Energy Benchmark System for Mondi BP Austria AG

Diploma Thesis

by

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Abstract

"The Mondi Business Paper Group, one of the largest manufacturers of high-quality business papers, is a subsidiary of the Mondi Group, which is part of the Anglo American PLC."

As of 2004, Mondi Business Paper has production facilities at a total of nine sites in Austria, Hungary, Israel, the Slovak Republic, Russia and South Africa. During the year, around 17,000 employees produced approximately 2 million tons of paper on 16 paper machines. Some 1.8 million tons of this was uncoated wood-free (ucwf) paper. Additionally, around 1.7 million tons of pulp was produced at four mills. The group also has forestry operations in Russia and South Africa. With each new acquisition, Mondi Business Paper commits itself to implementing internationally accepted quality, environmental and social standards.[1]

Since 2005 the Holding of MONDI BUSINESS PAPER (MondiBP) is situated in Hausmenning, Austria. In Kematen is the second paper mill of Austria MondiBP, producing mainly coloured paper. Both Austrian mills had a paper production of 361,683 t in the year 2004.

[1] Mondi business performance and sustainability review (2004): p. 2

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Abbreviations

€	Euro
adt	air dried tons
Atm	atmospheres
Bar	Bar = 10^5 pascal
BAT	Best Available Technology
BP	Business Paper
C°	degree celsius
cp.	compare
cos φ	cosinus phi
ds	dry solids
dsc	dry solid content
EJ	exa joule, 10^{18} joule
GJ	giga joule, 10^9 joule
H_2O	water
ΔI	delta current
I_m	active current
I_n	nominal current
K	Kelvin
kPa	kilo Pascal
kWh	kilo watt hour
MBPAT	Mondi Business Paper Austria
MJ	mega joule, 10^6 joule
mt	mega ton, 10^6 tons
MWh	mega watt hour
Pa	Pascal
P_m	active power
P_n	nominal power
PM	paper machine
SEC	specific energy consumption
SEC_e	specific electricity consumption
SEC_h	specific heat consumption

THE	Theresienthal
ucwf	uncoated wood free
Wh	Watt hour

1 Process

My diploma thesis is divided into a theoretical part and an empirical part.

The theoretical part gives some information about systems engineering, energy analysis and energy balances and of course about benchmarking. Then I will explain the configuration of a paper mill and the principle of the paper production. Also some information of the types of energy used and the average amount needed will be listed. This will help to understand the practical procedure and will show how difficult it is to benchmark paper machines as there is no PM like the other.

The theoretical skills will then be implemented in the empirical part. As test object the PM6 in Hausmenning was chosen. Here I will mention the data gathering and the development of the excel-sheet.

Finally I will present the test-results and give explanations, so the work can be evaluated critically.

2 Theoretical Part

Systems engineering

Systems engineering should be seen as guidance based on special model for further discussion and first principles for precise structuring of complex systems.[2]

2.1.1 Systems thinking

It is a type of thinking that should make it possible to better understand and create complex systems.

Systems thinking includes mainly:

- Terms that describes complex connections
- Models to figure real and complex events without making them less complex
- Approaches that assist the whole thinking area

2.1.2 Fundamental terms and criteria of systems

For describing systems, some fundamentals will be used that are first defined and characterised.

System/element/correlation

Systems consist of elements (parts/components). But elements could be systems again. The elements are connected with each other by correlations.

System boarders/environment

A system boarder is a boarder between the system and its environment it is situated in. Normally the systems behave "open" which means they have not only correlations to each other but also to its environment.

The environment is the system or element that is outside the system boarder but it can have influence or be influenced by the system.

Typically the grade of connection within the system boarder is significantly higher than the connection between system and environment. (see Fig. 1)

[2] Haberfellner (1997): p. XVIII

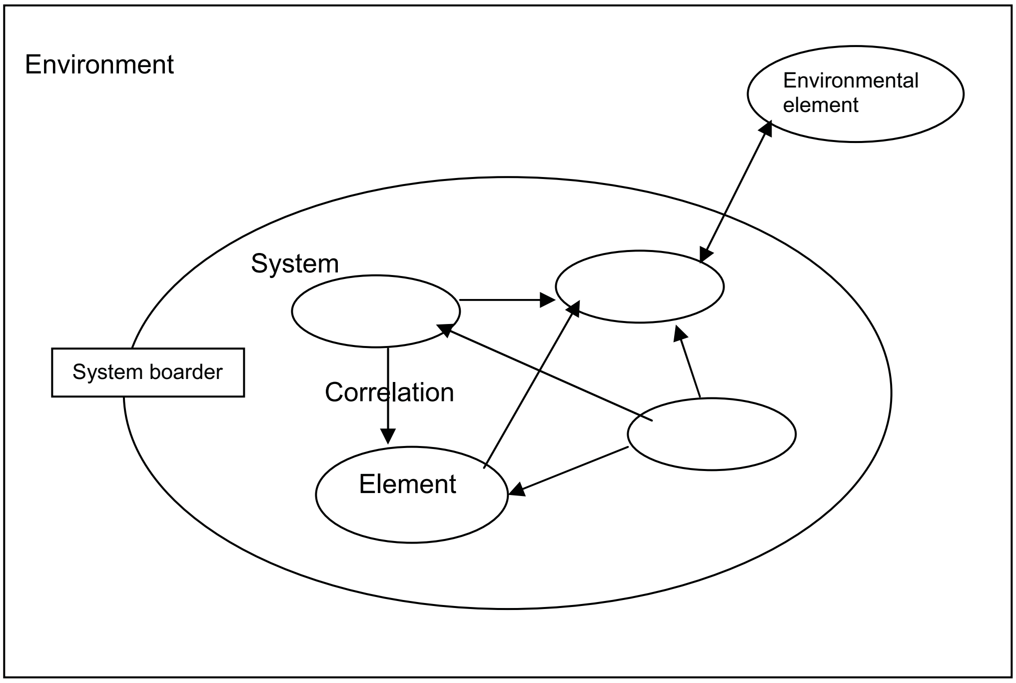

Fig. 1: Main terms of systems thinking[3]

2.1.3 Structure of a system

Elements and connections show a type of arrangement; this is called structure of a system. Examples of a structure would be hierarchical structure, web structure or structure with feedback.

In the following example the system terms are applied for a paper mill:

If you define the paper mill as a system, it contains of a lot of different elements like machines, products, employees…
Within the paper mill a lot of correlations are effective which is important to guarantee the functionality of the mill. These correlations combine the elements with each other e.g.: material correlations, energy correlation, information correlation…

As we are talking of an open system the mill also has correlations to the environment like customers, contractors, competitors…

Between the system and the environment there are different types of correlations like on material basis, informational basis, energetically basis…
As system boarder you can use area and/or organisational and/or judicial criteria.

[3] cp. Haberfellner (1997): p. 5

Sub system

If you take an element of a system, you can call it a system if there are new elements in a deeper section and there are correlations together. This is called subsystem.

Upper system

This is the combination of two or more single systems. In case of the paper mill the upper system would be Mondi BP. (see Fig. 2)

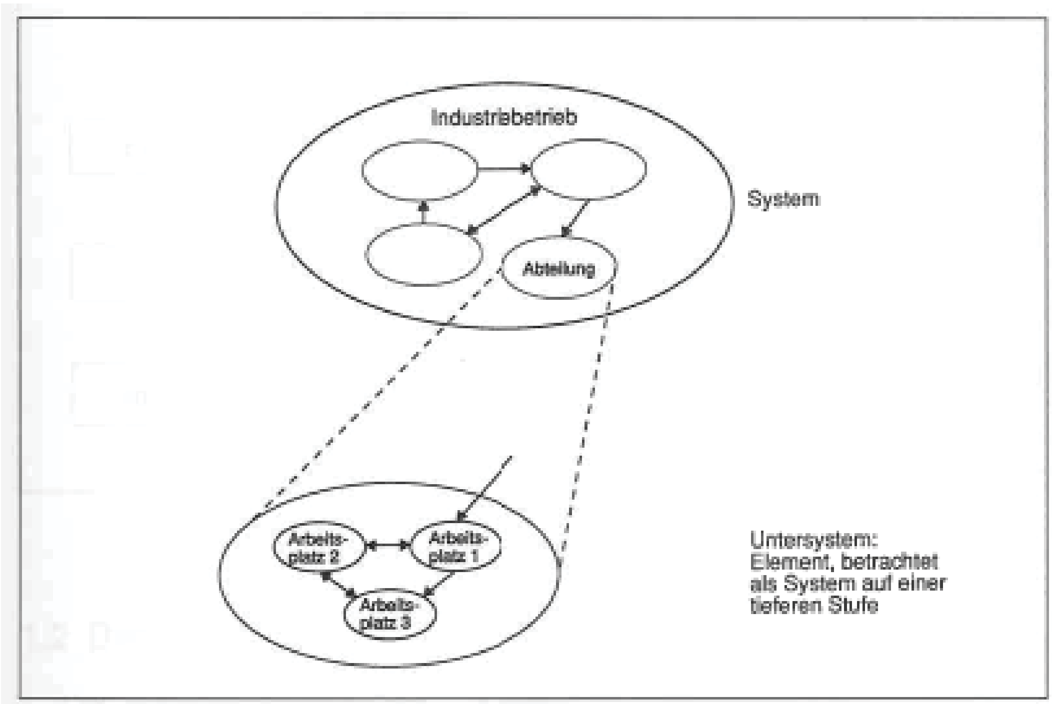

Fig. 2: System and sub-system[4]

