ZERO BRINE

D8.2 Report on the circular business model suggested for the large-scale demonstration in Rotterdam Port

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[1] **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

[2] **PU**=Public, **CO**=Confidential, only for members of the consortium (including the Commission Services), **CI**=Classified

Executive Summary

This report represents deliverable 8.2, outcome of task 8.1, within WP8 of the Zero Brine project. WP8 focuses on the market exploitation of the Zero Brine project, entailing important work related to business planning, business modelling and intellectual property management. In particular, task 8.1 is about designing a business model to pave the way towards the commercial implementation of the Zero Brine technologies piloted in the large-scale demonstration, taking place at the Botlek site, Rotterdam Port. The report is structured as follows.

Chapter 1 consists of a concise introduction with the function of putting the rest of the report in context.

Chapter 2 reports on the outcome of a literature review. First, circular economy and industrial symbiosis theories are reviewed, outlining their key features and ultimately explaining how they are related. Circular economy theory proposes an economic paradigm aiming to optimize economic and environmental performance simultaneously by creating a system in which resource input and waste, emission, and energy leakage are eliminated or minimized. Relatedly, industrial symbiosis theory proposes approaches to concretely achieve this, through the creation of cooperative networks of separate industries and business entities aiming to collectively achieve competitive advantage by physical exchange of materials, energy, water, and/or by-products as well as services and infrastructures. Establishing these industrial symbiosis networks requires establishing new circular business models. Therefore, this theory is also reviewed, explaining that circular business models are based on a circular value proposition and on the related mechanisms for value creation, delivery and capture, that the stakeholders in the industrial symbiosis network may leverage to make a positive impact and profit, while working together. Given the complexity of aligning different goals and multiple stakeholder priorities, the circular business model innovation process is experimental and iterative in nature, often requiring the support of specific tools in order to be performed effectively.

Chapter 3 reports on the process carried out for designing the circular business model to commercially implement the Zero Brine technologies at Botlek, Rotterdam Port. In line with the aforementioned theoretical background, the circular business model design process was based on a circular business experimentation method. This entailed gradually and iteratively re-shaping and detailing the initial ideas outlined in the Zero Brine grant agreement, towards the definition of a circular business model proposal. This effort took place through a series of co-design activities, in which Zero Brine Stakeholders were approached collectively, as well as individually, to provide their view and inputs, indeed resulting in a final circular business model proposal. Based on stakeholder inputs, the implementation of the proposed model is around the Zero Brine technologies at the Botlek site might not be possible. This is mainly to the business case behind it, which is lacking due to several barriers outlined in section 3.3. Nevertheless, specific barriers, drivers as well as potential next steps were identified, flowing into a future vision.

Chapter 4 consists of a concise conclusion of the report, explaining that its content may be leveraged to inform other tasks of the Zero Brine project, as well as potential follow-ups.

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1. Introduction

This report represents deliverable 8.2, outcome of task 8.1, within WP8 of the Zero Brine project. WP8 focuses on the market exploitation of the Zero Brine project, entailing important work related to business planning, business modelling and intellectual property management. In particular, task 8.1 is about designing a business model to pave the way towards the commercial implementation of the Zero Brine technologies piloted during the large-scale demonstration at Botlek, Rotterdam Port. Business model design is based on the notion of industrial symbiosis, which is about collaboratively creating value from waste in industrial processes amongst geographically near businesses, within a wider circular economy paradigm. After this brief introductory chapter 1, the remainder of the report is structured as follows. The following chapter 2 consists of a literature review about underlying circular economy, industrial symbiosis and business model innovation theories. Chapter 3 describes the work carried out to design the circular business model, as well as the final outcome. Finally, chapter 4 consists of a brief conclusion.

2. Literature review

This literature review chapter is divided into two parts. Part 2.1 provides an overview of the circular economy and industrial symbiosis concepts, outlining their key features and ultimately explaining how they are related. Part 2.2 focuses on circular business model innovation. First it explains what circular business models are. Then, it outlines the process needed to realize them. Finally, it provides an overview of existing tools that were developed to support this effort.

2.1 Circular economy and industrial symbiosis

Circular economy theory

In the past decade, the concept of a circular economy has gained significant momentum worldwide. In 2009 China put forward the "Circular Economy Promotion Law of the People's Republic of China", while in the EU the issue of raw material scarcity was framed as a circular economy challenged through the circular economy Action Plan (The Raw Materials Initiative - Meeting Our Critical Needs for Growth and Jobs in Europe, 2008; Closing the Loop - An EU Action Plan for the Circular Economy, 2015). Currently, EU policy making is striving to catalyze the circular economy within its borders as well as overseas (European Commission, 2019, 2020). Nevertheless, the theoretical roots of the circular economy are older than a decade and can be traced back to the 1960s (Carson, 1962; Fuller, 1969; Hardin, 1968). Although, from a theoretical standpoint, this paradigm differs from the concept of sustainable development (i.e. a narrower focus on resource efficiency) (*Transforming our world: The 2030 agenda for sustainable development*, 2015), it can also be argued that core similarities can be leveraged to achieve analogous goals (Geissdoerfer et al., 2017). Specifically, a circular economy incentivizes firms in framing sustainability challenges as business opportunities in order to achieve a positive environmental impact and economic growth simultaneously (Geissdoerfer et al., 2017; Lüdeke-freund et al., 2018), while current industry examples demonstrate that a prominent focus on resource efficiency does not necessarily entail neglecting the social aspects (Akemu et al., 2016). The circular economy is defined as a system in which resource input and waste, emission, and energy leakage are eliminated or minimized (i.e. closing their loops) (Geissdoerfer et al., 2017).

Circular economy principles

The circular economy is based on a clear set of principles (Lewandowski, 2016; MacArthur, 2013):

- Design out waste (design for reuse)
- Build resilience through diversity
- Rely on energy from renewable sources

- Waste is food (think in cascades / share values)
- Think in systems

In practice, these principles are often leveraged for the creation of eco-industrial clusters (Baldassarre et al., 2019; Mulrow et al., 2017).

Eco-industrial clusters

An eco-industrial cluster is defined as a physical “community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in managing environmental and resource issues including energy, water, and materials” (Massard et al., 2014). The development of eco-industrial clusters brings three main types of benefits: reduction of natural resource consumption and pollution, sustainable regional development, economic benefits (Massard et al., 2014).

Industrial symbiosis

The way eco-industrial clusters function is based on industrial symbiosis, namely an approach where separate businesses entities create a cooperative network to achieve competitive advantage by physical exchange of materials, energy, water, and/or by-products as well as services and infrastructures (Massard et al., 2014). Usually, the industrial symbiosis cooperative networks include the following type of actors:

- Knowledge company
- Network coordinator
- Cluster coordinator
- Recycling company
- Infrastructure company
- Process industry company

Indeed, collaboration play a central role in industrial symbiosis because this dynamic process presents technical, organizational and financial challenges (Boons et al., 2011, 2014; Lange et al., 2017; W. A. H. Spekkink & Boons, 2016; Walls & Paquin, 2015). Consequently, when analyzing industrial symbiosis, it is also relevant to discuss the nature of collaborations and how they emerge (Boons et al., 2014, 2015; Spekkink, 2015; Sun et al., 2017). Collaborations, including industrial symbiosis, can be seen as dynamic processes originating from certain starting conditions and leading to certain outcomes (Spekkink, 2015). Concerning their emergence, collaborations can be a generated either by a single agency or by multiple actors in a formerly established cooperation (Spekkink, 2015). Furthermore, it has been noted that collaborative capacity can originate already before the start of a collaboration due to bridging actors that establish a common ground between sub-groups within a collaborative network (Spekkink, 2015). Concerning their nature, they can be either administrative when they stem from policy decisions, or experimental when policy decisions are supposed to follow up on the outcome of first and uncertain implementation steps (Boons et al., 2014). Ultimately, realizing industrial symbiosis entails addressing both technical and institutional challenges (Sun et al., 2017), as further specified below.

Technical challenges include:

- Facilitating technical synergies
- Creating a supporting infrastructure

Institutional challenges include:

- Stimulating social interaction
- Providing knowledge support
- Providing political and managerial support
- Recruiting the suitable companies
- Starting the first pilot implementation pilot

Industrial symbiosisdynamics

In order to address the challenges mentioned above, industrial symbiosis can be realized in different ways, both from a technical and organizational point of view. These are referred to as industrial symbiosis dynamics. From a technical standpoint, industrial symbiosis can be realized as follows (Boons et al., 2015):

- Process oriented industrial symbiosis (refers to a cooperative network around an industrial process)
- Residue oriented industrial symbiosis (refers to a cooperative network around a residual flows)
- Place oriented industrial symbiosis (refers to a cooperative network bound to a specific location)

From an organizational standpoint, industrial symbiosis can be realized as follows (Boons et al., 2011; Mulrow et al., 2017; Spekkink & Boons, 2016):

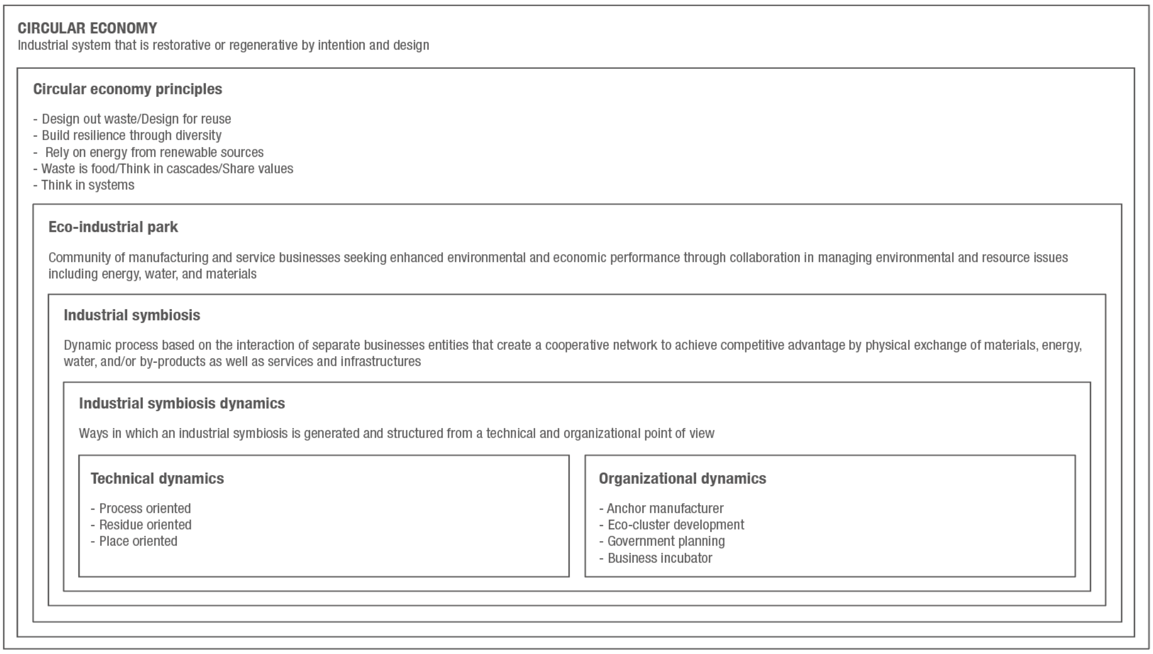
- Anchor manufacturer (the industrial symbiosis is initiated by an industrial actor who seeks economic, strategic and environmental benefits. The anchor firm is typically the largest in terms of production volumes / resource use and its byproducts are used by other actors in the network)

- Eco-cluster development (the industrial symbiosis is initiated by a governmental and/ or industrial actors who make a joint strategic plan to create the network. The aim is generally boosting innovation and economic development while gaining competitive advantage)
- Government planning (the industrial symbiosis is initiated by a public / governmental institution aiming to boost the economy's productivity and resilience while reducing environmental impact)
- Business incubator (the industrial symbiosis is initiated by a private project implementer who is economically interested in attracting or growing industrial or commercial tenants capable of engaging in symbiosis)

Relationship between circular economy and industrial symbiosis

Industrial symbiosis is thus essentially an approach to leverage circular economy principles, and to realize a circular economy. In particular this is achieved through the interaction of separate businesses entities within an eco-industrial cluster, aiming to achieve competitive advantage by physical exchange of materials, energy, water, and/or by-products as well as services and infrastructures (Massard et al., 2014). Furthermore, they clarified that the realizing industrial symbiosis entails the collaboration of several actors while addressing both technical and institutional challenges in different ways, referred to as industrial symbiosis dynamics. Figure 1 puts industrial symbiosis in context within the broader concept of circular economy.

Figure 1: Industrial symbiosis in the context of a circular economy. Based and adapted from: (Baldassarre et al., 2019)



The main message of this section is that industrial symbiosis is a collaborative approach that can be adopted for the creation of eco-industrial clusters and foster the transition towards a circular economy.

From a business perspective, industrial symbiosis can be understood as a specific type of business model, a conceptual architecture that explains how stakeholders can innovate together in order to profit while optimizing their environmental performance (Bocken et al., 2014; Zucchella & Previtali, 2019). The next section focuses on the subject of circular business model innovation.

2.2 Circular business model innovation

Circular business models

A business model is a theoretical conceptual framework that organizations can use to execute their strategy (Richardson, 2008; Teece, 2010). The framework is based on four main elements:

- A value proposition that describes what an organization provides to customers (e.g. a product, a service, a process, etc.)
- A value creation system that describes what the organization has to do in order to concretely produce the value proposition
- A value delivery system that describes how the organization brings the value proposition to the intended customers
- A value capture system that describes how entailed costs and revenues allow the organization to profit (Osterwalder & Pigneur, 2010; Richardson, 2008; Teece, 2010).

