PlastLIFE Project deliverable D6.1

Report on innovation management challenges for sustainable plastics

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Contents

Introduction

The world of plastics is currently run and fueled by fossil ingredients, and that needs to be changed for a sustainable future. Plastics have become ubiquitous due to their properties: they are cheap, light, durable, and easy to mold (Andrady and Neal 2009) – all of which make them versatile materials for various purposes, but also highly likely to be discarded after their first use (The World Economic Forum 2016). Hence, the known problems associated with the use of fossil-based raw materials in the plastics industry include the growing greenhouse gas emissions in production and the leakage of plastic waste (including microplastics) into the environment (Siltaloppi and Jähi 2021; Stegmann et al. 2022). Perhaps the most prominent solutions for these problems and in increasing the sustainability of plastics are bio-based solutions, or "bioplastics," which loosely refer to plastics that could replace fossil-based raw materials or address the environmental issues of plastics due to biodegradability. These materials are expected to provide us with innovative solutions that could enable a sustainable future for the plastics industry.

However, unleashing the potential of such innovations would also call for a major restructuring of current industry practices and modes of operation. To begin, the proliferation of bioplastics would disturb the established principles of how the plastic industry operates, shifting the flow of materials and value from a linear and firm-centric model to a more circular and cross-sectional one (Siltaloppi and Jähi 2021). Such transformation calls for a thinking model that emphasizes inter-firm collaboration, complementarities, and joint investments, often described as "ecosystems" in the management context (Adner 2017; Shipilov and Gawer 2020). The necessary changes extend to all stages and various stakeholders across actors, institutions, industries, and sectors. Unfortunately, the management literature is filled with practical examples and theories that describe why change is notoriously difficult to achieve, and the involved parties are often slow and even reluctant to change (Lawrence and Shadnam 2008; Lawrence and Suddaby 2006). Moreover, since "plastics" can mean practically anything (i.e., it is an umbrella term for hundreds of different polymers, fossil-based or renewable, biodegradable or not, and made from virgin or recycled resources), it becomes extremely challenging to pinpoint the most prominent stakeholders and applications for initiating the collective change.

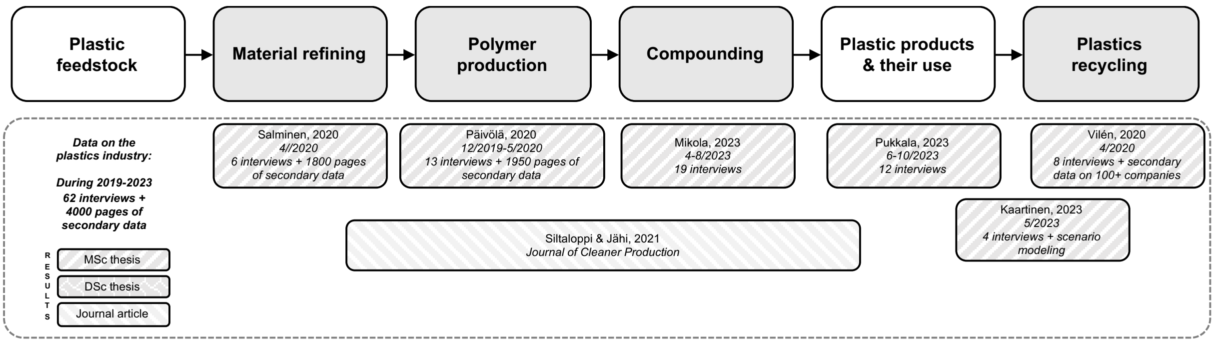
The purpose of this report is to briefly summarize typical challenges related to innovation management in the path of more sustainable plastics. We present two types of identified challenges: ones that are specific to the plastics industry context and ones that are related to the broader industry transition from self-reliant firms toward interlinked ecosystems. Accordingly, the remainder of this report is structured under two main themes: first, we present implications derived from the empirical work conducted on different ways to improve the circularity of plastics and find business models that would accommodate circularity. Second, we provide observations and key conclusions related to ecosystem-level businesses and explain how those can complement the implications of improving the circularity of plastics. We conclude by presenting a summary of potential steps forward for improving the sustainability of plastics by highlighting the need for wide alignment within and across industries that link to the world of plastics.