Systems hierarchy

If you partition a system in more levels, it results in a hierarchical system (see Fig. 3). In this content you may realize the sense of the terms system, subsystem and element. The level with no further partition is called element level. Typical for an element level is that the element will be handled as a black box.

[4] source Haberfellner (1997): p. 7

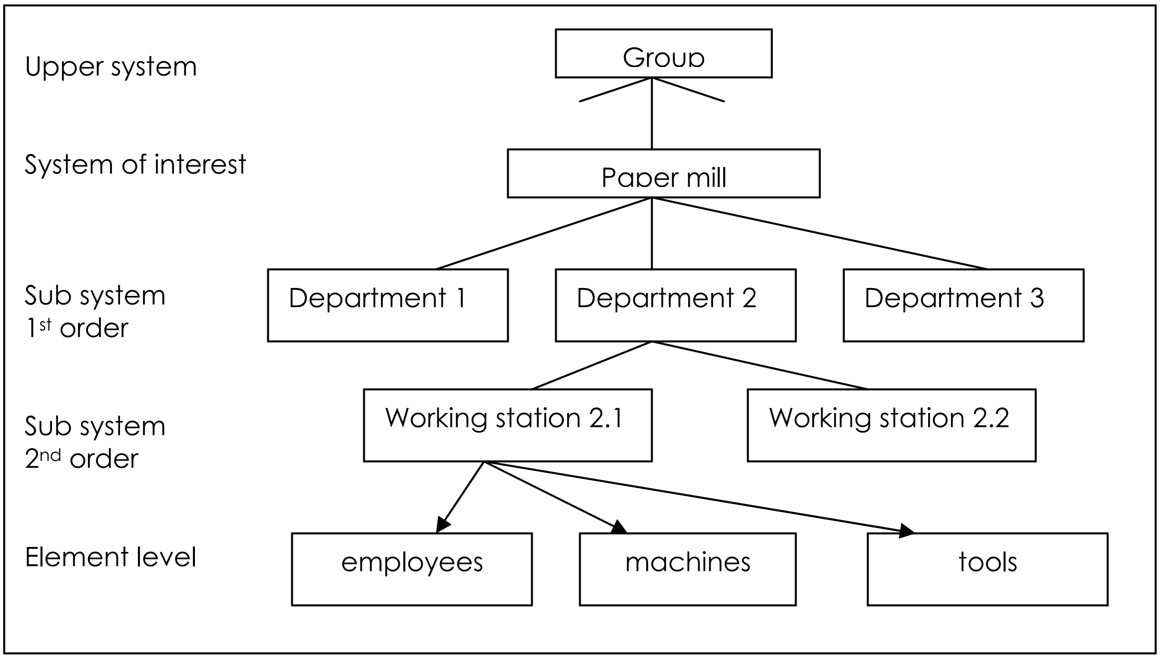

Fig. 3: Systems hierarchy[5]

Black box

If the inner content is not of interest at the moment we call this a black box. Only the inputs and outputs are of interest. This is an important tool to reduce the complexity.

[5] cp. Haberfellner (1997): p. 8

Aspects of a system

Each system consisting of elements and correlations can be seen with a filter. This means that only special characteristics of the elements or their correlations are of interest (see Fig. 4). This type of description is called aspect of a system.

E.g.: Showing the mill under the aspect of the energetic basis or the informational basis will result in different structures, elements and correlations.

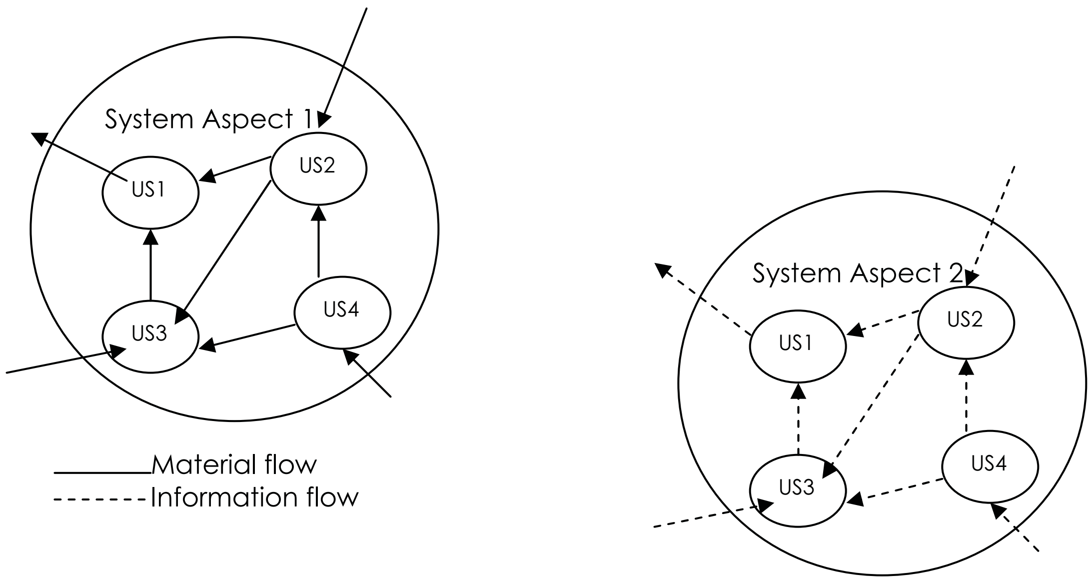

Fig. 4: Aspects of a system[6]

2.1.4 Approach to the system consideration

Now different types of approach, that are of importance, will be explained.

System models as basis of system thinking

The main principle of system thinking is to image systems and complex coherences by models. These models are simplifications of the reality and just show detail aspects. Therefore it is of great importance that the models in consideration of the situation are meaningful enough. This means that you have always to ask for the sense and the relevance.

The environmentally orientated consideration

With the environmentally orientated consideration you neglect the system and concentrate on the relation between the system and its environment. The system itself will be handled as black box. First of all you should ask for the type and the volume of the external factors. Therefore it would make sense to differ between the environmental system and the correlations to the system of interest (see Fig. 5).

Concerning the figure it would make sense to think about:

[6] cp. Haberfellner (1997): p. 9

Who are the customers?
Which type of customer relationship do we have?
How good do we satisfy them?