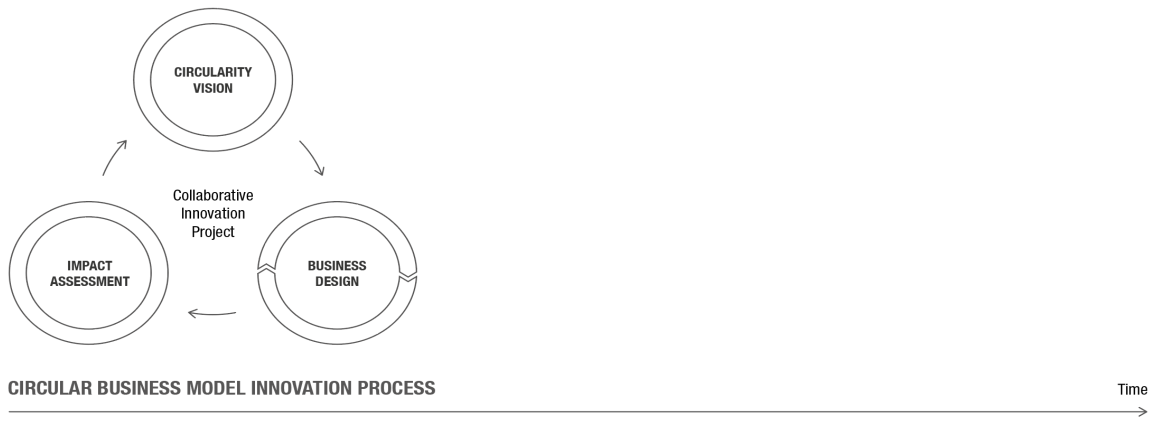
The business model framework can be leveraged to embed sustainability into firms' objectives and operations (Bocken et al., 2014; Boons & Lüdeke-Freund, 2013; Stubbs & Cocklin, 2008). This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling" (Lüdeke-freund et al., 2018; MacArthur, 2013). The circular business model framework is based on the business model pillars integrated with circular economy principles and strategies (Lüdeke-freund et al., 2018). Accordingly, it includes:

- Circular value proposition aimed at concurrently generating economic value and measurable environmental (and social) benefits
- Circular value creation system characterized by the collaboration between multiple stakeholders sharing resources, infrastructure and knowledge
- Circular value delivery system based on the collaboration of multiple stakeholders to achieve the valorization of waste streams through service provision and reverse logistics
- Circular value capture mechanism characterized by cost structures, multiple (and recurring) revenue streams and long-term strategic benefits shared across participating stakeholders

Circular business model innovation process

Realizing a circular business model is challenging because it requires aligning the needs and objectives of multiple stakeholders, and at the same time finding an overlap between economic and environmental benefits (Diaz Lopez et al., 2018). For this reason, the circular business model innovation process has to be iterative and experimental in nature (Bocken et al., 2018; Konietzko et al., 2020b). Indeed, experimentation allows to gradually align diverse stakeholder needs and to find a way to achieve economic and environmental benefits simultaneously (Antikainen & Valkokari, 2016; Guldmann & Huulgaard, 2020). Going into more detail, this experimental process can be understood as a collaborative innovation process unfolding over time through the iteration of three main steps: defining a circularity vision, business modeling itself, and impact assessment (Baldassarre et al., 2019; Bocken et al., 2018). The first step consists of developing a shared vision. Concretely speaking, collaborating stakeholders agree upon the economic as well as environmental (and social) objectives that the innovation project should achieve (Baldassarre et al., 2019). The second step consists of designing a business model to achieve the vision. This step is in itself iterative. Concretely speaking, the design of the business model occurs through a set experiments and stakeholder interactions. These, allow to gradually define the technical and operational details that characterize circular business model in terms of value proposition, value creation and delivery, value capture, value missed and destroyed of the circular business model (Bocken et al., 2018). The third step consists of measuring the impact of the business model, in order to find out whether the circularity vision was actually achieved. Concretely speaking, this entails performing an analysis of the economic, environmental (and social) impact of the project (Baldassarre et al., 2019). This can be done through quantitative methods including Life Cycle Assessment (LCA) for environmental impact, Social Life Cycle Assessment (S-LCA) for social impact and Life Cycle Cost (LCC) for economic impact (Dreyer et al., 2006; Massard et al., 2014; Norris, 2001; Sala et al., 2015). In turn, the impact assessment performed in the third step, is functional, not only to verify if the circularity vision was achieved, but also to redefine the vision and align to address evolving stakeholder and unforeseen impacts.

Figure 2: Circular business model innovation process. Based and adapted from: (Baldassarre et al., 2019; Bocken et al., 2018)



Circular business model innovation tools

Considering the complexity of the circular business model innovation process, researchers started to develop several tools for supporting innovators and organizations to perform it in practice (Lüdeke-Freund et al., 2016). A recent literature review has categorized them according to their purpose: ideating, implementing, and evaluating circular business models (Bocken et al., 2019).

The main goal of existing tools for ideating circular business models, such as the circularity card deck (Konietzko et al., 2020a), is supporting multiple stakeholders in collectively generating and exploring business opportunities to jointly profit while reducing their current negative impacts (Bocken, Strupeit, et al., 2019). The main goal of existing tools for evaluating circular business models, such as the rapid environmental value proposition assessment tool (Manninen et al., 2018), is supporting organizations to better understand what are the positive and negative impacts of the aforementioned opportunities (Bocken et al., 2019). Finally, tools for implementing circular business models are particularly important because they support organizations in the complex and long design process of turning potential opportunities into reality (Bocken et al., 2019). However, the number of these tools is rather limited and they resemble more to conceptual frameworks (e.g. Antikainen et al., 2017) that do not provide sufficient hands-on guidance. Relatedly, most circular business models that are ideated, do not make it to market implementation (Tukker, 2015). In order to address this critical issue in the context of the Zero Brine project, the process to design the circular business model for demonstration was supported by a tool, created ad-hoc to pave the way towards market implementation.

3. Circular business model design

This circular business model design chapter is divided into 3 sections. Section 3.1 provides an overview of the objective, method and activities of circular business model design. Section 3.2 illustrates the circular business model design process, describing how each activity was performed as well as its results. The section encompasses a summarized version of the process illustration. The full illustration is reported in annex A. Section 3.3 reports the outcomes of the process, proposing a circular business model concept for the Zero Brine project, before listing all the barriers for its implementation at Botlek, as well as the drivers and next steps to move towards a future vision.

3.1 Circular business model design overview

Objective

The scope of circular business model design is specified within the description of task 8.1 in the Zero Brine grant agreement. Task 8.1 entails designing a business model to pave the way towards the commercial implementation of the Zero Brine technologies piloted in the large-scale demonstration taking place at Botlek, Rotterdam Port. The proposed business model is based on the notion of industrial symbiosis, which is about collaboratively creating value from waste in industrial processes amongst geographically near businesses, considering the following aspects: land sharing, equipment and service share, information sharing, managing organization, collaborations, synergies and value chains. In particular, the idea is to establish a cross-organizational business collaboration optimizing the economic and environmental performance at Botlek (industrial symbiosis). The aim of this cross-organizational collaboration is leveraging the Zero Brine technologies for recovering and putting back on the market valuable resources (primarily magnesium hydroxide, sodium chloride and clean water) from the brines (industrial wastewater with a high concentration of salt and minerals), generated at Botlek. The grant agreement outlines the key stakeholders (and their roles), that should be considered in the definition of the cross-organizational collaboration:

- Evides Industriewater has the key role of anchor manufacturer (Mulrow et al., 2017), which means that it provided its facilities to implement the technologies, as well as the wastewater in the form of brine, which is the essential input for resource recovery.
- Air Products (or other neighboring industry) has the role of providing the waste heat to make the water treatment and resource recovery process less environmentally impactful, by reducing its energy needs.
- In addition, Sealeau, ARVIA, Lenntech, TU Delft and UNIPA have the key role of technology manufacturers. Each of them manufactures a key component of the Zero Brine technologies

applied in the demonstration, for recovering clean water, sodium chloride and magnesium hydroxide from the Brines.

- Finally, Europiren, which is a firm that commercializes magnesium hydroxide, has the key role of bringing the recovered materials into the market.

Ultimately, the objective of the business model design process is co-defining with the aforementioned Zero Brine stakeholders a value proposition, value creation and delivery, and value capture mechanisms defining how their cross-organizational collaboration at Botlek may concretely take place.

Methods

The method employed to co-design the circular business model is circular business model experimentation (Antikainen et al., 2017; Bocken et al., 2018; Bocken & Antikainen, 2018). This approach is widely discussed in the circular economy academic literature as well as increasingly adopted in circular innovation practice (Baldassarre et al., 2020; Bocken et al., 2018; Bocken & Antikainen, 2018; Konietzko et al., 2020a). Circular business model experimentation entails defining an initial circular business model idea, and then iteratively refining it over time in collaboration with key business stakeholders (Bocken, Boons, et al., 2019; Kraaijenhagen et al., 2016). This is needed to gradually align diverse stakeholder needs into a solution that can work, and that delivers economic and environmental benefits simultaneously, according to a circular economy rationale (Antikainen & Valkokari, 2016; Guldmann & Huulgaard, 2020). Given the complexity and time-consuming nature of the process, tools are often needed to support its execution in practice (Bocken, Strupeit, et al., 2019). Such tools are important to make the experimentation process and business design outcomes more tangible and understandable over time to the involved stakeholders (Bocken, Strupeit, et al., 2019; Breuer et al., 2018; Calabretta et al., 2016; Lüdeke-Freund et al., 2016). The tools can be deployed using specific experimentation practices, which include collaborative co-creation sessions with multiple stakeholders, as well and individual interviews, where the circular business model idea is shaped in a discussion between the main designer and a single stakeholder (Baldassarre et al., 2017; Bocken, Boons, et al., 2019; Schuit et al., 2017). Although multiple tools for circular business model experimentation exist (Bocken, Strupeit, et al., 2019; Breuer et al., 2018; Lüdeke-Freund et al., 2016), not many focus on both the design and the implementation of a circular business model (Bocken, Strupeit, et al., 2019), which is the objective of task 8.1. Therefore, in order to support the execution of this task properly, we created a circular business model design and implementation tool on an ad-hoc basis. The development of this tool followed a rigorous method called design science research (Grenha Teixeira et al., 2017; Peffers et al., 2007; Romme & Reymen, 2018). As part of the method, a first version of the tool was developed using as a backbone the business models canvas tool (Osterwalder & Pigneur, 2010). This is a tool to co-design business models by defining the underlying value proposition as well as related value creation, delivery and capture mechanisms (Osterwalder et al., 2015). This backbone was upgraded by integrating it with circular economy and experimentation theories. In particular, this entailed incorporating a multi-stakeholder perspective, environmental impact metrics from circular economy theory, as well as a prototyping logic from experimentation theories such as strategic design and effectuation (Calabretta et al., 2016; Sala et al., 2020; Sarasvathy, 2008), which are essential to design and implement circular business ideas (Baldassarre et al., 2020). Consequently, this first version of the tool was gradually improved and refined by applying it and evaluating it in practice. Applications and evaluations included efforts carried out within the Zero Brine project itself (see the report for 10.5 within WP10), as well as efforts in other circular business model design projects (see Baldassarre et al., 2020), with the aim of making the tool more robust. Ultimately this allowed to derive a final version of the tool, visualized in Figure 4.

Figure 4 Tool supporting the circular business model design for the large-scale demonstration: see Annex B

The tool was used to co-design with Zero Brine stakeholders the circular business model for the demonstration of the technologies at Botlek, within task 8.1. The tool is essentially a large poster template that enables stakeholders to discuss and co-define the business model concept in terms of the circular value proposition, circular value creation, circular value delivery and circular value capture.

The circular value proposition element of the business model is embedded in the first top box of the template, which prompts stakeholders to co-define the backbone of the circular business model idea by addressing the following set of questions:

- What is the idea?
- What does Zero Brine offer?
- Who will use it / buy it?
- Why will they use it / buy it?

In order to ensure that the business idea can generate economic as well as environmental value, this element was integrated by circular economy theory, thus incorporating an impact box to probe stakeholders with the following set of questions:

- What is the impact?
- Why is Zero Brine circular?
- How do you measure it?

The circular value creation element of the business model is embedded in second box of the template. In line with a multi-stakeholder perspective necessary in a circular business model, this element can be used to list all the stakeholders involved in the business model and to detail their role with regard to key aspects outlined in the task description within the grant agreement including land sharing, equipment and service share, information sharing, managing organization, collaborations, synergies and value chains. The idea here is to gradually probe the stakeholders on these specific aspects starting from the following set of high-level questions:

- *How do we make it happen?*
- *Which stakeholder is involved?*
- *What does it do?*
- *What does it get out of it?*
- *What can go wrong?*

The circular value delivery element of the business model is embedded in the third box of the template, which, in line with effectuation theory, prompts stakeholders to co-define a way to bring the value proposition to users and/or customers by planning a sequence of actions unfolding in time, and that can be executed with know-how and resources already available in the project, as defined in parallel within the value creation element. This entails having a discussion starting from the following high-level questions, and then gradually zooming into details while keeping in check their feasibility:

- *How does it work?*
- *How does the Zero Brine business reach its users / clients?*

Finally, the circular value capture element of the business model is embedded in the fourth box of the template, which prompts task force stakeholders to discuss the financial aspects by addressing the following set of questions:

- *How do we profit?*
- *What are the Zero Brine costs?*
- *What are the Zero Brine revenues?*

In line with the aforementioned multistakeholder perspective, in asking these questions is important to consider how such costs and revenues would be shared amongst the stakeholders collaborating within the proposed circular business model.

Co-design activities

Throughout the execution of task 8.1, the tool was iteratively applied through a set of co-design activities, in line with circular business experimentation theory (Bocken et al., 2018). These activities mainly consisted in co-design sessions involving either multiple stakeholders in a workshop format at the stakeholder consultation events, or an individual stakeholder in a qualitative interview format. During the activities post-it notes were used to map and discuss upon the tool elements of the emerging circular business model. Activities were spread in time across the duration of the entire project, and interspersed with reflection moments and more informal stakeholder contacts. These were functional for the IDE team leading task 8.1 to leverage emerging empirical insights, theoretical insights from literature on circular business models and industrial symbiosis, and the results of other project activities, performed within other work packages, to progressively inform the planning and execution of new co-design activities. Co-design activities were planned and executed by PhD researcher Brian Baldassarre, in close collaboration with Associate Prof. Giulia Calabretta and under the supervision of Prof. Erik Jan Hultink at the IDE faculty of the TU Delft. All co-design activities conducted to execute task 8.1 are listed in Table 1 below.

Table 1: List of activities conducted to execute task 8.1.

