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A case study on industrial collaboration to close material loops for a domestic boiler

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Abstract

This paper presents a practical implementation of circular principles in a case study on domestic boilers. The manufacturer and a recycling company collaborated by performing pilot studies on closing the aluminium cycle. The case study proved economically viable and not limited by technical or practical aspects. Additional benefits for both companies have been implemented and additional insights on the circular economy were observed. The results indicate that this form of sustainable manufacturing quickly transcends the boundaries of individual companies, which confirms the necessity of close collaboration with stakeholders in the value chain.

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Keywords: circular economy; closed material loop; industrial collaboration; case study; end of life

1. Introduction

This paper describes a practical case study in industry to illustrate how two companies can collaborate to discover the opportunities of implementing principles from the circular economy. The companies requested transfer of knowledge about the circular economy tailored to their specific industrial context, supported by a practical pilot case to investigate the actual opportunities and the necessary operations to realize the proposed benefits.

The two involved companies, Van Gerrevink and Remeha have been engaged in business relations throughout their existence. Both companies see the circular economy as an opportunity for securing their long term interests. A joint effort using the principles of the circular economy would allow for a unique opportunity for a circular collaboration with leverage on two ends of the chain.

After explaining the problem statement in section 2, details about the involved companies and a succinct description of the framework supporting the case study are mentioned in section 3. In the subject of study, section 4 a typical domestic boiler and its life cycle is illustrated. In section 5, the case study is described, including the set-up and the application of the framework. To implement the selected principle, a pilot case for reverse logistics and a second pilot case for material reutilization have been developed. The evaluation of the case study follows in section 6. Additional outcomes of the case study are discussed as insights in section 7, followed by conclusion and future research.

2. Problem statement of case study

Despite interest in the application of circular principles, both companies realized that their knowledge and experience was not yet sufficient for successful implementation. Therefore, they decided to request the assistance of the University of Twente in developing a practical case study to illustrate how principles of the Circular Economy can be applied in an industry context, cumulating in knowledge transfer and shared experiences.

From discussing the objectives, the following main questions have been identified for this project:

- What are the opportunities of applying principles from the Circular Economy for both companies?

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- How can the collaboration between Remeha and Van Gerrevink be intensified and prepared for the circular economy?
- How can the transition towards the circular economy be illustrated by a practical show case?
- Which insights can be derived from the implementation of circular principles in an industry specific context?

By resolving these questions through a practical case study, industry is provided with an illustration of initial steps associated with the transition towards a circular economy.

3. Background

3.1. Van Gerrevink BV

As a recycling company, Van Gerrevink BV is already involved in material recycling through their conventional commercial activities. Collection, destruction, separation and trading of material waste streams for recycling is their core business. Van Gerrevink is a five generations old family business with approximately 30 employees, located in the city of Apeldoorn, in a central region of the Netherlands. The daily operations of Van Gerrevink depend on the dynamic and unpredictable international market for secondary material streams. Dismantling and separation efforts need to be balanced against the expected profits from selling that particular waste stream to recyclers and traders. Van Gerrevink is mainly interested in the opportunities engendered by closer collaboration with its clients with regard to sustainability and resource conservation. By developing the collaboration with business relations, embedded within the circular economy, Van Gerrevink is provided with ample long term business opportunities for a sustainable future. The close collaboration between Van Gerrevink and Remeha is an example of a sustainable business relation.

3.2. Remeha BV

As a formerly family-owned business, Remeha is historically bound to Apeldoorn, where its production facility is located. Remeha employs over 500 people, and is currently part of a larger international holding called BDR Thermea, with a total of around 6500 employees in Europe. Remeha is one of the major manufacturers of boilers in the Netherlands for domestic, commercial and industrial usage. Although Remeha started with an on-site smelter and foundry for cast iron products, they have outsourced all the parts manufacturing and focus on the development and assembly of boilers. Boilers for domestic use are sold predominately through wholesale channels to installation companies and housing associations. As a traditional manufacturing company Remeha is not involved in the use and end-of-life phases of their boilers. For this case study, is Remeha primarily interested in improving the sustainability of its products and organization. Remeha applies the knowledge and recommendations from this case study in the development of its future generation of products and business practices.

