Could pyrolysis be the solution to plastic pollution?

Insights into the barriers and enablers of the technological innovation system surrounding pyrolysis to create food-grade packaging within the European Union.

Vera van Velsen

Student number: 6626092
V.vanvelsen2@students.uu.nl
+31681053497
Supervisor: Gaston Heimriks
Second reader: Dr. X.S. Yap
Unilever contact: Mike Ross
Mike.Ross@unilever.com

Abstract

Plastics have become a relentless boundary-crossing threat to the ecosystem and human health. Without improvements to managing waste beyond what is already in place today, 99 million tons of uncontrolled plastic waste would end up in the environment by 2030. The existing plastic industry is locked into an unsustainable linear production and consumption model; thus, a comprehensive new approach is necessary. The European Union decided to use the concept of a circular economy, whereby plastic waste is recycled into new packaging through a chemical recycling process called pyrolysis. The technology behind pyrolysis is researched and documented, but food-grade recycled polyolefins is a recent development. Creating these food-grade recycled polyolefins requires a new network and system of which the dynamics, interactions, barriers, and enablers are unknown. The technological innovation system, using the system elements and functions provided by Hekkert et al. (2007), was used to get insight into the previously mentioned points.

Using an event analysis and key actor interviews, a cohesive narrative was formed showing the fulfilment of the different system functions and shedding light on the barriers and enablers. Six barriers could hold back the diffusion of pyrolysis within the European Union. 1) Acceptance within the EU waste framework directive by providing study results that show the potential and sustainability of pyrolysis to the European commission and continue with the lobby work already being done. 2) The high resin costs of pyrolysis could be lowered by scaling up or governmental intervention to level the playing field. 3) Difficulties of scaling up an entire pyrolysis system by investing and innovating the entire process. 4) The location of new plants by collaboratively choosing to work on a local or international level. 5) The possible competition between mechanical and chemical recycling by governmental intervention on the prioritisation and waste resources. The last barrier 6) is consumer acceptance of chemical recycled plastic packaging products through an industry standard-setting on the wording to communicate to the public.

So to conclude, the technological innovation system surrounding pyrolysis has grown into a strong network with much legitimacy, but to continue to grow, it needs to overcome the barriers. Nevertheless, this thesis suggests that the enablers are in reach, and the future could be bright.

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1. Introduction

Plastics have become a relentless boundary-crossing threat to the ecosystem and human health (Patrício Silva et al., 2021). Global production of plastic has risen from two million to 380 million metric tons in the last 65 years (Hong & Chen, 2017; Geyer, Jambeck & Law, 2017), half of which was produced from 2000 to 2015 (Jambeck et al., 2015). Plastics' building blocks come from fossil fuel that is finite and non-biodegradable (Geyer, Jambeck & Law, 2017). This non-biodegradability results in an accumulation in landfills or the natural environment (Barnes, Galgani, Thompson & Barlaz, 2009; Patrício Silva et al., 2021). With no improvements to managing waste beyond what is already in place today, about a hundred milion tons of plastic waste would end up in the environment by 2030 (National Geographic, n.d.).

The European Union (EU) created the 'Circular Economic Action Plan' to address this growing problem (European Parliament & ERBACH, 2019). This plan intends to promote sustainable use of resources and has a specified plastic strategy to ensure complete recyclability of all plastic packaging by 2030 (European Parliament & ERBACH, 2019). The ambitious goals outlined in this plan require a change in the plastic packaging's industrial approach. The existing plastic industry is locked into a linear production and consumption model, which has resulted in the current amounts of plastic production and pollution and is therefore not sustainable ("Plastic recycling efforts "stifled" by regulatory and technological "lock-in", 2020). The use of a circular economy (circular handling of material, by closing loops, shows the most potential) requires a comprehensive approach that starts with the existing plastic packaging industry ("The key elements of the circular economy", n.d.). This existing incumbent industry have set their own goals regarding the reuse and recyclability of plastic packaging. One of the more daunting challenges for the packaging industry is re-incorporating recycled plastics, called post-consumer plastics (PCP), back into food-grade packaging, due to intricate and detailed legislation within the EU and the member states themselves to ensure food safety and reliability of consumables ("Rethinking plastic packaging", n.d.; "US and EU Requirements for Recycled Food-Contact Materials", 2013).

To re-incorporate PCP back into food-grade packaging materials, mechanical recycling and chemical recycling offer solutions. However, mechanical recycling is currently seen as a partial solution due to the inability to reuse plastic after the 6^{th} cycle and the non-usability of polyolefins-based PCP, which is the primary plastic type used in food packaging, including polypropylene (PP) and polyethene (PE) (Tullo, 2021). To deal with the polyolefin-based PCP, chemical recycling shows the most potential. Chemical recycling is used as an umbrella term, including multiple technologies like depolymerisation, gasification, and the focus of this thesis, pyrolysis. Pyrolysis has been around for years and has already been used to recycle nylon, but recent developments make it suitable for polyolefins ("Recycling 101: Advanced Recycling - This Is Plastics" 2021). The process of chemical recycling starts with pyrolysis itself. During this process, the plastic waste is heated in the absence of oxygen and transforms the polyolefin materials into pyrol or Naptha oil (Oliveira, 2021; "Recycling 101: Advanced Recycling", n.d.). The produced oil still needs to be purified, thus hydrotreatment is necessary, creating a synthetic crude oil that can be used as a feed stock input for conventional steam cracking (Bezergianni et al., 2017). Creating food-grade packaging from pyrol oil is about 14% less greenhouse gas-intensive than creating it from fossil feedstock, and pyrolysis can therefore be seen as a sustainable innovation (Benavides et al., 2017).

Chemical recycling through pyrolysis has been around for a long time, and the technology itself is well researched and documented. However, the entire process to create food-grade recycled polyolefins is a recent development. For pyrolysis to work, a stable input of PCP is necessary to fuel the process. To achieve this stable input, a circular network needs to be in place, comprising of waste management, recyclers and the petrol-chemical industry, and logistics, creating an embedded system around the technology itself that goes beyond just the actors involved but also includes, e.g., governmental institutions, lobbying groups, and NGO's. Furthermore, to understand the entire system, it is essential to note that the dynamics between the different system actors also influence how pyrolysis develops and diffuses.

This paper aims to conceptualise and empirically describe the current state of development of chemical recycling of polyolefins through pyrolysis to create food-grade packaging within the EU. This will be done using the Technological Innovation System (TIS) approach. This framework is designed to understand and explain innovation processes and determine a technological change within a specific technology field, particularly sustainable innovations (Suurs and Hekkert, 2009; Hekkert et al., 2007). Technological development is not a self-governing process and requires management because technology interacts with the system that it is embedded in. Therefore, is it not enough to exclusively look at the network but to take a broader view and incorporate other parts of the innovation system, to fully understand the dynamics surrounding pyrolysis (Hekkert et al., 2007).

A commonly used method that should give insights into the dynamics and interactions in an innovation system is the use of system elements and functions provided by Hekkert et al. (2007). System elements consist of actors, networks, and institutions used to understand the system's appearance and the seven system functions (e.g. knowledge development) used to analyse the system's performance (Suurs and Hekkert, 2009). It is expected that by mapping the fulfilment of these system elements and functions, a better understanding of the current state of development can be reached, and barriers and enables can be pinpointed (Hekkert et al., 2007).

The following research question will guide this thesis; *What barriers and enablers set the start and define the growth of the technological innovation system surrounding the pyrolysis of polyolefins to create food-grade packaging within the EU?*

This research question will be answered in two parts, starting with research on the fulfilment level of the seven system functions and the accompanying actors, institutions, and networks. First, an event analysis was used to create a starting point, using literature gathered from Lexis Nexis to create a database of events. The events were addressed to the different system functions based on their typology. Secondly, to triangulate the results from the event analysis, expert interviews were held. The interview data was also be used to shed light on the initial push, the barriers actors encounter, and the enablers they perceived answering the research question. All data was supplemented with additional literature related to the results.

In the next section, a theoretical review of the TIS will be provided, followed by the methodology section that describes the practical steps for determining TIS structure and its performance. Next, the results section gives an overview of the findings of the event analysis, expert interviews, and additional literature. This leads to the conclusions where the research questions will be answered, after which implications and limitations are examined in the final discussion section.

2. Theory

This section starts a literature review, which introduces the concept of an innovation system, after which an elaboration on the technological innovation system is given.

The Innovation System approach emerged in the 1980s and is entrenched in evolutionary and industrial economics (Decourt, 2019). The critical observation of the innovation system approach tells us that innovation is both an individual and collective act. It involves the cooperation between multiple actors who are rationality bounded (Decourt, 2019), which means that technology diffusion is not found by investigating individual actor strategies alone. Therefore, it requires a systemic view of the involved actors, networks, and the link with the institutional setting the innovation is embedded in (Decourt, 2019).

The overarching goal of the Innovation System is the generation and diffusion of innovation (Suurs and Hekkert, 2009). Various scopes can be used to reach this goal, for example, national, regional and technical. The Technical Innovation System (TIS) seems to fit best for this research because it focuses on the dynamics of specific technological innovations. Furthermore, the TIS approach can be used to understand and determine technological change, which is especially important for sustainable innovations (Suurs and Hekkert, 2009; Hekkert et al., 2007). Technological change is not an autonomous process, technology interacts with the system that it is embedded in, requiring a broad approach (Hekkert et al., 2007). Furthermore, according to Carlson's and Stankiewicz (as cited in Decourt, 2019), the technological innovation system can be defined as "a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilisation of technology". This broader view incorporates system elements and functions, which will be further explained in the following paragraphs. The use of the TIS function approach, provided by Heckert et al. (2007), makes the comparison between technologies more feasible. It further permits a systematic innovation mapping method, thus increasing the analytical power and delivers a clear set of policy targets and instruments to meet these targets. (Hekkert et al., 2007).

The TIS's technological knowledge crosses national institutional infrastructures, which means that the relevant knowledge base can originate from multiple geographical areas. Still, there are some national boundaries like regulations and subsidies. This means that the TIS is a global system with a substantial regional variation in structure and functioning (Hekkert et al., 2007). This thesis will therefore focus on the European Union.

2.1 Structural elements

The TIS is formed by a set of structural elements comprising of actors, networks and institutions. *Actors* are a combination of individuals and organisations that form the innovation system (Decourt, 2019). It is often referred to as the quadruple helix, which includes actors from academia, governments, the industry, and civil society (Schütz, Heidingsfelder and Schraudner, 2019).

