Institute for Sustainable Process Technology

ReBBBloCS

Renewable Building Blocks from Complex and wet waste Streams

MOOI-regeling 2022

(Missie gedreven Onderzoek, Ontwikkeling en Innovatie)

MOOI422006

28/08/2025

ISPT

Introduction.

The project "Renewable Building Blocks from Complex and wet waste Streams" (ReBBloCS) is registered by RVO as MOOI422006. The project is coordinated by Institute for Sustainable Process Technology (ISPT), and its participants are Alucha, BioBTX, Bostik, Brightsite, Chemcom, CHemportEurope, DOPS BV., EEW, ESD-SIC, PeelPioneers, Q8Research, Recell, Riwald, RUG, SABIC, Sappi, Smurfit Kappa, Spark904, TejinAramid, Twence, University of Twente, VNP, and the WUR. Starting 1 August 2024 GF Biochemicals, Natures Principles, and OCI have joined the ReBBloCS project for the remaining time of the project. The company iMenz Bio-engineering went out of business and left the ReBBloCS project. Due to a reorganization in Q8Research, the legal entity in Q8 connected to the ReBBloCS project did cease to exist. Q8 is now longer participating in the project.

The project officially has started on the 1 August 2023 and was intended run for a period of 4 years. Since PhD students were not hired at the start of the project (the hiring process of the PhD students can only kick off, after the start of the project), the parties of the project together decided that the project duration will be extended with one year. In this way PhD students can finish their PhD thesis within the timeframe of the project.

This report is the non-confidential report of activities, progress, and results of the first two years of the project.

The ReBBloCS project is part of the Separations For Circularity cluster of ISPT.

General summary of the ReBBloCS project.

Motive.

A large share of CO2 emissions by industry is related to the production of fossil-based chemicals (approximately 3.6Mton oil was used in the petrochemical industry in 2021), and all this oil will be converted in CO2 at the end of life of products, if these products are not recycled. By transitioning towards circular and biobased (bulk and platform) chemicals, the CO2 emissions of this sector can be strongly reduced. The rising prices of conventional (oil-based) feedstock have further intensified the incentive for industry to transition towards alternatives. However, as seen today, the quantities of potential biobased/circular input streams to provide these chemicals is by far not enough to source the demand of industry. Therefore, the aim of industry is to efficiently use all available alternative, circular, and renewable feedstock; this includes the so-called complex and mixed waste streams. When value chains are in place that enable valorisation of currently wasted complex and mixed waste streams, it allows the paper and (specialty) chemicals industry to achieve this goal towards reducing its environmental impact.

Goal of the project.