3.3. Framework for circular life cycle planning

In order to implement the principles of circular economy in industry a framework has been developed [1] to support this transition towards a circular economy. The ideas of the circular economy, as described by the Ellen MacArthur Foundation [2], have been summarized in a couple of principles:

- Closing material loops
- Functional life extension
- Cascading
- Using renewable energy sources
- Performance Economy

Application of these principles should lead to solution directions in line with the circular economy. Combining the circular economy with the approach of Life Cycle Engineering [3] results in a framework suited for industry-specific contexts, as represented in figure 1.

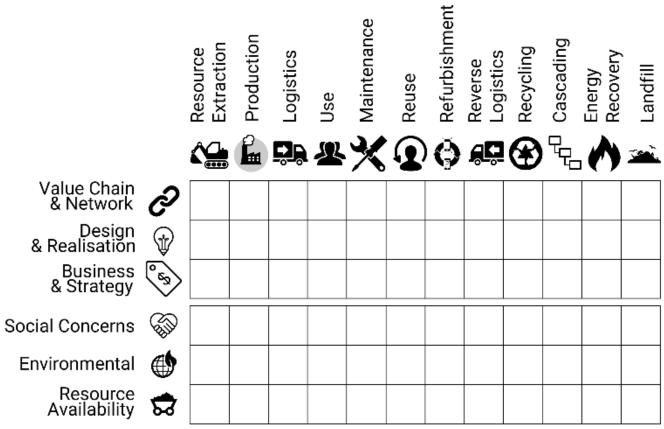

Fig. 1. Morphological matrix for circular development.

This morphological matrix displays the different phases of a product lifecycle on one axis while on the other, three organizational categories of business development are paired with three categories of sustainability, in accordance with the LCE definition by Jeswiet. For each application in industry, the aforementioned principles can be matched with certain combinations of lifecycle stages and categories. Together they form a context specific solution space.

In order to generate a solution space matrix, a thorough understanding of the product (or material) lifecycle is required together with the stakeholders of the value chain. The suggested solution directions, derived from the circular economy principles, transcend the traditional boundaries of individual companies and require close cooperation between multiple stakeholders. This requires development of new business models to redistribute costs & profits and shared responsibilities amongst the stakeholders. Legal matters, such as ownership of the material and resources within the closed loop, have to be resolved as well.

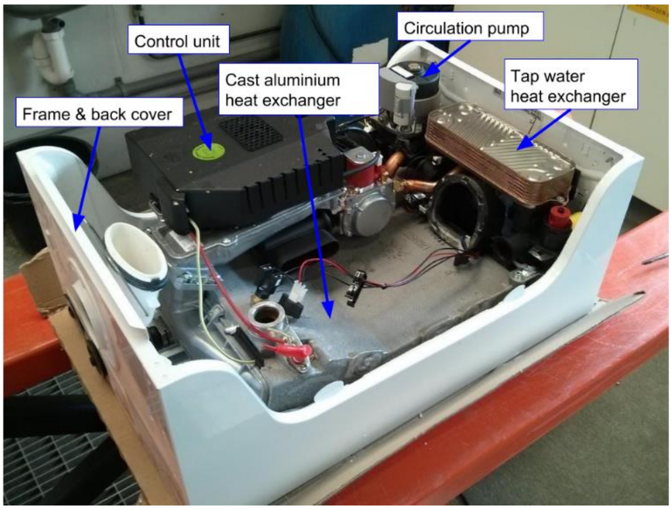

Fig. 2. Remeha's domestic boiler, with the front cover, intake and exhaust ducts removed.

4. Subject of case study

A typical 'gas burning domestic condensing combined boiler' has been selected as subject of the case study. This type of boiler is still very common in the Netherlands and a wide variety of these boilers are available on the recycling market. This type of boiler supplies both central heating and potable hot water for living accommodations. Therefore, it contains typical components such as heat exchangers, control unit, circulation pumps and air ducts (see figure 2). Most residences in the Netherlands are still connected to a natural gas distribution network. The typical lifespan of these boilers is 15 years. See figure 3 for a simplified lifecycle of a boiler in the current linear consumption economy.