The *network* is used to describe cooperative relationships between the different actors (Hekkert et al., 2007). The network encompasses formal groups like industry associations or certification groups and informal interactions between actors like buyer-seller relations (Decourt, 2019). The goal of networks is to exchange information crucial to create and build legitimacy and support innovation diffusion (Decourt, 2019).

Lastly, *institutions* referred to the rules of the game (Hekkert et al., 2007). There are two types of institutions hard and soft, whereas soft institutions are based on norms & values, shared beliefs and hard institutions revolve around laws, regulations and technical standards (Smink, Hekkert and Negro, 2013).

2.2 System functions

The second part of the TIS incorporates seven system functions that embody types of activities within the TIS that influence the build of the innovation system (Suurs and Hekkert, 2009)

1) Entrepreneurial activities

Many studies see entrepreneurs as an essential part of the innovation system, and it can even be argued that entrepreneurs are vital for a well-functioning innovation system (Hekkert et al., 2007). Entrepreneurs try to exploit new and potential showing knowledge, markets, products, or technologies by creating new business opportunities. Therefore, entrepreneurial activities function as a good indicator of an innovation system's performance. Entrepreneurial activities can come either from new entrants or from the incumbent industry. (Suurs and Hekkert, 2009; Hekkert et al., 2007; Decourt, 2019). According to Heckert et al., this function can be analysed by "mapping the number of new entrants, the number of diversification activities of incumbent actors and the number of experiments with new technology" this can be supplemented by mapping the creation of start-ups and the number of demonstration projects. (Hekkert et al., 2007; Decourt, 2019).

2) *Knowledge development*

Technology research and development (R&D) is essential for innovation as it stimulates the creation of new knowledge, and knowledge can be seen as the most fundamental resource (Suurs and Hekkert, 2009; Decourt, 2019). There are multiple ways to indicate knowledge development, namely, R&D projects and the investment therein, patents, new academic studies and launch or announcement of (lab skill) pilot plants.

3) *Knowledge diffusion through the network*

A network's fundamental function is the diffusion of knowledge, especially in fields where R&D connects with government, competitors, and markets. Therefore, learning by interacting plays a vital role in this function (Nooteboom, 2000). Successful knowledge diffusion requires the creation of locations or structures for actors to meet and knowledge to be exchanged across (Decourt, 2019). This function can be analysed by the number of workshops and conferences within the TIS, network size and intensity (over time), and industry association activities (Hekkert et al., 2007; Decourt, 2019).

4) *Guidance of the search*

The function guidance of the search is all about the process of selection required to aid and advise the search in the development of the innovation (Suurs & Heckert et al.). It requires an interactive knowledge exchange within the innovation system (Hekkert et al., 2007). Activities like performing academic studies, setting expectations, and fostering internal alignment can be used as indicators for this function (Decourt, 2019). An assessment of this function can be made by mapping specific governmental or industry targets regarding one particular technology and the number of academic articles that establish expectations about technological developments. These articles can either be positive or negative regarding the new technology; this can be used to evaluate the state of the debate (Hekkert et al., 2007).

5) *Market formation*

New technologies often have difficulty competing within established markets (Hekkert et al., 2007; Suurs and Hekkert, 2009). Therefore, it is essential to create a protected and safe space for new technologies like niche markets, providing a learning environment where experimentations and innovation can be fostered (Hekkert et al., 2007; Suurs and Hekkert, 2009). This function's analysation method maps niche markets and specific tax regimes for new technologies such as exemptions or mandatory targets (Hekkert et al., 2007; Decourt, 2019).

6) Resources mobilisation

Resources are essential input for the stimulation and creation of new technologies within the innovation system. Resources can be financial capital, material and physical infrastructure and human capital (Suurs and Hekkert, 2009; Decourt, 2019). Activities like lobbying for resources, public funding granting, governmental subsidies or private investment into companies could be a suitable indicator.

7) Creation of legitimacy/counteract resistance to change

New technologies have the potential to be incorporated into the current institutional regime or, in the best situations, overthrow the regime, which is called creative destruction. Therefore, actors with a vested interest will often oppose the new technology (Hekkert et al., 2007). For a TIS to fully develop, actors need to raise a (political) lobby that cancels out the created inertia by the current regime, thereby creating supports and legitimacy for the new technology trajectory (Hekkert et al., 2007; Suurs and Hekkert, 2009). Suitable indicators for this function can be the actions undertaken to raise technical awareness and map the spread and growth of interest groups and their lobby activities (Hekkert et al., 2007; Decourt, 2019).

The seven functions are not separate but interact with each other and are therefore non-linear. The fulfilment of one function is connected to the fulfilment of other functions and the overall performance of the innovation system, this effect can be either positive or negative (Hekkert et al., 2007). The positive interaction between the different functions could be considered a prerequisite for structural change. A constant positive feedback loop can be created, strengthening the seven functions and creating momentum for creative destruction within the current regime (Hekkert et al., 2007).

3. Methodology

This section elaborates on the methodological approach for this research. The first part will validate the methodological approach. After which, data collection through the different search engines and the interview approach will be elaborated on. Concluding with the data analysis through which the research questions are answered.

3.1. Methodological Approach

A prominent TIS analysis method is the event analysis (Suurs & Hekkert, 2009). This method rests on the notion that the different system functions within the TIS can be determined based on a set of activities that lead to each function's performance. All relevant events should be collected and grouped according to the seven system functions to analyse the activities within the innovation system. The variation over time between the number of events within a system function provides information on the development of the TIS on a quantitative level, the surroundings around the event provide qualitative information on the TIS. The event analysis is mainly used to assess the innovation system's transition over a longer period. As events surrounding chemical recycling through pyrolysis of polyolefins to create food-grade packaging only started to take off around the beginning of 2018, a more extended time period is not applicable for this research. Therefore, this thesis used the event analysis method to analyse the innovation system surrounding chemical recycling over the last three and a half years (January 2018 till July 2021), during which the technology started to develop and defuse.

3.2 Data collection

This thesis uses data from three sources, starting with online articles containing events pertinent to pyrolysis's TIS. These online articles were collected through Lexis Nexis with the search criteria; January 2018 until June 2021, chemical recycling (of PP, PE or polyolefins), food-grade recycled packaging, circular polymers, pyrolysis (of polyolefins, PP or PE), pyrol oil or combinations of these words. For the selection of the initial data set, the title and, if provided, a summary was read to make sure the article was related to this research. Once the data set was collected, the articles were fully read, if they did not contain events relating to the TIS of pyrolysis, the articles were removed from the database. The list of all the used articles can be found in appendix A.

Secondly, information on the initial push, barriers, enablers and other relevant information was collected through nineteen key actor interviews. The key actors were selected through convenience and snowball sampling, as Bryman (2016) explained using Unilever connections. A semi-structured interview guide was written based on the partial results derived from the event analysis (the interview guide can be found in appendix C). Semi-structured interview guides have the useful purpose of exploring several concepts in a structured and thorough way and keeping the interview focused on the desired direction (Jamshed, 2014). The semi-structured method uses open-ended questions, in which the interviewer is open to new concepts and theories that may arise from the data, which is seen as an inductive approach. All interviews (except one) were done using online video call service Microsoft teams, the calls lasted between 30 minutes and an hour. All interviewees were asked permission to be recorded (using a voice recorder only) and transcribed. The list of interviews includes employees from recycle and waste management companies (Renewi and Suez), Petro-chemical companies (Dow, Sabic, Borealis), plastic packaging and supporting industries (plastic energy and Jokey), consumer goods companies (Unilever) and others (ISCC, Zero Waste Europe and the municipality of Zuid Holland (see appendix B).

Lastly, to create an as complete as possible overview of the innovation system, additional information like NGO reports, European policy reports. Other data was collected through Google Scholar, Web of Science, and the Google search engine.

3.3 Data analysis

The database set up through Lexis Nexis resulted in an initial amount of 227 articles. Of these 227 articles, 132 were found to contain events applicable to this research. These 132 articles came from newspapers, magazines, press releases, online news (wires), and other sources. Further drilling down showed that nine articles addressed events in 2018, forty-one in 2019, fifty-two in 2020 and twenty-five in 2021.

The actors and institutions related to this TIS were noted, and the network was identified by checking which actors often appear in the same events or who announced a collaboration together, completing the overview of the structural elements. The collected events were connected to their corresponding system functions typology as Suurs and Hekkert (2009) suggested (see the indicators in table 2 for examples). The coding scheme can be found in appendix D. Based on the event database, trend patterns were found by plotting the number of events per year per system function. After that, related events were linked, and interaction patterns were discerned. These steps created a narrative over time that was split up into three periods to create a concise storyline.

Table 1 The seven system functions of the TIS, their descriptions and indicators (Hekkert et al., 2007; Decourt, 2019; Suurs and Hekkert, 2009)

Functions	Description	Indicator
1. Entrepreneurial activities	Entrepreneurial exploitations of new knowledge, markets, products, or networks	New project, entrants, diversification activities and experiments
2. Knowledge development	Knowledge gathering activities	R&D activities, patents, new studies and pilot plants
3. Knowledge diffusion through networks	Diffusion of knowledge	Networks, workshops and conferences
4. Guidance of the search	Process of selection and the setting of expectations	Expectation and standard-setting, academic study outcomes and technological debate
5. Market formation	Establishment of a protected environment or niche	Niche markets and tax regimes
6. Resources mobilisation	The ability of actors to mobilise financial, material and human capital	Lobbying activities, subsidies, private investments and public funding
7. Creation of legitimacy/counteract resistance to change	Development of support for the new regime	Raising of awareness, interest groups and lobbying activities

To triangulate the results from the event analysis, expert interviews were held. Each interview was transcribed and coded using open coding, which is a process of reading through the transcriptions and labelling parts of data, which will be converted into concepts and finally into categories that correspond with one of the seven system functions or other nodes like barriers and enablers (Bryman, 2016). The coding schema can be found in appendix E.

To prevent personal bias during the coding processes, reliability will be assured through the performance of an intercoder reliability check. This was achieved by having two other researchers (both experienced in innovation sciences) study several statements from the interview and the event analysis and checking if they had labelled and connected the statements or event similarly.

4. Setting the stage

This chapter explains the production process of chemical recycling polyolefins to produce food=grade packaging.

