JOURNAL OF
BUSINESS CHEMISTRY

The academic journal for management issues in the chemical industry

Volume 23

Issue 2

Heiko Brunner
Platform Strategies in Specialty Chemicals:
From Value Chain Design to Value-Based Pricing and Intellectual Property

Georgios Giotis
The Sticky Truth: Analyzing the Employment Impacts of the Adhesive Industry

Jesper Frost Thomsen, Simon Lux
A Transport Perspective on Designing European Battery Supply Chains: The PowerCo Case

Universität Münster

provadis Hochschule

ISSN 1613-9623

JOURNAL OF
BUSINESS CHEMISTRY

Editorial Board

Editors-in-Chief

Executive Editors

Advisory Board

Aim and Scope

The Journal of Business Chemistry (JoBC) focuses on current developments and insights at the intersection of management and chemistry, biotechnology or pharmacy.

The JoBC provides an international forum for researchers and practitioners in companies, research institutes, public authorities, consultancies or NGOs to present and discuss current challenges as well as potential solutions in an interdisciplinary manner. Thus, the JoBC aims to foster the dialog between science and business, to support management practice in the chemical and pharmaceutical industry and to indicate where further research from academia is needed. The JoBC offers high quality publications with academic standards, a fast publishing process and global reach. With this multidisciplinary and boundary-spanning approach, the JoBC intends to become the leading journal for decision makers in the chemical and pharmaceutical industry.

Publisher

The Journal of Business Chemistry (Online ISSN 1613-9623) is jointly published by Prof. Dr. Jens Leker (affiliated with the Institute of Business Chemistry, University of Münster) and Prof. Dr. Hannes Utikal (affiliated with the Center for Industry and Sustainability, Provadis School of International Management and Technology). It is published every four months as an open access journal.

Subscription

Online-Subscription is possible at:
subscription@businesschemistry.org
or LinkedIn: www.linkedin.com/company/jobc/
The articles are available for download free of charge at
www.businesschemistry.org.

Abstracting and Indexing

The Journal of Business Chemistry is covered by the following abstracting and indexing services:
- EBSCO Publishing
- Hamburg Institute of International Economics
- German National Library of Economics
- Chemical Business NewsBase (CBNB) by Elsevier Engineering Information, Inc.

Copyright

JOURNAL OF
BUSINESS CHEMISTRY

Vol.23, Iss.2, June 2026

Contents

Practitioner's Section

Platform Strategies in Specialty Chemicals:
From Value Chain Design to Value-Based Pricing and Intellectual Property
Heiko Brunner.....87

Research Paper

The Sticky Truth: Analyzing the Employment Impacts of the Adhesive Industry
Georgios Giotis.....103

Research Paper

A Transport Perspective on Designing European Battery Supply Chains: The PowerCo Case
Jesper Frost Thomsen, Simon Lux.....116

ISSN 1613-9623

JOURNAL OF
BUSINESS CHEMISTRY

Letter from the Editors

Reshaping Industrial Value Chains in an Era of Technological Change

The second issue of the Journal of Business Chemistry of 2026 brings together three contributions that address different industrial contexts and analytical perspectives, while sharing a common underlying theme: the restructuring of industrial value creation under conditions of technological change, strategic realignment, and evolving sustainability efforts. Across specialty chemicals, adhesive applications, and advanced battery supply systems, the contributions in this issue collectively highlight how modern industrial systems are increasingly shaped by platform-based architectures, supply chain design choices, and shifting employment and innovation dynamics. Rather than following linear production logics, value creation emerges within interconnected systems in which technology, organization, and geography jointly determine competitive advantage and structural outcomes.

The first contribution by Heiko Brunner, "Platform Strategies in Specialty Chemicals: From Value Chain Design to Value-Based Pricing and Intellectual Property", featured in the Practitioner's Section, examines how platform strategies shape value creation in specialty chemicals. It shows how platform architectures influence value chain design, enable proprietary additive development, and support value-based pricing. Based on long-term revenue data (2013–2022), the paper reports strong growth for products with internally developed additives and highlights 11 patents as evidence of increased appropriability and competitive advantage.

The second contribution by Georgios Giotis, "The Sticky Truth: Analyzing the Employment Impacts of the Adhesive Industry", develops an integrative framework to assess employment effects in the adhesive sector. Combining multiple economic theories, it examines direct, indirect, and induced employment and discusses how automation and sustainability transitions are reshaping skills and occupational structures. The paper positions the sector within broader industrial and labor market dynamics and outlines implications for workforce development.

The third paper by Jesper Frost Thomsen and Simon Lux, "A Transport Perspective on Designing European Battery Supply Chains: The PowerCo Case", analyzes battery supply chain design from a transport economics perspective. Using PowerCo as a case study, it evaluates alternative logistics scenarios in terms of cost and emissions and compares supply options for Volkswagen's Wolfsburg plant.

Collectively, the three papers in this issue reflect a shared analytical concern with how industrial systems evolve under the pressure of technological innovation, strategic restructuring, and sustainability imperatives. Whether through platform-based value creation in specialty chemicals, employment dynamics in adhesive applications, or transport-optimized supply chain design in battery manufacturing, each contribution sheds light on different dimensions of a broader structural transformation currently reshaping industrial economies in Europe and beyond.

We hope you enjoy reading this issue of the Journal of Business Chemistry. Should you have any comments or suggestions, please feel free to contact us at contact@businesschemistry.org. For ongoing updates and insights, we invite you to follow us on LinkedIn (www.linkedin.com/company/jobc) and subscribe to our newsletter. We sincerely thank all authors, reviewers and readers for their continued support and engagement.

Warm regards,

Friederike Fontes
(Executive Editor)

Sabrina Duswald
(Executive Editor)

JOURNAL OF
BUSINESS CHEMISTRY

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818653605
DOI: 10.17879/19818652327

Practitioner's Section

Heiko Brunner[a]

Platform Strategies in Specialty Chemicals: From Value Chain Design to Value-Based Pricing and Intellectual Property

Platform strategies in specialty chemicals are traditionally associated with efficiency and modularity. This paper demonstrates their broader economic implications by showing how platform architectures shape value chain configuration, differentiation, intellectual property generation, and value capture. Building on prior work on accelerated innovation under time pressure, the analysis explains how selective vertical integration enables proprietary additive development and strengthens value-based pricing. Empirical long-term revenue data (2013–2022) show approximately sixfold indexed revenue growth for products containing internally developed proprietary additives, with platform-based additives accounting for approximately 45–50% of this proprietary additive business by 2022. In total, eleven patents were filed and granted as a direct result of the platform strategy, underscoring its structural impact on appropriability and competitive advantage. The findings highlight that platform strategies provide a scalable and legally defensible mechanism for translating technological capabilities into sustained differentiation and superior value capture in specialty chemicals.

Keywords: Competitive Advantage, Innovation Management, Platform Strategy, Specialty Chemicals, Value-based Pricing

1. Introduction

The specialty chemicals industry is increasingly shaped by intensified global competition, rising regulatory complexity, and growing customer demand for highly specific functional performance. In contrast to commodity markets, value creation is rarely driven by the molecule itself, but by its performance within complex formulations and application environments. Firms therefore face the challenge of simultaneously achieving operational efficiency and defensible differentiation (urjahn, 200 urmann, 200 orter, 2008).

A central strategic issue in this context concerns the configuration of the value chain. Many firms rely on formulation-driven business models based on commercially available substances. While such approaches provide flexibility and relatively low capital intensity, they also limit the potential for sustainable differentiation because competitors often have access to similar material bases. As a result, competitive dynamics tend to shift toward price-based competition and imitation risks increase (Williamson, 1985).

At the same time, pricing remains one of the most important, yet insufficiently developed, strategic levers in the chemical industry. Prior research has shown that value-based pricing can substantially improve profitability, but many firms continue to treat pricing primarily as a reactive commercial function rather than as an integrated strategic capability (Rüdiger et al., 2007).

---

[a] Independent Industry Expert, Jessnerstr. 19, D-10247 Berlin; heikoh.brunner@t-online.de

The effective implementation of value-based pricing depends on defensible differentiation and therefore on the underlying technological architecture of the firm (Hinterhuber, 2008; Nagle & Müller, 2018).

Against this background, platform strategies have emerged as an important mechanism for structuring value creation. In the broader strategic management literature, platforms have been discussed primarily in the context of digital ecosystems and multi-sided markets (Parker et al., 2016). At the same time, research in engineering and product development has emphasized modularity and the reuse of common technological building blocks as sources of flexibility, scalability, and accelerated innovation (Baldwin & Clark, 2000; Meyer & Lehnerd, 1997). For this paper, platform strategies are understood as organizational and technological architectures based on reusable core components, shared development structures, and modular variation mechanisms that enable the efficient generation of differentiated products across multiple applications. In specialty chemicals, such platforms may include common molecular building blocks, synthesis pathways, analytical routines, and proprietary additive technologies.

These concepts are highly relevant for specialty chemicals, where products are composed of multiple interacting components such as additives, binders, and functional materials. However, despite these structural similarities, the application of platform strategies in formulation-driven industries remains underexplored. Existing research in specialty chemicals has focused predominantly on product innovation, process optimization, and market segmentation, while platform architectures as integrated mechanisms of differentiation, intellectual property generation, and value capture have received comparatively little attention (Murjahn, 2004; Murmann, 2004).

Recent work has shown that platform-based approaches can accelerate innovation processes by enabling more parallelized development structures under time pressure (Brunner, 2026). Yet their broader strategic implications remain insufficiently understood, particularly with respect to value chain configuration, differentiation, intellectual property generation, and value-based pricing.

Against this background, the question of how platform strategies influence value chain configuration, differentiation, intellectual property, and value capture in specialty chemicals has not yet been systematically addressed.

The empirical observations presented in this study are based on anonymized and aggregated industrial data. The contribution of this paper is fourfold. First, it transfers and adapts platform strategy concepts, which have been discussed primarily in digital and engineering contexts, to the setting of formulation-driven specialty chemicals. Second, it develops an integrated framework linking platform architecture, selective vertical integration, differentiation, intellectual property generation, and value-based pricing. Third, it provides empirical longitudinal evidence showing how platform-based additive strategies translate into sustained revenue growth and patent-protected business expansion. Fourth, it offers a structural explanation for why value-based pricing remains difficult to implement in formulation-driven business models that rely predominantly on commercially available inputs.

By transferring and adapting platform strategy concepts to the context of formulation-driven specialty chemicals, this paper contributes to closing the gap between established platform theory and its application in the chemical industry, while providing a structural explanation for the persistent implementation gap in value-based pricing identified in prior research.

2. Main Part

Building on the conceptual foundations outlined in the introduction, the following sections analyze how platform strategies shape value creation and value capture in specialty chemicals. The focus is not on platforms as digital ecosystems or network-based market structures, but on platform architectures as organizational and technological systems that enable the reuse of common building blocks, the selective integration of performance-critical activities, and the scalable generation of differentiated solutions (Baldwin & Clark, 2000; Meyer & Lehnerd, 1997; Gawer, 2014).

In specialty chemicals, competitive advantage rarely derives from isolated molecules alone. Instead, it emerges from the interaction of formulation expertise, proprietary additives, process know-how, application performance, and customer-specific adaptation (Murjahn, 2004; Murmann, 2004). Firms therefore face the strategic challenge of aligning efficiency, differentiation, and appropriability within increasingly complex competitive and regulatory environments (Porter, 2008).

The analysis developed in this chapter argues that platform strategies provide a structural mechanism to address this challenge. By organizing innovation around reusable technological cores while selectively internalizing strategically relevant components, firms can simultaneously improve development efficiency, strengthen differentiation, and enhance intellectual property generation. In this sense, platform architectures function not merely as operational efficiency tools, but as integrated strategic systems linking value chain configuration, technological control, and value capture.

This perspective also connects platform strategies to transaction cost logic. Selective internalization becomes particularly relevant when externally sourced inputs are strategically critical, highly specific, or difficult to coordinate efficiently through market transactions (Williamson, 1985). Platform architectures therefore enable hybrid governance structures that combine internal control over differentiation-relevant assets with external flexibility in less critical domains.

The chapter proceeds as follows. First, the industry context and the structural pressures shaping specialty chemicals are examined. Second, the role of platform strategies in value chain design is analyzed. Third, an integrated framework linking cost structure, differentiation, intellectual property, and value capture is developed. Building on this framework, the chapter discusses strategic positioning, operational mechanisms underlying platform advantages, empirical evidence on long-term revenue development, and the role of intellectual property in sustaining competitive advantage. Finally, conclusions are made for management with regard to platform-based business models in the specialty chemicals sector.

2.1 Industry Context and Structural Pressures

The specialty chemicals industry is characterized by intense competitive pressure, increasing customer specificity, volatile input costs, and rising regulatory requirements. These developments have fundamentally changed the strategic environment in which firms operate. In many segments, companies are caught in a structural tension: customers demand highly differentiated, application-specific performance, while competitive and regulatory pressures simultaneously limit the ability to pass on costs. This creates a setting in which both operational efficiency and defensible differentiation become indispensable.

2.1.1 Price-Cost Squeeze and Regulatory Complexity

A central structural feature of specialty chemicals is the growing price-cost squeeze. On the cost side, firms face rising raw material prices, increasing energy and compliance costs, and substantial expenditures related to testing, registration, quality assurance, and environmental standards. On the revenue side, however, customers often exert strong pressure on prices, especially in mature application fields with multiple suppliers and limited switching barriers. This combination of cost inflation and constrained pricing flexibility creates a structurally difficult competitive environment (Murjahn, 2004).

At the same time, regulatory complexity has increased significantly. Specialty chemical producers must navigate demanding frameworks regarding product safety, environmental compatibility, handling, labeling, and application suitability. These requirements increase development effort, prolong qualification processes, and raise the threshold for successful commercialization. Regulation therefore does not only represent a compliance issue it also changes the economics of innovation and market participation.

From a competitive strategy perspective, these pressures reinforce the relevance of industry structure. Buyer power, substitution threats, and rivalry among existing competitors intensify when products are insufficiently differentiated and customers perceive limited performance differences across suppliers (Porter, 2008). Under such conditions, price competition becomes more likely and margins become more vulnerable.

2.1.2 Limits of Formulation-Based Business Models

Many firms in specialty chemicals rely on formulation-based business models that combine commercially available raw materials, additives, and intermediates into customer-specific solutions. Such approaches offer clear advantages. They tend to be asset-light, organizationally flexible, and relatively fast to implement because they do not require extensive in-house synthesis capabilities or deep upstream integration.

However, these business models also face structural limitations. When multiple firms have access to the same externally available building blocks, the scope for defensible differentiation remains limited. Even if individual firms possess superior formulation know-how, the underlying material base remains accessible to competitors. As a result, imitation risks are high and differentiation can erode quickly once market success becomes visible.

This problem is particularly relevant in application fields where performance improvements depend on critical functional components rather than on formulation skill alone. In such cases, firms that rely exclusively on commercially available substances may be able to optimize around the margin, but they often struggle to create truly proprietary performance profiles. Their offerings remain exposed to comparison on price, specification, and delivery conditions rather than on uniquely protected customer value.

The limits of formulation-based business models are therefore not merely technological; they are strategic. They constrain the degree to which firms can shape customer value, defend margins, and establish long-term competitive asymmetries. In industries where competitors can draw on the same supplier base, orchestration alone often proves insufficient as a durable source of advantage.

2.1.3 Strategic Relevance of Value Chain Configuration

Against this background, value chain configuration becomes a strategic issue of central importance. Firms must decide which activities and technologies to control internally and which to source through the market. This is not merely an operational make-or-buy question. Rather, it directly affects cost structure, dependency on suppliers, differentiation potential, intellectual property opportunities, and pricing power.

In the specialty chemicals context, the strategic relevance of value chain configuration is especially pronounced because value creation is often linked to performance-critical components whose characteristics are not fully separable from the final product architecture. The decision to internalize the development of additives, intermediates, or process steps can therefore fundamentally alter the firm's competitive position.

Without proprietary control over strategically relevant parts of the value chain, pricing often remains tied to cost logic. Firms may be able to justify modest premia for service, reliability, or formulation competence, but their ability to implement consistent value-based pricing remains limited. Value-based pricing requires differentiated, reliable, and customer-relevant performance that customers cannot easily obtain elsewhere (Hinterhuber, 2008; Nagle & Müller, 2018). The more a firm depends on shared inputs, the harder it becomes to sustain such a position.

For this reason, value chain configuration should be viewed as a foundational strategic lever. It determines whether a firm remains primarily an orchestrator of available substances or evolves into a provider of differentiated, protectable, and economically superior solutions.

2.2 Platform Strategies and Value Chain Design

Platform strategies offer a way to respond to these structural pressures without requiring full vertical integration across the entire value chain. Their core logic lies in the development and reuse of shared technological building blocks across multiple products, applications, or solution families. In specialty chemicals, such building blocks may include common molecular cores, precursor chemistries, synthesis routes, analytical routines, testing procedures, and manufacturing processes.