Activity	Activity type	Stakeholders	Participants
1	Co-design workshop at the first stakeholder consultation event, taking place at the faculty of applied sciences, TU Delft	Europiren Sealeau TU Delft DCMR Akso Nobel ISPT PlantOne RVO RHDHV Evides Industriewater	Cristinel Degeratu (chemical engineer) Dimitris Xevgenos (managing director) Fred Govaert (engineer, MBA, advisor) George Tsalidis (engineer, postdoc) Koen de Kruif (senior sustainability advisor) Hans Gerritsen (senior sustainability advisor) Thijs de Groot (innovation technologist) Menno Plantega (program manager) Gabriel Tschin (owner, managing director) Corinne van Voorden (circular economy program manager) Steve Lemain (environmental consultant, project manager) Wilbert van den Broek (senior process engineer)
2	Co-design interview	Europiren	Cristinel Degeratu (chemical engineer)
3	Co-design interview	TU Delft	Roelof Moll (executive project coordinator)
4	Co-design interview	TU Delft	Luuk Rietveld (scientific project coordinator)
5	Co-design interview	TU Delft	Paul Althuis (director valorization center)
6	Co-design interview	Evides Industriewater	Wilbert van den Broek (senior process engineer)
7	Co-design interview	Sealeau	Dimitris Xevgenos (managing director)
8	Co-design workshop at the second stakeholder consultation event, taking place at the yearly project meeting at EURECAT	All Zero Brine partners	All the representatives of the Zero Brine partners presents at the yearly project meeting
9	Co-design interview	IVL	Steve Harris (project manager)
10	Co-design interview	DCMR	Koen de Kruif (senior sustainability advisor)
11	Co-design interview	Evides Industriewater Witteveen+Bos	Jan Willem Mulder (manager process & technology) Arjen van Nieuwenhuijzen (R&D circular innovation)
12	Co-design interview	Sealeau	Dimitris Xevgenos (managing director)
13	Co-design interview	Sealeau	Stefano Iannacone (senior program manager)
14	Co-design interview	TU Delft	Henri Spanjers (process engineer, associate professor)
15	Co-design interview	Europiren	Henk Don (managing director)

16	Co-design interview	ARVIA	Nigel Brown (managing director) Joseph Weston (business developer)
17	Co-design email contact	Huntsman	Bart de Waele (procurement director) Maarten ter Weeme (employee)
18	Co-design interview	Lenntech	Lorenzo Salin (director)
19	Co-design interview	TU Delft	Roelof Moll (executive project coordinator)
20	Co-design interview	UNIPA	Andrea Cipollina (professor, industrial engineer) Giorgio Micale (professor, chemical engineers) Fabrizio Vassallo (PhD, engineer) Serena Randazzo (researcher)
21	Co-design interview	Zero Brine Advisory Board	Michiel van Haersma Buma (independent innovation advisor)
22	Co-design interview	Evides Industriewater	Jan Willem Mulder (manager process & technology) Jan Robert Huisman (director)
23	Co-design interview	Port of Rotterdam	Monique de Moel (manager business development)

3.2 Circular business model design process

This section encompasses a summarized version of the illustration of the circular business model design process: a concise overview of each activity is provided, followed by a concise table reporting the related results. In each table, all activity results are coherently organized and reported around the four elements of the circular business model, namely circular value proposition, creation, delivery and capture (in line with the tool that was used to derive such results). A full illustration of the circular business model design process activities and results is reported in annex A.

Co-design at the first stakeholder consultation event

Co-design at the first consultation event was performed in a workshop format, taking place at the faculty of applied sciences of the TU Delft at the beginning of the project. The overall result of this activity was to start establishing mutual trust and understanding towards the definition of the circular business model elements. Results are reported in Table 2.

Table 2: Results of co-design at the first stakeholder consultation event

Circular value proposition	Circular value creation	Circular value delivery	Circular value capture
Centred on resource recovery. Main focus is on magnesium hydroxide and sodium chloride recovery. Economic and environmental impact	Necessitates brine inputs from Evides. Evides confirms ability to provide them with interest only in sodium chloride for internal reuse. Evides not able to install the technology in its facilities. Installation for the demonstration must be moved to PlantOne. The location of installation for a full-scale business is uncertain and needs to be discussed with Rotterdam Port. Europiren confirms its interest and ability to put the recovered magnesium hydroxide back on the EU market.	Remains an open question. Preliminary ideas are generated, inspired by the RHDHV concept of chemical leasing, but consensus is not reached.	Remains an open question. Consensus is reached on the need to eventually define this, once the technical results of the demonstration are be available.

quantified with KPIs derived from LCA and LCC within WP7. Objectively quantifying social impact is a challenge.	Waste heat, as input for the evaporator technology supplied by Sealeau is essential to achieve acceptable energy efficiency. Huntsman may provide this. Consensus on the ownership of the Zero Brine technologies is not reached. This remains an open question.		

Co-design at the second stakeholder consultation event

Co-design at the second consultation event was performed in a workshop format, taking place at the premises of EURECAT, half way through the project on the occasion of the second yearly project meeting. The overall result of this activity was to nudge the Zero Brine stakeholders to generate more concrete circular business models ideas. This, however, proved to be challenging. Results are reported in Table 3.

Table 3: Results of co-design at the second stakeholder consultation event

Circular value proposition	Circular value creation	Circular value delivery	Circular value capture
Competitive rationale defined around the adaptability of the technology to different customer needs and its energy efficiency compared to existing solutions based on evaporation. Consensus is reached on who is the provider, namely the Zero Brine technology suppliers, possibly through a joint spin-off. Divergent views emerge concerning who is the customer. Intended customer segment is companies in the process industry willing to treat wastewater and recover raw materials. However, Evides does not consider itself a potential customer and is not willing to purchase and install the solution.	Definition of stakeholder roles advances only to a limited extent compared to the previous joint co-design session.	Two options are discussed: a leasing model or a one-off sale model. Delivery scope is discussed: clients at Botlek, or in the entire Port of Rotterdam, or beyond that, encompassing also different industrial sectors (e.g. also silica, textile and coal-mining industries). Consensus is not reached.	Revenue streams are discussed. The profitability of selling recovered materials cannot be defined due to uncertainties around quality (purity) and quantity (the results of the demonstration are needed to advance this discussion). Agreement is reached on that profit sharing amongst technology manufacturers is based on their contribution. Agreement is not reached on how the profit from resource recovery and sale will be shared. Agreement is not reached on cost sharing. No stakeholder is willing and / or able to invest its own resources in the spin-off. The need of additional EU funding is mentioned.

Co-design with TU Delft

Co-design with TU Delft was performed through a series of interviews, taking place at different points in time throughout the project. This resulted into important specifications of the circular business models elements, reported in Table 4.

Table 4: Results of co-design with TU Delft

Circular value proposition	Circular value creation	Circular value delivery	Circular value capture
Further specified in terms of two main sources of value for customers: (a) resource recovery that can be either be sold or reused internally, and (b) reduction / elimination of potential taxes on wastewater discharge. (a) does not apply to Evides, which does not have to pay taxes (or very limited) for brine discharge in Botlek. (b) is quantified based on the results of WP2 (see annex A for more detail). The purity of recovered magnesium hydroxide is high but quantity is very limited (approx. 50 tons/year). The quantity of recovered sodium chloride is high but the resource holds low commercial value.	Supported by the supply of the EFC technology from the faculty of applied sciences. The Valorization Center is willing to support the creation of a spin-off after in case of positive end results of the project, in turn of an equity share.	Affected by feasibility concerns. Due the low TRL of the EFC technology, it is not possible to define it the technology is suitable for commercial sale or lease. Brine excellence centers developed within WP5 could be used to conduct lab experiments for clients, as a first delivery step of the value proposition. In this regard, it is possible to leverage the software developed by DLR and the matchmaking platform developed by ISPT.	This is a critical issue, due to concerns on how to monetize (a) and (b) and due to the low TRL level of EFC. TU Delft looks at value capture also in terms of using Zero Brine as a platform to acquire new funded research projects.

Co-design with Europiren

Co-design with Europiren was performed through two interviews, taking place at different points in time throughout the project. This resulted into important specifications of the circular business models elements, reported in Table 5.

Table 5: Results of co-design with Europiren

Circular value proposition	Circular value creation	Circular value delivery	Circular value capture
Europiren interested only in the recovery of magnesium hydroxide. Currently Europiren sources this material from a mine in Eastern Russia, processes it nearby Moscow and sells to clients in Europe.	Europiren is willing to contribute by reselling recovered magnesium hydroxide to its current clients. Europiren can play this role only if purity and quantity are adequate. Purity of 67% is adequate but quantity is not. 50 tons/year can be recovered from Evides Plant but for quantities inferior to 2,000 tons there is no business case for Europiren. Europiren is not interested in remarketing other resources other than magnesium.	Europiren is not able to play an active role in this regard, since installing the technologies into process companies fall outside the scope of its business model.	Europiren can convert recovered magnesium hydroxide into revenues for Zero Brine. In turn, Europiren expects to profit from this effort either entirely or through a percentage to be negotiated. Europiren is able to target a profitable niche in the magnesium hydroxide market, specifically: thin fire-retardant rubber cables. With a purity of 67% selling price could range between 2,000 and 3,000 EUR/ton. Next to selling price, production cost also has to be considered, which is difficult to estimate at this stage in the project.

Co-design with Sealeau

Co-design with Sealeau was performed through three interviews, taking place at different points in time throughout the project. This resulted into important specifications of the main circular business models elements, reported in Table 6.

Table 6: Results of co-design with Sealeau

Circular value proposition	Circular value creation	Circular value delivery	Circular value capture
Important concerns emerge in regards to the two main sources of value previously defined (a) and (b) (see co-design with TU Delft). First (related to a), current brine discharge regulation in Botlek does not involve significant taxation, in particular for Evides. Second (related to b), the quantity and market value the materials recovered from the brines of Evides is limited. This may result in the lack of a business case for implementing the technology at the premises of Evides. A stronger business case may be in place beyond Botlek and in other industries (e.g. silica industry at the premises of IQE) but this effort falls outside the scope of task 8.1. KPIs to measure circular impact should be kg of recovered materials put back on the EU market and / or market size of recovered materials compared to virgin materials.	Sealeau's main role relates to supplying the evaporator. Another role is potentially being the main solution contractor (managing organization) when providing the entire Zero Brine treatment train to clients. Sealeau can also play a role in finding new clients and technology suppliers to improve the treatment train. Sealeau mentions intellectual property concerns: the treatment train as a whole cannot be patented. Clients with relevant know-how may learn about it and implement it on their own.	May be based on a stepwise approach: (0) connect to a potential client in the Botlek area; (1) make a brine lab test in the Dutch excellence center; (2) run a small-scale pilot in the facility of the client (3) full-scale implementation of the technology in the facilities of the client. Two options for delivery would be possible: one-off sale (this entails high upfront costs for the client, which may result in a barrier for purchase); service based / leasing (this entails requires lower commitment from the client but creates additional burdens for the solution provider. see annex A for more detail).	Must align with the costs and revenues of the value delivery steps. Costs associated to step 1 and 2 with Evides were already covered in the Zero Brine project, but with other clients they would be in place again. The cost of step 3 is difficult to assess for the time being. Revenues streams are associated to each step, but quantifying them is difficult for the time being.

Co-design with Lenntech

Co-design with Lenntech was performed through one interview. This resulted into important specifications of the circular business models elements, reported in Table 7.

Table 7: Results of co-design with Lenntech

Circular value proposition	Circular value creation	Circular value delivery	Circular value capture
Lenntech does not have additional inputs or remarks.	Requires an important role of Lenntech. Lenntech is willing to provide its nanofiltration and reverse osmosis membranes only under a sub-contractor agreement and it expects to charge the Zero Brine managing organization for the provision of such membranes. Lenntech is able to provide its expertise in system design and maintenance, expecting to be paid by the hour through a consultancy fee.	Lenntech does not have specific considerations. In line with its desired role of sub-contractor, its accountability relates only to delivering to Zero Brine, not being involved with the final delivery to clients.	Lenntech does not have specific considerations around how Zero Brine should charge clients for the provision of the integrated Zero Brine solution.

Co-design with ARVIA

Co-design with ARVIA was performed through one interview. This resulted into important specifications of the circular business models elements, reported in Table 8.

Table 8: Results of co-design with ARVIA

Circular value proposition	Circular value creation	Circular value delivery	Circular value capture
ARVIA does not have additional inputs or remarks.	Requires ARVIA to provide its Nyex technology for total organics removal. ARVIA is willing and able to provide it. In turn, it expects to charge the Zero Brine managing organization for the provision, or to charge the end client directly. Both options are acceptable. ARVIA has an interest in acquiring new clients via Zero Brine and is willing to support the managing organization in business development, while contributing with its network of clients.	ARVIA suggests a stepwise approach (step 0, 1, 2, 3) in line with its current business model and Sealeau's idea (see co-design with Sealeau).	ARVIA advises for multiple revenue streams, associated to the above-mentioned steps and provides indicative estimations based on its current business model: step 1, 6,000 EUR; step 2, 18,000 EUR; step 3, is difficult to quantify but ideally this is where most revenue is made. The price of step 1 and 2 should be calibrated to attract clients toward step 3. ARVIA suggests to incorporate a fourth revenue stream associated to client assistance for operation and maintenance. This may be charged as a hourly service fee.

Co-design with UNIPA

Co-design with UNIPA was performed through one interview. This resulted into important specifications of the circular business models elements, reported in Table 9.

Table 9: Results of co-design with UNIPA

Circular value proposition	Circular value creation	Circular value delivery	Circular value capture
UNIPA does not have additional inputs or remarks.	UNIPA is willing to be a technology supplier for the pilot, providing the crystallizer. At the same time, UNIPA is hesitant to supply in a post Zero Brine project business model, due to concerns on the intellectual property.	Not discussed.	Not discussed.

Co-design with Huntsman

Co-design with Huntsman in the form of an interview was not conducted because email contact with procurement director Bart de Waele and employee Maarten ter Weeme, already provided sufficient inputs concerning Huntmans's role in the circular business model. This resulted in the business model specifications reported in Table 10.

Table 10: Results of co-design with Huntsman

Circular value proposition	Circular value creation	Circular value delivery	Circular value capture
Not discussed.	Huntsman not willing to provide any resources to assist with the project, and unable to supply waste heat because their processes are already highly "heat integrated".	Not discussed.	Not discussed.

Co-design with IVL

Co-design with IVL was performed through one interview. This resulted into important specifications of the circular business models elements, reported in Table 11.

Table 11: Results of co-design with IVL

Circular value proposition	Circular value creation	Circular value delivery	Circular value capture
IVL does not have additional inputs concerning the two main sources of value (a and b, see co-design with TU Delft). The results of IVL's LCA and LCC performed in WP7 show that implementing the Zero Brine solution may result in a negative impact, both in environmental and economic terms (see annex A for more details). This represents an issue for the definition of a business case underpinning a circular business model at Botlek.	IVL is willing to provide LCA as a complementary service to Zero Brine clients as a way to strengthen the circular value proposition. IVL expects to charge clients for this independently from Zero Brine, through a consultancy fee.	IVL takes care of the delivery of the aforementioned LCA service.	Discussed only for the part concerning IVL, namely that IVL expects to monetize its LCA services to clients.

Co-design with Evides Industriewater

Co-design with Evides was performed through three interviews, taking place at different points in time throughout the project. This resulted into important specifications of the circular business models elements, reported in Table 12 below.

