FAU Friedrich-Alexander-Universität
Department Chemie- und
Bioingenieurwesen

# Scaling up of a polystyrene recycling process

## Executive Summary

CBI project course fall 2022

Partner: RECENSO GmbH, Remscheid

# Outline

The CBI project course is a curriculum event of no commercial interest organised by the Department of Chemical and Biological Engineering (CBI) at the Friedrich-Alexander University Erlangen-Nuremberg (FAU) in cooperation with an industrial partner. The partner of the CBI project course in fall 2022 is Recenso GmbH, located in Remscheid, Germany, which specialises in the recycling of materials in order to be able to return them to the material cycle as secondary raw materials.

The task of the project course is "Scaling up of a polystyrene recycling process". The polystyrene waste comes mainly from the insulation of houses. As they are heavily contaminated with the previously used flame retardant HBCD, they have to be chemically recycled in order to recover polystyrene and return it to the material cycle as secondary raw materials. In chemical recycling, the polystyrene is first dissolved in a solvent and then precipitated again without affecting the chain length. The HBCD is not precipitated and remains in the solution, thus separating it from the polystyrene. The CreaSolv® process of the Fraunhofer IVV serves as the basis for the upscaling. Based on this process, a recycling plant with a capacity of 3000 tons per year is already in operation in Terneuzen, Netherlands. The aim of this course is now to plan a new plant that can recycle a capacity of 30000 tons per year. Figure 1 shows a simplified flow diagram of the process.

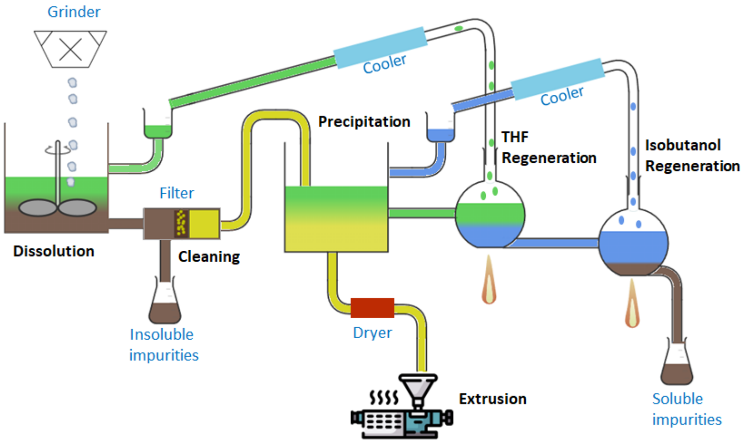

*Figure 1: Simplified flow diagram of the EPS recycling process (created with chemix.org).*

It was assumed that the expanded polystyrene (EPS) waste would be pre-compacted for transport to the plant and delivered in the form of briquettes. The briquettes have to be crushed in the first step. The crushed EPS is then dissolved in a reactor in the solvent tetrahydrofuran (THF). After the reactor, the solution is filtered to separate insoluble impurities. In the next step, the dissolved EPS is precipitated and purified by adding the antisolvent isobutanol. The precipitated EPS is then dried and extruded into uniform polystyrene granules using an extruder. The solvent and antisolvent are regenerated by distillation and returned to the process. HBCD and other soluble impurities are separated from isobutanol by evaporation.

# Results

In order to fulfil the task, the students were organised into different groups. These groups can be divided into specialists and generalists. The specialists focused on a specific process unit, whereas the generalists had to consider the entire process. The specialists are the groups pretreatment of PS, dissolution, purification, extrusion and solvent and antisolvent recycling. The generalists are process simulation, handling of impurities, piping and pumps, heat management, automation, costs and management.

## Management

The main task of the management group is the overall coordination of the project and ensuring smooth cooperation between the individual groups. In addition, the management group ensured that the schedule was maintained (see Figure 2) and organised the interim presentations and the final presentation.

*Figure 2: Timeline for the CBI project course fall 2022.*

To ensure that the project is finished on time, a design freeze was set in the middle of the course, where the design of the respective process units was fixed by the specialists, so that the generalists still had enough time to complete their tasks.

## Pretreatment of PS

In ordinary recycling processes as well as in the recycling of expanded polystyrene (EPS), the pretreatment of the waste material, including comminution and the removal of impurities and water, plays an essential part in enabling all further downstream processes.