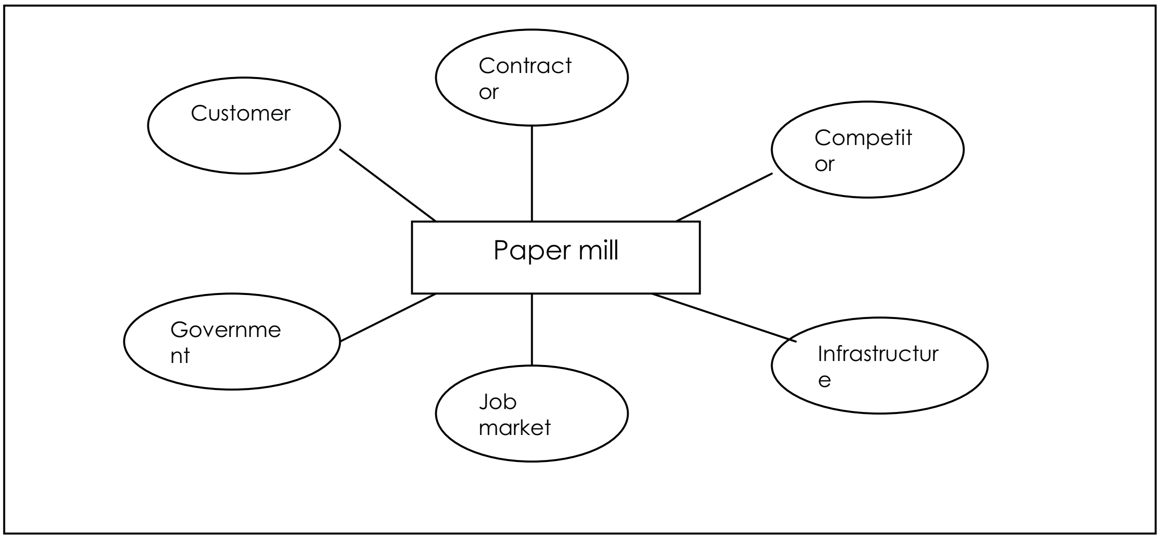

Fig. 5: Environmentally orientated consideration[7]

Input/Output-consideration of a system

This is based on the question which important Inputs, from the environment, together with the behavioural possibilities of the system have which consequences for Outputs to the environment. The effects inside the system are of no interest in this consideration. So the system will be handled as a black box. But sometimes the internal connections by using this step response cannot be ignored totally and so the topic black box is sometimes changed into grey box.

Examples: Energy balance of a company: What goes inside in which state of aggregation and what does come out? What is the efficiency factor and how large are the losses?

[7] cp. Haberfellner (1997): p. 11

The Input/Output orientated consideration is a good tool to judge the condition and the quality of a system roughly. On the other side it is a good tool to roughly figure out problem areas and solutions. Before starting detailed observation, functionality blocks should be defined. Afterwards you start with a structure orientated and so to say more detailed consideration.

Fig. 6: Input-Output Consideration[8]

Structure orientated consideration of a system

For this consideration you are interested in the elements of a system and their correlations, but especially in the dynamic action and development. This point of view is valuable to explain how the Output is developed through the Input, or to explain how the Input is changing to the required Output.

Consequently the structurally assembly and the structurally based interrelations are the main purpose of the structure orientated consideration. System internal elements and correlations will be defined and figured.

Additives to build up correlations and structures

Graph

Graphs are commonly used to build up structures. Elements of the system are "knots" of a graph and will be drawn as e.g.: circles or triangles. Correlations are shown by lines. Depending on the conclusion the correlations can be shown by arrows (direct correlations) or lines (undirected correlations).

Matrix

In this case the components will be ordered with the help of lines and columns. Existing correlations will either be showed by marks at the crossing points of the lines and columns or information of the correlations intensity (numerical values).

[8] cp. Haberfellner (1997): p. 11

Aspects of a system consideration

It is already mentioned that systems and their elements and correlations can be described "filtered" under different aspects.

Examples would be:
System <Europe>
Elements (subsystems): e.g. countries, political unions like Austria, Germany, and France …
System aspects: traffic, currency relations, goods flow...

System <company>
Elements (subsystems): e.g. sales, production, research...
System aspects: information flow, material flow, ordering process…

The structure orientated consideration of a system under different aspects is similar to the consideration of the system with different filters.

You have to notice the following:[9]

Elements of a system can be relevant for different system aspects and so they can occur in diverse figures.
The different system aspects serve as temporary reduction of the complexity, but they are in correlation to each other. So the information flow will guide the material flow as an example.
The message reading out of a systems view will be dominantly influenced by the system aspects.

The consideration of a system under different aspects is the basis for describing the structures in a system. Some aspects will be more important than others but this is a way to handle the complexity.

Application of the system hierarchical thinking

The system thinking should avoid the danger of defining problems too tight. Otherwise there is the risk of too much elements and correlations with the widening of the horizon. The idea of system hierarchical thinking in combination with the black box principle offers methods for an easier contact with the complexity.

Thereby a system will be roughly structured by building up a limited number of sub systems and the main developed correlations. Normally the sub systems behave as black boxes. Just if there is no sufficient conclusion on the level of the rough main consideration then the sub-systems change into a structure orientated consideration.

The concept of the system hierarchy is so to say a principle, comparable to the look through a "zoom objective". Depending on the demand you can have a look in detail or watch the total view (see Fig. 7).

[9] Haberfellner (1997): p. 15

So two different ways of thinking are possible:

- The sub system consideration looks top down by asking of which elements a system or a sub system exists? Each of these components can be again considered.
- The upper system consideration is asking which system belongs to which upper system (see Fig. 8). Considerations like these are made in regard of bigger correlations and can be suitable by finding the "correct" starting level.[10]

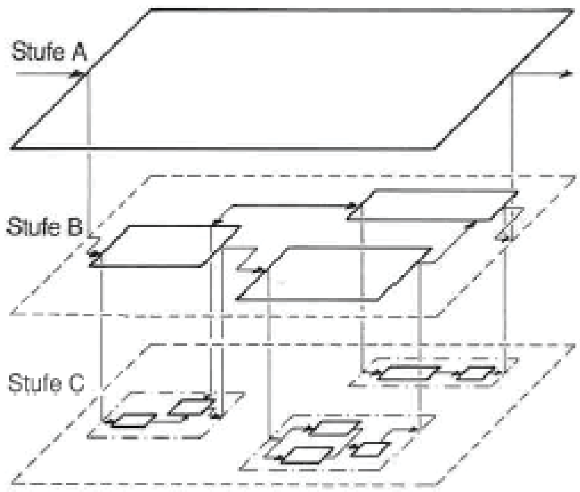

Fig. 7: Stepwise splitting of the system[11]

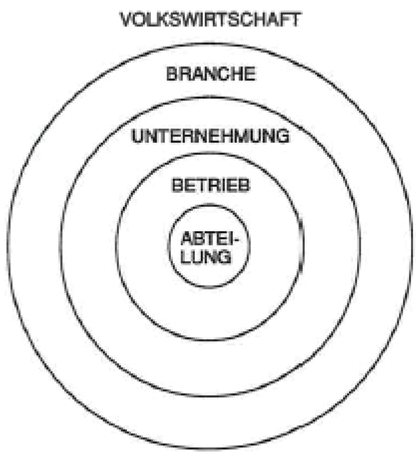

Fig. 8: View of levels of an upper system[12]

[10] Haberfellner (1997): p. 17
[11] source Haberfellner (1997): p. 18
[12] source Haberfellner (1997): p. 18

2.2 Energy balance

2.2.1 General

It is obvious that especially nowadays the question for sufficient and save energy supply is of high importance. Therefore an authentic imagination for the energy demand of the future is interesting. An energy balance should relate the energy consumption to the energy extraction.

Although it is clear that the creation of energy balances is an efficient and good tool, the practical execution brings problems. The reasons are diverse. First of all the total energy flow from the raw energy source to the demand of the ultimate consumer has to be recognized. Only if the structures and connections of all energy sections are known, the energy flow can be detected quantitatively and qualitatively. Basically the energy balance has the flaw that it does not sufficiently consider the qualitative differences between the different energy sources. This can clearly be shown for the production of electricity by hydropower, which is only 11, 6 % of the total energy production. This definitely does not correspond to the real impact.[13]

Another problem lies in the fact that many energy sources have different measuring units. Therefore a unique measuring unit is needed to compare the different energy sources and combine them to an energy flow.

So the first exercise is to establish criteria which divide the whole energy flow into economically relevant phases.

2.2.2 Types of flow charts

To describe an operation clearly a graphical illustration, a so called flowchart, is required. This illustration of the build up and function of a system can be different in its content of information and its illustration, which can be shown by three types of flow charts.

- Block diagram
- Process flow chart
- RI-flow chart

The block diagram gives a rough overview of the method used. The content of information is little and only consists in the description of the stages of the method, as well as the main flow and mentioning the Input and Output. Additionally connections between the steps, flow figures, energy figures and phase conditions (pressure, temperature) can be given. The illustration of main operations and partial facilities is done by boxes, energy and material flow is illustrated by arrows.

The process flow chart has additional information of required machines and tools and names the discharge and the flow rate of the energy source.

The RI-flow chart is the most detailed chart and gives almost any information one can imagine. I will not go into more detail now with this chart.

[13] Zach O. (1982): p. 52

The steps of an energy flow fundamental for an energy balance

Following the way of the different energy sources from their extraction or production to their ultimate use, gives many possibilities to calculate the energy flow.