Short methodological note

The observations and conclusions in this report are based on a long stream of research conducted at the Aalto University, Department of Industrial Engineering and Management. Our research group at Aalto University has conducted hundreds of research interviews among different industry actors and other stakeholders over the last decade that have enlightened us as to why and how attaining such a change is slow and difficult. These insights have supported our analysis of the innovation management challenges for improving the sustainability of plastics. Overall, this research has involved 256 informants through interviews conducted between 2013-2023. These data have been utilized in 13 Master's theses, 2 Doctoral dissertations, and 6 academic articles that provide the foundation for our conclusions and implications. During 2023, we have conducted 31 additional interviews among the stakeholders relevant to the PlastLIFE project[1], while also reaching out to connections attained through the ValueBioMat project[2]. Figure 1 summarizes the related material and research outputs. A complete list of the referred works can be found in Appendix 1. Each work also includes a more complete methodological description about the particular study.

Figure 1. Research data and results that provide the foundation for this report

Studies regarding the plastics value chains – the main foundation for the observations specific to the plastics industry context

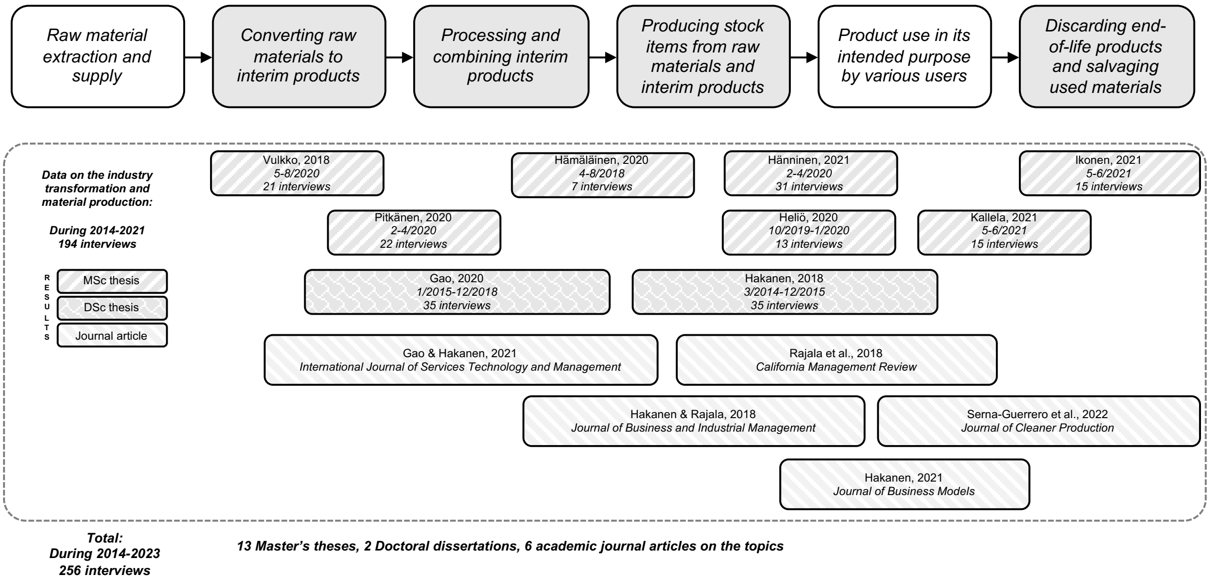


1 Read more about PlastLIFE at https://www.materiaalitkiertoon.fi//en-US/PlastLIFE

2 Read more about the ValueBioMat at https://valuebiomat.fi

Figure 1. Research data and results that provide the foundation for this report (continued)

Studies on industry value chains in different contexts (not in the plastics industry) – the main foundation for observations on broader industry transition from self-reliant firms toward interlinked ecosystems



