Innovative Approaches Improve Competitiveness – Dongil Paper

Executive Summary

The paper industry in developed countries has been facing challenges from a mature market. In spite of challenging economic forecasts, investments in innovative technologies have proven to improve the competitive edge as well as the profitability of a company.

Dongil Paper has taken a unique approach to increasing profitability. Instead of reducing costs in the hope of constant market price, they have made small scale investments to existing production machines. These investments simultaneously accomplish cost savings and address new environmental requirements, which in turn can lead to production of new higher margin grades and an increased return on investment.

Dongil Paper found their competitive edge in this challenging economic market using starch spray application and curtain coating on a low brightness base sheet.

Abstract

The paper industry in developed countries i.e. North America, Western Europe, Scandinavia, Japan and South Korea has for many years been struggling with the incapability of maintaining profitable operation, justifying new capital investments and expanding the market areas. Dongil Paper, located in South Korea,
has through considered risk taking expanded its position as a market leader in the local packaging industry. In spite of challenging economic forecasts for the industry, investments in innovative technologies have proven to improve the competitive edge in the market as well as the profitability of the company. Capital investments in new technology provide manufacturing cost savings, positive environmental impact and give great return in the short term.

Producers of liner and corrugating medium grades from recycled fiber often struggle with challenges to reach required strength properties compared to packaging grades produced from virgin fiber. Starch can be used on the size-press to compensate for the lost fiber strength, weakened from recycling. However, conventional size-press technologies have limitations when high starch amounts are targeted or at high machine speeds in modern packaging board machines. Spray sizing overcomes many road blocks and sufficient strength improvements are achieved for recycled testliner and corrugated medium. Starch spraying on the size-press has been practiced by Dongil in South Korea for many years to achieve sufficient strength improvements, but has also presented other challenges. The latest development of the spray application technology has resulted in a commercial spray device, capable of providing a large window for the starch application amount and giving an exceptional transfer rate to the web. A clean operation with no starch contamination to the machine surroundings is maintained.

The theoretical provisions for an effective starch transfer to the web and starch penetration control are described in this paper. The theories are supported by pilot trial results as well as production experience. Starch application with spray is a new innovative approach to produce packaging board grades economically from a fully recycled fiber source.

Curtain coating gives excellent coverage and a low brightness base sheet is easily covered up by the coating applied in two layers. When curtain coating is used to make the surface white, the high cost bleached virgin fiber layer in white top liner grades, often seen as non-environmental friendly, can be replaced with recycled unbleached fiber. Dongil Paper started up its curtain coater at the end of 2008, making the unbleached base board white.

**Introduction**

**Paper Industry Trends**

The paper industry in Western Europe and North America has been facing challenges from a mature market for at least a decade. Also Japan and South Korea have experienced the same situation. In opposite, China is the best example of an emerging market. Focusing on containerboard, South Korea is a country where containerboard production exceeds consumption and the yearly consumption increase is marginal. In consumption/production ratio, the containerboard situation is very similar to that of Germany, and the total volume is not far behind. In the United States containerboard consumption slightly decreases and production expansion efforts should be questioned. Contrarily, in corresponding figures for China, consumption demand exceeds production and the yearly increase is consistent, as seen in Figure 1. The increasing production of the entire Chinese industry raises demand for containerboard as a packaging material. It is not surprising that the new containerboard machine investments take place in China.
Dongil Paper Manufacturing

How then to survive in a mature market? The conventional attempt to improve profitability in the paper industry has in most cases ended up in cost saving attempts. Decreasing the production cost naturally will give a higher margin assuming at least a constant market price for the product. A consistent high market price for the product is of course not a given. Are there other ways to improve profitability? Dongil Manufacturing in South Korea has taken a unique approach to improve profitability when struggling in a mature containerboard market. Small scale investments to existing production machines open up the field to produce new products, simultaneously accomplishing cost savings and addressing new environmental requirements. After rebuilding the production line, new higher margin grades can be produced and the return on investment is reasonable. When the investment focuses on new machine technology instead of tuning existing machines, and being the first user of the new technology, a competitive edge is found. It will take a long time for the competition to catch up with new machine technology. Risks are naturally involved with new technology. However, considered risk taking is necessary to reach this position. The incapability of risk taking has generally harmed paper industry innovation for a long time and has run many companies into a critical financial position, common today in mature market countries.

