Pulp and Paper Industry

HIGHLIGHTS

■ **PROCESS AND TECHNOLOGY STATUS –** The pulp and paper industry (PPI) produces pulp, paper, board and other cellulose-based products. The main steps of the process are pulping, papermaking and paper finishing. Pulping can be based on mechanical, semi-chemical or fully chemical methods. Wood used to make pulp contains three main components: cellulose fibers (desired for papermaking), lignin and hemicelluloses. In pulping, the bulk structure of the fiber source is broken down into the constituent fibers. In chemical pulping, this is accomplished by degrading the lignin and hemicellulose into small, water-soluble molecules which are washed away from the cellulose fibers. Mechanical pulping methods physically tear the cellulose fibers apart. Chemical pulping is the dominating pulping method and accounts for 70% of today's global pulp production. Paper-making involves several steps including making a pulp slurry, pressing and drying. The appearance and properties of the final products are supplemented and enhanced by finishing treatments, which can be simple processes where the reel are cut into sheets or more complex processes, such as coating or super-calendering. North America, Asia and Europe are the dominating world regions for PPI, and accounted for 37, 24 and 25%, respectively, of the global pulp production in 2010.

■ **PERFORMANCE AND COSTS –** The PPI is a highly energy and capital-intensive industry. Comparing chemical/kraft mills, mechanical mills, and paper mills (without virgin pulp production), chemical/kraft mills generally have the largest on-site fuel use, which is mainly biomass-based. However, a mechanical mill uses large amounts of electricity, implying that the primary energy use of the mechanical pulp mill may be significantly higher than its final use. A paper mill using imported pulp and/or de-inked paper has a lower energy use than mechanical or chemical pulping. In regard to feedstock use, the pulp yield in chemical processes is about half compared to the production of mechanical pulp from the same amount of pulpwood. A large-scale chemical pulp mill with an annual pulp production of around 1.4 million tons has an investment cost of about 2.5 billion USD if built from the ground up. The specific investment costs (investment cost per production capacity) are around 1500-2000 USD/(ton/year). As for many capital-intensive industries, economies of scale apply, giving lower specific investment costs for larger mills. Generally, the largest capital cost in a chemical pulp mill is linked to the power generation and chemical recovery part of the mill, which could account for about a third of the capital cost.

■ **POTENTIAL AND BARRIERS –** The PPI is a globalized industry sector where several countries that were strong producers in the past now face growing competition from new producers. On national level, cost-efficient production is crucial for the survival of the industry. A future increase in competition for biomass resources from the energy sector implies further challenges. In meeting climate targets, biomass resources, including pulpwood, will likely become a sought after resource for energy products. However, measures and new technologies for increased cost-efficiency and competitiveness exist and include option for increased energy efficiency and diversification of products. An increased societal demand for "green", high-value energy products can therefore be turned into an opportunity for the PPI, which has well-established biomass supply-chains and plants that can be converted to efficient energy combines with multiple outputs. In relevant countries, this could make the PPI a key actor in a future "greener" energy system. The chemical/kraft PPI has the largest potential for implementation of new technologies for production of biomass-based, high-value energy products (electricity, motor fuels) in addition to the pulp and paper. In this respect, integrated black-liquor gasification systems can become a key technology.

PROCESS

The pulp and paper industry (PPI) produces pulp, paper, board and other cellulose-based products. The main steps of the industrial process are pulping, papermaking and paper finishing.

■ **Pulping** – Pulp, the main raw material for paper-making, is a ligno-cellulosic fibrous material, which is produced from separation of the cellulose fibers in wood, fiber crops and waste paper. The pulp-making process can be divided in timber and debarking, chipping, pulping, cleaning, bleaching, and washing and drying. Timber utilized for pulping is denoted pulpwood. Examples of wood types that is often used for pulp making include softwoods such as spruce, pine, fir, larch and hemlock, and hardwoods such as eucalyptus, aspen and birch.

Wood and other plant materials used to make pulp contain the following main components: (1) cellulose fibers, which are desired for papermaking, (2) lignin, which is a polymer of aromatic alcohols which binds the cellulose fibers, and (3) hemicelluloses, which is a shorter branched carbohydrate polymer. The purpose of pulping is to break down the structure of the fiber feedstock into its constituent fibers.

In **chemical pulping,** the lignin and hemicellulose are degraded into small, water-soluble molecules which can

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be washed away from the cellulose fibers without depolymerizing, and thus weaken, the cellulose fibers. This is achieved by putting wood chips into a digester where it is mixed and cooked with chemicals and water under high pressure [1]. Most chemical pulp is produced through the ***sulphate*, or *kraft*, process**, in which caustic soda (NaOH) and sodium sulphate (Na2S) are used in a chemical mixture (called **white liquor**) [1]. The resulting slurry contains loose but intact fibers which preserve their strength. Approximately half of the wood dissolves into so-called **black liquor**, formed mainly by the chemicals, lignin and hemicelluloses. The pulp, which initially is dark brown in color, can be bleached to a high brightness if required [1]. The black liquor is separated out from the pulp before the bleaching process.