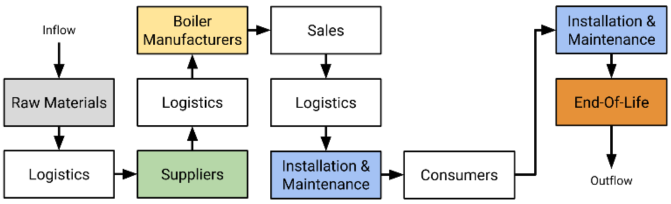

Fig. 3. Simplified linear product chain for the boiler.

Made-to-order components for the boilers are supplied to Remeha and assembled on-site in Apeldoorn. The finished boilers are shipped to wholesale organizations throughout the country. Large and small installation companies as well as housing associations acquire their boilers primarily through wholesale channels. Only in private homes are the actual users involved in the selection of their new boiler. Installation, service and decommissioning is controlled by the installation companies, without direct involvement of the manufacturer. Therefore, Remeha has very little feedback on the lifecycles of the boilers.

After decommission, the old boilers are removed by the installation company and sold for scrap to the nearest commercial recycler. These recycling companies receive a mix of various boilers, which can be different in type, condition and manufacturer. At these recyclers, information about material composition and recommended disassembly procedures are barely available. Depending on the current material values on the international scrap market most recyclers apply destructive techniques to obtain specific materials.

5. Case study

The collaborative case study, which was initiated by Van Gerrevink and Remeha, considered the main question; what are the opportunities of using the principles from the Circular Economy and Life Cycle Engineering in the collaboration between Remeha and Van Gerrevink and other stakeholders? This has been investigated through the identification, prioritization and practical implementation of circular principles for a domestic boiler.

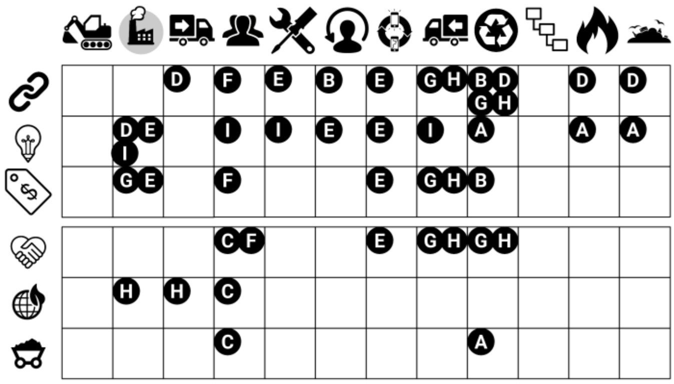

Fig. 4 Morphological problem space matrix for the boiler case study.

5.1. Identification of opportunities

The framework (as discussed in section 3.3) was applied to this industry specific context of the collaboration between Remeha and Van Gerrevink and the case study on the boiler. From an initial assessment of the product lifecycle and value chain, the problem space was represented in the morphological matrix (Fig. 4). Different opportunities (each represented by a letter) for the application of circular principles, in relation to the considered categories, were identified and discussed with Van Gerrevink and Remeha. Among a broad range of opportunities that were identified (as indicated by the letters in figure 4), three development concepts stood out. One of the more promising long term options was the development of new business models to facilitate the implementation of *refurbishment* of end-of-life products as an extension to the current, small scale refurbishment schemes (letter E in fig.4).

As a product group, 'domestic condensing combined boilers' also provided an interesting circular economy case in the creation of a *performance economy*. For example, these boilers comply with criteria for the development of product service systems [4]. Boilers represent a relatively expensive purchase for many home owners. Also, the boilers are advanced technical systems while the users are mainly interested in the delivered comfort (in the form of heat and hot water). The boilers are easy to transport, being a self-contained unit and developed to be handled by a single technician. There is actually very little direct interaction between the product and the user. And finally, their lifespan is hardly influenced by fashion trends. Structural oriented models such as lease and rental constructions already exist for this kind of boilers, but higher order PSS, such as functional or demand oriented propositions [5] are currently not available to consumers. However, the implementation of the latter types of product service systems requires not only a redesign of the boilers, but also changes in the current business model and product lifecycle.