In the history of the Dongil company, many new equipment products have been installed to differ from the conventional container board manufacturing process. A competitive edge has continuously been created resulting in increased market share of the Korean market. The most significant machine improvements by Dongil to reach its goals have been:

- Installation of the CondeBelt dryer in Ansan 1999, resulting in a new linerboard grade with improved strength and smoothness in linerboard.
- Installation of a size-press in Ansan, 2003, further improving the testliner strength.
- In the summer of 2008, installation of new starch spray technology in Uiryeong mill, opening a window to improve strength in testliner and corrugating medium not reachable with any conventional starch application methods when using Korean recycled furnish.
- In the end of 2008, installation of curtain coating in the linerboard machine in Ansan, giving an opportunity to produce white top liner and coated liner grades, never previously produced in

Figure 1. Container board production and consumption figures for selected countries [1]

Source: RISI Forecast 25.4.2008
Korea. The recent developed curtain coating technology made it possible to complete the transition into higher value grades, which was strategically started already a decade earlier with the CondeBelt installation.

**Improving strength in recycled fiber grades**

Use of recycled fiber is encouraged in the paper industry today. A model at Youngstown State University suggests that 1.5 tons carbon dioxide total output is reduced if one ton virgin fiber is replaced with one ton recycled fiber [2].

In South Korea, the paper recovery rate is the highest in the world as seen in Table 1. According to the Korean Paper Manufacturer’s Association, the recycling rate has increased to as high as 81% in 2007.

As a result of the high recycling rate combined with a limited import of foreign fiber to Korea, the strength of the Korean recycled fiber becomes by default low. Manufacturing of high strength liner and corrugating medium from 100% Korean OCC becomes challenging and use of more fiber and higher basis weight may become the only way to reach the strength targets required in corrugated boxes. Size-press starch improves strength as well. It can be calculated that it is more economical to add starch to the sheet than to add fiber to reach the required strength properties. Conventional size-press technology however has some limitations:

- A pond size-press limits the speed; splashing and runnability issues prevent operating at high speed, necessary for today’s profitability demands. The starch application amount is hard to control and starch concentration ends up being low and drying energy demand high, which harm the economics.
- A film size-press (metered size-press) sets limitations in how much starch can be applied and how well the starch penetrates into the web. Attempts to apply thick films on the applicator roll, in order to increase the starch pick up to the web, will result in ponding in the nip, and the downsides of the pond size-press become apparent also with the film sizer.

Spray application of starch prior to the nip adds penetration thanks to the dwell time from application to the pressurized nip. The challenges of the film sizer technology are faced. However, misting of starch to the surrounding area must be prevented so as not to cause additional contamination and runnability issues in the process.

**Making brown liner white**

Coated white top liner is gaining increased interest in the world market. Corrugated boxes are used for transportation of any type of goods and provide excellent protection for the product. A white or coated surface liner can be printed with high quality advertising text or pictures, simultaneously giving the box a good appearance. In many cases these high surface quality boxes can be placed directly on the re-sellers.

<table>
<thead>
<tr>
<th>Country</th>
<th>Paper Recovery Rate¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>48%</td>
</tr>
<tr>
<td>China</td>
<td>33%</td>
</tr>
<tr>
<td>Japan</td>
<td>66%</td>
</tr>
<tr>
<td>Germany</td>
<td>66%</td>
</tr>
<tr>
<td>Canada</td>
<td>43%</td>
</tr>
<tr>
<td>Finland</td>
<td>38%</td>
</tr>
<tr>
<td>Sweden</td>
<td>62%</td>
</tr>
<tr>
<td>South Korea</td>
<td>77%</td>
</tr>
<tr>
<td>France</td>
<td>53%</td>
</tr>
<tr>
<td>Italy</td>
<td>46%</td>
</tr>
<tr>
<td>World</td>
<td>45%</td>
</tr>
</tbody>
</table>

¹ Note: Paper Recovery Rate is calculated as recovered paper and paperboard divided by apparent paper and paperboard consumption. These percentages reflect the average recovery rate from 2000-2005

Table 1. Paper recycling rates for top ten paper producing countries and the world 2000-2005 [3].
shelves, tempting customers to purchase the product. For large quantity and smaller size goods this approach is favorable and it is gaining great interest in the emerging markets in Asia.