Figure 1 illustrates an overview of the main energy and material streams in a conventional sulphate/kraft pulp mill with a recovery boiler. In the recovery boiler, the black liquor is burned and chemicals are recovered and reformed. Before combustion, the black liquor, which only contains about 15-20% dry solid content, is vaporated to a dry solid content of 70-80%. The exhaust gases are utilized for steam production and the rest of the liquor ends up at the bottom of the boiler as a smelt, which is dissolved to form green liquor [2]. The green liquor is sent to the chemical preparation where white liquor for the digester is produced. The high-pressure (HP) steam produced in the recovery boiler is utilized for electricity generation in a back-pressure steam turbine (ST). The steam (low pressure, LP, and medium pressure, MP) is then used to provide heat to the pulping processes such as digesting, evaporation and drying [2]. If the steam produced in the recovery boiler is not enough to meet the internal steam demand, an additional boiler is used to produce HP steam for the back-pressure turbine [2]. Fuel for this boiler could be bark from the debarking of the logs or other purchased fuels. If a surplus of steam is produced by the recovery boiler, it can be utilized for additional electricity generation in a condensing steam turbine [2].

An alternative chemical pulping method is the ***sulphite* process**, which is appropriate for bleached speciality pulp. The sulphite pulp accomplish the requirements for chlorine-free products for hygiene papers as well as for printing and writing papers [1]. The liquor from sulphite pulping is usually called **brown liquor**. Likewise to the kraft pulping process, the brown liquor can be burned in a recovery boiler to generate steam and recover chemicals for the pulping process.

In **mechanical pulping**, the cellulose fibers are physically torn apart. In its basic form, wood is ground against a water-lubricated rotating stone, the heat generated softens the lignin binding the fibers, and the mechanized forces separate the fibers [1].

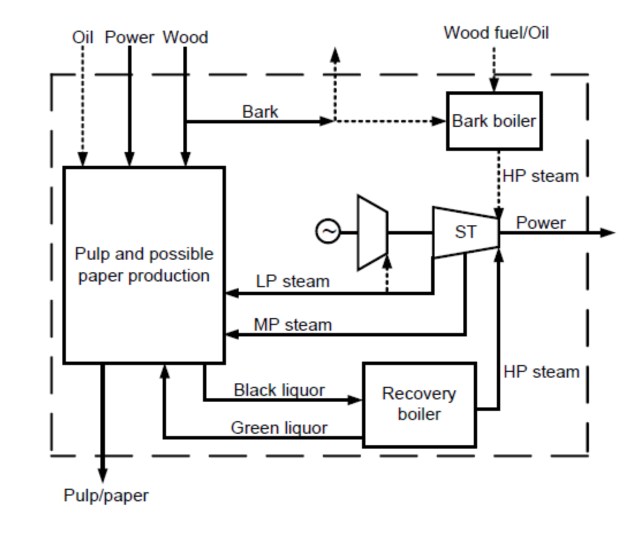

Figure 1. Main energy and material streams at a conventional kraft pulp mill with a recovery boiler. (Pettersson, 2011) [2]

The process results in that much of the lignin stays on the fibers. Strength is reduced since the fibers could be cut. Mechanical pulp results in paper with a yellowish/grey tone, high opacity and a smooth surface [1]. Mechanical pulping provides a high yield from the pulpwood; however, the process is also very electricity intensive [1].

In the second half of the 20th century, mechanical methods that use refiners were developed [1]. In a refiner, woodchips are subjected to shearing forces between a rotating steel disc and a fixed plate. In later alterations to this process, the woodchips are pre-softened by heat [1]. This pulping method is called **thermo-mechanical pulping** (TMP).

A further development is the **chemical-thermomechanical pulp** (CTMP), in which the wood chips are chemically treated with sodium sulphite before the grinding [1]. Chemical and thermal treatments reduce the amount of energy subsequently required by the mechanical treatment, and also reduce the strength loss of the fibers.

Pulp is graded and classified according to: the method of production (e.g., chemical or mechanical pulp); the type of tree used (e.g., softwood or hardwood); and by processing level (e.g., bleached or unbleached) [1]. Table 1 summarizes different pulp types, their production and end-uses.

■ **Paper making** - In an integrated pulp and paper mill, pulp is fed directly to the paper making processes while in stand-alone pulp mills, pulp is dried and pressed into bales and transported to paper mills [2]. For the paper making process, pulp is mixed in water with other additives into a slurry.