As this paper focuses on the European Union, it is essential to understand the severity of plastic pollution with this geography. In 2017 alone, an average European citizen used 173 kilograms of plastic (European Commission, 2020). Furthermore, about 40% of the EU's total plastic demand was explicitly used for packaging, of which most is designed for single-use and are for the more significant part thrown away instead of reused or recycled (Geijer, 2019). There are two ways to tackle this problem from a recycling perspective, mechanical and chemical recycling. To gain an understanding of these recycling technologies, it is essential to understand the system in which they work (see figure 1). The process of plastic packaging production starts on the left side with the steam cracking of naphtha (or renewable feedstock) into smaller unsaturated hydrocarbons building blocks ("Steamcracker", n.d.). These hydrocarbons are transformed into virgin plastic resin (plastic beats or pellets) in the Polymer plant. The resins go into the packaging supplier that coverts the plastic packaging used by the brand owners who use or fill the packaging and sell it to the consumers or industry.

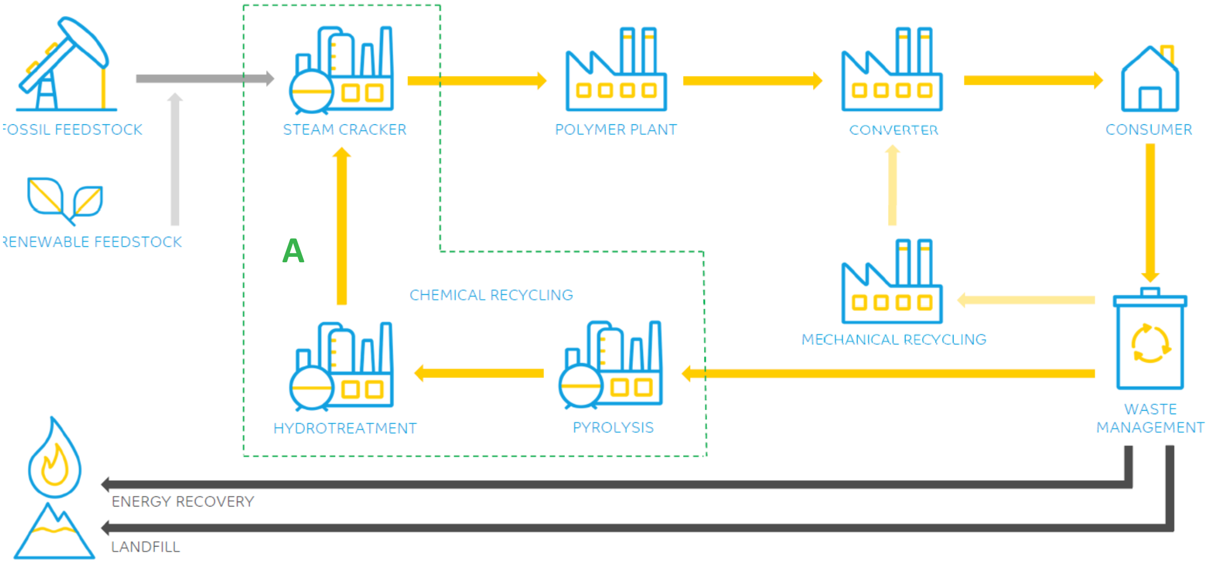

Figure 1 Production cycle of plastic packaging production (de Boer & Sekar, 2021)

The consumer or the industry uses the product and discard the plastic packaging, which ends up in a waste stream. Mixed waste (i.e. black bag waste) is sent directly to landfills or incineration as it is highly contaminated. Where separation systems exist, consumers and industry can and do separate packaging waste into various streams collected by municipal or industrial waste management companies. These companies (some sponsored by the state/regional administration) then send the various waste streams to material recovery facilities (MRF), who then separate the materials further (i.e. plastic, metal, drink cartons, paper and glass) and prepare them for recycling, either within their facilities or to a recycler further in the circular supply chain. There are different mechanical recycling technologies, but they all revolve around separating, washing, and grinding the raw material and finally melting the material and produce new products like park benches and paint buckets. In general, this can only be done six times (depending on the type of plastic waste used) before the plastic has degraded and cannot be used anymore ("Mechanical recycling", n.d.). When it comes to food-grade packaging, mechanical recycling only offers a small solution that requires specifically sorted waste streams and is only viable for PET (plastic bottles). This viability has to do with the strict regulations from the European Food Safety Authority (EFSA) regarding food packaging.

A fraction of waste, primarily polyolefins-based flexible packaging also called hard to recycle plastics, is currently seen as zero value for mechanical recycling and where it is collected, sorted, and processed. Today, it is primarily sent to incineration/energy creation. This is where chemical recycling shows the most potential. Chemical recycling is used as an umbrella term that includes multiple technologies like depolymerisation, gasification, and the focus of this thesis, pyrolysis. The pyrolysis process starts back at the MRF's (waste management in figure 1), who collect the hard to recycle plastic waste and sell it to recycling facilities who perform the first step in the chemical recycling process pyrolysis (see box A in figure 1). During this process, the plastic waste is heated in the absence of oxygen and transforms into pyrol or Naptha oil ("What is Pyrolysis?", 2017).

A fraction of the material that is not polyolefin (i.e. aluminium, PET or other materials) ends up as char. This char and other contaminants are still in the pyrol oil. Therefore, it undergoes a purification step called hydrotreatment. During this process, hydrogen is used to transform unstable alkenes and aromatics into stable paraffin (saturated alkanes) and cycloalkanes that are less reactive ("Hydrotreatment to HVO", n.d.). This step is essential for the steam cracker as any impurity can damage the cracker resulting, i.e., in corrosion. Hence pyrol oil needs to fulfil certain strict specifications for safety precautions and operational excellence. This will be increasingly important when the pyrolysis is scaled up. After the hydrotreatment, the pyrol oil is ready to be fed into the steam cracker together with other feedstocks, and the whole plastic packaging circle can start over again.

5. Results

This chapter combines the results from the event analysis, the interviews, and the literature research. The chapter starts with a narrative explaining the progression over time and closes with discussing the barriers and enablers. The symbols [F1]-[F7] refer to the different system functions discussed in chapter 2.2. References to articles used during the event analysis are referred to as An and can be found in appendix A and references to the interviewees can be found in appendix B.

5.1 The rise of chemical recycling to the public eye

The technology of chemical recycling of plastic waste via pyrolysis has been around for years. So why did it become relevant in recent years? From 2010 onward, movies and more and more documentaries about plastic pollution were shared via TV, streaming services and social media [F7]. Documentaries like Straws, A plastic ocean, The majestic plastic bag etc., put the matter in full public view. This resulted in outspoken social pressure on plastic producing and using companies to take responsibility for their part in the plastic pollution [F7]. In response to this pressure, companies started to create and announce sustainability goals [F7].

> *Interviewee 1: "The polymer manufacturer, the plastic manufacturer, started to feel that the pressure on plastic was going higher and higher, and that they really needed themselves to step up that they cannot just continue to sell plastic and do nothing about it."*

The UK saw the plastic waste problem early on and created the UK Plastics Pact in 2018 ("A Roadmap to 2025: The UK Plastics Pact", 2018). Giving the innovation system a jump start. The UK plastic pact is a world-first initiative, which aims to change the plastic packaging value chain and drastically reduce plastic in the environment [F3]. This included a collaboration between all stakeholders within the plastic packaging value chain and outside the value chain, like NGOs and the government. Over 42 major businesses like Sabic, Marks & Spencer, Unilever and Tesco committed to the pact. Creating shared goals between all actors to reach ambitious targets by 2025 in order to eliminate avoidable plastic waste [F4] [A116]. The UK plastic pact aims to be replicated in other countries to form a powerful global movement as part of the Ellen MacArthur Foundation's New Plastics Economy Initiative ("Plastics and the circular economy", n.d.) [F3, F4 & F7].

The European Union saw the growing social concern and the environmental repercussions the plastic waste pollution could have thus included and adopted a European strategy for plastics in the circular action plan in January 2018 ("Plastics strategy", n.d.) [F3]. By the end of 2018, the European Commission launched the Circular Plastic alliance to reach the targets set in the above-mentioned circular action plan. This Alliance includes industry actors representing the complete supply chains, whom all pledged voluntary actions and commitments to reach the goals of 20 million tons recycled plastic by 2025 ("Pledges", n.d.) [F3 & F4].

The European strategy for plastic together with the UK Plastic Pact, put pressure on the industry to acknowledge the plastic waste problem and incorporate it into its core business. This led to a string of announcements from companies proclaiming new green sustainability goals centred around reuse, reduce, and recycle ("Plastics 2030 – Voluntary Commitment", n.d.) [F7]. However, recycled plastic's goals offered a considerable challenge for food-grade recycled packaging as no viable scaled up solution was available yet. This is where a slight technology push started to happen.

Interviewee 3: "The developed technology to retransform plastic waste, in such a way that oil is created that technology that actually already been developing 10 or 15 years ago, but then the market was not really ready for it. Back than sustainability wasn't a real thing yet. So, actually only yes in the last 2, 3 years that there is now really more of a market pool. But the original push was indeed the conventional technology Push."

Some incumbent petrol-chemical companies like Sabic began to announce that they are working on food-grade recycled plastic and showed the technology of pyrolysis and its possibility to create food-grade packaging on fairs and exhibitions [F1, F2 & F3]. The showcasing of pyrolysis as the sole option to create food-grade packaging and the public announcement surrounding that created a technology push. The importance of the push of pyrolysis is that, as mentioned in chapter 4, its output, pyrol oil, can be fed into existing steam crackers. Therefore, the current petrol-chemical infrastructure and existing regime (the locus of established practices and associated rules) do not have to change (Geels, 2014). This can be seen as a protection mechanism for the incumbents to keep their practices and returns.

Next to incumbents, some start-ups work on chemical recycling technologies [A39, A68]. Although the event analysis did not show a lot of start-up entrepreneurial activities, the interviewees mentioned that a lot is going on behind the scenes.

Interviewee 3: "There are going to be different generations of the technology, it will continuously evolve. We did take the first steps, generation one, with our current partner Plastics Energy. But there are a lot of companies worldwide that are looking at alternative technologies. And it may well be that technologies are coming up that are not only more cost efficient but can also be scaled more easily. On a global scale there are over 100 relatively small companies working in this space."

