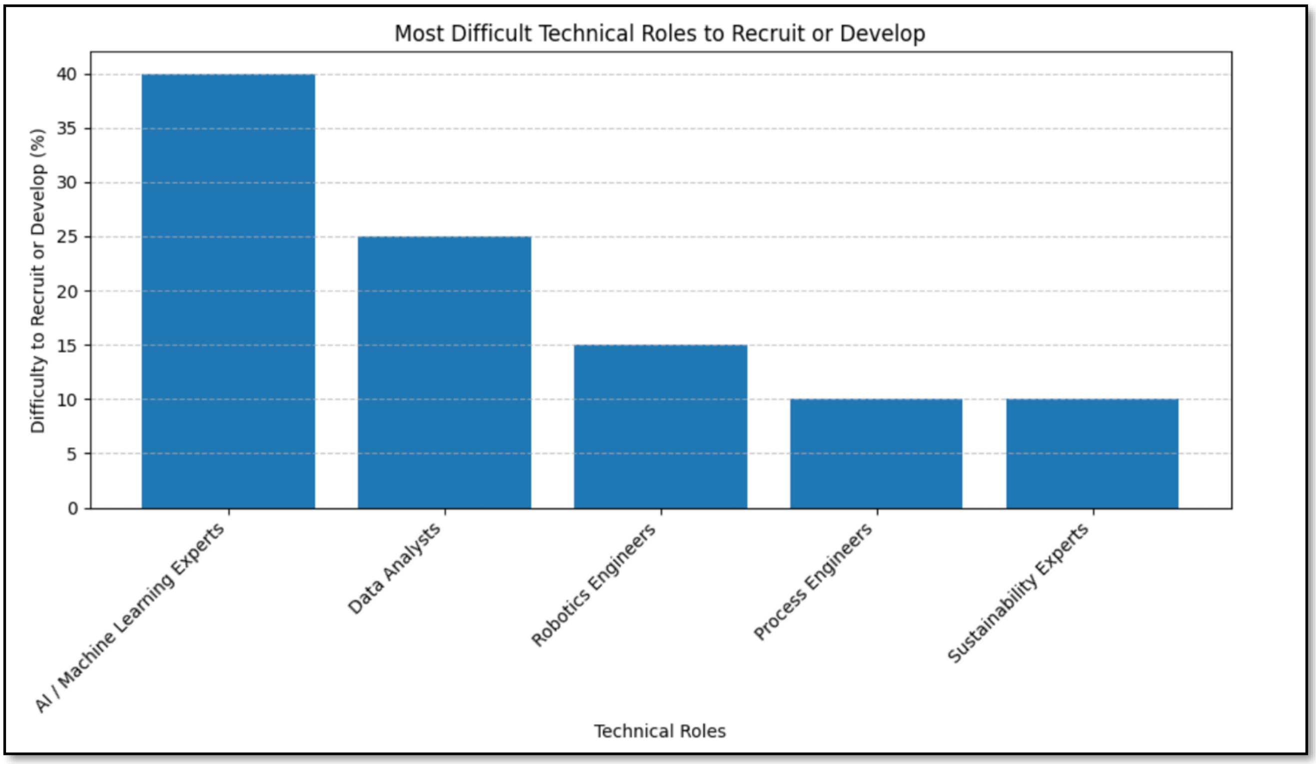

Figure 24 Workshop - Most difficult technical roles to recruit or develop

The discussion also revealed that organizations are not only struggling to fill these roles but are also facing structural challenges in adopting new digital functions. Participants cited internal knowledge gaps, limited time or resources, and a lack of clear strategic roadmaps as some of the most persistent barriers. Moreover, concerns around the uncertain return on investment (ROI) and shortages of qualified candidates further complicate efforts to modernize technical capabilities. In some cases, there was also mention of employee resistance to change and insufficient training infrastructure—issues that underline the cultural and organizational transformation required alongside technical development.