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Table 1 - Pulp varieties (PaperOnline, 2013) [1]			
Type	Variant	Description	End-use
Mechanical Pulp	Stone groundwood pulp	Mechanically grinds the wood into relatively short fibres.	Used mainly in newsprint and wood-containing papers, such as lightweight coated and super-calendered papers.
	Thermo-mechanical pulp (TMP)	The wood particles are softened by steam before entering a pressurized refiner.	To large degree the same as for stone groundwood pulp
Semi-chemical pulp	Semi-chemical pulp	Produced in a similar way to TMP, but the wood particles are chemically treated before going into the refiner.	Appropriate for tissue manufacture. Some chemi-thermo mechanical pulp (CTMP) is used for printing and writing grades.
Chemical pulp	Sulphite pulp	Produced by cooking wood chips in a pressure vessel in the presence of bisulphite liquor. Can be bleached or unbleached.	Varies from newsprint, printing and writing papers, to tissue and sanitary papers.
	Sulphate / Kraft pulp	Pulp produced by cooking wood chips in pressure vessels in the presence of sodium hydroxide (soda) liquor. Can be bleached or unbleached.	Widespread uses – pulp used for graphic papers, tissue and carton board, wrappings, sack and bag papers, envelopes and other specialty papers.

Apart from pulp, common raw materials are clay, chalk or titanium dioxide, which are added to adjust the optical properties of paper and board, or as fiber substitute [1].

The slurry is pumped to the paper machine where more water is added to produce a fiber suspension consisting of as little as 1-10 parts of fiber and 1000 parts of water. The mixture is passed into a so-called head-box which squirts it through a thin, horizontal slit across the full machine width (typically 2 - 6 m) on to a moving wire mesh [1]. Subsequently, the water is removed on the wire section by a mixture of gravity and suction, in a process known as sheet formation. In this process, the fibers start to spread and consolidate into a thin mat [1].

The web of wet paper is lifted from the wire mesh and squeezed between a series of presses in which the water content is reduced to about 50%. For further drying, it passes around heated cast-iron cylinders. This process reduces the water content to the final level of 5-8% [1]. During its way from the wire mesh to the drying operations, the paper web is supported by fabric belts moving at the same speed. After drying, some papers may also undergo surface treatments e.g. sizing and calendering. The paper is then wound into a reel [1].

■ **Paper finishing** - The appearance and properties of the paper products are supplemented and improved by finishing treatments [1]. These can be simple processes in which the reel is slit into a number of more narrow reels or cut into sheets, or more complex processes such as coating or super-calendering [1].

Coating is a process that improves the opacity, lightness, surface smoothness, lustre and color-absorption ability of the paper. It implies that a layer is applied to the paper, either in the papermaking machine or separately. The coat consists of a mix of pigments, extenders such as china clay and chalk, and binders such as starch or latex [1]. Further, different chemicals are added to give the paper the desired characteristics [1].

Super-calendering is done primarily for magazines and coated papers and gives an even smoother paper surface. In the process, the paper passes through rollers, which are alternately hard and soft. Through a combination of heat, pressure and friction, the paper obtains a surface with high lustre. The process compresses the paper to some extent, and super-calendered paper is therefore slightly thinner than the corresponding matt product [1].

TECHNOLOGY STATUS

In 2010, the world´s total production of pulp and paper amounted to 186 and 394 million tons, respectively [3]. Table 2 presents the regional distribution of the production. North America, Asia and Europe are the dominating world regions within the PPI. North America accounted for the largest production of pulp (37% of world total) and Asia accounted for the largest production of paper (42% of total).

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Table 2 – Pulp and paper production by region and world total 2010 (Swedish Forest Industries Federation, 2013 [3])

	Pulp production	Paper production
North America	37%	23%
Latin America	11%	5%
Oceania	2%	1%
Africa	1%	1%
Asia	24%	42%
Europe	25%	28%
Total	186 million tons	394 million tons

The ten largest pulp producing countries are (as of 2012, in falling order): USA, China, Canada, Brazil, Sweden, Finland, Japan, Russia, Indonesia and Chile [3]. Ten largest countries in terms of production of paper and paperboard are (as of 2010, in falling order): China, USA, Japan, Germany, Canada, South Korea, Finland, Sweden, Brazil and Indonesia.

Figure 2, 3 and 4 visualizes characteristics of the PPI in terms of final products in paper production, to what extent different pulping methods are utilized, and raw materials used. Figure 2 and 3 presents the global perspective, while Figure 3 refers to Europe.

The packaging industry is a major user of paper products. As presented in Figure 2, corrugated material and paperboard together account for almost half of the total global paper production. Printing and writing paper is another major product accounting for more than one fourth of the total production.

As is clear from Figure 3, chemical pulping is by far the dominating pulping method, accounting for 70% of the pulp produced globally. Mechanical pulping accounts for 21% while the remaining 9% is categorized as other pulping methods.

The dominance of chemical pulp over mechanical pulp is also clear when looking at raw material use in European papermaking (Figure 4). A large significance for recovered paper can also be noted. About half of the paper and board produced is produced from recovered paper [1].

PERFORMANCE

The energy use of the PPI differs depending on type of production. Subject to production category, the amount and type of energy sources and feedstock used vary.

