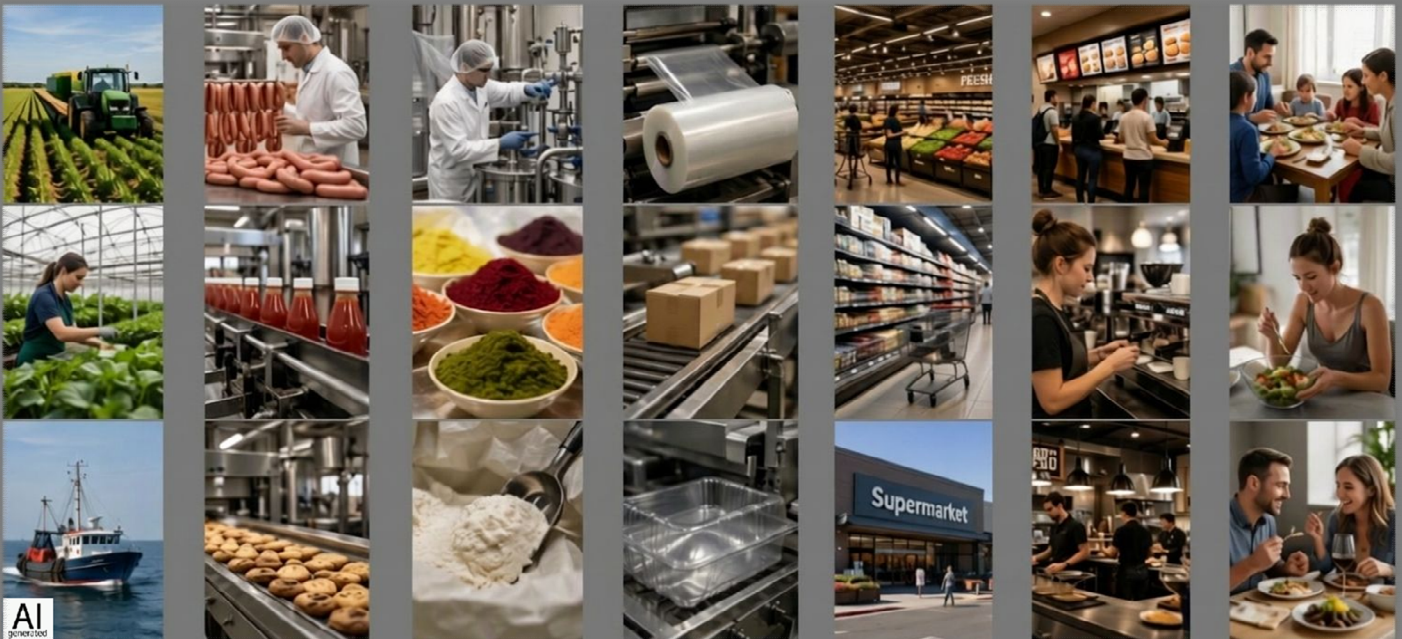




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Food Sidestream Opportunity Study



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Executive Summary

The global food industry is increasingly challenged to move beyond linear models of production, consumption, and disposal. Across agricultural production, food processing, manufacturing, distribution, retail, food service, and consumption, substantial sidestreams, by-products, and losses continue to arise. These materials are often treated as operational challenges or waste-management costs, even though many retain nutritional, functional, economic, or strategic value. This report examines how leading organizations across the food ecosystem understand and pursue the valorization of such sidestreams, and what conditions are required for these opportunities to become scalable sources of value.

The study is based on 16 qualitative research conversations with representatives from 12 organizations operating across agriculture, biotechnology, food manufacturing, ingredients, packaging, retail, and food service. The purpose was not to generate statistically representative findings, but to identify recurring patterns, mechanisms, barriers, and opportunities across different organizational contexts.

A central finding is that sidestream valorization is best understood as an ecosystem challenge rather than a company-specific challenge. Opportunities rarely emerge from isolated technical interventions alone. Instead, successful valorization depends on the interaction of mindset, material-flow visibility, technology, regulatory feasibility, business-model development, collaboration, economic viability, and market acceptance. Across the cases, the most promising initiatives were those that reframed sidestreams from disposal problems into strategic resources capable of supporting innovation, resource efficiency, resilience, and future growth.

Several cross-cutting insights emerged. First, valorization often begins with a shift in perspective. Some of the companies demonstrate that materials historically regarded as low-value residuals can become valuable inputs when organizations reassess their properties, potential applications, and position within broader resource systems. Second, mapping and understanding material flows is a prerequisite for action. Without reliable visibility into volumes, quality, location, timing, and composition, organizations are often unable to identify or act upon opportunities. Third, technology is an essential enabler, but not a standalone solution. Processing technologies, biotechnology, traceability systems, intelligent packaging, enzymatic conversion, fermentation, and digital tools create new possibilities, but they only generate commercial impact when embedded in viable business models and operational systems.

The analysis also shows that collaboration is both essential and difficult. Many valorization opportunities require actors across different sectors to align incentives, share risk, combine capabilities, and coordinate logistics. This is particularly visible in cases involving biotechnology platforms, food-rescue partnerships, ingredient development, packaging-enabled visibility, and large-scale restaurant or retail systems. At the same time, economic viability remains the decisive scaling mechanism. Sustainability ambitions can initiate exploration, but long-term implementation depends on clear value propositions, measurable benefits, and credible pathways to market.

Four analytical perspectives are used to structure the findings. The Farm-to-Fork perspective shows that valorization opportunities occur throughout the value chain, from agricultural biomass and processing residues to retail losses, food-service streams, packaging systems, and consumer-facing waste. The Material Stream perspective demonstrates that each resource must be understood according to its specific characteristics, including volume, consistency, perishability, safety requirements, functional properties, and logistical complexity. The Barrier and Solution perspective highlights recurring obstacles related to economics, information visibility, collaboration, regulation, food safety, consumer perception, and market creation. Finally, the Strategic Intent and Valorization Hierarchy perspective shows that organizations pursue valorization for different reasons: operational efficiency, sustainability, circularity, product and business-model innovation, strategic positioning, and ecosystem transformation.

Additional examples reviewed in the report reinforce the central findings, while a quick overview of the emerging U.S. upcycling ecosystem further demonstrates that specialized startups, scale-up companies, corporate ventures, industrial processors, certification systems, and industry associations are transforming upcycling from a niche sustainability activity into a recognizable business domain.

The perspectives from the Danish Technological Institute add practical and strategic depth to these findings. Organizationally, the report points to the importance of broad sustainability leadership, decentralized execution, continuous reassessment of sidestream potential, and specialized partnerships with external actors. Technologically, it highlights the role of biorefining, fractionation, fermentation, enzymatic conversion, downstream processing, pasteurization, insect bioconversion, digitalization, automation, LCA, techno-economic analysis, and biomaterial development. Together, these capabilities can help bridge the gap between laboratory feasibility, pilot-scale demonstration, and industrial implementation.

Overall, the study concludes that the future potential of food-sidestream valorization not only lies in discovering new resources, but also in recognizing, processing, connecting, commercializing, and scaling resources that already exist within the food ecosystem. The organizations best positioned to lead this transition will be those capable to combine technological rigor with sound economics, robust food-safety validation, compelling market propositions, and effective ecosystem collaboration. Sidestreams are not merely residues to be managed. They are strategic assets that can support circularity, innovation, competitiveness, and long-term value creation across the food industry.

1. Introduction

The global food industry is a vast and interconnected ecosystem that transforms natural resources into food products through a complex network of agricultural production, processing, manufacturing, distribution, retail, foodservice, and consumption. Rather than functioning as a simple linear supply chain, it operates as an integrated system in which biological processes, technology, regulation, economics, and human behavior continuously interact to create and preserve value. Increasing pressures from climate change, resource scarcity, population growth, and sustainability expectations have intensified the need to understand this system not only as a producer of food, but also as a generator of significant sidestreams, by-products, and losses.

Within this context, the valorization of food industry sidestreams has emerged as an important opportunity to simultaneously improve resource efficiency, reduce food loss and waste, create new revenue streams, and support circular economy objectives. Across the food value chain, sidestreams include materials such as agricultural residues, processing by-products, manufacturing outputs, and surplus ingredients that may retain nutritional, economic, or functional value.

Rather than viewing these materials as waste, leading companies increasingly explore how they can be redirected into higher-value applications for human consumption, animal feed, industrial materials, bio-based products, or energy generation.

This study builds on a series of research conversations with major international actors across the food ecosystem, including companies operating in agriculture, manufacturing, retail, foodservice, biotechnology, packaging, and sustainability leadership.

The participating companies are (in alphabetical order):

- Aldi Süd
- Avery Dennison
- Bayer
- Empirical Foods
- Kroger
- Nestlé
- Novolex
- Novonesis
- Oterra
- RBI
- Starbucks
- Tyson Foods

The objective has been to identify current practices, successful approaches, structural barriers, and future opportunities related to sidestream utilization and food loss reduction. Particular attention has been given to the operational realities companies face when attempting to scale valorization initiatives, including issues related to economics, regulation, food safety, technology, logistics, and collaboration across value chains.

The findings reveal that sidestream valorization cannot be understood in isolation. Successful initiatives often require a systems perspective that considers entire value streams rather than individual products. As demonstrated by examples from agricultural production, a single crop can generate multiple interconnected value streams serving food, feed, industrial, and energy markets simultaneously. At the same time, organizations must navigate complex regulatory requirements, market conditions, and technical constraints to ensure that higher-value uses are both feasible and scalable.

By synthesizing insights from leading organizations across the food ecosystem, this report aims to provide a comprehensive understanding of how businesses currently approach sidestream valorization, what barriers continue to limit progress, and where the greatest opportunities for innovation and collaboration exist. Ultimately, the study contributes to a growing discussion about how the food industry can transition from a predominantly linear model toward a more circular and resource-efficient future.

2. Methodology

2.1 Exploring Valorization Through Research Conversations

The findings presented in this report are primarily based on a series of qualitative research conversations with representatives from organizations operating in different parts of the food industry ecosystem. The participating organizations included actors involved in agriculture, food manufacturing, ingredient production, packaging, retail, food service, biotechnology, and related fields. Together, these conversations provided diverse perspectives on food loss, sidestreams, circularity, and resource valorization.

A total of 16 semi-structured research conversations were conducted across 12 participating organizations. All sessions were held virtually via Microsoft Teams, each lasting between 45 and 60 minutes. Participant distribution varied by organization: five companies were represented by a single participant, four by two participants, and three by three participants. The participants represented key decision-makers across core functional areas, primarily within sustainability, operations, and business development.

Rather than approaching these interactions as traditional interviews designed to validate predefined hypotheses, the study adopted an exploratory approach inspired by Design Thinking principles. The primary objective was to develop a deeper understanding of how organizations perceive and experience the challenges and opportunities associated with valorization within their specific contexts. The conversations were therefore used as a means of exploring perspectives, uncovering assumptions, and understanding practical realities from the viewpoint of the individuals involved in the work.

This approach is based on a recognition that many of the barriers and opportunities associated with sidestream utilization are complex and context-dependent. If the pathways to successful valorization were obvious and straightforward, many of them would likely already have been implemented, although technological developments may make previously investigated opportunities viable. Consequently, understanding the less visible factors shaping decision-making becomes particularly important. These factors may include operational constraints, organizational priorities, market dynamics, regulatory considerations, technological limitations, or informal practices that are not immediately apparent through quantitative analysis alone.