Implications for improving the circularity of plastics

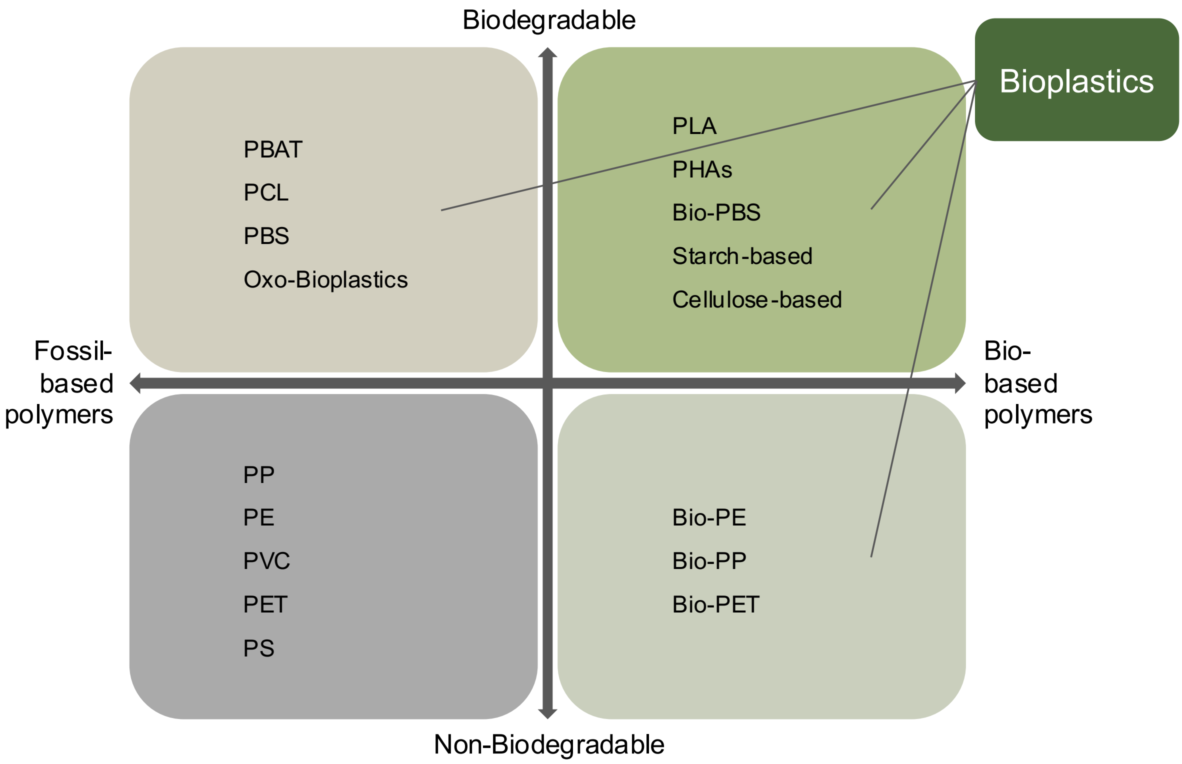
This section presents a brief summary of two key discussions for improving the sustainability of plastics. First, we address the approach of bioplastics and biocomposites, both of which aim to reduce the reliance on fossil-based raw materials. Second, we present the discussion on circular business models and how they can help in shaping a more sustainable future.

Reducing the reliance on fossil-based raw materials: Bioplastics and biocomposites

For some time now, "bioplastics" have been portrayed as an inevitable part of improving the sustainability of the plastics industry. This line of thought follows from a simple observation that as long as the majority of the raw materials used in contemporary plastics are derived from fossil-based resources, the whole industry is a source of CO_2 emissions that aggravate global warming. In response, by replacing unsustainable fossil-based raw materials with renewable resources, the plastics industry could mitigate its role in driving climate change.

However, while the underlying premise is easy to understand and applaudable, this discussion is more complicated than it initially sounds. To start, the term "bioplastics" is confusing as it is widely used to refer to many completely different materials, even different functions that those materials are designed for (Palm and Myrin 2018). A generally used and accepted definition for bioplastics categorizes these as materials that are either biobased, biodegradable, or both (European Bioplastics e.V. 2023). Biobased polymers include products that are made entirely or partially from biomass, which can be organic raw materials (e.g., plants), organic waste, or different side streams (Di Bartolo, Infurna, and Dintcheva 2021). In turn, biodegradable materials are ones that natural microorganisms can decompose at their end of life, deconstructing them to basic elements such as CO_2, water, and biomass (Di Bartolo, Infurna, and Dintcheva 2021; European Bioplastics e.V. 2023). Even some fossil-based plastics can be biodegradable and, hence, referred to as "bioplastics" according to these categorizations (Palm and Myrin 2018). Figure 2 below illustrates the classification of different plastic materials and indicates ones commonly referred to as bioplastics.