Entrepreneurial activities done by start-ups, small and medium-sized enterprises (SME) are more prone to develop key technologies like the next generation of pyrolysis. One of the problems start-ups and SMEs face is the high entre and scale-up costs. Therefore, strategic partnerships with an incumbent player who provides the necessary resources (money, technology, knowledge, expertise) are common. A worthwhile mention would be Plastic Energy, a former start-up, and Sabic, petrol-chemical incumbent, who together announced the build of a plant in the Netherlands. This strategic partnership was the first to actively and publicly support pyrolysis [F2]. If a strategic partnership does not offer the best option, incumbents can also buy new technologies or start-ups and incorporate them into their own company to secure ownership.

To summarise, the growing social pressure made the existing industry and the UK government aware of the plastic pollution problem [F7]. This resulted in the creation of the UK plastic pact and, following that, the EU plastic strategy and other initiatives, creating a fair amount of legitimacy for the plastic waste problem and the possibility pyrolysis offers for recycled food-grade packaging [F3, F4 & F7]. The targets and pacts made also established the initial industry network, creating a place for cooperation and knowledge diffusion [F3]. Furthermore, 2018 also signalled a start of entrepreneurial activities from a few incumbents who showcased the potential of pyrolysis using start-up technologies [F1].

5.2 The acceleration

Already at the start of 2019, an acceleration in the field of chemical recycling can be seen. On the 4th of March, the EU adopted an extensive report on the application of the circular action plan (European Parliament & ERBACH, 2019) [F3, F4 & F7]. The report showed that strong momentum is present within the plastics value chains favouring the use of recycled plastics ("European strategy for plastics - voluntary pledges", 2019).

Actors within the innovation system started to acknowledge that they cannot tackle the plastic recycling and waste problem on their own and started taking collective action by joining coalitions and starting (strategic) partnerships [F3]. For example, brand owners who made public commitments to their consumers announced partnerships with recyclers, and actors in the petrol-chemical industry started cooperating with brand owners, MRFs and recyclers [F3]. This created the start of a network which is visualised in figure 2.

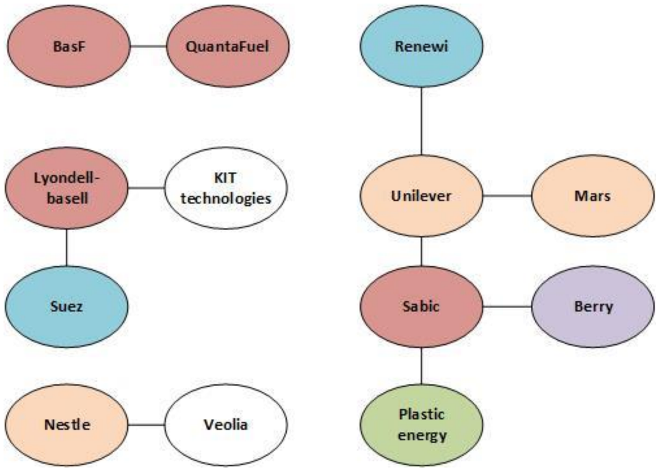

Figure 2 Network visualisation including actor names
Red = petrol-chemical industry, Blue = MRFs, Orange = brand owners, Purple = plastic and supporting industries, White = other

Next to industry partnerships, coalitions started to pop up in 2019. For example, the Alliance to End Plastic Waste (AEPW) is the first-ever international coalition between all actors in the plastic packaging industry (including chemical and plastics manufacturers, converters, consumer goods companies, retailers, and waste management companies) ("Committed to Act with a Clear Vision", n.d.; A36) [F3, F4]. The Alliance is dedicated to partnering with the finance community, government, and NGOs to find the best market-based solutions to end plastic waste in the environment. Interestingly enough, a couple of the founding members are large petrol-chemical companies like LyondellBasell and Dow with money and power to create change or speculatively try and retain the current regime, which is in the best interest of the petrol-chemical industry [A109; A80]. The AEPW pledges to invest 1.5 billion dollars over the next five years to reach its goal of no plastic waste in the environment, including specific investments in chemical recycling and pyrolysis [F6].

Next to the AEWP, more and more consortia started up [F3]. These consortiums offer a place where actors in the industry can join forces and search for a solution to reach the goals they have committed to [F3].

Interviewee 19: "There are two types of consortia, there's a consortium, which is about building technology, and building demonstrator plants. The second one is then the consortium that helped to, you know, build consensus amongst industry and NGOs."

One of these consortia worth mentioning is Citeo in France, which provides advice and solutions to their members to help them meet their end-of-life packaging materials responsibilities (Hornan, 2019). As part of Citeo's call to promote eco-design, recycling and recovery projects, companies like Total, Nestle and Mars joined forces to develop an innovative industrial chemical recycling industry in France (Hornan, 2019, A34) [F3]. The consortium of global players from across the plastic packaging value chain will examine the technical and economic feasibility of including chemical recycling of complex plastics to create food-grade packaging [F4].

The year 2019 also signalled a start to showcase commercial trails with recycled food-grade packaging through pyrolysis [F5]. Products launched by Sabic and Unilever like the Magnums tub and Knorr's bouillon buckets were well received. As well as BASF and Mondi's cooperation who launched food-grade pouches. As a result of the successful product launches, pilot plants were being scaled up to ramp up production for the following year [F5]. As well as new announcements of investments in pyrolysis and the purification process, most of which come from the petrol-chemical industry and waste management companies [f6].

A closer look at Knorrs Bouillon buckets reveals an interesting case in which Unilever joined Fieldlab (a regional network, working on international issues) organised by the government of South Holland to research and explore options for collection and recycling of plastic waste ("Kick-off Event Fieldlab Circulaire Plastic Verpakkingen Provincie Zuid-Holland", 2019). This Fieldlab served as a place for actors to connect [F3]. It resulted in a collaboration between Unilever and Renewi (waste management service) to create a separate collection stream of PMD (collection PMD: Plastics, Metal and Drink Cartons) that could fuel pyrolysis and create circular packaging [Interviewee 16] (Unilever, 2020). Through lobby work by Renewi, the Dutch government decided to subsidise the creation of this new PMD collection program from industrial sources like professional kitchens [F5 & F6]. However, collection is only a part of the circular network. Through discussions, interest alignment and collaboration, other actors were gathered, like material recycling facilities (e.g. EING in Germany) to sort, clean and bail the various materials in the PMD waste stream and pyrolysis companies like Plastic Energy (in Spain) [Interviewee 16] (Unilever, 2020). Thus, through the Knorr buckets, a world-first complete and operational circular polymer network was created, showing that the incumbent industry can change and work together to reach the goals set by the EU and the different coalitions [F7].

An essential part with regards to recycling is transparency within the industry and to the public [F7]. Therefore, the International Sustainability and Carbon Certification (ISCC) started to investigate how to certify chemically recycled plastic. ISCC is a global independent multi-stakeholder organisation that creates a sustainability certification system. Certifying a technology requires transparency, and the produced pyrol oil goes into the same steam cracker that also uses fossil-fuelled naphtha feedstock. Therefore, a transparent system needs to be in place. For traceability and reliability, it is vital to trace the pyrol oil as best as possible throughout the entire process, starting at the MRFs and ending at the converter. As pyrolysis requires different chemical processes, it is not easy to track plastic waste. This is thus done through the principle of mass balance. Mass balance is an acknowledged chain of custody system specifically used in complex value chains like Fairtrade chocolate or cotton (Ellen Macarthur Foundation & BASF, n.d.) [F4]. However, the mass balance approach also comes with its challenges, especially when communicating to the industry, the public, and regulators.

Interviewee 19: "We (ISCC) also tried to explain to regulators, because at this point in time, to be honest, I think there's still a big gap, and lack of understanding with regulators on what chemical recycling actually means and what the mass balance approach means and why it is required to really scale up."

To summarise, the EU's circular action plan showed strong momentum in the plastic value chain and more (strategic) partnerships, consortia and coalitions were created [F3]. Resulting in a more robust industry network that was able to start mobilising (financial) resources and showcasing the first ISCC certified market-ready recycled packaging [F5, F6 & F7].

5.3 A industry front started to appear

The year 2020 signalled a real start to the innovation system. At the beginning of this year, more companies announced partnerships, and the network surrounding pyrolysis was growing fast [f3]. Figure 3 shows the network of actors in 2020 (black lines) and 2021 (orange lines). When compared to 2019, significant growth can be seen, as well as a clear focus of the petrol-chemical industry to initiate partnerships with mostly recyclers. Partnerships formed in earlier years published their first results, like the Magnum tubs initially introduced in Spain, Belgium and the Netherland. Due to its good results, it will be rolled out across Europe [A82; A83] [F5]. Furthermore, companies like Neste and Paccor both announced the production of new chemically recycled plastic resins that is food grade and certified [f4]. In addition, companies like Chevron Philips BASF and Nextloopp announced publicly to put chemical recycled materials on the market within the next five years. Additionally, companies were still signing up for the plastic pact, the plastic Alliance AEWP and other public-facing initiatives, strengthening the existing industry front [F3 & F7].