2.2 Structured but Open Exploration

To balance consistency with flexibility, all research conversations followed a shared overall structure. This ensured that comparable themes were explored across organizations while allowing sufficient space to pursue topics that emerged naturally during the discussions.

The intention was not to guide participants toward specific answers, but rather to encourage reflection and exploration. This enabled the conversations to move beyond surface-level descriptions and toward a deeper understanding of how valorization opportunities are identified, assessed, and acted upon in practice. In many cases, the most valuable insights emerged not from direct questions about barriers or opportunities, but from broader discussions about organizational priorities, operational realities, stakeholder relationships, or strategic decision-making.

By maintaining a degree of openness, the conversations also allowed unexpected themes to emerge. Several issues that emerged as important findings in this study, including the significance of ecosystem collaboration, information visibility, consumer perception, organizational alignment, and investment risk, cut across multiple sectors and were not necessarily linked to specific types of sidestreams or technologies.

2.3 Moving Beyond Assumptions

An important motivation for adopting this approach was the desire to move beyond the assumptions held by both researchers and participants. Research concerning food loss, waste, and circularity often begins with apparently self-evident assumptions regarding what the main problems are and how they should be solved. However, the conversations repeatedly demonstrated that challenges viewed as technical from one perspective often contained organizational, economic, regulatory, or cultural dimensions. Likewise, opportunities initially perceived as highly promising sometimes proved difficult to realize when viewed within the realities of day-to-day operations.

The exploratory nature of the conversations therefore helped create space for participants to discuss complexities, contradictions, and unresolved challenges that may not have emerged through more structured questioning. This was particularly valuable in discussions about why certain opportunities remain unrealized despite widespread interest in the valorization of sidestreams based on circularity and resource efficiency.

2.4 Identifying Patterns Rather Than Measuring Prevalence

The purpose of the research conversations was not to generate statistically representative findings about the food industry as a whole. The participating organizations do not constitute a representative sample of all food industry actors, nor was the study designed to quantify the prevalence of specific practices, barriers, or opinions. Instead, the conversations were used to identify patterns, mechanisms, recurring themes, and emerging insights that appeared across different organizational contexts. The emphasis was placed on understanding how and why particular challenges arise, how organizations navigate them, and what this may reveal about broader opportunities for valorization. This type of qualitative understanding is particularly valuable when examining complex systems in which outcomes are shaped by the interaction of multiple factors rather than by isolated variables.

Consequently, the findings presented in the following chapters should be interpreted as insights derived from cross-case exploration rather than as definitive statements about the wider food industry. They represent observations about recurring patterns and shared experiences that emerged across the research conversations, providing a basis for reflection, discussion, and future investigation.

2.5 From Conversations to Insights

Taken together, the research conversations enabled an exploration of food-sidestream valorization from multiple perspectives across the food ecosystem. They provided insight into the practical realities facing organizations, the barriers that continue to inhibit circular resource use, and the opportunities that emerge when technologies, business models, partnerships, and market conditions align.

By focusing on understanding before solution generation, the study sought to illuminate aspects of valorization that may otherwise remain hidden. The resulting findings therefore focus not only on what organizations are doing today, but also on the underlying conditions, relationships, and systemic factors that shape what becomes possible tomorrow.

2.6 Inclusion of DTI Perspectives

To leverage domain-specific insights, a dedicated chapter has been added to this report focusing on recommendations derived from prior DTI experience and academic findings. This section synthesizes established DTI best practices and institutional expertise to provide context-aware strategic guidance tailored to the objectives in the report.

3. The Food Industry Ecosystem

3.1 Understanding Sidestreams in a Complex and Interconnected System

Food loss, waste, and sidestream valorization are often discussed as isolated challenges associated with individual companies or stages of production. The research conversations conducted for this study suggest a different perspective. Rather than occurring at a single point in the value chain, sidestreams emerge throughout a highly interconnected ecosystem in which biological resources, products, materials, information, capital, technologies, and regulations continuously interact. More specifically, across organizations as diverse as Bayer, Empirical, Novonesis, Oterra, Kroger, Starbucks, Restaurant Brands International (RBI), Avery Dennison, and Novolex, sidestream management consistently emerged as an issue shaped by interactions across the broader food ecosystem rather than within any single organization. Understanding this ecosystem is therefore a prerequisite for understanding both the opportunities and the barriers associated with valorization.

While the participating companies operate in different parts of the world and the food value chain, many described similar challenges relating to information flows, market demand, logistics, consumer acceptance, regulatory requirements, collaboration, and technology deployment. Materials considered sidestreams in one organization often become valuable inputs elsewhere, demonstrating the interconnected nature of the system.

For this reason and for analytical purposes, the ecosystem can be viewed as consisting of six interconnected domains: Inputs and Innovation, Primary Production, Food Processing and Manufacturing, Distribution and Market Channels, Consumption, and the Circular Economy. Together these domains shape how resources move through the food system and where opportunities for valorization emerge.

3.2 Inputs and Innovation

The ecosystem begins with those organizations developing agricultural inputs, biological technologies, scientific knowledge, and innovation capabilities. Activities in this part of the system influence not only the quantity of food produced but also the characteristics and potential applications of sidestreams generated later in the value chain.

Both Bayer and Novonesis highlighted how decisions made at the earliest stages of agricultural and technological development have significant consequences for downstream valorization opportunities, and that opportunities for valorization are, in fact, often determined long before a crop is harvested or a food product is manufactured. Bayer emphasized that sidestream opportunities are often determined by understanding the full value stream of crops rather than focusing solely on primary products, while Novonesis described ecosystem-based innovation efforts aimed at transforming agricultural and food-processing residues into valuable new products.

These perspectives suggest that valorization frequently begins long before waste or sidestreams emerge. Opportunities can be influenced by crop selection, biological processes, technological design decisions, and innovation partnerships that determine what becomes technically and economically possible later in the value chain. In short, rather than focusing solely on waste management after waste occurs, emerging approaches seek to optimize entire resource systems from the outset.

3.3 Primary Production

Primary production includes agricultural activities such as crop cultivation, livestock production, and harvesting. At the primary production stage, agricultural activities generate large volumes of biomass and residual materials that do not necessarily enter food markets directly but which hold potential value beyond their initial purpose. These include crop residues, biomass, imperfect produce, and other forms of agricultural sidestreams. Bayer described examples where agricultural sidestreams already contribute value through energy production and nutrient cycling, including the use of corn cobs and biomass remaining after seed production. Rather than viewing such materials as waste, the company emphasized understanding their role within broader agricultural systems.

Similarly, Oterra described working with a broad range of agricultural raw materials including beetroot, carrots, paprika, turmeric, grapes, and sweet potatoes. The company's work mapping sidestreams demonstrated how agricultural by-products can be systematically assessed for higher-value applications.

Together, these examples illustrate that significant valorization opportunities may arise before materials ever enter food manufacturing. At the same time, primary production is characterized by biological variability, geographical dispersion, and dependence on weather and environmental conditions. These characteristics create challenges related to collection, consistency, quality, and economics that continue to influence valorization possibilities further downstream.

3.4 Food Processing and Manufacturing

Many of the most visible sidestream opportunities emerge during food processing and manufacturing, where raw materials are transformed into finished products. Several participating companies demonstrated how residual materials can become valuable resources through technological innovation and business model development.

Empirical provided one of the clearest examples, describing how beef trimmings historically viewed as low-value materials are transformed into high-value food products through proprietary processing technologies and highly efficient resource utilization. The organization explicitly frames its mission around eliminating waste and maximizing the value extracted from available resources.

Similarly, Oterra described a company-wide effort to classify by-products according to a value hierarchy and identify opportunities to move materials toward higher-value uses, while Nestlé discussed examples involving by-products such as wheat bran and spent coffee grounds. Novonesis highlighted innovation projects focused on converting food and agricultural

sidestreams into commercially viable ingredients and products. In general, successful valorization depends upon combining technological capabilities with market demand and regulatory acceptability.

Importantly, these examples illustrate that the distinction between waste and resource is often determined not by the material itself, but by the availability of suitable technologies, markets, partnerships, and business incentives.

3.5 Distribution, Packaging, Retail, and Food Service

The ecosystem extends beyond manufacturing into distribution networks, logistics systems, packaging functions, retail operations, and food-service environments; as products move through these steps, different forms of food loss and waste occur. Several participating organizations emphasized that issues at this stage often relate less to processing and more to visibility, forecasting, inventory management, shelf life, and consumer behavior.

Avery Dennison argued that food waste is frequently a visibility challenge rather than a production challenge. The company described using RFID-enabled labeling and traceability systems to improve inventory management and reduce losses within complex supply chains.

Packaging also emerged as a critical enabling technology. Novolex emphasized that packaging should not be understood solely as a waste issue because its primary role is protecting food quality and extending shelf life. Similarly, Avery Dennison highlighted the role of intelligent packaging and information systems in reducing waste across the value chain.

Retail and food-service companies provided additional examples, as they occupy a unique position within the ecosystem because they maintain direct contact with consumers while simultaneously coordinating activities across extensive supply networks. Kroger described a structured hierarchy prioritizing food sales, markdowns, donations, animal feed, and other recovery options. Aldi described collaborations that transform surplus ingredients into marketable products. Starbucks highlighted coffee-ground reuse programs and donation initiatives, while RBI discussed sustainability efforts spanning thousands of restaurants across multiple brands.

3.6 Consumption

Consumers ultimately determine demand patterns that influence decisions throughout the food ecosystem; thus, consumer behavior plays a significant role in shaping valorization opportunities. The participants frequently pointed to consumer expectations regarding appearance, quality, convenience, shelf life, and food safety as factors that directly or indirectly shape food loss and sidestream generation, effectively either enabling or constraining innovation.

For example, participants discussed the long-term consequences of negative consumer perceptions surrounding products derived from processing sidestreams, as well as the ongoing challenge of communicating value to customers and stakeholders. Additionally, Aldi highlighted the importance of consumer acceptance when introducing products made from rescued or surplus ingredients. This discussion is also relevant to the emerging “Upcycled Certified” certification.

These examples suggest that technical feasibility alone is insufficient. Successful valorization frequently depends on convincing consumers that products derived from sidestreams are desirable, safe, and valuable. In some cases, perceptions regarding quality or safety create obstacles to valorization initiatives. In others, increasing interest in sustainability and resource efficiency generates market opportunities for new products and business models.

3.7 The Circular Economy as a Cross-Cutting Domain

Across all research conversations, circularity emerged not as a separate stage of the value chain but as a principle connecting all stages of the ecosystem. Companies including Novonesis, Oterra, Aldi, Empirical, and RBI all described initiatives intended to extract greater value from resources, develop new uses for sidestreams, or establish partnerships capable of moving materials to higher-value applications.

A particularly important insight came from organizations such as Novonesis, Avery Dennison, and RBI, which emphasized that successful circular solutions often depend on collaboration among multiple actors rather than actions by individual firms. New value frequently emerges through partnerships that connect technologies, infrastructure, markets, and material streams across organizational boundaries. Thus, these activities frequently involve actors beyond the traditional food sector, including biotechnology firms, ingredient manufacturers, packaging companies, technology providers, waste-management organizations, and research institutions, as well as external companies (often startups) bringing innovative utilizations of sidestreams to the value chain as independent operators, such as Unverschwendet, Too Good To Go, etc.