An overview of energy use per produced ton of pulp or paper for different pulp and paper categories is given in Figure 5. Values are averages for Swedish mills in 2011 (based on Wiberg, 2012 [4]).

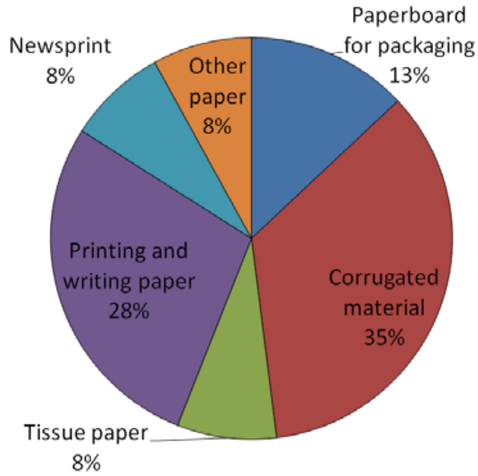

Figure 2. Global paper production 2010 by grade, the total is 394 million tons (Swedish Forest Industries Federation, 2013) [3]

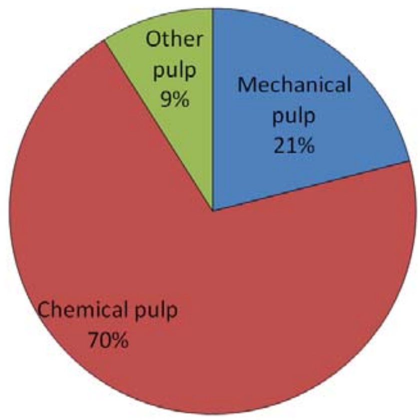

Figure 3. Global pulp production 2010 by grade, the total is 186 million tons (Swedish Forest Industries Federation, 2013 [3])

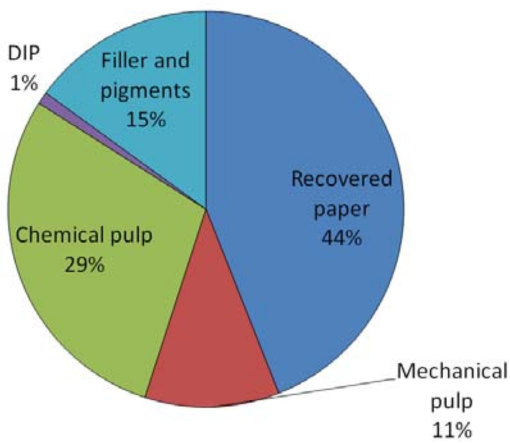

Figure 4. Raw materials in European papermaking 2011, the total is 95 million tons (Swedish Forest Industries Federation, 2013) [3]

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Generally, kraft mills have the largest on-site fuel use out of the different production categories. The fuel utilized is mainly biomass-based originating from the recovery boiler and (for integrated kraft mills) the bark boiler [4, 5]. A mechanical mill has lower onsite fuel use than a kraft mill of the same size but uses large amounts of electricity. However, taking into account the energy utilization for the electricity generation, the primary fuel use of the mechanical pulp mill could be significantly higher. A paper mill using imported kraft pulp or mechanical pulp and/or de-inked paper has a lower energy demand than mechanical or kraft pulping [5].

Comparing feedstock use in mechanical and chemical pulping, the yield in chemical processes is much lower than in the manufacture of mechanical pulp. For mechanical pulp, yield levels from the wood feedstock is about 95% while, for chemical pulp, the corresponding figure is about 45% [1]. The reason for the low yield in chemical pulping is that the lignin is completely dissolved and separated from the fibers. However, the lignin from the sulphate and some sulphite processes can be burnt as a fuel oil substitute. Further, as indicated, in modern mills, recovery boiler operations and the controlled burning of bark and other residues makes the chemical pulp mill an energy producer which can often supply power to the grid, steam to local heating plants, or heat to a district heating grid.

Due to the different characteristics of the respective processes, the products also differ. The pulp of mechanical processes is made up of fiber fragments of different sizes resulting in paper products with comparably low paper strength [1]. The pulp of chemical processes is mainly made up of longer fibers, resulting in a paper with high strength [1].