From a strategic perspective, platform strategies provide an architectural principle for reconciling efficiency and differentiation. They enable firms to standardize and reuse what can be shared, while selectively developing and controlling those elements that are critical to performance and competitive advantage.

2.2.1 Selective Vertical Integration

One of the most important implications of platform strategies is that they enable selective vertical integration. Rather than fully internalizing the entire upstream value chain, firms can choose to integrate only those components that are particularly relevant for product performance, customer value, and differentiation.

This selective integration is highly attractive in specialty chemicals. Full integration is often economically inefficient because it requires substantial fixed investment, broader organizational capabilities, and reduced flexibility. At the same time, a purely market-based sourcing model can create dependency on suppliers precisely where performance-critical inputs are concerned. Platform strategies allow firms to navigate between these extremes.

By internalizing strategically relevant components, firms gain greater control over the properties of key additives or intermediates. This improves the ability to tailor performance, ensure consistency, and generate proprietary features that cannot easily be reproduced by competitors. At the same time, non-differentiating activities can remain externally sourced, preserving flexibility and limiting capital intensity.

Such selective vertical integration also changes the nature of competition. Firms are no longer constrained to combine broadly available materials in slightly different ways. Instead, they can shape the architecture of the performance-critical elements themselves. This creates new opportunities for both technological differentiation and strategic insulation from price competition.

2.2.2 Modular Structures and Economies of Scope

A second core feature of platform strategies is modularity. The platform literature has long shown that complex systems can be decomposed into modules with relatively standardized interfaces, allowing for variation and innovation without redesigning the entire system each time (Baldwin & Clark, 2000). In product development, this enables the efficient creation of product families and derivative solutions from common core elements (Meyer & Lehnerd, 1997).

Transferred to specialty chemicals, this logic implies that firms can organize innovation around reusable technological modules. These may include molecular building blocks, established reaction pathways, shared raw material sets, analytical methods, application protocols, or process know-how. Once such a platform is established, new products can be developed more efficiently because large parts of the technological and organizational architecture already exist.

This creates economies of scope rather than merely economies of scale. The firm benefits not only from producing more of the same, but from using common technological foundations across a broader range of products and applications. Development costs can be distributed across multiple offerings, learning effects accumulate faster, and the commercial exploitation of technological knowledge becomes more scalable.

Importantly, modularity does not imply commoditization. On the contrary, in this context modular structures enable a disciplined combination of shared cores and proprietary variation. They create the basis for scalable differentiation because novel products can emerge from recombination without requiring each project to start from scratch.

2.2.3 Transaction Cost Logic in Platform Choices

The economic logic underlying these choices can be interpreted through transaction cost economics. Williamson (1985) argues that firms internalize activities when market coordination becomes inefficient due to asset specificity, uncertainty, and transaction frequency. This perspective is highly relevant for specialty chemicals, where upstream inputs may be strategically critical and difficult to specify completely in contractual terms.

If a performance-critical additive is sourced externally, and if its availability, quality, or development trajectory depends on third-party suppliers, the focal firm may face substantial strategic vulnerability. Supplier dependency can constrain differentiation, slow innovation, and expose the firm to hold-up risks or imitation. Under such conditions, internalization becomes attractive not because markets fail per se, but because market coordination becomes inefficient for strategically critical assets.

Platform strategies can therefore be understood as hybrid governance structures. They do not require full internalization of all activities, but they do support the targeted integration of those elements for which transaction costs and strategic dependence are particularly high. At the same time, they preserve market-based flexibility in non-critical domains.

This hybrid character is one of the main strategic strengths of platform architectures. They combine internal control over valuable, differentiation-relevant assets with external openness where flexibility and cost efficiency matter more. In doing so, they translate transaction cost logic into a practical architecture for competitive advantage in specialty chemicals.

2.3 An Integrated Framework of Cost Structure, Differentiation, Intellectual Property, and Value Capture

The preceding discussion suggests that platform strategies affect more than isolated operational variables. Their strategic significance lies in the fact that they connect cost structure, differentiation, intellectual property, and value capture in a mutually reinforcing way. To make this relationship analytically explicit, the following section develops the paper's core conceptual framework.

2.3.1 The Strategic Triangle

The interaction of the key dimensions can be represented through a strategic triangle linking cost structure, differentiation, and value capture (Figure 1). While cost structure and differentiation constitute the primary drivers of competitive positioning, value capture reflects the economic outcome in terms of pricing power and profitability.

Cost structure influences value capture directly by determining the margin potential of a given offering. At the same time, it affects the firm's ability to invest in development, scale production, and maintain competitive cost positions. Differentiation, in turn, enables value capture by creating customer-relevant performance advantages that justify price premium. The relationship between cost structure and differentiation is not purely antagonistic. While higher levels of differentiation often require additional investment, platform-based architectures can partially relax this trade-off by enabling the reuse of technological building blocks and the more efficient development of tailored solutions.

The triangle illustrates a central insight of this paper: sustainable competitive advantage arises not from optimizing isolated dimensions, but from aligning cost structure, differentiation, and value capture within a coherent system. Firms lacking differentiation remain exposed to price competition, whereas firms unable to capture differentiated value fail to translate customer benefits into economic returns.

Intellectual property acts as a cross-dimensional mechanism within this system. It enhances differentiation by enabling proprietary performance characteristics and strengthens value capture by protecting these advantages from imitation. At the same time, the generation and protection of intellectual property increase cost structure, reflecting the investments required for research, development, and legal protection. Intellectual property thus introduces a structural trade-off: it raises costs while simultaneously improving the firm's ability to differentiate and to appropriate the resulting value.

The degree of vertical integration, operationalized through platform strategy, forms the underlying design parameter of the triangle. By selectively internalizing performance-critical components, firms influence both cost structure and differentiation potential. Greater control over key technologies enables more fundamental performance improvements and supports the generation of intellectual property, while also requiring additional investment. Conversely, lower levels of integration preserve flexibility and reduce capital intensity but limit the scope for proprietary differentiation.

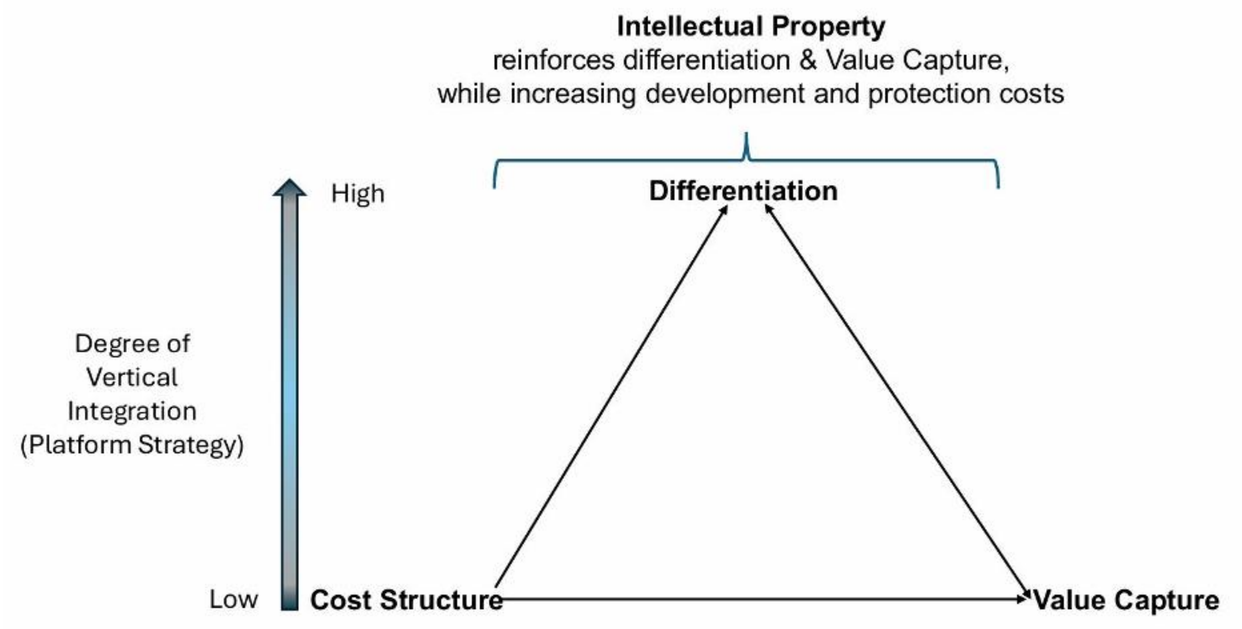


Figure 1. Interplay between cost structure, differentiation, intellectual property, and value capture

Taken together, the framework shows that platform strategies shape competitive advantage not through isolated effects, but by structuring the relationships between cost structure, differentiation, intellectual property, and value capture. The strategic relevance of platform architectures therefore lies in their ability to align these dimensions into a coherent and economically effective system.

2.3.2 Interaction of Cost Structure and Differentiation

In classical strategy logic, cost leadership and differentiation are often treated as competing positions (Porter, 2008). Although this trade-off remains relevant, platform strategies can partially relax the tension between efficiency and differentiation. Because platform architectures allow firms to reuse technological cores across multiple products, they improve efficiency through shared development effort, process standardization, and economies of scope. At the same time, they support differentiation by enabling tailored variation and proprietary performance-critical elements.

This dual effect is strategically important. In many specialty chemical markets, differentiation is expensive because every new solution typically requires significant experimentation, testing, and qualification. Without platform logic, these efforts remain fragmented and difficult to scale. A platform architecture changes this by allowing firms to build on validated structures. As a result, differentiation can be pursued more efficiently.

Conversely, cost efficiency becomes strategically more meaningful when it does not come at the expense of customer-relevant uniqueness. The ability to offer differentiated products at economically attractive cost positions improves not only margins, but also resilience against competitive pressure. It creates room for investment, innovation, and selective pricing strategies.

2.3.3 IP as a Structural Component of Value Capture

Beyond cost structure and differentiation, intellectual property constitutes a critical structural dimension of value capture. While the former defines the economic potential of a firm, intellectual property determines the extent to which this potential can be appropriated and sustained over time.

Proprietary additives, controlled architectures, and derivative families create not only technical advantages, but also protectable assets. These assets increase the firm's ability to appropriate the economic returns generated by differentiation.

This is particularly relevant in specialty chemicals because imitation pressures can be substantial once successful products become visible in the market. Even when exact replication is difficult, competitors may develop close substitutes unless the innovative firm possesses legal or technical barriers that limit such responses. Intellectual property therefore plays a direct role in stabilizing value capture over time.

From a pricing perspective, this connection is critical. Value-based pricing depends on the existence of differentiated performance that customers recognize and are willing to pay for (interhuber, 200 agle Müller, 2018). Yet such pricing power remains fragile if competitors can quickly imitate the underlying value proposition. IP strengthens value-based pricing because it extends the period during which differentiated performance remains commercially defensible.

In this sense, intellectual property is not merely complementary to value capture it is constitutive of it. Platform strategies that systematically generate   are therefore strategically superior to those that produce only temporary differentiation without robust appropriability.

2.4 Strategic Positioning and Business Models

The conceptual framework developed above has direct implications for strategic positioning. Firms in specialty chemicals differ substantially in the degree to which they control value-relevant parts of the value chain and in the extent to which they can generate proprietary differentiation. These differences can be represented through a positioning logic that links value chain depth and differentiation potential.

2.4.1 Value Chain Depth vs. Differentiation Matrix

The manuscript conceptualizes business models in functional additive markets along two dimensions: value chain depth and differentiation potential. Firms with low value chain depth typically rely more heavily on externally sourced components, whereas firms with greater depth control more upstream technologies, materials, or development capabilities. Differentiation potential captures the extent to which firms can create unique and defensible performance outcomes.

This matrix provides a useful way to interpret

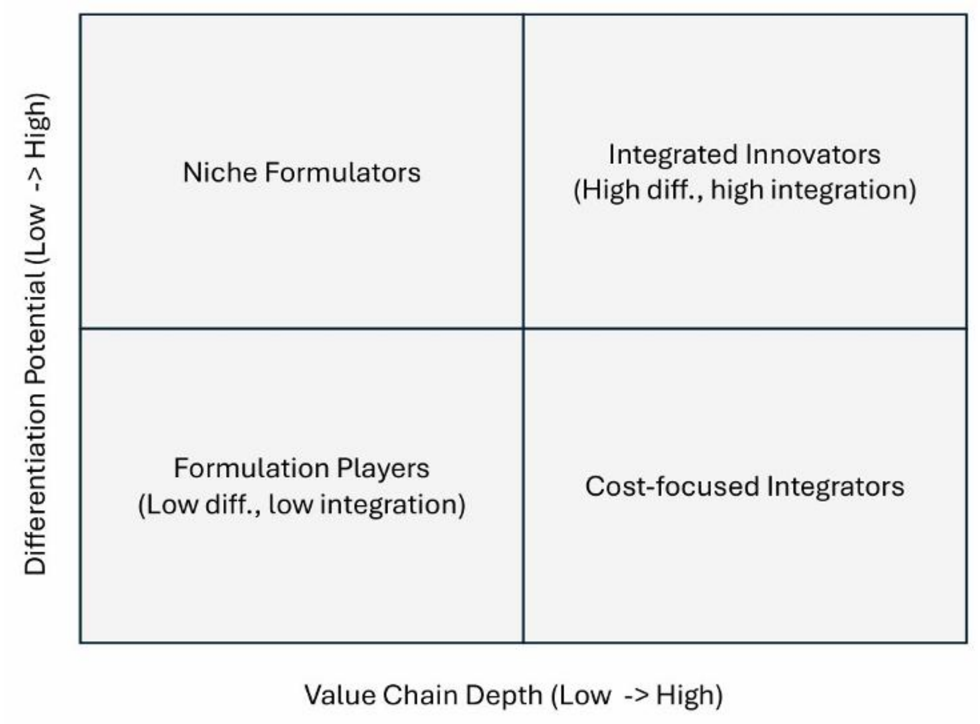


Figure 2. Strategic positioning based on value chain depth and differentiation potential.

competitive heterogeneity in specialty chemicals. Firms located in the lower-left area tend to exhibit both low integration and limited differentiation. They depend strongly on shared market input and compete largely through formulation skill, customer proximity, and commercial execution. By contrast, firms in the upper-right area combine deeper value chain control with stronger differentiation capabilities. These firms are better positioned to shape customer value and protect it from imitation.

The matrix is not meant as a rigid classification tool, but as an analytical device. It makes it visible that value chain choices and differentiation logic are structurally linked. A firm's business model cannot be understood adequately by looking at product features alone one must also consider the underlying architecture of control, development, and appropriation.

2.4.2 Weak vs. Strong Strategic Positions

Viewed through a Porterian lens, the positions in this matrix differ substantially in strategic strength (Porter, 2008). Firms with limited differentiation and shallow value chain control typically occupy weak positions. Because they offer solutions built largely from widely available inputs, they face stronger rivalry and are more exposed to price pressure. Their ability to defend margins depends heavily on execution rather than on structural advantage.

Such firms may still be commercially successful in certain niches, especially if service levels, customer relationships, or application expertise are strong. However, their positions remain vulnerable because competitors can often emulate the relevant elements without fundamental architectural change.

Stronger positions arise when firms control critical parts of the value chain and use this control to create differentiated performance. Here, strategic strength stems not only from superior products, but from the fact that the underlying sources of advantage are less accessible to others. Control over performance-critical inputs, proprietary development capabilities, and IP-backed architectures make competitive imitation more difficult and margin erosion less immediate.

2.4.3 Integrated Platform-Based Innovators and Pricing Power

The distinction between weak and strong positions therefore depends less on current market share than on structural defensibility. Platform strategies contribute to stronger positions because they embed differentiation in an architecture of control and reuse, rather than relying on isolated product features.

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818653605
DOI: 10.17879/19818652327

The upper-right quadrant of the matrix can be described as the domain of integrated platform-based innovators. These firms combine deeper control over strategically relevant components with the ability to develop a stream of differentiated solutions based on common technological foundations. Their advantage lies not only in innovation output, but in the scalability and repeatability of innovation.

Because these firms are less dependent on externally available building blocks, they can shape performance more fundamentally. Because their development efforts are organized around a platform, they can do so more systematically and efficiently than firms that treat each project as a stand-alone undertaking. This combination increases their ability to create reliable, application-specific value and to defend it over time.

These characteristics directly support pricing power. Customers are more willing to accept higher prices when performance differences are meaningful, robust, and difficult to obtain elsewhere. At the same time, the supplier's stronger control over the underlying technology reduces the likelihood that competitors can immediately undermine such pricing by offering similar solutions at lower cost.