3.8 Key Insight

The company cases suggest that sidestream valorization is fundamentally an ecosystem challenge rather than a company-specific challenge. Bayer illustrated the importance of understanding agricultural value streams; Empirical demonstrated how processing technologies can transform low-value materials into high-value products; Avery Dennison and Novolex highlighted the role of visibility and packaging; and Novonesis, Oterra, Aldi, Kroger, Starbucks, and RBI demonstrated the importance of collaboration, market creation, and circular business models. Taken together, these examples suggest that the most significant opportunities for future valorization will emerge not within individual organizations but at the intersections between organizations operating across the food ecosystem.

4. General Analysis and Discussion

4.1 Why Multiple Analytical Perspectives Are Necessary

The research conversations undertaken for this study demonstrated that there is no single "correct" way to analyze food sidestream valorization. Different companies naturally frame challenges and opportunities according to their position within the ecosystem.

For example, Empirical primarily views valorization through the lens of resource recovery and manufacturing efficiency, whereas Avery Dennison focuses on visibility, data transparency, and supply-chain coordination. Bayer approaches the challenge from an agricultural systems perspective, while Novonesis emphasizes innovation ecosystems and the development of new markets for currently underutilized resources. Retailers and food-service companies such as Kroger, Aldi, Starbucks, and RBI often focus on inventory management, consumer demand, and waste prevention closer to the point of consumption.

Because these perspectives emphasize different aspects of the problem, the findings can be organized in several complementary ways. First, a general analysis and discussion will be presented in which common, cross-cutting themes and issues will be explored and discussed. Then, four different analytical "lenses" will be applied to highlight different patterns, drivers, barriers, and opportunities. No analytical approach provides a complete picture on its own, but together they help illuminate the complexity of sidestream valorization across the food ecosystem.

4.2 From Individual Cases to Cross-Case Patterns

The research conversations generated a rich and diverse body of empirical material spanning organizations operating in different parts of the food ecosystem. Participating organizations included agricultural and life-science companies such as Bayer; ingredient and biotechnology companies such as Novonesis and Oterra; food manufacturers including Empirical, Nestlé, and Tyson Foods; as well as retailers, food-service operators, and supply-chain actors such as Aldi, Kroger, Starbucks, RBI, Avery Dennison, and Novolex. Although these organizations differ considerably in terms of value-chain position, business model, technological capabilities, and sustainability maturity, several recurring patterns emerged across the conversations.

The purpose of this chapter is not to compare individual companies. Rather, the objective is to identify broader patterns that emerge when examining the experiences of organizations operating across different parts of the food ecosystem. The analysis therefore focuses on how organizations recognize, evaluate, and pursue sidestream valorization opportunities rather than on individual organizational performance.

The findings indicate that sidestream valorization is not a single phenomenon. Companies such as Empirical approach it through manufacturing efficiencies and resource recovery, Oterra through systematic by-product mapping, Novonesis through innovation ecosystems, and Avery Dennison through information visibility and supply-chain optimization. Despite these differences, several common patterns can be identified regarding how opportunities are recognized, evaluated, and pursued.

4.3 Valorization Begins with a Shift in Perspective

One of the most consistent observations across the research conversations was that successful valorization often begins with a conceptual shift: viewing sidestreams not as waste requiring disposal, but as resources with unrealized value potential. This perspective was particularly evident in Empirical, where materials historically regarded as low-value beef trimmings are treated as valuable inputs for food production. Similar thinking appeared in Oterra's efforts to identify higher-value uses for processing by-products, in Nestlé's distinction between waste and usable sidestreams, and in Bayer's focus on maximizing value across entire crop systems rather than focusing solely on primary outputs.

Across sectors, companies described reassessing materials that had historically been treated as unavoidable by-products. In many cases, the physical materials remained unchanged. Instead, changes in technological capabilities, sustainability priorities, market demand, or organizational thinking opened new possibilities. For example, Empirical, Oterra, and Bayer each described situations where previously overlooked materials gained value because organizations began viewing them as resources rather than disposal challenges.

This finding suggests that valorization is often driven as much by mindset as by technology. Before technical solutions can be developed, organizations must first recognize that a potential opportunity exists.

4.4 Mapping and Understanding Material Flows is a Critical First Step

A second recurring pattern concerns the importance of understanding material flows and ensuring sound data management. Oterra provided perhaps the clearest example through its systematic mapping of by-products across global operations and its categorization of sidestreams according to a value hierarchy. Similarly, Bayer emphasized the importance of understanding complete crop-value systems, while RBI and Avery Dennison highlighted the importance of data and visibility in identifying inefficiencies and opportunities throughout complex supply chains.

These mapping activities often revealed opportunities that previously received limited attention. Oterra found materials already being utilized in lower-value applications while identifying opportunities to move them further up the value hierarchy. Similarly, Bayer's ecosystem view demonstrated how agricultural sidestreams often possess additional value that becomes visible only when the full system is analyzed.

The findings suggest that organizations frequently underestimate what they do not actively measure. Experiences from Avery Dennison and RBI indicate that improved visibility is often a prerequisite for identifying opportunities and making informed decisions regarding sidestream utilization.

4.5 Technology is an Enabler, Not a Standalone Solution

Technology featured prominently throughout many conversations. Empirical described proprietary food-processing technologies that enable the recovery of value from beef sidestreams. Avery Dennison highlighted RFID-enabled traceability systems, RBI discussed

data and AI opportunities, Novolex focused on packaging innovation, and Novonesis presented biotechnology as a mechanism for creating new value from agricultural residues and by-products.

However, these companies also demonstrated that technology alone rarely explains success. Novonesis repeatedly emphasized the importance of ecosystem partnerships and business models. Empirical highlighted the need for economically viable markets, while Avery Dennison demonstrated that technology creates value only when organizations are able to integrate it into operational decision-making and supply-chain practices.

In many cases, suitable technologies already exist. The larger challenge concerns adoption, implementation, scaling, collaboration, and economic viability. This observation appears consistently across companies operating in very different parts of the food ecosystem.

4.6 Data and Visibility are Emerging Strategic Capabilities

One of the strongest cross-cutting themes was the growing importance of data and visibility throughout the food ecosystem. This theme was particularly evident in the perspectives of Avery Dennison and RBI, both of which described situations where food losses, inefficiencies, or unrealized opportunities persisted primarily because relevant information was unavailable, fragmented, or poorly connected across organizational boundaries. Avery Dennison discussed food waste as fundamentally a visibility challenge, while RBI highlighted the importance of data for understanding resource flows across large and complex operational networks.

Conversely, improved visibility frequently enabled better forecasting, inventory management, resource allocation, and identification of sidestream opportunities. Avery Dennison described the role of RFID-enabled traceability and intelligent labeling systems in improving visibility across supply chains, while RBI discussed growing interest in AI, digitalization, and analytics as mechanisms for improving resource utilization and reducing losses.

The findings suggest that data increasingly functions as an enabling resource in its own right. Just as companies seek to maximize the value derived from physical materials, organizations such as Avery Dennison and RBI increasingly seek to maximize the value derived from information flows, recognizing that better decisions depend upon better visibility.

4.7 Collaboration is both Essential and Challenging

The research conversations consistently highlighted collaboration as a critical prerequisite for successful valorization. This was especially evident in the experiences of Novonesis, Aldi, and RBI, all of which described initiatives that depend upon cooperation among organizations with complementary capabilities, resources, and market access.

For example, Novonesis repeatedly emphasized that successful utilization of sidestreams often requires collaboration among startups, technology providers, ingredient companies, manufacturers, customers, and investors. Likewise, Aldi's partnership model for transforming surplus ingredients into consumer products illustrates how valorization opportunities often emerge from cooperation across organizational boundaries rather than from internal activities

alone. RBI similarly highlighted the need to coordinate sustainability initiatives across extensive supply networks and multiple business units.

However, collaboration was also repeatedly described as a source of complexity. Novonesis emphasized that partnerships depend upon aligned incentives, shared objectives, risk-sharing mechanisms, and trust. When these conditions are absent, even highly promising opportunities may struggle to advance beyond pilot stages. Similar concerns emerged from the perspectives of RBI, where large-scale coordination introduces substantial operational complexity.

The findings therefore suggest that valorization should not be viewed solely as an organizational capability. Rather, the experiences of Novonesis, Aldi, and RBI indicate that it frequently emerges as an ecosystem capability created through productive relationships among multiple actors across the food system.

4.8 Economic Value Remains the Key Scaling Mechanism

Although sustainability objectives featured prominently throughout the conversations, companies consistently emphasized the importance of economic viability. Organizations such as Tyson Foods, Starbucks, RBI, and Empirical all highlighted that long-term implementation and scaling require business models capable of generating measurable value alongside environmental benefits.

This does not imply that sustainability and profitability are conflicting goals. On the contrary, several organizations described situations where resource efficiency and waste reduction created both economic and environmental benefits. Empirical provides a particularly clear example, as its business model is built on converting previously undervalued beef processing streams into commercially valuable food products. Similarly, Starbucks and Tyson Foods discussed sustainability initiatives that seek to create value while reducing waste and environmental impacts.

The research conversations indicate that opportunities are significantly more likely to scale when the value created is visible and measurable for participating organizations. As a result, companies increasingly frame valorization not simply as an environmental responsibility, but as a strategic opportunity related to competitiveness, innovation, resource efficiency, and long-term growth. This perspective was particularly evident in Novonesis, Empirical, and Starbucks.

4.9 Consumer Acceptance Influences What Becomes Possible

While many discussions focused on technical and organizational factors, several companies highlighted the importance of consumer perceptions. Both Empirical and Aldi emphasized that products created through circular approaches ultimately depend upon consumer acceptance. Regardless of technical feasibility, market adoption remains necessary if valorized products are to succeed commercially.

The experiences of these companies suggest that consumer attitudes can function both as barriers and enablers. Empirical discussed how perceptions surrounding products derived from processing sidestreams continue to influence market acceptance, while Aldi highlighted challenges and opportunities associated with introducing products made from rescued

ingredients. At the same time, growing interest in sustainability and responsible consumption creates opportunities for diversification and new product categories.

Consequently, successful valorization depends not only on technical feasibility, but also on the ability to communicate compelling value propositions that resonate with customers, retailers, and other stakeholders. The experiences of both Empirical and Aldi suggest that effective communication can be just as important as the underlying innovation itself.

4.10 From Waste Reduction to Value Creation

Perhaps the most important pattern emerging across the company cases is a gradual shift from a waste-management mindset toward a value-creation mindset. Historically, many organizations approached sidestreams primarily as costs, compliance obligations, or disposal challenges. The experiences of Empirical, Bayer, Oterra, and Novonesis suggest that this perspective is increasingly being replaced by a more strategic view in which sidestreams are regarded as sources of innovation, competitive advantage, and new business opportunities.

This transition can be seen in different ways across the participating organizations. Empirical focuses on creating high-value food products from previously undervalued materials. Bayer emphasizes extracting greater value from agricultural systems. Oterra systematically evaluates opportunities to move by-products higher up a value hierarchy. Novonesis explores new business opportunities by converting food and agricultural residues into commercially viable products and ingredients.