The waste to be recycled consists of EPS briquettes made from former construction material compacted to 300 kg $m^{-3}$ to ensure economic transportation.[1] Those briquettes are assumed to contain up to 3 wt% of inert impurities like sand, glass and metal pieces as well as up to

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[1] Udo Knauf, Andreas Mäurer und Wolfgang Albrecht (2005): EPS-Loop: Recycling von EPS-Abfällen zu reexpandierbarem Polystyrol: Schlussbericht; Projektlaufzeit: 1.8.2003 - 31.7.2005. Unter Mitarbeit von TIB - Technische Informationsbibliothek Universitätsbibliothek Hannover, Technische Informationsbibliothek (TIB)

3 wt% of water, bound on the surface and primarily within the pores. Visibly heavily contaminated product is preseparated manually.

As the first step in the pretreatment process, the EPS waste is roughly comminuted in an EPS cutting mill (shredder) to the inlay grid size of 50 mm and smaller. In the next step, the material is transported into a wind sifter to facilitate a rough separation of the inert components. At this point it is assumed that the metal fraction and 90 wt% of the sand and glass fraction can be separated from the process due to their far greater inertia, leaving only fine sand and glass as impurities in the process.

Next, the EPS particles are fed into the second milling machine, a hammer mill. Using a 6 mm grid mesh width the required $x_{90,3}$-value of 5 mm can be guaranteed.[2] The particles are stored in a silo to act as a buffer and then transported to a drying unit, which operates in batch mode, in order to remove residual pore water. The employed vacuum paddle dryer can guarantee a residual moisture content of 0.01 %.

The dried EPS is handed over to the dissolution step. After dissolution, the polystyrene/THF/isobutanol solution is still contaminated with small sand and glass particles. In order to purify the solution, multiple edge filters with a pore width of 50 µm are employed to enable a continuous removal of residual solid material. The filter cake is continuously removed and then transported to a collection tank. The permeate stream flows into an insulated buffer tank and is then sent to the subsequent precipitation unit.

## Dissolution

In the dissolving process, 20 wt.% of EPS was combined with 80 wt.% of THF, both the solid and liquid feed were combined in a continuously stirred tank reactor (CSTR). To determine the residence time in this continuous process it is of high importance to set up the correct solubility kinetics. After obtaining the solution kinetics and the resulting residence time, it is possible to plan the dimensions of the reactor and stirrer. Therefore, an overview of the challenges and solutions will be given in the following summary.

The dissolving rate of EPS in THF is the main part of the solution kinetics. Furthermore, the main influences on the kinetics is the diffusion coefficient of EPS in THF and the degree of turbulence and dispersion in the stirred reactor. Both these parameters are affected by the viscosity of the solution. Hence, it was important to set a fixed temperature of 60° C in combination with the determined ratio of EPS and THF. This leads to a solution with a viscosity of 350 mPas. The literature research in finding a diffusion coefficient for PS in THF at the given

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[2] Fehn, Thomas; Elsner, Martin P.; Schweppe, Rainer; Teipel, Ulrich (2022): Bestimmung der Prozessparameter von Zerkleinerungsprozessen für dämmstoffhaltige Kompositmaterialien. In: *Chemie Ingenieur Technik* 94 (3), S. 427–439. DOI: 10.1002/cite.202100137.

state variables was successful. However, there was no published information about the dissolution of compressed EPS (300 kg $m^{-3}$) in THF. As a result of that, the findings of the EPS-Loop on the solution time of EPS briquettes were used as a basis for calculating the residence time.

The residence time amounts to 1.3 h with a resulting reactor volume of 48.2 $m^3$, which was calculated by the total volume flow of 23.5 $m^3$ $h^{-1}$ and the residence time. The reactor is only operated at a capacity of 65 % to prevent an overflow of the reaction medium. The stirrer of choice was a propeller stirrer, mainly due to its axial flow profile which prevents the layer formation of the EPS, fed from above. The stirrer needs a motor with the power of 44.4 kW.

THF is highly volatile, resulting in its high vapor pressure of 0.83 bar at 60 °C. At 1.5 bar in the reactor, a rich atmosphere is created. This prevents explosions. However, THF may not be released into the atmosphere and a condenser is needed to purify the exhaust stream of the reactor. The condensed THF is then recycled.