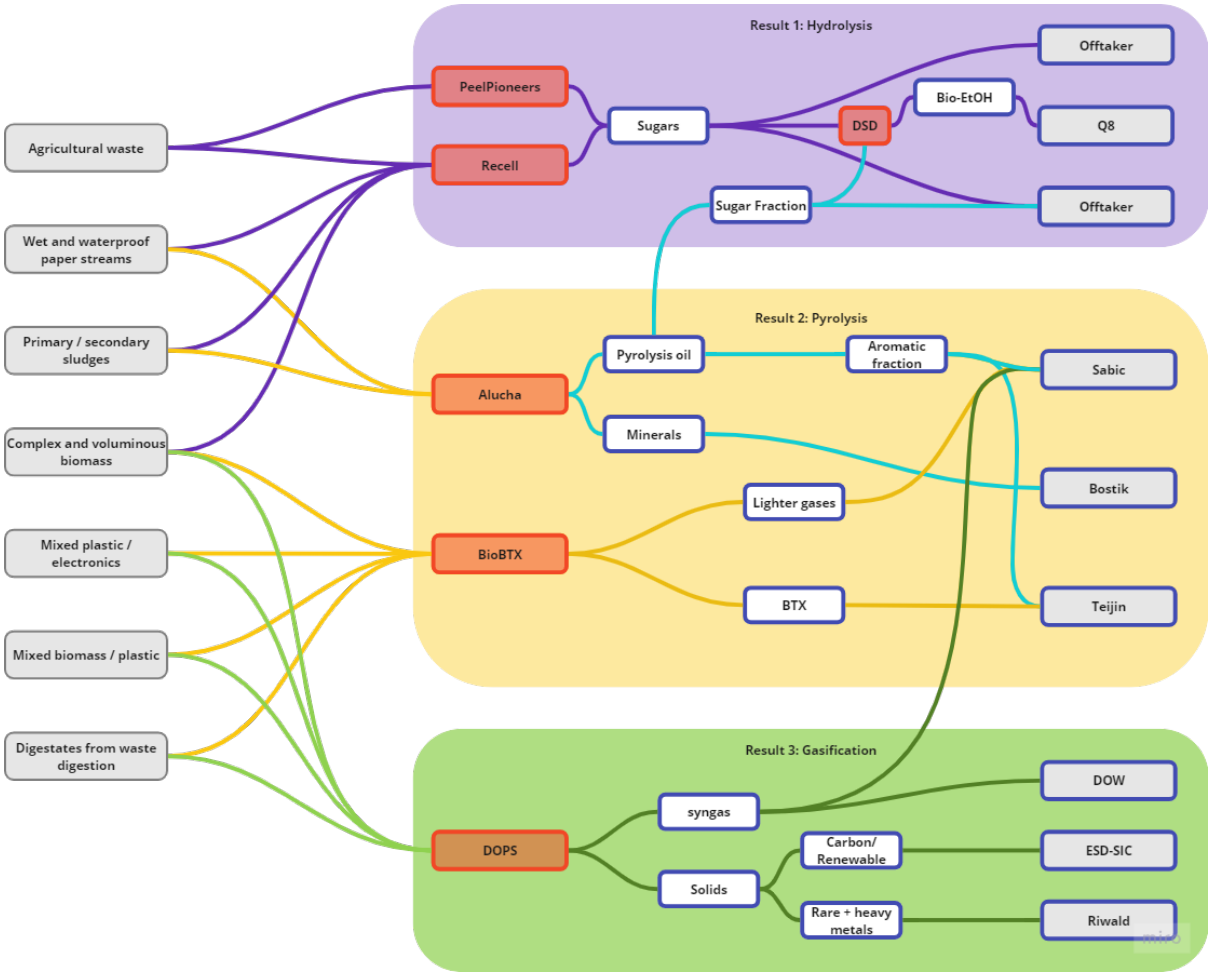
To provide industry with circular and biobased bulk and platform chemicals, new value chains need to be developed, where 'challenging' waste sources (e.g., agro/food residues, mixed biomass/plastic, sludges etc.) are converted through innovative technologies (based on hydrolysis, pyrolysis & gasification) into new chemicals. These chemicals can be used to replace current fossil-based chemicals. In the ReBBloCS project these value chains are developed in collaboration with relevant stakeholders (private sector, technology providers & knowledge institutes). The goal is to close the carbon cycles of the specific bulk- and platform chemicals considered by ReBBloCS as much as possible by utilizing and valorising (fractions of) the considered complex waste streams.

Activities.

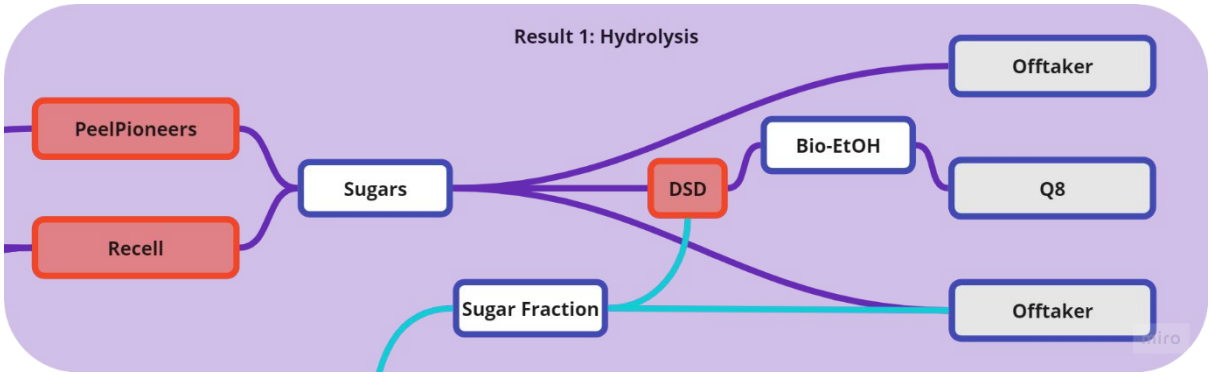
The activities of the project are structured along the following perspectives:

