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Arnold, Mona

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# Ecosystem analysis for the plastic chemical recycling value chain. Value creation in a regional setting

Mona Arnold

VTT Technical Research Centre of Finland ltd, P.O. Box 1000, 02400 VTT, Finland.
E-mail: mona.arnold@vtt.fi

**Abstract:** Recycling is a key way to reduce the environmental impact of plastics waste. For optimal effectiveness, it is important to concomitantly develop both recovery and recycling technologies as well as functioning value chains and ecosystems. Economy of scale is an important factor for impact; actors within the plastics recycling value chain have noted the necessary collaboration between waste collection and recycling systems, and with potential users of the recyclate. While waste collection and processing is typically carried out on a local or regional basis, technological innovations driven by directives and sustainability commitments shift resource circularity systems towards the international arena and drive the formation of partnerships in wider geographical settings. The capacity of a plastics recycling ecosystem to operate agilely in a local setting and efficiently in a global context is vital for its success.

**Keywords:** circular business ecosystem; plastic waste; chemical recycling

## 1 Introduction

Europe produces more than 30 million tonnes of plastic waste annually, and the amount is increasing. Currently, only 30% of collected plastics are recycled (PlasticsEurope 2021). Plastic waste management is a core element of the European circular economy agenda and a global issue of high environmental and economic relevance. The plastics recycling sector is quite dynamic at present, both in regard to technological and business innovations as well as the formation of public-private partnerships in various parts of the world (Arnold 2022).

The European Union (EU) has defined a strategic approach to plastics as part of its transition to circular economy. Among others, the targets for recycling of plastic packaging waste have been set at 50% by 2025 and 55% by 2030. Here, sorting, collecting, and processing of waste are only the first steps for successful recycling. For material to be truly recycled, it needs ultimately become a raw material in a new product. Recent estimations indicate that these targets are challenging for many European countries (e.g., Abnett 2020, Eunomia 2020). In this context, chemical recycling is viewed as a necessary complement to established mechanical recycling practices. Chemical recycling enables recycling of a wider range of waste plastics than traditional, mechanical recycling and produces monomers and chemicals which can be used as

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feedstock in the (petro)chemical industry. It is a still evolving, more complicated process with larger investment needs and energy requirements compared with mechanical processes. Mechanical recycling is an established solution for plastic waste and produces plastics pellets of varying grade, depending on the waste material used.

On several fronts, there are clear signs of increased focus and commitment to overcome challenges to scaling-up the recycling of plastic waste. New directives and regulations together with commitments from multinationals on the increased use of recyclates and sustainable design are supporting this trend. Industry collaboration platforms for collection and recycling, and the identification of potential users of plastic recyclates illustrate the increasing interest in and commitment to scaling up plastic waste recycling (Mapleston 2021). Recycling is a key way to reduce the environmental impact of plastics; however, to achieve optimal impact it is important to develop both recovery and recycling technologies as well as functioning value chains. The concomitant development of effective technologies concomitant with functioning value chains ensures that technology investors and/or recyclate producers have access to raw material (plastic waste) for their processes, and that there are end-users for the recyclate and markets for the recycled materials.

Stricter regulations and ambitious targets for plastic recycling have driven both technology and market development during recent years. It is clear that targets cannot be met using current collection systems and recycling technologies (Abnett 2020), and that both recovery of end of life plastic products and advanced recycling technologies need to be widely adopted. While there is substantial market pull for sustainable products, the availability of sorted waste plastics is limited and applicable technologies for the processing of various polymer combinations are still developing to meet the needs of both the industry and policy makers.