Coated white top liners have been produced for decades in Central Europe, North America and Scandinavia. In Asia, the grade is anticipated to expand faster than most other grades. Part of the increasing container board demand in Asia will be filled by coated liner grades [4]. New machines are built to produce these grades, but it is also a very tempting solution to upgrade existing liner machines for coating. When rebuilding an existing linerboard machine for coating, the production capacity is simultaneously increased thanks to the coating mass addition. The high price of bleached fiber challenges conventional manufacturing methods, using unbleached kraft or recycled fiber covered with bleach fiber on top. Using a coating method with good coverage, i.e. curtain coating, the high cost bleached layer can be reduced or completely eliminated.

Curtain coating is an established technology for coating of carbonless copy paper, thermal paper and photo papers and pressure-sensitive adhesives [5]. Advantages over conventional blade and film coaters are contact-free coating, no leveling and no pressure dewatering - and a perfect contour coating covering the low brightness base sheet is the result. However when using a curtain coater, smoothness is lost of about 1 unit PPS after multinip calendering compared to conventional blade coating methods, according to Hamers et al. Multilayer curtain coating gives further advantages over one layer curtain coating [6]. To best cover up a brown base sheet with white coating, a two-layer concept with an opacifying bottom layer and a top layer tuned for printability and shade has been developed [7]. In spite of opacifying titanium dioxide in the bottom layer, optical brightener can be used in the top layer without losing its effect as it is added in a separate layer, as seen in Figure 2.

Air knife coaters have for decades been the technology used when good coating coverage is desired. However, many operational limitations are seen with air knife coaters. Already at relatively low machine speeds the coating solids need to be decreased below 45 % to avoid frequent clogging of the nozzle [8]. Consequently, installed drying power demand and energy consumption will be high. Separation of air from the blown-off coating is difficult and in most cases causes an environmental load in the form of coating losses and noise.

In curtain coating solids can be kept the same or close to the level of blade coatings. The volumetric coating feed will as a whole be applied to the web, no metering takes place and the coating losses are minimal. The coat weight is regulated with the coating feed pump and the coat weight response to adjustments is very precise.

Starch application theoretical considerations
Conventional techniques to apply starch to the web are pond size-presses and film size-presses (metered size-presses).

In a pond size-press the hydrodynamic forces are dominant and ensure good penetration of starch into the web.

In a film size-press the starch solution is premetered on the applicator roll, and mainly mechanical nip forces will impact on how the starch solution penetrates into the web, i.e. pressure penetration and some hydrodynamic forces. Depending on the base sheet thickness and absorptivity, only a limited amount of liquid starch solution can pass through the nip and be applied to the web. When exceeding this limit, a mini-pond is formed before the nip and the film size-press gradually turns into a pond size-press process.

In a spray size-press, starch can be applied to the web prior to the pressurized nip, which is schematically shown in Figure 3.

The spray application will introduce the starch solution to some pressure penetration when the spray fans hit the web. During the dwell time from spray application to the nip, capillary penetration as well as some diffusion and filtration take place. In the nip the starch solution is exposed to pressure penetration introduced by hydrodynamic and mechanical nip forces.

The penetration phenomena in the nip of the spray sizer are very similar to those of the conventional size-press techniques. However, the spray application provide a longer starch/web dwell time before the nip, and during the dwell time, penetration of the starch solution takes place mainly through capillary penetration. Capillary penetration was thoroughly studied by Pekka Salminen in 1988 [9]. Capillary penetration is dependent on viscosity, base sheet hydrophobicity and of course time. Salminen demonstrated a temperature dependence for liquid transfer, and a higher temperature accelerates the penetration, see Figure 4 on the next page. The temperature dependence should be understood when comparing pilot trials (cold and cured web) and production environment (hot surroundings and freshly formed web). The dwell time in the spray-sizer at speeds typical for containerboard grades is in a magnitude of 0.2 - 0.4 s\(^{1/2}\).
The liquid transfer, which takes place at the web prior to the nip in the spray application, enhances the starch solution penetration. In addition, some pressure penetration takes place when the high speed starch spray fan hits the web, which further enhances the penetration. Compared to a conventional metered size-press, higher wet films of starch can be applied to the web without pond forming in front of the nip when using spray application.