- *Increasing the technological readiness levels*: The technology providers and knowledge institutes will develop the required conversion technologies and value chains. Value chains go along the path of: Source (waste) -> pre-treatment -> conversion (hydrolysis/pyrolysis/gasification) -> post-treatment -> Circular & biobased chemicals for industry.
- *Solving non technological issues:* The development of the decision tool allows partners to determine which route is viable in which instance. Also, relevant stakeholders will address legislative and policy related issues paving the way for successful implementation of circular solutions & value chains.
- *Ensuring implementation:* Through learning communities, knowledge dissemination and implementation strategies societal and industry awareness is strengthened and uptake of the developed value chains by industry is ensured.

Progress and results of ReBBloCS year 2024-2025.



Result 1: Hydrolysis.



In result 1 waste streams are converted into valuable building blocks using hydrolysis. These waste streams at least include agricultural waste, wet and waterproof paper streams, primary & secondary sludges, and complex and voluminous biomass streams. Recell, PeelPioneers, and DSD are the technology providers in this workstream.

Just before the kick-off of the project one end-user had decided to not participate in the project (Corbion). In the year 2024 a second end-user iMENZ Bio-engineering, had to declare bankruptcy. GF Biochemicals and Natures Principles, will cover the activities of these two organizations in the future course of the project.

Activity 1.1: Conversion of biomass to carbohydrates.
The first steps in this activity include the specifying the contents from streams provided by the feedstock providers for biomass carbohydrates. The resulting specification sheet has now been fully developed. In the upcoming period, the DSD-process can be tested on several streams, also creating input for Recell (residual cellulose) and the glucose end-users (Q8, GF Biochemicals, Natures Principles). PeelPioneers has been successful in running their pilot operation on Orange Peels.

The activities of DSD are a slightly delayed, and the tests are foreseen in Q4 2025, mitigating the delay. The intent is that the newly joined partner Natures Principles will test one of the outputs of DSD outputs in their test equipment simultaneously. PeelPioneers incurred some delay as well. Discussions how to recover the planning have been initiated.

Activity 1.2 Conversion of tertiary cellulose with Recell Chem Technology.
Also, for this activity, specification sheets of streams from feedstock providers needed to be developed. This activity focusses on tertiary cellulose. Tertiary cellulose screens from Smurfit Westrock have now been used as feedstock for Recell Chem Technology. Furthermore, successful pilot operations have been run on WWTP and paper fractions by Recell. In the upcoming period, technology development and product quality validation with end-users will be central.

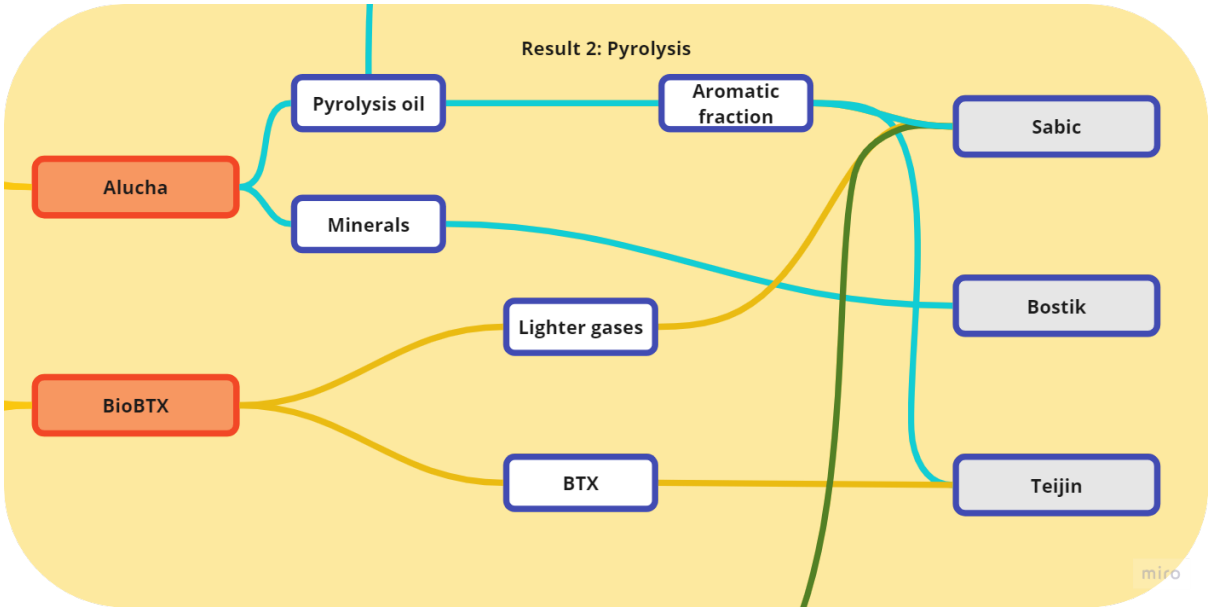
Residuals from the processes in this activity have been sent to Result 2 and 3, meaning that the first steps toward a full value chain for the waste streams coming into this activity is development.