Table 12: Results of co-design with Evides industriewater

Circular value proposition	Circular value creation	Circular value delivery	Circular value capture
Evides does not consider itself to be a potential client or immediate user of the Zero Brine technologies. The two main sources of value put forward by the value proposition (see co-design with TU Delft) are not relevant for the company: (a) Evides does not need to pay (significant) taxes for brine discharge at Botlek; (b) Evides is not interested in magnesium recovery and in sodium chloride recovery for internal reuse (for more details see annex A). Potential interest is also jeopardized by the fact that implementing the technology would lead to a significant increase of operating costs (see annex A, co-design with Evides and co-design with IVL). The rationale of Evides for collaborating with Zero Brine stakeholders is learning more about the technologies, especially EFC, in order to be able to independently design and operate a more advanced brine treatment system, in case regulations may require it in the future.	Evides not willing to provide its facilities to install the Zero Brine technologies at a full-scale, commercial business model. Evides is willing to provide brines to a prospective plant for magnesium recovery, if sufficient quantity to justify a business case can be reached using also the brines of nearby industries. Evides willing to provide expertise to build this plant, which should not be located at its premises (see annex A for more details).	Evides is not willing to play an active role in value delivery, related to the prospective plant for magnesium recovery (see annex A for more details).	Evides would be willing to discuss how to share with Europiren and other stakeholders the revenues related to selling magnesium hydroxide, but it would not be willing to invest any of its resources into building the plant. In Evides' opinion, the resources should come from other parties of from public funding.

Co-design with Rotterdam Port

Co-design with Rotterdam port was performed through one interview. This resulted into the business model specifications reported in Table 13.

Table 13: Results of co-design with Rotterdam Port

Circular value proposition	Circular value creation	Circular value delivery	Circular value capture
Rotterdam Port has doubts on tax reduction being a source of value for process industries at Botlek (see co-design with TU Delft and with Evides) because currently, process industries located in the Port do not need to pay to discharge brines (or very little). The Port thinks that	The Port mentioned has no direct interest to engage with Zero Brine at the moment. The port would be able to allocate physical space for a plant recovering raw materials (in particular magnesium hydroxide) out of wastewater only if such plant would be financially successful and able to pay for that space, which requires a very solid business case.	the Port is not willing to play any active role in a potential Zero Brine business model and does not have specific	The Port does not have specific suggestion. The potential revenues from Zero Brine

there is not a problem with brines in Botlek. Concerning value associated to resource recovery, the Port sees alignment with its circular economy vision, but based on the results of WP2 does not see business potential around the recovery of magnesium hydroxide yet.	If business case is in place, the Port could provide the space in turn of rental fee. The Port is not interested in owning the plant, or in helping to build it. In relation to waste heat, the port mentions that opportunities to use it to power Zero Brine technologies may be very limited (see annex A for more detail).	suggestions in this regard.	magnesium recovery and sale appear to the Port very far from justifying a business case.

Co-design with DCMR

Co-design with DCMR was performed through one interview. This resulted primarily into important specifications related to the criteria that a Zero Brine spinoff would need to meet in order to establish a circular business model in the Botlek area within the port of Rotterdam (see annex A for more details). Furthermore, this resulted into the specifications reported in Table 14.

Table 14: Results of co-design with DCMR

Circular value proposition	Circular value creation	Circular value delivery	Circular value capture
DCRM has not direct remarks on the value proposition, but raised some doubts on its applicability in Botlek.	DCMR may support the circular business model by providing Zero Brine stakeholders with a “waste processor” permit to operate at Botlek for the sake of brine treatement and resource recovery. In turn, it requires a solid environmental and possibly economic rationale to issue such permit, which do not seem to be there.	DCMR has no major inputs and remarks.	DCMR has no major inputs and remarks.

Co-design with Zero Brine Advisory Board

Finally, the last co-design moment with the Zero Brine advisory, performed through one interview, allowed to elaborate upon the results of the co-design with all other stakeholders, in order to explicitly identify the barriers and drivers related to the implementation of a Zero Brine circular business model at Botlek. Potential next steps were also discussed. More details in this regard are provided in section 3.3.

3.3 Circular business model design outcome

The final outcome of the circular business model design process is a circular business model concept proposal, mapped upon the tool that was used to conduct all the co-design activities, and based upon the coherent integration of their results. This is visualized in Figure 5. In particular, the figure explains what would be the circular value proposition of the business, as well as, how such value proposition could be delivered to potential clients at Botlek, and how this could, in principle, generate profit. The figure also explains how circular value creation would take place, clarifying what would be the stakeholder roles needed within the business, as well as the challenges that emerge in relation to these roles. In this regard, we raise an important point concerning the business impact and risk of the implementation of a Zero Brine business model at the premises of Evides Industriewater at the Botlek site of the Port of Rotterdam. In particular, we point out that for the time being, implementing this circular business model at this site is, for the time being, not possible, mainly due to the lack of a solid business case. Below the figure, specific barriers and drivers related to business impact risks of the business model are listed, followed potential next steps flowing into a future vision.

Figure 5 Proposed circular business model concept, mapped upon the co-design tool, and based on the combined results of all co-design activities: see Annex C

Barriers

The barriers that hinder the implementation of a Zero Brine circular business at the premises of Evides at the Botlek site of Rotterdam Port are listed below:

- At Botlek there is currently no regulation restricting the discharge of brines. This means that firms operating at the site, currently have no limitations in terms of discharge requirements, volumes and taxation. Regulations are very unlikely to be put in place in the future as well. In turn, this severely undermines the foundations of business case for implementing the technology in the area.
- The outcome of the demonstration points out that it is not possible to recover from the brines supplied by Evides a quantity of magnesium hydroxide that is significant from a commercial stand point. This undermines the foundations of a business case based on magnesium recovery. More specifically, if larger quantities of magnesium recovery cannot be guaranteed, Europiren is not willing to engage as a commercial partner within a Zero Brine circular business.
- The outcome of the demonstration points out that reusing the recovered sodium chloride within the demineralized water plant of Evides is not desirable due to the firm’s concerns around the unwarranted quality of the resource, which could damage their equipment. Considering the low cost of the resource, the challenges of recovery and remarketing do not outweigh the benefits of purchasing virgin sodium chloride. Relatedly, the provision of recovered sodium chloride to other parties in the area would face similar challenges. This undermines the foundations of a business case based on sodium chloride recovery.
- A business case based on water recovery cannot be laid out, due to the fact that there are no water scarcity issues in the Botlek area.
- Evides is not willing to purchase and / or use Zero Brine solution as provided by the technology suppliers within the Zero Brine consortium, which undermines the possibility to implement a collaborative circular business (see Table 12 for detailed information on the reasons). In turn,

the approach preferred by Evides is learning from the results of the project in order to be able to implement potential brine treatment solutions independently, if necessary, in the future.

- The results of the life cycle assessment point out that implementing the technologies would not necessarily lead to significant environmental benefits, due to rebound effects. In particular, rebound effects mainly consist in increased resource use to produce the Zero Brine technologies, increased water acidification and eutrophication due to micropollutant released in the brines by the technologies, increased greenhouse emissions associated to the energy needed to power up the technologies (see Table 11 for more detailed information on rebound effects identified in WP7). Regarding the latter, the use of residual heat from nearby industries is essential to achieve a positive environmental impact. However, Huntsman is not able to supply Zero Brine with residual heat because it processes are already highly heat-integrated. Similarly, the Port of Rotterdam mentioned that connecting the residual heat streams of its tenants has already proven to be a very problematic issue both from a logistic and economic standpoint.
- The results of the life cycle cost analysis indicate that implementing the technologies at the premises of Evides would lead to an increase in operating costs for the firm by a factor of five.
- DCMR is not able to grant Zero Brine the permit to operate commercially in the Port of Rotterdam through a circular business model unless significant environmental benefits (and a solid business case) can be demonstrated.
- The Port of Rotterdam, as land owner, is not willing to invest time and resources to support the commercial upscale of the Zero Brine project, unless a solid business case is present.

Drivers

A potential future implementation of a Zero Brine circular business model at the Botlek site of Rotterdam Port (and beyond the specific case of Evides) may leverage the following drivers:

- Evides is willing to supply its brines for the recovery of magnesium hydroxide, given that recovery equipment is not installed at its own plant. Furthermore, Evides would be willing to support the construction and operation of such plant if this turns out to be a profitable effort. At the same time, Evides is not willing to invest its own resources into this up front, suggesting that additional EU public funding or private resources of the technology suppliers should be leveraged to this end.
- At Botlek there are multiple firms that generate and discharge brines. If these brines were combined with the brines of Evides, it may be possible to recover the magnesium hydroxide quantity required by Europiren to step in and put the resource back on the market and generate revenue. In particular, 50t/year can be recovered from the brines of Evides. Europiren mentioned that the minimum quantity needed to support a business case is 2,000t/year. To meet this target 39 brine suppliers like Evides are needed. The results of the demonstration show that magnesium hydroxide recovered from the brines of Evides has a

purity of 67%. With this level of purity, Europiren would be able to target the a market-niche (thin fire-retardant rubber cables) with a selling price of 2,000€/t. If quantity target can be met by involving 39 additional brine suppliers, this would result into yearly revenue of 4,000,000 €.

- The Port of Rotterdam may be willing to provide the land to build a plant for recovering and reselling magnesium hydroxide, if there is a business case. However, 4.000.000 €/year may not be a sufficient to justify action in this direction, since this is a relatively small amount from the perspective of the Port of Rotterdam.

Next steps

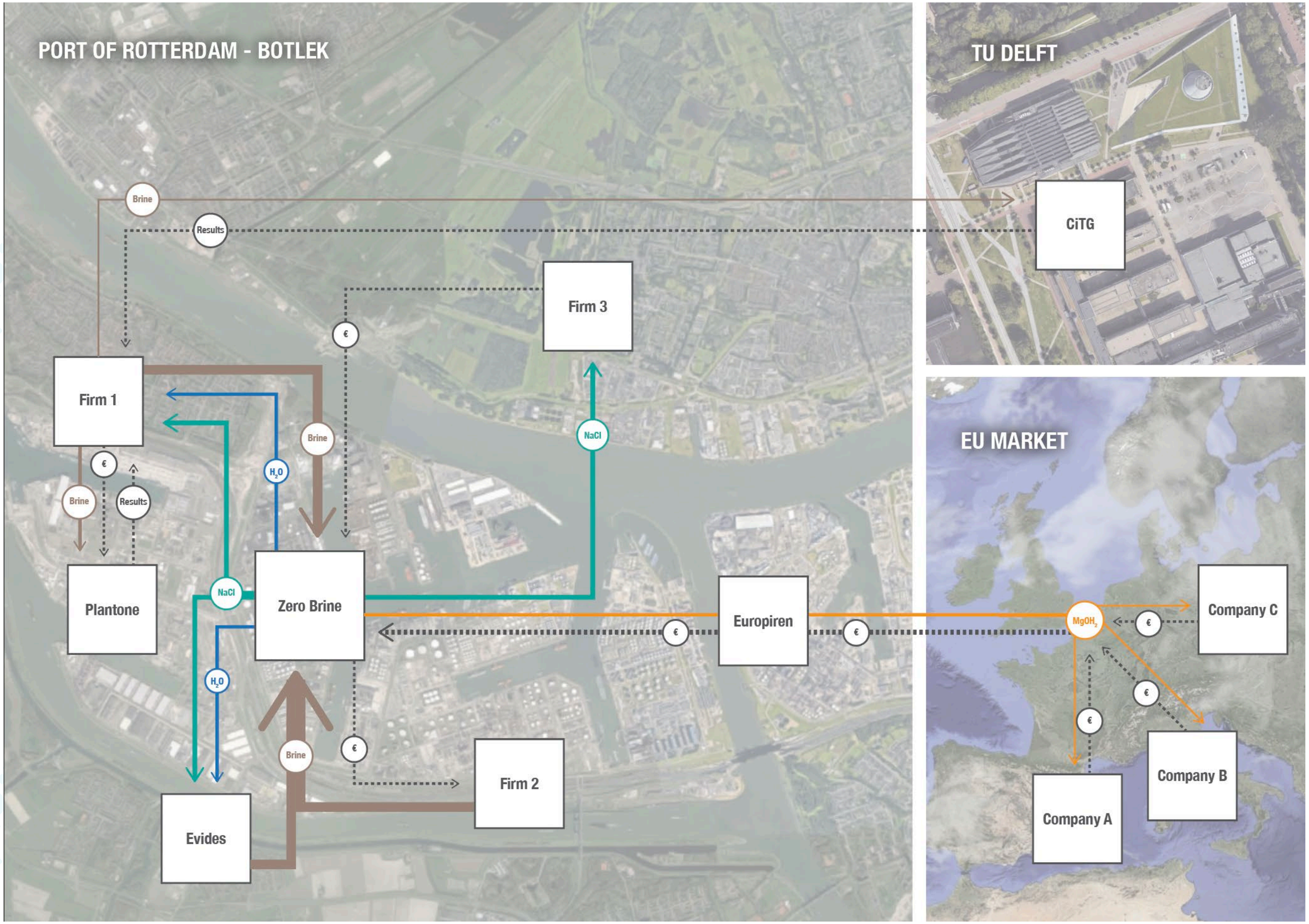
Based upon the drivers listed above, the following next steps are recommended:

- Investigate how many firms in Botlek would be willing to supply their brines for magnesium recovery.
- Make a lab test of their brines to verify if recovery is relevant to meet purity and quantity targets.
- If the aforementioned targets are met, and enough suppliers are willing to get on board, estimate the potential costs and revenues associated to building and operating a magnesium hydroxide recovery plant located at Botlek.
- Discuss the business case with all brine suppliers, Zero Brine technology providers, Europiren and the port of Rotterdam to align on commitments and expectations towards the definition of a business plan.
- Define a business plan clarifying roles and responsibilities (who builds the plant, where the resources come from, how is the brine transported to the plant, how is profit shared) on the way forward.

Future vision

The next steps mentioned above are geared towards a future vision of a plant located at Botlek for brine recovery and re-commercialization of magnesium hydroxide. This vision is sketched in Figure 3. In particular, the figure shows that in the future Zero Brine (possibly in the form of a spin-off involving key stakeholders) may play a role in collecting brines from Evides and other process industries located at Botlek (brown flows), and in turn supply them with clean water (blue flows) and sodium chloride (green flows) as inputs into their processes. In addition, in collaboration with Europiren, Zero Brine would contribute to put recovered magnesium hydroxide back on the EU market (orange flows). The figure also shows that the CiTG faculty of TU Delft may play a key role in running a first lab test of the brines of process industries, while PlantOne may be involved to run the next piloting step before moving forward with a full-scale commercial agreement with the involved firms. Finally, the figure also shows how this effort would be monetized (black dotted flows).