This does not imply that all organizations have reached the same level of maturity or pursue identical objectives. Nevertheless, a common direction is visible across many of the conversations. The emphasis is increasingly moving beyond preventing waste toward creating value from underutilized materials, information, technologies, and partnerships.

4.11 Key Insight

The company cases collectively suggest that sidestream valorization is best understood not as a single technical challenge, but as a process of organizational and ecosystem innovation. The experiences of Empirical, Oterra, Novonesis, Avery Dennison, Aldi, RBI, Bayer, Starbucks, and Tyson Foods indicate that successful initiatives rarely depend upon one factor alone. Instead, they emerge from the interaction of mindset, information, technology, collaboration, economics, and market acceptance.

Across the research conversations, the most promising opportunities tended to arise where organizations were able to combine these elements into coherent approaches that transformed underutilized resources into sources of economic, environmental, and strategic value. Viewed collectively, the cases suggest that the future of food-sidestream valorization may depend less on discovering entirely new resources and more on developing new ways of recognizing, connecting, and utilizing resources that already exist within the food ecosystem.

5. Framework-Based Analyses

5.1 Introduction: Viewing the Same Phenomenon Through Different Lenses

The general analysis identified a number of recurring patterns across the research conversations. These included the importance of mindset shifts, material-flow visibility, technological capabilities, collaboration, economic viability, consumer acceptance, and the broader movement from waste management toward value creation. However, these patterns emerged in different ways depending on whether organizations operated in agriculture, manufacturing, biotechnology, packaging, retail, or food service.

For example, Bayer primarily framed valorization in terms of agricultural systems and crop-value optimization, while Empirical focused on resource recovery and value creation from processing streams. Avery Dennison emphasized visibility and supply-chain transparency, and Novonesis focused on ecosystem innovation and collaboration. Retail and food-service organizations such as Kroger, Aldi, Starbucks, and RBI were more likely to frame opportunities through inventory management, redistribution, consumer engagement, and operational optimization.

As previously discussed, no single framework fully captures the interactions between materials, technologies, markets, organizations, and ecosystem actors that characterize sidestream valorization. Different analytical lenses reveal different aspects of the same phenomenon.

The following four analyses therefore examine the empirical material from four complementary perspectives:

- Farm-to-Fork Value Chain Perspective
- Material Stream Perspective
- Barrier and Solution Perspective
- Strategic Intent and Valorization Hierarchy Perspective

Taken together, these perspectives provide a more comprehensive understanding of the opportunities, challenges, and patterns that emerged across the participating organizations.

5.1.1 Approach 1: Farm-to-Fork Analysis

The most intuitive approach is to analyze opportunities and challenges according to their position in the food value chain, moving sequentially from agricultural production to final consumption. This approach aligns naturally with how organizations often view their operations and allows us to follow the movement of resources through the food system.

Using this approach, companies such as Bayer and Oterra illustrate opportunities emerging during agricultural production and raw-material processing. Empirical, Nestlé, and Tyson Foods demonstrate opportunities within large-scale food manufacturing. Avery Dennison and Novolex illustrate the role of packaging and supply-chain management, while Kroger, Aldi, Starbucks, and RBI highlight issues related to distribution, retail, food service, and consumption.

The strength of this approach is its simplicity and accessibility. It makes it easy to identify where particular sidestreams arise and where opportunities for intervention exist. However, several participants highlighted challenges that span multiple stages simultaneously. Information sharing, collaboration, traceability, regulation, risk management, and consumer acceptance often cut across traditional value-chain boundaries and therefore become less visible when analysis is confined to sequential stages.

5.1.2 Approach 2: Commodity and Material Stream Analysis

A second approach focuses on specific materials rather than organizational locations within the value chain. Instead of following stages, the analysis follows individual resource streams as they move through the ecosystem.

Several participating companies naturally adopted this perspective. Empirical focused on beef trimmings and associated processing streams. Oterra discussed sidestreams derived from vegetables, fruits, color crops, and botanical ingredients. Nestlé highlighted examples including wheat bran and spent coffee grounds, while Starbucks described efforts related to spent coffee grounds and food donations. Aldi focused on surplus ingredients that remain suitable for food use but no longer fit conventional market channels.

Analyzing individual material streams reveals how apparently similar resources can encounter very different barriers depending on their composition, perishability, logistics requirements, market potential, and regulatory status. A material-centered perspective is therefore particularly useful when identifying concrete valorization pathways for specific sidestreams.

However, focusing solely on individual materials risks overlooking systemic issues that affect multiple material streams simultaneously. Challenges such as collaboration, investment risk, infrastructure limitations, and information visibility often transcend specific commodities and therefore require broader analytical lenses.

5.1.3 Approach 3: Barrier and Solution Analysis

Many of the participants were less concerned with specific materials and more concerned with recurring barriers that repeatedly prevent valorization opportunities from reaching scale. This observation supports a third analytical approach focused on identifying common obstacles and corresponding solution pathways.

For example, Avery Dennison repeatedly highlighted limited visibility and fragmented information systems as major contributors to waste. Novonesis emphasized collaboration challenges, investment uncertainty, and the difficulty of creating entirely new ecosystems around sidestreams. Aldi described consumer perception, market acceptance, and operational complexity as significant barriers, while Empirical discussed how historical consumer perceptions continue to influence opportunities for valorization. Similarly, companies such as Oterra, Nestlé, and Tyson Foods described technical, economic, and regulatory considerations that influence whether valorization projects can progress beyond initial concepts.

This analytical approach is particularly valuable because it reveals common patterns across otherwise very different sectors of the food ecosystem. Organizations working with entirely different materials often encounter remarkably similar implementation challenges.

5.1.4 Approach 4: Strategic Intent and Valorization Hierarchy

A fourth approach focuses on the intended outcome of valorization activities rather than on materials or barriers. This perspective examines how organizations attempt to move resources toward higher-value applications within a hierarchy of potential uses.

Several participating companies explicitly described using hierarchical approaches when evaluating sidestreams. Oterra developed a framework for classifying by-products according to different value levels and prioritizing higher-value opportunities where feasible. Kroger described a food-recovery hierarchy prioritizing sales, redistribution, donation, animal feed, and other options before disposal. Tyson Foods discussed waste-reduction programs and recovery initiatives intended to maximize value from available resources.

Similarly, Empirical exemplifies a strategic goal of transforming materials historically considered waste into high-value food products, while Novonesis focuses on creating entirely new value propositions from agricultural and food-processing residues through innovation and collaboration.

This perspective is useful because it aligns analytical discussions with organizational objectives. Rather than asking where sidestreams originate, it asks what value organizations are attempting to create and what factors influence success.

5.1.5 Comparative Assessment of the Four Approaches

Each analytical approach highlights different dimensions of the same phenomenon. Briefly put, the Farm-to-Fork perspective focuses on where opportunities emerge within the food system. The Material Stream perspective focuses on what is being valorized. The Barrier and Solution perspective explores why opportunities succeed or fail. Finally, the Strategic Intent and Valorization Hierarchy perspective examines what kinds of value organizations seek to create and why they pursue particular pathways.

The Farm-to-Fork approach helps explain where opportunities arise. Bayer, Oterra, Empirical, Kroger, and Starbucks collectively demonstrate how sidestreams emerge at different stages of the value chain. The Commodity and Material Stream approach helps explain how particular resources move through the system, drawing on examples from Empirical, Nestlé, Oterra, and Starbucks. The Barrier and Solution approach reveals recurring challenges encountered by organizations including Avery Dennison, Aldi, Novonesis, and Empirical. Finally, the Strategic Intent approach highlights how companies such as Oterra, Kroger, Tyson Foods, Empirical, and Novonesis seek to increase the capture of value by moving resources toward higher-value applications.

Together, these four approaches transform a diverse set of company experiences into a richer understanding of the broader phenomenon. Rather than treating valorization as a purely technical or operational challenge, they reveal it as a multidimensional issue shaped by

materials, markets, technologies, organizational choices, ecosystem relationships, and strategic priorities.

The following analytical sections apply these four approaches to the empirical findings from the research conversations, using each framework to illuminate different dimensions of the opportunities and challenges associated with food sidestream valorization.

5.1.6 Key Insight

The research conversations suggest that no single analytical framework fully captures the complexity of food sidestream valorization. Companies positioned at different points in the ecosystem naturally emphasize different priorities and challenges. Consequently, the most robust understanding emerges when multiple analytical lenses are applied simultaneously. The following sections therefore draw selectively from all four perspectives to identify cross-cutting insights, recurring barriers, enabling factors, and opportunities for future value creation across the food ecosystem.

5.2 Farm-to-Fork:

5.2.1 Understanding Where Valorization Opportunities Emerge

The Farm-to-Fork approach examines sidestream valorization through the sequential flow of food and materials across the value chain. Viewed through this lens, one of the clearest findings is that opportunities for valorization exist throughout the food ecosystem rather than being concentrated in any single stage. Companies operating at different positions in the value chain encounter different forms of sidestreams and therefore pursue different approaches to extracting value from underutilized resources.

5.2.2 Primary Production

At the agricultural stage, sidestreams frequently take the form of crop residues, biomass, imperfect produce, and secondary outputs from crop production.

This perspective was particularly evident in Bayer, which described how agricultural sidestreams such as corn cobs and residual biomass can already generate value through energy recovery and nutrient cycling. Rather than viewing such materials as waste, Bayer emphasized understanding complete crop-value systems and optimizing value across the entire production ecosystem.

Similarly, Novonesis highlighted opportunities to create higher-value applications for agricultural sidestreams through biotechnology, fermentation, and ecosystem-based innovation. These examples illustrate how emerging technologies and biological solutions are expanding the range of potential uses for agricultural resources.

5.2.3 Processing and Manufacturing

Processing and manufacturing emerged as one of the most active areas for sidestream valorisation. This is partly because industrial environments generate relatively consistent material streams that can be measured, controlled, and integrated into new products or applications.

Empirical provides one of the clearest examples, transforming beef trimmings traditionally regarded as low-value processing materials into commercially valuable food products. The company explicitly frames its activities around eliminating waste through highly efficient utilisation of available resources.

Similarly, Oterra described a company-wide effort to map processing by-products and identify opportunities to move them towards higher-value applications, while Nestlé discussed examples involving wheat bran, spent coffee grounds, and other manufacturing sidestreams with potential for further valorisation.

Together, these examples demonstrate that manufacturing environments frequently provide favourable conditions for valorisation because material streams are relatively consistent, measurable, and easier to integrate into industrial-scale processes.

5.2.4 Distribution and Retail

Further downstream, the challenge shifts from production residues towards inventory management, shelf life, forecasting, and maintaining product value before products become unsaleable.

This perspective was particularly evident in Avery Dennison, which argued that food waste often arises not from production inefficiencies but from limited visibility across supply chains. The company highlighted the role of intelligent labelling and RFID-enabled traceability systems in improving inventory management and reducing avoidable losses.

Retail organisations such as Kroger similarly described efforts to maximise food utilisation through structured recovery hierarchies that prioritise sales, markdowns, redistribution, donations, and secondary applications before disposal becomes necessary.

These examples suggest that retail and distribution actors play a critical role in preventing value loss by ensuring that products remain visible, traceable, and usable for as long as possible.

5.2.5 Food Service and Consumption

At the food-service and consumer stages, sidestreams are often linked to behavioural factors, demand uncertainty, and operational complexity.