For economic reasons the energy balance only needs to cover and figure the important steps of energy flow. These steps can be easily illustrated in the scheme below:

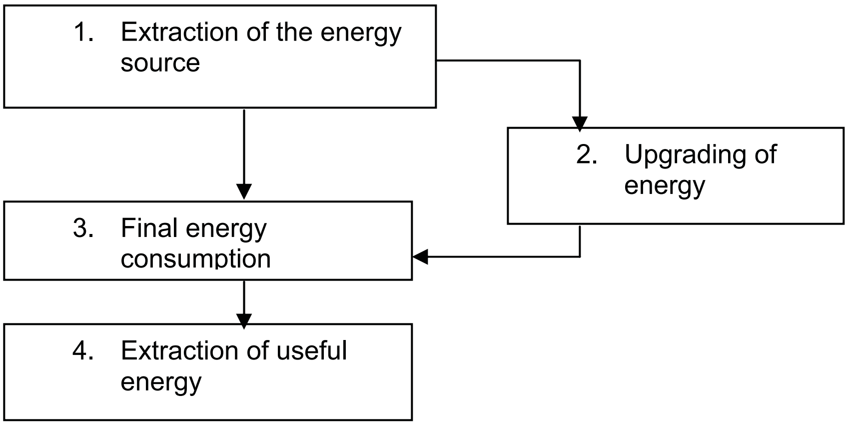

Fig. 9: Important steps of energy flow

The extracted raw energy sources will be directly sent to the ultimate consumer, where they are conversed into useful energy like heat, light or power, or they will be upgraded before they get to the ultimate consumer. (see Fig. 9)

This very simple chart includes the main information about an energy flow chart. It is created step wise and each step stays in an organic composition to each other. Each step is only a part of the total energy flow and so it is only a part of the energy balance. Only the combination of all steps gives an overview of the energetic structure of an economy.[14]

[14] Rumler F. J. (1960): p. 21

2.2.3 Types of energy

The following types of energy are important for consideration:

- Potential energy
- Kinetic energy
- Internal energy
- Magnetic and electric field

Putting energy in and out into the process can be done by:

- Linked to mass
- Efficiency
- Heat transfer
- Field effects

Because mass does not change, only the change in energy and not the absolute value based on the mass is of interest. So enthalpy is always given as ΔH.

The transported energy is given in [J/s].

For unique definition it was established that all substances that take place with a reaction, have to be in standard conditions. These standard conditions are a temperature of 25°C = 298, 15[K]. For gases it's the ideal gas phase, for liquids and solids it's the most stable phase at a pressure of 1 [atm]. (1 atm = 1, 01325 bar)[15]

[15] Schnitzer H. (1991): p. 170

Energy management

The arrangement of an operational energy supply is not only important; it also is a multi-level task.

2.2.4 Common basic structure of energy supply

Of main importance is the orientation along the economic principles and its adherence. These principles are the basis for each commercial (rational) action and are based on the cheapest solution possible. The area of conflict is built by rare resources on one side and hardly boundless human needs on the other side. Rationally we should act the way that:

With the given fund a highest possible coverage in demand is given
The given coverage in demand will be reached with relatively low expense
Generally there is a good relation between expense and coverage in demand realised.

As parameters we have to distinguish between:

Productivity

It is the relation of quantitative output and quantitative input of production factors. Thereby you distinguish productivity of work and productivity of material. This leads to the following based on the energy application:

Energy-application-productivity = $\frac{number\_of\_produced\_items}{energy\_amount\_used}$

The reciprocal of this productivity data is called specific energy consumption.

Specific energy consumption = $\frac{energy\_amount\_used}{number\_of\_produced\_items}$

Efficiency factor

This technical parameter shows the relation between energy beneficial emitted to a system and energy admitted to the system.

Efficiency factor = $\frac{energy\_beneficial\_emitted}{admitted\_energy} * 100[\%]$

The difference between the energy beneficial emitted and the admitted energy results in the losses in the energy system.

Economic efficiency

This parameter is a monetary evaluation of the prepared activity (output) and the input factor based on the principle of economics.

Calc. profitability = $\frac{activity\_based\_revenues}{\cos ts}$

Gross Profit Margin

First some basic profitability equations:

Gross Profit Margin = $\frac{Gross\_\Pr ofit}{Turnover} * 100$

Turnover = Sales
Gross Profit = Turnover - Cost of Sales

The gross profit margin ratio tells us the profit a business makes on its cost of sales, or cost of goods sold. It is a very simple idea and it tells us how much gross profit per 1€ of turnover our business is earning.

Gross profit is the profit we earn before we take off any administration costs, selling costs and so on. So we should have a much higher gross profit margin than net profit margin.[16]

Liquidity

This parameter should show the possibility of a company to fulfil payment obligations in time.

Liquidity = $\frac{available\_funds}{payment\_obligations}$

This parameter is also of high importance for investments in the energy sector.

[16] www.bized.ac.uk

Cash flow

The cash flow is based on input and output. Accordingly it will be evaluated on the level of the monetary profit. Therefore the following positions are considered:

Earnings before tax
+ Depreciation and amortisation of fixed assets
+ Generation of reserves
+ Generation of provisions
- Dissolution of reserves
- Dissolution of provisions
= Cash flow[17]

2.2.5 Characteristics of the operational energy supply

The demand in effective energy occurs in two ways in an industrial firm. On one side it is required in the production process in the form of

- Process heat
- Mechanical energy
- Effective electricity

On the other side for the use of auxiliary equipment in form of

- Thermal heat (buildings, water treatment…)
- Mechanical energy (ventilation, pumps, transport…)
- effective electricity (EDV) and
- lighting energy[18]

The purchased energy sources have to be dissipated once or more often inside the firm. Therefore a number of technical installations are used. This is just mentioned without further explanation, because it is not part of this thesis.

2.2.6 The energy management function after the operational energy flow

According to the resulting demand in energy an operational energy flow is necessary, which also precipitates in the energy management function.

Partition in operational energy flow

The partitions in operational energy flow can be resumed in the following six categories.

[17] Wohinz J. W. (1989): p. 27f.
[18] Wohinz J. W. (1989): p. 33

The reference to Energy source

This part includes all energy sources supplied to the firm within a specific time, both the purchased energy source on market and the energy out of environment.

Energy-dissipation and level-change

This area includes the energy-technical installations, that dissipate the primary- or final energy sources into the "use energy" sources required within the firm.

Energy allocation

To transport the required "use energy" source to the energy using machines and installations, adequate energy transmission and distribution aggregates are needed.

Energy partition by usage

After the internal partition and distribution of energy, the proper "use-energy" source will be feed to the production process and the additional systems and converted to the required effective energy by machines and installations.

Energy disposal

After the "use-energy" was used by a machine, normally only no valuable rest heat occurs, which will be emitted to the system (energy-output).

Energy recycling

Depending on quantity, quality, time-conformity and place of rest heat, the continued usage in the operational energy flow is possible. With the help of appropriate installations (energy recovery installations) such lost heat can be used again.

Energy saleable

If the use of recovered energy in the own operation is not possible or common, you can think about selling the energy to a third party.[19]

[19] Wohinz J. W. (1989): p. 37f.

2.2.7 The energy management function after the closed loop model

The simplest form would be to figure the operations management as a sequence of sub activities – starting with the target followed by the planning to the implementation and control.

The closed loop in energy management

To correctly figure the normal operational energy management after the closed loop model, the following facts are important:

Formulation and commitment of targets

You should define the targets that should be reached in the future. These are based on analysis of the closer area and the energetic situation of the own operation.

Analysis and planning of energy requirements

Constitutive on a detailed energetic operations analysis the energy planning implements the principles and targets of the operational energy management in respect of material and time. Also it coordinates the actual energy demand of the production with activities of energy supply and serves as a basis for the regulation and control of the energy flow.

Allocation and application of "use-energy"

These are all activities concerning conversion, distribution and finally application of energy or energy sources, so to say the supply of the operation with "use-energy".

Control of energy use and energy cost

The reason for controlling the energy use is to measure the grade of achievement of objectives by comparing the given norms with the already realised status. This serves as the basis for control and correction arrangements. The main issues will be the evaluation of the current status, the comparison with the planned data and the execution of abnormality analysis.

Development of energy saving programs

For economisation of the operational energy flow, the introduction of energy saving programs is a suitable tool of the regularly running activities concerning the operational energy management. This completes the closed loop model.[20]

[20] Wohinz J. W. (1989): p. 42f.