**Experimental**

Pilot trials preparing for the production machine installation took place at the Valmet Technology Center in Järvängä, Finland. The pilot coater is shown in Figure 5.
A selection of different base sheets was used for starch application and curtain coating trials. The base sheet furnish was in all cases OCC-based; 110 and 115 g/m² corrugated medium and 135 and 175 g/m² testliner. The machine speed varied in the starch sizing trials from 400 to 1700 m/min. At high starch applications and in the high end speed trial points, the web was run two times through the pilot coater with only drying in the second pass to reach the final moisture target of 7%. The curtain coating trials were run at 850 m/min. The starch solids varied from 7 to 20%, depending on the starch grade. The viscosity was in the range 30-60 cps, Brookfield 100.

In the curtain coating trials the pigment composition was clay and carbonate, and additionally 26 parts of titanium dioxide were used in the bottom layer coating only. Totally 18 g/m² coating was applied in the pilot trial results, 6 g/m² was applied to the bottom layer and 12 g/m² to the top layer.

Surface compression test (SCT) was tested in the starch treated samples according to SCAN-P 46:83. Huygen internal strength was tested in the starch treated samples according to TAPPI UM 403.

The starch penetration and starch amount determination was tested at VTT, Jyväskylä, Finland, using potassium iodine stained starch samples with cross sections which are digitally imaged in a light microscope.

The applied spray film amount was calculated based on the calibrated pumping rate and pressure on the spray feed pump. For the metered size-press film amount on the roll, a 5 cm wide scraper was used for collecting starch solution into a container and using a timer. Suitable rod groove sizes were selected to apply the target film, based on speed and starch solids.

The difference between applied and measured actual starch difference, as seen in Figure 9, was calculated subtracting the actual laboratory determined starch amounts, using TAPPI 419om-91, from the calculated applied wet film to the web.

Spray starch uniformity was tested visually in UV light after OBA containing starch was applied to the paper. A bleached non-OBA containing fine paper base sheet was used for the evaluation, as the uniformity differences are more visible on this paper than in testliner.

PPS smoothness in the curtain coated testliner was tested with hard backing at 2000 kPa pressure.

**Results**

**Spray application of starch**

Several pilot trials were conducted to evaluate parameters and process phenomena using film (metered size-press, pond and spray size-press application. The target of the first trial was to compare conventional technology, pond and film to the newly developed spray application, located at a 1m distance from the nip. The main purpose of applying starch to recycled based containerboard grades is to improve strength properties. Ring Crush is commonly seen as the most important strength property in testliner, or SCT, which is a corresponding method used in Europe. The starch application method has minor impact on the SCT development, as seen in Figure 6. The totally applied starch amount determines the SCT level, which is not dependent on whether the starch application is done with pond, film or spray.
Also for the internal strength, the total amount of starch is most important, as seen in Huygen. Metered size-press lost slightly in internal bond to spray and pond, which was expected due to less penetration of starch into the base sheet. However, when plotting the result against the actual starch pick-up (Figure 7), a more likely explanation was found. The total measured starch pick-up compared to applied amount was lower using film, and the film application trial points actually fall well on the Huygen versus total actual starch amount curve. This suggests that the total starch amount is the most significant parameter on internal strength, and the apparent lower internal strength using metered size-press is a consequence of a lower starch transfer rate to the web, due to nip ponding.

During this trial the ponding tendency in front of the nip was visually detected. It was observed that using film application, a mini-pond was formed in all trial points. Using spray, a tendency for ponding took place only in one trial point.