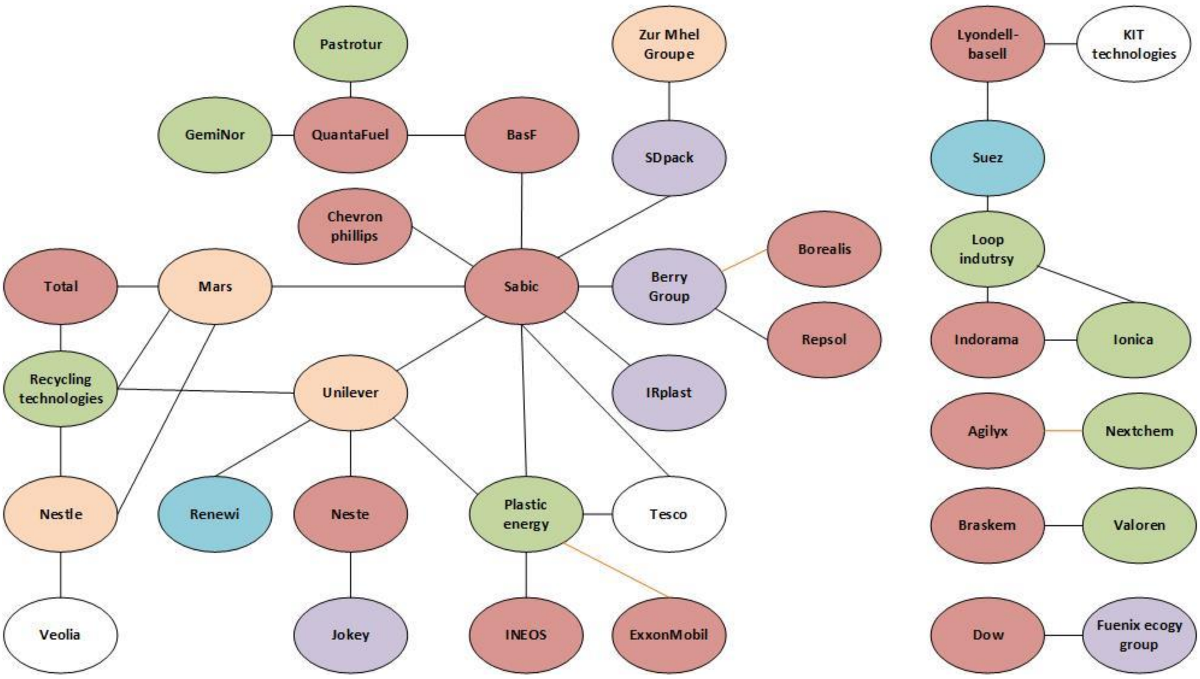

Figure 3 Network visualisation including actor names
Red = petrol-chemical industry, Blue = MRFs, Orange = brand owners, Purple = plastic and supporting industries, White = other

Another part of the extension of the pyrolysis network is the introduction of circular trials [F1 & F3 & F5]. Unfortunately, the Knorr bucket circle mentioned before got rolled out just as Covid-19 hit, resulting in low media and public attention. Luckily later in 2020, an event in the UK where a large supermarket chain (Tesco) asked consumers to return their cheese packaging to chemically recycle it into new cheese packaging got a lot more public attention [F7]. This trial went so well that more plastic was returned than expected, and Tesco is considering expanding this system to more stores [F1 & F3 & F5] [A55]. This business to consumer trial shows the willingness of the public to participate in a circular economy and brings the possibilities that pyrolysis offers to the public eye [F7].

The growing network, trials and product launches mentioned above showed a maturing of the industry, which is an essential step. It helped explain and show to the public and NGOs the progression and sustainable possibilities pyrolysis has to offer [F7]. This is especially important as the media perception on pyrolysis still stated;

Article 55: Many players do not expect industrial scale food-grade recycled polyolefins (R-PO) to be available until chemical recycling reaches maturity.

This maturity requires the economic feasibility of pyrolysis, which is hypothesised to take 5 to 10 years [F5]. Nevertheless, the industry sees the future brighter and more announcements of plants and investment flood the web [F6]. The pyrolysis process used to be a niche, but since 2021 the technology has matured, and more and more pyrolysis plants are being built [F6]. Furthermore, the industry sees itself as the centre of transition and tries to educate the public and the NGOs through fairs, seminars, webcasts, webinars, and workshops to show that pyrolysis offers a sustainable future and that the current industry can change [F3] [A11].

5.4 Opposing voices, barriers, and enablers

As mentioned before, public awareness of plastic waste and its pollution has grown over the last decade. This opened up a door for NGOs to recognise the problem and begin challenging the industry to change. These opposing voices questioned chemical recycling and pyrolysis on sustainability and other topics. This created two opposing sides, with most NGOs focussing on stopping the industry from using and producing plastic. This non-plastic world would be an NGO view of the ideal. However, some NGOs did see the necessity for plastic and recycling technologies and tried to work with the industry and governments to create a sustainable plastic future [F4]. NGOs like Zero Waste Europe, Greenpeace, Gaia, Environmental Action Germany, and Chemtrust are worthwhile to mention and began to be actively involved with the industry, joining different consortiums, pacts, and coalitions to voice the opposing side.

"While new types of plastics reprocessing systems are being discussed, chemical recycling processes are complicated, expensive and have not been proven at commercial scale to cost-effectively reprocess diverse post-consumer plastic waste and produce a resin that can be manufactured into another product. Furthermore, significant concerns persist about the energy and fresh water requirements and environmental impacts of chemical recycling systems." (Greenpeace, 2020)

When the NGOs started questioning the effectiveness of pyrolysis, specifically on energy intensity, pollution, and environmental damage, the industry network started to counteract the claims made by the NGOs. The industry provided pyrolysis supporting reports, including life cycle analysis (LCA) that measures the environmental impact of a product or technology ("Life Cycle Assessment - Complete Beginner's Guide", n.d.). The LCAs compared pyrolysis with the same products made from fossil feedstock or against landfilling, incineration or other packaging materials like aluminium and glass, concluding that pyrolysis is more sustainable (de Boer & Sekar, 2021).

Next to the LCAs, the industry also tried to educate the public and the NGOs on the European version of pyrolysis, as most critiques were based on the American pyrolysis processes. These American processes are more focused on plastic to fuel and using older, less sustainable technologies.

Article 51: Supporters also accuse NGOs of focusing too heavily on US-models for chemical recycling and argue that although yields are currently low and economics unfavourable this is largely due to the current stage of the process's life cycle.

This focus on plastic to fuel led to an important decision around the acceptance of pyrolysis in the European waste framework directive. NGOs argued that pyrolysis should not be considered recycling, it is not plastic to plastic in a direct way as mechanical recycling is. Therefore, it should be considered as recovery instead of recycling.

This controversy fuels the main barrier pyrolysis faces “will pyrolysis be a part of the EU's waste framework directive?”. EU approval is essential as the different member states look at the EU for a leading opinion in this area, especially when it comes to recycled material targets [F4 & F7]. The EU stated that it is looking into the different chemical recycling technologies, including pyrolysis but is still waiting on multiple reports and LCAs from different actors to substantiate their choice. What is interesting to mention is that during the interview with Zero Waste Europe, one of the points made was that the (petrol-chemical) industry seems to have convinced independent reputable research organisations by lobbying that pyrolysis should be part of the recycling future [F6].

Interviewee 11: “We (Zero Waste Europe) see a lot of reports coming out and claiming, you know, actually also from a lot of very influenced the research institutes such claiming that in the future you will need to have chemical recycling so.
There are a lot of claims and I think it's mainly quite surprising actually that the chemical companies have actually even convinced some of these very reputed research organizations. Sometimes in a in a very wild.”

These research organisations are part of the advisory board to the European Commission on this topic, and the lobbying work by the incumbents could be seen as an enabler that opens the door for pyrolysis and the future it holds in the recycling industry [F7].

One of the first-mentioned barriers during the interviews was costs. Compared to the virgin material, the high cost of chemical recycled polyolefin resins has to do with the enormous investments necessary to build the (pilot) plants. In addition, due to the small scale and minimum viable resin on the market, the prices are very high compared to virgin resin.

Interviewee 3: “So here we are talking about mega investments, so that means that in the first years there are significant premiums attached to that.”

The opinions on how the cost could be lowered differ throughout the network. The petrol-chemical industry says that the costs will decrease when the production ramps up, initiating economies of scale. Contrary to that, other actors see the need for governmental intervention. Governmental intervention could come in different ways. For example, the EU Council approved a new plastic tax, in which member states have to pay €0,80 per kilogram of non-recycled plastic waste their country produces ("A new European plastic tax?", n.d.). Even though this tax was introduced at the start of 2021, just one of the interviewees knew about it. The reason is that the repercussions that come with this tax have not yet trickled down to the plastic industry players and are still solely paid for by the government.

Interviewee 9: "So if the financial model of chemical recycling isn't right, it won't get off the ground. And why is the financial model not feasible? Because the Virgin price is way too low. What is not integrated in the Virgin price? That is environmental pollution. And the moment you start taking that into account, you get a level playing field."

A classic way of governmental intervention is subsidising, which is done mainly by national governments, especially when it comes to chemical recycling as it requires vast investments [F6]. The UK plays an exemplary role in this as they are contributing 25% towards a pyrolysis plant build in Scotland. However, other subsidising schemes are not yet rolled out due to the indecisiveness of the EU commission surrounding the inclusion of chemical recycling and pyrolysis in the waste framework directive, returning to the previously mentioned barrier.

Chemical recycling was set into the market as the solution for hard to recycle plastic polyolefin waste. However, after the first trials started, it looked like pyrolysis required additional process steps (sorting and cleaning) to reach optimal and safe production requirements. This raises a barrier as feedstock for mechanical and chemical recycling could be very similar. Following the EU's waste framework directive, as it is, mechanical recycling should be chosen first. As mechanical recycling is more sustainable, and less energy-intensive compared to chemical recycling. However, chemical recycling offers the only solution for creating food-grade recycled polyolefin packaging, creating a considerable challenge for the EU and other legislators [F7]. In an ideal world, both technologies should complement each other instead of competing. Following that logic, the next barrier is obtaining enough plastic waste for both mechanical and chemical recycling. This requires the MRFs to investigate and invest in upgraded sorting systems and the municipalities or national governments to look into better collection systems (e.g. PMD collection as mentioned before) [F2]. Suppose there is not enough waste in a country to facilitate both mechanical and chemical recycling. Then, the national government or even the EU have to decide which technology to supply first or how to acquire more waste. The industry already saw these feedstock barriers, and by the middle of 2021, different enabling initiatives were developed. Some petrol-chemical companies bought recyclers or MRFs, others invested in new waste management systems, and some started explicit partnerships with MRFs [F6].

Interviewee 19: "The truth is even if the scale ramps up dramatically overnight, the quality of the oil, it still needs a further refinement step. And that in itself needs infrastructure and needs development, which also is another important factor."

"So, it's not just about the technology providers themselves, it's about, you know, infrastructure being developed to upscale the oil in order to feed into conventional crackers. And that's where a lot of the focus is, and these things aren't cheap, you know, you're talking and upscaling plans, you know, hundreds of millions of euros."

The barriers with scaling up are not yet complete without mentioning the purification step. Furthermore, hydrotreatment can only be done, with the current technology, in smaller quantities. Meaning that the current infrastructure is not ready yet and thus requires investment and research and development as an enabler for the entire system to be scaled up [F2 & F6].

Another essential factor in the future of pyrolysis is where to locate the different newly built industrial plants? MRFs tend to be local and small, but pyrolysis plants and steam crackers tend to be spread across Europe. Meaning that one must transport plastic waste or pyrol oil, both coming with risk and considerations. Resulting in an essential consideration for the current industry actors regarding future plant builds [F5].