In line with earlier observations that pricing represents a major profitability lever in the chemical industry (Rüdiger et al., 2007), this architecture-based differentiation enables firms not only to command higher prices, but also to sustain them over time. Pricing power thus emerges not as a purely commercial capability, but as a direct consequence of underlying value chain design and technological control.

2.4.4 Value-Based Pricing Implications

Value-based pricing is widely recognized as a central mechanism for translating differentiated customer value into economic returns. In contrast to cost-based or competition-oriented pricing approaches, it is grounded in the customer's willingness to pay and therefore depends fundamentally on the supplier's ability to deliver meaningful, reliable, and application-relevant performance advantages (interhuber, 200 agle Müller, 2018).

However, the effective implementation of value-based pricing requires more than analytical pricing tools or persuasive sales arguments. It presupposes a structural foundation of differentiation that is technologically real, operationally consistent, and competitively defensible. Without such a foundation, pricing remains anchored in cost logic or benchmarked against competitors, limiting the firm's ability to capture the full economic value it creates.

This observation is consistent with earlier findings in the chemical industry. Prior research has identified value-based pricing as the most powerful lever for profitability, showing that even small price increases can have a disproportionately strong impact on EBIT (Rüdiger et al., 2007). At the same time, this work highlights that pricing remains insufficiently developed in many firms and is often treated as a reactive function rather than a strategic capability. The persistence of this gap suggests that the challenge lies not in the conceptual understanding of value-based pricing, but in the absence of structural conditions that enable its consistent execution.

The present analysis provides an explanation for this gap. In formulation-driven business models based on commercially available inputs, differentiation is inherently constrained because competitors have access to similar material bases. Even when firms possess superior formulation expertise, the underlying performance drivers remain at least partially replicable. As a result, the ability to justify and sustain premium pricing is limited, and pricing practices tend to revert to cost-based or competitor-oriented logic.

Platform-based business models fundamentally alter these conditions. By enabling the development and control of proprietary, performance-critical components, platform strategies create a more robust and scalable basis for differentiation. This differentiation is not limited to isolated product features but is embedded in a broader technological and organizational architecture. At the same time, platform strategies facilitate the systematic generation of intellectual property, which protects differentiated performance and reduces the risk of imitation.

These structural characteristics directly strengthen the foundations of value-based pricing. Firms can more credibly demonstrate customer-relevant value, ensure consistent performance across applications, and defend their offerings against competitive erosion. As a result, pricing decisions can increasingly be aligned with customer value rather than with cost structures or competitive benchmarks.

Value-based pricing should therefore not be understood as a purely downstream commercial practice. Rather, it represents the economic manifestation of platform-enabled differentiation and intellectual property. Pricing power emerges as the outcome of a coherent strategic system in which value chain design, technological control, and appropriability are tightly aligned.

2.5 Mechanisms Underlying Platform Advantages

To understand why platform strategies generate superior strategic positions, it is necessary to examine the underlying mechanisms through which they affect day-to-day business operations. Their advantages do not arise from abstraction alone. They are rooted in concrete effects across research and development, sourcing, manufacturing, and innovation speed.

2.5.1 R&D Acceleration and Reduced Uncertainty

In research and development, platform architecture enables the reuse of established synthesis pathways, validated intermediates, analytical routines, and application knowledge. This reduces the need to reinvent fundamental elements for every new development project. Instead, teams can build on prior learning and focus their efforts on those variations that are most relevant for the new performance target.

This results in two important effects. First, development cycles become faster because less foundational experimentation is required. Second, uncertainty declines because a significant part of the technological architecture has already been validated. In specialty chemicals, where development work often involves multiple interdependent parameters and substantial trial-and-error, this reduction in uncertainty is economically highly valuable.

The platform therefore acts as a knowledge repository and an innovation scaffold. It makes R&D more cumulative, less fragmented, and more scalable. Modular innovation logic, as described in the product architecture literature, becomes operationally meaningful in this context because it allows firms to recombine proven building blocks into new solution variants (Baldwin & Clark, 2000; Meyer & Lehnerd, 1997; Gebhart et al., 2016).

2.5.2 Sourcing and Supply Chain Simplification

Platform strategies also affect the supply chain. When multiple products are based on a common set of intermediates, raw materials, or process steps, procurement becomes less complex. Supplier relationships can be managed more efficiently, specifications become more standardized, and purchasing volumes can be pooled across product lines. This simplification improves cost efficiency and operational reliability. It can reduce coordination effort, facilitate quality management, and strengthen bargaining power vis-à-vis suppliers. Moreover, when the firm internally controls selected critical building blocks, it reduces dependency precisely where supply risk would otherwise have the greatest strategic consequences.

In volatile or highly regulated environments, such simplification can be especially valuable. It helps firms respond more effectively to disruptions, changing input conditions, or qualification requirements. Platform architecture thus supports not only efficiency, but also resilience.

2.5.3 Manufacturing Standardization and Scale Effects

In manufacturing, platform strategies enable the standardization of equipment usage, processing conditions, testing routines, and quality assurance procedures. This reduces the frequency with which production systems must be adapted to highly idiosyncratic product requirements. Standardization lowers complexity and facilitates more efficient capacity utilization.

The economic benefits are significant. Shared manufacturing logic allows fixed costs to be spread across a wider product base, improves process learning, and supports more transparent cost allocation. These are classic scale and scope effects, but they become strategically relevant because they are embedded in a differentiation-supporting architecture rather than in a pure volume logic.

At the same time, standardization improves reproducibility, which is highly important in specialty chemicals. Reliable product performance often depends as much on manufacturing consistency as on molecular design. By stabilizing both the technological and operational foundations of products, platform strategies strengthen the firm’s credibility in the market.

2.5.4 Time-to-Market Advantages Through Parallelization

A particularly important mechanism concerns time-to-market. Classical innovation processes often

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818653605
DOI: 10.17879/19818652327

follow sequential, stage-gated structures intended to reduce risk through careful progression. While such processes provide control, they can also be slow. Under competitive pressure, however, speed can become a decisive strategic variable.

Platform strategies enable different logic. Because core technologies, synthesis pathways, and analytical methods are already available and validated, firms can parallelize development activities more effectively. Workstreams that would otherwise need to occur sequentially can be advanced simultaneously with lower risk of failure. This accelerates development without requiring the firm to accept the full uncertainty of ad hoc experimentation.

Recent work has emphasized this role of platform architecture in accelerating industrial innovation under time pressure (Brunner, 2026). The critical point is that speed becomes economically meaningful only when it is compatible with controlled risk. Platform architectures function here as risk absorbers: they allow the firm to move faster because the underlying architecture has already reduced the exploratory uncertainty of parallelized work.

This mechanism directly supports the strategic triangle described above. Faster development improves responsiveness, shortens commercialization cycles, and helps firms capture value earlier. Time-to-market is therefore not an isolated operational benefit, but part of the broader value capture logic of the platform strategy.

Taken together, these mechanisms explain why platform strategies can improve cost efficiency, differentiation capability, and operational robustness simultaneously. Yet their strategic relevance depends ultimately on whether these effects translate into measurable economic outcomes. The following section addresses this issue through an empirical analysis of long-term revenue development.

2.6 Empirical Evidence: Revenue Development

The preceding sections have shown conceptually how platform strategies can create economic advantages. The next question is whether these mechanisms translate into sustained business performance. The empirical evidence presented here addresses this question by examining the long-term revenue development of proprietary additives within the analyzed case.

2.6.1 Strategic Timeline of Platform Investments

To interpret the revenue development correctly, it is essential to consider the strategic timeline underlying the business outcomes observed. The case reflects a company that began making substantial efforts around 200 to develop proprietary, non-commercially available additives in-house. These efforts were not incidental. They were part of a strategic attempt to reduce dependency on commercially available substances, increase differentiation, and create a stronger basis for long-term value capture.

The years following this strategic shift were characterized by intensive research and development work, including molecular design, process development, performance testing, and application validation. As is typical in specialty chemicals, these activities require considerable time before producing commercially viable products. Qualification cycles, customer adoption, and internal scaling all contributed to a delay between investment and revenue realization.

Initial market introductions occurred in the early 2010s. The subsequent period was one of gradual scaling, during which the platform-based innovations increasingly penetrated multiple applications and markets. This temporal sequence is important because it underscores a general feature of platform strategies in industrial settings: they often involve substantial up-front investment, with economic returns materializing only after a significant lag.

2.6.2 Revenue Growth Analysis (2013–2022)

The revenue data examined in this study cover the period from 2013 to 2022 and capture the phase in which proprietary additive strategies increasingly translated into commercial growth. Figure 3 illustrates the indexed revenue development of products containing internally developed and synthesized proprietary additives over this period (2013 = 100). It is important to note that the observation period refers to the industrialization and commercial deployment of additives rather than to their initial discovery. In specialty chemicals, substantial time lags often exist between early-stage invention, process development, qualification, and successful industrial commercialization.

The observed pattern reveals a strong and sustained growth trajectory. Based on indexed annual revenues, products containing proprietary additives exhibited approximately sixfold revenue growth between 2013

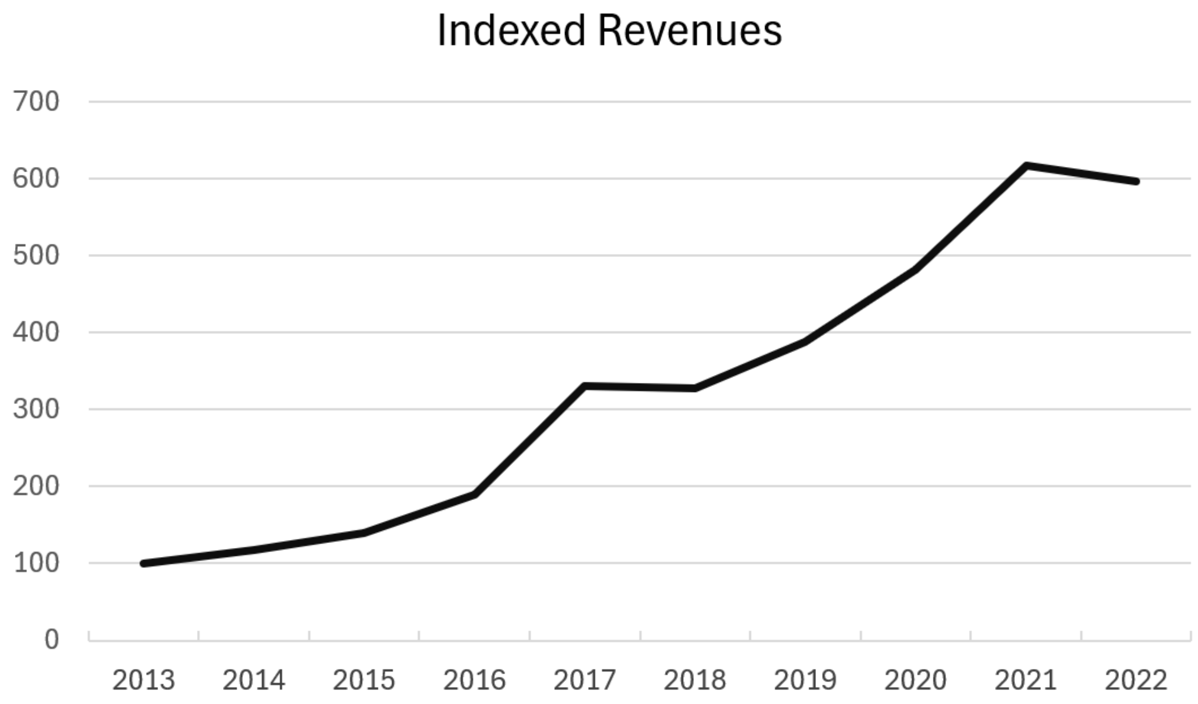


Figure 3. Indexed revenue development of products containing internally developed proprietary additives (2013 = 100), illustrating the long-term commercial impact of proprietary additive and platform-based innovation.

and 2022. This development is notable not only for its magnitude, but also for its persistence over a long observation horizon. The growth pattern does not appear to result from isolated short-term product success but rather reflects the cumulative commercial impact of systematic proprietary additive development.

By 2022, approximately 45–50% of revenues within this proprietary additive portfolio were attributable to platform-based additives. The strategic relevance of the platform architecture also became visible at the level of innovation output. Approximately 57% of all industrialized additives during the observation period originated from the platform-based development architecture. Notably, around 62.5% of these platform-derived industrializations occurred during the later phase of the observation period (2018–2022), suggesting cumulative learning effects and increasing innovation scalability over time. The findings therefore indicate that the platform increasingly evolved into a cumulative innovation system capable of repeatedly generating differentiated derivative solutions from shared technological foundations. The platform architecture thus evolved from a technological development approach into a strategically significant component of the broader proprietary additive business.

The findings suggest that reusable technological cores and selectively integrated additive development enabled scalable differentiation across multiple applications and markets. In this sense, the observed revenue trajectory can be interpreted as the commercial expression of a platform-enabled innovation architecture.

Additional evidence for the platform logic emerged from the cross-application redeployment of proprietary additives. In several cases, additives originally developed for one application environment were subsequently transferred to additional application fields and generated substantial follow-on revenues without requiring entirely new molecular development. This illustrates that the platform strategy supported not only the generation of new industrialized additives, but also the scalable recombination and repeated monetization of previously validated technological building blocks across multiple market contexts. Such transfer effects are characteristic of platform-based innovation systems because they extend economies of scope beyond development efficiency toward the cumulative commercial exploitation of proprietary technological assets.

2.6.3 Economic Interpretation of Growth Patterns

The economic interpretation of this growth pattern is analytically significant. In highly competitive markets where commercially available substances are widely accessible, opportunities for sustained differentiation are structurally limited. Platform-based approaches alter this condition by enabling firms to develop proprietary additives that can be deployed across multiple applications and market segments.

The resulting growth should therefore be understood as the commercial expression of an architectural advantage. Reusable technological cores allow the firm to generate multiple differentiated products more efficiently and with greater strategic control than would be possible in a purely formulation-based model. The observed revenue trajectory is consistent with this logic.

The observed differentiation effects did not result merely from increased proprietary R&D intensity, but from the cumulative innovation logic of the platform architecture, in which validated technological cores repeatedly reduced the uncertainty and development effort of subsequent derivative additive innovations.

Equally important, the growth pattern suggests that the benefits of platform strategies are cumulative. Once a functioning platform has been established, each additional innovation can leverage prior investments in knowledge, process design, and validation. This creates a compounding effect: the platform does not merely support one successful product, but a stream of commercially relevant developments.

The empirical findings thus reinforce the conceptual argument of this paper. Platform strategies are not merely supportive mechanisms for isolated innovation projects. They can become a dominant factor shaping long-term business performance and sustained revenue expansion.

2.7 Intellectual Property and Appropriability

The strong revenue effects documented above raise a further question: to what extent are the economic benefits generated by platform strategies protectable and sustainable This question leads directly to the issue of intellectual property and appropriability.

2.7.1 Platform Architecture and Systematic IP Generation

The evidence suggests that platform strategies do not merely facilitate innovation they also support the systematic generation of protectable intellectual property. This is not accidental. Platform architectures organize development around reusable cores, controlled molecular structures, and derivative pathways. Such structures are particularly conducive to the creation of related, yet distinct, technical inventions.

As a result, platform-based development can generate not only isolated patents, but broader families of protectable innovations. The architectural coherence of the platform makes it easier to identify technological novelties, define claimable variations, and develop follow-on inventions that remain connected to a common strategic core.

This systemic quality is important. It implies that the relationship between platform strategy and is structural rather than incidental. The platform does not simply happen to produce patentable outcomes it is organized in a way that makes repeated generation more likely and more scalable.

2.7.2 Patent Portfolio Structure

The empirical evidence strongly supports the interpretation that platform strategies contribute not only to innovation efficiency, but also to the systematic generation of protectable intellectual property. In total, eleven patents were filed and granted as a direct result of the platform-based additive strategy, indicating that the underlying platform architecture repeatedly generated patentable technological variation and derivative innovations.

The strategic relevance of these patents extends beyond the protection of isolated end products. Because the platform architecture was based on reusable technological cores and internally controlled additive development, patent activity increasingly evolved into a broader portfolio logic. The resulting patent structures protected not only individual formulations, but also related application areas, derivative additive concepts, and platform-associated technological domains.

This portfolio-based protection mechanism is strategically important because it increases both appropriability and competitive defense. Rather than relying on temporary differentiation alone, the company was able to stabilize technological advantages through legally protected proprietary additive structures and application-specific performance characteristics.

The economic relevance of this intellectual property position is reflected in the revenue structure observed in 2022. Approximately 70% of revenues generated with platform-based additives were attributable to patent-protected products. This suggests that a substantial share of the economic value created through the platform strategy was linked directly to protected technological differentiation.

From a strategic perspective, the findings indicate that platform architectures can systematically strengthen the relationship between innovation, intellectual property generation, and value capture. Intellectual property therefore emerges not as a secondary outcome of successful innovation, but as an integral structural component of platform-based competitive advantage.