The aspiration for circular plastic involves both private and public sectors and requires the adaptation of new business models and a systemic approach. However, most of the circular economy (CE) business models proposed currently adopt the firm perspective. Integrating CE into businesses requires a systemic view that considers different elements of the system and their interrelations (Evans et al. 2017, Zucchella and Previtali 2018). Circularity - a situation in which economic and social structures are organized such that they maximize the value of material resources and minimize overall resource use and environmental impacts – is inherently systems based. In this case, circularity means multi-actor closed loops for used plastics, rather than existing as a property of an individual actor's product or service/process. As noted by Konietzko et al. (2020), a business model perspective is too narrow to achieve higher levels of circularity. Thus, an ecosystem approach that equally considers the business models of all relevant actors is required to advance beyond the level of individual businesses. An ecosystem approach considers how a multitude of business models may be combined to achieve a collective outcome (Fuller et al. 2019, Konietzko et al. 2020, Tamar et al. 2020).

In general, a single company does not readily possess the resources needed to develop and commercialise a complex value proposition (Talmar et al. 2020). Collaboration and partnership are decisive to build an ecosystem-wide value proposition, which materializes when the individual contributions of different actors are combined (Hannah and Eisenhardt 2017). Collaboration has both benefits and trade-offs. The interdependency of ecosystem relationships confines firms to some extent, e.g., by delaying the launch of new products or services until complementary elements from ecosystem actors become available. Conversely, firms can leverage ecosystem relationships for wider value creation by exploiting the synergies and network effects arising from complementarities across actors (e.g., Dattée et al. 2018).

Herein, the formation of a new ecosystem for increased plastic circularity by regional actors is examined, including an analysis of the elements of the ecosystem and each actor. The objective was to investigate plastics recycling from a system rather than firm perspective and assess how the value proposition of the ecosystem can be achieved with regional partners.

## 2 Methods and framework

Circular economy is a systemic concept requiring high degree of collaboration among actors, involving, among others, whole-systems design, a transformation of production and consumption systems, cascading skills, cross sector collaboration and a shift from supply chains to value networks (Konietzko et al. 2020). A circular value proposition is typically complex and entails sustainability values parallel to financial aspects.

To analyze the potential of a regional ecosystem for plastics circularity, interviews were conducted with fourteen regional stakeholders, of which twelve represented actors in current and prospective value chains. These are companies and public organisations already operating in the plastics recycling value chain, as well as plastics companies and technology providers targeting plastic waste as a new business strategy in the sustainable business environment. The main components of such a circular plastic system are depicted in Figure 1. Key interview questions related to current and future offerings, possible missing parties in the value network, impacts of directives and regulation, and risk factors in the supply chain.