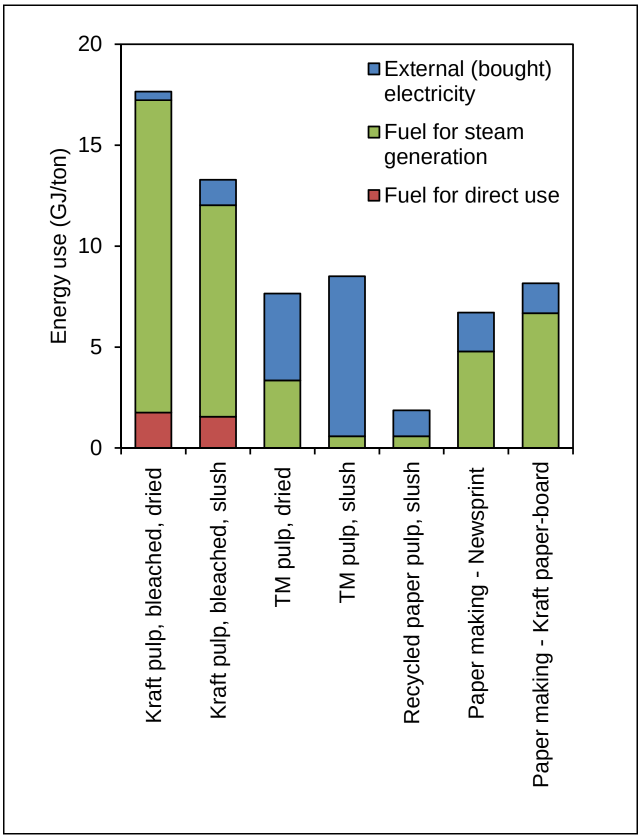

Figure 5. Specific energy use for different pulp and paper production processes. Values are averages for mills in Sweden in 2007. (Wiberg, 2012) [4]

POTENTIAL AND BARRIERS

The PPI is to high degree a globalized industry and several countries which traditionally have had a strong position within the industry now face growing competition from new cost-competitive production locations. Pressure on cost-efficient production is hard and in some Western countries mills have been forced to shut-down. In contrast, South America shows an expansion in chemical pulp mill capacity, resulting in that actors in Europe and North America are left with a smaller proportion of the global pulp trade [6]. China has in recent years become the number one global market for chemical market pulp [7].

Increasing competition is not only a fact within the global PPI but also from other industry sectors. Looking into the future, a challenge for the PPI is related to an increased competition for biomass resources. In meeting ambitious climate targets, biomass resources will most likely become a desired resource for production of heat, electricity and fuels. Such development could very well affect pulpwood prices resulting in further pressure on the PPI.

In order to keep up with increasing competition from within the industry and, in regard to biomass resources, from the energy sector, the potential for pulp and/or paper mills to increase energy efficiency and diversify production have been investigated in several contexts. Potentially, today's conventional mill producing pulp and/or paper could be converted to a multiple generation plant that, in addition to conventional products, also produces energy products such as district heat, electricity and transport fuels. Thus, a future increased demand for biofuels and "green" electricity and heat may not only present a threat but also an opportunity for an industry with well-established biomass supply-chains and mills, which with new technologies can be re-constructed to highly efficient energy combines with multiple outputs.

Between chemical/kraft pulp (and paper) mills, mechanical pulp (and paper) mills, and pure paper mills without any virgin pulp production, the kraft PPI has the largest potential for implementation of new technologies for production of biomass-based, energy products in addition to the pulp and paper [5]. The reason is that in the chemical/kraft pulping process the wood fibres are separated from the rest of the wood components. The fibres are used for production of pulp (or paper), and the rest of the wood components, i.e. lignin and parts of the hemicelluloses, are dissolved in the black liquor, which is usually burnt in the recovery boiler producing steam and recovering the process chemicals. Thus, the kraft PPI holds a large potential for implementation of new

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technologies in that it could utilize the lignin and hemicelluloses in the black liquor in more efficiently, e.g., through extracting the lignin or through black liquor gasification [5].

A market kraft pulp mill, which has a lower steam demand than an integrated kraft pulp and paper mill, can be self-sufficient on thermal energy based on the pulpwood material alone and, if the mill is energy-efficient, it can even generate a steam surplus [5]. The fact that there are different biomass streams (lignin, hemicelluloses and bark) as well as a potential for an energy surplus, which can cover the energy demand of new processes, makes the kraft mills particularly interesting for consideration of new technology implementations. Typically, in a conventional market kraft pulp mill, some of the excess heat has a high temperature (around 100°C) while the most of the excess heat has a lower temperature (around 40°C). However, for kraft pulp mills, studies have shown that if the water use is reduced, the amount of excess heat at high temperatures can be increased [5].

Black liquor gasification could be a future key technology for efficient production of high value energy products. A gasification unit generating product gas could be connected to a gas turbine combined cycle for electricity generation (BLGCC) or, alternatively, to a synthesis unit for motor fuel production (BLGMF), such as di-methyl ether (DME) or methanol. Different configurations for integration of black liquor gasification in pulp mills are possible. In the case of a kraft pulp mill with excess steam, it can be installed in parallel with the existing recovery boiler, potentially resulting in a system without need for additional fuel supply [8]. Alternatively, for maximized production of motor fuel or electricity, the recovery boiler can be replaced with a gasification system both producing energy products and recovering the chemicals to the pulping operations [9]. In this case, additional fuel (e.g., biomass) needs to be supplied for generation of the steam required for the pulping operations. Even so, studies have shown high overall energy efficiency for the motor fuel or electricity generation compared to stand-alone biomass gasification plants [9]. Further, if the investment occurs when the recovery boiler is to be replaced due to old age, and only the additional cost involved is allocated to the BLGMF or BLGCC, very competitive cost estimates have been reported [9]. An overview of the principal differences between a conventional pulp mill and a mill with a BLGMF plant is given in Figure 6.