Lastly, another barrier is consumer acceptance of pyrolysis. Starting with ‘chemo phobia’, the term the petrol-chemical industry has given to consumers who are afraid of anything with the word chemical in it [F7].

Interviewee 9: “The thing that is going on at the moment is what we call ‘chemo phobia’. Consumers are scared that chemicals are added to things from food production to medicines. Therefore, a strong resistance to the word chemical is gradually beginning to arise in society.”

The industry has decided to rename chemical recycling to remove this barrier, and words like ‘advanced recycling’, ‘dense recycling’ and ‘infinity recycling’ are introduced. However, adding these words could also confuse the consumers as it is unclear what they actually mean. The same can be said about the use of claims on consumer packaging. Different claims are used over the industry, i.e., ‘made with chemical recycled plastic’, ‘Made with 100% Certified Circular Polymer’, ‘made by Advanced Recycling’ or 'Infinitely Recyclable’. An enabler to overcome this confusion would be to make industry-wide agreements on the terminology that will be used [F7].

During 2020 and the first half of 2021, the network grew even more prominent as more companies started to work together and join consortia and plastic pacts, resulting in more market-ready products and the start of circular trails [F3, F5]. The growing opposing voices created different debates around pyrolysis and resulted in more studies on the technology's sustainability and the industry's transparentness [F4 & F7]. These years also show a growth in resource mobilisation as additional private investments were announced, and subsidies slowly started to appear [F6].

6. Conclusion

The following research question guided this thesis.

What barriers and enablers set the start and define the growth of the technological innovation system surrounding the pyrolysis of polyolefins to create food-grade packaging within the EU?

This thesis followed an abductive approach using an event analysis based on the TIS as a starting point to answer the research question. First, events were extracted from 132 articles and connected to the system elements (actors, institutions and network) and the different system functions. Then, the results were put through a trend and interaction analysis and were triangulated using 19 expert interviews distributed over different industry actors.

The research question was answered in two parts, starting with the fulfilment of the seven system functions provided Hekkert et al. (2007). Function 1 entrepreneurial activities and function two knowledge development are fulfilled mainly by the incumbents that started new projects, pilot plants and product trials. The necessary financial requirements of pyrolysis made it a hard to enter field for start-ups and SMEs. Thus, their activities primarily focussed on the next generation or other possible technologies to solve the current plastic pollution problem.

The founded initiatives and the EU's Circular Action Plan created a start to the industry network, generating a place for function three knowledge diffusion through alliances, (strategic) partnerships, consortia, and coalitions. Function 3 created a solid industry network capable of countering opposing voices that became stronger and stronger over time. This industry network has enormous lobby capacity and was able to sway (as opposing voices would call it) research organisations and legislators in favour of pyrolysis and started to set industry standards improving function four guidance of the search. From 2019 onwards, more and more companies started function six research mobilisations, announced private investments in pyrolysis and adjoining industries. These investments came from incumbents involved in entrepreneurial activities that were scaled up the following years, creating a (niche) market and establishing function five market formation. The existing incumbent plastic industry felt the social pressure and publicly announced goals to minimise their part in the pollution problem. Opening up the door for pyrolysis and a technology push from the petrol-chemical industry. All these events together created a fair amount of legitimacy to the plastic waste problem and, by doing so pushing function seven creation of legitimacy and counteracting resistance to change. So, to summarise, all system functions are fulfilled in one way or another, but F3 knowledge diffusion through networks, F4 guidance of the search and F7 creation of legitimacy pushed this innovation system the furthest.

Continuing with the core of this research, the innovation system surrounding pyrolysis faces different barriers that could become problematic during its future growth. The fulfilment of the seven system functions gave only a slight glance of the barriers and did not address possible enablers, but the interviews gave more insight into this. First and foremost is the incorporation of pyrolysis in the European waste framework directive and the approval of EFSA on the use of chemical recycled material and mass balance for food-grade packaging. This barrier needs to be addressed by the European Commission for pyrolysis to flourish and grow. Secondly, the high production costs of chemical recycled plastics. As virgin plastic resin is cheap and the investments necessary for pyrolysis are high, a discrepancy in the economic feasibility appears. The opinions about enablers for this barrier differ but can be combined into a cohesive approach. By scaling up the existing plants and lowering production costs, the resin price should decrease, initiating economies of scale. Nevertheless, if the price of virgin plastic resin remains lower than recycled resin, governmental interaction to level the playing field is necessary. The scale-up of pyrolysis, which is the third barrier, is complicated due to the number of process steps involved, but the collection and sorting systems and the hydrotreatment require the most research and development and thus investments. The fourth barrier, plant location, is up to the actors, who have to decide between a local, national, or international approach, requiring different logistics. The fifth barrier is the possible competition with other plastic recycling technologies, in particular mechanical recycling. Governmental intervention on technology prioritisation or input allocation is essential for this barrier. Lastly, the sixth barrier is consumer acceptance. The enabler for this barrier is split into two parts: being open and transparent to the consumer as an industry and setting industry standards regarding used phrases. Both can be forced if the government or the EU mandates the use of certification.

So, to conclude, the technological innovation system surrounding pyrolysis has grown into a strong network with much legitimacy, but to continue to grow, it needs to overcome the barriers. This thesis suggests that the enablers are in reach, and the future could be bright.

7. Discussion & Limitations

This chapter discusses the theoretical implications of this thesis as well as the limitations of this research and fields of future research.

This thesis researched pyrolysis conceptually and empirically as an emerging sustainable technology. It also mapped the fulfilment of the system elements and functions to understand the current development state better. By doing so, barriers and enables were pinpointed. Using the TIS framework, a general idea of important events surrounding pyrolysis was found, and a cohesive narrative was produced. This narrative included the reason behind the initial push of pyrolysis and showed the barriers that affect pyrolysis's growth and possible enablers. Due to the novelty of pyrolysis as a technology to create food-grade plastic packaging, this thesis confined itself to a three and a half year time period and was thus only able to create a 'base line' narrative that gives slightly limited insight into a growing innovation system. In a few years' time, pyrolysis could be more developed; thus future research could be necessary (more on that later).

The core focus of this research was to reveal the barriers and possible enablers thus, policy and managerial implications can be derived. Starting with policy implications, the first and main barrier is the incorporation and approval of pyrolysis by the European Commission, the EFSA and national governments. This approval should be done through careful consideration, as this thesis suggested that one of the reasons for the push of pyrolysis could come from the incumbent industry that wants to protect the current regime with all (financial) advantages that this regime offers the industry. Furthermore, as mentioned in the barriers, a governmental intervention will be necessary to prioritise recycling technologies. This choice should again be made by carefully considering the strengths and weaknesses of the different technologies and the needed infrastructure and optional subsidising. As for managerial implications, there are two sides to consider. Existing actors in the network surrounding pyrolysis have to keep lobbying and promoting pyrolysis's possibilities and advantages the industry thinks it offers. Actors outside the network who want to become part of it have to (re)consider if chemical recycling is the best way to go and if it helps them reach their set goals

This research, although using a well-established theoretical and methodological framework, has its limitations. Starting with the methodological limitations, the event analysis data was retrieved from news articles that do not always provide a balanced view of reality. News outlets should bring interesting news and, thus portray extraordinary situations rather than general practices. Therefore, expert interviews were performed to triangulate the outcome of the event analysis and shed light on general practices. Although different industry actors were interviewed, it could not be managed to interview legislators of a national government or European Commission. Their impact on the TIS was triangulated using the other experts' knowledge and literature on legislative choices.

furthermore, as this thesis focuses explicitly on pyrolysis, it cannot be generalised to other plastic recycling technologies. The same goes for the geographical boundaries, as this research focuses on the European Union, other countries or continents may have different innovation systems around pyrolysis. Therefore, other researchers should critically assess if findings are transferable to different contexts.

The theoretical TIS framework itself has limitations as well. The Technological innovation system focuses on one particular technology that could become inconvenient when applied to technologies that function in a more extensive, more complex system. This could result in a loss of sight of the system the technology is embedded in. This thesis struggled with that particular problem as well, as the sole focus on pyrolysis excluded other technologies that influenced the TIS.

Furthermore, the TIS approach focuses on radical innovations that overthrow the incumbent regime, but it often doesn't come this far. This thesis is no exception, as this research pointed out that pyrolysis could be seen as a way to keep 'the old' incumbent infrastructure and regime alive and thereby not to evoke radical change. One might see parallels here with the hydrogen-based transition that incumbent oil and gas industries would like to push to be able to reuse the majority of existing infrastructure and profit model.

These limitations open up future research possibilities. For example, future research could investigate expanding the innovation system to include more recycling technologies like mechanical recycling. Future research can also focus on the entire system surrounding the recycling of plastic waste and investigate if different technologies influence each other, also including research on legislation, governmental and EU intervention. Furthermore, it is important to note that possible substantial reduction in the convenient use of plastics by industry and consumers or the use of bioplastics could have an impact on the future development of plastic recycling as they will influence both the need for recycled resin and the availability of raw plastic.

So to finally conclude, due to the current plastic pollution problem, recycling has become an essential part of everybody’s everyday life. Creating food-grade recycled plastic asked for a comprehensive new approach that includes chemical recycling through pyrolysis. The technological innovation system surrounding pyrolysis is still in its infancy state. However, it shows much promise if the barriers regarding, e.g., legislation and cost, can be solved by actively participating governments and industry.