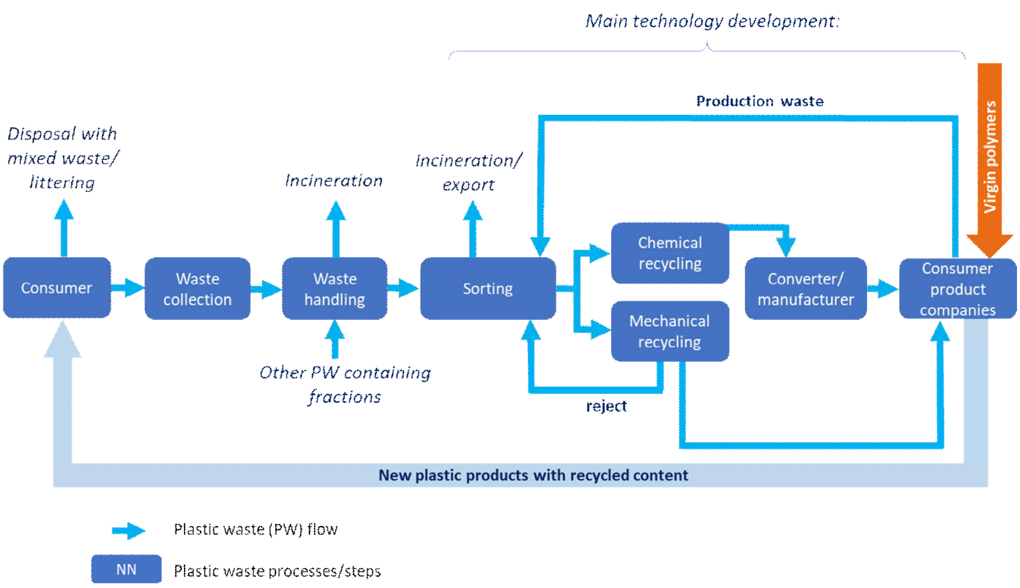


**Figure 1** Plastic waste value chain for optimal circularity.

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To assess each actor's contribution to and dependence on the ecosystem, we applied the Ecosystem Pie Model developed by Talmar et al. (2020) (Figure 2). This structural and visual tool is intended to provide a basis for representing how a real world or prospective ecosystem functions in terms of value creation and capture. Its underlying principle is that the operational logics are dependent both on the properties of individual actors as well as the properties of the ecosystem network (Dattée et al. 2018). For a detailed description see the methodological description in Talmar 2018.

The pie is filled in clockwise following the waste process steps and their corresponding actors. With the mapping analysis we aimed to assess and confirm the contribution of each actor to the common ecosystem value proposition and to identify possible missing actors.

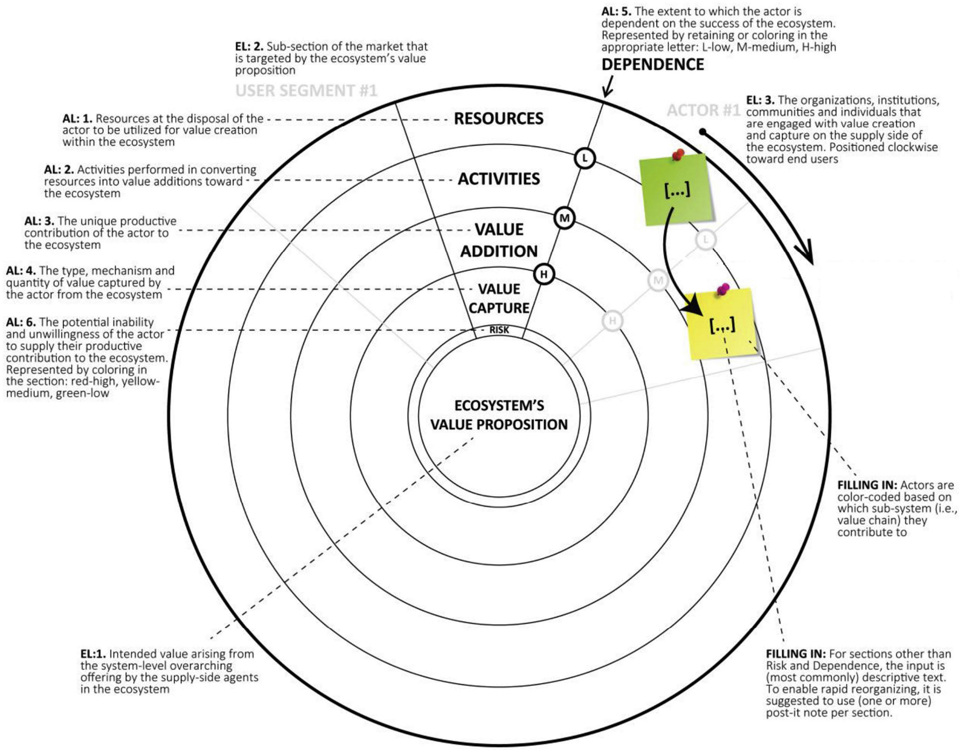


**Figure 2** The Ecosystem pie model. Modified from Talmar et al. (2020).

## 3 Results

Interviewed actors were mapped on the value network (Figure 3). Their role was further analysed using the ecosystem pie model, which was completed based on information from the interviews conducted (Figure 4).