2.3 Energy analysis

2.3.1 Methods of energy analysis

Generally three types of energy analysis are used:

- statistical analysis
- input-output-analysis
- process-chain analysis

Statistical analysis

This is based on statistics of the energy consumption of industries and sectors of a national economy. But the method of the statistical analysis is quite imprecise and normally just gives a rough overview of the amount of energy demanded for a product. Sometimes it is not possible to calculate the indirect energy demand. Besides that there can be significant errors like double counting of services.

Input-output-analysis

This method is based on input-output-tables of an economy or a company. The advantage to the statistical analysis is the consideration of indirect effects. Besides that this method has high problems and disadvantages compared to the process analysis:

- The consideration in monetary units is a disadvantage and so they have to be converted to physical units first
- The final demand is not based on the finished saleable price
- Double count can occur
- Different production processes for the similar product will not be considered
- Industries with different energy intensity will be summed up in one sector

Based on badly defined system borders, purchased resources are given in provided energy and not as gross energy demand.

Input-Output-Analysis normally serves as total economic considerations. Also they can give important information for international energy politic decisions. Not suitable is it for decision finding in the operational sector.

Process analysis

The most accurate statement will give the Process-Chain Analysis. The complex part of production is split in many smaller single processes. For these single processes the relevant In- and Outputs will be acquired and evaluated energetically. The biggest processes of production are equipment, material and energy source. This type of energy analysis brings the most accurate results and so it is mainly used in the micro economy. There it is used to calculate the energy demand of one special product. Problems occur if an Input should be based on an energy value that should finally be a result. To solve this problem you can use already existing values from literature or other analysis.

It is possible to find a satisfying solution for an energy analyst, assuming he knows the system that has to be handled. Often he will be asked: how much energy do you need to produce one ton of this product? The big difference between this question and the description of the industrial process is that the question is based on a finished product but the description mentioned above belongs to the industrial process. So the first step of each analyst is to transform the product based question into a process based one. This requires the choice of system borders that consider all important and necessary operations that are needed for the process description. So each well defined system can then be analysed.

Maybe the most important decision for the further analysis is the choice of the system. As there is no absolute correct choice of a system in energy analysis, it mainly depends on the specific task. Similar to this the system border should show the grade of comparisons that are possible. Because if you compare a production process based on the material and energy demand with a process where intermediate inputs (e.g.: energy efficiency of power plants – they need a multitude of primary energy to produce one unit of final energy), are considered, there can be significant variations.

Therefore it should be noticed: "there is no such thing as a \`correct\` or \`absolute\` value for the energy needed to produce a kilogram of any commodity. The values obtained depend critically upon the systems boundary chosen." [21]

[21] Boustead J.: p.52

2.3.2 Approach to an energy analysis

The steps for a process analysis are the following:

- decision of the specific targets of the analysis
- choosing a system and setting system borders
- specification of all possible Inputs
- evaluation of the Inputs
- specification of all possible Outputs
- evaluation of the Outputs and specification of allocation criteria

Decision of the specific targets of the analysis

The main impact of an energy analysis is in the technology of energy supply and energy saving. Very easily you can check the energy balance of such facilities by comparing the energy Output with the energy that is needed to build and run the facility.

Choosing a system and setting system borders

We can estimate that the very first (main) system border will be the production cycle with its different Inputs of materials, fuels …. Machines, buildings and other production goods will be chosen as second system border. To assign them will be possible after contacting the particular company. Additionally inputs will be considered if the impact of energy demand on the good produced is more than 5 %. Because energy analyses rarely have an accuracy of more than 90 – 95 % further borders (section 4) can be neglected. The difference to the effective energy demand won't be more than 5 %.

Specification of the possible Inputs

The specification of the Inputs is normally done with a material flow chart or a network that contains all Inputs. Now you have to consider all factors that influence the energy demand of the production process or the product based on the system border.

Evaluation of the Inputs

The manpower is no Input-factor because it is no industrial production process. There is one standard unit (kWh) used to solve the problem with recalculating different physical units depending on the use of energy. In case of a thermodynamic process as well as a recalculation in primary energy the unit is kWh_{th}, in case of electro magnetic action it is kWh_e.

For the conversion of electrical energy into primary energy it is necessary to consider the high losses that occur especially in thermal power plants. So there is a conversion factor established that is valid for the OECD-countries:

$$\frac{energy_{th}}{energy_{el}} = 3{,}03$$

This is an energy efficiency η = 33 %

Specification of all possible Outputs

Corresponding to this, the term "positive" and "negative" energy balance is used. The energy balance should characterise the relation of energy Input to energy Output. The energy balance is basically meaningful for the evaluation of energy conversion and energy savings technology. Also it should give the time when the energy generated compensates the energy required to build up the plant (amortisation time). Figure 10 shows the energy balance for building a plant. Note: This figure is only valid for plant powered by renewable energy, e.g.: Recovery boiler powered by black liquor.

The two blocks have the same area and the first block gives the amount of Energy Input that was required to build this plant. When the plant starts generating it gives an energy output. After the Output of the plant equals the Input to build the plant we reach the amortisation point. From this time on in total more energy is produced than required, so a "positive" energy balance is given.

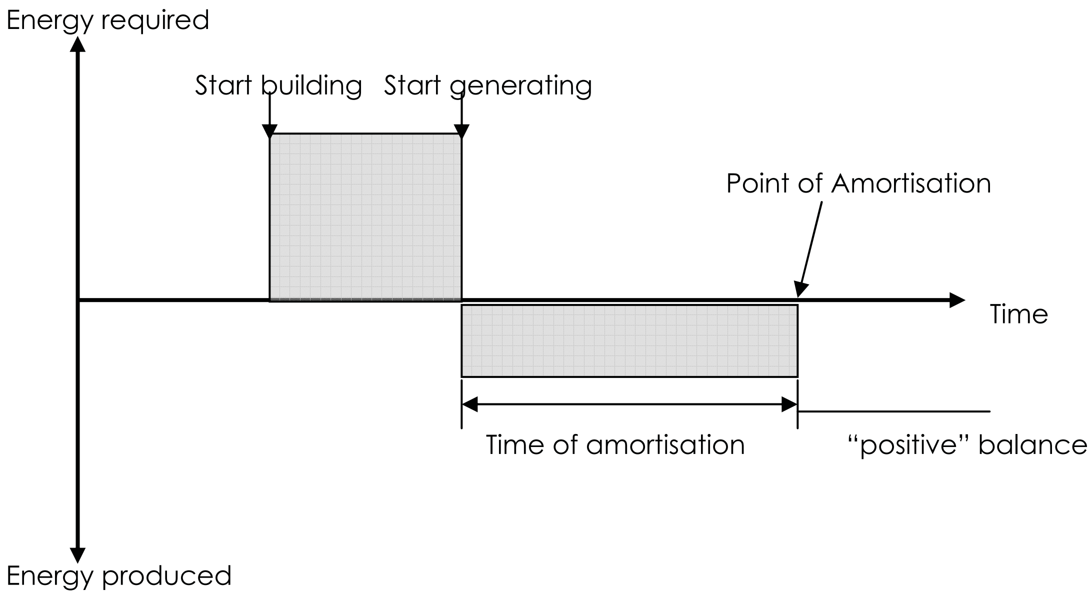

Fig. 10: Energy balance[22]

So the assumption that the energy analysis is the basis for an energy balance is valid.[23]

[22] cp. Zach O. (1982)
[23] Zach O. (1982): p. 52 ff.

2.4 Basics of Benchmarking

Benchmarking can be a very valuable instrument to improve the competitiveness. It gives a company the chance to compare with another company, to realize their "factors of success" and to imitate them. Consequently a company is only interested in comparisons that give information about the reasons for the success. Benchmarking is the process of identifying, understanding and adapting outstanding practices from within the same organisation or from other business to help improve performance. This involves a process of comparing practices and procedures to those of the best to identify ways in which an organisation can make improvements. Thus new standards and goals can be set which, in turn, will help better satisfy the customers' requirements for quality, cost, product and service.

In this way, organisations can add value to their customers and distinguish themselves from their competitors.

2.4.1 Why benchmarking is needed

Benchmarking helps organisations focus on the external environment and improve process efficiency. The number, extent and pace of changes in the external environment mean that no person or business can afford to be complacent. The increasing sophistication of marketplaces and rise in competition means that an organisations competitive advantage is constantly being eroded as barriers to entry decrease.

There has been a continuous shift towards flatter, non-hierarchical organisations. In the new working environment, grater emphasis has been placed on teamwork, involvement and continuous improvement. The output of this movement is a greater awareness of customer needs and a more commercial and competitive focus within organisations.