Figure 2: Classification of plastics with example plastic types. Figure from Mikola (2023), adapted from Mecholr-Martínez et al. (2022).



Biobased materials could reduce the plastic industry's reliance on fossil-based raw materials, which are a key component of the environmental issues associated with plastics. The biobased feedstocks could directly mitigate the industry's dependency on unsustainable and polluting resources (Di Bartolo, Infurna, and Dintcheva 2021). The biobased feedstocks are considered as a renewable resolution for replacing the problematic and finite fossil resources (Rosenboom, Langer, and Traverso 2022) that could also reduce the energy consumption of the materials production (Shogren et al. 2019). Biodegradability can address the problem of accumulating end-of-life waste of plastics. Biodegradable plastics can also reduce the damage caused by unintentional leakage of plastic waste into natural ecosystems, as they would naturally decompose to their basic elements over time (Di Bartolo, Infurna, and Dintcheva 2021).[3]

3 Also, the use of the term "biodegradability" is very vague and lack a commonly shared and agreed definition. This problem has been noted, for instance, by the European Commission, with the attempt to provide clearer definitions and product labels regarding biodegradability (i.e., specifying the conditions for considering a product biodegradable). One avenue in these discussions is to limit the use of concept of "biodegradable plastics" only to applications where it is seen most beneficial.

An alternative approach to incorporate more biobased ingredients into the plastics is the so-called "biocomposites", which essentially are products incorporating different fillers that are of renewable origin (Manu et al. 2022). Traditionally, fillers have been utilized in plastics to produce various functionalities, such as reinforcing the material and its polymer matrix (Mohanty et al. 2018). By adding biobased fillers to plastics made from synthetic materials it is possible to improve the products functionalities and properties, while also lowering its environmental impacts (Manu et al. 2022). However, such composite materials are likely to complicate the reuse and recycling of the materials in contrast to more conventional plastics, especially if the recycling process would require separating individual components (e.g., the biobased fillers) from their structures (Mohanty et al. 2018).

As the complications regarding the material recycling illustrate, bioplastics or biocomposites cannot provide a straightforward solution to all problems associated with the plastic industry but are likely to cause different kinds of challenges to resolve. One major issue preventing the expansion of biobased feedstocks is that they are most commonly derived from carbohydrate-rich plants (e.g., corn, sugar cane, castor beans, potato, or wheat), which could be otherwise utilized for feeding humans or animals (Brizga, Hubacek, and Feng 2020). This tradeoff between nutrition and plastic feedstock causes a major controversy from a social justice point of view, as it can be argued that limiting food production by directing edible plants to other uses diminishes their value and can be regarded as unethical behavior (Rosenboom, Langer, and Traverso 2022). Limiting the biobased feedstocks to "second-generation" resources, such as cellulose or waste streams from food production (e.g., wheat straw and sugarcane bagasse) that cannot be utilized for food, would greatly limit these ethical concerns (Brizga, Hubacek, and Feng 2020; Rosenboom, Langer, and Traverso 2022). Biocomposites are a good alternative for this purpose, as they are less likely to rely on edible raw materials (Mohanty et al. 2018). However, even such an approach would not resolve all concerns related to biobased feedstocks since the associated criticisms link also to the increasing land use (Palm and Myrin 2018), fresh water consumption (Di Bartolo, Infurna, and Dintcheva 2021), and deforestation caused by growing biobased feedstocks for plastics (Rosenboom, Langer, and Traverso 2022). Novel approaches are required to improve the circularity and sustainability of plastics.

Empirical observations on improving the circularity and sustainability of plastics

Shifting the raw material feedstock would also require complex restructuring of operations and practices across the plastics industry. On a general level, key challenges for facilitating more sustainable businesses in the plastic industry relate to technological, organizational, market-related, and environmental aspects. The way these issues and their impact are described differs slightly from the chosen research focus and approach. However, all of these issues can be linked to the need for restructuring the operations and practices across the plastic industry. Next, we provide four examples how these problems have been described and portrayed in the field.