Research on the residual stream from Smurfit Westrock is done by Recell on lab scale to improve the yields. The PhD of the RUG is working on the pretreatment steps to remove impurities from this feedstock, which will also result into a higher yield. EMI is working on the Downstream process of the produced glucose to make it suitable for activity 1.3.

Activity 1.3: Glucose on market spec.
For this activity, specification sheets of sugars for industrial users have been developed. The first results on the fermentability of these sugars have been analysed by an industrial user. When the new-end users are integrated into the project, this activity will continue. Optimizing the product quality will create a feedback loop with activity 1.1 and activity 1.2.

The RUG has done some first fermentation test to convert Recell sugars into levulinic acid. The following period will be used to improve the yields in this process.

Result 2: Pyrolysis.



In result 2 waste streams are converted into valuable building blocks using pyrolysis. Use waste streams include carbon rich waste such as plastic and biomass, paper sludge and screening rejects from the paper industry. Twence, EEW, Riwald, Smurfit Kappa and Sappi are waste providers for this work package. BioBTX and Alucha are technology providers and Sabic, Bostik and Teijin are end users of the produced building blocks. University of Twente, Spark904 and EMI Twente are knowledge institutes providing knowledge, research and services to other work package members.

Activity 2.1: BioBTX pyrolysis studies on biomass.
For this activity, the specification sheet related to the feedstock i.e., type of Biomass to be tested needs to be prepared. In 2025, a few runs will be carried out on the Mini plant and process optimization will be carried out.

Activity 2.2: BioBTX pyrolysis on plastic from post-consumer electronic devices and industrial waste streams.

In this activity, feedstock analysis has been completed by SPARK 904 for the feedstock provided by Riwald Recycling to BioBTX. The University of Twente has identified two feedstocks provided by Twence ideal to produce Benzene, toluene, and Xylene (BTX). These feedstocks were tested in the Mini plant at BioBTX in Q4 2024.

BioBTX has successfully completed runs on the Mini plant with the different feed streams obtained from the recycling of electronics equipment (WEEE) provided by Riwald Recycling. Analysis of pyrolysis oil has been completed by SPARK 904, as well as analysing the contaminants present in the oil. In Q4 2024, the process parameters in the Mini plant were optimized to (further) increase BTX yield and process stability. Additionally, the viability of the feed stream from Smurfit Kappa for BTX production were evaluated.

BioBTX has also completed runs with feedstocks provided by Twence viz. Films and foils as well as mixed plastics waste (mainly containing polycarbonates). The pre-treatment of the feedstock was carried out at BioBTX mainly shredding and extrusion.

BioBTX has also studied the effect of contamination in the feedstock on it process yields. Riwald provided feedstock stream mainly consisting of ABS:PS and PE (1:1) with varying degree of inerts i.e. one stream was washed, and the other was unwashed. BioBTX process observed no impact of the inerts on the process yields.

SPARK 904 has completed the tracing of the contaminants (mainly Halogens) from feedstock to the final product oil. It is also developing a method with Dynamic scanning calorimetry (DSC) to identify the components more accurately in the feedstock stream.

BioBTX has also provided sand samples from the fluidized bed after the trial runs to TU Twente for probable metal leaching.