In contrast to the chemical process, mechanical pulping utilizes all of the cellulose, hemicelluloses and the lignin in the pulp operations. Therefore, the only biomass stream available for other purposes is the falling bark (i.e. no other potential use of lignin and hemicelluloses). However, thermal integration of new technology processes and better utilization of excess heat are potential options for increased energy efficiency for mechanical mills. This is also true for a paper mill without virgin pulp production (having neither bark nor any other biomass streams available) [5].

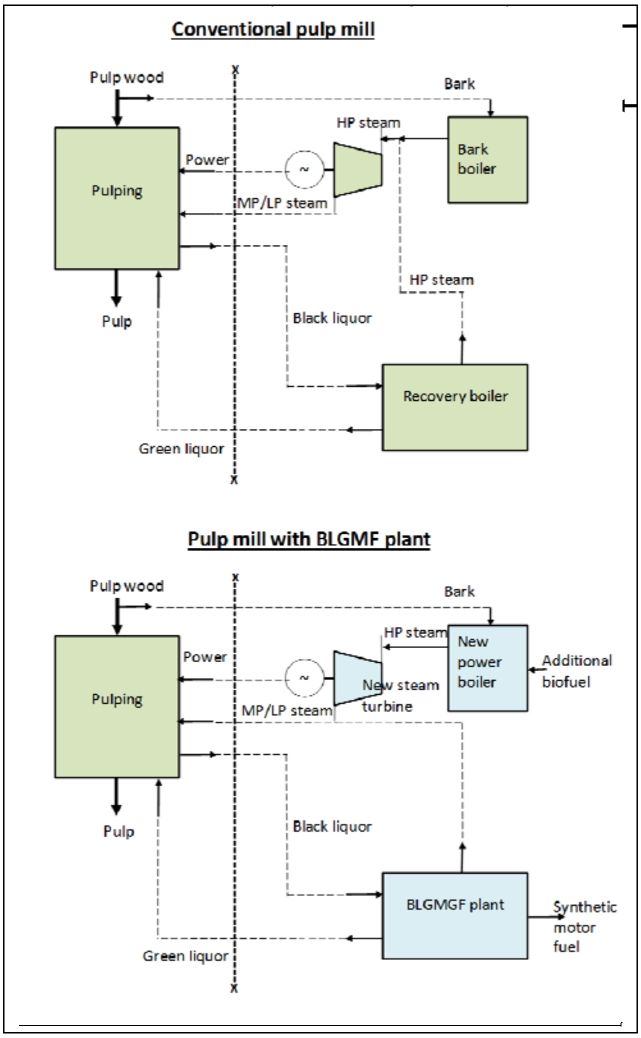

Figure 6. An overview of the principal differences between a conventional pulp mill and a mill with BLGMF plant according to Ekbom et al. (2005) [9].

Costs

The PPI is a highly capital-intensive business. A new large-scale chemical pulp mill with an annual pulp production of around 1.4 million tons can cost around 2.5 billion USD if built from the ground up, i.e. being a so-called “greenfield” investment [10]. It has been suggested that a pulp mill greenfield investment requires 50% equity to survive the market cycle. In practice, this implies that only a few top pulp and paper producers of the world have the resources and commercial interest to pull off a project of this kind [10].

The construction of new greenfield mills is not very common, in particular in western countries. In order to increase cost-efficiency and competitiveness, investors in Europe and North America tend instead to focus on existing mills. In large pulp producing countries such as Finland, Canada, Sweden and USA, no greenfield mills have been built in the past decade [10]. Instead, Uruguay has been the location for the majority of greenfield plants built in this time. Other examples of greenfield investment locations during the last decade include Brazil, China and Chile [10].

Figure 7 presents estimated investment costs from a study in which large pulp mill greenfield investments in different locations have been compared [10]. As can be seen, the specific investment costs (investment cost per capacity) are around 1500-2000 USD per annual production (ton/year). Cost differences are due to site-specific conditions, such as whether hard or soft wood feedstock is used.

A bleached market pulp mill can be said to consist of six major process areas: wood yard, pulp mill, chemical preparation, pulp dryer, causticizing & lime kiln, power and recovery, water & waste water treatment; and two non-process areas: non-process building area and the mill general area. The largest capital cost in a pulp mill is the power generation and chemical recovery area accounting for about a third of the capital cost [12].

As for most capital-intensive industries, economies of scale apply in the PPI. This implies that specific investment cost decrease with larger mill sizes (within reasonable limits and with other things equal). For investments calculations related to the pulp and pulp industry, a scale factor (R) of 0.6-0.7 expressing the relation between investment cost and size as a power function exponent, according to $(Cost/Cost_{base})=(Size/Size_{base})^{R}$, is often used (see, e.g., [2]).