First, a study on the creation and deployment of sustainable business models for renewable innovations emphasized the benefits of collaboration and openness among companies that could enable leveraging complementary assets among them (Salminen, 2020).[4] The key implications of this study highlighted how innovations for improving sustainability require complex integrations into existing businesses and how they often emerge from niche markets, making them unattractive to incumbent organizations. Hence, the change often requires engagement with external (or new) stakeholders that, in turn, requires considerable effort to develop new relationships and ways of working. Such relationships are, however, required for effective collaboration that could balance the tradeoffs between environmental, social, and economic value. Understanding such tradeoffs across the industry is essential for more reliable evaluations of the sustainability of certain options and for finding collective improvements that benefit multiple stakeholders.

Second, work investigating the role of competition among industry actors argued that industry incumbents are likely drivers of a broader sustainability transition (Päivölä, 2020).[5] Drawing from the works on sustainability transitions, institutions, and strategic management, the study highlighted how the proponents of the sustainability transition need to acknowledge and utilize business and economic incentives as the motivators for change. To address the identified challenges in technological, organizational, market competition, and environmental issues, the incumbents need to be motivated by business and institutional drivers.

Third, when categorizing business models facilitating circular economy and plastics reuse and recycling, three main types were identified: “technology”, “circular reuse”, and “flow” (Vilén, 2020).[6] These categories have different foci guiding the operation. They focus on either developing technologies for plastics collection, sorting, or recycling (technology), creating services to replace single-use plastics with circular or reusable products (circular reuse), or taking responsibility for materials handling related to collection, sorting, or recycling of plastics waste streams (flow). Overall, these business models could potentially address some of the identified barriers to plastic reuse and recycling, such as the need to initiate supply and demand for circularity or the limitations of current recycling processes and operating practices. However, notable further changes were found necessary according to the informants: it was considered that regulative agencies need to do more to drive sustainable development, whereas different industry actors need to find better alternatives to transform the collected waste into value.

Fourth, the most recent work on investigating the potential role of biocomposites for sustainable plastics noted several issues that resemble the previously identified challenges associated with bioplastics (Mikola, 2023).[7] The study found that biocomposites can provide an alternative to reducing the carbon footprint of plastics by simply increasing a biobased component to more conventional materials. However, the applicability of the biocomposites

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4 Salminen, Satu. 2020. Sustainable Business Models for Commercializing Renewable and Circular Plastics – A Multiple Case Study Research. Aalto University. Available at: https://valuebiomat.fi/wp-content/uploads/2023/10/sci_2020_salminen_satu.pdf.

5 Päivölä, Pyry. 2020. Socio-technical transition to a sustainable plastics economy: Strategic approaches for FMCG industry brand owners. Aalto University. Available at: https://valuebiomat.fi/wp-content/uploads/2023/10/sci_2020_paivola_pyry.pdf.

6 Vilén, Lars. 2020. Emerging business models in plastics reuse and recycling. Aalto University. Available at: https://valuebiomat.fi/wp-content/uploads/2023/10/sci_2020_vilen_lars.pdf.

7 Not publicly available at the time of this writing.

was found limited or impossible in certain use cases (e.g., food packaging) and would likely be more suited to products with longer lifespans. The production of biocomposites would require changes to the existing operations and practices of the plastic industry, greatly hindering their proliferation. Also, the current recycling system is largely incompatible with biocomposites and would require considerable changes to accommodate them, or the biobased composite material would have to be separated from the rest of the conventional plastic materials before recycling. Such changes, in turn, are difficult to achieve as the economics of recycling processes are defined by limited margins and small volumes, making it unlikely to see substantial investments in new, complicated processes. As a result, currently, most biocomposite materials end up in landfills or incineration at their end-of-life (Mohanty et al. 2018). Overall, the study found that the sustainability impact of biocomposites is unclear as it relies on multiple complicated factors, including the source of the biobased feedstock, specific application context, and the required changes to the production and recycling processes.

Taken together, the context-specific findings on the challenges of innovation management for sustainable plastics question the extant structures across the plastic industry. The firms are likely to need to collaborate more actively and forfeit their established, largely linear value chains. Conversely, the industry operators need to find better ways to collaborate and engage in collective value-creation processes. These demands reflect the prevalent management discourse on "ecosystems".