To address these challenges, the workshop emphasized the value of practical and collaborative learning formats. Participants showed a strong preference for training courses, hands-on workshops, joint pilot projects, and knowledge exchange initiatives with partners, rather than relying solely on theoretical or isolated training. These preferences directly support the earlier conclusion that capacity-building strategies must be experiential and embedded within real-world operational contexts. They also align with the upskilling recommendations highlighted for roles such as the Polymer Process Engineer, Bioreactor Technician, and Production Data Analyst, where immersive, context-specific learning was seen as a priority.

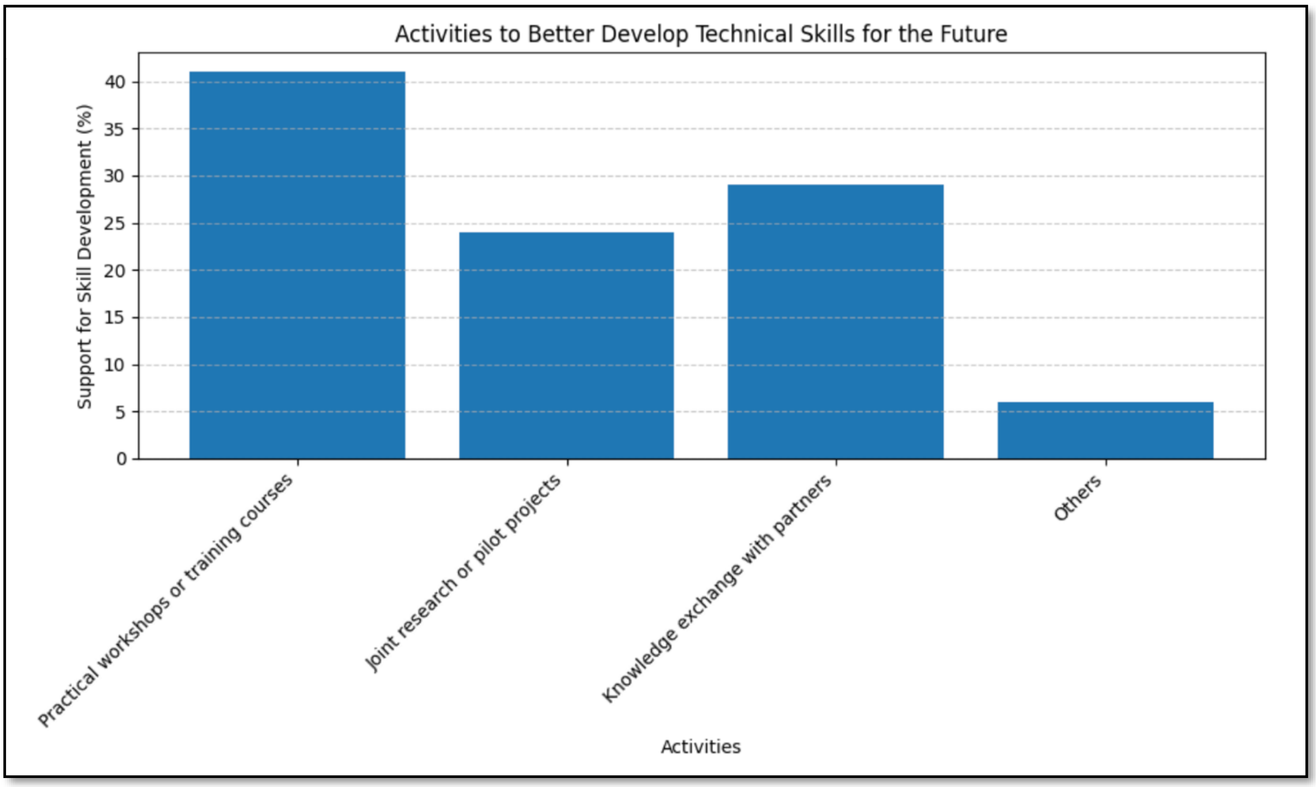

Figure 25 Workshop - Activities to better develop technical skills for the future

Regarding current strategies for closing skill gaps, organizations reported a combination of approaches, including internal training programs, external training courses, hiring new personnel, and collaboration with external partners. While outsourcing was mentioned as a short-term solution, the long-term emphasis was clearly on strengthening internal capabilities through structured training and targeted recruitment. This aligns with the survey findings where organizations expressed the need to transition from external dependency toward in-house expertise, particularly in high-demand domains such as AI, robotics, and sustainable material innovation. Accordingly, the POLIMI team serves a supportive role, assisting project partners and external organizations in identifying skill gaps and recommend training activities for addressing and bridging these skill gaps.