## Purification

The task was to precipitate the EPS dissolved in the previous step in such a way that enough HBCD can be removed with the liquid phase, while the polystyrene forms a gel through the contact to an antisolvent. This antisolvent had to be chosen from a selection made of water and different short-chained alcohols. In the end, an HBCD content of 100 ppm in the polystyrene should not be exceeded.

First, based on the boiling temperatures, the Hansen solubility parameter for hydrogen bonds and the evaporation enthalpies, the antisolvent was selected to be isobutanol, since it is more suitable than water and the other short-chained alcohols in terms of the quality of the precipitation and the simplicity of the separation of solvent and anti-solvent. It does not form an azeotropic mixture with THF and is comparable when regarding toxicity as well as corrosion. To precipitate the previously dissolved polystyrene, the ratio of EPS to the antisolvent isobutanol was set at 1:10.

In a spray apparatus, at 100 °C and 3 bar, the THF-EPS stream from the filter, the isobutanol stream from the recycle and an internal recycle stream are combined. The mixture remains in this step for a residence time of 2 hours, resulting in a recovery of 98 wt.% of the EPS. It forms a gel phase with a residual moisture content of 30 wt.%. Natural sedimentation is not sufficient for phase separation. Therefore, all contents of the spray apparatus are fed into a decanter centrifuge.

The liquid output from the centrifuge is delivered to the solvent/antisolvent recycling, whilst the gel requires further processing, because the HBCD content is still too high. It is lowered by washing with another stream of isobutanol in the ratio of 1:5. Due to the gel consistency, an inline mixer is used to apply high shear forces and to promote the contact of the phases. This mixture is then separated again in another decanter centrifuge. The liquid phase is the internal recycle that is fed into the spray apparatus. Even after the washing it still has a high fraction of isobutanol and can support the precipitation.

In the next step, the EPS gel is dried in a roller dryer under vacuum (0.5 bar, 90°C) and is then conveyed to the extruders by a screw conveyor and with a remaining residual moisture of 3 wt.%. The waste stream from the roller dryer is fed to the internal recycle stream and thus also returns to the spray apparatus.

The precipitation and purification processes can lower the HBCD content in the final product to 56 ppm, well below the legal limit.

## Extrusion

After the drying step, an extrusion line and a storage system must be implemented. The goals of the extrusion process step are reducing the remaining moisture of isobutanol from 3 wt.% to 0.047 wt.%, shaping the product to uniform PS-granulate with an average diameter of 3 mm and preparing it for sale.

First, the material which is coming from the dryer is fed into a silo where the stream is split up equally to feed two extrusion lines via screw conveying. Since the selected extruders from MAS Plastic Processing Technology are designed for throughputs of up to 2500 kg $h^{-1}$, two extruders are necessary to ensure the total output of 4169 kg $h^{-1}$. At the beginning of each extrusion line a volumetric dosing station is feeding the extruders. Due to the high moisture content of the material entering the extruders, twin screw extruders with degassing must be used. For the degassing, vacuum water ring pumps with a closed water circuit are installed and the resulting isobutanol outflow is condensed and recycled. A continuous disc filter is placed after the extruder to separate potential larger impurities from the melt. Next, this melt is led through an additional single screw extruder for further degassing. As a last step a water ring pelletizer forms the final product. The PS-granulate is stored in flexible silos, filled into Big Bags and thus is ready for transportation to customers. The final product respects the legal limits of HBCD-content and, with the reduced moisture content, has properties close to new PS-granulate.

## Solvent and antisolvent recycling

The process step regarding the recycling of the solvent Tetrahydrofuran (THF) and the antisolvent isobutanol aims the recovery of both substances in high purity to enable the establishment of recycle-loops within the process. The purity of THF and isobutanol is set to

99 wt.% and 98 wt.%, respectively. The recovered solvent THF is fed back into the reactor for the dissolution of the expanded polystyrene (EPS), while the stream of the recovered antisolvent isobutanol is split between the apparatus for the precipitation of the polystyrene and the washing unit. The entire process step is designed in a continuous mode and consists of a rectification unit, followed by a two-step evaporation unit in steady-state operation. An integrated energy recovery is established using the hot vapor stream from the first evaporator to provide the heat supply for the evaporation of the boil-up stream at the bottom of the column.