Starbucks discussed programmes focused on coffee-ground reuse, food donations, and community engagement, while RBI described sustainability initiatives spanning several thousand of restaurants across multiple brands. Both organisations highlighted the importance of extending resource lifetimes and finding productive uses for materials that might otherwise become waste.

These examples demonstrate that opportunities at the food-service stage frequently depend on redistribution systems, customer engagement, operational practices, and partnerships that help retain value within the food ecosystem.

5.2.6 Key Insight

The Farm-to-Fork analytical approach demonstrates that valorisation opportunities exist throughout the value chain, but their characteristics vary substantially depending on where they occur. Bayer and Novonesis illustrate opportunities at the production stage, Empirical, Oterra, and Nestlé demonstrate manufacturing opportunities, Avery Dennison and Kroger highlight distribution and retail perspectives, while Starbucks and RBI illustrate opportunities at the food-service and consumption stages. Consequently, successful interventions must be tailored to the realities of each part of the food ecosystem rather than relying on a universal solution.

5.3 Material Streams:

5.3.1 Understanding the Characteristics of Different Resources

Where the Farm-to-Fork approach follows organizational activities, the Material Stream approach follows the materials themselves. Viewed through this lens, the company cases suggest that the characteristics of individual sidestreams often influence valorization opportunities as much as their location within the value chain. The experiences of Bayer, Empirical, Oterra, Nestlé, Starbucks, Kroger, Avery Dennison, and Novolex demonstrate that different materials present fundamentally different technical, logistical, economic, and market-related opportunities and constraints.

5.3.2 Agricultural Biomass and Crop Residues

Agricultural sidestreams are generally characterized by large volumes but dispersed geographical distribution. Their potential utilization therefore depends heavily on collection systems, logistics capabilities, processing technologies, and local infrastructure.

This pattern was particularly evident in Bayer, which described agricultural sidestreams such as corn cobs and residual biomass from seed production. These materials often exist in substantial quantities but require system-level thinking to unlock additional value. Rather than focusing on individual materials in isolation, Bayer emphasized understanding entire crop-value systems to identify optimal utilization pathways.

Similarly, Novonesis discussed opportunities to utilize agricultural residues such as wheat bran, rice bran, and other crop-derived by-products through biotechnology and fermentation-based approaches. These examples illustrate how biotechnology may enable the conversion of dispersed agricultural materials into higher-value ingredients and products.

Taken together, the experiences of Bayer and Novonesis suggest that agricultural biomass often contains significant value potential, but the challenges of collection, transportation, and processing frequently determine whether that value can be realized in practice.

5.3.3 Food Processing Residues

Materials originating from industrial food-processing environments often display relatively stable and predictable characteristics. This consistency increases their attractiveness as inputs for new products, ingredients, or industrial applications.

Empirical provides a particularly clear example. The company works with highly consistent beef-processing streams that can be integrated into industrial-scale food production through proprietary technologies. Because the materials are produced within controlled manufacturing environments, quality, composition, and availability are relatively predictable, making large-scale utilization economically viable.

A similar perspective emerged from Oterra, which processes a wide range of agricultural raw materials and systematically maps resulting by-products according to their characteristics and potential applications. Through this process, the company identifies opportunities to move materials toward higher-value uses.

Likewise, Nestlé discussed examples involving wheat bran, spent coffee grounds, and other sidestreams generated during food manufacturing. These materials often possess valuable nutritional or functional properties that make them attractive candidates for further utilization.

The cases therefore suggest that food-processing residues frequently offer favorable conditions for valorization because they combine consistency, traceability, and relatively high concentrations of recoverable value.

5.3.4 Organic Consumer-Facing Waste Streams

Food service and retail environments generate a much wider variety of organic materials whose composition, timing, and quality can vary considerably.

This perspective emerged strongly from the experiences of Starbucks, RBI, and Kroger. These organizations described waste streams that are influenced by customer behavior, fluctuating demand, operational practices, and inventory conditions. Unlike industrial processing streams, consumer-facing materials tend to be generated across many locations and in more variable forms.

Starbucks highlighted examples including spent coffee grounds, food waste, packaging materials, and donation programs. RBI described the challenges associated with managing food resources across thousands of restaurant locations, while Kroger focused on systems designed to maximize food utilization before products leave commercial channels.

These examples suggest that consumer-facing streams place greater emphasis on forecasting, redistribution, collection systems, donation networks, and operational coordination than on processing technologies alone.

5.3.5 Packaging and Information Streams

The research conversations also suggest that packaging should not be understood solely as a physical material stream. Increasingly, packaging functions as a carrier of information that enables traceability, visibility, inventory optimization, and resource management.

This perspective was most clearly articulated by Avery Dennison and Novolex. Avery Dennison described the use of RFID-enabled labels and intelligent traceability systems that connect physical products with information flows capable of improving inventory management and reducing waste. In this view, the value of packaging extends beyond the material itself and includes its role in facilitating better decisions throughout the supply chain.

Similarly, Novolex emphasized that packaging's primary function is protecting food quality and extending product shelf life. The company argued that packaging often creates system-wide value by reducing food loss, preserving product quality, and supporting efficient resource utilization.

Together, these examples suggest that packaging increasingly represents both a physical material stream and an information stream. Consequently, the value generated by packaging may derive as much from the information it carries as from its material characteristics.

5.3.6 Key Insight

The Material Stream perspective demonstrates that valorization opportunities are shaped not only by where a sidestream originates, but also by the intrinsic characteristics of the material itself. The experiences of Bayer and Novonesis illustrate the opportunities and challenges associated with agricultural biomass, while Empirical, Oterra, and Nestlé demonstrate the advantages of relatively consistent processing streams. Starbucks, RBI, and Kroger highlight the complexity of consumer-facing organic materials, while Avery Dennison and Novolex reveal how packaging increasingly functions as both a material and an information resource. Together, the findings suggest that volume, consistency, perishability, nutritional value, safety requirements, information content, and logistical characteristics all influence which utilization pathways become feasible.

5.4 Barrier and Solution:

5.4.1 Understanding Why Opportunities Remain Unrealized

While the Farm-to-Fork and Material Stream approaches help explain where opportunities emerge and what resources are involved, the Barrier and Solution approach focuses on why many promising opportunities remain difficult to realize in practice. The research conversations suggest that the primary obstacles are rarely technical alone. Instead, economic, informational, organizational, and market-related barriers frequently interact, creating implementation challenges even when viable valorization opportunities already exist.

5.4.2 Economic Challenges

The most frequently recurring barrier concerns economic viability. Across sectors, organizations consistently emphasized the need to balance sustainability ambitions with commercial realities.

This perspective was particularly evident in Tyson Foods, Starbucks, RBI, and Empirical. While each organization expressed strong sustainability ambitions, all highlighted that long-term implementation depends on the existence of viable economic models capable of supporting investment, operational resources, and organizational commitment.

For Empirical, economic viability is achieved by converting previously undervalued beef-processing streams into commercially valuable food products. Starbucks similarly stressed that sustainability initiatives must create both societal and business value. Meanwhile, RBI and Tyson Foods highlighted how waste-reduction initiatives must ultimately align with broader operational and business objectives to achieve scale.

These examples suggest that technologies, partnerships, and sustainability ambitions may create opportunities, but implementation generally depends upon whether organizations can identify an attractive and measurable value proposition.

5.4.3 Information and Visibility

A second recurring barrier concerns information availability and decision-making. The experiences of Avery Dennison and RBI demonstrated that many opportunities remain unrealized because organizations lack sufficient visibility into the quantities, locations, timing, quality, or characteristics of available resources. In many cases, food losses occur not because technical solutions are unavailable, but because organizations lack the information necessary to identify and act upon opportunities.

Avery Dennison repeatedly framed food waste as a visibility challenge, advocating the use of RFID-enabled labels, traceability technologies, and intelligent inventory systems. Similarly, RBI identified data, analytics, and AI as important tools for improving resource management within large-scale food-service systems.

These examples suggest that improved data collection, traceability, and information sharing function not merely as operational improvements, but as foundational enablers of valorization itself.

5.4.4 Collaboration and Ecosystem Coordination

Many valorization opportunities extend beyond organizational boundaries. As a result, successful implementation frequently depends upon collaboration among actors with different objectives, capabilities, incentives, and resources.

This challenge was particularly evident in the perspectives of Novonesis, which repeatedly emphasized that successful sidestream utilization often requires cooperation among technology providers, startups, manufacturers, investors, customers, and research organizations. Valorization opportunities frequently depend on the ability to connect previously disconnected actors within the ecosystem.

A similar pattern emerged from Aldi's collaboration with food-rescue partners to transform surplus ingredients into consumer products. In this case, successful valorization depended not only on the materials themselves, but on the existence of partnerships capable of connecting suppliers, processors, retailers, and consumers.

However, collaboration also introduces complexity. Novonesis highlighted challenges relating to risk sharing, governance, alignment of incentives, and stakeholder commitment. These factors often determine whether opportunities progress beyond pilot projects into scalable business models.

The findings therefore suggest that valorization is frequently an ecosystem challenge rather than a company-specific challenge. Many opportunities depend on successful coordination among multiple actors rather than the actions of a single organization.

5.4.5 Consumer Acceptance

Even technically successful solutions may fail if they do not achieve market acceptance. This challenge emerged particularly strongly in the experiences of Empirical and Aldi. Both organizations highlighted how consumer perceptions influence the feasibility of valorization initiatives. Products derived from sidestreams, rescued ingredients, or unconventional resources may face questions regarding quality, safety, legitimacy, or desirability, regardless of their objective characteristics.

Empirical discussed long-standing challenges associated with consumer perceptions of products created from processing streams, while Aldi described the importance of normalizing products made from rescued surplus ingredients. Both cases demonstrate that commercial success often depends as much on communication and trust as on technological innovation.

Consequently, organizations frequently need to address perceptions relating to quality, safety, sustainability, and product identity before valorized products can achieve widespread adoption.

5.4.6 Emerging Solutions

Although no universally applicable solution emerged from the research conversations, several recurring response strategies appeared across industries. For example, Oterra demonstrated the value of comprehensive sidestream mapping and hierarchical evaluation of by-products, while Avery Dennison illustrated how improved data visibility and traceability can support better decision-making. Novonesis highlighted ecosystem partnerships, pilot projects, and collaborative innovation models as mechanisms for overcoming implementation barriers.

Across the cases, recurring solution strategies included:

- Improved resource mapping and measurement, exemplified by Oterra.
- Enhanced data sharing, traceability, and transparency, exemplified by Avery Dennison.
- New ecosystem partnerships, illustrated by Aldi and Novonesis.
- Technological innovation, demonstrated by Empirical, Novonesis, and Avery Dennison.
- Alternative business models and market creation, illustrated by Empirical, Aldi, and Novonesis.
- Increased focus on communication and market development, highlighted by Empirical and Aldi.
- Cross-sector collaboration involving multiple ecosystem actors, particularly visible in Novonesis initiatives.

What makes these responses particularly noteworthy is that they frequently address multiple barriers simultaneously rather than targeting isolated challenges.

5.4.7 Key Insight

The Barrier and Solution approach suggests that barriers to valorization are rarely independent. The experiences of Empirical, Avery Dennison, Novonesis, Aldi, RBI, Tyson Foods, and Starbucks demonstrate that economic, technical, organizational, informational, and market-related challenges frequently interact. As a result, successful solutions typically involve coordinated interventions across multiple dimensions rather than isolated technological improvements. The cases indicate that the greatest opportunities arise when organizations simultaneously address information visibility, collaboration, market acceptance, and economic viability while leveraging technological innovation and ecosystem partnerships.