Finally, when asked to reflect on the current technical skill within their teams, participants reported a mixed picture. Some noted advanced capabilities in selected domains, while others acknowledged that their teams were largely at the beginner level or reliant on external support. This variability points to unequal levels of digital maturity among partners and reinforces the importance of tailoring training efforts to the specific context and readiness of each organization. Looking ahead, skills in AI and data science, robotics and automation, sustainable materials engineering, and process simulation were seen as the most critical for the next two to three years. These priorities mirror the role-based gaps identified in earlier sections and should directly inform the design of future training interventions and workforce planning strategies within the project.

7. TRAINING ACTIVITIES

Based on the findings from earlier phases in previous chapters, partners emphasized that training courses represent one of the most effective strategies for addressing identified skill gaps. Accordingly, by Month 18 (M18) of the project, approximately 30 training courses were evaluated in order to support the ten roles evidenced within the use cases. These courses were curated from recognized and credible platforms such as Coursera[7], Udemy[8], Alison[9], POLIMI Open Knowledge[10], among others.

An assessment framework was employed to categorize the courses into three progressive learning levels: "Awareness," "Foundation," and "Extended Know-How." The Awareness level includes introductory materials designed to offer a basic understanding of the topic. The Foundation level provides more practical and structured content aimed at developing core competencies. The Extended Know-How level contains advanced materials intended to deepen expertise and facilitate the practical implementation of relevant technologies. Each course was systematically analyzed according to this framework, and a mapping exercise was carried out to assess the degree of alignment between the training content, the identified occupational profiles, and the associated skill requirements. This mapping also ensured that the course recommendations were appropriately tailored to the different stages of learning and professional development relevant to the targeted roles.

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[7] https://www.coursera.org/
[8] https://www.udemy.com/
[9] https://alison.com/
[10] https://www.pok.polimi.it/

Table 1 Training Courses

ROLES	COURSES	Knowledge Level	Organizational Level
Waste Management and AI / Robotics Integration Engineer	Clustering & Classification With Machine Learning In R	Foundations	Mid Level Employee
	Programming in Python	Awareness	Junior (Fresh Employee)
	Robotics: Human-Robot Interaction - Theory and applications	Extended Know-How	Senior Employee
	Strategic Waste Management	Awareness	Mid Level Employee
Robotics Automation Engineer	Modern Robotics: Mechanics, Planning, and Control Specialization	Foundations	Mid Level Employee
	ROS2 C++ Robotics Developer Course - Using ROS2 In C++	Foundations	Junior (Fresh Employee)
	Robotic Process Automation (RPA) Specialization	Foundations	Mid Level Employee
	Robotics With V-REP / CoppeliaSim	Foundations	Junior (Fresh Employee)
Polymer Process Engineer	Advanced Chemistry Polymerisation	Extended Know-How	Senior Employee
	Plastics Engineering I Intro To Polymers	Foundations	Mid Level Employee
	AI-Powered Predictive Analysis: Advanced Methods and Tools	Awareness	Mid Level Employee
	Machine Learning: Modern Computer Vision & Generative AI	Foundations	Mid Level Employee
	Improving Communication Skills	Foundations	Junior (Fresh Employee)
ML Process Optimization Engineer (Extrusion Systems)	Complete A.I. & Machine Learning, Data Science Bootcamp	Foundations	Senior Employee
	Machine Learning in Production	Foundations	Mid Level Employee
	Introduction to Data Analytics and AI	Awareness	Junior (Fresh Employee)
	Data Analytics - Mining and Analysis of Big Data	Foundations	Mid Level Employee
Research Engineer, Polymer Additive Manufacturing	Plastics and Polymers - A Material Class Shaping the World	Awareness	Junior (Fresh Employee)
	Additive Manufacturing Specialization	Foundations	Mid Level Employee
	3D Printing and Additive Manufacturing Specialization	Foundations	Mid Level Employee
Chemical Analysis Specialist (PhD/Postdoc Level)	The Fundamentals of Chromatography	Foundations	Senior Employee
	ISO/IEC 17025 – Laboratory Management Systems Certification	Extended Know-How	Mid Level Employee
	Regression Models	Foundations	Senior Employee
Production Data Analyst (with AI/ML Integration Potential)	Data Analytics - Mining and Analysis of Big Data	Foundations	Junior (Fresh Employee)
	Python for Data Science, AI & Development	Awareness	Junior (Fresh Employee)
	Programming in Python	Foundations	Junior (Fresh Employee)
Thermochemical Process Engineer (HTC and Gasification)	Process Capability Analysis	Foundations	Mid Level Employee
	Engineering System Design Modeling Techniques and Simulations	Foundations	Senior Employee
Thermochemical Machinery Operator	Maintenance Management & Reliability Crash Course	Extended Know-How	Senior Employee
	AI-Powered Predictive Analysis: Advanced Methods and Tools	Awareness	Mid Level Employee
	Introduction to TensorFlow for Artificial Intelligence, Machine Learning, and Deep Learning	Foundations	Mid Level Employee
	Data Entry Tools and Techniques	Awareness	Junior (Fresh Employee)
Bioreactor Technician (Syngas-to-Detergent Process)	Machine Learning: Modern Computer Vision & Generative AI	Foundations	Mid Level Employee
	Introduction to Microbiology	Awareness	Junior (Fresh Employee)
	AI-Powered Predictive Analysis: Advanced Methods and Tools	Awareness	Mid Level Employee