2.7.3 Implications for Competitive Defense and Value Capture

The empirical findings suggest that the strategic relevance of platform-based intellectual property extends well beyond formal legal protection. By combining reusable technological cores with internally controlled additive development, the platform architecture created a scalable basis for differentiated and protectable product performance.

This has direct implications for competitive defense. Patent-protected platform-based additives increase the difficulty of imitation and reduce the likelihood that competitors can rapidly reproduce comparable performance characteristics using commercially available inputs. As a result, differentiated market positions become more durable and less vulnerable to erosion through price-based competition.

The observed relationship between platform architecture and patent-protected revenues also has important implications for value capture. Because differentiated performance remained legally and technologically defensible, the firm was better positioned to sustain value-based pricing over time. Intellectual property therefore reinforced not only differentiation itself, but also the firm's ability to appropriate the economic returns generated by that differentiation (Hinterhuber, 2008; Nagle & Müller, 2018).

From a broader strategic perspective, the findings indicate that platform strategies influence both value creation and appropriability simultaneously. The platform architecture enabled the repeated generation of differentiated innovations, while the associated intellectual property portfolio stabilized these advantages against imitation and substitution pressures. In this sense, intellectual property emerged not as a secondary by-product of innovation, but as an integral component of platform-based competitive advantage.

2.8 Managerial Implications

The analysis has implications that extend well beyond the immediate case. It suggests that platform strategies in specialty chemicals should be understood not merely as operational efficiency tools, but as integrated strategic architectures that connect technology, organization, and commercial logic.

At the same time, the findings sharpen the theoretical interpretation of platform strategies in industrial settings. Unlike much of the platform literature, which focuses on digital ecosystems and network effects (Gawer, 2014; Cusumano et al., 2019; Parker et al., 2016), the present analysis shows that platform architectures in specialty chemicals can serve as mechanisms of selective vertical integration, scalable differentiation, systematic IP generation, and value capture. They also extend competitive strategy by indicating that platform architectures can partially relax the classical trade-off between efficiency and differentiation (Porter, 2008), and they align well with a transaction cost interpretation of hybrid governance structures (Williamson, 1985).

2.8.1 Value Chain Configuration as Strategic Choice

First, firms should treat value chain configuration as a strategic choice rather than as a purely operational decision. Make-or-buy choices directly influence not only cost positions, but also differentiation potential, supplier dependency, and pricing power. In environments where customer value depends on performance-critical components, sourcing decisions can fundamentally shape the firm's competitive trajectory.

Managers should therefore ask not only whether external sourcing is cheaper in the short term, but also whether it limits the ability to generate and appropriate differentiated value over time. A narrow efficiency perspective may underestimate the long-term strategic costs of dependence on shared market inputs.

2.8.2 Selective Integration and Platform Architecture

Second, full vertical integration is neither necessary nor generally desirable. The more effective approach is selective integration: firms should internalize those elements of the value chain that are particularly critical

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818653605
DOI: 10.17879/19818652327

to customer value, technological uniqueness, and strategic control, while preserving external flexibility in less critical domains.

Platform architecture provides organizational logic for implementing this principle. By structuring innovation around reusable cores and modular variation, firms can combine focused internal control with scalability and flexibility. This allows them to avoid the inefficiencies of blanket integration while still capturing the benefits of proprietary development.

2.8.3 IP-Integrated Platform Design

Third, intellectual property should be integrated into platform design from the outset. Too often, IP is treated as a downstream legal function that reacts to completed innovation. The evidence presented here suggests that firms gain more by designing their platforms in ways that facilitate systematic IP generation and portfolio development.

This means identifying which core elements, derivative paths, and application variants are not only technically relevant, but also potentially protectable. It also means recognizing that the strategic value of IP lies not only in individual patents, but in coherent portfolios that stabilize differentiation and reinforce value capture.

2.8.4 Managing Platforms as Integrated Strategic Systems

Finally, firms should manage platforms as integrated strategic systems. The benefits of platform strategies arise not from isolated design choices, but from the alignment of technological architecture, R&D processes, sourcing logic, manufacturing structures, IP strategy, and pricing approach.

This systemic view is crucial. Firms that optimize only one element in isolation may fail to realize the full value of the platform. A technically elegant platform that is not commercially monetized remains underexploited. A differentiated product without IP protection remains vulnerable. An efficient architecture without customer-relevant performance remains strategically weak.

Managers should therefore view platform strategies as cross-functional strategic systems that link technology, operations, and commercial logic into a coherent whole. When this alignment is achieved, platform strategies can become a powerful mechanism for sustained differentiation, competitive defense, and superior value capture in specialty chemicals.

2.9 Limitations and Future Research

The findings of this study should be interpreted in light of several limitations. First, the empirical analysis is based on a single industrial case and therefore does not aim at statistical generalization across the specialty chemicals industry. Instead, the objective is analytical generalization and theory development regarding the strategic role of platform architectures in formulation-driven industrial environments.

Second, the empirical data are anonymized and aggregated due to confidentiality constraints. The data utilized in this study are aggregated across multiple functional applications within the specialty chemicals sector. To prevent the disclosure of commercially sensitive information and proprietary competitive structures, all financial figures are presented in indexed and normalized form without disclosure of absolute sales values or identifiable product-level information. While this limits external reproducibility at the product level, it enables transparent analysis of long-term strategic mechanisms such as platform scalability, intellectual property generation, and value capture in industrial settings characterized by proprietary technologies and commercially sensitive business models.

Third, the study focuses primarily on proprietary additives and platform-based innovation in specialty chemicals. Although the conceptual mechanisms identified here may also be relevant for adjacent process industries, the transferability of the findings to other industrial contexts requires further investigation.

In addition, the study emphasizes strategic and economic mechanisms rather than formal causal measurement. The observed relationship between platform architectures, intellectual property generation, and revenue development should therefore be interpreted as analytically and conceptually consistent rather than as definitive proof of direct causality.

Future research could extend the present analysis through comparative multi-case studies, quantitative performance analyses, or longitudinal investigations of platform-based innovation systems across different specialty chemical segments. Further work may also examine how platform architectures interact with sustainability-driven innovation, regulatory adaptation, and digitalization in industrial R&D and value chain management.

3. Conclusion

Platform strategies are central drivers of competitive advantage in specialty chemicals. By enabling selective vertical integration, they enhance differentiation, improve cost structures, and support value-based pricing.

Empirical evidence demonstrates strong revenue growth and a substantial contribution to patent-protected business. Platform strategies therefore not only create economic value but also enhance appropriability and competitive protection.

Sustainable competitive advantage arises from the alignment of value chain design, differentiation, intellectual property, and pricing logic. Platform strategies provide a coherent mechanism to achieve this alignment and represent a key managerial lever in increasingly competitive and complex markets.

Statement of AI Usage

Generated AI tools were used solely for language editing and manuscript refinement. All scientific content, analyses, interpretations, and conclusions remain the sole responsibility of the author.

4. References

Baldwin, C. Y.; Clark, K. B. (2000): Design Rules, Volume 1: The Power of Modularity, Cambridge, MA: MIT Press.

Brunner, H. (2026): Accelerating Industrial Innovation under Time Pressure. Journal of Business Chemistry, 23(1), 7-16.

Cusumano, M. A.; Gawer, A.; Yoffie, D. B. (2019): The Business of Platforms: Strategy in the Age of Digital Competition, Innovation, and Power. Harper Business.

Gawer, A. (2014): Bridging differing perspectives on technological platforms: Toward an integrative framework. Research Policy, 43(7), 1239-1249.

Gebhart, N.; Kruse, M.; Krause, D. (2016): Gleichteile-, Modul- und Plattformstrategie in: Lindemann, U. (Ed.), Handbuch für Produktentwicklung, Carl Hanser Verlag, München, 111-149.

Hinterhuber, A. (2008): Customer value-based pricing strategies: Why companies resist. Journal of Business Strategy, 29(4), 41-50.

Meyer, M. H.; Lehnerd, A. P. (1997): The Power of Product Platforms: Building Value and Cost Leadership, 1st ed., New York, Free Press.

Murjahn, R. (2004): Kostenmanagement in der chemischen Produktentwicklung. Dissertation, Universität Düsseldorf.

Murmann, J. P. (2004): Knowledge and Competitive Advantage: The Coevolution of Firms, Technology, and National Institutions. Cambridge University Press.

Nagle, T. T.; Müller, G. (2018): The Strategy and Tactics of Pricing: A Guide to Growing More Profitably, 6th ed., New York and London: Routledge.

Parker, G. G.; Van Alstyne, M. W.; Choudary, S. P. (2016): Platform Revolution: How Networked Markets Are Transforming the Economy - and How to Make Them Work for You, New York, W. W. Norton.

Porter, M. E. (2008): The Five Competitive Forces That Shape Strategy. Harvard Business Review, 86(1), 78-93.

Rüdiger, S.; Elliger, C.; Weigel, C. (2007): Value Pricing in the Chemical Industry – Most Powerful Lever to Profitability. Journal of Business Chemistry, 4(1), 33–39.

Williamson, O. E. (1985): The Economic Institutions of Capitalism, New York, Free Press.

JOURNAL OF
BUSINESS CHEMISTRY

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818650834
DOI: 10.17879/19818650088

Research Paper

Georgios Giotis[a]

The Sticky Truth: Analyzing the Employment Impacts of the Adhesive Industry

This study develops an integrative theoretical framework to analyze the adhesive sector's employment impacts by synthesizing input-output theory, labor demand theory, structural change theory, human capital theory, and cluster theory. Through this approach, the paper examines direct, indirect, and induced employment effects, emphasizing how technological shifts, such as automation and sustainable adhesive development, reshape labor dynamics and skill requirements. The study highlights the sector's role in broader economic systems and discusses implications for workforce development in the context of environmental and technological transitions. By addressing a relatively underexplored area in the literature, the paper provides a conceptual basis for future empirical research and offers insights relevant for policymakers and industry stakeholders.

Keywords: Adhesive industry Employment Input-output theory Labor demand Human capital Automation Sustainability.

JEL Classification: 6 , J23, , J2 , 33,

1. Introduction

The adhesive industry plays an important role across diverse sectors, such as manufacturing, construction, automotive, aerospace, and consumer goods, offering foundational support for product integrity and innovation. Globally, the sector's economic footprint is substantial. According to market analyses, the global adhesives and sealants market was valued at approximately 123.0 billion in 2023 and is projected to continue growing in the coming years due to increasing demand from manufacturing, construction, automotive, packaging, and consumer goods industries (pherical nsights Consulting, 202). Regionally, similar expansion patterns prevail. The . . adhesives and sealants market stood at . billion in 2021 and is on track for steady annual growth of around . to 2030 (rand iew Research, 2022), while Canada's adhesive manufacturers are expected to reach CA 1.1 billion by 202 (CA R 1.1) (B orld, 202). This sustained growth generates significant employment, both direct and indirect. For example, in Canada, adhesives and sealants manufacturers employed 2,036 workers, contributing CA 1.3 billion in revenue, with further employment from upstream (3,010 jobs) and downstream (contractors, applicators, retailers) segments (rr and Boss Consulting, 2023). In the United States, the specialized occupation of Adhesive Bonding Machine Operators and Tenders comprised nearly 11, 00 workers in 2022, with about 0 female representation and average earnings of 3 ,200 (ata A, 202). While these figures are based on industry reports, they are used here to provide contextual background rather than as part of the analytical contribution.

The industry also supports employment through multiple channels. First, there is a direct employment

---

[a] Laboratory Teaching Personnel, Department of Tourism, Ionian University, 49132 Corfu, Greece
ORCID: https://orcid.org/0000-0002-8379-2829

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818650834
DOI: 10.17879/19818650088

impact, since manufacturing facilities employ operators, machine tenders, R personnel. . . adhesive manufacturing jobs declined slightly (about 1.1 annually from 201 -202) but remain integral to industrial clusters (B orld, 202). Second, there are indirect effects. For instance, suppliers of raw materials (resins, packaging), distributors and retailers servicing contractors and customers. Third, induced effects exist as workers spend incomes in local economies, benefiting other sectors.

Despite its importance, the sector's workforce dynamics vary mainly due to technological and sustainability trends (e.g., waterborne adhesives, hot-melt technologies) which are reshaping labor requirements and are constantly creating new skill demands. Given this backdrop, a holistic examination, analyzing direct and upstream employment, assessing occupational trends and projecting future workforce needs, is essential. This analysis delves into the employment impacts of the adhesive industry, exploring economic contributions, labor dynamics, and policy implications amid evolving technological, environmental, and market forces.

More specifically, this study contributes to the theoretical understanding of labor dynamics in the adhesive sector in three ways. First, it synthesizes multiple economic frameworks - including input-output theory, labor demand theory, human capital theory, and structural change theory - to develop an integrative, sector-specific conceptual framework and derive theoretically grounded propositions linking technological change, industrial structure, and skill formation to employment outcomes. Second, it extends existing research by applying these theoretical perspectives to a relatively underexplored but economically relevant industrial context. Third, the paper provides a forward-looking discussion of how technological and environmental developments may influence labor structures and skill requirements. In doing so, it offers a structured conceptual perspective that can inform future empirical research and policy discussions. In particular, the paper identifies sector-specific mechanisms and conditional relationships that distinguish the adhesive industry from other manufacturing sectors. This allows the paper to move beyond an additive combination of theories and to develop a sector-specific theoretical explanation of employment dynamics in the adhesive industry.

This study adopts a conceptual research design in which selected academic contributions and industry reports are used to support theory development, rather than to conduct a formal systematic or scoping review.

For the purposes of this study, several key concepts are defined as follows. The 'adhesive industry' refers to the sector encompassing the production, formulation, distribution, and application of adhesive and sealant products across manufacturing, construction, and related activities. Direct employment denotes jobs created within adhesive manufacturing firms, including production, research and development, and administrative functions. Indirect employment refers to employment generated in upstream and downstream industries that supply inputs to or utilize adhesive products, such as chemical suppliers, logistics providers, and end-user industries. Induced employment captures jobs created as a result of consumption expenditures by workers employed directly or indirectly in the adhesive sector, thereby reflecting broader multiplier effects within the economy.

2. Literature Review

2.1 Employment in the Adhesive Industry: Sector-Specific Literature

The adhesive industry has received comparatively limited attention in the academic literature, despite its important role across multiple manufacturing and construction sectors. Existing studies and industry reports emphasize the sector's economic significance and its contribution to employment through both direct and indirect channels. For example, the European adhesive and sealant industry contributes significantly to the economy and directly employs tens of thousands of workers, while also supporting broader employment through its integration in supply chains (CA, 201 , A bari and cClelland, 2020). Similarly, industry-level analyses highlight the role of adhesive manufacturing in generating employment not only within production facilities but also in upstream chemical industries and downstream application sectors such as construction and packaging (rr Boss Consulting, 2023 CA, 201).

At the firm level, employment in the adhesive industry is shaped by production processes that combine chemical formulation, precision application technologies, and quality control systems. These characteristics create demand for a mixed workforce, ranging from machine operators and technicians to highly skilled research and development personnel. Evidence suggests that specific occupations, such as adhesive bonding machine operators, represent a distinct segment of the labor force with defined skill profiles and wage structures (Data USA, 202). At the same time, technological developments - including automated dispensing systems and environmentally friendly adhesive formulations (Arán-Ais et al., 2012) - are increasingly influencing the structure of employment and skill requirements within the sector (Bogue, 201 , Archer, 1).

However, the existing literature on the adhesive industry remains fragmented and largely descriptive. Most contributions focus on technological innovation, material science, or environmental considerations, such as the development of advanced or bio-based adhesives (Bogue, 201 , Cui and Liu, 2021), while employment-related analyses are typically embedded within broader discussions of the chemical or manufacturing industries (uanhlee, 202). As a result, there is limited conceptual synthesis of how employment effects emerge within the adhesive sector itself, particularly in terms of the interaction between technological change, supply-chain integration, and labor market dynamics.

2.2 Employment Dynamics in Related Manufacturing Sectors

In contrast to the relatively limited literature on the adhesive industry, a substantial body of research examines employment dynamics in manufacturing and related industrial sectors more broadly. This literature provides important insights into how employment is shaped by factors such as technological change, globalization, and industrial restructuring (uanhlee, 202).

A central theme in this research concerns the role of production linkages and employment multipliers. Input-output studies demonstrate that manufacturing industries generate employment not only directly within production facilities but also indirectly through upstream suppliers and downstream users. These interdependencies highlight the importance of considering sectoral employment effects within a broader economic system (Miller and Blair, 200). The concept of indirect and induced employment has been widely applied in other sectors where similar multiplier effects are observed across interconnected industries (Ardahaey, 2011). In addition, a growing body of research in industrial organization and labor economics examines employment dynamics in technologically evolving manufacturing sectors, including chemicals, advanced materials, and high-value production systems. These studies emphasize the interaction between automation, skill-biased technological change, and global value chain integration, providing a relevant analytical foundation for understanding employment transformations in specialized industries.