A third opportunity was identified in the development of *closed material loops*, as indicated by letters G and H in fig. 4. According to the Directive 2012/19/EU of the European Parliament on waste of electrical and electronic equipment [6], often called the WEEE-recast directive, boilers have to be disposed by professionals since they are not suitable for curbside or even municipal disposal scenarios. No significant changes in applied technology are expected, meaning that new generations of boilers will probably contain similar components and materials and have similar performance profiles. Although the current generation of boilers are not specifically developed for closing material loops, Remeha is interested in design guidelines to increase the recyclability of their future generations of boilers. The current suppliers are OEM's with stable business relations with Remeha and BDR Thermea. The necessary elements required to close the material loops appear to be already present within the product value chain.

5.2. Prioritization

The retrieval of valuable materials from disposed boilers already proved to be a valid business case. To elaborate on this principle and to illustrate the impact of the transition towards more circular practices, the principle of *closing material loops* was selected, as represented by letter H in fig. 4. This offered potential and familiar benefits for the involved stakeholders. The expected benefits of achieving a closed material cycle is considered most interesting as best practice, while the captured experiences can already be applied in the development of new boilers.

However, to include as many practical aspects of closing a material loop within the limited timeframe of the case study, it was decided to prioritize efforts by focusing on one material. The cast aluminium within the boiler was the largest mass and represented the highest material value (figure 5), factors which were likely to increase the potential for an economically feasible business case. Additionally, the cast aluminium was mainly concentrated in a single component, the heat exchanger, (see figure 2) which reduces the effort of extracting the material from the disposed boiler. An additional benefit of closing the cast aluminium cycle is the reduced environmental impact of recycling versus primary aluminium production from bauxite.

Neither company has been in a position to fully organize closing of this loop, as product ownership was lost through wholesale and product end-of-life is currently managed by various independent installation companies (as discussed in section 4). Involvement of other stakeholders like installation companies and material suppliers was a prerequisite. Within this case study, two pilots were initiated with different stakeholder partners to achieve the intended end-result of a closed cycle for the cast aluminium of the heat exchangers.

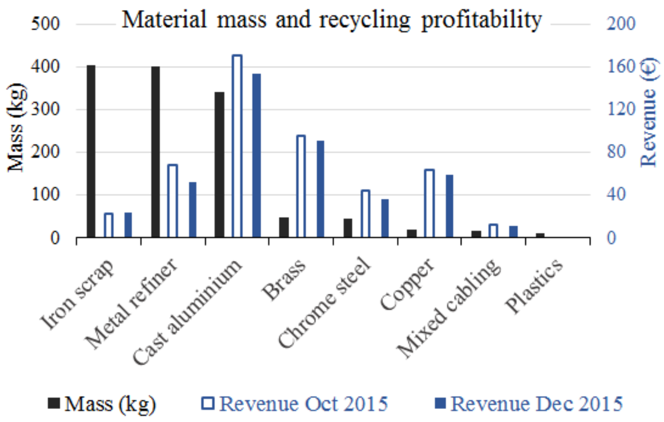

Fig. 5. Material weight and recycling profitability in end-of-life boilers

5.3. Reverse logistics pilot

The first challenge in organising the reverse logistics pilot involved product ownership and the incentive to collaborate. Most replaced domestic boilers remained the legal property of installation companies. Additionally, both collection and recycling of these boilers are outsourced to commercial recycling companies. Even though the scrap value of a single boiler was substantial, the costs for organising boiler end-of-life treatment quickly equalled or even exceeded the raw scrap value for commercial recyclers.

A partnership was formed with an installation company for the pilot on reverse logistics. The opportunity of creating a closed material loop suited the company's Corporate Social Responsibility (CSR) ambitions. Collaboration supported the creation of Corporate Shared Value [7]. The potential savings throughout the lifecycle could be used to offset additional costs to improve reverse logistics and the product recycling process.