5.5 Strategic Intent / Valorization Hierarchy:

5.5.1 Understanding Why Organizations Pursue Valorization

The final analytical approach examines sidestream valorization through the lens of strategic intent. Rather than focusing on the materials themselves or the barriers they encounter, this approach explores the different forms of value organizations seek to create through valorization activities. The research conversations suggest that although many organizations pursue similar activities, they often do so for different strategic reasons.

For some organizations, valorization is primarily an operational efficiency initiative. For others, it is a sustainability strategy, an innovation platform, a growth opportunity, or part of a broader organizational transformation agenda. The diversity of motivations observed across the participating companies highlights the importance of understanding not only what organizations do, but why they choose to do it.

5.5.2 Resource Efficiency and Cost Reduction

For some organizations, valorization begins as an effort to reduce waste, improve operational efficiency, and avoid unnecessary losses.

This perspective was particularly evident in Tyson Foods and Kroger. Both organizations discussed strategies aimed at reducing food loss and improving resource utilization within existing operations. In these contexts, valorization is closely linked to operational performance and efficient use of available resources.

Kroger's food-recovery hierarchy illustrates this approach clearly. The company's primary objective is to maximize the use of existing resources through sales, markdowns, donations, and alternative utilization pathways before disposal becomes necessary. Similarly, Tyson Foods described programs focused on waste reduction, resource recovery, and operational efficiency across production facilities.

Viewed from this perspective, valorization is not primarily about creating entirely new business opportunities. Instead, it begins with reducing inefficiencies and recovering value that would otherwise be lost.

5.5.3 Sustainability and Circularity

Many participating organizations framed valorization within broader environmental and circular-economy ambitions.

This perspective emerged particularly strongly from Oterra, Tyson Foods, and Starbucks. For these organizations, sidestream valorization forms part of a broader commitment to sustainability, waste reduction, resource stewardship, and circularity.

Oterra described systematic efforts to understand and improve the utilization of by-products across global operations, while Starbucks discussed programs focused on coffee-ground reuse, food donations, regenerative agriculture, and community engagement. Tyson Foods similarly linked waste reduction efforts to broader sustainability objectives and environmental performance goals.

These examples suggest that sustainability motivations frequently act as catalysts for experimentation, investment, and organizational commitment, even when immediate commercial returns may be uncertain.

5.5.4 Product and Business Model Innovation

A more advanced form of valorization involves creating entirely new products, ingredients, services, or markets from underutilized resources. In these cases, the objective moves beyond waste reduction toward the creation of entirely new forms of value.

This perspective was especially evident in Empirical and Novonesis. Empirical built its business model around converting beef-processing sidestreams into commercially valuable food products, effectively transforming what had previously been considered low-value materials into a core source of value creation.

Similarly, Novonesis discussed multiple initiatives aimed at developing new products, ingredients, and commercial opportunities based on agricultural and food-processing residues. Rather than treating sidestreams as disposal challenges, the organization views them as opportunities for innovation, venture development, and ecosystem creation.

These examples illustrate a significant shift in perspective. Sidestreams are no longer viewed merely as materials requiring management, but as inputs capable of supporting entirely new products, markets, and business models.

5.5.5 Strategic Positioning and Future Growth

The most ambitious examples viewed valorization not simply as an operational or sustainability initiative, but as part of long-term organizational transformation and future growth strategies.

This perspective was particularly evident in Novonesis, which described sidestream utilization as part of a broader innovation strategy focused on developing future business opportunities through ecosystem partnerships and external collaboration. The organization repeatedly emphasized creating entirely new value networks rather than optimizing existing processes alone.

A similar perspective emerged from Empirical, where continuing innovation around food-processing streams supports long-term competitiveness and market development. Starbucks likewise highlighted the strategic importance of sustainability programs in supporting stakeholder engagement, community value creation, and long-term organizational objectives.

For these organizations, valorization contributes not only to operational performance, but also to innovation capacity, resilience, stakeholder relationships, competitive diversification, and future growth.

5.5.6 A Hierarchy of Value Creation

Viewed collectively, the company cases suggest an implicit hierarchy of valorization objectives:

- Avoiding disposal and reducing losses.
- Recovering value from existing materials.
- Creating new products, ingredients, or applications.
- Developing new business opportunities and revenue streams.
- Contributing to broader ecosystem transformation.

Examples of the first stages can be observed in organizations such as Kroger and Tyson Foods, where the emphasis is strongly linked to reducing waste and improving resource utilization. Intermediate stages can be observed in organizations such as Oterra and Empirical, which actively seek to move materials toward higher-value applications. The most advanced stages are exemplified by Novonesis, where sidestream utilization becomes part of a broader strategy for business innovation, ecosystem building, and future value creation.

Importantly, these objectives are not mutually exclusive. Many successful initiatives create multiple forms of value simultaneously by combining environmental benefits, economic returns, operational improvements, innovation opportunities, and strategic advantages. This pattern was visible across organizations including Oterra, Novonesis, and Empirical.

5.5.7 Key Insight

The Strategic Intent approach reveals that valorization is not solely about resource utilization. It is equally about value creation. The company cases demonstrate that organizations pursue valorization for different reasons: Kroger and Tyson Foods focus strongly on efficiency and waste reduction; Oterra, Starbucks, and Tyson Foods emphasize sustainability and circularity; Empirical focuses on product and business-model innovation; while Novonesis increasingly positions valorization as part of a broader strategy for innovation, ecosystem development, and future growth.

Together, the broader pattern suggests a gradual movement from viewing sidestreams as waste-management challenges toward viewing them as strategic assets capable of supporting innovation, competitiveness, resilience, and long-term value creation. The most mature approaches appear to combine efficiency, sustainability, innovation, and ecosystem collaboration into a coherent strategic vision for the future.

6. Additional Examples

6.1 Established Valorization Pathways: Learning from Proven Upcycling Models

The analyses presented in the preceding chapters focused primarily on patterns emerging from the research conversations conducted as part of this study. To place those findings in a broader context, it is useful to examine examples of food-sidestream valorization that have already achieved a degree of commercial maturity and market acceptance.

The following is based on DTI experience and academic findings.

These examples are not presented as direct benchmarks for the participating organizations. Rather, they serve as illustrations of how sidestreams that were once regarded as low-value residuals have, in a variety of contexts, become inputs for new products, ingredients, and business opportunities. Collectively, they demonstrate that valorization is neither a hypothetical concept nor a niche activity. In many instances, it has already evolved into established commercial practice.

6.1.1 From By-Products to Ingredients

One of the most striking features of established upcycling examples is the extent to which they challenge traditional distinctions between primary products and by-products.

Perhaps the best-known example is spent grain from brewing. Historically regarded as a residual material from beer production, spent grain is now increasingly processed into high-fiber and protein-rich ingredients used in snacks, baked goods, pasta products, breakfast foods, and specialty ingredients. What was once treated primarily as a secondary output has become a resource capable of supporting entirely new product categories.

A similar transformation can be observed in dairy production. Whey, which for many years was viewed as a difficult and costly by-product of cheese and yogurt manufacturing, has been successfully converted into high-value proteins, nutritional ingredients, sports beverages, and functional food products. Today, whey-based ingredients are among the most commercially successful examples of food-industry sidestream utilization.

These examples illustrate an important principle that also emerged from the research conversations: the value of a sidestream is not fixed. Materials acquire value when technologies, markets, and business models align in ways that make new applications possible.

6.1.2 Unlocking the Potential of Previously Overlooked Resources

Many successful upcycling initiatives focus on materials that were not traditionally considered edible or commercially attractive.

Examples include:

- Chickpea cooking water (aquafaba), which can replace egg whites in various food applications.
- Cocoa pulp, which historically remained largely unused despite constituting the majority of the cocoa fruit.
- Coffee fruit (cascara), which surrounds the coffee bean and has increasingly found applications in beverages and snack products.
- Orange peels, now utilized as sources of fibers, flavor compounds, and essential oils.

These examples demonstrate how innovation often emerges not from entirely new resources, but from reconsidering existing resources through a different lens. In many cases, the primary challenge is less about discovering a material than about recognizing its potential value.

6.1.3 Reimagining Food Loss

Several established examples focus specifically on edible surplus food. Bread is among the most frequently wasted food products globally. However, multiple initiatives have demonstrated that surplus bread can be transformed into new foods, beverages, snacks, ingredients, and bakery products. Similar approaches have been applied to cosmetically imperfect fruits and vegetables that fail retail quality standards despite retaining their nutritional value.

These examples illustrate a broader trend identified throughout this study: increasing efforts to move resources upward in the value hierarchy wherever possible. Instead of viewing surplus food primarily through a waste-management lens, organizations are increasingly exploring how surplus materials can re-enter food systems in forms that preserve both nutritional and economic value.

6.1.4 New Protein Sources from Existing Resources

Another notable trend is the growing use of sidestreams as sources of alternative proteins and functional ingredients. Okara, the fibrous residue generated during tofu and plant-based milk production, is increasingly being used to create protein-rich and fiber-rich flours. Oilseed press cakes, generated during vegetable oil production, are similarly being explored as sources of proteins for human consumption. Potato-processing sidestreams have also become important sources of functional plant proteins.

The significance of these examples extends beyond waste reduction. They demonstrate how sidestreams may contribute to broader sustainability challenges, including the development of alternative protein systems and more resource-efficient food production models.

6.1.5 Lessons from Established Examples

Viewed collectively, these established upcycling pathways reveal several recurring characteristics:

- They often begin with an improved understanding of material properties.
- They typically require technological innovation to unlock value.
- They depend on market acceptance and viable business models.
- They frequently emerge through partnerships that connect previously separate actors.
- They move materials toward applications that create higher forms of value.

Perhaps most importantly, these examples demonstrate that successful valorization rarely happens overnight. Many pathways that appear obvious today required years of technological development, market creation, regulatory adaptation, and consumer education before becoming commercially established.

6.2 The Emerging U.S. Upcycling Ecosystem

While the previous section focused on established valorization pathways, the U.S. market provides a useful perspective on how a broader upcycling ecosystem is beginning to emerge around these opportunities.

The examples reviewed suggest that food-sidestream valorization is increasingly evolving beyond individual projects and experiments. Instead, a diverse landscape of startups, scale-ups, corporate ventures, industrial processors, and ecosystem organizations is developing around the creation of value from underutilized resources.

This development is noteworthy because it reflects a broader shift identified throughout the present study: moving from isolated waste-reduction initiatives toward dedicated business models centered on resource valorization.

6.2.1 The Rise of Specialized Upcycling Companies

One notable feature of the U.S. landscape is the emergence of companies whose primary purpose is the utilization of specific sidestreams.

Examples exist across numerous resource categories:

- Brewing sidestreams transformed into food ingredients.
- Dairy sidestreams converted into beverages and nutritional products.
- Vegetable trims transformed into sauces, broths, and prepared foods.
- Fruit residues converted into snacks and functional ingredients.
- Plant-based manufacturing residues turned into alternative protein products.

These organizations differ from traditional food manufacturers in an important respect: sidestreams are not peripheral to their business models. They constitute the core resource around which the business is built.