2.4.2 The benefits of benchmarking

Benchmarking brings many advantages to an organisation:

It sets performance goals.
It helps accelerate and manage change.
It improves processes.
It allows individuals to see "outside the box"
It generates an understanding of world-class performance[24]

[24] Cook S. (1995): p. 14f.

2.4.3 Overview of the benchmarking process

Benchmarking is an on-going process which requires a systematic approach. There are six discrete steps to effective benchmarking (see Fig. 11).

Fig. 11: Six steps in the benchmarking process[25]

Identify and understand your processes

This stage involves gaining an in-depth knowledge of the organisations processes in order to fully understand its operation and the key factors which determine its success.

This stage is critical to the effective outcome of the benchmarking project as unless a careful analysis has been undertaken of the organisations chosen process prior to selecting benchmarking partners, the project team will not be in a position to select the right partners

Agree what and who to benchmark

The project team may already have a perception of potential benchmarking partners. However, intuition needs to be supplemented with detailed knowledge. It is important at this stage of the benchmarking process clearly to identify what and who to benchmark through careful analysis of the options available. This stage also involves the team in identifying how best to collect data.

[25] source Cook S. (1995): p. 17

Collect data

There are a variety of methods for collecting data from benchmarking partners. This can come about through the direct exchange of information or through desk research. However the information is gathered, its quality will directly reflect the appropriateness of the questions asked.

Analyse data and identify gaps

Once data has been allocated, both quantitatively and qualitatively, it is possible to establish best practice and identify the gaps between the organisations performance and the performance of the benchmarking partners who provide the highest standards. In this way differences can be established and a plan of action for improvement developed.

Plan and action improvements

The action-planning stage of the benchmarking process involves generating ideas on how improvements can be made and putting forward ideas for implementation. The communication of the results of the benchmarking exercise to other parts of the organisation (and benchmarking partners where possible) is very important.

The project team needs to define clearly the changes which need to take place in order to reach and exceed the benchmarks which have been established as part of the programme. The team will also be responsible for introducing the improvements into the organisation and for ensuring their smooth implementation.

Review

The benchmarking process is iterative. Each stage of the study progress should be reviewed and the next steps adjusted in the light of the findings. For example, after completing stage 3, the collection of data, it may turn out that further information is required from benchmarking partners or that other criteria need to be assessed or further benchmarking partners found.

The process of undertaking benchmarking should be never-ending and part of the culture of continuous improvement.[26]

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[26] Cook S. (1995): p. 39ff.

2.4.4 Types of benchmarking

The following section should figure out all types of benchmarking used, divided in objects, partners and scales.

Classification in order to the benchmarking object:

- product benchmarking
- functional benchmarking
- process benchmarking

Product benchmarking

The product benchmarking is the main form of the benchmarking. This can be explained by the following two reasons:

- Comparison of the objects surveyed: The comparison of the objects is the main requirement for a suitable benchmarking study. Important is that the received data out of the comparison gives us the answer for the formulated problem. The significance of product comparisons is of a high grade in this sense. The direct correlation between products – market clearly defines the more popular and the less popular products. Based on this comparison, product attributes in benchmarks for the own company can be realized.

- Possibilities of data acquisition: The second reason for the dominance of product benchmarking in praxis is the easy acquisition of meaningful data. Because these data are free on the market. There are no lacks of information so the company does not rely on co-operations. Also the literature gives numerous models for evaluation of product attributes.

The comparison is not only on product level. Besides this the comparison of the product benchmark will also be broke down on the different levels. Here each single module of the product is of interest. For comparison reasons the product will be deconstructed to its single parts. Alternative details of the competitors will be recognized and evaluated in the order of the customers' profit. So the product benchmarking is often called "reverse-engineering". [27]

The product benchmarking is limited by boarders. These boarders are reached at the moment a company does not understand which product processes are responsible for the development of a product attribute. These problems occur especially when economical considerations are based on technical details.[28]

[27] Kiese (1993)
[28] Schmidt F. (1999): p. 15ff.

Functional benchmarking

Users of this method use the fact that the exercise of a company can be quite too complex for a single person if it reaches a specific volume. Consequently a superior instance is required for the value added. This instance analyses the process and splits it in meaningful subtasks. Close to this we have the problem to find an optimal arrangement and delegation of responsibility in the company. The required comparability of a functional benchmarking will be enabled with similar creation and methods of organisational work sharing. So this procedure can result in similar exercises, independent of the type of company. Exercise and exercise user will be consolidated in a structure element called function.

The functional benchmarking is based on the high grade of comparability of these structure elements. Main advantages occur if it is possible to assign a method to the own company that has not been used in the own sector. This can lead to jumps in competitiveness which is one reason for the high grade of acceptance of benchmarking in economy.

Example: the part of the „Hydro Aluminium Extrusion Group", with the highest turnover was visiting the central warehouse of "Karstadt AG" in Unna in 1992. Comment of responsible manager Hans-Georg Mangold: „Die wälzen 180.000 verschiedene Artikel um, und wir haben nur um die 8.000 verschiedene Profile – es ware doch gelacht, wenn wir von deren Logistik nicht lernen könnten."[29]

But there are some problems in practical consideration:
The higher the grade of comparison, the faster the results can be used. This increases the chance of imitating the process.

Complete benchmarking can only be achieved with similar products. But the result out of this is very low in order to the benchmark ideology. With growing comparability of an object the innovation for a company decreases.[30]

[29] Krogh (1992): p. 215
[30] Schmidt F. (1999): p. 19 f.

Process benchmarking

The thinking in processes is very beneficial. In one way it is a perfect tool to identify factors of success, on the other side is the process management an accepted method with increasing implementation in real world. Especially for the benchmark of objects the process management has two main advantages:

- Ideal typical process structure: As mentioned before the growing comparability of an object results in a decrease in innovation for the company at the functional benchmarking. The process management is based on the premises that all companies have the same border processes. So each company, independent of its section, consists of a similar process structure, so their processes are comparable in order to its achievements. The abstract definition of border processes brings a minimum of comparability with a maximum of innovation.

- Consistent assessment norms: The process management includes the factors costs, quality and time, whereby the process performance is influenced by all three factors. The advantage is obvious, because if the appraisal of the process performance of all company's is based on the same key data, then the data for a benchmarking project are automatically given in a comparable norm.[31]

2.4.5 Classification in order of the benchmarking partner

There are four types of benchmarking which can be undertaken by an organisation:

- internal
- competitive
- non competitive
- best practice / world class

Internal

This is the easiest type of benchmarking to conduct since it involves measuring and comparing company data on similar practices from other parts of an organisation, one branch office with one another, for example.[32] There is the suggestion that the performance processes in the different branches can deviate because of geographical, political, technical, personal or historical reasons.

Internal benchmarking creates an environment of two-way communication and sharing within an organisation. The main advantage of this lies in the way to generate the data as it overcomes any problems of confidentiality and trust.[33]

On the other side the chance to identify a "best-practice" within the own company is limited. So the data received with an internal benchmarking should not be overestimated.

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31 Schmidt F. (1999): p. 22 f.
32 Cook S. (1995): p. 18
33 Cook S. (1995): p. 18

Competitive

The second type of benchmarking is against direct competitors. This is often easier, however, for larger industries than smaller ones. It is also sometimes difficult to collect competitive information, although independent industry surveys and reports, if available, do offer insightful information.[34]

Non competitive

It is possible to benchmark a process by measuring and comparing:

- a related process in a non-competitive organisation
- a related process in a different industry
- an unrelated process in a different industry

In this way, improvements can be identified which can be adapted to the organisation.[35]

Best practice/world class

This approach to benchmarking involves learning from best practice or world-class organisations – the leaders of the process being benchmarked.

2.4.6 Classification in order to the benchmark-measure

Besides the choice of appropriate objects and partners the benchmarking additionally demands the choice of a correct parameter. This parameter is for the quantification of the object.

A comparison is only meaningful if the used parameters have a similar measure. Only this measure enables the relative positioning of the operational achievement. So it is the main condition for any comparison.

Benchmarking-measures can be on a monetary or non-monetary basis.[36]

2.4.7 General risks

Benchmarking is used most often to create a climate for change and to bring about continuous improvement. However, statistics show that nearly 70 percent of all process improvement initiatives fail. The most common reasons for failure are:

- lack of focus and priority
- lack of strategic relevance
- lack of leadership
- lack of perseverance
- lack of planning

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34 Cook S. (1995): p. 18
35 Cook S. (1995): p. 19

36 Schmidt F. (1999): p. 31

Before an organisation begins a benchmarking programme, therefore, it is important to recognise the most typical causes or obstacles preventing the smooth and fast completion of the review.