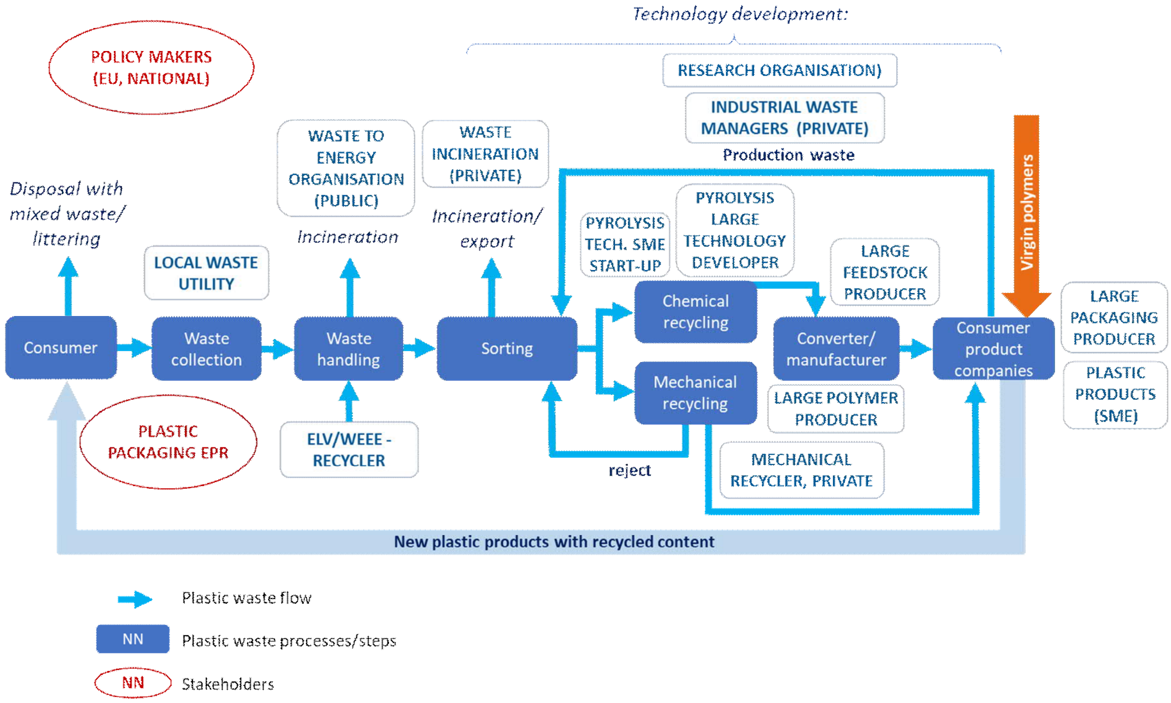


**Figure 3** Plastic waste value chain for optimal circularity. Pyrolysis represents the selected chemical recycling.

Figure 3 illustrates that interviewed actors covered almost every step of the circular process. However, a closer look at the recycling process segment reveals that a missing component in the regional network at present. The operator of a chemical recycling plant was not defined; the new technology solution was represented here by technology providers whose business models do not necessarily include BO (Build-Operate). Without a chemical recycler, the regional input to the feedstock producer remained unsolved.

A chemical recycler is also a necessary partner for the mechanical recycler due to the technological limits of mechanical recycling. In order to produce good quality recyclate, the input (waste) needs to be clean and homogenous, and the remainder is discharged. Thus, mechanical recycling generates a substantial reject stream, which currently goes to incineration and is thus not countable as recycled. It is foreseen that chemical solutions can process at least part of that reject stream, thus strengthening the overall recycling rate and decreasing the gap between Europe's current plastics recycling capacity and its plastics recycling target.

The two interviewed converters (plastic product manufacturer) also indicated the need for a chemical recycler, and for a supply of high quality recyclates, which are currently missing from the supply market. In particular, smaller players have limited access to such non-commodity markets, where supplies are assured through partnerships.