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Appendix A list of news articles

nr	Name	Date	Publisher
A1	3-Day Conference_ Plastics Beyond Petroleum - Biomass, GHG, Recycling; Disrupting Petroleum as Feeds	November 01 , 2019	Business Wire
A2	A Plastic Designed to Die	August 07 , 2018	NY Times
A3	Advanced packaging solutions from Sabic	December 05 , 2019	Gulff Industry
A4	Agilyx and Braskem Announce Collaboration to Explore Advanced Recycling Project in North America	December 16 , 2020	Cision
A5	Agreement With Borealis for the Supply of Circular Polyolefins	April 28 , 2021	Market News Publishing
A6	-ALPLA Group - Companies join forces to help tackle plastic waste with BP's enhanced recycling techn	December 20 , 2019	ENP
A7	Amcor Launches First Recyclable Shrink Bag for Meat, Poultry, and Cheese	December 08 , 2020	Product News Network
A8	Analysis on the $240B Plastic Bottles Industry, 2020-2025	January 31 , 2020	PR
A9	BASF invests in Quantafuel to drive chemical recycling	October 07 , 2018	Chemical week
A10	BASF Invests in Quantafuel to Jointly Drive Chemical Recycling of Mixed Plastic Waste	October 09 , 2019	Targeted News Services
A11	BASF SE R&D Webcast_ Circular Economy at BASF - Final	November 11 , 2019	Business Wire
A12	BASF, SABIC and SDPACK use plastic waste for new organic sausage pack	June 18 , 2020	GDP
A13	Batteries, plastics, renewable raw materials_ new ideas for the circular economy	December 11 , 2020	Impact Financial News
A14	Berry Collaborates with SABIC	November 15 , 2019	GDP
A15	Berry Global and Borealis in supply pact for chemically recycled polyolefins	April 28 , 2021	ICIS
A16	Berry Global and Repsol to Boost Sustainable Circular Resins in Packaging	December 05 , 2019	Gulff Industry
A17	-Berry Global Announces Agreement With Borealis for the Supply of Circular Polyolefins	May 05 , 2021	ENP
A18	Berry Global Joins SABIC in the Production and Use of Circular Polymers from Chemical Recycling	November 11 , 2019	Business Wire
A19	Berry Global Updates on Pact with Borealis for the Supply of Circular Polyolefins	May 03 , 2021	Manufacturing Close-up
A20	Biscuits and Chips Wrappers Can be Recycled Soon	December 05 , 2019	Sustainability Next
A21	BP rolls out new plastics recycling effort	December 19 , 2019	News Tex
A22	BP to produce R-MEG and R-PTA from chemically recycled PET	October 24 , 2019	ICIS
A23	BPF and PlasticsEurope Co-host Online Seminar	March 04 , 2021	Impact Financial News
A24	Can we reinvent plastic - cleaner and greener_;Scientists are desperately searching for ways to rein	May 9, 2018	The Evening Standard (London)
A25	CEO of Biofuels Giant Neste Shares Way Forward into Aviation	September 02 , 2019	Energy Intelligence Group
A26	Chemelot als hart van groener Limburg	July 20 , 2020	De Limburger
A27	Chemical Recycling	28. Mai 2021	PROCESS Worldwide
A28	Chemical recycling faces big hurdles;Technology often relies on feedstocks which have been sorted, p	February 07 , 2020	ICIS
A29	Chemical recycling offers major potential for plastic packaging	October 09 , 2019	GDP
A30	Chemically recycled plastic used in Mondelez packaging	June 15 , 2020	Plastic News
A31	Chemisch bedrijf van de baan	April 02 , 2020	Algemeen Dagblad
A32	Chemische recyclingfabriek in Geleen	September 13 , 2018	FD
A33	Circular economy;A beyond-borders initiative	May 20 , 2020	Chemical week

A34	-Citeo, Total, Recycling Technologies, Mars and Nestle Join Forces to Develop Chemical Recycling of	December 11 , 2019	News Wire
A35	Closed-Loop Recycling Recaptures High-Value Food Packaging	August 11 , 2020	GDP
A36	Closing the loop on plastics;Industry steps up investment and innovation to address waste challenge	September 06 , 2019	Chemical week
A37	Closing the Plastics Cycle ___ A Review of Current Best Practice around the Whole Cycle...60 Seconds	May 31 , 2019	European Union News
A38	CMT's RecyclePlast in a Circular Economy Draws Plastics Recyclers, Brand Owners, Tech Providers to M	March 27 , 2019	PR EU
A39	Coca-Cola gooit alles op recyclen	September 12 , 2020	Trouw
A40	Coca-Cola investeert in proeffabriek van CuRe Emmen om plastic te recyclen	July 16 , 2020	Algemeen Dagblad
A41	Consortium formed to develop chemical recycling in France	December 16 , 2019	Chemical week
A42	Consortium to Develop Chemical Recycling in France	December 11 , 2019	Waste360.com
A43	Dairy Dialog podcast 109_ Chr. Hansen, Greiner Packaging, Schuman Cheese	November 18 , 2020	Dairy Reporter
A44	DGAP-News_ Loop Industries and Suez Announce Strategic Partnership to Build First Infinite Loop(TM)	September 10 , 2020	DPA
A45	DGAP-News_ Loop Industries and Suez Announce Strategic Partnership to Build First Infinite Loop(TM)(2)	September 10 , 2020	EQS
A46	Dow sees recycling momentum;CEO Jim Fitterling expects more recycling initiatives for waste plastics	February 07 , 2020	ICIS
A47	DSM partner APK in recyclen plastics	July 27 , 2018	De Limburger
A48	Energy Transition_ Total Is Investing More Than _500 Million To Convert Its Grandpuits Refinery Into	September 25 , 2020	Impact Financial News
A49	-Eni - Versalis, new certified product range for sustainability	February 17 , 2021	ENP
A50	EPCA 20_ The rocky road to circularity	October 07 , 2020	ICIS
A51	EU chemical recycling approval contingent on full lifecycle impact - EU Commission	December 09 , 2020	ICIS
A52	EU Flexible Film Recycling Report Provides Market Data; Identifies Challenges	July 08 , 2020	News Tex
A53	Europe chem group Cefic joins Circular Plastics Alliance	September 20 , 2019	ICIS
A54	Europe top stories_ weekly summary	September 14 , 2020	ICIS
A55	First commercially available chemically recycled food-grade R-PP pellets enter market	September 11 , 2020	ICIS
A56	First in Europe to chemically recycle plastic packaging	June 12 , 2020	GDP
A57	From the wasteland, opportunity rises	October 31 , 2019	Investors Chronicle
A58	From the wasteland, opportunity rises;Almost two years after China introduced its waste import restrictions	November 01 , 2019	Investors Chronical
A59	Germany _ BASF invests in Quantafuel to jointly drive chemical recycling of mixed plastic waste	October 10 , 2019	Tenders info
A60	GREEN PIONEERS	June 05 , 2020	Investors Chronical
A61	How to meet the challenge of plastic waste	May 20 , 2019	Financial Times
A62	Indorama to increase PET recycling capacity to 750,000 tonnes_year by 2025	April 16 , 2020	Investors Chronical
A63	INEOS, Plastic Energy to build pyrolysis-based chemical recycling plant	April 22 , 2020	ICIS
A64	INSIGHT_ A decisive year for chemical recycling	January 12 , 2021	ICIS
A65	INSIGHT_ Challenges for recycled polymers in Europe	February 24 , 2021	ICIS
A66	INSIGHT_ Chemical recycling development in EU hinges on debate over legal status	October 16 , 2021	GDP
A67	INSIGHT_ Chemical recycling must not hinder mechanical recycling progress	January 29 , 2021	ICIS

A68	INSIGHT_ European recycling markets reel from coronavirus	March 19 , 2020	ICIS
A69	INSIGHT_ Major challenges lie in wait for FMCGs relying on chemical recycling to hit sustainability	January 27 , 2020	ICIS
A70	INSIGHT_ Ocean plastics may buoy Europe R-PET market	June 08 , 2020	ICIS
A71	INSIGHT_ sustainability and recycling set to dominate 2021 agenda	December 18 , 2020	ICIS
A72	Italy _ Versalis (Eni) joins the Circular Plastics Alliance and announces its pledges for plastic re	March 14 , 2020	Tenders info
A73	K curtain-raiser_ Solutions from plastics;Companies position themselves to meet the growing environm	July 15 , 2019	Chemical week
A74	'Life in plastic, it's fantastic' - Braskem invests $67M in recycling line, DOE Plastics Innovation	December 07 , 2020	News Tex
A75	Lightweight, homogenous and sturdy;Food stays safe - even with less plastic	March 09 , 2021	Fleischwirtschaft International
A76	Loop Industries Loop Industries and Suez Announce Partnership	September 10 , 2020	London Stock Exchange
A77	LyondellBasell advances chemical recycling by signing agreement with the Karlsruhe Institute of Tech	July 26 , 2018	MENA Financial News
A78	LyondellBasell Announces Construction of New Small-Scale Molecular Recycling Facility	November 08 , 2019	ICIS
A79	LyondellBasell seeks to expand plastics recycling platforms	November 08 , 2019	ICIS
A80	-LyondellBasell takes leadership role in global effort to end plastic waste	January 17 , 2019	EMP
A81	LyondellBasell to scale up recycling;CEO Bob Patel seeks scale for both chemical and mechanical recy	November 08 , 2019	ICIS
A82	Magnum Launches New Tubs Made From Recycled Plastic	September 02 , 2020	The Shellby Report
A83	Magnum launches new tubs made using certified circular polypropylene from SABIC's TRUCIRCLE_ portfol	August 13 , 2020	MENA Financial News
A84	INEOS Energy to sell its Norwegian oil and gas business to PGNiG for $615m	April 22 , 2021	News Bites Finance
A85	Mars and Nestle join plastic recycling consortium in France	December 15 , 2019	Just Food Global News
A86	Mars to trial SABIC chemically recycled PP in pet food packaging	November 03 , 2020	ICIS
A87	Mars, Nestle to work for chemical recycling of plastics in France	December 13 , 2019	Nuffoods Spectrum
A88	Minimising waste takes center stage	November 01 , 2019	Chemical Energy
A89	Mondi, BASF & COROOS create prototype stand-up pouch from recycled plastic(2)	September 25 , 2019	Backery and Snacks .com
A90	Mura bouwt grote fabriek in VK voor chemische recycling van plastic	March 25 , 2021	FD
A91	Navigating flexible packagings many paths to a circular economy	April 16 , 2021	GDP
A92	-Neste RE enables a future where all plastic products can be made of renewable and recycled material	November 27 , 2020	ENP
A93	Neste, Recycling Technologies and Unilever combine expertise to test and validate systems to chemica	October 16 , 2020	CISION
A94	Nestl_ UK boss calls for more plastics recycling	May 16 , 2019	foodmanufacturing.co.uk
A95	Nestl_, Mars & Total to develop chemical recycling industry in France	December 17 , 2019	Food & Beverages News
A96	Nestlé and Veolia partner on plastic materials recycling	March 20 , 2019	Market Line
A97	Nestle to invest $2.1bn in virgin-to-recycled polymer packaging shift	January 16 , 2020	ICIS
A98	Netherlands Government Gazette_ Regulation of the Minister of Economic Affairs and Climate of 16 May	May 28 , 2018	Impact News Service