The feed from the previous process step of precipitation comprises isobutanol, THF and the flame retardant HBCD in descending order regarding the mass fraction and hereby only traces of HBCD. The stream is fed into the rectification column, where the light boiler THF is separated from the heavy boiling components with HBCD being dissolved in the isobutanol. To increase the lifetime of the column, the lower part of the column is equipped with more robust sieve trays, since it is not ensured that the feed stream is free from dissolved polystyrene. In the upper part of the column packings are used to allow an effective phase separation with the assumption that no polystyrene is present in the upcoming gas phase.

The THF exits the head of the column with a purity of 99 wt.% and can be recycled within the process. The bottom product is fed into the first evaporator for further purification. The first unit is built as a falling film evaporator, while the second smaller unit is a continuous stirring tank evaporator. The aim of this unit is the stepwise concentration of HBCD in the solution of isobutanol up to the saturation concentration. The procedure strives to minimize the loss of isobutanol. At 4 bar and 143 °C, isobutanol and the residues of THF are evaporated and leave the evaporator at the top. The hot vapor is cooled down in a heat exchanger, causing the boil-up stream of the column to evaporate. Here, an evaporator with a sufficient power of 7.8 MW was selected to fully cover the necessary heat supply.

The bottom stream of the first evaporator is transferred into the second evaporation unit, where it is fully concentrated to the saturation concentration at atmospheric pressure and at a temperature of around 150 °C to 160 °C. The elevated operation temperature is a result of the elevation of the boiling point temperature of the isobutanol due to the dissolved HBCD. The gaseous isobutanol stream at the top is merged with the top stream of the first evaporator after the heat exchanger and the expansion to 1 atm. The merged stream is then fully condensed and with a purity of 98 wt.%, it can also be recycled within the process. The waste stream at the bottom of the second evaporator containing the HBCD is intended for hazardous waste treatment.

# Process simulation

The process simulation group has the goal to run important sections of the process in the simulation program Aspen Plus. The overall process was calculated. It includes dissolution, precipitation, and purification of the polystyrene, as well as the solvent recycle. The simulated process is shown in Figure 3. There are 3 recycle streams in the process. The first stream is necessary to recycle the THF. The second recycles the isobutanol. The third recycle is for the washing fluid and reduces the HBCD content in the precipitated polystyrene. In the overall process, losses of solvent and antisolvent occur during the dissolution, filtration, extrusion and evaporation. Therefore, make-up streams for the solvent and antisolvent are necessary for a steady state operation of the plant. The group was able to build a converged simulation system with closed recycles to calculate the make-up streams. The calculated make-up stream for isobutanol is 189.83 kg $h^{-1}$. To compensate for the losses of THF, only a stream of 1.04 kg $h^{-1}$ is necessary.

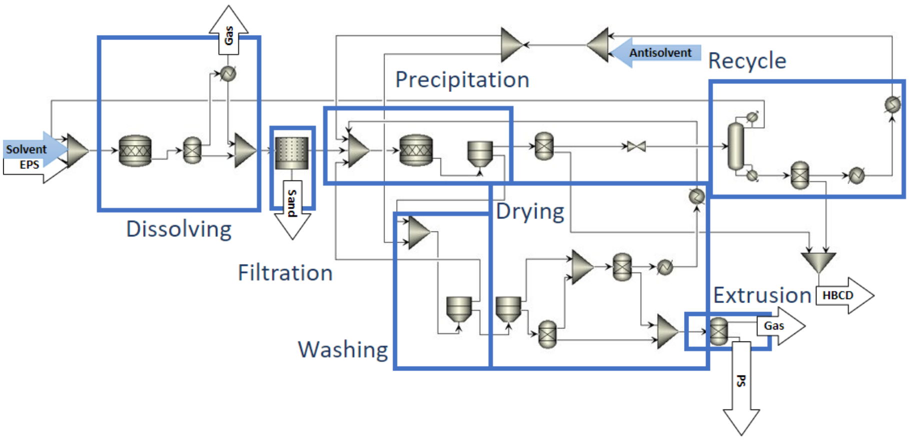

*Figure 3: Flowsheet of the simulated process.*

# Handling of impurities

The main task of this group is to handle all occurring impurity streams in the polystyrene recycling process. This includes several waste streams, which leave the polystyrene process at three points:

1: A dry waste stream from the initial wind sifter that contains metal, glass, minerals, and other solids (3.2 t $day^{-1}$),

2: A waste stream from the filter after the dissolution of the polystyrene foam that still contains small particles of metal, glass and minerals that passed the wind sifter. This filter cake is mixed with residues of the solvent THF and dissolved polystyrene (266 kg $day^{-1}$),

3: A waste stream from the distillation, the final HBCD removal unit that contains crystallised HBCD and HBCD dissolved in isobutanol (4.7 t $day^{-1}$).