Ecosystems in the management discourse

The concept of ecosystems in the management context has been gaining traction in recent years among researchers and practitioners alike (Jacobides, Cennamo, and Gawer 2018; Adner 2017). In strategic management literature, ecosystems have recently been described as a new way to depict the competitive environment (Jacobides, Cennamo, and Gawer 2018) and argued to potentially be critical in shaping firm success (Hannah and Eisenhardt 2018). Alongside several related ideas–such as business models, platforms, and networks–ecosystems have also raised attention on new models of value creation and value capture (Adner 2017; Lorenzo Massa, Viscusi, and Tucci 2018), as digital technologies have increased interdependence between organizations and their boundary-spanning activities across different industries (Amit and Zott 2015; Hakanen 2018). Such perspectives highlight that reconfiguration of firm activities and experimenting with new mechanisms of value creation is seen as critical for future business success (Lorenzo Massa, Viscusi, and Tucci 2018; Zott, Amit, and Massa 2011).

Ecosystems and activity systems in boosting circular business models across industries

The management discourse on ecosystems that highlights the reliance on external collaborators and finding ways to restructure or reconfigure existing activities could provide a solution to the previously identified problems on the path toward more sustainable plastics. This discussion provides a suitable perspective on investigating the imminent transition from linear value chains to circular ecosystems and, hence, can provide a more nuanced understanding of the type of necessary actions for boosting the circularity in the plastic industry business models. In the management discourse, ecosystems are loosely coupled structures that require collective efforts from multiple participants that are brought together by a shared goal or desired outcome (e.g., Adner 2017; Gomes et al. 2021; Shipilov and Gawer 2020). More specifically, an ecosystem is commonly defined as "*a set of actors with varying degrees of multi-lateral, non-generic complementarities that are not fully hierarchically controlled*" (Jacobides, Cennamo, and Gawer 2018, 2264). However, while such a perspective is well applicable to analyzing the potential and effect of collective restructuring of complex activities (Lorenzo Massa, Viscusi, and Tucci 2018; Zott and Amit 2010), it also highlights how the necessary business model changes need to happen at the level of complex "activity systems" within ecosystems (Hakanen 2021; Lorenzo Massa, Viscusi, and Tucci 2018).

The concept of activity system suits particularly well to understanding firms' boundary-spanning activities and their impact on the value creation (L Massa, Tucci, and Afuah 2017; Zott, Amit, and Massa 2011). This perspective complements the existing literature on value creation and value capture by focusing on dynamic resource configurations rather than static resource bundles (Demil et al. 2015). While activity systems have become one of the most common conceptualizations in the academic literature on business models (Lorenzo Massa, Tucci, and Afuah 2017; Zott, Amit, and Massa 2011), the literature still lacks agreement on many central aspects of defining the activity systems, such as which activities are important, who performs them, and what resources are needed to perform them (L Massa, Tucci, and Afuah 2017).

Activities are commonly included in business model conceptualizations either explicitly or implicitly in the form of processes, functionalities, or transactions (Zott, Amit, and Massa 2011).[8] Whereas the activity system is a relatively new angle in business model literature, it closely connects to similar, established notions of strategic management (Lorenzo Massa, Tucci, and Afuah 2017). For instance, in his work on competition dynamics and value chain analysis, Porter (1996) emphasizes how companies' activities are what create differences among them and, thus, the conducted activities and their interlinkages are deeply rooted in explaining how firms can attain or uphold competitive advantage over other firms. Such connections highlight how the activity system is commonly associated with a single, focal firm. The activity system can be centered on the focal firm, but not limited to it, as the focal firm connects to many other firms and their resources as a part of their business model (Amit and Zott 2015). This notion implies that the firms need to consider how to attract and align other participants to participate in their activity system, and what kind of restructuring of operations can facilitate effective collaboration at the industry level (Zott and Amit 2009).

Ecosystems as a solution to restructuring operations at the industry level

The managerial discourse on ecosystems clearly indicates that the activity system perspective can facilitate more efficient value creation and sharing among collaborating firms, bringing a new perspective to improving the sustainability of business processes (Hakanen 2021; Serna-Guerrero et al. 2022). Unfortunately, despite the collectively identified potential, achieving concrete changes at the industry level can be a tedious process, filled with uncertainties and

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[8] In their activity system approach, Amit and Zott (2015, 331) define business model as a *"system of interdependent activities performed by a focal firm and its partners and the mechanisms that link these activities to each other"*. This definition highlights firms' ability to create and appropriate value together with its partners, suppliers and customers. By an activity, Amit and Zott (2015, 331) mean *"engagement of human, physical, and capital resources of any party to the business model […] to serve a specific purpose toward the fulfilment of the overall objectives*".

problems. By looking at the common challenges associated with the emergence and growth of an ecosystem, it is possible to identify what kind of restructuring they require for transforming operations and activities. Next, we explain the commonly observed opportunities and barriers for creating value through ecosystems at the industry level.