This observation supports one of the central findings from the Strategic Intent analysis: The most advanced forms of valorization do not simply reduce waste; they create entirely new value propositions.

6.2.2 The Importance of Scale-Up Companies

The U.S. examples also highlight the emergence of a category that bridges the gap between startup experimentation and large-scale industrial production.

These scale-up organizations focus on commercializing technologies, processes, and products that have already demonstrated technical feasibility but require further development before achieving broad market penetration. Examples include businesses focused on spent grain, fruit residues, fermentation-based applications, and alternative proteins.

Their presence is significant because many valorization opportunities fail not during invention, but during scaling. Developing technologies capable of processing sidestreams at industrial volumes remains one of the key challenges identified both in this study and in wider industry discussions.

6.2.3 Corporate Ventures and Industrial Integration

Another notable trend is the growing involvement of large established organizations. Some companies have established dedicated ventures focused on extracting high-value proteins, fibers, and ingredients from processing sidestreams. Others have integrated valorization directly into existing industrial operations.

This development suggests that valorization is increasingly being viewed as a strategic business opportunity rather than solely a sustainability initiative. As technologies mature and markets develop, resource recovery becomes integrated into mainstream industrial strategy.

This observation closely mirrors discussions with several participants in the present study, who emphasized the need to combine sustainability ambitions with economic value creation.

6.2.4 Valorization at Industrial Scale

Perhaps the most striking U.S. examples involve organizations operating at a very large scale. Large ingredient manufacturers, agricultural processors, and rendering companies have long extracted value from animal by-products, processing fractions, oilseeds, and agricultural residues. Products derived from these streams include proteins, feed ingredients, specialty fats, food ingredients, biomaterials, and renewable fuels.

These examples remind us that valorization is not exclusively associated with novel startups or innovative consumer products. Some of the most mature and economically significant forms of valorization occur at industrial scale and have been embedded within food systems for

decades. In this sense, the distinction between "traditional" resource utilization and "modern" upcycling is often less clear-cut than it first appears.

6.2.5 Building an Industry Ecosystem

Finally, the U.S. examples reveal growing efforts to create shared infrastructure around upcycling. Industry organizations have emerged to develop standards, certification programs, terminology, and networks that support collaboration among companies working in this field.

The emergence of such ecosystem institutions is particularly significant. It suggests that food-sidestream valorization is evolving from a collection of isolated activities into a more coherent industrial domain with its own actors, practices, and support structures.

6.2.6 Key Takeaway

Taken together, the U.S. examples demonstrate that a wide variety of organizational models can support successful valorization. This diversity reinforces one of the central conclusions of this study: there is no single pathway to successful valorization. Different materials, technologies, markets, and organizational contexts give rise to different solutions.

However, across all these examples, a common pattern remains visible: Economic value is created when underutilized resources are reimagined not as waste streams to be managed, but as assets that can support innovation, new products, new partnerships, and new forms of business development.

6.3 Five Particularly Important Lessons

6.3.1 Successful Valorization Starts with Reframing Waste as a Resource

Across all examples of successful valorization of food industry sidestreams, the same pattern appears repeatedly: materials that were once viewed as disposal problems are increasingly viewed as potential sources of nutrition, functionality, ingredients, products, and revenue streams. This aligns closely with one of the strongest findings from the research conversations: valorization often begins with a change in perspective before it becomes a technological project.

6.3.2 Technology Matters, But It Is Rarely the Whole Story

Many successful upcycling pathways depend on technologies for drying, extraction, fermentation, protein isolation, stabilization, or ingredient processing. However, the examples also show that technology alone is not enough.

Commercial success typically requires a reliable supply of sidestreams, market demand, consumer acceptance, business-model innovation, distribution channels, and ecosystem partnerships. This supports one of the central findings from the empirical analysis: technology is usually an enabler rather than the primary driver of successful valorization.

6.3.3 There Is No Single Valorization Model

The examples reveal an impressive variety of approaches. Materials can be transformed into e.g. food ingredients, finished consumer products, beverages, functional proteins, biomaterials, animal feed, industrial ingredients, and renewable fuels.

The overall lesson is that there is no universal blueprint. Different resources, markets, technologies, and capabilities create different pathways.

6.3.4 The Largest Opportunities Often Arise at the Intersection of Industries

Many of the most interesting examples involve actors connecting parts of the ecosystem that were previously disconnected, for example breweries partnering with food producers, dairy streams becoming beverage products, vegetable sidestreams becoming ingredients for food-service operators, ingredient companies creating new applications for agricultural residues, and food-processing sidestreams becoming inputs for biotechnology platforms.

This strongly reinforces one of the principal conclusions from the framework analyses: Valorization is best understood as an ecosystem challenge rather than an individual-company challenge.

6.3.5 Upcycling Is Moving from a Niche Activity to a Recognizable Industry

Perhaps the most strategic lesson concerns maturity. The examples show evidence of an emerging industrial field characterized by:

- specialized companies
- dedicated business models
- technology providers
- large-scale industrial actors
- certification systems
- industry associations
- shared terminology and standards.

This suggests that upcycling is gradually evolving from isolated sustainability projects into a more established economic activity. Importantly, this echoes a finding from the Strategic Intent analysis: The most advanced organizations increasingly view valorization not merely as waste reduction, but as a core engine of strategic value.

6.3.6 Overall Takeaway

Together, the study findings and the additional examples suggest that the future potential of food-sidestream valorization lies not primarily in discovering new resources, but in developing new ways of recognizing, processing, connecting, commercializing, and scaling resources that already exist.

The examples demonstrate that many pathways are already technically and commercially feasible. The remaining challenge is increasingly one of coordination, market creation, business-model development, and ecosystem building. In that sense, the most important lesson from both chapters may be that successful valorization is rarely about a single technology or a single company. It is about creating systems in which underutilized resources can continuously find higher-value uses.

7. DTI Perspectives

7.1 Organizational perspectives

7.1.1 Placement of Sustainability Leadership

Evidence suggests that maximizing strategic impact often correlates with how broadly the sustainability lead or Chief Sustainability Officer (CSO) is anchored within the organization. When this role maintains open channels with diverse stakeholders, strategic alignment appears easier to sustain. In contrast, positioning the role within a narrower department could restrict visibility, potentially constraining the ability to leverage cross-functional synergies.

While high-level leadership tends to thrive on broad organizational access, day-to-day execution may be well served by a decentralized structure. Placing practitioners directly within business units can offer deeper insight into ground-level operational realities.

Linking these distributed roles via a hub-and-spoke or network model may offer a practical compromise, providing unified strategic direction while allowing individual business units the autonomy to champion and scale relevant initiatives.

7.1.2 Reevaluating Potential Sidestream Valorization

While sidestream valorization inherently involves technical and operational hurdles, treating past constraints as fixed parameters can inadvertently limit future opportunities.

Because external factors, such as processing technologies, policy incentives, and market demand, are in continual flux, technical and economic feasibility thresholds are also shifting. Solutions that were previously out of reach may become practical over time.

7.1.3 Key External Factors of Circular Sidestream Valorization

Unlocking value from secondary sidestreams within a circular economy framework is often influenced by four key external dimensions: political priorities, regulatory frameworks, sociocultural dynamics, and technological capabilities.

Shifts in any one of these domains can stimulate progress, whether through the emergence of new processing technologies, supportive policy agendas, evolving compliance standards, or growing consumer demand for sustainable alternatives.

Transitions tend to proceed more smoothly when these forces align. When technological feasibility is complemented by policy support, coherent regulation, and market acceptance, the friction associated with scaling circular initiatives is often reduced, potentially improving both efficiency and commercial viability.

7.1.4 Strategic Dimensions in Sidestream Valorization

Unlocking sustainable value through sidestream valorization is often supported by an integrated focus across five interconnected areas: efficiency, collaboration, innovation, business development, and recirculation.

In practice, these dimensions tend to reinforce one another. Operational efficiency helps reduce baseline waste generation, while recirculation pathways allow secondary outputs to be retained and reintroduced into higher-value cycles rather than treated as simple waste. In parallel, technical and process exploration aids in discovering new uses for raw sidestreams, complemented by business development efforts that help identify viable commercial routes, monetization models, and clear market pathways.

Furthermore, because valorization frequently extends beyond the boundaries of a single enterprise, engaging in cross-sector partnerships and supply chain coordination can facilitate the scale and logistical alignment needed for viable operations. Considering these elements as part of an interconnected system can help organizations build complementary capabilities, supporting both resource productivity and longer-term commercial resilience.

7.1.5 Accelerating Sidestream Valorization Through Specialized External Partnerships

While internal business model innovation remains a central pathway for sidestream valorization, organizations may not always find it necessary to build every technical capability and market channel in-house. An alternative approach is to explore strategic partnerships with external entities, such as startups, niche technology providers, or specialized commercial partners, to help capture value from specific secondary streams.

The broader entrepreneurial landscape, particularly in regions like the United States, includes an expanding ecosystem of agile companies focused on upcycling and sidestream utilization. These specialized actors often bring proprietary processing methods, relevant supply networks, or established customer access that might otherwise require significant time and capital for larger enterprises to develop independently.

As a potential avenue forward, exploring these external collaborations can offer a practical way to test circular initiatives. Organizations might consider mapping available sidestreams, initiating exploratory dialogues with relevant startups, and considering flexible collaboration models, such as joint development, licensing, or supply offtake agreements, to assess feasibility with relatively lower upfront exposure.

7.2 Technology Perspectives

7.2.1 Bridging Feasibility and Industrial Scale

Extensive practical experience with the valorization of food industry sidestreams has been accumulated across the entire value chain, from initial material assessment through laboratory analysis, pilot-scale process development, and techno-economic evaluation. Dedicated facilities such as biorefining pilot plants, fermentation suites, and development test kitchens

serve as a critical bridge between laboratory feasibility and full industrial implementation. The following sections examine key technology domains spanning biological, mechanical, digital, hygiene-related, and material-based approaches, while outlining the strategic opportunities these capabilities unlock across the food ecosystem.

7.2.2 Biorefining and Fractionation Technologies

Biorefining, defined as the cascade utilization of value-based components in biomass, serves as a foundational technology for sidestream valorization. Food-grade biorefining pilot plants enable companies to transform low-value biomass and residual streams into high-value functional products through gentle, highly efficient processes, including enzymatic hydrolysis, mechanical treatment, and mild heat or pH adjustments. Typical modular facilities integrate temperature-controlled process tanks, heat exchangers, wet mills, fiber refiners, membrane filtration, mechanical separation systems, and spray drying, providing an integrated environment for scaling up processes from the bench to the pilot demonstration.

Practical experience demonstrates that biorefining does not simply extract a single high-value molecule; rather, it enables a systematic cascading approach. By separating multiple fractions, such as proteins, dietary fibers, and specialty functional components, maximum value is recovered from each input stream. Operational data shows that fine-tuning process flows can simultaneously increase plant-level yield, lower water consumption, and decrease total residual volumes. This yields dual economic and environmental benefits, including reduced greenhouse gas (GHG) emissions from transporting concentrated residuals. Furthermore, when process water is adequately treated and recycled, it becomes a valuable operational resource, creating closed-loop systems that directly support broader circular economy objectives.