Another important strand of literature focuses on technological change and automation. Studies in manufacturing sectors show that automation tends to reduce routine, low-skill tasks while increasing demand for higher-skilled labor, particularly in areas such as system operation, maintenance, and process optimization (Acemoglu and Restrepo, 2020). This shift is often accompanied by a growing emphasis on workforce adaptability, continuous training, and the development of new technical competencies (Becker, 1 6).

In addition, structural change literature emphasizes the long-term transformation of economies toward more knowledge-intensive and service-oriented activities (Herrendorf et al., 201). Within this context, manufacturing sectors increasingly integrate advanced technologies and sustainability-oriented innovations, which reshape both production processes and employment structures. Environmental and regulatory pressures, such as those related to emissions and material sustainability, further contribute to this transformation by encouraging the adoption of cleaner production methods and circular economy practices (ei et al., 202 , Wojnarowska et al., 2021).

While these studies provide valuable theoretical and empirical insights, they typically analyze manufacturing industries at an aggregated level (Rani et al., 202). As a result, sector-specific characteristics -such as the technological particularities and supply-chain roles of the adhesive industry- are not explicitly addressed. This creates a disconnect between general theoretical insights and their application to specific industrial contexts.

2.3 Synthesis and Research Gap

The comparison between adhesive-industry-specific studies and broader manufacturing literature reveals a clear gap in the existing research. On the one hand, sector-specific analyses highlight the economic

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818650834
DOI: 10.17879/19818650088

relevance of adhesives and their integration within complex industrial value chains, but they rarely adopt a systematic theoretical perspective on employment dynamics (CA, 201). On the other hand, the broader manufacturing and labor economics literature offers well-developed theoretical frameworks -such as input-output analysis (Miller and Blair, 200), labor demand theory (Hamermesh, 1 3), and human capital theory (Becker, 1 6) - but does not explicitly address the adhesive industry.

This fragmentation suggests the need for an integrative approach that combines sector-specific insights with established theoretical perspectives. In particular, there is a lack of conceptual frameworks that systematically link firm-level labor decisions, sectoral interdependencies, and macroeconomic structural changes within the context of the adhesive industry.

Addressing this gap, the present study develops an integrative conceptual framework that brings together multiple theoretical approaches to analyze employment effects in the adhesive sector. By synthesizing these perspectives, the paper aims to provide a more structured understanding of how employment is generated, transformed, and distributed across different levels of the economy.

3. Theories on the Employment Effects of Adhesive Industry

This study is grounded in a multi-disciplinary theoretical framework that draws from industrial organization theory, labor economics, and input-output economic modelling to analyze the employment impacts of the adhesive industry. These theories combine economic, labor market, and industrial organization theories to provide an integrative lens for analysis and are presented in what follows.

3.1 Input-Output Theory

At the macroeconomic level, Leontief's Input-Output Model provides the foundation for assessing the adhesive industry's employment impact across sectors. Adhesive production and consumption are integral to supply chains in manufacturing, construction, and consumer goods. As per Miller and Blair (200), input-output analysis enables the quantification of both direct and indirect employment effects by examining inter-industry transactions (Miller and Blair, 200). This approach is particularly suitable for capturing upstream (e.g., chemical suppliers) and downstream (e.g., packaging, construction) employment linkages.

3.2 Labor Demand Theory

Neoclassical labor demand theory posits that firms demand labor based on the marginal productivity of workers, relative to the wage rate (Hamermesh, 1 3). In the adhesive industry, labor demand is influenced by factors such as automation, regulatory changes (e.g., restrictions on volatile organic compounds), and shifts in global supply chains. As production becomes more technology-driven, labor intensity may decline, though demand for skilled labor in R and green technology development may increase.

3.3 Structural Change Theory

Clark's and Kuznets theories of structural economic transformation offer a framework to understand employment shifts as economies move from agriculture to industry to services (Rani et al., 202). The adhesive industry, as part of manufacturing, is impacted by structural shifts toward high-tech and service-based economies, which may cause employment contraction in traditional roles but expansion in innovation, sustainability, and supply chain management.

3.4 Human Capital Theory

Becker's (1 6) human capital theory is employed to evaluate how the adhesive industry invests in workforce skills and training to adapt to new technologies and regulatory requirements (Becker, 1 6). The increasing need for skilled labor in developing eco-friendly adhesives and automated manufacturing processes underscores the role of education and vocational training in employment dynamics.

3.5 Labor Demand Theory

Porter's (1) cluster theory suggests that industry agglomeration leads to innovation, knowledge spillovers, and employment growth (Porter, 1). The adhesive industry is often located near automotive, aerospace, or packaging hubs, where proximity to end-users and suppliers enhances productivity and labor demand.

Taken together, these theoretical perspectives provide a multi-level and integrative framework for analyzing employment dynamics in the adhesive industry (Bivens, 201). Input-output theory captures macroeconomic interdependencies and the generation of direct, indirect, and induced employment effects across sectors. Labor demand theory explains firm-level employment decisions in response to productivity, wages, and technological change. Human capital theory highlights the role of skills, education, and workforce adaptation, particularly in the context of technological upgrading and sustainability transitions. Structural change theory situates these developments within broader long-term economic transformations toward more knowledge-intensive production systems, while cluster theory emphasizes the spatial dimension of employment effects through regional agglomeration and spillovers. Rather than operating in isolation, these theories interact to explain how technological change, industrial structure, and skill formation jointly shape employment outcomes at the firm, sectoral, and economy-wide levels.

4 Conceptual Framework and Theoretical Development

4.1 Conceptual Framework

This study develops a conceptual framework for analyzing employment dynamics in the adhesive industry by integrating multiple theoretical perspectives across different levels of analysis. The framework combines insights from labor demand theory, input-output theory, human capital theory, structural change theory, and cluster theory in order to explain how employment effects emerge within and beyond adhesive manufacturing activities.

Figure 1 presents the conceptual model developed in this study. The model distinguishes between firm-level, sectoral-level, and macroeconomic regional mechanisms through which the adhesive industry may influence employment outcomes. Rather than

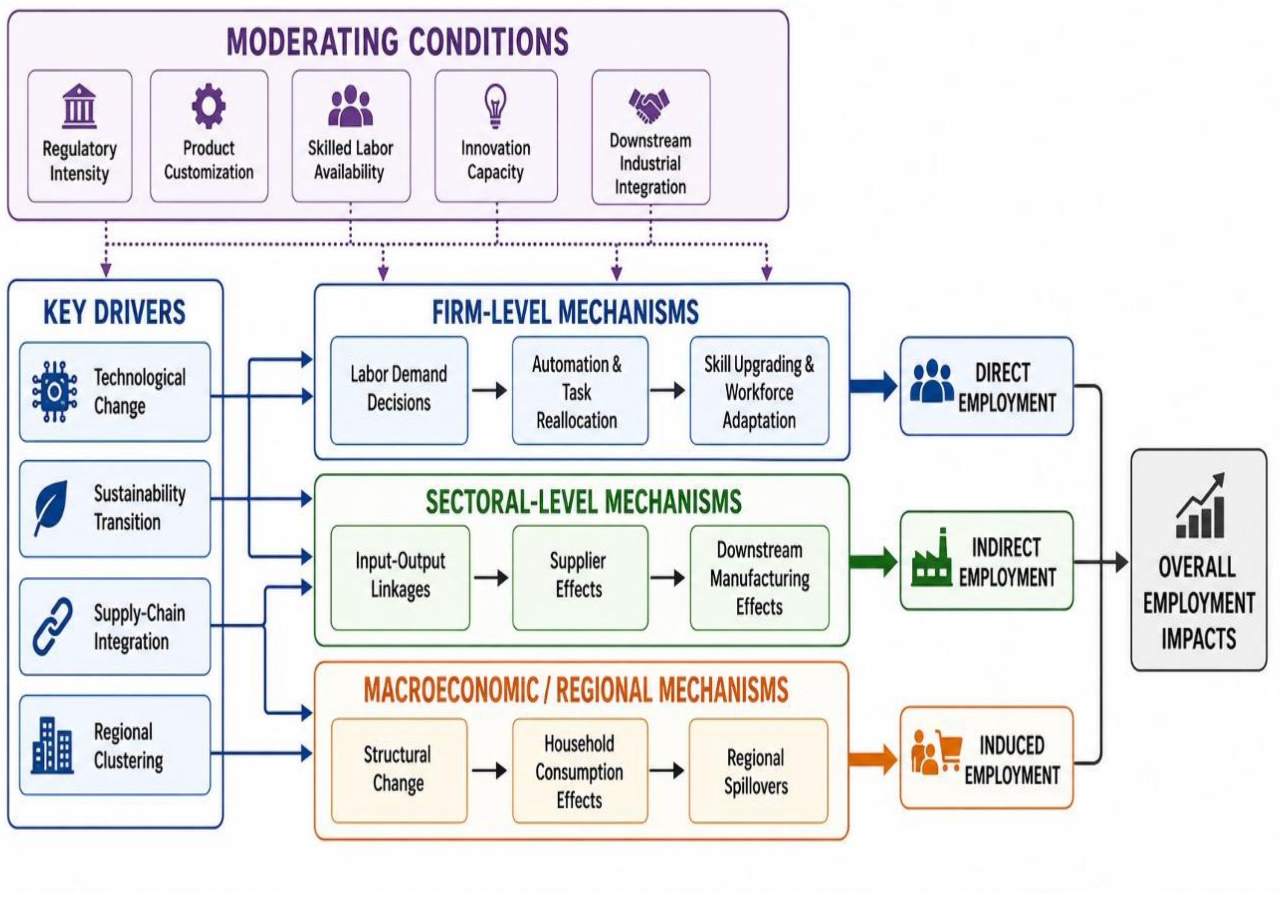


Figure 1. Conceptual model of employment dynamics in the adhesive industry.

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818650834
DOI: 10.17879/19818650088

viewing employment generation as a purely firm-based phenomenon, the framework conceptualizes employment effects as the result of interconnected technological, organizational, industrial, and spatial processes.

The model links key drivers, mechanisms, levels of analysis, moderating conditions, and employment outcomes. Firm-level mechanisms mainly shape direct employment, sectoral input-output mechanisms generate indirect employment, and macroeconomic regional mechanisms contribute to induced employment.

At the firm level, employment dynamics are primarily shaped by technological change, automation, and labor demand decisions. Technological upgrading and digitalization may alter production processes, influence workforce composition, and reshape the balance between routine and specialized labor tasks. While automation may reduce demand for certain routine activities, it may simultaneously increase demand for highly skilled technical, engineering, research, and regulatory personnel. Human capital theory is particularly relevant at this level because workforce adaptation depends on skill acquisition, training, and organizational learning. Consequently, employment effects at the firm level are not limited to job displacement but may also involve task reallocation and skill upgrading processes that contribute to direct employment generation.

At the sectoral level, the framework emphasizes the role of input-output relationships and supply-chain integration. Adhesives function as enabling intermediate inputs across numerous downstream industries, including construction, automotive manufacturing, packaging, electronics, furniture, aerospace, and consumer goods production. As a result, employment effects extend beyond adhesive-producing firms themselves and influence upstream suppliers and downstream manufacturing activities. Input-output theory helps explain how changes in adhesive production may generate indirect employment effects through supplier networks, industrial linkages, and production interdependencies. The framework also recognizes that the magnitude of these effects may vary depending on the degree of downstream industrial integration and the structure of regional manufacturing systems.

At the macroeconomic and regional level, employment outcomes are shaped by broader structural and spatial mechanisms. Structural change theory suggests that technological transformation and sustainability transitions may gradually alter industrial composition and labor-market structures over time. At the same time, cluster theory highlights the importance of regional concentration, industrial proximity, knowledge spillovers, and innovation ecosystems. In regions characterized by strong industrial clustering, adhesive manufacturing may contribute to broader employment multipliers through spillover effects, supplier specialization, and localized innovation dynamics. In addition, household consumption effects associated with industrial employment may further stimulate induced employment across related sectors and local economies.

The framework also incorporates a set of moderating conditions that influence the strength and direction of employment outcomes. These include regulatory intensity, product customization requirements, skilled labor availability, innovation capacity, and the degree of downstream industrial integration. For example, stricter environmental regulations may accelerate the transition toward sustainable adhesive technologies, thereby increasing demand for specialized research and compliance-related occupations. Similarly, industries characterized by high levels of product customization may remain more labor-intensive despite ongoing automation trends.

Figure 1 therefore conceptualizes employment dynamics in the adhesive industry as the outcome of interacting mechanisms operating across multiple levels of analysis. Direct employment effects emerge primarily through firm-level labor demand and workforce adaptation processes, indirect employment effects arise through supply-chain and inter-industry linkages, and induced employment effects develop through broader macroeconomic and regional spillovers. The framework thus moves beyond a static classification of theories and instead provides an integrative explanatory model linking technological change, industrial interdependencies, regional dynamics, and labor-market transformation within the adhesive industry.

4.2 Theoretical Propositions

Building on the conceptual model presented in Figure 1, this section develops a set of theoretical propositions concerning the mechanisms through which employment effects may emerge within the adhesive industry. The propositions are organized across firm-level, sectoral-level, and macroeconomic regional dimensions and reflect the interaction between technological change, sustainability transitions, industrial linkages, and regional dynamics. In addition, the framework recognizes that employment outcomes are shaped by moderating conditions, including regulatory intensity, product customization requirements, innovation capacity, skilled labor availability, and the degree of downstream industrial integration.

At the firm level, employment dynamics are expected to be strongly influenced by technological change and automation. The increasing adoption of digital production systems, process automation, and advanced manufacturing technologies may reduce the need for certain routine manual activities while simultaneously increasing demand for highly specialized technical, engineering, regulatory, and research-related occupations. Consequently, employment transformation within adhesive manufacturing should not be understood solely in terms of job displacement, but also in relation to task reallocation and workforce adaptation.

Proposition 1. Technological change and automation within adhesive manufacturing are likely to reduce demand for routine production tasks while increasing demand for specialized technical, engineering, and regulatory skills.

The effects of automation, however, are unlikely to be uniform across firms and regions. The ability of firms to adapt to technological transformation depends significantly on human capital availability, workforce training, and innovation capacity. Firms operating within regions characterized by stronger technical education systems and higher levels of industrial specialization may therefore experience more positive employment adjustment outcomes than firms facing significant skill shortages.

Proposition 2. The employment effects of automation in the adhesive industry are moderated by skilled labor availability, workforce adaptation capacity, and regional innovation systems.

The framework further suggests that sustainability transitions may create new employment opportunities within adhesive manufacturing. Increasing regulatory pressure regarding environmental performance, emissions reduction, product safety, and circular production systems is likely to stimulate investment in bio-based adhesives, sustainable materials, and environmentally compliant production processes. Such transitions may increase demand for occupations associated with research and development, environmental compliance, product testing, and specialized production activities.

Proposition 3. Sustainability transitions within the adhesive industry are more likely to generate net employment gains when firms possess strong innovation capacity and access to highly skilled labor.

At the sectoral level, the adhesive industry exhibits extensive interdependencies with upstream suppliers and downstream manufacturing sectors. Because adhesives function primarily as enabling intermediate inputs rather than final consumer products, changes in adhesive production may influence employment conditions across broader industrial networks. Input-output linkages are therefore expected to generate substantial indirect employment effects through supplier relationships, downstream manufacturing integration, logistics, packaging, maintenance, and specialized industrial services.

Proposition 4. Stronger upstream and downstream industrial linkages are expected to increase indirect employment effects associated with adhesive manufacturing activities.

The magnitude of these indirect effects may vary considerably depending on the structure of regional manufacturing systems and the degree of downstream industrial integration. Regions characterized by dense manufacturing ecosystems may experience stronger employment multipliers because adhesive technologies are embedded simultaneously across multiple interconnected production chains.

Proposition 5. The indirect employment effects of the adhesive industry are likely to be stronger in regions characterized by high levels of manufacturing integration and industrial clustering.

At the macroeconomic and regional level, the framework also emphasizes the importance of structural change and regional spillover dynamics. Industrial clustering may facilitate knowledge diffusion, supplier specialization, labor mobility, and collaborative innovation processes, thereby strengthening regional employment generation. In addition, employment generated within adhesive manufacturing and related sectors may stimulate household consumption effects that contribute to induced employment across local economies.

Proposition 6. Regional clustering and industrial proximity are likely to strengthen employment multipliers through knowledge spillovers, supplier specialization, and localized innovation dynamics.

Taken together, these propositions suggest that employment dynamics in the adhesive industry emerge through interacting mechanisms operating across multiple levels of analysis. Direct employment effects arise primarily through firm-level labor demand and workforce adaptation processes, indirect employment effects emerge through supply-chain integration and industrial interdependencies, and induced employment effects develop through broader macroeconomic and regional spillovers. The framework therefore conceptualizes employment generation not as an isolated outcome of production activity, but as the result of interconnected technological, organizational, industrial, and spatial processes.