In agreement, Remeha's domestic boilers that reached their end-of-life, were collected during a timeframe of 2 months, resulting in a batch of 40 boilers. As expected, older models in the pilot batch tended to be heavier and contained more metal parts, as opposed to the use of (composite) plastics in more recent models. Most boilers in the pilot batch contained considerable amounts of cast aluminium of a specific alloy composition that is still being used in the production of current models.

5.4. Aluminium reutilization pilot

The intended result of material reutilization was to close the material cycle by applying the reclaimed cast aluminium in new heat exchangers. In order to maximize the expected benefits, a number of priorities were determined.

Because the alloying composition of both the older and newer boilers were identical, priority was given to the direct reuse of the aluminium, to limit the need of an energy intensive re-smelting process to bring the alloy to the desired specifications. Another priority was to close the material loop within control of Remeha's value chain. Even though this was not strictly necessary from a resource conservation point-of-view, the used business model for reverse logistics relied on creating Corporate Shared Value. Additionally, closing the material loop with the least amount of transportation movements to reduce the environmental impact footprint was preferred. Nonetheless, the contribution of transport movement in the lifecycle proved to be limited when compared with the impact associated with aluminium smelting and refining.

Remeha's heat exchanger suppliers were approached to collaborate in the pilot to close the cycle of the previously retrieved aluminium. These OEM's were reluctant to participate due to various reasons. Alternatively, another business relation of Remeha was identified for collaboration to utilize this material in a closed loop. Direct application of the reclaimed heat exchangers by adding them to the crucible at the aluminium sand casting line was considered. This solution was both technically and practically feasible as rejected casts were already recycled internally in the process. However, current legal and strategic concerns prevented the practical realization of this solution.

6. Case study evaluation

The case study, considering reverse logistics and aluminium reutilization, culminated in interesting insights. Overall, the results of the case study were favorable, as closing the material cycle for cast aluminium were unrestricted by technical or practical limitations. Based on the expectation of Remeha's compliance to the WEEE-recast directive, the amount of cast aluminum retrieved from decommissioned boilers would exceed the threshold for economical business cases both on the necessary end-of-life processes as well as for recasting of the melted aluminium into new heat exchangers. A scale-up of reverse logistics appeared to be attainable by extensive collaboration with installation companies and commercial recycling firms. Material reutilization however, proved to be challenging due to sensitivities originating from unconventional use of existing buyer-supplier relationships. In this case study, multiple stakeholders from the value chain were required to create a Corporate Shared Value to distribute the costs and benefits across the participating stakeholders. In a closed loop value chain, a single link (e.g. a supplier) can undermine the Corporate Shared Value of the circular business model. Further discussion, trust and transparency are required in order to ensure the full commitment of all stakeholders.

6.1. Additional benefits of the collaboration

The case study also revealed additional benefits of the collaboration between Remeha and Van Gerrevink. The reverse logistics pilot proved to be beneficial with regard to WEEE compliance, as this legislation dictates that boiler manufacturers are responsible for the collection and certified recycling of end-of-life boilers by licensed companies like Van Gerrevink.

Van Gerrevink's staff were assisted by Remeha's quality engineers in optimizing the disassembly procedure of existing Remeha boilers. For example, some destructive disassembly steps have been replaced by manual operations to improve the safety, accuracy or cost-efficiency of disassembly.

Vice versa, the collaboration also resulted in the decision to employ Van Gerrevink's recycling expertise into Remeha's product development process in order encourage implementation of design-for-recycling principles and to prioritize development decisions that improved the potential for material reutilization throughout the life cycle.

7. Insights

7.1. Role reversals

During the case study, an interesting role reversal was observed, both within the value chain as well as internally in the company. For example, Remeha had to utilize existing supplier relations to sell materials (instead of buying), whereas Van Gerrevink was involved with the manufacturing phase of the product, instead of merely product end-of-life processes. Subsequently, traditional 'linear' B2B channels, such as purchasing or sales, were used in reverse to establish contact with suppliers and the installation sector, leading to some confusion and hesitation by employees during the early stages of the case study.