Figure 8 presents non-capital costs, including operation and maintenance costs (O&M), pulpwood costs, and pulp transport cost, for the same investments as presented above (based on EBRD & PÖYRY, 2012 [10]). In this particular case, the pulp transport cost from each respective location to paper mills located in China is given. For Russia, the average costs of three different potential investments sites are presented.

As mentioned, a large part of investments within the industry occurs at existing mills. Table 3 presents investment and operating costs for some potential energy related investment options in kraft pulp mills. For the non-conventional pulp mill technologies presented, such as BLGCC and BLGMF, see also earlier sections.

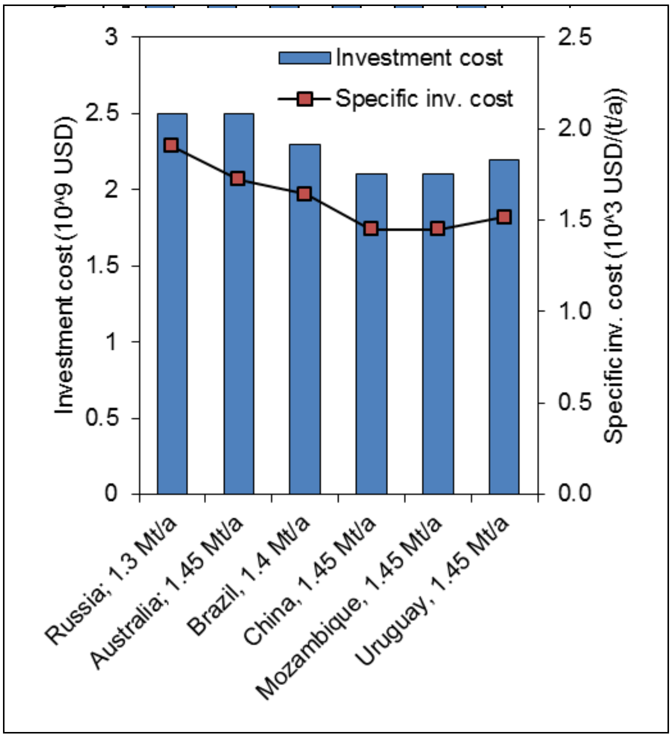

Figure 7. Investment cost for large-scale (1.3-1.5 Mt/a) greenfield pulpmills for different locations and capacities. Total investment cost (bars) are given in billion USD. Specific investment cost refers to total investment cost divided by mill capacity. (EBRD & PÖYRY, 2012) [10]

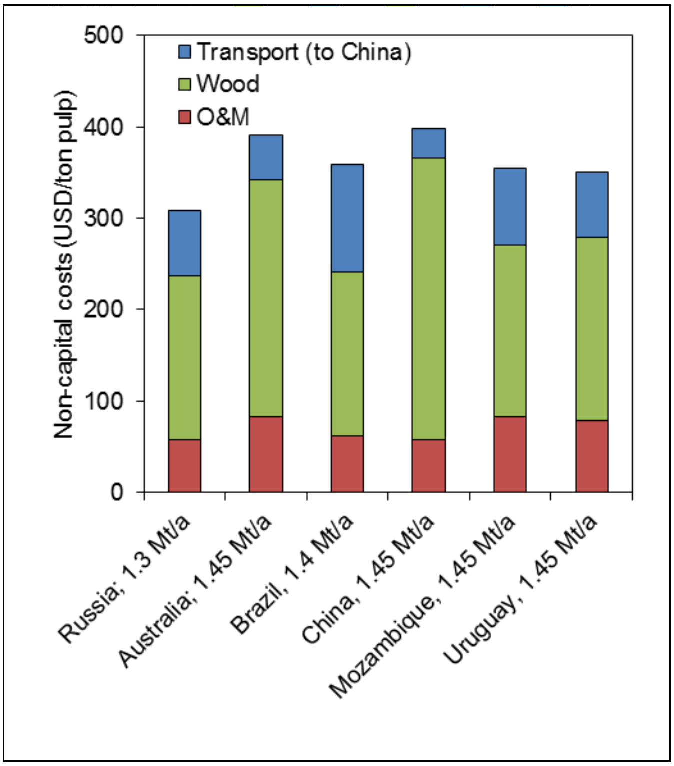

Figure 8. Operation and maintenance costs (O&M), pulpwood costs, and pulp transport cost for large scale (1.3-1.5 Mt/a) greenfield pulpmills for different locations and capacities. (EBRD & PÖYRY, 2012) [10]

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Table 3 – Investment and operating costs for different potential energy related investment options in a kraft pulp mill (from: Jönsson et al., 2013) [8]