On a general level, firms could benefit from ecosystems by transforming the value creation processes from sequential and transactional to concurrent and collaborative. This notion builds on argumentation juxtaposing linear value chains against more organizational designs relying on networks and other collaborative agreements (Stabell and Fjeldstad 1998; Fjeldstad and Snow 2018). By letting go of the linear thinking models that rely on dyadic transactions, the companies can better utilize the competencies across parties and find new opportunities to optimize their operations by taking advantage of the expertise and knowledge of both sides (Veijola, Hakanen, and Rajala 2022). Hence, the ecosystem approach also transforms the business model analysis into multilateral, complex activity systems, requiring a considerable change in the mindset of the companies (Hakanen 2021).

Firms can benefit from ecosystems by improving the way they can explore new opportunities and exploit existing knowledge for their business operations. They can use these benefits to restructure and reconfigure the activities in their proximity and among their (new) partners. They can develop collective operational practices to build up mutual trust and understanding between the parties (Veijola, Hakanen, and Rajala 2022).

In turn, firms often struggle to move to ecosystems despite the identified potential and opportunities. Due to their dynamic, unpredictable, and multilateral nature, investments in a loosely defined ecosystem can seem unattractive and difficult to justify (Hakanen 2021). In fact, it has been argued that an ecosystem can only be unconditionally defined ex-post, meaning after some successful collaboration between companies and different interested parties has taken place (Wolff et al. 2023).

Thus, firms likely experience unclarity and uncertainty about if and how the potential benefits of the ecosystems can be captured in their concrete business operations. Such unclarities easily demotivate the firms and can prevent them from partaking in the ecosystem. In addition, any participation in collaborative value-creation processes within the emerging ecosystem is likely to cause changes in the current operational activities performed by the firm. Since those operational activities have been shaped through a process of trial and error, likely over a long time period, it requires considerable motivation to invoke drastic changes in those activities. Yet, the notion of adjusting the value-creating activities and processes of a single firm to better match and utilize complementary, external resources available through its collaborators is considered the fundamental premise of the ecosystems (Adner 2017; Jacobides, Cennamo, and Gawer 2018). The existence of such friction to change and doubtfulness about whether to invest in an identified opportunity exemplifies how the firms may find it difficult to motivate their participation in a certain ecosystem using typical cost-benefit estimations (Hakanen 2021). Moreover, the more complex the activities to be mapped, the more challenging it becomes to make concrete calculations of the likely outcome and their business rationale (Lorenzo Massa, Viscusi, and Tucci 2018).

Practical example: Using biocoke from plastic waste in steel production

Overcoming the identified challenges may require considerable changes to the way the problems are investigated. One opportunity to conduct such reconsideration is to extend the scope of the analysis, taking in a broader set of possibilities as a part of the envisaged solution. Such thinking might be necessary in situations where all apparent solutions seem impossible or unattractive to carry forward. To demonstrate this idea, we will provide an illustrating example of finding a business model that could boost circularity by restructuring activities among multiple industries. This example will address the concept of “biocoke.”

Biocoke could be utilized to reduce the need for fossil-based raw materials for steel production and, hence, lessen the environmental issues in the steel production (Mousa and Ahmed 2022). The possibility for the reduction of CO_2 emissions in steel industry processes is based on utilizing biocoke (a lightweight black residue consisting of carbon and ashes that can be made from biomass through pyrolysis) to reduce the need for “traditional” coke (a critical process element in steel manufacturing, typically made from coal or oil through a pyrolysis process). As its name implies, biocoke is made from (waste) biomass through a pyrolysis process, in a similar fashion that coke is made from coal in a more conventional steel-making process. However, the notable difference is that this process does not essentially add carbon to the atmosphere, as it can directly reduce the need for using fossil-based resources.