Figure 3: Future vision for brine recovery and re-commercialization of magnesium hydroxide (as well as potential reuse of sodium chloride and water in the area)



4. Conclusion

The main conclusion of task 8.1 is that that for the time being, implementing a circular business around the Zero Brine technologies installed at the premises of Evides Industriewater at the Botlek site of the Port of Rotterdam is not feasible, mainly due to the lack of a solid business case. The barriers, drivers, next steps and future vision outlined above, may be leveraged to inform other tasks of the Zero Brine project, as well as potential follow-ups of the project.

ZERO BRINE

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Annex A

Co-design at the first stakeholder consultation event

Overview of the activity: Co-design at the first consultation event was performed in a workshop format, taking place at the faculty of applied sciences of the TU Delft at the beginning of the project. At the workshop the following stakeholders were present: Europiren (Cristinel Degeratu - chemical engineer), Sealeau (Dimitris Xevgenos - managing director; Fred Govaert - engineer, MBA, advisor), TU Delft (George Tsalidis - engineer, postdoc), DCMR (Koen de Kruif - senior sustainability advisor; Hans Gerritsen - senior sustainability advisor), Akso Nobel (Thijs de Groot - innovation technologist), ISPT (Menno Plantega - program manager), PlantOne (Gabriel Tschin - owner, managing director), RVO (Corinne van Voorden - circular economy program manager), RHDHV (Steve Lemain - environmental consultant, project manager), Evides Industriewater (Wilbert van den Broek - senior process engineer). The activity started with a presentation where participants were introduced to the basics of circular economy and business model innovation theory, to pave the way to the actual co-design phase. To this end, the stakeholders were split into three working groups sitting at different tables. Each group worked separately for one hour to discuss their role in the Zero Brine project and in a prospective business model. As part of this process, they mapped with post-it notes ideas and insight onto the tool (see Figure 4), printed as a large poster. This process was guided by IDE researchers Dr. Brian Baldassare and Associate Professor Giulia Calabretta, who played the role of facilitators, while also taking separate written notes. Finally, the working groups reconvened in in a plenary discussion to jointly reflect on the outcomes of the activity. At the end of the activity, the IDE researchers collected the filled-in tool templates and qualitatively analyzed them (Miles et al., 2013) along with their own written notes to derive results. The most relevant insights were summarized and re-mapped by the researchers on a clean version of the tool to inform future co-design activities.

Results of the activity: The main result of this activity was to start establishing mutual trust and understanding toward the definition of the circular business model around the elements put forward by the tool. Concerning the circular value proposition, it was largely agreed that resource recovery would be the core of it. Relatedly, there was consensus around the need of quantifying both economic and environmental impact, which would be possible through the LCA and LCC tasks performed within WP7. KPIs suggested to measure environmental impact included kg/tons of recovered minerals (sodium chloride an importantly magnesium hydroxide, which is a listed as critical in the EU list of raw materials), and liters of recovered water. Uncertainties on how to quantify positive social impact emerged.

Concerning circular value creation, PlantOne agreed to provide its facilities as a test-bed location within the Port of Rotterdam. While this role of PlantOne was considered sufficient to support the demonstration, the need to consult the Port of Rotterdam concerning land-use arose as a key priority, in view of full-scale implementation of the Zero Brine technologies. In addition, next to Air Products, Huntsman was mentioned as potential provider of waste heat as an input for the evaporator supplied by Sealeau, which is a key component of the Zero Brine technologies. Evides Industriewater confirmed its key role in circular value creation based on the supply of their wastewater output, consisting of brines containing a high concentration of minerals to be recovered, including sodium chloride and magnesium hydroxide. Evides mentioned no interest in the recovery of magnesium hydroxide, but a potential interest in the reuse of recovered sodium chloride and water, which are needed for its demineralized water production processes. Europiren confirmed its key role related to remarketing the recovered magnesium hydroxide. Participating stakeholders also discussed the ownership of the Zero Brine process technologies within the prospective business model, which entails sharing equipment, information and service provision on behalf of the technology manufacturers. However, consensus on this issue was not reached. Concerning circular value delivery consensus was not reached and no ideas were generated except the insights related to the chemical leasing model used by RHDHV, which could become a source of inspiration for the Zero Brine business model. Concerning circular value capture consensus was not reached, mentioning that this would be defined eventually in the course of the project, once the technical results of the large-scale demonstration would be available.

Co-design at the second stakeholder consultation event

Overview of the activity: Co-design at the second consultation event was performed in a workshop format, taking place at the premises of EURECAT, half way through the project in occasion of the second yearly project meeting. At the workshop all Zero Brine stakeholders were present. The activity started with a brief presentation on the insights deriving from the previous co-design workshop and other co-design interviews performed in the meantime with individual stakeholders. After being triggered with these inputs, twenty participants from Zero Brine partner organizations worked together in five groups of four members, each focusing on co-defining a potential circular business model. The co-design session lasted two hours. As part of this process, each group outlined a suggested business model within the tool template (see Figure 4), printed on an A4 page. This process was facilitated by IDE researchers Dr. Brian Baldassare, who played the role of facilitator rotating across groups, while also taking separate written notes. At the end of the activity, the IDE researchers qualitatively analyzed (Miles et al., 2013) the filled-in tool templates and along with the written notes to derive results. The most relevant insights were then summarized and then re-mapped by the researchers on the clean version of the tool, gradually being populated by the emergent business model idea, to inform future co-design activities.

Results of the activity: The main result of this activity was to nudge the Zero Brine stakeholders to generate circular business models ideas, which would be complete in terms of the definition of a value proposition, as well as value creation delivery and capture. This however, proved to be very challenging. Concerning the circular value proposition, consensus had been already reached on resource recovery being at its core. However, divergent views emerged concerning who would be exactly the provider of such proposition, and who would be the customer. In particular, on the customer side, companies in the process industry who are willing to treat their wastewater flows while recovering raw materials were mentioned. Relatedly, divergent views emerged on the role of Evides Industriewater within the business model, which in line with the aforementioned view could be considered as a potential and "archetypical" client. At the same time Evides' expertise on wastewater treatment processes would also allow to position this stakeholder on the side of the solution provider. Further discussions on this point were considered to be necessary. On the solution provider side, consensus was reached upon the need of focusing on a joint effort of the technology manufacturers, which could take place in the form of a Zero Brine project spin-off launched by some of the key stakeholders upon project completion. The main source of competitive advantage of such spin-off on the market was also outlined in terms of the high-energy efficiency of the process for raw material recovery, compared to existing solutions based primarily on evaporation. Concerning circular value creation, the discussion on stakeholder roles advanced only to a limited extent compared to the previous joint co-design session. Concerning circular value delivery two options were identified. The first option would entail providing the Zero Brine solution (as a "modular technology system") to clients through a leasing model. The second option would entail providing it through a one-off sale model. Furthermore, the scope of value delivery performed by the spin-off was also discussed, raising the issue of whether it would make sense to reach potential customers only in Botlek and in the demineralized water industry as indicated by the grant agreement, or rather to broaden the scope to the entire Port of Rotterdam and potentially even beyond that, targeting also companies operating in different industrial sectors (e.g. also silica, textile and coal-mining industries). Concerning the value capture element of the circular business model the issues of revenue streams and costs were discussed and mapped on the tool template. In particular, an open question remained around the profitability of selling recovered materials, mainly sodium chloride and magnesium hydroxide. This could not be defined due to uncertainties around the quality and purity of such recovered materials, which was still to be confirmed by the technical results of large-scale demonstration. Also, who would profit from the sale of recovered materials, and in particular from magnesium hydroxide, remained an open issue. An option could be that only Europiren would benefit, while another option would be that all stakeholders involved in the spin-off would profit. In contrast, agreement was reached on the fact that technology manufacturers would share the revenues deriving from leasing or selling their "modular solution". Finally, on the cost side, a last crucial insight was related to the need of supporting the spin-off in the startup phase, potentially through additional EU funding or external private investor, because none of the involved stakeholder indicated to be willing and / or able to invest its own resources in this effort.

Co-design with TU Delft

Overview of the activities: Co-design with TU Delft was performed through a series of interviews, taking place at different points in time throughout the project. Two interviews were conducted with Roelof Moll, the executive project coordinator. These two interviews were complemented by frequent email exchanges about the content of the circular business model. One interview was conducted with Prof. Luuk Rietveld, the scientific project coordinator. One interview was conducted with Paul Althuis, the director of the TU Delft valorization center. One interview was conducted with Associate Professor Henri Spanjers. This interview was complemented by email exchanges. All interviews were conducted by IDE researcher Dr. Brian Baldassarre, in some cases in collaboration with Associate Professor Giulia Calabretta. Some interviews were performed face-to-face and some through video-conferencing. All interviews were audio recorded. During the interviews, interviewees were shown the tool template (printed on paper in the case of face-to-face interviews and on a digital whiteboard in the case of video-conferencing) partially filled in with the circular business model elements that had already emerged in previous co-design activities. After briefly summarizing this content, interviewees were asked to elaborate further and on it and generate additional ideas that could inform the final circular business model. In this instance, they were given the opportunity to map their inputs on the tool themselves, while the researchers also took care of mapping their inputs on the tool as they responded to prompt questions. At the end of the activity, the IDE researchers qualitatively analyzed (Miles et al., 2013) the filled-in tool template. The most relevant insights were then summarized and then re-mapped by the researchers on the clean version of the tool, gradually being populated by the emergent business model idea, to inform future co-design activities.

Results of the activities: Co-design with TU Delft resulted into important specifications of the main circular business models elements of value proposition, creation, delivery and capture. Concerning the circular value proposition, it was specified that prospective users and / or clients of the Zero Brine technologies may benefit in relation to wastewater discharge regulation affecting their current business. In other words, companies discharging wastewater have to pay taxes for it, and in some cases, they are not allowed to discharge more than a certain amount, which may turn into a limitation for their business productivity. In addition, the value associated to resource recovery from the brines supplied by Evides Industriewater was quantified, according to the results of pilot 1 and pilot 2 performed within WP2. In particular, in terms of the resources that could be recovered from the brines provides by Evides, it was estimated that from the total 106 tons/day of ion brines currently discharged by Evides, assuming continuous operation of the Zero Brine technologies at full capacity it would be possible to recover: 8.2 kg of calcium per ton of brine; 1.3 kg of magnesium hydroxide per ton of brine; 0.35 tons of kg of sodium chloride solution (target 9%), which corresponds to 350 kg of sodium chloride per ton of brine. The quantity of recovered calcium was considered fair; however, this resource holds low commercial value. In contrast, magnesium hydroxide holds high commercial value but the quantity was considered extremely limited, equal to an amount of approximately 50 tons/year. Finally, the quantity of recovered sodium chloride was considered high. It was also specified that reverse osmosis step produces 6000 tons/day of brines, which is also discharged, but does not contain calcium and magnesium hydroxide, only sodium chloride, which would be recovered in pilot 2. However, sodium chloride holds very low commercial value. In relation to the latter, TU Delft mention that this sodium chloride may be reused within the plant of Evides to support the demineralized water production process. Alternatively, it could also be supplied to Nouryon, a nearby company in Botlek that needs salt for its processes. However, doubts were raised around the practicalities of doing so, since sodium chloride is cheap to buy, the one coming from Zero Brine is not yet guaranteed in terms of quality, and quantities may not be sufficient anyways, requiring Nouryon to have multiple suppliers instead of just one, which is a complication. Concerning circular value creation, TU Delft reported strong willingness to be a supplier of the EFC technology through the faculty of applied sciences. In this regard, the valorization center mentioned its willingness to support with its competences and resources the creation of a spin-off after in case of positive end results of the project, as well as to act as a glue across stakeholders to facilitate the creation of such spin-off. In this regard, the valorization center would expect to get a share of the spin-off. Concerning circular value delivery, concerns were raised around its feasibility. Considering the relatively low TRL of the EFC technology, it was difficult to estimate if this technology in its current state would be suitable for sale or lease. Brine excellence centers, which are the output of work carried out in WP5, were also mentioned as a potential platform to kickstart a first step of value delivery in the form of lab experiments, nonetheless leveraging as well the software developed by DLR and the matchmaking platform developed by ISPT. Concerning circular value capture, the relatively low TRL was also mentioned an important concern. Therefore, TU Delft looked at value capture not only in terms of the commercialization of the ZEROBRINE technology, but also and importantly in terms of being a platform to start complementary research projects on smart brine management and brine design.

Co-design with Europiren

Overview of the activities: Co-design with Europiren was performed through two interviews, taking place at different points in time throughout the project. The first interview was conducted with Cristinel Degeratu, the chemical engineer working on research and development for Europiren. The second interview was conducted with Henk Don, Europiren's managing director. The latter interviews was complemented by email exchange through which documents that could inform the circular business model were shared. The two interviews were conducted by Dr. Brian Baldassarre, the first one face-to-face and the second one over video conferencing. Both interviews were audio recorded. The first interview had more of an exploratory connotation, discussing the current business model of Europiren in interest in the Zero Brine project, while the second one was more focused on the co-design of the circular business model, conducted upon a digital version of the tool template. After briefly summarizing previous inputs, the tool was consequently collaboratively populated with post-it notes containing Europiren's insights. At the end of the activity, the IDE researchers qualitatively analyzed (Miles et al., 2013) the filled-in tool template. The most relevant insights were then summarized and then re-mapped by the researchers on the clean version of the tool, gradually being populated by the emergent business model idea, to inform future co-design activities.

Results of the activities: Co-design with Europiren resulted into important specifications of the main circular business models elements, primarily in terms of Europiren's essential role for circular value creation and value capture. Concerning the circular value proposition, Europiren was mostly interested in the resource recovery part, in particular magnesium hydroxide, in line with its current business model based on selling this material to various clients in different sectors for various applications including: flame retardant polymers, reagents for marine scrubbers, gas and water purification, technical rubber products, metallurgic flux, fertilizers, pulp and paper. Currently Europiren sources brucite from a mine in Kuldur, Eastern Russia. From there brucite is shipped to Vyazma, close to Moscow, where it is mechanically processed, removing impurities, into magnesium hydroxide, in various forms (powder vs liquid, etc.) depending on the final client. Concerning circular value creation, Europiren would be willing to contribute by reselling recovered magnesium hydroxide to its current clients. In turn, Europiren would expect to profit from this effort either entirely or through a percentage. This aspect would need to be negotiated eventually in the business model implementation phase, when an agreement should be reached considering the costs for Zero Brine related to recovering the magnesium and the final price that Europiren would be able to charge its clients. In addition, Europiren would be interested in playing this role only if the recovered magnesium would be high in purity. The purity of 67% reported by pilot results is satisfactory for Europiren. In terms of quantity, that would need to be at least 2,000 tons per year, considering that current sales volumes of European are approximately 35,000 tons per year. For quantities inferior to 2,000 tons per year there is no business case for Europiren. Finally, Europiren would not be interested in supporting the business model by remarking other resources other than magnesium since that is too distant from its current business model. Concerning circular value delivery, Europiren would not be able to play an active role, since that is about defining how to install, operate and maintain the Zero Brine technologies into process industry company clients. This is outside the competences of Europiren. Concerning circular value capture, Europiren would play the role of converting recovered magnesium hydroxide into revenues for Zero Brine. With a purity of 67%, Europiren would be able to enter in an emergent, small, yet profitable niche in the magnesium hydroxide market, specifically: the niche of thin fire-retardant rubber cables. Other bigger players are doing this but they still do not meet all the market demand. Since production capacity is limited, supply of high purity magnesium is currently lower than demand. Europiren cannot capture this market niche with current brucite, which has a selling price of around 500 EUR/ ton and production cost of 200 EUR/ton. The reason why applications for thin cables is a small niche is that application is new and very big investments are needed. If Europiren was to produce magnesium with this purity from brucite they would need to invest 120 million Euro in a plant that first turns brucite into brine and then extracts the magnesium hydroxide. Starting already from brines supplied by Evides would be much cheaper, and this could be a case where secondary materials are actually cheaper than virgin ones. In terms of pricing, Europiren would be able to sell 67% purity magnesium for thin fire-retardant cables in a range between 2,000 and 3,000 EUR/ton. Next to selling price, cost also has to be considered, but at this stage in the project this would be difficult to estimate with accuracy. DLR has been focusing on this.