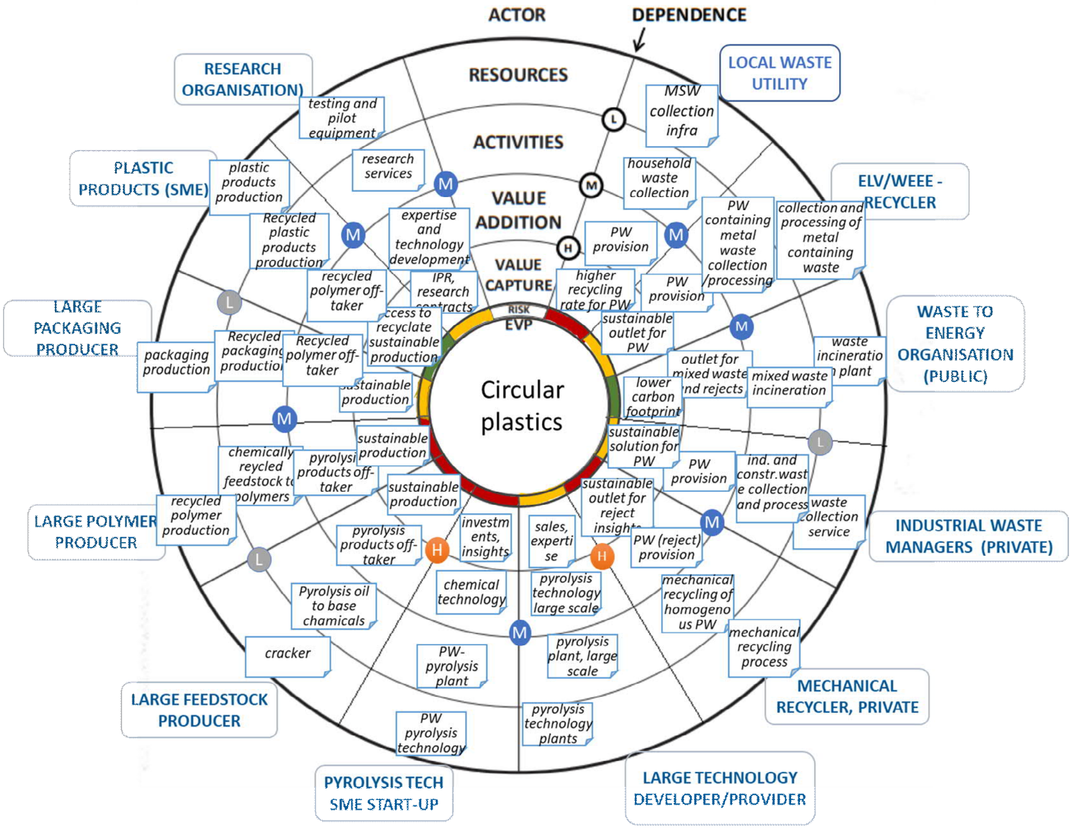


**Figure 4** Plastic waste ecosystem analysis *Note:* PW Plastic Waste; MSW Municipal Solid Waste; ELV End-of-Life Vehicle; WEEE Waste Electrical and Electronic Equipment.

The way in which the performance of a given actor relates to that of the ecosystem represents the *dependence* of that actor on the ecosystem. For some ecosystem actors, accomplishing the Ecosystem Value Proposition (EVP) may be highly significant, while for others contributing to this particular EVP, circular plastic, is just a small share of their overall activities. Based on the interviews conducted and complemented by companies' press releases and newsletters, the dependences were qualitatively evaluated as being low (L), moderate (M) or high (H). In this context, large companies appear less dependent upon the particular ecosystem, as they have a wide network and better access to external and internal research services, and their material suppliers and customers are typically both regional and international. Circular ecosystems are often regional networks (e.g., Orko and Åkerman 2019, Mitra et al. 2019) as they typically imply the transfer of significant (waste) material, product or energy flows between partners and customers, and transport across long distances is usually cost-prohibitive.

Stability and long term relationships were key aspects when building partnerships but at the same time, the rapid pace of technology development at present introduced some challenges with respect to building partnerships with technology providers. Such challenges typically arise in relation to intellectual property or market share. When parallel chemical solutions are emerging, which technology will rise to the top when markets mature?