Typical blockages include:

- management not "buying into" the idea
- no clear "owner" of the programme
- failure to consider customer requirements
- change of sponsor before completion of the programme
- programme taking too long; loss of interest
- not involving "right" staff in the programme
- team not measuring issues it agreed to address
- programme causing too much disruption of work; not seen as relevant to work
- conflicting objectives of the organisation and those of its benchmarking partners

As we will see, careful preparation is the key to effective benchmarking programmes. Awareness of potential mistakes is an important step in the process.[37]

2.4.8 Common misconceptions about benchmarking

Every manager has a responsibility to seek continually to improve the operations he or she controls. What frequently stops them is simple lack of knowledge – not knowing how much better he or she could be doing. It is human nature, without something to measure up against, to assume that current performance is near enough as good as you can get. Benchmarking leaves no room for such complacency.

For example, a factory supervisor was proud at having an unplanned downtime of only two hours a week on his manufacturing line. This was by far the best performance of any of the three workshops on the site. Then he made an overseas visit and saw a company with a similar operation, which had reduced unplanned downtime to less than 30 minutes. Though not all the practices of the other firm were transferable, he and his engineers were able to devise their own ways to match and even improve on a standard he had previously thought impossible.[38]

2.4.9 A systematic approach

Successful benchmarking involves a systematic and measured approach. This comprises a series of activities which enable managers to identify where improvement is needed to business performance and how this may be achieved.

[37] Cook S. (1995): p. 20f.
[38] Cook S. (1995): p. 23

2.4.10 Reasons for benchmarking

There may be a number of reasons why organisations adopt a benchmarking programme as a catalyst for change: it could be to:

- increase efficiency
- create customer awareness
- enhance customer satisfaction
- improve profitability
- promote understanding
- make continuous improvements
- gain commitment to corporate goals

It is vital, upon embarking on a benchmarking project, therefore, that the objectives of the programme are clearly stated and that results can be measured.[39]

2.4.11 Preparing for the benchmarking project

There are five steps in the planning process in preparation for benchmarking (see Fig. 12):

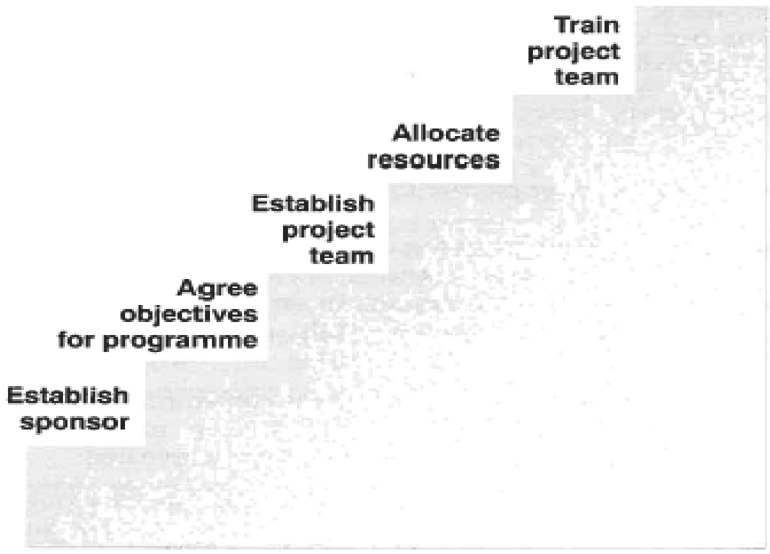

Fig. 12: Five steps of the planning process[40]

Establish a sponsor

Before a benchmarking initiative is undertaken, a "sponsor" or "champion" of the process must be established. This person should best be sufficiently senior within the organisation to drive the project through and to support the findings of the benchmarking exercise. Importantly the "sponsor" needs to be familiar with the process under review and be desirous of the need for change.

[39] Cook S. (1995): p. 27
[40] source Cook S. (1995): p. 32

Agree objectives for the programme – with time frames

It is useful to be as clear as possible about the objectives of the benchmarking project. It is also helpful to remember the intangible objectives of the programme, such as increased teamwork and understanding, as well as the tangible outcomes.

In addition, time frames should always be set, as frameworks, for a benchmarking programme. This establishes parameters in which the project team can operate.

Establish a project team

Success of a benchmarking project largely depends on the care that is taken in selecting the appropriate project team members for the task and in training and supporting them.

Having gained commitment and a sponsor for the project, the next step is to form a project team headed by a project team leader. Ideally this person should be the process owner – the person who has ultimate responsibility for the outcome of the process. Alternatively the leader should be actively involved in the process to be benchmarked.

Team members should have sufficient power of persuasion and credibility to get their recommendations approved, otherwise their efforts will fail. Members should be drawn from across the organisation. The team should ideally consist of five to eight people.

Participants should have the knowledge/influence/capacity to undertake the programme. Ideally, the mix of team members should include those who are:

- good communicators
- good motivators
- prepared to question and challenge the status quo
- systematic and analytical in their approach
- creative in their outlook
- willing to progress the task in their own time, outside team meetings
- able to promote good team spirit
- willing to achieve the task
- credible within the organisation

It is beneficial to ensure the team consists of both managers and staff who are both users and customers of the process which is under review. The team should include a mix of seniority and knowledge.

At the initial meeting, the project leader needs to ensure that the team understands the objective of the project and is working to a common aim. Also timescales should be established both for the project as a whole and for the project team meetings.

Allocate resources

Once project team members have been established, it is prudent to ensure that the time has been allocated to them to undertake the project. Benchmarking does not have to be a costly exercise in terms of purchases; it is time and people which are the biggest outlays.

A helpful tip is to schedule time in team members' diaries at the beginning of the project. Likewise, team members should establish the importance of the project with their managers and colleagues so that the review does not suffer at a later date through a conflict of priorities.

Train the project team

It is wrong to believe that a benchmarking project team does not require training. Team members often need training in four discrete areas:

- the benchmarking process
- research techniques
- data analyses
- team working[41]

[41] Cook S. (1995): p. 32ff.

2.5 The configuration of a paper mill

A paper mill is a paper and/or pulp producing factory. Depending on the range of production we differ between an integrated and a non-integrated mill.

An integrated paper mill (IPM) produces pulp as well as paper whereas a non-integrated paper mill (nIPM) is only a paper producer. This is a very important differentiation for the observation in case of energy consumption. Because benchmarking an IPM with a nIPM is similar to comparing apples with pears.

2.5.1 Wood yard (only at integrated mills)

The major responsibilities of the wood-yard are to receive the raw material, so called logs and store them for further production. A debarking drum removes the bark from the wood (see Fig. 13). Then a chipper cuts the logs into small wood chips. They will be screened to ensure uniform quality of the chips for the digester. Finally an adequate supply of chips and bark for use in the mill will be stored.

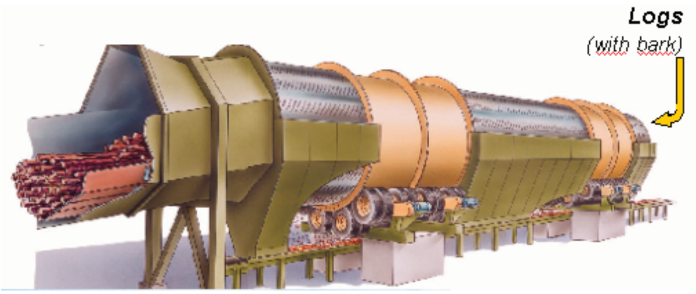

Fig. 13: Debarking drum[42]

2.5.2 Pulp Production (only at integrated mills)

The pulp is the main raw material for paper production. It can be produced in a pulp mill (see Fig. 14) or in an integrated pulp and paper mill. There are a few different types of pulp production that are commonly used:

- The KRAFT (SULPHATE) PULPING Process
- The MECHANICAL PULPING Process
- The CHEMI-MECHANICAL PULPING Process

[42] source Neusiedler Presentation (2004)