Co-design with Sealeau

Overview of the activities: Co-design with Sealeau was performed through three interviews, taking place at different points in time throughout the project. The first two interviews were conducted with Dimitris Xevgenos, the managing director of Sealeau. The third interview was conducted with Stefano Iannacone, senior program manager at Sealeau. One of the interviews with Dimitris Xevgenos was conducted by Dr. Brian Baldassarre face-to face. The other two interviews took place over video conferencing, conducted collaboratively by Associate Professor Giulia Calabretta and Dr. Baldassarre. All interviews were audio recorded and conducted using as a support either a paper or digital version of the tool. After briefly summarizing previous inputs, the tool was collaboratively populated with post-it notes containing Sealeau's insights. At the end of the activity, the IDE researchers qualitatively analyzed (Miles et al., 2013) the filled-in tool templates. The most relevant insights were then summarized and then re-mapped by the researchers on the clean version of the tool, gradually being populated by the emergent business model idea, to inform future co-design activities.

Results of the activities: Co-design with Sealeau resulted into important specifications of the main circular business models elements of value proposition, creation, delivery and capture. Concerning the circular value proposition, Sealeau was aligned with TU Delft. In particular, Sealeau saw the value proposition revolving around two main aspects. First: reducing / eliminating the taxes that process industry clients have to pay to discharge brines; or allowing them to discharge where they are currently not allowed to do so; or allowing them to increase their discharge volumes, which are directly correlated to their production volumes, hence their profit. Second: resource recovery (including water), which can be turned by the client into profit either by reusing them in the facility or by selling them to other parties. In the latter case, and in relation to magnesium hydroxide, cooperation with Europiren would have to be discussed. Regarding the relevance of this value proposition Sealeau raised two important concerns. The first concern is related to current brine discharge regulation in Botlek, which may not be stringent enough to make the first source of value relevant for Evides Industriewater. The second concern is related to the quantity and market value the materials recovered from the brines of Evides. Taking into consideration these concerns, which may result in the lack of a business case for implementing the Zero Brine technologies in Botlek at the premises of Evides Industriewater, Sealeau mentioned that there may be potential to implement the Zero Brine technologies beyond Botlek and in other industries. Investigating such business cases however, is an effort that fall outside the scope of task 8.1 Finally, Sealeau had important consideration around how the circular impact of the Zero Brine value proposition could be measured. In particular, the following KPIs could be used: kg of recovered materials; kg of materials put back on the EU market; market size of recovered materials compared to virgin materials; number of clients acquired across different industry sectors (in other words: number of companies and number of sectors that are treating their wastewater and recovering materials thanks to Zero Brine). The latter is an economic KPI with an environmental background, compared to kg of recovered materials that is just environmental. Concerning circular value creation, the contribution of Sealeau to the business model would be the following: being a technology supplier for the evaporator, which is a key component of the Zero Brine treatment train; potentially being the managing organization, meaning the main solution contractor for all the technologies in the treatment train, while other technology suppliers could play the role of sub-contractors. In addition, in case of possibilities to expand the business model beyond the plant of Evides, Sealeau would be willing to play a business development role, finding other process industry clients that may be interested of implementing the Zero Brine technology in their facilities. Relatedly, when finding such clients and discussing with them the technical specifications of the technologies needed to treat their wastewater, Seleau may be able to get in touch with new technology suppliers to meet the client requirements for the desired solution, if needed. Finally, Sealeau mentioned concerns around intellectual property. Indeed, while the technologies in the treatment train may be patented individually, it does not seem to be possible to patent their combination into the treatment train itself. This represents a risk because clients may be able to then purchase the single technologies from competing parties and then assemble them into the treatment train on their own, provided that they have the know-how to do so. This is a risk of the entire circular business model and should be taken into careful consideration. Concerning circular value delivery, Sealeau discussed a stepwise approach. The first step is reaching out to potential process industry client in the Botlek area. After contact is established, the second step entails getting a sample of their brines and make a lab test. The Dutch brine excellence center may support this effort. If the outcome of the lab test shows potential for effective wastewater treatment and resource recovery, and if the client is interested to proceed, the next step installing a small-scale version of technologies in the facility of the client, to run a pilot. The latter step was already covered with Evides within the course of the Zero Brine project, through pilot 1 and pilot 2 performed within WP2. Nevertheless, looking at a prospective circular business model upon project completion entails acknowledging that these steps may have to be repeated with other process industry companies in Botlek. If the results of pilot are positive, the following step is then full-scale implementation of the technologies in the facilities of the client. Two options for full-scale technology delivery would be possible. The first option is that the technology suppliers, coordinated by the managing organization sell the technologies up front to the client, supporting it with operation and maintenance for several years. This first option entails high upfront costs for the client, which may result in a barrier for purchase. The second delivery option is service based / leasing. In this scenario, the Zero Brine technology suppliers, coordinated by the managing organization, retain ownership of the equipment over time, while the client pays a recurring fee (frequency would need to be agreed upon). Afterwards, when the equipment is depreciated, ownership shifts to customer, which is the meantime has learned to operate and maintain it. Based on the depreciation and lifetime of regular desalination plants, a reasonable ownership transfer time could be 20 years, but this of course would have to be assessed case by case. If at any point in time, the client does not need or want the solution anymore, technology suppliers would take the equipment back and re-use it with other clients. This model is indeed leaner since it requires much lower commitment and upfront investment from the client. On the other hand, it has two critical aspects: evaluation of to what extent the equipment can be disassembled and reused which may not always be possible (e.g. membranes have a lifespan of 2 years and are not so expensive. In this case service model may be possible. if the treatment train also includes an evaporator, it is necessary to evaluate if this piece can then be collected back by the task force and reused with another client); and very high upfront investment costs for the technology providers, which are unlikely to be able to cover them, and would therefore require an external source of funding (e.g. additional EU project funding). The choice between the first and second option depends upon multiple business as well as technical aspects, which must be assesses case by case. For the time being, it is not possible to make a clear choice, and in the specific case of Evides it is not clear which option would be more suitable. Concerning circular value capture, costs and revenues associated to a circular business model in Botlek would be aligned with the above-mentioned value delivery steps and options. In particular, costs would be associated to financing a first feasibility study, a pilot, and eventually full-scale implementation. The costs for the first steps with Evides were already covered via the EU project funding, while the costs of full scale implementation seems at the moment difficult to assess. Targeting other clients in the Botlek area would entail also covering again the costs for the first two steps. In terms of revenues streams, they would have to be associated to each step: a revenue stream for the test, a revenue stream for the pilot, and a revenue stream for the full-scale implementation. Quantifying the amount that should be charged to clients within each stream it is difficult for the time being.

Co-design with Lenntech

Overview of the activity: Co-design with Lenntech was performed through one interview, conducted with Lorenzo Salin, one of the senior directors at the firm. The interview was led by Dr. Brian Baldassarre, over video conference, using as support a digital version of the tool. The interview was audio recorded. After briefly summarizing previous inputs, the tool was collaboratively populated with post-it notes containing Lenntech's insights. At the end of the activity, the IDE researchers qualitatively analyzed (Miles et al., 2013) the filled-in tool template. The most relevant insights were then summarized and then re-mapped by the researchers on the clean version of the tool, gradually being populated by the emergent business model idea, to inform future co-design activities.

Results of the activity: Co-design with Lenntech resulted primarily into important specifications related to the role of this stakeholder in circular value creation. Concerning the circular value proposition, Lenntech did not have additional inputs or any remark on top of the main sources of value for clients being resource recovery and solving wastewater treatment issues (e.g. permits, taxes, etc.). Concerning circular value creation, Lenntech is willing to provide its nanofiltration and reverse osmosis membranes under a sub-contractor agreement. In turn, Lenntech expects to charge the Zero Brine managing organization for the provision of such membranes, while having a direct interest in gravitating around the business model as a way to learn about innovative solutions and expand its network of clients and partners. In addition, Lenntech would also be able to provide its expertise in system design and maintenance, expecting to be paid by the hour through a consultancy fee. At the same time, Lenntech is not willing to be the main contractor of the Zero Brine technology-train, because of accountability risks associated to the delivery to clients of technologies produced by other manufacturers in the Zero Brine consortium. In particular, concerns are associated both to the usability of these technologies (which are in some cases experimental e.g. EFC), and to the ability of Zero Brine partners to deliver them on time. Concerning circular value delivery, Lenntech did not have specific considerations. In line with its desired role of sub-contractor, its accountability relates only to delivering to Zero Brine, not being involved with the final delivery to clients. Concerning circular value capture, Lenntech did not have specific considerations around how Zero Brine should charge clients for the provision of the integrated Zero Brine solution.

Co-design with ARVIA

Overview of the activity: Co-design with ARVIA was performed through one interview, conducted with Nigel Brown, managing director, and Joseph Weston, business developer at ARVIA. The interview was led by Dr. Brian Baldassarre, over video conference, using as support a digital version of the tool. The interview was audio recorded. After briefly summarizing previous inputs, the tool was collaboratively populated with post-it notes containing ARVIA's insights. At the end of the activity, the IDE researchers qualitatively analyzed (Miles et al., 2013) the filled-in tool template. The most relevant insights were then summarized and then re-mapped by the researchers on the clean version of the tool, gradually being populated by the emergent business model idea, to inform future co-design activities.

Results of the activity: Co-design with ARVIA resulted primarily into important specifications related to the role of this stakeholder in circular value creation, and some suggestions related to circular value delivery and capture. Concerning the circular value proposition, ARVIA did not have additional inputs or any remark on top of the main sources of value for clients being resource recovery and solving wastewater treatment issues (e.g. permits, taxes, etc.). Concerning circular value creation, ARVIA is willing to provide its Nyex technology for total organics removal. In the grant agreement it was rated TRL 5 but it was 5 years ago, also because ARVIA did not have experience with treating brines. But now the technology is market-ready. In turn, ARVIA expects to charge the Zero Brine managing organization for the provision of the technology, or to charge the end client directly. Both options are acceptable. Indeed, ARVIA has an interest in gravitating around the business model as a way to learn about innovative solutions and expand its network of clients and partners, but at the same time it is willing to put an active effort in business development, while also helping Zero Brine to reach potential clients through ARVIA's network, beyond Botlek and possibly in the pharmaceutical industry, where there could be immediate opportunities. Concerning circular value delivery, ARVIA suggested a stepwise approach which is similar to their current business model. The first step would be a lab test of brines. This is in line with the outcome of the co-design session with Sealeau, and the brine excellence centers could be leveraged in this regard. The second step would be a pilot in the facility of the client, lasting between 1 and 3 months. The third step would then be full-scale implementation. Concerning circular value capture, ARVIA advised to establish multiple revenue streams, associated to the above-mentioned steps. The first revenue stream would be a payment for the lab-test of the brines. While ARVIA was not able to provide indications on how to quantify such stream, it provided information on how much they are currently charging their clients, which could be used as a rough guideline: 6,000 EUR. The second revenue stream would be a payment for the pilot. While ARVIA was not able to provide indications on how to quantify such stream, it provided information on how much they are currently charging their clients, which could be used as a rough guideline: 18,000 EUR. The third revenue stream would be a payment for the full-scale implementation. Estimating the amount of this up front is very challenging, nevertheless in terms of pricing strategy ARVIA advised to charge less for step 1 and 2 in order to attract clients towards step 3, which is where most revenue is made. At the same time, ARVIA mentioned that this strategy also entails risk. In particular, the risk is that once clients learn how the pilot is executed, they could then try to implement the full-scale solution independently, provided that they have the know how to do so. While ARVIA does not have particular IP concerns because their technology is patented and there are not many similar solutions on the market, this should be a concern for the overall Zero Brine solution since the overall train cannot be patented. Finally, ARVIA suggested to incorporate a fourth revenue stream associated to client assistance for operation and maintenance. This could be charge by the hour as a service fee.

Co-design with UNIPA

<u>Overview of the activity:</u> Co-design with UNIPA was performed through one interview, conducted with Andrea Cipollina (professor, industrial engineer), Giorgio Micale (professor, chemical engineers), Fabrizio Vassallo (PhD, engineer), and Serena Randazzo (researcher). The interview was led by Dr. Brian Baldassarre, who shared a digital version of the tool already fully populated with content with the interviewees, who had the opportunity to look into it. Consequently, a discussion on the suggested circular business model took place, where UNIPA provides his view and inputs in line with the co-design approach. This discussion was not audio recorded. During the activity the IDE researcher took written notes, which were then qualitatively analyzed (Miles et al., 2013) and then summarized and re-mapped

on the clean version of the tool, gradually being populated by the emergent business model idea, to inform future co-design activities.

Results of the activity: Co-design with UNIPA resulted primarily into important specifications related to the role of this stakeholder in circular value creation. Concerning the circular value proposition, UNIPA did not have additional inputs or any remark on top of the main sources of value for clients being resource recovery and solving wastewater treatment issues (e.g. permits, taxes, etc.). Concerning circular value creation, UNIPA is willing to be a technology supplier for the pilot, providing the crystallizer. At the same time, UNIPA reported hesitancy around involvement and technology supply in a post Zero Brine project business model, due to concerns on the intellectual property of their solution, which could be copied by clients. Concerning circular value delivery, the discussion with UNIPA did not touch upon specific considerations around how the Zero Brine technologies could be delivered to clients. Concerning circular value capture, the discussion with UNIPA did not touch upon specific considerations around how Zero Brine should charge clients for the provision of the integrated Zero Brine solution.