The main objective is to treat the impurities in a **safe and economical way.** Part of this is choosing suitable disposal facilities and checking their respective guidelines. For this, the **contamination of the waste mixtures** needs to be estimated and **storage and transportation** must be discussed.

1: During the project, the pretreatment of PS group implemented a wind sifter to precede the dissolution and filtration process. This means a considerable amount of metal, sand and glass will initially be removed. It is assumed to be free of polystyrene and HCBD, contains no solvent and could be landfilled. Harvesting of the metals for recycling purposes might be feasible and both ecologically and economically more sensible.

2: Regarding the insoluble waste stream, two options are considered: Washing and drying the filter cake to extract residual solvent and therefore reducing the loss of valuable components or leaving it untreated and sending it to an incineration plant. Because there is residual THF in this impurities stream, landfilling the waste would not be possible.[3] Due to the fact that the second impurity stream is relatively small, washing and drying the filter cake would probably not be economical and rather incinerating this stream would be favourable. Research into conventional waste incineration plants shows that flammable fluids are not disposable there, which is why special hazardous waste incineration plants must be used for approximately double the disposing cost.[4] Considering storage and transportation of impurities containing Tetrahydrofuran, it is important to note that THF can form explosive peroxides through auto-oxidation. For this, an inert gas like nitrogen can be used, and will add to the cost.

3: The remaining soluble waste stream contains mainly halogenated flame retardants solved and suspended in isobutanol. This waste can either be repurposed in a bromide-recycling-plant or must be disposed very expensively in a hazardous incineration plant. Also, the extremely high Bromine content and immense quantity of this waste would make it impossible to incinerate it in a single waste incineration plant.[4,5]

## Piping and pumps

This group's task was subdivided into three major tasks: creating a layout plan of the plant, designing of the piping system, and selecting suitable pumps for the process.

At the beginning, and to get an overview of all streams, process units and pumps, a basic flow diagram was created, and the respective components were numbered. For this purpose, all necessary information were requested from the other groups. Based on the basic flow diagram the layout plan was modelled in the software SketchUp. There, the minimal distance between

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[3] DepV from 27.04.2009 §7; §14

[4] https://zvaws.de/wp-content/uploads/2021/07/1_benutzungmhkw.pdf

[5] Telephone call GSB Bayern

the different components of the plant resulting from safety and maintenance reasons were taken into consideration.

Thereafter the construction of the piping system for the whole facility had to be planed. All volume flows and other properties of the streams were provided by the specialist groups for each process step. For the streams containing tetrahydrofuran (THF), stainless steel tubes are used, as this is one of the few suitable materials for this chemical. In addition, stainless steel is widely available and considered safe to use. For the flows without THF, black steel is used because it is cheaper than stainless steel and meets the safety criteria. Depending on the volume flows and common flow velocities the minimum inner pipe diameter was calculated ensuring at the same time that the minimum thickness of the pipe walls withstand a maximum water hammer pressure. Pressure losses over the pipe length and through geometries or fittings were determined to position necessary with the layout plan being used as the basis for this calculation. Stabilization calculations were carried out to ensure that the pipes would not vibrate or might get damaged because of pump vibrations. To ensure that plant workers would not burn themselves on the outer wall of the pipe, the temperature there should not exceed 50 °C. To achieve this, mineral wool was chosen as insulation for most of the pipes.

In the process four types of substances with different flow properties have to be transported. Centrifugal pumps were chosen to transport liquid, membrane pumps for liquid with particles, a gear pump for gel-like liquid and an eccentric screw pump to transport filter cake. Appropriate pumps were used for the different flows depending on their characteristics. Furthermore, the Net Positive Suction Head (NPSH) value of the centrifugal pumps was calculated to avoid cavitation.