7.2. Paradigm shifts

The observation of role reversals indicated that for the implementation of closed material cycles, a paradigm shift is required where the value chain is no longer perceived as a linear one-way trajectory, but as a closed loop system. The actions of one stakeholder can reverberate throughout the chain and (at least partially) feed back onto itself. In this context, a manufacturer not only has to take into account the needs of its neighboring stakeholders, but all stakeholders in that value chain. In this context, the creation of Corporate Shared Value, which involves all key stakeholders, becomes a necessity. Competitive business models have to be developed, which are not undermined by 'traditional' self-centered or short-term interests of individual stakeholders.

7.3. Time dependencies

The current interpretation of the circular economy of closed material cycles appears to disregard the notion that the implementation of it principles can be time dependent. For example, during the case study, a number of time related factors affected the applicability of circular principles. Design decisions to improve product recycling are likely to take at least an additional 15 years to bear fruit. The design of the previous generations of boilers differed significantly from the current model, which poses severe challenges in closing all material cycles. Additionally, Remeha has experienced a significant growth over the last decades. Even though newer boiler models require less aluminium, an imbalance between the number of decommissioned and newly produced boilers was observed. This implied an artificial material scarcity if every boiler has to be manufactured under a circular business model, or additional sources of aluminium are required to meet demand.

7.4. Incentives for transition

In traditional end-of-life processes, market forces incentivize or discourage recycling of certain materials. Because of fluctuating market prices, commercial recyclers adapt their disassembly procedures on a daily basis in order to balance operational costs against the expected profitability of recycling materials. In a closed loop where the identical materials are applied in subsequent generations of similar products, materials no longer need to be sold on, or purchased from a volatile global market. Material costs during manufacturing would then primarily consist of the 'operating cost' to keep the materials in circulation, i.e. manufacturers are not faced with material purchasing cost, but with material recovery costs.

In the current economic model, material acquisition costs often outweigh recovery costs, resulting in the absence of economic incentive to develop closed material cycles for low-cost or hard to recycle materials such as composites. Inversely, valuable and easily recyclable materials, such as aluminium are ideal candidates for the development of closed material cycles. A cost structure based on material recovery is likely to be more stable than one based on traditional material acquisition as it is less sensitive to volatility in the resource market. The resulting predictability in cost and resource availability make long term developments and commitments more attractive.

8. Conclusion

Multiple opportunities could be identified from the implementation of circular principles for both companies. From a product point of view, refurbishment of end-of-life boilers, the development of a performance economy and closing material cycles constituted favorable opportunities.

From a company point of view, additional possibilities emerged. The inclusion of manual operations in the disassembly procedure of end-of-life boilers resulted in improved recycling efficiency. During product development, expert knowledge from recycling firms was beneficial to design-for-recycling. Both Remeha and Van Gerrevink can use circular principles to support their respective WEEE compliance. Overall, the dissemination of stakeholder-specific knowledge and expertise throughout the value chain supports lifecycle oriented optimization and provides opportunities for the development of Corporate Shared Value.

The transition towards the circular economy was successfully illustrated through a case study on closing a material loop for a domestic boiler. The closing of the cast aluminium cycle through reverse logistics and subsequent material reutilization in the production of new heat exchangers is technically feasible, but currently limited by strategic and tactical considerations of individual stakeholders.

In general, a number of insights can be gained from adopting circular practices. The observed role reversals indicate that a change in mind-set is required from 'linear' product oriented thinking to 'circular' lifecycle oriented thinking. The implementation of circular and life cycle engineering principles tends to transcend the boundaries of individual companies, which necessitates considerable value chain collaboration efforts. As most businesses will be unaccustomed with transitions for circularity, a certain amount of boldness is therefore required to look beyond short term individual gains and assure long term interests.

Future research

To substantiate the successes of the applied framework, additional case studies in different industries are required to determine the influences of industry-specific context and the role of value chain collaboration of the implementation of circular principles. Furthermore, it could be interesting to use serious games as an instrument to research the role of strategy, tactics and incentives of individual stakeholders in a circular value chain as well as the emergent properties of such a closed loop system.

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