EMI Twente will start the testing of gas mixtures on their setup

Activity 2.3: Alucha pyrolysis studies on paper sludge and fine screening rejects.

The first step in this activity is, to analyse the composition of the paper sludge streams provided by the feedstock suppliers. Alucha has received the first batch of paper sludge and fine screen reject samples from Sappi and Smurfit Kappa between 2023-2024.

- The initial round of feedstock characterisation has been evaluated with respect to the expected product quality of Circular Calcium Carbonate. Currently, the paper mills and Alucha are assessing consistency of the feedstock over the span of a year.
- Within this activity Spark904 has examined the initial batches of feedstock from both paper mills, as well as their recovered minerals (Alucha lab test). The preliminary assessments of contaminants and the first-round selection of the feedstock stream from each paper mill have been completed.
- The feed stock specification sheet is currently being developed for the paper sludge streams.
- Along with the end customer, the quality of the CCC—from these two paper mills—is being evaluated collaboratively.
- A second round of representative feedstock samples from Sappi and Smurfit Westrock has been provided to Alucha for characterization and production of on-spec material for the end user Bostik.
- The first round of samples was characterized by Spark904 using the EDX method.
  The sample preparation and calibration of the EDX still needs to be done for specific to CCC samples.
- A feedstock specification sheet has been prepared for the two selected streams.
- A first modest number of different grades of CCC test samples from the two paper mills was produced for Bostik.
- The end user Bostik is currently conducting application evaluation tests with different CCC samples from the two paper mills (Sappi and Smurfit Westrock).

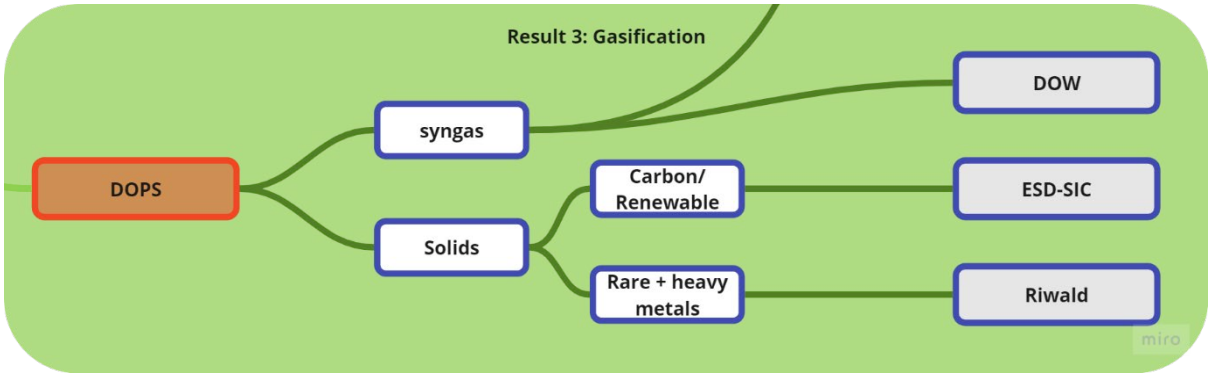
Planning 2025/2026

- Alucha plans to operate the pilot plant on selected paper sludge during 2025/2026 to produce sufficient test material for application tests by the end user Bostik.

Planning 2026:

- The second round of a representative feedstock stream selection will be assessed and examined in Q4 in preparation for the Alucha pilot plant test.
- A preliminary laboratory experiment aimed at producing modest amounts of CCC for end customer evaluation will be conducted.
- Alucha plans to run the pilot plant on selected paper sludge in 2025 to produce enough test material for application tests on industrial scale by the end user Bostik.

Result 3: Gasification



In result 3 waste streams are converted into valuable building blocks (syngas and solid residue) using DOPS proprietary gasification technology “Direct Carbon Immobilisation” to strip hydrocarbons from waste material. Used waste streams include hydrocarbon rich waste such as WEEE, plastics and biomass, also dried paper sludge and screening rejects from the paper industry.

Twence, Riwald and Smurfit Kappa have provided various testing waste materials of different grades and composition. Also, from process activity 1.1 (ReCell hydrolysis) the residual waste stream is a potential feedstock for the gasification process.