## Heat management

The aim of the heat management group was to optimize the process by identifying possibilities of heat recovery and thus reduce the energy requirement of the plant. To achieve that goal, the group started by tracing which process streams and operation units needed heating and/or cooling. Afterwards, mass and energy balances were established to quantify the heating and cooling duties of each stream. The total heating requirement corresponds to a value of 17.7 MW and the cooling requirement to 25.4 MW to produce 4169 kg $h^{-1}$ of polystyrene. This corresponds to an annual cost of 4.8 million euros.

After determining the thermal energy requirement, a Pinch analysis was performed. This analysis method enabled the estimation of how much heat could be recovered through heat integration within the process. The heating and cooling demands that could not be provided internally had to be supplied by an external heating or cooling system. As a result, the best possible heat exchanger configuration could be achieved. This improvement promoted a reduction of around 36 % of the total external energy requirement for heating and cooling, representing a reduction of 63 % in the annual energy cost.

Considering the optimized heat exchanger network, the heat exchanger models were chosen. The proposed network consists of 13 heat exchangers in the entire process with a total exchange area of 559 $m^2$. The choice of heat exchanger models took into consideration the composition and the physical and chemical characteristics of the streams. For most of the streams a U type Shell and Tube heat exchanger with cocurrent operation could be applied without further complications. A spiral plate heat exchanger was considered for the condenser and reboiler of streams connected to the rectification column to minimize fouling effects caused by crystallization of HBCD present in the streams. For the boiler used in the solvent and antisolvent process, a falling film heat exchanger was considered in order to concentrate the HBCD present in the streams and ensure high energy efficiency.

Due to technical reasons, most of the thermal energy that was thermodynamically available for recovery could not be used in the heat integration system. Therefore, the implementation of an Organic Rankine Cycle, the use of heat pumps and adsorption chillers could be interesting possibilities to utilize the exhaust heat.

## Automation

Normally, deviations from the desired values can occur in any plant. To correct these, the plant needs an automation system, measuring points and intervention options. In this part, the designed polystyrene recycling process is automated for stationary operation.

Therefore, the entire process is divided into subprocesses. For each of them, a Piping and Instrumentation (P&I) flow diagram is created and provided with control and regulation units. In a next step these subprocesses are linked to one overall process with a functioning automation system. Furthermore, some possible deviations from stationarity and the reaction of the system are considered. In addition, a first start-up and shutdown concept are prepared.

Part of the P&I flow diagram are closed-loop cycles, which consist of a sensor and actuator. The former measures the actual value (e.g. temperature, pressure, flow, level, etc.) and the latter (e.g. valves, pumps, heat exchangers, etc.) can affect this value by changing system parameters if there is a difference between the actual value and defined setpoint. Some of the Subprocesses are sensitive to fluctuations of input parameters. So, it is essential to install some equipment between the subprocesses like buffer tanks that can absorb fluctuations. Both Starting-up and shutting down a chemical plant are processes having strong deviations from stationary operation. Hence, critical points in these procedures are examined, an order for turning the process units on or off is mentioned and it is determined, where additional equipment for preheating, buffering etc. is required.

Due to these automation measures, the polystyrene recycling process can be operated in a stationary and safe way. Additionally, the flow diagrams give a detailed overview over the total process and each of the subprocess and show their connection to each other.

# Costs

As evidenced by the *Chemical Engineering Plant Cost Index* (CEPCI), the costs for constructing a chemical processing plant have seen a sharp increase since 2020, mainly due to political factors. This index is used for an initial estimate of the total investment costs of the plant with the capacity method as a function of plant complexity, output, number of functional units and number of recycle loops. As such, the **initial total investment costs** for the plant are estimated to be **€ 21MM**. The equipment costs are calculated using offers from different plant and machine construction companies and estimated with regression and correlation methods, where needed. The **calculated total investment costs** amount to **€ 19MM** including engineering and planning. By applying the so-called *Hand-Factor,* considering necessary side costs for the construction of the plant, the **total investment costs** amount to **€ 60MM**. A reasonable estimate for the total investment costs is **€ 50MM**.

Half of these investment costs result from the shredding, filtering and extrusion related components of the plant. Here, specialized machinery is needed, which results in higher equipment prices. For the rest of the plant, standard chemical industry equipment is used.

The **processing costs** of the plant amount to **€ 24MM per annum**. The bulk of the processing costs are made up of heating (45%) and cooling (15%). Other significant cost factors are staffing (12 %) and waste disposal (10%).