Co-design with Huntsman

Overview of the activity: Co-design with Huntsman in the form of an interview was not conducted because email contact with procurement director Bart de Waele and employee Maarten ter Weeme, already provided sufficient inputs concerning Huntmans's role in the circular business model. The email exchange took place between the aforementioned stakeholders and IDE researchers including Dr. Baldassare and Associate Professor Giulia Calabretta. The content of the email exchanges was summarized and mapped on the clean version of the tool, gradually being populated by the emergent business model idea, to inform future co-design activities.

Results of the activity: The email contact with Huntsman resulted in the clarification that this stakeholder is not willing and / or able to support circular value creation within a Zero Brine business model. Concerning the circular value proposition, Huntsman was not involved in discussion and co-design. Concerning circular value creation, Huntsman reported that they had already clarified to Dimitris Xevgenos from Sealeau, that the company would not be able to provide any resources to assist with the project. The rationale for this choice is that Huntsman processes are already highly "heat integrated" and therefore they do not have any "waste heat" to provide as an input for operating the Zero Brine technologies and in particular the evaporator. Finally, Huntsman suggested to contact other companies in the Botlek area, which may have a lower degree of heat integration and may therefore have "spent condensate" to provide as a source of waste heat. In this regard, specific suggestion in terms of company names were not provided. Concerning circular value delivery, Huntsman was not involved in discussion and co-design. Concerning circular value capture, Huntsman was not involved in discussion and co-design.

Co-design with IVL

Overview of the activity: Co-design with IVL was performed through one interview, conducted with Steve Harris, project manager. The interview was led by Dr. Brian Baldassarre, over video conference, using as a digital version of the tool. The interview was audio recorded. After briefly summarizing previous inputs, the tool was collaboratively populated with post-it notes containing DCMR's insights. This interview was complemented by email exchange through which documents that could inform the circular business model were shared. At the end of the activity, the IDE researchers qualitatively analyzed (Miles et al., 2013) the filled-in tool template. The most relevant insights were then summarized and then re-mapped by the researchers on the clean version of the tool, gradually being populated by the emergent business model idea, to inform future co-design activities.

Results of the activity: Co-design with IVL resulted into important considerations related to the environmental and economic impact of the circular value proposition, as well as about the potential role of IVL in circular value creation. Concerning the circular value proposition, IVL did not have additional inputs or any remark on top of the main sources of value for clients being resource recovery and solving wastewater treatment issues (e.g. permits, taxes, etc.). However, within WP7, IVL collaborated with TU Delft on performing an environmental life cycle assessment (LCA) and a life cycle cost (LCC) analysis to estimate the environmental and economic impact related to the prospective implementation of the circular value proposition. The results of the LCA show that implementing the Zero Brine solution may result in a negative impact against the following environmental indicators: CO_2 emissions; acidification; freshwater eutrophication; freshwater acidification; resource depletion. The reason why the environmental impact is negative mainly boils down to two factors. The first factor is that the Zero Brine technologies requires a lot of energy to function, in particular the evaporator. Energy demand might be reduced using waste heat, but at the moment a supplier of waste heat was not found. The second factor is that the materials used to produce the total organics removal technology (from ARVIA) are high impact materials. Overall, LCA results suggest that the environmental cost of extracting and processing those material outweighs the benefits related to the recovery of water, sodium chloride and magnesium hydroxide. It has to be considered though, that that the results of LCA are related to the pilot. In the future as the system becomes technologically more efficient, and when operating on a bigger scale, the outlook may be more positive. In the present these results may be used to create policy leverage (and therefore funding) to advance the Zero Brine toward commercial implementation. On the other hand, the results of the LCC show that implementing the Zero Brine technologies would not be economically attractive for Evides, raising its demineralized water production costs from 2.8€/m^3 to 10.3€/m^3. These figures do not include potential benefits deriving from the sale and reuse of magnesium hydroxide and sodium chloride.

Concerning circular value creation, IVL would be willing to provide LCA as a complementary service to Zero Brine clients as a way to strengthen the circular value proposition. This could be used by the client to prove to the public sector and business partners that it is complying or being ahead of environmental regulations related to wastewater discharge. IVL would expect to charge clients for this independently from Zero Brine, through a consultancy fee. Concerning circular value delivery, IVL would take care of the delivery of the aforementioned LCA service. Concerning circular value capture, IVL contribution would be a standalone from Zero Brine, getting separate revenues for the aforementioned LCA.

Co-design with Evides Industriewater

Overview of the activity: Co-design with Evides Industriewater was performed through three interviews, taking place at different points in time throughout the project. The first interview was conducted with Wilbert van den Broek, senior process engineer, over video-conference by Dr. Brian Baldassarre. The second interview was with Jan Willem Mulder, manager of process and technology, by Dr. Brian Baldassarre and Associate professor Giulia Calabretta, again over video conference. The third interview was again with Jan Willem Mulder and with Jan Robert Huisman, director at Evides Industriewater, conducted by Dr. Brian Baldassarre and Associate professor Giulia Calabretta in collaboration with the TU Delft executive project coordinator Roelof Moll, again over video conference. All interviews were audio recorded and conducted upon a digital version of the tool template. After briefly summarizing previous inputs, the tool was consequently collaboratively populated with post-it notes containing Evides' insights. At the end of the activity, the IDE researchers qualitatively analyzed (Miles et al., 2013) the filled-in tool template. The most relevant insights were then summarized and then re-mapped by the researchers on the clean version of the tool, gradually being populated by the emergent business model idea, to inform future co-design activities.

Results of the activity: Co-design with Evides Industriewater resulted into important specifications of the main circular business models elements of value proposition, creation, delivery and capture. Concerning the circular value proposition, Evides clarified that it's role is not being the client. Evides considers itself a potential user of the Zero Brine technologies. Evides clarified that its rationale for collaborating with Zero Brine stakeholders is learning more about the technologies, especially EFC, in order to be able to independently design and operate a more advanced brine treatment system, in case regulations may require it in the future. Evides would not consider purchasing the Zero Brine solution from other stakeholders in the consortium, because while learning about the solution through the project, they are acquiring the know how to proceed independently (being water treatment a core expertise of the company), and this is the approach that the company prefers. Evides does not see the need to proceed in this direction in the present nor in the future, because there is no business case that justifies the implementation of advanced brine treatment technologies in its facilities in Botlek. This relates to the two main proposed sources of value, which are not applicable to the firm. As mentioned, the first source of potential value would be reducing / eliminating the taxes that a process industry client has to pay to discharge brines. In the case of Evides in Botlek, brines containing salt and magnesium minerals are discharged next to the sea and do not pose any environmental threat to local ecosystems nor to agricultural activities (which could be affected negatively by an increase in the salinity of the soil). At the moment there are no regulations preventing Evides from discharging its brines in the area, and there are no concerns that such regulations may be implemented in the future. Hence, Evides is not required not interested to further treat its brines with new technologies. The second potential source of value is resource recovery. In the case of Evides in Botlek, clean water, sodium chloride, magnesium hydroxide and calcium could be recovered. Evides is not interested in the recovery of such resources. In the area there are no water scarcity concerns that justify integrate recycled water into the supply system. Evides hold no interest in the recovered calcium nor in the recovered magnesium hydroxide, unless a significant profit could be derived from the latter, which is not the case (according to the results of WP2). In principle, Evides could have an interest in reusing recovered sodium chloride to regenerate the ion exchange columns used within its current demineralized water production process. However, there are important concerns related to the purity of recovered salt, which is not guaranteed and may therefore damage the columns. The low price of virgin salt, which Evides currently purchases from a supplier, does not justify the risk and then technical challenge of installing and operating the Zero Brine technologies in its plant for salt recovery. Considering these issues, next to the fact that implementing the Zero Brine technologies would also result in a cost increase (see results of LCC from IVL), a circular business model in Botlek centered in the facilities of Evides in not an unattractive option for the firm. Evides also mentioned that in the future internal sustainability goals be leveraged to unlock funding for investing in brine treatment, but not at the moment. Concerning circular value creation, Evides mentioned already at the beginning of the project that it would not be willing to provide its facilities to install the Zero Brine technologies for the large-scale demonstration. Similarly, this applies to a prospective full-scale and commercial business model. However, Evides mentioned an interest in being involved in circular business model centered on magnesium recovery, if profitable. In this case, Evides would be willing to contribute by supplying its brines, from which 1.3 kg of magnesium hydroxide per ton could be recovered. Since this quantity would not justify a business case, according to Europiren, other brines from nearby process industries in Botlek would have to be added. In this scenario, Evides would also bring to the table its expertise to build and operate the plant from magnesium recovery, given that it would not be located at its premises. Concerning circular value delivery, taking as a reference the scenario sketched above, Evides would not want to play an active role in value delivery, meaning that it would not take up on the responsibility to find other brine supplier, not take care of the arrangements needed to get such brines into the plant (either by truck of by a piping system that would have to be built). Concerning circular value capture, evides would be willing to discuss how to share with Europiren and other stakeholders the revenues related to selling magnesium hydroxide, but it would not be willing to invest any of its resources into building the plant. In Evides' opinion, the resources should come from other parties of from public funding.

Co-design with Rotterdam Port

Overview of the activity: co-design with Rotterdam port was performed through one interview with Monique de Moel, manager of business development, by Dr. Brian Baldassarre and Associate professor Giulia Calabretta and Roelof Moll, over video conference. The interview was audio recorded and conducted upon a digital version of the tool template. After briefly summarizing previous inputs, the tool was consequently collaboratively populated with post-it notes containing insights from the Port of Rotterdam, specifically related to its potential role, but also to the drivers, barriers and next steps to be considered on the way forward. At the end of the activity, the IDE researchers qualitatively analyzed (Miles et al., 2013) the filled-in tool template. The most relevant insights were then summarized and then re-mapped by the researchers on the clean version of the tool, gradually being populated by the emergent business model idea, to inform future co-design activities.

Results of the activity: Co-design with Rotterdam Port mainly resulted into clarifications concerning the potential role of this stakeholder in the Zero Brine project, and in particular in relation to circular value creation. Concerning the circular value proposition, Rotterdam Port held important doubts concerning the fact that Zero Brine would help its potential clients in reducing / eliminating the taxes that they have to pay to discharge brines. Currently, process industries located in the Port do not need to pay to discharge brines (or very little) and the Port authority was very clear on the fact that there is no problem with brines in the area. Concerning value associated to resource recovery, the Port saw potential and alignment with its circular economy vision, which is being able to map all the resources and waste streams flowing through the port in order to help tenants to operate more environmentally friendly (both in terms of resource use and carbon emissions). This is essential for the future of the port because when in the future EU regulations will become more stringent the port must offer a solution to tenants to comply with the regulations. If tenants cannot reach the EU targets then they cannot operate and the port goes out of business too. Concerning circular value creation, the port mentioned that at the moment there is no direct interest to engage with Zero Brine. The business model of the port is based on land ownership and rental to tenants. Thus, as land owner, the port would be able to allocate physical space for plant recovering raw materials (in particular magnesium hydroxide) out of wastewater only if such plant would be financially successful and able to pay for that space, which requires a very solid business case to compete for that space with other potential tenants. If a solid business case would be in place, the Port could provide the space in turn of rental fee, but it would not be interested in owning the plant, or in helping to build it. In general, the Port of Rotterdam is not willing to own any infrastructure except that essential to connects its leasers (e.g. roads). The Port's approach in pursuing the circular economy vision thus consists in being a knowledge integrator, meaning connecting tenants who might be able to improve circularity performance by working together. In relation to waste heat, the port mentioned that this is not a problem for them either:

being a land owner the Port does not have a significant carbon footprint directly associated to its business model. Nevertheless, in line with the role of integrator, the port is currently engaging in an effort to connects the waste heat streams of different tenants, as a way to reduce their carbon footprint. About this, the port mentioned that it has no intention to own any infrastructure, that there not a solid business case, thus tenants are reluctant to invest in it themselves. The Port could not reveal the indentity of the parties involved in this initiative. Concerning circular value delivery, the Port would not be willing to play any active role in a potential Zero Brine business model and did not have specific suggestions in this regard. Concerning circular value capture, the Port did not have specific suggestion, except mentioning that the potential revenues from Zero Brine magnesium recovery and sale are very far from the amount that would be needed for them to consider allocating land to allow full-scale commercial application.

Co-design with DCMR

Overview of the activity: Co-design with DCMR was performed through one interview, conducted with Koen de Kruif, senior sustainability advisor. The interview was led by Dr. Brian Baldassarre and Associate professor Giulia Calabretta, over video conference, using as a digital version of the tool. The interview was audio recorded. After briefly summarizing previous inputs, the tool was collaboratively populated with post-it notes containing DCMR's insights. At the end of the activity, the IDE researchers qualitatively analyzed (Miles et al., 2013) the filled-in tool template. The most relevant insights were then summarized and then re-mapped by the researchers on the clean version of the tool, gradually being populated by the emergent business model idea, to inform future co-design activities.

Results of the activity: Co-design with DCMR resulted primarily into important specifications related to the criteria that a Zero Brine spinoff would need to meet in order to establish a circular business model in the Botlek area within the port of Rotterdam. In particular, DCMR is the regional agency that oversees environmental protection and regulations in the area. Indeed, DCMR permit is the last touchpoint of EU environmental regulations cascading down from EU level to national Dutch level to province and region level where they encounter specific cases and businesses. In this regard, DCMR clarified that its role in the Zero Brine project is not related to checking that wastewater effluents generated from Evides comply with the environmental regulations set for the Botlek area, because this is already the case and there are no concerns. On the contrary, DCMR's role is checking if the Zero Brine project, the firms in the consortium, and / or a potential commercial entity deriving from their joint efforts are compliant with present regulations. Specifically, DCMR has checks: if the wastewater that is generated after implementing the Zero Brine solution is compliant with standards; if the recovered materials are compliant with standards. If the checks on the wastewater and recovered resources have a positive outcome, DCMR would be able to provide Zero Brine stakeholders with a "waste processor" permit, that is essential for them to operate commercially in Botlek through a circular business model. Nevertheless, in order for this permit to be granted, it is important and recommended to demonstrate that there is a solid business case around the recovery or resources from wastewater. If the business case is there, then DCRM would be able to support Zero Brine in getting not only the permit, but also a certification that recovered resources are a valuable byproduct that can be sold on the EU market. The reason why obtaining a waste processor permit to operate in Botlek is difficult is that in the 1980s there was a case of fraud in the Port of Rotterdam, where a waste processor company did not comply with environmental standards. Since then, the Dutch government has been very strict on issuing such permits, requiring a strong rationale (i.e. the business case). DCMR understands that this is necessary but also barrier for the implementation of a Zero Brine business model, since this kind of innovation, although potentially beneficial, often require a long trial and error approach to get a business case around it in place.