The tests for the conversion of these low-grade wastes were scheduled for the summer/autumn of 2024, the laboratory set-up is now fully operational to accommodate these tests, it took more effort to handle the different types of waste streams (i.e. fluffy vs hard material handling and feeding systems). The activities are part of milestone 3.1.

Together with EMI Twente a plan is developed about the refining/upgrading the quality of the products by application of membrane technology if necessary for downstream processing.

After the conversion tests, sample materials of the products (syngas and solid residue) were made available for activity 3.2 and 3.3.

The first-year information was shared with WP4 to give input for the generic MILP model.

Recently Spark904 issued the analysis results of the activities conducted under milestone 3.1. These will be reviewed in the coming period.

The University Twente is conducting additional testing activities under milestone 3.2, these are scheduled to be ready by early 2026.

Milestone 3.3. needs to be scheduled in 2026 together ESD-SiC.

Result 4: Total value chain analysis.

This work package aims to develop decision support models that can be used to optimize the design and planning of multi-waste valorisation systems. This part of the projects mainly builds on a PhD project at Wageningen University, for which the PhD student started in October 2023, and a detailed research plan been written. The 4 main research questions that will be answered are:

1. What are the key factors influencing the design and planning of multi-waste valorisation systems and how can they be considered in a decision support model?

2. How to quantify the trade-offs between economic and environmental indicators as well as identify the implications on supply chain configurations of multi-waste valorisation systems when considering multiple objectives?

3. What strategies could be implemented to improve the robustness of multi-waste valorisation systems, considering the inherent uncertainties in the waste streams and valorisation technologies?

4. How to distribute the benefits and burdens (economic and environmental) of the efficient network among multiple actors in multi-waste valorization systems?

Activity 4.1 *Development of the MOMILP tool (WUR).*

A generic optimization model was developed capturing the key dynamics of integral valorisation systems. An initial data collection from feedstock and technology providers has been the basis for the modelling work. The model is an adaptation from current network optimization models in the literature. The model optimizes mass flows of various waste resources and side streams to different technology options. It enables recycling of side streams to achieve complete fractionation of the waste resources. The model also considers the capacity of the processing technologies as well as transportation of materials within the systems. The tool development is an iterative process throughout the project duration. As the next step, the model will be extended to include environmental indicators, e.g. human health, ecosystem quality, and resource scarcity. The extended model is going to be used for the second manuscript on the multi-objective optimization of integral valorisation systems.

Activity 4.2 *Optimization of the sustainability performance of the value chains (WUR, input from allpartners from previous activities)*

The generic model of activity 4.1 was tested on various case studies relevant to the project, using data from literature. The data obtained from literature was checked and discussed with some project partners. Baseline scenarios to compare the performance of the integral system to the individual valorisation were developed and simulated. The results show that the profitability of the integral valorisation system in the case study could reach up to three times of the individual counterpart. In addition, sensitivity analysis was performed to observe how the configuration can be adjusted as responses to the uncertainties from the market and availability of waste resources. The results have been drafted into a manuscript for scientific publication.

The data collection will be extended during the remainder of the project to address the specific aspects mentioned in the remaining research questions.

Result 5: non-technological challenges.

Chemical recycling routes face not only technical challenges; non-technical issues such as limiting legislation. This work package focusses on these challenges and aims to either find temporary solutions or instigate structural change in the system.

This result consists of several elements. These elements are in part dependent on the activities and results of other work packages. Therefore, the results 5.1, 5.2, and 5.3 have started.

Activity 5.4 Addressing legal constraints and solutions.

The first step for this objective was to specify what the project group(s) need. There are several initiatives running on alternatives to existing legislation. To prevent ReBBloCS from inventing the wheel for a second time, the first step was taking by making inventory of ongoing initiatives. The second step is finding a role for the ReBBloCS consortium, either within these running projects or to fill in a white space. For this the UTwente is currently in the process of hiring a MSc student for a Master thesis.

Result 6: Knowledge dissemination.

Activity 6.1 Waste Valorization to Building Blocks Platform.

The ReBBloCS project is part of the Separations For Circularity program of ISPT. During the program meetings, held two times per year, the ReBBloCS project work package leaders have presented current progress and challenges. Furthermore, individual partners in the project have presented at program meetings to further elaborate on their participation in this MOOI project and highlight their technology.