A99	New PACCOR_Total thermoform container highlights growing R-PP buying interest from packaging sector	December 04 , 2020	ICIS
A100	NEXTLOPP expects industry compliant food-grade R-PP in UK by 2022	March 24 , 2021	ICIS
A101	No Headline In Original	April 24 , 2020	ICIS
A102	No Headline In Original(2)	October 09 , 2020	ICIS
A103	No Headline In Original(3)	April 24 , 2020	ICIS
A104	OUTLOOK '20_ Europe R-PE to remain under substitution pressure prior to packaging sector growth	January 09 , 2020	ICIS
A105	OUTLOOK '20_ Mid-term Europe R-PP demand to substantially increase	January 09 , 2020	ICIS
A106	OUTLOOK '21_ Food-grade recycled material a priority for packaging	January 05 , 2021	ICIS
A107	Plastic Energy and ExxonMobil join forces for pyrolysis-based chemical recycling plant	March 15 , 2021	ICIS
A108	Plastic waste_ how to square the circle	December 07 , 2020	EUROACTIV
A109	Plastics recycling gaining momentum - Dow CEO	January 29 , 2020	ICIS
A110	Plastics sector touts novel waste treatments;Chemicals. Recycling Critics say technical advances dis	January 20 , 2021	Financial Times
A111	PS recycling to compete with virgin even with drastically low crude prices - Agilyx exec	Augustus 6 , 2019	ICIS
A112	Q1 2021 Maire Tecnimont SpA Earnings Call - Final	April 29 , 2021	Fair Disclosure
A113	Renewable feeds to help LyondellBasell meet sustainability goal	September 30 , 2020	ICIS
A114	SABIC and Customers Launch Certified Circular Polymers From Mixed Plastic Waste	January 26 , 2019	PR Asia
A115	Sabic introduces new caps closures material, outlines strategies for growth and the circular economy	May 23 , 2018	MENA Financial News
A116	SABIC signs agreement to be part of 'UK Plastics Pact' initiative	April 29 , 2018	Arabian Oil & Gas
A117	Sabic to showcase circular polymers at Europe expo	July 12 , 2019	Trade Arabica
A118	Sabic to showcase leading edge certified circular solutions at k 2019	July 12 , 2019	Trade Arabica
A119	SABIC unveils new TRUCIRCLE range of circular polymer solutions at K 2019	October 22 , 2019	GDP
A120	SCS completes second test in quest for R-PS food-contact approval	February 09 , 2021	ICIS
A121	SCS members INEOS Styrolution, Total, Trinseo and Versalis evaluating Pyrowave depolymerisation tech	January 29 , 2020	ICIS
A122	Spain's Repsol to supply Berry with recycled PP	December 17 , 2020	ICIS
A123	Supply crunch boosts PP waste bale prices, R-PP flake and pellet grades mostly rollover	December 18 , 2020	ICIS
A124	The end of waste as we know it_ 4 ways to turn waste into treasure	May 11 , 2021	Impact News Service
A125	Topic Page_ Circular economy	January 13 , 2021	ICIS
A126	Total S.A. Citeo, Total, Recycling Technologies, Mars and Nestl_ Join Forces to Develop Chemical Rec	December 10 , 2019	London Stock Exchange
A127	UK Research and Innovation Funding Puts UK at the Forefront of Next Generation Plastic Recycling	October 17, 2020	Targeted News Service
A128	UK s Recycling Technologies to install plastic chemical recycling machine in mainland Europe	April 22 , 2020	ICIS
A129	UK to invest _20m in next generation plastic recycling market	October 16, 2020	ICIS Chemical News
A130	Upcycling used mixed plastic back to the original polymer	November 06 , 2020	GDP
A131	Versalis_ new certified product range for sustainability	February 17 , 2021	Impact News Service
A132	Visiongain Report_ The Global Recycled Polyethylene Terephthalate Market Will See a Capital Expendit	January 14 , 2020	Targeted News Services

Appendix B List of interviewees

Interviewees number	Company	Role
I1	Unilever	Science & Tech Discov Mgr R&D Science & Technology Discovery
I2	Jokey	Key Account Manager
I3	Sabic	Sr Manager Innovation Management Packaging
I4	Sabic	Sustainability Leader Petrochemic
I5	Unilever	HBPC Packaging Director R&D Packaging Development
I6	Renewi	Manager Product development
I7	Unilever	Regulatory Affairs Manager, Sustainability
I8	Unilever	GDC Packaging Manager Hair/Laundry – Sustainability
I9	Seuz	Director of SUEZ.circpack®
I10	Borealis	Strategic Platform Leader Circular Economy Solutions (CES)
I11	NGO Zero Waste Europe	Climate, Energy and Air Pollution Programme Coordinator
I12	Dow	Sustainability Director
I13	Unilever	F&R Global Sustainability Senior Manage
I14	Plastic energy	Head of Policy & Sustainability
I15	Provincie zuid holland	Beleidsmedewerker Circulair (kunststoffen) & Industrie Afdeling Samenleving & Economie, Bureau Economische Zaken
I16	Unilever	Global R&D Packaging Leader- Unilever Food Solutions
I17	ISCC	Key Account Manager
I18	external	EU Regulatory & Industry Advocacy Leader - Thermal & Specialized Solutions
I19	Unilever	Rigid packaging technology manager

Appendix C Interview guide

Thank you for taking the time today to answer some of my questions. I like to start with a quick explanation on my thesis subject. I'm researching the innovation system surrounding chemical recycling this means looking into the actors involved the laws but also the infrastructure. In order to get a clear overview, I've used the TIS technical innovation system as a theoretical and methodological approach. I started with a large literature review over the last three years to set so to say the stage. Right now I'm trying to see if what I found in my literature review actually reflects the real world and get additional information from experts in the field.

Could you describe in your own words what your function within …. is?

Entrepreneurial activities

- So as far as I can see, there is a lot of knowledge development, collaborations joint ventures but most names that pop up are already established actors, to your knowledge are there any new maybe smaller companies like start up or scale ups that you see or work with?
- Are the amount and type of experiments of the actors sufficient?

Knowledge development

- Are there enough actors involved in knowledge development and are they competent?

Guidance of the search

- Do actors and institutions provide a sufficiently clear direction for the future development of the technology?
- Is there a clear direction to the future of chemical recycling within EU?
  - who provides the direction?

Resource mobilisation

- What role should the government or the EU play?
- is there any financial support from the government or the EU?

Creation of legitimacy

- How much resistance is present towards the technology, project set up or permit procedure?
- Is there much resistance from NGO or other activist groups?
- How important is certification and iscc?

What in your view where or are the biggest barriers that this technologies faced/ faces?

What are the main opportunities?

Appendix D Coding scheme event analysis

System functions	Node names	References
Function 1. Entrepreneurial activities	- Experiments - New entrants - New projects	1 10 13
Function 2. Knowledge development	- Forecasts - New plant build - New product trail - Pilot activities - R&D activities	4 17 1 5 1
Function 3. Knowledge diffusion through networks	- Consortium - Conferences - Collaborations - Exhibition, Fair - Industry activities - Plastic alliances, pact - Seminar, webcast & interviews	8 3 46 2 2 5 2
Function 4. Guidance of the search	- EU plastic laws - Expectation setting - Legal debate -Positive -Negative - Public debate -Positive -Negative - Technological debate -Positive -Negative	3 4 4 3 1 40 26 14 10 6 4
Function 5. Market formation	- Growing demand - Niche markets - Product launches - Products on market	6 1 8 9
Function 6. Resources mobilisation	- First mover in market - Lobbying activities - New plant first production - Private investments - Production target - Public funding - R-PP availability - Subsidies - Upping existing capacity	3 1 1 21 1 6 1 1 3
Function 7. Creation of legitimacy and counteract resistance to change	- Active interest groups - Certification - Claims - Company commitment - Laws & agreements EU - possible tax regime - Pricing - Raising awareness	7 12 1 5 11 1 2 4

Appendix E Coding scheme expert interviews

Nodes and sub nodes	References
Barriers	12
- Capacity	7
Ability of scaling up	1
Effectiveness of chemical recycling	1
Yield	2
- Consumer acceptance and Chemo Phobia	4
Alternative names	2
Consumer acceptance	1
Education needed	1
- Costs	13
- Government support	1
Regulators need to understand technology	1
- Legislation	20
CR gray area in certification	2
CR part of recycling ny EU	3
- Mass balance	4
Mass balance discussion	2
Mass balance instead of recycled content	1
Negative mass balance mentioned	1
Transparency and mass balance	4
- Mechanical recycling vs Chemical recycling	18
CR complements MR	1
CR fight with incineration	1
- Necessity of chemical recycling	3
- Plastic waste input	4
- Purification	4
Pyrol still needs cleaner input stream	5
Consortiums	2
- Types of consortia	2
Entrepreneurial activities	2
- Tesco project	6
EU and Government actions	32
- EU doing studies	1
- EU needs to give clarity first	2
- Government role	1
- Industry take on gov responsibility	1

- Role of the government - UK tax - Waste hierarchy	1 4 1
Industry response to NGO - Good PR work against chemophobia - LCA proving chemical recycling validity - Plastic is not the problem - Plastic to fuel no recycling but bridge to plastic to plastic - Pyrol bridging technology - Role brand owner - View companies on NGO act	3 2 2 3 1 2 1 13
ISCC info - Certification - Different than wood etc - ISCC necessity - ISCC unknow by people - Educate people - Tech stakeholder community for ISCC - Why looking into chemical recycling	14 2 1 1 2 1 1 1
NGO activity - Energy intensity - Greenwashing - NGO being cautious - Chemical recycling not recycling - NGO perspective on Mass balance - NGO why investment in chemical recycling - Plastic to fuel	1 1 1 1 2 9 2 1
Initial Push - Added value for chem industry - Chemical recycling feedstock (buying from outside EU) - Ellen MacArthur foundation - EU regulations around climate change and plastic waste - External pressures - Industry feeling pressure - Initial push from brand owners - Need for chemical recycling - New found awareness for plastic pollution - Resin suppliers buying recyclers - Setting of recycling goals - societal pressure - Sustainability need - Unilevers backing tech	12 2 1 3 1 1 3 1 1 1 1 4 6 1 1