4.3 Sector-Specific Theoretical Insights

The adhesive industry exhibits several characteristics that distinguish its employment dynamics from those of many other manufacturing subsectors. Unlike industries focused primarily on final consumer goods, adhesive manufacturing operates largely as an enabling intermediate-input sector embedded across a broad range of downstream production systems. Adhesive technologies are integrated into construction materials, automotive assembly, packaging systems, electronics manufacturing, furniture production, aerospace engineering, medical technologies, and consumer goods industries. Consequently, employment effects associated with adhesive manufacturing extend far beyond direct production activities and become closely connected to wider industrial ecosystems.

This cross-sectoral embeddedness gives the adhesive industry a distinctive employment structure. While direct employment is generated within adhesive-producing firms themselves, a substantial share of employment effects may emerge indirectly through supplier industries, downstream production activities, logistics networks, equipment manufacturing, technical services, and regulatory compliance systems. In some industrial contexts, indirect employment effects may exceed direct employment effects because adhesive technologies support production processes across numerous manufacturing sectors simultaneously.

The framework presented in Figure 1 therefore conceptualizes the adhesive industry not as an isolated manufacturing segment, but as a technologically embedded enabling industry whose employment impacts are distributed across interconnected value chains. This characteristic differentiates the adhesive industry from many manufacturing sectors where employment generation is concentrated primarily within final-product production.

The sector-specific role of adhesives also shapes the relationship between automation and employment transformation. In many traditional manufacturing activities, automation is often associated primarily with labor displacement. In adhesive manufacturing, however, technological upgrading may simultaneously increase demand for specialized occupations related to materials science, chemical engineering, sustainability management, digital production systems, environmental compliance, and product customization. As adhesive technologies become increasingly specialized and application-specific, firms may require more highly trained technical personnel capable of supporting innovation-intensive production systems.

At the same time, the employment consequences of automation are likely to vary according to product complexity and customer requirements. Standardized high-volume adhesive production may become increasingly automated, whereas customized industrial adhesive applications may continue to rely heavily on specialized technical expertise and close collaboration with downstream manufacturing clients. This suggests that automation and skill upgrading may coexist within the industry rather than operate as mutually exclusive processes.

The framework also highlights the importance of sustainability transitions as a distinctive driver of employment transformation within adhesive manufacturing. Regulatory pressure concerning emissions, recyclability, toxic substances, and environmental performance is likely to accelerate the development of bio-based adhesives, low-emission formulations, and circular production systems. These developments may generate additional employment demand in research and development, testing laboratories, environmental certification, process engineering, and specialized compliance functions.

Moreover, the industry's strong integration into broader

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818650834
DOI: 10.17879/19818650088

manufacturing systems amplifies the significance of regional and spatial dynamics. In regions characterized by industrial clustering, adhesive manufacturers may benefit from proximity to downstream producers, specialized suppliers, research institutions, logistics infrastructure, and skilled labor pools. Such regional ecosystems may strengthen innovation diffusion and employment multipliers while also increasing the adaptability of firms to technological and regulatory change.

In contrast to more isolated manufacturing activities, employment effects in the adhesive industry are strongly shaped by the intensity of downstream industrial integration. Because adhesive technologies are embedded across multiple value chains, relatively small technological, regulatory, or market changes within adhesive production may generate amplified employment effects across related sectors. This feature gives the adhesive industry a particularly important role within broader manufacturing ecosystems and helps explain why its employment dynamics cannot be fully understood through single-firm or single-sector perspectives alone.

Overall, the sector-specific insights developed in this study suggest that employment dynamics in the adhesive industry emerge through the interaction of technological change, industrial interdependencies, sustainability transitions, and regional clustering processes. The industry should therefore be understood as a strategically interconnected enabling sector whose employment effects extend across multiple layers of industrial organization and regional economic activity.

5. Labor Dynamics and Emerging Trends

This section describes how labor dynamics are shaped by industry structure, supply chains, technology, and regulation, and what emerging trends, such as automation and green adhesives, imply for future employment. First, regarding the industry structure and supply chains, the adhesive industry features extensive backward linkages to chemical producers and forward linkages to industries like automotive, construction, aerospace, and electronics. These inter-industry connections amplify labor demand beyond manufacturing plants into upstream and downstream sectors (Bivens, 201). Regional variations in supplier density also influence local multiplier effects, as seen in regional - systems like R (Bureau of conomic Analysis, 1).

Second, concerning technology and automation, manufacturers are integrating automated adhesive dispensing systems to improve precision and speed. This shift replaces manual tasks while increasing demand for technicians capable of operating and maintaining automated systems (ongo et al., 201).

Third, with respect to regulation and environmental standards, the environmental regulations aimed at reducing C emissions and hazardous chemicals, can drive production toward waterborne or bio-based adhesives, reshaping production processes and skill requirements (ucintel, 202). Firms must invest in cleaner technology and green chemistry expertise, creating specialized roles in R and quality control oriented toward sustainability.

Within this framework, some implications of emerging trends can be identified. Initially, automation tends to reduce lower-skill roles but increases the need for higher-skilled staff for system configuration, monitoring, maintenance, and continuous improvement. In addition, the rapid growth in sustainable adhesives is driven by policy mandates and corporate sustainability initiatives. Transitioning to green adhesives expands roles in R&D, certification, process engineering, and sustainability compliance, which is demanding new skills in environmental chemistry, lifecycle assessment, and process design. It is also worth mentioning that these technological and regulatory transformations necessitate workforce reskilling and upskilling. Human capital theory suggests that investments in education and training are important to bridging skills gaps in green chemistry, digital operations, and smart manufacturing. Firms and policymakers must therefore design training programs aligned with these evolving needs.

Overall, labor dynamics in the adhesive industry are shaped by the interaction of supply-chain linkages, technological change, and regulatory pressures. These mechanisms jointly influence labor demand, skill requirements, and employment structures, forming the basis for further analytical and empirical investigation.

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818650834
DOI: 10.17879/19818650088

6. Future Research Directions

While this study provides a theoretical foundation for analyzing the employment impacts of the adhesive industry, significant opportunities remain for empirical and interdisciplinary research. First, there is a pressing need for empirical validation of employment multipliers specific to the adhesive sector. Existing estimates often aggregate adhesives into broader chemical or manufacturing categories, obscuring the sector's distinct contribution to job creation. Input-output and computable general equilibrium modeling at regional and global levels could yield more precise employment figures and multiplier effects across upstream and downstream industries (iller and Blair, 200).

Second, future research should explore the labor market consequences of automation and digitalization in adhesive manufacturing. Future research should quantify the extent to which automation leads to job displacement versus skill upgrading in adhesive manufacturing. Comparative research could also draw on evidence from automation studies in related manufacturing sectors to determine whether adhesive production follows similar or divergent patterns (arancic, et al., 2020).

Third, the rise of sustainable and bio-based adhesives presents fertile ground for research into green job creation. Future studies should examine how emerging technologies, such as bio-based adhesives and circular production models (Cui and iu, 2021), reshape occupational structures across R , production, and compliance functions.

Fourth, there is scope for research into the regional clustering and global value chain integration of the adhesive industry. By applying cluster theory, scholars can examine how adhesives interact with adjacent industries such as automotive, aerospace, and packaging, and how these clusters foster innovation, productivity, and localized employment growth (orter, 1). Comparative studies across developed and emerging economies would help clarify how geographic and institutional contexts shape workforce outcomes.

Finally, future work should adopt longitudinal and interdisciplinary approaches to track how evolving regulations, trade policies, and sustainability agendas affect adhesive-sector labor markets. Combining labor economics, environmental studies, and industrial policy analysis could generate holistic insights into workforce transitions. For instance, integrating human capital theory with sustainability research could help design adaptive training systems that align labor supply with the industry's transition toward greener and more technologically sophisticated production models (Bec er, 1 6).

In summary, advancing adhesive-sector employment research will require moving beyond conceptual frameworks toward empirical, cross-sectoral, and global perspectives. Such efforts will not only fill current knowledge gaps but also provide policymakers and industry leaders with evidence-based tools to navigate the adhesive industry's role in shaping future labor markets.

7. Discussion

This section reflects on the broader significance of the analysis presented, considering its theoretical implications, alignment or divergence with existing literature, and relevance to policy and economic planning. It also addresses potential theoretical limitations and acknowledges alternative interpretations.

First, regarding the theoretical implications, the analysis suggests the relevance of multiple theoretical lenses, particularly input-output theory, labor demand theory, and human capital theory, in understanding employment dynamics within the adhesive industry. These arguments are consistent with existing empirical research (ojnarows a et al., 2021). Furthermore, labor demand theory reinforces how firms respond to productivity-enhancing technologies, such as automation, by altering their skill composition and labor utilization (amermesh, 1 3). The role of human capital theory is also reinforced, particularly in the context of the growing demand for specialized skills associated with sustainable adhesives and smart manufacturing. The increasing focus on eco-innovation reflects broader structural transformation toward knowledge-intensive production (Rani et al., 202).

Second, with respect to consistency or contradiction with existing literature, the conceptual arguments are broadly consistent with patterns identified in empirical research, particularly regarding manufacturing's high employment multipliers and supply-chain linkages. Report from the Economic Policy Institute confirm that manufacturing industries, including adhesives, exhibit total job multipliers ranging between 1. and 3.0, supporting the paper's claim that adhesive production is expected to generate employment effects beyond direct production. However, there is limited empirical data specific to the adhesive sector in the peer-reviewed academic literature. Most data are embedded in broader manufacturing or chemical industry statistics, which introduces ambiguity in measuring adhesive-specific labor trends. This paper partially bridges that gap through theoretical generalization, yet it acknowledges that the employment structure in niche sectors (e.g., marine adhesives, electronics adhesives) may deviate from national manufacturing averages. Moreover, the theoretical stance on automation is cautiously optimistic, suggesting skill transformation rather than displacement, which partially contrasts with automation-focused literature that predicts significant job losses in mid-skill roles (Narancic et al., 2020). However, this divergence is mitigated by the industry's unique reliance on precision, customization, and regulatory compliance, all of which resist full automation.

Finally, concerning the broader economic and policy meaning, the conceptual framework offers insights that may inform policy discussions. First, recognizing the adhesive industry's indirect employment contributions strengthens the argument for including it in industrial policy discussions, particularly in regions with dense manufacturing clusters. Regional development agencies can use this theoretical framework to justify investment in adhesive technologies as a lever for broader employment gains. Second, the emerging demand for sustainable adhesives and digitalized production processes necessitates policy responses in workforce development. The need for mid-to-high skill training in chemical engineering, robotics, and sustainability aligns with ongoing discussions around the "just transition" to a green economy. Governments, industry associations, and educational institutions must therefore collaborate to ensure training and certification systems align with evolving industry demands. Third, trade and environmental policies that affect chemical inputs, emissions regulations, and circular economy initiatives will likely reshape employment patterns across the value chain. The paper's framework supports the idea that labor policies must be integrated into environmental and industrial strategies to ensure resilience and fairness in labor market transitions.

Overall, the analysis suggests that the adhesive industry should be understood not as an isolated manufacturing segment, but as a node within interconnected industrial systems, where employment effects emerge through technological, structural, and spatial interactions. It is also important to note that the present study is conceptual in nature and does not provide empirical validation of the proposed relationships. As such, the arguments developed should be interpreted as theoretically grounded propositions rather than empirically confirmed findings.

8. Concluding Remarks

This study examined the employment dynamics of the adhesive industry through an integrative theoretical framework applying concepts from input-output theory, labor demand theory, human capital theory, and structural change theory. The analysis suggests that the adhesive sector, while often perceived as a niche manufacturing domain, may generate a broad spectrum of employment impacts. These include direct jobs within production facilities, indirect roles in supporting industries such as raw materials and logistics, and induced employment through household consumption effects.

The analysis shows that employment effects extend beyond direct production roles to include indirect and induced impacts across supply chains. By linking firm-level labor demand, sectoral interdependencies, and broader structural changes, the study provides a structured perspective on how employment is generated and transformed in this industry. While the analysis is conceptual, it offers a basis for future empirical research and contributes to understanding employment dynamics in specialized manufacturing sectors.

Statement of AI Usage

The author used generative artifical intelligence (AI) tools solely to support language editing and improve the clarity of expression during manuscript preparation. All conceptual development, literature synthesis, theoretical arguments, interpretation, and final content were developed, reviewed, and approved by the author, who takes full responsibility for the accuracy and integrity of the manuscript.

9. References

Acemoglu, ., Restrepo, . (2020): Robots and jobs: Evidence from labor markets, Journal of Political Economy, 12 (6), pp. 21 -22 .

A bari, ., cClelland, R. (2020): Corporate social responsibility and corporate citizenship in sustainable supply chain: a structured literature review, Benchmarking: An International Journal, 2 (6), pp. 1 -1 1.

Ar n-Ais, . rez- imi ana, . . nchez- avarro, . . rgil s-Barcel , C. (2012): Developments in microencapsulation technology to improve adhesive formulations. The Journal of Adhesion, (-6), pp. 3 1- 0 .

Archer, B. (1): Water based contact adhesives - new developments. International Journal of Adhesion and Adhesives, 1 (1), pp.1 -1 .

Ardahaey, . T. (2011): Economic impacts of tourism industry. International Journal of Business and Management, 6 ( ), pp. 206-21 .

Bec er, . . (1 6): Human Capital: A Theoretical and Empirical Analysis, with Special Reference to Education, University of Chicago Press, Chicago.

Bivens, J. (201): Updated Employment Multipliers for the . . Economy, Economic Policy Institute, retrieved from http: epi.org 1602 2, accessed 1 .06.202 .

Bogue, R. (201): Recent innovations in adhesive technology. Assembly Automation, 3 (3), pp. 201-20 .

Cui, C., iu, . (2021): Recent advances in wet adhesives: Adhesion mechanism, design principle and applications, Progress in Polymer Science, 116, 1013 .

ata A. (202): Adhesive Bonding Machine Operators & Tenders, retrieved from https://datausa.io/profile/ soc adhesive-bonding-machine-operators-tenders, accessed 20.06.202 .

amermesh, . . (1 3): Labor Demand. Princeton University Press, Princeton, New Jersey.

errendorf, B., Rogerson, R., alentinyi, . (201): Growth and Structural Transformation. Chapter 06 in Handbook of Economic Growth, 2, pp. - 1, Elsevier, Amsterdam.

B orld. Adhesive manufacturing in Canada - Market research report (201 -2030). 202 , available at: https: www.ibisworld.com canada industry adhesive-manufacturing 3 , accessed 1 June 202 .

B orld. (202): Adhesive Manufacturing in Nova Scotia – Market Research Report, retrieved from https: www.ibisworld.com canada industry nova-scotia adhesive-manufacturing 1630 , accessed 1 .06.202 .

rand iew Research. . . adhesives and sealants market size, share trends analysis report by technology, by end-use, by region (Northeast, Midwest, West, South), and segment forecasts, 2022-2030. 2022, available at: https: www.grandviewresearch.com industry-analysis us-adhesives-sealants-market-report. accessed 1 June 202 .

ongo, ., icoletti, ., adovano, A. (201): Smart operators in industry .0: A human-centered approach to enhance operators capabilities and competencies within the new smart factory context. Computers Industrial Engineering, 113, pp. 1 -1 .

ucintel. (202): Adhesives in Global Composites Market: Market Size, Trends and Growth Analysis, August 202 , retrieved from https: www.lucintel.com adhesives-in-composites-market.aspx, accessed 20.06.202 .

iller, R. . Blair, . . (200): Input-output analysis: Foundations and extensions (2nd ed.). Cambridge University Press, Cambridge.

arancic, T. Cerrone, . Beagan, . Connor, . . (2020): Recent advances in bioplastics: Application and biodegradation. Polymers, 12, 20.

rr Boss Consulting. (2023): Economic Impact Report. Canadian Paint and Coatings Industry Making Real Contributions to Canadas Economy, retrieved from https: canpaint.com wp-content uploads 2023 12 Economic-Impact-Report.pdf, accessed 1 .06.202 .

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818650834
DOI: 10.17879/19818650088

Ouanhlee, T. (2024): The influence of the manufacturing industry environment, organizational structures, and economic trends on employee responsibilities in the manufacturing industry. Technology and nvestment, 1 (1), pp. 3 - 6.

ei, . talia, . elazzini, . (202): nhancing circular economy practices in the furniture industry through circular design strategies. ustainability, 16, 6 .
23. orter, . . (1): Clusters and the new economics of competition. arvard Business Review, 6 (6), pp. - 0.

Rani, A. Tyagi, . ingh, A. oel, A. ingh, . . Chauhan, A. (202): ustainable manufacturing for rubber waste industries with integrated circular economy. iscover ustainability, 6 (263).