Co-design with Zero Brine Advisory Board

Overview of the activity: Co-design with the Zero Brine advisory board was performed through one interview with Michiel van Haersma Buma, chair member of the advisory board and independent innovation advisor, by Dr. Brian Baldassarre and Associate professor Giulia Calabretta and Roelof Moll, over video conference. The interview was audio recorded and conducted upon a digital version of the tool template. After briefly summarizing previous inputs, the tool was consequently collaboratively populated with post-it notes mainly related to the drivers, barriers and next steps to be considered when implementing a circular business model in Botlek. At the end of the activity, the IDE researchers qualitatively analyzed (Miles et al., 2013) the filled-in tool template. The most relevant insights were then summarized and then re-mapped by the researchers on the clean version of the tool, deriving a final circular business model proposal.

Results of the activity: The results of the co-design process with the advisory board mainly consisted in elaborating upon the results of the co-design with all other stakeholders, in order to explicitly identify the barriers and drivers related to the implementation of a Zero Brine circular business model in Botlek. Potential next steps were also discussed. More details in this regard are provided in section 3.3.

Annex B - figure 4

Figure 4: Tool supporting the circular business model design for the large-scale demonstration

CIRCULAR BUSINESS MODEL for the Zero Brine project

Organizational architecture to collaboratively recover resources from industrial wastewater in the Port of Rotterdam

Created by Brian Baldassarre

TU Delft

1. WHAT IS THE IDEA? What does Zero Brine offer? Who will use it/buy it? Why will they use it/buy it?

WHAT IS THE IMPACT? Why is Zero Brine circular? How is it measured?

2. HOW DO WE MAKE IT HAPPEN? Which stakeholder is involved? What does it do? What does it get out of it? What can go wrong?

3. HOW DOES IT WORK? How does the Zero Brine business reach its users / clients?

4. HOW DO WE PROFIT? What are the Zero Brine costs? What are the Zero Brine revenues?

Annex C - figure 5

Figure 5: Proposed circular business model concept, mapped upon the co-design tool, and based on the combined results of all co-design activities

CIRCULAR BUSINESS MODEL for the Zero Brine project

Organizational architecture to collaboratively recover resources from industrial wastewater in the Port of Rotterdam

Created by Brian Baldassarre

TU Delft

1. WHAT IS THE IDEA? What does Zero Brine offer? Who will use it/buy it? Why will they use it/buy it?

Zero Brine offers a technology for treating industrial wastewater (brines) while recovering valuable resources from it. Potential users / clients include companies discharging brines in the port of Rotterdam. In particular, in the Botlek area the main target user / client is Evides Industriewater, producing demineralized water and generating brine effluents containing sodium chloride (NaCl), magnesium hydroxide (MgOH2) and calcium (Ca). Other potential users / clients include chemical companies Exxon and Nouryon, amongst others. Clients adopting the Zero Brine solution (and in particular Evides) may benefit by: reducing or eliminating the taxes and or underlying costs for treating / discharging brines; recovering resources (MgOH2; NaCl; Ca; clean water), which can be either sold to third parties or, if possible, reused internally.

WHAT IS THE IMPACT? Why is Zero Brine circular? How is it measured?

Zero Brine fosters circularity by helping clients to close the loop of resources, which can be measured by: kg or tons (t) of recovered materials; liters (L) or m3 of water saved. Full-scale continuous operation of the Zero Brine technology in the plant of Evides would lead to: recovery of approx. 50t of MgOH2 per year; recovery of approx. 317t of Ca per year; recovery of approx. 13500 m3 of NaCl solution (9%); small savings of clean water. Rebound effects include: increased CO2 emsissions (due to energy use); increased resource use (to produce the tecnology); freshwater eutrophication and acidification (for operating the technology).

2. HOW DO WE MAKE IT HAPPEN? Which stakeholder is involved? What does it do? What does it get out of it? What can go wrong?

TU DELFT - technology supplier and research partner

The faculty of Applied Sciences supplies the Eutectic freeze Crystallization (EFC) technology, a key component of the integrated Zero Brine solution. It allows revovering high purity resources by gradually cooling down wastewater until separation of solid crystals from the liquid. The technology is powered by electricity and has a high-energy effieciency perfomance compared to evaporation. Applying the ECF technology in the plant of Evides would lead to the recovery of additional resources including sulphate (SO_4). The faculty of Civil Engineering provides the facilities for the lab-test and core competences to excute the pilot at the premises of potential clients, including Evides. The valorization center provides competences and resources needed to establish an enterprise encompassing all the stakeholders who provide the Zero Brine solution on the market. The faculties of Applied Sciences and Civil Engineering expect to leverage the technology as a platform to conduct acedemic work and establish new research projects. The valorization center expects an equity share of the commercial enterprise, to exploit the Zero Brine technology commercially. Challenges: EFC has a low technology readyness level (TRL 5), which results in challenges when operating it on a full-scale for commercial purposes.

SEALEAU - technology supplier and main solution contractor

Provides the evaporator technology, a key component of the integrated Zero Brine solution, needed to separate NaCl from brines using thermal energy. Provides expertise, network and time while being the main solution contractor. Establishing contact and acquiring new potential users/clients in the Port of Rotterdam, next to Evides. Finding new potential technology suppliers, which may be needed for incorporating additional components in the Zero Brine integrated solution, in order to meet the needs of new potential users/clients. Acquiring public funding to finance pilots and full-scale implementations in case potential users/clients are not willing or able to pay for all the costs. Benefits by: making revenue as a technology supplier; making revenue as main contractor (fee for the expertise and time invested in getting on board new potential clients and technology suppliers, and for acquiring public funding). Revenues would be a fraction (to be agreed upon in each case) of total revenues coming from a client. Challenges: hesistancy in establishing a joint enterprise, preferring to operate through a main contactor and subcontractor partnership formula; Intellectual property of the integrated Zero Brine solution cannot be patented. Users / clients may buy the seprated components and implement independently if they have the know how to do so, which Evides has.

ARVIA- technology supplier and business development support

Provides the Nyex technology for total organics removal, a key component of the integrated Zero Brine solution for removing organic components and micropollutants from the brines, by destroying them with an electrical current passing through a surface that has previously captured them. Provides support the main contractor in business development, through its own network of clients. Benefits by. making revenue as a technology supplier. Revenues would be a fraction (to be agreed upon in each case) of total revenues coming from a client. Benefits by leveraging the Zero Brine integrated solution and the networks of other technology suppliers, to acquire new clients. Challenges: TRL of the Nyex technology is low (5), but it has grown quickly in the past years and ARVIA considers it ready for commercial application; ARVIA shares the concers of Sealeau around intellectual property of the integrated solution, but is not concerned about its own technology, which is patented.

LENNTECH - technology supplier

Provides: the nanofiltration and reverse osmosis technologies, key components of the integrated Zero Brine solution, which use electricity to filter brines before the evaporation step; expertise in wastewater treatment design, needed to install and maintain the Zero Brine integrated solution in the facilties of a client. Benefits by: making revenue as a technology supplier, exclusively as a subcontractor; making revenue through a fee for system design, installation and maintenance. Revenues would be a fraction (to be agreed upon in each case) of total revenues coming from a client. Challenges: unwillingness to collaborate within a joint enterprise due to concerns on the reliability of other technology suppliers and lack of explotitative mindset of research partners. Not willing to contribute by opening its network of clients. Only willing to operate as sub-contractor for its technologies and as independent consultant for design, installation and maintenance.

UNIPA - technology supplier and research partner
Provides: the membrane crystallization technology, a key component of the integrated Zero Brine solution, which uses electricity to recover MgOH2 and Ca from brines. Benefits by: making revenue as a technology supplier. Revenues would be a fraction (to be agreed upon in each case) of total revenues coming from a client. Challenges: hesitancy in collaborating on a commercial level beyond the Zero Brine project due to concerns related to the intellectual property and replicability of the membrane crystallizer.

IVL - research / commercial partner
Provides: complementary environmental impact assessemement service to potential users/clients, which may help to increase the relevance of the overall value proposition. Benefits by: charging for the complementary service, as a fee. Challenges: impact assessement results may not always be positive due to rebound effects, discouraging clients to invest in the Zero Brine solution.

EVIDES - end user /client
Provides: brines rich in resouces to be recovered; expertise in continuosly operating a full-scale water treatment plant. Benefits by: implementing the Zero Brine solution into its plant, as a way to treat its wastewater while optimitizing the water footprint and recovering NaCl that can be reused internally as input for the process to produce demineralized water; accessing the lab-test and technology pilot stepst via the EU funding of the Zero Brine project. Challenges: not willing to install the Zero Brine solution within its demineralized water plant due to the issues that might arise from it (in a potential full-scale implementation but also in the pilot step - see PlantOne); not willing to be client of the Zero Brine solution. After learning from Zero Brine, Evides wants to use its water treatment know-how to build a solution independently, if relevant. The main challenges is the lack of business rationale to use the Zero Brine solution. No direct interest in magnesium and calcium recovery. NaCl recovery may be interesting for internal reuse but there are concerns around purity and operational hurdles. Purchasing virgin salt is a more attractive options (considering the low cost). No interest in the limited water savings (there are not water scarcity issues in Botlek). Evides is not taxed for brine discharge in Botlek because there are no environmental regulations that prevent this. The last issue undermines the possibility to acquire other clients in the Rotterdam Port area.

PLANTONE - commercial partner
Provides: the facility to run the pilot step using the brines supplied by Evides. This was necessary given the resistance of Evides to implement the Zero Brine solution at its own premises; may be able to provide the facility again, when running the pilot with other potential clients, if requested . Needs futher discussion. Benefits through the rental fee for using its facilities, charged to the Zero Brine solution provider. Challenges: may not be always have availability in its facility. Needs futher discussion.

HUNTSMAN - commercial partner
Provides residual heat from its own processes, as a thermal energy input for the evaporator within the Zero Brine solution. Benefits by: potentially selling its residual heat to Zero Brine; reducing its emissions by turning them into an input for Zero Brine. Challenges: not willing to supply residual heat because its processes are already "heat integrated"; unclear responsibility on who would finance, build and own the infrastructure (pipes) to bring residual heat from Huntsman to the place where the Zero Brine solution would be located.

EUROPIREN - commercial partner
Provides its knowledge and parterns and client network in the European market of MgOH2 , needed to sell the this resource after recovery. Benefits by making revenue through a commission on the sale of MgOH2 . The amount of this commission would need to be negotiated eventually with the Zero Brine enterprise (ecompassing the technology suppliers) taking into consideration both production cost (through the Zero Brine technology) and final selling price of the resource. Challenge: Europiren is willing to engage as a commercial partner only if the purity and quantity of MgOH2 are adequate. Full-scale continuous operation of the Zero Brine technology in the plant of Evides would allow to recover 50t of MgOH2 per year. With the achieved purity of 67% , Europiren would be able to capture a highly profitable market-niche (application into thin fire-retardant rubber cables) with a final selling price of approx 2000 €/t. However, the minium quantity that Europiren would require is 2000t per year, which is 40 times lower than the recovered amount. Recovering more MgOH2 from the bines of Evides is not possible due to the low concentration of this resources in the surface water in the Port of Rotterdam, where evides gets its water supply.

PORT OF ROTTERDAM - land owner
Provides the space where the Zero Brine solution is implemented. That includes either the facility of potential clients, or a separate facility built ad-hoc and owned by Zero Brine. Benefits by: space rental fees; boosting circularity in the Port, in view of more stringent future EU regulations. Challenge: does not see a business case in Zero Brine and not interested in supporting its commercial application.

DCMR - policy actor / regulator
Provides: the permit for Zero Brine to operate commercially as a waste processor in the Port; support in getting an official quality certification for the recovered resources. Benefits by ensuring compliance with environmental regulations. Challenge: requires a solid environmental rationale to issue the permit. Business rationale is also important. In both cases, the rationale is not solid enough.

3. HOW DOES IT WORK? How does the Zero Brine business reach its users / clients?

STEP 0 - Client acquisition
Zero Brine gets in touch with potential clients in the Rotterdam Port area. The effort is lead by the main contractor, which discusses the steps and terms of the potential collaboration

STEP 1 - Lab-test
The client provides a sample of the brines, which is analyzed by TU Delft. Potential for brine treatment and resouce recovery is discussed with the client. The following pilot step is discussed, specifying duration and which technologies are needed

STEP 2 - Pilot
The technologies to run the pilot are installed at the premises of the client. In case that is not a viable option, performing the pilot at PlantOne may also be a possibility. This needed to be discussed, taking into consideration additional costs and how to transport the brines from the client to PlantOne

OPTIONAL STEP - Impact assessment
IVL offers the possibility to perform an environmental impact assessement using data from the pilot. If the economic rational in the business case in uncertain, evironmental impact assessment may determine whether it is sensible to proceed with full-scale implementation

STEP 3 - Full-scale implementation
If the results of pilot are positive, follows full-scale implementation in the facilities of the client. Two delivery options are possible, which should be negotiated ad-hoc. The first option is that Zero Brine sells the technology to the client up front to the client, including in the contract support for operation and maintenance. This first option entails very upfront costs for the client, which may result in resistance to purchase. The second option is service based / leasing. In this case Zero Brine retains ownership of the technology over time as the client pays a recurring fee (e.g. yearly). When the equipment is depreciated (e.g. 20 years) ownership shifts to the client, which is the meantime has learned to operate and maintain it. If at any point in time the client does not want the equipment anymore, Zero Brine takes it back to re-use it with other clients. This option requires less commitment and upfront investment from the client (making it easier to sell) but poses two challenges for Zero Brine: disassembling and reusing the equipment elsewhere may not always be possible; very high investment costs for the technology providers, which are unlikely to be able to cover them, and would therefore require an external source of funding (e.g. additional EU project funding). The choice between the first and second option depends upon several aspects and can only be made case by case.

4. HOW DO WE PROFIT? What are the Zero Brine costs? What are the Zero Brine revenues?

Costs for the Zero Brine solution providers: financing the lab-test; financing the small/large-scale technology pilot; financing full-scale technology implementation. Cost for the Zero Brine potential users / clients: continuos technology operation in the plant of Evides would lead to a 5x increase of demineralized water production cost (from approx. 2 €/L to 10 € /L). Costs can be covered either by client revenues, or by public funding, or by investment of Zero Brine solution providers. Revenues: lab-test fee (approx. 6000 €); small scale technology pilot fee (approx. 18000 €*); full-scale technology implementation fee (?**). Criteria for revenue share across solution providers to be determined. (*) indicative and based onARVIA's technology alone. (**) fee for full-scale implementation can't be estimated.*