	Investment cost (MEUR)	Annual operating cost	Comments
Back-pressure steam turbine	$1.3*P^{0.6}$	-	DH, district heating P, power output in MW Q, heat supplied by heat pump or heat exchanged in the heat exchangers in MW BL, flow of black liquor in MW LR, Lignin extraction rate in kg/s
Condensing steam turbine	$2.4*P^{0.6}$	-	
Heat exchanger DH - steam	0.68+0.033*Q	-	
Heat exchanger DH - heat	0.059+0.042*Q	-	
Heat pump for DH	0.11*Q		
BLGCC	$5952*BL^{0.6}$	1.0 kEUR/yr/BL	
BLGMF	$7055*BL^{0.6}$	9.7 kEUR/yr/BL	
Lignin extraction plant	$7.2*LR^{0.6}$	5.8 EUR/MWh	

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Table 4 – Summary Table - Key Data on Pulp and Paper Industry

		Technologies for pulp and paper production					
By technology variant		**Chemical Pulping**		**Mechanical Pulping**	**Other Pulping**	**Paper Making**	
Energy use [a]	Unit	Sulphate pulp, bleached, dried (slush)	Sulphate pulp, unbleached, dried (slush)	Thermo-mechanical pulp, dried (slush)	Recycled paper, slush	Newsprint	Kraft paper-board
1. Fuel use	[GJ/ton]	17.2 (12.0)	17.6 (10.0)	3.4 (0.6)	0.4	4.8	6.7
1.1 For direct use	[GJ/ton]	1.7 (1.5)	1.2 (1.3)	0.0 (0.0)	0.0	0.0	0.0
External, oil/other	[GJ/ton]	1.3 (1.2)	0.7 (1.2)	0.0 (0.0)	0.0	0.004	0.05
Internal	[GJ/ton]	0.5 (0.4)	0.5 (0.1)	0.0 (0.0)	0.0	0.0	0.0
1.2 For steam generation	[GJ/ton]	15.5 (10.5)	16.4 (8.7)	3.4 (0.6)	0.6	4.8	6.7
External, oil/other	[GJ/ton]	0.2 (0.3)	0.2 (0.2)	3.0 (0.0)	0.1	0.9	0.7
Internal, liquors	[GJ/ton]	17.5 (15.6)	16.4 (13.3)	-	-	-	-
Internal, bark/others	[GJ/ton]	2.3 (3.4)	1.2 (2.5)	0.4 (5.9)	1.2	4.4	6.4
Fuel surplus	[GJ/ton]	-4.5 (-8.8)	-1.4 (-7.3)	0.0 (-5.3)	-0.9	-0.6	-0.5
1.3 For backpressure power generation	[GJ/ton]	2.9 (1.4)	2.1 (1.2)	0.5 (0.01)	0.03	0.2	0.9
External, oil/other	[GJ/ton]	0.3 (0.5)	0.5 (0.6)	0.2 (0.004)	0.02	0.2	0.7
Internal	[GJ/ton]	2.5 (0.9)	1.7 (0.6)	0.3 (0.004)	0.01	0.0	0.2
2. Steam use (internal, excl. backpressure power gen.)	[GJ/ton]	13.9 (9.4)	14.8 (7.8)	3.0 (0.5)	0.3	4.3	6.0
3. Electricity use	[GJ/ton]	2.9 (2.4)	2.7 (1.8)	4.7 (7.9)	1.3	2.1	2.3
Internal electricity from backpressure power gen.	[GJ/ton]	2.4 (1.2)	1.8 (1.0)	0.4 (0.0)	0.03	0.2	0.8
External electricity (bought)	[GJ/ton]	0.4 (1.2)	0.9 (0.7)	4.3 (7.9)	1.3	1.9	1.5
4. Total energy use; Fuel use (1) + External electricity	[GJ/ton]	17.6 (13.3)	18.5 (10.7)	7.6 (8.5)	1.6	6.7	7.6
Efficiency in steam generation	[%]	90 (90)	90 (90)	90 (90)	90	90	90
Market shares, yield and size	Unit	**Chemical Pulping**		**Mechanical Pulping**	**Other pulping**		
Market share, pulping (global) [b]	[%]	70		21	9		
Product yield from wood material[c]	[%]	45		95	n/a		
Average mill size, USA 2000 [d]	kton/a	400		130			
New large mill size [e]	kton/a	1300-1500					
Costs	Unit	**Chemical Pulping**		**Comment**			
Investment cost	[Billion USD]	*1.85*Capacity*$^{0.6}$		Rough estimates based on data and references in "Costs" section (Fig. 7). Capacity refers to pulp production in Mt/year. Scale factor of 0.6 and fraction of investment cost related to power generation and chemical recovery of 0.33 are assumed.			
Investment cost - power generation and chemical recovery	[Billion USD]	*0.61*Capacity*$^{0.6}$					

References:
a) Wiberg, 2012 [4]; b) Swedish Forest Industries Federation, 2013 [3]; c) PaperOnline, 2013 [1]; d) Smith et al., 2003 [11]; e) EBRD & PÖYRY, 2012 [10]