. . epartment of Commerce, Bureau of conomic Analysis. (1): Regional ultipliers. A ser andboo for the Regional nput- utput odeling ystem (R), Third dition, arch 1 , retrieved from https: apps.bea.gov scb pdf regional perinc meth rims2.pdf, accessed 1 .06.202 .

pherical nsights Consulting (202): lobal adhesives and sealants market size to worth 326. billion by 2033, available at: https: www.sphericalinsights.com our-insights adhesives-and-sealants-market, accessed 12 ay 2026.

CA. (201): The uropean Adhesive and ealant ndustry: acts igures 201 , retrieved from https: www.feica.eu application files 31 0 3 factandfigures14.pdf, accessed 16.06.2025.

Wojnarowska, M. Sołtysik, M. Guzik, M. (2021): Socio-economic importance of biomaterials in the transition to the circular economy model. eb of Conferences, 2, 02 .

JOURNAL OF
BUSINESS CHEMISTRY

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818648342
DOI: 10.17879/19818647580

Research Paper

Jesper Frost Thomsen[1*] & Simon Lux[1,2]

A Transport Perspective on Designing European Battery Supply Chains: The PowerCo Case

This paper examines the process of designing a modern battery supply chain, emphasizing the complexity of establishing a supply chain with more than six components and 25 production steps. Focusing on PowerCo in Salzgitter, Germany, the study evaluates supply chain design from a transportation perspective, analyzing transport costs and emissions across six different scenarios. It explores how optimization strategies can minimize both costs and environmental impact, acknowledging the higher premiums associated with using European production. Additionally, the total transportation impact for cells supplied to Volkswagen's Wolfsburg plant from PowerCo Salzgitter and three other European manufacturers is assessed, highlighting the strategic advantage of PowerCo's plant location.

Keywords: Battery logistics European Battery supply chain Supply chain Battery Transport impact Battery market PowerCo.

1. Introduction

The demand for lithium-ion battery cells is increasing globally, with Europe experiencing particularly rapid growth. The discussion of supply chain security and independence remains prominent at all levels, from small industries to European policymakers. Although European cell manufacturing has expanded in recent years, these facilities have primarily been established by non-European companies. Prominent examples include , which operates the largest plant in Europe, others are CAT and , each managing two plants across the continent (Bockey and Heimes, 2026). European firms venturing into gigafactory-scale production have encountered mixed results, notably the bankruptcy of Swedish Northvolt in 202 (Northvolt, 202). Nonetheless, 202 also marked positive developments for European battery manufacturers, exemplified by the opening of new production lines by French Verkor and German PowerCo, alongside existing operators like ACC, all of which aim to strengthen their presence in the battery industry (Automotive Cells Co, 2023 PowerCo, 202 Verkor, 202).

The three have different origins but share similar public goals: low-emission European cells with secure manufacturing. Both ACC and PowerCo have founders connected to the automotive sector, with the goal of establishing domestic cell production. The key distinction is that ACC was formed by a consortium initially of Stellantis and TotalEnergies Saft, later expanded to include Mercedes-Benz, whereas PowerCo was spun off from Volkswagen, primarily to supply cells for vehicles (Automotive Cells Co, 2022 Kilian et al., 2022). Since PowerCo is expanding its supply chain around a fully German-made cell production facility, analyzing the influence of various supply chain configurations on overall transport emissions and costs for the cells produced at the Salzgitter plant can provide insights into potential improvements to the supply chain.

---

[1] Institute of Business Chemistry, University of Münster, Leonardo Campus 1, 48149, Münster, Germany
[2] Fraunhofer Research Institution for Battery Cell Production (FFB), Bergiusstrasse 8, 48165, Münster, Germany
[*] Jesper.f.thomsen@uni-muenster.de

This work will build on the authors previously presented work on battery supply chain transport (Thomsen and ux, 202) by using a prismatic Lithium Nickel Manganese Cobalt Oxide 811 (NMC 811) graphite cell as a proxy for the top-tier unified cell using NMC chemistry, intended for production at the PowerCo plant (ro , 202).

This cell raises three different aspects of interest when considering the impact of transport on the PowerCo supply chain.

(1) How do differently designed scenarios affect transport costs (€/kWh) and emissions (kg$_{eq\text{-}CO_2}$/kWh) of PowerCo's cell manufacturing at its plant in Salzgitter, Germany

(2) How does an increased number of European suppliers in the supply chain influence transport costs (€/kWh) and emissions (kg$_{eq\text{-}CO_2}$/kWh) for PowerCo's Salzgitter plant

(3) How does PowerCo compare to three European competitors as a cell supplier for VW, specifically from a transport perspective

By examining these three aspects, we gain a clear understanding of whether the location of the PowerCo cell plant is strategic for its main customer, (ro , 202). It also explores how PowerCo might reduce transportation impacts in its supply chain through optimization and assesses how including European locations can further mitigate these impacts.

2. Methods

The methods and approach used in this work follow those published by the authors in their previous work (Thomsen ux 202). Using the in-house developed multimodal point-to-point transport model, considering road, rail, and ocean-going transport, to determine the distance between factory locations in the data set. The distance is then converted to transport cost and emissions using material content, packaging and process efficiency, with emissions factors from The European Chemical Industry Council (Cerif) (c innon iecy , 2021) and cost factors from anteia (van der eulen et al., 2023).

The previous work focused on establishing a basis for analyzing the impact of transport in the battery supply chains. The findings showed a consistent, flexible, and independent approach to simulating transport and determining total supply chain transport cost and emissions. This work is in part based on the learnings from the first publication by extending. The scope of the original publication is extended by increasing the number of scenarios considered, introducing new

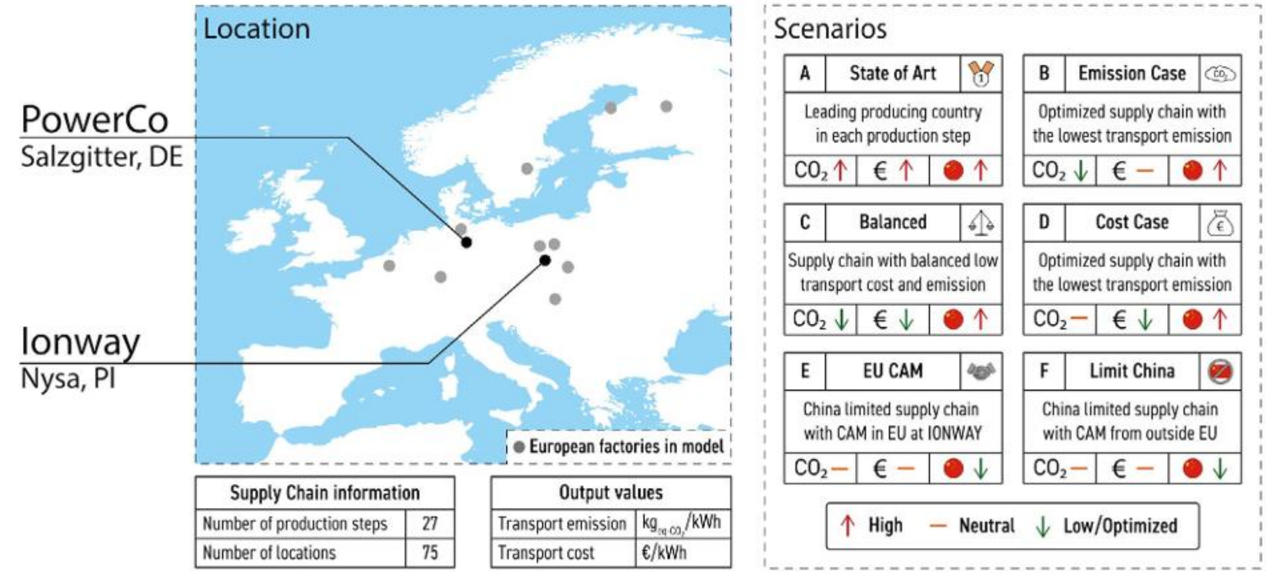


Figure . The figure shows four elements. (Location) The locations of the PowerCo Salzgitter plant, Ionway Nysa plant and all European factories included in the model. (Scenarios) The six scenarios are presented with title, description and indicators for the cost, emission and China dependency. (Supply Chain information) The number of production steps and total number of factories. (Output values) The output values and their units.

cell manufacturers and a new module manufacturer, improving material information, and focusing on a predominantly uropean supply chain. The owerCo plant location, scenarios and outputs are shown in igure 1 and described in the sections below.

2.1 Scenario

The dataset from the paper, rom mine to manufacturer: Assessing transport impacts in the battery supply chain, (Thomsen ux 202) was used to broaden the analysis to six scenarios. These include (a) the state-of-the-art (A), (b) the lowest transport emissions scenario, and (d) the lowest transport costs scenario. The scenarios represent the material flows within the SOA and the optimal setups for each parameter.

sing this data, a balanced scenario (c) was constructed by selecting the nearest supply chain to the intersection of minimum emissions and cost to approximate a supply chain that minimizes combined emissions and costs. A scenario (f) with the fewest locations within China was developed to depict a China-limited supply chain. The China-limited supply chain was then adapted to a uropean cathode active material supply chain (CA) built around the joint venture on ay, formed by owerCo and micore, for the production of cathode active materials in oland (e) (rnst and cheers, 2023 A , 2023). The scenarios were chosen to illustrate non-idealized supply chains and to evaluate the impact of a potential exclusion of China on transportation impacts.

2.2 Cell manufacturing comparison

To compare uropean cell manufacturers delivering to the ol swagen plant in olfsburg, the A supply chain for each manufacturer was designed, and the distance between the cell manufacturer and the automotive plant was determined using the simulator. These distances were then converted to cost and emissions. The plants chosen were the amsung battery cell plant in Göd, Hungary, the LG plant in Wrocław, Poland, the er or battery cell plant in un ir , rance, and the ol swagen Automotive plant in olfsburg, ermany. The cell manufacturers were selected based on size and location, with representing the largest plant in urope, amsung as a proxy for a multitude of the plants in ungary, and er or representing a battery-centric region in rance.

3. Results

The results for the six scenarios are shown in two parts: igure 2A displays the greenhouse gas ( ) emissions in g$_{\text{e -C 2}}$ h, while igure 2B shows the associated transport costs in h. The data is divided into eight categories: Cathode Active aterial, atural raphite, ynthetic raphite, Aluminum Casing, Aluminum oil, Copper oil, olvent, and eparator.

The total transport emissions in the A scenario are calculated to be .1 g$_{\text{e -C 2}}$ h, with a transport cost of 3.96 €/kWh. The first important finding is that all modified scenarios have both lower cost and lower emissions than the A scenario. This indicates that, from the A scenario, there is a high potential for optimization through even small changes to the supply chain, including bringing parts of the supply chain to or near urope. After adjusting the full-cell cost and emissions reported by utsch and e er (utsch e er, 202) to the cell capacity used in this study, transport was found to account for .0 of total cell emissions and 3.2 of total cell cost.

By design, the largest savings are observed for the optimized scenarios, with the cost-optimized scenario showing a potential 61 cost reduction and the emission-optimized case showing a potential 1 emission reduction. The balanced scenario shows a potential cost reduction and a 3 potential emission reduction. The balanced scenario proves to be a good compromise between the best emission and cost scenarios. specially for emissions, the balanced scenario performs 10 percentage points better than the cost-optimized scenario.

n the material level aspect, in all scenarios, transport of the separator accounts for the smallest contribution, while the main contributor varies depending on the scenario and ey performance indicator. n the A case, the copper supply chain has the highest transport costs and emissions, but also offers the greatest potential for savings, with potentially 6 reduction in emissions and reduction in costs.

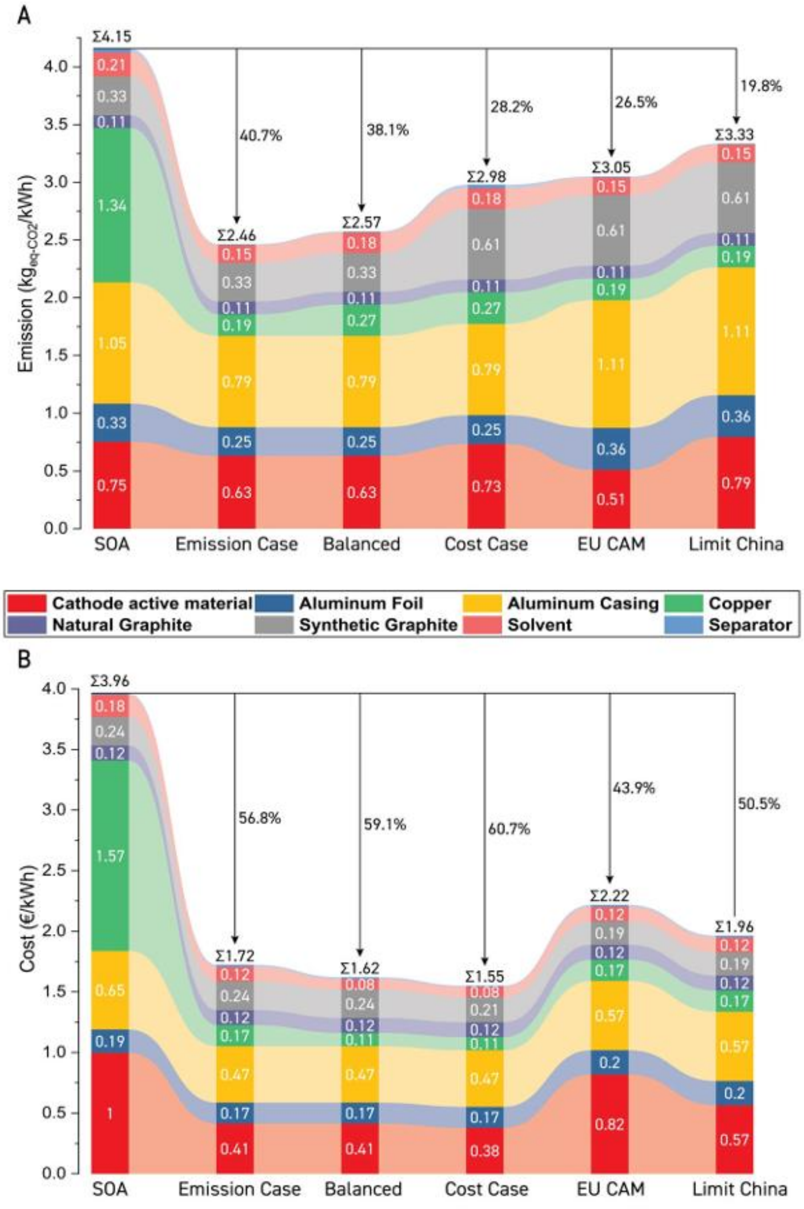
hen comparing the costs, emissions, and balanced scenarios, three of the eight categories show no significant variation: Aluminum Foil, Casing, and Natural raphite. mall variations are seen in the cathode active material, Copper foil, separator, and solvent. The most significant variation occurs in emissions for Synthetic

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818648342
DOI: 10.17879/19818647580

Graphite, which nearly doubles from the emission to the cost scenario.

An interesting aspect is the comparison between the two scenarios constructed to target a Chinese-limited supply chain. These scenarios propose that owerCo would aim to limit the use of Chinese materials in the cell consequently, the resulting scenarios involve only three manufacturing steps in China, all related to graphite production.

These two scenarios exhibit the highest overall transport costs and emissions for the modified scenarios, primarily due to the cathode active material and aluminum casing. Here, the CA scenario incurs the highest overall transport cost, with CA transport costs in this scenario being double that of the cost-optimized scenario and 0 of the A scenario. Despite this, the CA supply chain records the lowest emissions among all scenarios, suggesting that a European supply chain for the CA scenario results in a transport cost premium, but emission savings. Conversely, the China-limited scenario has the highest total transport and CAM-specific emissions, although its transport costs are lower than those of the CA scenario.



igure 2 This figure shows the emissions ( ) and transport costs ( ) for the six scenarios designed in this study. The transport costs and emissions are shown for each of the eight components of the cell. t the top of each bar is the total transport cost or emission reported and the reduction in percentage compared to the state of art (S) scenario.