7.2.3 Biofermentation and Enzymatic Conversion

Fermentation remains one of the most versatile biological technologies for converting organic sidestreams into higher-value ingredients and commercial materials. Dedicated suites equipped with lab- and pilot-scale fermenters allow organizations to optimize development pipelines from initial microbial strain selection through downstream pilot production. Fermentation pathways can transform agricultural and food-processing residues into functional proteins, natural colorants, flavor compounds, and specialized bio-based ingredients that would otherwise end up as disposal losses.

7.2.4 Enzymatic Conversion of Animal Processing Sidestreams

Animal-processing sidestreams represent an especially promising opportunity for enzymatic conversion. For example, slaughterhouse blood fraction contains a total protein content comparable to standard meat products. While blood plasma is widely utilized in the food industry for its foaming, emulsifying, and gelling properties, the red blood cell fraction is historically underutilized due to its dark pigmentation and metallic flavor profile caused by hemoglobin-bound iron.

Through multi-stage enzymatic processing, these technical barriers can be overcome. Endoproteases break down the hemoglobin structure and release heme iron, while exopeptidases reduce bitterness by selectively cleaving free amino acids. In addition, glutaminase converts glutamine into glutamic acid, resulting in a hydrolysate with a clean, umami-dominant flavor profile.

The resulting decolorized, transparent liquid can be spray-dried into a white, functional protein powder that serves as both a nutritional enhancer and a savory flavoring agent. Simultaneously, the separated heme iron fraction offers substantially higher bioavailability than traditional non-heme iron supplements, reinforcing the overall commercial business case.

7.2.5 Prebiotic Fibers from Agro-Industrial Sidestreams

Agro-industrial processing residues also serve as valuable feedstocks for producing prebiotic dietary fibers, specifically functional oligosaccharides. Both enzymatic hydrolysis and autohydrolysis methods can be evaluated to maximize yield, purity, and overall process efficiency while curbing energy and resource demands.

The target oligosaccharide fractions are subsequently purified using advanced membrane filtration, and their functional efficacy can be validated in vitro for digestibility, gut microbiome modulation, and short-chain fatty acid (SCFA) production. When combined with rigorous Life Cycle Assessment (LCA), this approach ensures that resulting ingredients deliver documented physiological benefits and measurable environmental improvements.

7.2.6 Downstream Processing: Separation, Concentration, and Drying

Once target components are liberated from sidestream matrices via biorefining or enzymatic conversion, downstream processing technologies become critical for separating, purifying, concentrating, and stabilizing the target outputs. Comprehensive pilot plants allow food manufacturers to validate entire valorization pipelines within a compliant, food-grade processing environment.

Centrifugal Separation: Operational workflows frequently leverage complementary separation steps, using decanter centrifuges to isolate coarse solids and fibers, alongside high-speed disk-stack centrifuges for liquid polishing, microbial clarification, and lipid phase separation.

- **Membrane Filtration:** Crossflow membrane systems (including microfiltration, ultrafiltration, and nanofiltration) facilitate precise molecular fractionation, desalting, and concentration of aqueous food solutions without thermal degradation.
- **Spray Drying:** Transforming concentrated liquid streams into stable, shelf-ready dry powders is a crucial final step for commercializing sidestream-derived proteins, soluble fibers, and specialty nutrients.

These technologies offer broad application across commodity sectors. In seafood processing, fish skin can be upcycled into high-grade marine gelatin and collagen products. In meat processing, nutrient-dense organ streams (such as lungs, hearts, kidneys, and spleens),

frequently downgraded to animal feed or anaerobic digestion, can be fractionated into purified food-grade proteins with documented functional and sensory profiles.

7.2.7 Hygiene, Food Safety, and Pasteurization Technologies

Hygiene and food safety considerations are foundational requirements for any viable sidestream valorization pathway in the food domain. Food industry sidestreams are often more perishable and microbiologically sensitive than primary products, as they may be produced under elevated temperatures, undergo multiple handling stages, or possess nutrient profiles that readily support microbial proliferation. Securing food-grade safety standards requires that hygienic design be integrated into process architectures from the outset.

Thermal treatments, particularly optimized pasteurization, are essential for inactivating pathogens and spoilage organisms in liquid streams (such as raw blood fractions, whey streams, and process wash waters) while safeguarding the functional integrity and nutritional quality of heat-sensitive compounds. By matching precise time-temperature regimes to the thermal tolerance of target proteins and flavors, stabilization can occur directly in-line. Where spore-formers or heat-tolerant microorganisms are present, thermal steps can be combined with hurdle technologies, such as acidification, water activity reduction, or bio-preservation, to ensure product stability.

Equipment design plays an equal role: polished contact surfaces, closed sanitary transfer lines, Clean-in-Place (CIP) regimes, and clear physical separation between raw sidestreams and refined products prevent secondary contamination. Continuous microbiological testing and shelf-life modeling provide the regulatory evidence required to substantiate that upcycled ingredients are safe, consistent, and fit for commercial food or feed markets.

7.2.8 Insect Bioconversion

Insect bioconversion provides an alternative, non-fractionated pathway for valorizing complex, heterogeneous sidestreams. Black Soldier Fly Larvae (*Hermetia illucens*, BSFL) can efficiently convert low-value organic residual streams, expired retail foodstuffs, and institutional food waste into high-protein and lipid-rich insect biomass, along with frass (a nutrient-dense byproduct suitable for use as an organic soil amendment).

Optimizing BSFL rearing, climate parameters, and mechanical harvesting at pilot scale ensures clean, consistent larval production while establishing essential safety and traceability datasets for regulatory approval. Converting regional food waste streams into stabilized BSFL meals for pet food and aquafeed applications provides a scalable alternative to traditional fishmeal and soy proteins, recovering nutrient value far more efficiently than standard composting or energy-recovery channels.

7.2.9 Digitalization, Automation, and Process Optimization

While biological and mechanical methods form the foundation of sidestream processing, digital technologies and automation act as critical enablers of industrial implementation. Many sidestreams remain underutilized because their volume, generation schedule, biochemical composition, and geographical distribution are not continuously monitored. Sensor networks,

predictive analytics, and automated decision-support systems can transform fragmented operational data into actionable logistics for producers and processors. In-line optical and spectroscopic sensors facilitate real-time monitoring of sidestream composition and yield fluctuations, while machine-learning algorithms dynamically optimize enzymatic dosages, thermal treatments, and filtration pressures to maintain consistent product quality despite variability in raw materials. Furthermore, digital traceability frameworks create transparent links between food manufacturers generating sidestreams and downstream processors and off-takers, thereby strengthening coordination across the wider industrial ecosystem.

7.2.10 Sustainability Assessment: LCA and Techno-Economic Analysis

Technical feasibility alone does not ensure commercial adoption; valorization pathways must demonstrate verified environmental gains and clear economic returns. Incorporating Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) directly into early-stage process engineering prevents misallocations and confirms commercial viability before capital expenditure occurs.

Applying standardized LCA frameworks (such as the GHG Protocol and ISO 14040/44 standards) provides the quantitative baseline needed to confirm that upcycling a given sidestream delivers a net reduction in carbon emissions and resource consumption compared to conventional baseline methods. Coupling sustainability metrics with techno-economic modeling ensures that valorized processes yield scalable margins alongside substantiated environmental performance claims.

7.2.11 Biomaterials and Packaging Applications

Sidestreams rich in structural biopolymers, including cellulose, hemicellulose, proteins, and chitin, offer significant commercial potential beyond the food and feed sectors. Plant fibers derived from fruit, vegetable, and grain processing can be transformed into biodegradable pulp packaging, trays, and structural containers, providing renewable alternatives to single-use fossil-based plastics. Similarly, purified protein fractions can be formulated into edible coatings or biodegradable films with effective oxygen and lipid barrier properties, thereby extending food shelf life. Chitin, which can be recovered from crustacean processing by-products and black soldier fly larvae (BSFL) bioconversion residues, can be converted into functional biopolymers for applications such as specialty antimicrobials, active packaging layers, and agricultural coatings.

To ensure that these material innovations deliver genuine environmental benefits rather than shifting ecological burdens elsewhere in the value chain, it is essential to evaluate their tensile strength, barrier performance, compostability, and overall life-cycle footprint.

7.2.12 Emerging Opportunities Enabled by Technology

The convergence of these distinct technologies is creating entirely new valorization pathways for materials that were previously considered uneconomical. Refined sugars, nitrogen sources, and peptide fractions extracted from agricultural residues through biorefining are increasingly being used as nutrient feedstocks for precision fermentation platforms, enabling the production of recombinant proteins, industrial enzymes, biomaterials, and high-value nutritional compounds that are completely decoupled from the original sidestream's physical form. At the same time,

integrated biosolutions that combine biological conversion processes with artificial intelligence allow companies to model complex fermentation pathways, accelerate strain screening, and rapidly predict downstream product functionality.

Furthermore, modern processing architectures are shifting toward flexible multi-product platforms that avoid dedicating an entire facility to a single valorization pathway. Instead, modular biorefining systems enable the simultaneous production of high-value functional ingredients, biomaterials, and agricultural inputs from a single residual stream, thereby improving both resource efficiency and economic resilience.

7.2.13 Key Insight

Practical experience across these technological domains confirms that successful sidestream valorization requires a fully integrated methodology: linking initial raw-material characterization and pilot-scale process development directly to techno-economic modeling, life-cycle accounting, and food-safety validation.

Technology serves as the foundational engine that de-risks technical uncertainty, ensures operational consistency, and proves economic feasibility. However, technological tools achieve commercial impact only when integrated into broader ecosystem partnerships, supportive regulatory frameworks, viable business models, and market-driven value propositions. Building flexible, multi-product valorization infrastructure enables the food industry to transition underutilized sidestreams from disposal burdens into long-term strategic assets.

8. Concluding Remarks - From Residue to Resource

The transition from a linear "produce–consume–dispose" model to a circular food ecosystem is no longer a peripheral sustainability ambition; it is a strategic and commercial imperative.

As the findings of this report demonstrate, unlocking the untapped potential of food-industry sidestreams does not depend on discovering entirely new resources. The biomass, nutrients, and functional compounds already exist within the value chains. The true challenge and opportunity, lies in developing the capabilities, technologies, and cross-sector partnerships required to recognize, process, and scale these assets.

Moving forward, commercial leadership in sidestream valorization will be defined by four key commitments:

- **Reframing Waste as Strategic Capital:** Shifting corporate mindset from defensive waste management to proactive value creation, treating sidestreams as engines for product innovation, margin expansion, and supply-chain resilience.
- **Anchoring Technology in Sound Economics:** Leveraging modular biorefining, enzymatic processing, and digital traceability not in isolation, but as validated, techno-economically viable tools that bridge the critical gap between pilot-scale feasibility and industrial-scale production.
- **Pioneering Ecosystem Collaboration:** Acknowledging that no single company can scale circularity alone. Sustainable value will emerge at the intersections of our industries through shared risk, open innovation, and strategic partnerships with agile startups and technology specialists.
- **Aligning Rigor with Market Demand:** Combining rigorous Life Cycle Assessments (LCA) and uncompromising food safety standards with compelling consumer value propositions that turn upcycled ingredients into market-demanded products.

The pathways from sidestream to high-value product are proven and achievable. The food industry now stands at a decisive threshold: organizations that proactively build circular systems today will capture new economic value, safeguard against resource volatility, and lead the transformation toward a resilient, regenerative food future.