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8. CONCLUSION

This deliverable centers on the People dimension of the 6Ps framework, with a particular emphasis on identifying emerging job roles, defining the corresponding skill requirements, prioritizing essential competencies, and evaluating their availability and demand within the broader landscape of digital transformation and technological progress among project partners. Drawing from a comprehensive literature review and the application of the 6Ps model—specifically its focus on human capital—an initial round of surveys was implemented. These surveys aimed to assess and rank the skills essential to key professional roles, while also examining both the current (AS-IS) and anticipated (TO-BE) conditions of the project use cases partners in terms of workforce capabilities throughout the duration of the project.

The first survey employed an online voting mechanism to gather the partners insights on the relevance and priority of specific skills associated with predefined job profiles. The second instrument, titled the "Needed and Possessed" survey, captured information regarding existing skill levels and projected requirements among participating organizations. One of the major findings was the identification of inter-organizational collaboration and participation in structured training programs as highly effective measures for improving skill gaps and advancing workforce development.

In response, this deliverable presents a curated selection of training resources sourced from recognized platforms such as POLIMI Open Knowledge, Coursera, Udemy, Alison, and others. These learning opportunities will be made available through the project's official website, ensuring ease of access for both internal stakeholders and external entities, particularly those within the same project ecosystem. Ultimately, the deliverable titled "Skills Activities, Trainings and Lifelong Learning Programmes" achieves its intended objectives by offering a comprehensive, methodical approach to skill developement. It supports the alignment of workforce capabilities with the dynamic requirements of digitalization, while also ensuring the availability of accessible, high-quality training content tailored to partners' specific operational needs.

In summary, more than ten roles and corresponding thirtysix training resources have been categorized and referenced (on average more than 3 for each role identified) The skills of each of the ten roles have been prioritized within the context of the project, and the AS IS and TO BE situation of the partners involved in the four project use cases addressed have been analyzed. Finally a collaborative workshop including twelve internal persons-organizations and thirteen external persons- organizations has been held in M16 in order to reinforce and validate the results obtained.

As a next step, the People dimension of the methodology will be further advanced through the continued analysis of use case-specific activities and workforce requirements. Additionally, the training catalogue will be expanded by assessing a broader range of relevant courses. To facilitate dissemination and long-term accessibility, a dedicated webpage for training activities will be developed and integrated into the project's official website (as soon as the problems with the website will be solved), thereby enhancing visibility and usability for both consortium members and external stakeholders.

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