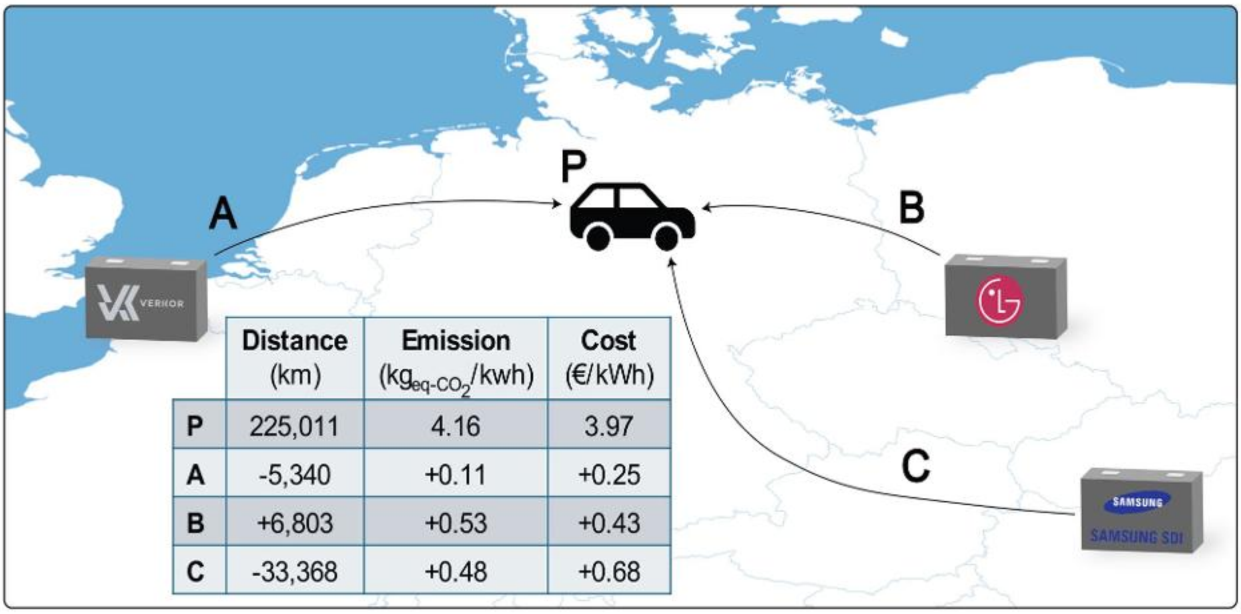
4. Discussion

The findings highlight the impact of transport costs and emissions throughout the supply chain and indicate that, while reductions are achievable, both the China Limited and the CA scenarios deviate notably from the optimized scenarios. The following aspects require further discussion. The first concerns how PowerCo's transport costs and emissions compare with those of other European cell manufacturers for cells delivered to the VW plant. The second concerns how reducing reliance on Chinese materials and increasing local sourcing may raise transport costs and emissions, but could provide greater supply chain security.

4.1 PowerCo as a cell Supplier for VW

VW created PowerCo as a key component supplier to their headquarters and production site in Wolfsburg, Germany. The chosen location for the first PowerCo plant in Salzgitter, Germany, took this into account. To evaluate the location choice, a comparison of total supply chain transport costs for cells from PowerCo and three other European cell manufacturers was conducted, with the cells arriving at the VW plant in Wolfsburg. The selected manufacturers are LG in Wrocław, Poland; Verkor in Dunkirk, France and Samsung SDI in Göd, Hungary.

The results for the VW scenario are shown in Figure 3. The results clearly indicate that for two of the three other cell manufacturers, the total supply chain transport cost is higher than for the PowerCo plant, ranging from a premium of 0.2 €/kWh for the Verkor plant to 0.6 €/kWh for the Samsung SDI. This suggests that, from a transportation cost perspective, the PowerCo plant's location in Salzgitter is advantageous, and reduced supply chain transport costs enhance PowerCo's competitiveness with other European cell manufacturers.



	Distance (km)	Emission ($kg_{eq\text{-}CO_2}$/kwh)	Cost (€/kWh)
P	225,011	4.16	3.97
A	-5,340	+0.11	+0.25
B	+6,803	+0.53	+0.43
C	-33,368	+0.48	+0.68

Figure 3. The map shows the location of the Volkswagen plant in Wolfsburg (car) and the nearby PowerCo plant (P), as well as the location of the three alternative cell plants chosen by Verkor (A), LG (B), and Samsung (C). The table shows the total supply chain distance, costs, and emissions for cells transported to the Volkswagen plant.

4.2 The implications of increased European material sourcing

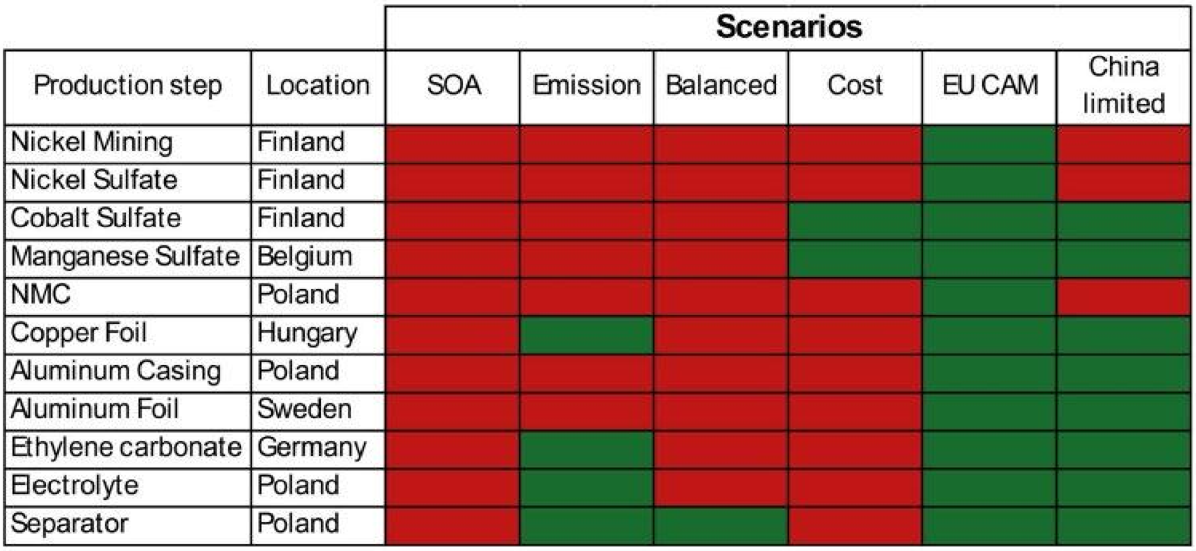
Production locations are linked directly to potential product cost, tariffs, and procurement times for input and output materials, connecting local content and supply chain security. The CA and China limited scenarios show how increased European content affects transport costs and emissions. Table 1 lists the 11 production steps that occur in Europe at least once across the six scenarios, based on the database used in this study. European factories for alumina, aluminum, and copper are readily available. Nevertheless, the database includes only the top 3 global producers for each category, and European locations are not among the top producers of alumina and aluminum an alternative would be to use recycled European copper in the manufacturing process, which has already been reported in industry (Volta Energy 2021).

As Europe is not currently the leading producer at any stage in the battery supply chain, the SOA scenario includes no European production. This supply chain not only illustrates the most likely material flow but also the most far-east Asia dependent supply chain analyzed in this study. Therefore, any inclusion of European manufacturers would be a deviation from the SOA supply chain.

In the optimized scenarios, a clear distinction appears between the cost- and emission-optimized scenarios. The cost scenarios include some of the NMC upstream precursor-refining stages in Europe. Meanwhile, the emission scenario includes manufacturing steps for copper foil, electrolyte, and separator occurring in Europe. This information can be used to compare the balanced scenario, in which only one production step is in Europe: separator manufacturing. This scenario balances cost and emissions equally to identify the best average outcome under these conditions, European steps are generally not favored. If the decision was made to use all European production sites from the optimized scenarios for the balanced scenario, it would yield greater cost savings but higher emissions. With transport cost at 1.6 h and transport emissions at 2. g$_{e\text{-}C\ 2}$ h.

Targeting a European-heavy, China-limited supply chain in the EU CAM and China-limited scenarios, higher costs and emissions were observed in the results. The higher cost is associated with more production sites in Europe: the China-limited has , whereas the EU CAM has 11. This equals 0 of the overall production locations located in Europe, compared with zero in the SOA scenario, the increase in transport costs due to the higher number of European sites are 0. h, or about 3 higher than in the cost-optimized scenario.

Table : Heat map indicating which of the European production steps are included in each scenario. Green is included, red is not included.



		Scenarios					
Production step	Location	SOA	Emission	Balanced	Cost	EU CAM	China limited
Nickel Mining	Finland	🟥	🟥	🟥	🟥	🟩	🟥
Nickel Sulfate	Finland	🟥	🟥	🟥	🟥	🟩	🟥
Cobalt Sulfate	Finland	🟥	🟥	🟥	🟩	🟩	🟩
Manganese Sulfate	Belgium	🟥	🟥	🟥	🟩	🟩	🟩
NMC	Poland	🟥	🟥	🟥	🟥	🟩	🟥
Copper Foil	Hungary	🟥	🟩	🟥	🟥	🟩	🟩
Aluminum Casing	Poland	🟥	🟥	🟥	🟥	🟩	🟩
Aluminum Foil	Sweden	🟥	🟥	🟥	🟥	🟩	🟩
Ethylene carbonate	Germany	🟥	🟩	🟥	🟥	🟩	🟩
Electrolyte	Poland	🟥	🟩	🟥	🟥	🟩	🟩
Separator	Poland	🟥	🟩	🟩	🟥	🟩	🟩

5. Perspective

Industrial supply chain information is hard to obtain outside joint-venture announcements, such as A . Because this information is often considered proprietary, Volkswagen publishes an annual Responsible raw materials report, in which they comment on raw material sourcing and refinement (Volkswagen AG, 2026). This report is at the group level and therefore covers more raw materials and other potential cell producers for Volkswagen however, it remains a good indicator of the PowerCo supply chain. Three points from this report are of interest for this publication. There is a high degree of similarity between the global leading mining countries in the report and those in this publication, and the three leading countries often appear as sources. PowerCo sources material from multiple countries simultaneously, rather than from a

Vol.23, Iss.2, June 2026
URN: urn:nbn:de:hbz:6-19818648342
DOI: 10.17879/19818647580

single origin as simulated in this study. Importantly, the report states that mapping battery materials across the full supply chain is difficult, but that “refining and processing remain highly concentrated in China. (Volkswagen AG, 2026). This indicates that PowerCo, as a company, is close to the mid- and downstream design of the A scenario, deviating from A by sourcing raw materials from multiple locations around the globe. This work demonstrates the potential savings achievable through supply chain optimization for a single company at a specific production step. However, the lessons drawn from transport are relevant beyond this particular case. Including transport in supply chain analysis provides a broader basis for evaluating location suitability in relation to both suppliers and customers. Because transportation costs often represent an additional cost borne by the buyer, a stronger understanding of supply chain transport costs can improve competitiveness in tight markets by supporting more effective supply chain and transport design, as illustrated here in the case of PowerCo and Volkswagen.

6. Conclusion

Six supply chain scenarios for battery cell manufacturing at the PowerCo plant in Salzgitter, Germany, were evaluated and analyzed. A cost-optimized and an emission-optimized scenario were used as theoretical bookends to approximate a balanced scenario. Additionally, the reduction in dependence on China was assessed, including the PowerCo special case involving a joint venture in Poland for the supply of cathode active material.

The optimized scenarios indicated potential savings of over 0 in transport emissions and 60 in transport costs, however these have very limited European contributions. In the CAM and China-limited scenarios, most categories exhibited lower costs and emissions than in the A scenarios. Notable values include the cost of the CAM supply chain in the CAM scenario, which shows only a 20 reduction compared to the A scenario and is twice that of the optimized scenarios. Regarding emissions, in both scenarios, the transportation of synthetic graphite is nearly twice that of the A and emission-optimized scenarios. Both scenarios involved numerous European locations, but the expanded European footprint increased transport costs and emissions.

Finally, the location of the PowerCo plant as a supplier for Volkswagen was evaluated by comparing it with three other European cell plants. The analysis showed that PowerCo has a 2 -cent-per-kWh transportation cost advantage over the second-best producer in a full-supply-chain transport analysis.

Overall, this study demonstrates that PowerCo, via its main offtake agreement with Volkswagen, was able to establish a factory with near-optimal transport costs and emissions for cell delivery. The research highlighted how this advantage could be enhanced through supply chain optimization and expanding the number of European manufacturers. Nevertheless, in some parts of the supply chain, utilizing a European supply chain would increase transport costs, which would have to be offset by lower production costs or balanced with greater supply chain resilience.

Statement of AI Usage

ChatGPT, version . , extended thinking has been used to improve content quality, and Grammarly, with the Grammarly AI writing assistant, has been used to improve writing. After employing these tools, we thoroughly reviewed and edited the content as necessary, assuming full responsibility for the final publication.

Acknowledgement

The authors would like to acknowledge that the map data used for this work are copyrighted by OpenStreetMap contributors and available from https://www.openstreetmap.org.
Calculations (or parts of them) for this publication were performed on the HPC cluster PALMA II of the University of Münster, subsidised by the DFG (INST 211 66 -1).

CRediT authorship contribution statement

Jesper Frost Thomsen: Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Conceptualization.
Simon Lux: Writing – original draft, Supervision, Conceptualization.

Funding sources

The authors thank the Ministry for Culture and Science of North Rhine-Westphalia (Germany) for funding this work within the International Graduate School for Battery Chemistry, Characterization, Analysis, Recycling, and Application (BACCARA).
The funder had no influence or impact on the work carried out in this study.

7. References

Automotive Cells Co (2022), Automotive Cells Company (ACC) welcomes Mercedes-Benz as future equal shareholder, alongside Stellantis and TotalEnergies Saft and plans third factory for Italy, available at https://www.acc-emotion.com/stories/automotive-cells-company-acc-welcomes-mercedes-benz-future-equal-shareholder-alongside, accessed 16 April 2026

Automotive Cells Co (2023), ACC inaugurates its first Gigafactory in Billy-Berclau Douvrin, available at https://www.acc-emotion.com/media/bbd-press-release, accessed 13 April 2026

Bockey, ., eimes ., (2026) Europe Battery Cell Production Atlas, available at https://battery-news.de/en/europe-battery-cell-production , accessed ay 2026

rnst, ., cheers, . (2023), PowerCo and Umicore get official “go” to start joint venture for EU battery materials production, available at https://www.volkswagen-group.com/en/press-releases/powerco-and-umicore-get-official-go-to-start-joint-venture-for-eu-battery-materials-production-1 06 uery , accessed 16 April 2026.

utsch, ., e er, J. (202) Costs, carbon footprint, and environmental impacts of lithium-ion batteries – from cathode active material synthesis to cell manufacturing and recycling, Appl. Energy, 3 3

ro , A. (202) Start of European battery cell production: PowerCo commissions Salzgitter gigafactory, available at https://www.volkswagen-group.com/en/press-releases/start-of-european-battery-cell-production-powerco-commissions-salzgitter-gigafactory-200 , accessed 13 April 2026.

A (2023), A – the PowerCo micore J –to locate its first production plant in Nysa, Poland, available at A – the PowerCo micore J – to locate its first production plant in Nysa, Poland – A , accessed 16 April 2026.

ilian, A., ro , A., rnst, . (2022), Ground breaking in Salzgitter: Volkswagen enters global battery business with PowerCo , available at https://www.volkswagen-group.com/en/press-releases/ground-breaking-in-salzgitter-volkswagen-enters-global-battery-business-with-powerco-16 uery , accessed 16 April 2026.

c innon, A., iecy , . (2021) Measuring And Managing C 2 Emissions of European Chemical Transport. Brussels: Cefic Aisbl - European Chemical Industry Council.

Northvolt (2025): Northvolt files for bankruptcy in Sweden, available at https://northvolt.com/articles/northvolt-files-for-bankruptcy-in-sweden/, accessed 16 April 2026.

Thomsen, J. ., ux, . (202): From mine to manufacturer: Assessing transport impacts in the battery supply chain, Journal of Power Sources Advances, 36.

van der eulen, ., rijspaardt, T., ars, ., van der Geest, W., Roest-Crollius, A., Kiel J. (2023) Cost figures for Freight transport – final report, Kennisinstituut voor Mobiliteitsbeleid. oetermeer: anteia. Available at: https://www. imnet.nl/binaries/ imnet/documenten/notities/2023/03/30/ osten engetallen-voor-het-goederenvervoer/Cost+figures+for+freight+transport_def.pdf

Verkor (202), Verkor reaches a decisive milestone and opens its first gigafactory, available at https://verkor.com/en/verkor-reaches-a-decisive-milestone-and-opens-its-first-gigafactory/, accessed 13 April 2026.

Volkswagen AG (2026), Responsible Raw Materials Report 202 , available at https: uploads.vw-mms.de system production documents cws 003 22 file_en/be7b323f3365873c121800c21992754bb402a66c/Volkswagen_Responsible_Raw_Material_Report_2025.pdf 1 3 , accessed 16 April 2026.

Volta Energy Solutions Hungary (2021), Non-Technical Summary, available at https: www.volta-energysolutions.com en pa publicannouncement iew id 1 page 0 , Accessed 16 April 2026.

JOURNAL OF
BUSINESS CHEMISTRY