The nip ponding tendency was further investigated in following trials. It was hypothesized that when high starch application amounts are desired, process parameters both in the nip and prior to the nip are important. For high starch pick-ups, a high wet starch film should be applied to the web, preferably without ponding in the nip. The advantage of spray application over metered size-press to apply high films without ponding were repeated, and the dwell distance of the spray device from the nip turned out to have a great impact on ponding tendency. When the spray device is located further away from the nip, the dwell time increases, and more time is given for capillary penetration. As
expected, a longer distance allows for higher wet films applied without ponding. Dwell distance using the spray device has a major impact on the wet film amount applied, and correspondingly how much starch is picked up by the web. Sizer nip pressure and machine speed have only marginal impact on the achievable wet-film amount, compared to the dwell distance. In the case of a film size-press, ponding generally takes place in the nip at wet film amounts exceeding about 25-30 g/m². The only tool to increase starch pick-up to the web with the film size-press, once the ponding limit is reached, is to increase the starch solids. Running high solids starch means that the starch chains must be converted for lower viscosity. Typically this will reduce the economics and also the strength capability of starch. No ponding was seen using spray application during this trial. With long dwell distances using the spray device, extremely high wet films can be applied without ponding and very high amounts of starch can be applied to the web. The discussed wet film trial experiments are presented in Figure 8.

Ponding in the nip decreases runnability due to splashing and sensitivity to base sheet moisture profile as the incoming profile will exaggerate moisture variations and also impact the starch pick-up profile. When running a pond at high speed, the hydrodynamic force in the nip may fully saturate the sheet with sheet breaks as a result. The additional starch pick-up to the web which ponding gives is marginal. When nip ponding takes place, the actual starch transfer rate to the web decreases, as shown in Figure 9. In this trial a 40 cm dwell distance was used for the spray, and ponding took place at wet film amounts exceeding about 30-35 g/m². Higher wet films resulted in ponding and the actual transfer of starch to the web decreased from...
the applied amount, as a result of decreased transfer rate. Without ponding, the actual transfer rate of sprayed starch amount picked up by the web is about 85-100 %.

When low wet film amounts (<15 gsm) are applied, the transfer rate to the web seems to decrease. This may be due to drying of the thin starch film prior to the nip with consequent higher starch film viscosity and reduced penetration and starch pick-up by the web in the nip.

Starch distribution in the sheet Z-direction was investigated for different starch application devices. Not surprisingly, the spray device (40 cm dwell distance) gave somewhat more distribution of starch into the middle of the web, thanks to the capillary penetration during the dwell, compared to the film size-press, in which case penetration takes place only in the nip. The applied starch amount was 2 g/m² per side.

Applying all 4 g/m² starch with the spray device on the top side only, naturally gives a superior distribution of starch to the top side of the sheet, and it penetrates fully to the middle of the web, see Figure 10, in the 115 g/m² corrugated medium sheet.

Starch spray application uniformity has thoroughly been followed while developing the spray process. High starch pick-ups always demonstrate great uniformity. Uniformity becomes a challenge when low starch applications are targeted at low speeds. Figure 11 demonstrates that low starch pick-ups can be applied at very low speeds also, providing that the nozzle pressure is high enough and that the spray is followed by a sizer nip. In picture c), the sizer nip load was released, and in picture d), the nozzle pressure was too low and the starch application was not completely uniform. At sufficient nip load and nozzle pressures, the application is uniform as seen in a) and b).

![Figure 10. Starch penetration distribution applying 4 g/m² starch with two-sided spray or metered size-press, and with a one sided spray application device](image1.png)

![Figure 11. OBA containing starch applied to fine paper at low speed, various nozzle pressures and starch application amounts for uniformity evaluation in UV-light](image2.png)
Production experiences with the spray starch application device.

The first commercial new technology spray device unit started up at the Dongil Uiryeong mill during the summer of 2008. A conventional metered size-press beam applies starch to the top side, while the bottom side starch is applied with a spray beam 2 m prior to the nip. The experience from the pilot trials and the capability to apply high starch pick-ups to improve strength in testliner and corrugated medium was reconfirmed in production. In fact, the capillary penetration during the dwell time is more detectable in the production environment. This is likely due to high web temperature and an uncured web in production, which enhance capillary penetration, as seen in Figure 4. Following spray beam deliveries to Dongil will have shorter dwell distance to the nip than this first unit. The general experience from the production spray unit has been:

- The operation is clean; no misting leaks out from the unit, and the machine environment stays clean.
- Very high starch amounts can be applied with consequent strength improvement.
- The starch application is uniform and back side (spray side) smoothness has been improved.
- The spray nozzles stay clean, and no consumables like rods and rod beds are needed for the spray device.

Curtain coating

A large number of pilot trials took place before the start-up of the curtain coating unit in Dongil Ansan. The coverage of the curtain coater is excellent, compared to a blade, as seen in Figure 12, but it does not give the same smoothness as a blade.