Knowledge from the cluster will be used in several activities, such as 5.4.

Activity 6.2 involvement and education of students.

The project partners have given several guest lectures; see the table under "Publications & public dissemination". Two MSc theses have been started, with a third MSc thesis position being published at the UTwente.

Contribution to MOOI program goals, spin-offs and mission.

ReBBloCS recognizes the integrated approach that is needed to achieve the sustainability goals, as written in policy article 4, for the Dutch industry. To close value chains and achieve a circular economy it is of utmost importance that stakeholders work together on developing innovative alternatives for current linear processes. It includes the main technical and societal themes as well as policy alignment, environmental impact studies and skill development. Multiple building block value chains are explored in parallel and at multiple sectors/industries to accelerate the transition and implementation at system level.

Currently the main building blocks for industry (bulk and platform chemicals) are "virgin" materials based on fossil sources, resulting in a mostly linear system, while end-of-life phase scenarios of the products have not been considered during development. ReBBloCS will focus on shifting the industries perspective on "waste". In close collaboration with separation and conversion technology providers ReBBloCS aims for transforming un(der) valorized complex streams into circular building blocks that are useful for industry partners and can replace the fossil-based chemicals without losing quality (or even quantity). Maximum impact is aimed at, with the focus on carbon-rich streams found in for example complex mixed biomass/plastic, wet paper streams and sludges. When waste and side streams are recycled as new useful building blocks, the carbon cycle is largely closed. A strong emphasis is on developing a decision tree, based on quantitative sustainability assessments like LCA,

for the different waste streams and routes towards building blocks. Hereby not only environmental impact is considered, but also economic impact (i.e. cost-effectiveness) and relevant social aspects.

ReBBloCS thus aims to have an excellent contribution to the objectives of mission C, the MOOI theme Industry.

There have been no spin-offs yet.

Publications & public dissemination.

Date	What	Where?	Links (if available)
2023 March	Media coverage	AfvalOnline	https://afvalonline.nl/archief?searchall=ReBBloCS&categorie=
2023 July	BOSTK ReBBloCS page	Bostik	https://www.bostik.com/belgium/nl_BE/media/news/construction/emea/netherlands/bostik-benelux-news-20072023-rebblocs-renewable-waste/
2023 August	WUR ReBBloSC page	WUR	https://www.wur.nl/en/project/renewable-building-blocks-from-complex-and-wet-waste-streams.htm
2023 August	ISPT ReBBloCS page	ISPT	https://ispt.eu/projects/renewable-building-blocks-from-complex-and-wet-waste-streams-rebblocs/
2023 September - 2024 June	MSc thesis – Thomas Heijmans	WU	
2023 September 07	Media coverage Utoday	Utoday	https://www.utoday.nl/science/73212/afval-omzetten-in-waardevolle-bouwstenen-voor-de-industrie
2023 September - 2024 June	MSc thesis – Mark van de Sol	WU	
2024 June 17	BNR Duurzaam (national radio broadcast)	BNR	https://www.bnr.nl/podcast/duurzaam/10550175/deze-nieuwe-reactor-maakt-van-afval-weer-grondstoffen
2024 May 22	Guest lecture in course Biobased Logistics	WU	
2024 May 29	Guest lecture in course	WU	

	Biobased Logistics		
2024 May 29	Media coverage Change.inc	Change.inc	https://www.change.inc/industrie/deze-revolutionaire-reactor-maakt-van-afval-weer-gas-en-andere-nuttige-grondstoffen-41022
Tbd.	Scientific article	Furqan et al.	Designing Efficient Integral Valorization Systems
3 November 2025	Conference abstract	NPS 2025	Hala et al., Netherlands Process technology Symposium (NPS 20) in Eindhoven, the Netherlands.
12 October 2025	Conference abstract	E2DT 2025	Marti and Schuur at E2DT Palermo, Italy

Learn more about the project.

To learn more of the project, please contact:

Gerard van Binsbergen (Project leader)

Gerard.binsbergen-van@ispt.eu

Irene ten Dam (Program manager Seperations for Circularity – ISPT)

Irene.tendam@ispt.eu

Otto Tobé (Program Officer Seperations for Circularity – ISPT)

otto.tobe@ispt.eu

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