Plastic waste provision was identified as the *value addition* by four of the twelve interviewed actors, which supports the understanding that a consistent waste flow of sufficient volume is of outmost importance to achieve the EVP and its economic sustainability. The emphasis on plastic waste supply might come as a surprise in today's society where the impact of plastic waste littering is acknowledged as a serious global environmental problem. However, plastic waste is light and voluminous, and local generation is dispersed. Separate collection of plastic waste using long distance transport poses economic and environmental challenges; long-distance transportation of plastic waste would require significant compaction for economic feasibility. Moreover, the plastic waste needs to be separated from other mixed waste either at the source (relying on consumer awareness) or with dedicated post-collection separation equipment, and cleaned before processing. Though the generation of plastic waste is an acknowledged global environmental issue, the availability of relevant volumes of sorted, relatively clean plastic waste is by no means guaranteed (Mapleston 2021). The involvement of plastic waste recovery organisations is crucial for economic stability, to ensure a supply of sufficient quantities of plastic waste.

The sustainability factor and environmental strategies appeared quite effective in the *value capture* analysis. As noted by, e.g., Lepak et al. (2007), actors may capture value from several levels in addition to financial gains. Actors can leverage the ecosystem for reputation or additional resources, such as knowledge. Non-monetary value, such as increased sustainability reputation and knowledge about emerging technologies or trends can be indirectly monetized outside this particular ecosystem, and thus be a strong motivator for actors to contribute to this ecosystem.

The *risk*, here categorised in three levels, represents risk of the actor to achieving and maintaining the EVP (Talmar 2018). Access to sufficient plastic waste volumes has been identified as an important factor. Thus, waste collectors and the partnerships/contracts such parties establish are essential for the value proposition. Again, the unique technological resources provided by the large feedstock producer and the polymer producer are unique, and at the same time, the inclusion of large international industries brings stability and guarantee to maintaining the EVP.

Risks were also discussed with all interviewees from a complementary point of view. Each actor was asked about possible risks in their current value chain. Several interviewees pointed out that supply chains are still evolving in this ecosystem with dynamic technology development. Somewhat surprisingly, the regulatory aspect was not mentioned as a business risk. The actors interviewed expressed confidence in existing regulatory aspects and the further development of appropriate regulatory structures. Commonly, (environmental) directives were perceived as driving the ecosystem businesses, and with respect to plastic recycling targets these directives were viewed as remaining valid in the future and being underpinned by climate mitigation policies. Standardisation and verification schemes for recyclates would, however, clarify the business environment further.

## 4. Discussion and outlook

For systematic analysis of the ecosystem, the ecosystem pie model was perceived as useful. While many analytical tools look at an ecosystem from individual companies' points of view, the advantage of the pie model is that it focusses on the value proposition targeted by the whole ecosystem and analyses the actors strictly as its building blocks. On the other hand, the pie model analyses existing actors and as such, does not readily reveal potential missing parties. The analysis of potentially missing parties is imperative for an evolving network. Herein, we examined potential missing parties from the plastics recycling ecosystem through a traditional value chain and/or material flow visualisation using information from interviewed actors. As pointed out by, e.g., Fuller et al. (2019), although very common today, an ecosystem is not always necessary for businesses, as a company can successfully run its business with only a straight value chain. However, building an ecosystem can be useful in new, less predictable environments where the aim is to disrupt an entire industry, giving one's model greater scale, scope, and influence by partnering with existing players. This description fits well the circular economy models and employment of new technology solutions.

Economy of scale is an important factor for impact and the necessity to partner with waste providers for needed raw material (plastic waste) was noted by all waste processing actors interviewed in the present study. However, regional plastic waste flows are not necessarily consistent and of sufficient volume. Typically, smaller companies were more dependent upon a specific ecosystem whereas large companies have more negotiating power and can source from larger international sources. While waste collection and processing has typically been a local or regional activity, technological innovations driven by directives and sustainability commitments shift such circular systems towards the international arena and the formation of partnerships within wider geographic settings. A geographically wider ecosystem brings logistical uncertainties when it comes to transferring large plastic waste volumes. Regional preprocessing would be a natural addition to a wider ecosystem and e.g. small scale pyrolysis can here be an alternative. The ability of an ecosystem to operate agilely in a local context whilst being globally efficient in its operations is vital for the ecosystem's success.

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