Steel manufacturing requires a considerable amount of coke, which is used to reduce iron ore (i.e., remove oxygen from the iron and its typical compounds FeO, Fe_2O_3, and Fe_3O_4). Traditionally, the coke has been produced from fossil-based coal in a pyrolysis process. The amount of coke is substantial – you might need somewhere between three to four tons of coke to produce ten tons of steel. In turn, coke is a notable source of CO_2 emissions in the iron and steel-making processes (Environmental Protection Agency 2016), whereas biocoke could significantly lower these emissions (Ng et al. 2011).

The idea of biocoke has been discussed for some time now (Hanrot et al. 2009; Ng et al. 2011). More recently, some steel manufacturing companies have publicly announced that they will investigate the possibility of biocoke as an alternative to reduce the CO_2 emissions of their processes (e.g., Outokumpu Oyj 2022; Suganuma 2022). In these examples, most often the biocoke is derived from organic waste streams of various origins, such as pulp or paper production. However, the possibility of using plastic waste (in contrast to other organic side streams) as the main ingredient for producing biocoke is far less explored (for notable exceptions, see, e.g.: Devasahayam et al. 2019; Jaimes and Maroufi 2020; Zakaria 2020). The production of biocoke may not seem like an ideal solution for plastics end-of-life, as it would seemingly take the waste away from the recycling stream through a combustion process that incinerates the plastic waste into energy, process gases or oils, and residual waste (including biocoke). However, the proponents of such processes can argue that it should be possible to categorize biocoke production as chemical recycling of plastic waste.

Moreover, if the plastic waste used for producing the biocoke is composed of various biocomposites (plastics made with organic waste streams as fillers), this could have a notable prolonging effect on the “carbon storage” associated with the products.[9] The same biomass could enhance and augment the plastic products first, before serving in biocoke production later. Such production might provide a practically infinite demand for one of the likely end products of bioplastics recycling streams (i.e., the solid, high-carbon fraction that is generated in the recycling process). Its most obvious environmental benefits would derive from the direct reduction of use as the raw material for the coke necessary in steel production but can also initiate a new type of thinking for finding synergies broadly across different industries.

Conclusion

This report summarizes some key observations and insights related to transforming businesses to establish more circular and sustainable practices across the plastics industry. As the examples from the academic literature and our empirical work indicate, achieving such a transformation is likely dependent on the complex restructuring of existing activities involving multiple stakeholders and participants. Many of these participants are profit-seeking firms with their own rationale for the business models they employ. Hence, they can be unlikely and slow to change their operational processes, unless a compelling business case can be drawn. Since a successful transformation of broader industry processes toward more sustainable options is likely to require concurrent changes from multiple participants, the transformation toward more sustainable plastics may feel like a daunting task.

The ultimate sustainability impact of any change hinges on multiple factors and may be evaluated differently by different stakeholders at different times. Moreover, the implementation of large-scale changes often requires successful management among multiple stakeholders across industries. As discussed, biocoke can provide a better option to current practices in a situation, where the plastic waste ends up in landfills or incineration. While it could be possible to convert waste from one industry (plastics) to reduce the need for virgin fossil raw materials in another industry (steel), whether such an arrangement provides overall environmental benefits is dependent on various complicated factors. In addition, implementing such an arrangement requires synchronized efforts (and likely notable adjustments to current operating practices) from multiple different stakeholders to make it worthwhile. Hence, the key question in improving the sustainability of an industry may not be about how to invent new opportunities to enhance current practices, but about how to attract and align multiple stakeholders to adopt and make use of the already identified improvement opportunities.

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[9] Such a claim holds notable assumptions. For instance, in the European Union’s Waste Framework Directive (WFD) fuel and energy production is not considered as recycling. Some exemptions can be made in this policy, for instance, in case that a Life Cycle Assessment (LCA) shows that following typical hierarchical order of actions (prevention–re-use–recycling–recovery–disposal) would not provide the best option regarding overall environmental impact. Hence, the possibility to store carbon and substitute fossil fuels in steel production could be seen as an environmental benefit that would support biocoke production. What remains to be seen is whether the obtained environmental benefits with biocoke production would exceed the ones achievable complete or partial material recycling of the waste in question.

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Appendix 1. List of works providing the basis for the presented observations

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