The revenue streams for this plant are selling recycled polystyrene at an estimated price of 1100 €/ton and receiving EPS at an estimated price of 100 €/ton. This results in a **total turnover** of **€ 36MM**. Consequently, the **annual gross profit** of the plant is **€ 12MM**. This results in an **annual cash-flow** of **€ 8MM** and a **simple payback time** of **7.5 years**, with respect to the total investment costs calculated with the Hand-Factor. The **return on sales** for this estimate is **33 %**.

The **main issues** for the economic feasibility of the plant are the recently fluctuating and rising costs for heating with steam and the expensive disposal of the HBCD waste stream. Furthermore, the price for receiving the EPS for recycling is uncertain, since transport and compression costs need to be considered. Hence, the profitability of the plant depends on cheap access to high pressure steam and a cheap disposal method for HBCD. It is recommended to process the HBCD waste stream either by purification or by recovering bromine. Opening these additional revenue streams would ensure the profitability of the plant.

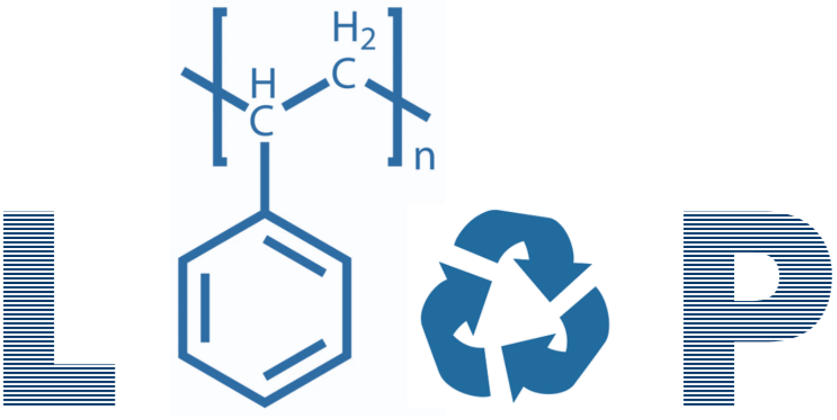
Additionally, the location of the plant should be chosen with cheap and easy access to high pressure steam and cooling water while minimizing transport costs.

# Résumé

Scaling up the recycling process to a capacity of 30000 tons per year is possible. For this purpose, the EPS delivered in briquettes must first be crushed to a $x_{90.3}$ of 5 mm in a two-stage crushing process. The crushed EPS is dissolved in the solvent THF in a continuous stirred tank reactor with a reactor volume of 48.2 $m^3$. The mixing ratio is 20 wt% EPS to 80 wt% THF. An axial stirrer with a power of 44.4 kW is used. The filtration to separate insoluble impurities is done in multiple edge filters with a pore size of 50 µm. For precipitation of the dissolved EPS a spray tower is used. In the spray tower, the antisolvent isobutanol is added in a ratio of EPS to isobutanol of 1:10, recovering 98 wt% of the dissolved EPS. The precipitated polystyrene is dried in a decanter centrifuge. Afterwards, it has to be washed again with isobutanol, to reduce the HBCD content to 56 ppm, which is below the legal limit. Two extrusion lines with a capacity of 2500 kg $h^{-1}$ each are required for the extrusion. The extruded PS granules have an average diameter of 3 mm and properties close to new PS granules. For the regeneration of THF and isobutanol, a rectification unit followed by a two-stage evaporation unit is required. Through heat integration, a great amount of energy can be saved here, so that only one evaporator with a sufficient power of 7.8 MW is needed. Due to losses, a 1.04 kg $h^{-1}$ make-up flow of THF and a 189.83 kg $h^{-1}$ make-up flow of isobutanol are required for the entire plant. The energy demand of the plant is 17.7 MW for heating and 25.4 MW for cooling. Through heat integration, the total energy demand can be reduced by 36 %. This requires 13 heat exchangers with a total area of 559 $m^2$.

The location of the plant is crucial for the profitability. The plant should have easy and cheap access to utilities, especially high-pressure steam and cooling water. In addition, it should be possible to recover the bromine at or near the site so that there are no costs for disposal. Our proposal would therefore be to construct the plant in a plant network and close to a bromine recovery plant.

# Imprint



Scaling-up of a polystyrene recycling process – CBI project course 2022

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