Smoothness is important in water-based flexo printing as well as surface energy and absorbance properties [10]. To create sufficient smoothness without a blade coater, the entire process must be optimized. Figure 13 shows pilot trial results which illustrate how the PPS smoothness of the Ansan CondeBelt dried OCC-based liner develops through the finishing process using curtain coating.
The CondeBelt provides a smooth base sheet suitable for the curtain process and the final smoothness target is achieved. Modern technology providing the same advantage of a smooth base sheet is the metal belt calender. If PPS smoothness levels below 2.0 are required, a blade should be added to the process.

The curtain coater in Ansan started up at the end of 2008. The mill produces two main coated grades. The WL grade is developed for end purposes where normally uncoated white top liner is used. The other grade, CWL, targets market segments where conventional coated white top testliner and white lined chipboard grades are used. The product specification is shown in Table 2.

<table>
<thead>
<tr>
<th>Unit</th>
<th>WL (White Liner)</th>
<th>CWL (Coated White Liner)</th>
<th>Remarks</th>
</tr>
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<tr>
<td>Printing method</td>
<td>Flexo</td>
<td>Flexo + Pre-printing</td>
<td></td>
</tr>
<tr>
<td>Coated Weight</td>
<td>gsm</td>
<td>8 + 8 gsm</td>
<td>11 + 12 gsm</td>
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<tr>
<td>Basis Weight</td>
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<tr>
<td>Roughness</td>
<td>μm</td>
<td>5.3</td>
<td>1.8 – 2.2</td>
</tr>
</tbody>
</table>

Table 2. Product specification for the curtain coated WL and CWL grades at Dongil, Ansan

Producing these two grades on the same machine creates some challenges. The WL grade should be absorbent with low smoothness requirements and should behave as closely as possible to an uncoated white top liner sheet in the converting process. The CWL grade is being compared to blade coated sheets and should be smooth and less absorbent. Process tools on the machine to accomplish these extreme requirements are press nip rolls (smoothing press), CondeBelt dryer, both calenders, coat weight and coating chemistry for the two layers in the curtain coater.

Coating chemistry has continuously been developed to fulfill these extreme requirements. The fundamental mechanisms determining water absorption of a coating layer have been investigated elsewhere [11]. To reach the WL grade printability targets, the liquid absorption rate and capacity of a coating layer are increased by: 1) higher surface roughness, 2) higher physical coating porosity and 3) higher chemical coating hydrophilicity. Figure 14 shows a practical example of the effect of coating porosity and hydrophilicity on water up-take.

![Figure 14](image-url)
Conclusions

- New technology can be used to upgrade machine equipment and find new market potential for products in a mature market, as demonstrated by Dongil Manufacturing in South Korea.

- A spray device used for starch application gives additional penetration before the size-press nip, compared to a conventional metered size-press, and higher total starch amounts can be applied.

- The total applied starch amount will determine the strength improvement achieved in recycled based testliner and corrugated medium, and is marginally dependent on what equipment has been used to apply the starch.

- To apply high starch amounts to the web, maintaining good runnability and cleanliness, a high wet film should be applied to the web without ponding in the size-press nip. This requires some dwell time for the starch solution to penetrate before the nip, and an advanced spray device is best for the application.

- The spray device applies a uniform starch film to the web, provided that the application pressure is high enough, and that the spray is followed by a pressurized nip.

- A two-layer curtain coater gives excellent coverage and can be used to make the surface white from a fully recycled unbleached base sheet and economical production of coated white top grades.

- The coating chemistry in the curtain coating layers can be tuned for desired printing and converting properties in curtain coated white top grades.

References


2. Kuzma, Daniel J., "Impact of recycled fiber on total carbon dioxide output during linerboard production", Degree, Master of Science in Environmental Studies, Youngstown State University, Department of Geological and Environmental Sciences, 2008.


This white paper combines technical information obtained from Valmet personnel and published Valmet articles and papers.

Valmet provides competitive technologies and services to the pulp, energy and paper industries. Valmet's pulp, paper and power professionals specialize in processes, machinery, equipment, services, paper machine clothing and filter fabrics. Our offering and experience cover the entire process life cycle including new production lines, rebuilds and services.

We are committed to moving our customers' performance forward.