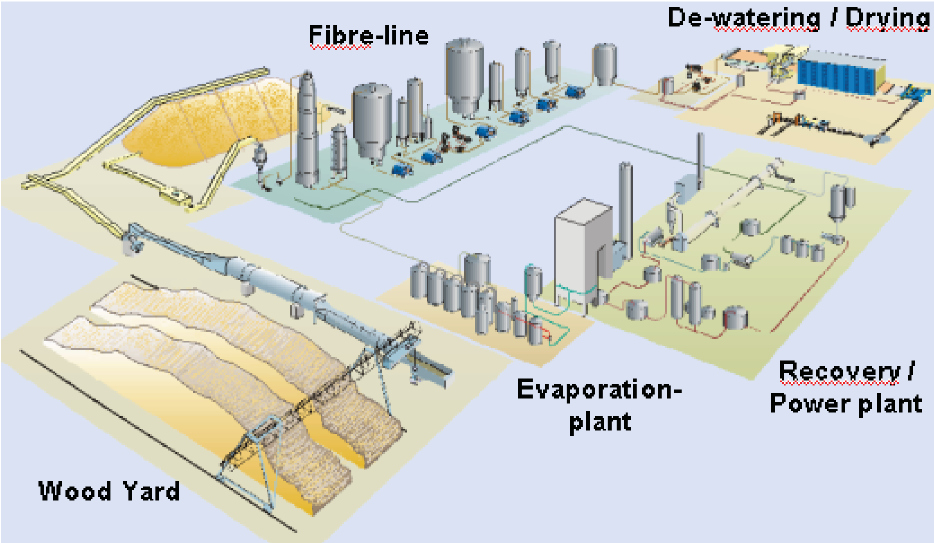

Fig. 14 pulp mill

The KRAFT (SULPHATE) PULPING

The sulphate or kraft process accounting for ca. 80% of world pulp production is the most applied production method of chemical pulping processes. The importance of the sulphite process has decreased steadily over the last years. Today, only 10% of the world production is obtained by this method.

The term "sulphate" is derived from the make up chemical sodium sulphate, which is added in the recovery cycle to compensate for chemical losses. In the chemical pulping process the fibres are liberated from the wood matrix as the lignin is removed by dissolving in the cooking chemical solution at a high temperature. Part of the hemi-cellulose is dissolved as well in the cooking.

In the kraft pulp process the active cooking chemicals (white liquor) are sodium hydroxide (NaOH) and sodium sulphide (Na_2S). As a result of the large amount of sodium hydroxide used, the pH value at the start of a cook is between 13 and 14 (alkaline pulping process). It decreases continuously during the course of cooking because organic acids are liberated from lignin and carbohydrates during the pulping reaction.

Today the kraft process is the dominating chemical pulping process worldwide due to the superior pulp strength properties compared with sulphite process, its application to all wood species, as well as to the efficient chemical recovery systems that have been developed and implemented.

But the chemistry of the Kraft process carries with it an inherent potential problem of malodorous compounds. As a result of chemical reactions in the cooking stage, chromophoric groups of the residual lignin are formed thus causing the pulp to become darker in colour than the original wood. Because of the higher pH, the Kraft pulping process induces more chromophores than sulphite pulping. Also unbleached Kraft pulp has a considerably lower initial brightness than unbleached sulphite pulp.[43]

[43] IPPC (2000): p. 17

MECHANICAL PULPING

In mechanical pulping the wood fibres are separated from each other by mechanical energy applied to the wood matrix causing the bonds between the fibres to break gradually and fibre bundles, single fibres and fibre fragments to be released. It is the mixture of fibres and fibre fragments that gives mechanical pulp its favourable printing properties. In the mechanical pulping the objective is to maintain the main part of the lignin in order to achieve high yield with acceptable strength properties and brightness. Mechanical pulps have a low resistance to ageing which results in a tendency to discolour.[44]

The main processes and techniques are:

- Stone Ground wood Pulping (SGW)
- Pressure Ground wood Pulping (PGW)
- Thermo-Mechanical Pulping (TMP) or Chemo-Thermo-Mechanical Pulping (CTMP).

The main raw materials, yields on wood and end-uses of pulps are summarised. (see Table 1).

Table 1 : Main raw material, yields and end-uses of mechanical pulp

Pulping process	Raw materials	Yield on wood	Typical end-uses
Ground wood pulp	Spruce and fir (softwood)	95 – 97%	Printing & writing papers and newsprint
TMP	Spruce and fir (softwood)	93 – 95%	Printing & writing papers and newsprint
CTMP	Dominantly spruce, bat also aspen and beech, NaOH, SO_2 and H_2O_2	90 – 94%	Printing & writing papers, tissue and packaging boards

CHEMI-MECHANICAL PULPING

The addition of chemicals in the refiner process has become important because wood chips can be impregnated very easily. The mild chemical pre-treatment of the chips enhances the softening of the wood and improves the properties of pulp produced by refining at atmospheric pressure (CRMP) or pressurised refining (CTMP). The latter combines the TMP process with a sulfonation of the wood chips.

Different kinds of treatment are used for different wood species and the properties of the CTMP can be varied to a great extent by changing the amount and the nature of the chemicals.

The chem.-mechanical pulping methods produce clean pulps of sufficient strength and acceptable optical properties and can be used as the main fibrous component in printing paper, packaging board and hygienic paper furnishes.[45]

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44 IPPC (2000): p. 163
45 IPPC (2000): p. 168

2.5.3 Supporting Processes

Apart from the main raw materials, i.e. fibrous material and fillers papermaking requires the use of various admixtures of chemical additives and auxiliaries. One part serves as a mean to achieve certain paper properties (e.g. sizing agents, wet strength agents, dyestuffs, coating colours); the other part improves operations in the production process (e.g. retention agents, anti-foaming agents, cleaning agents, and slimicides).

Chemical additives may be delivered to site ready for use or prepared on site - typically low volume speciality chemicals will be delivered ready for use whereas the higher volume chemicals may be either. This holds true for coatings as well as those added to the paper stock.[46]

2.5.4 Paper production

The paper production will be explained with the "principle of a paper machine" in the next section in a more detailed way.

2.5.5 Finishing

Finishing is the process where the produced paper is cut ready for the market. The PM6 in Hausmenning has a reel diameter of 4.4 m and one tambour has an average weight of 20 tons which equals a paper length of 54 km.[47]

The reel where the paper is rolled up out of the machine is called tambour. Normally one tambour will be reeled to two or three mother reel sets.

The products are finished by a cut size sheeter. Those are sharp rotary knives and guillotines off machine, by trimming rolls to exact widths and cutting to sheets before wrapping for dispatch. There may also be a stage of conditioning the paper product to a specified moisture content so it is consistent throughout, dimensionally stable and fit for intended use such as printing or packaging.[48]

The cut size paper is directly transported on a pallet and delivered to the customer.

Specification of large-size reel cutter at Mondi BP Hausmenning:

Speed:	<= 400 m/min (depending on format)
Production per day:	<= 140 ton/d
Width of cutter:	2,25m
Cost:	5 mio. € (ROI < 2 years)49

[46] IPPC (2000): p. 322
[47] Neusiedler paperstreet (2003): p. 12
[48] IPPC (2000): p. 323
[49] Neusiedler paperstreet (2003): p. 18

2.5.6 Storage

This is the complete warehousing of the cut size paper and the reels. For integrated mills also the storage of pulp bales is common. In Hausmenning the storage is automatically done by chaos principle, which means that the pallets are always stored at different places. The advantage of this system is that in case of a breakdown of one transport elevator, the company is still able to deliver.

Specification of the warehouse at Mondi BP Hausmenning:

Storage capacity:	19.700 tons at 23.000 panels
Input:	140 pallets/hour
Output:	270 pallets /hour
Transport volume:	80 LKW/day50

2.5.7 Transport

As the row material for paper or the finished product is handled in large amounts, several vehicles are needed to move things from one place to another. At paper mills high amounts of loads like dried pulp or finished paper have to be transported every day which is done by big types of fork lifts and cranes. In case of Hausmenning there is still an old steam locomotive in action, powered by the exhaust steam of the mill. This locomotive displaces the pulp bales and the finished paper to the train station.

2.5.8 Power Plant

There are several types of power plants possible at a mill, either depending on the production or depending on the fuel sources. An integrated mill (kraft mill) will always have a recovery boiler to produce its steam required for production. Also a common type of power plant is the cogeneration plant.

Recovery Boiler

The conventional recovery boiler is used in all Kraft mills. It separates the organic and inorganic components in the liquor. The organic portion is burned, allowing the inorganic portion, or smelt, to be recovered and ultimately converted back to white liquor. The recovery boiler typically produces enough steam to meet 60 to 80% of the mills steam demand.[51]

Cogeneration Plant

The power plant is the heart of each mill, because it distributes the power needed to run the machines. Any manufacturing plant requiring steam and power lends itself to cogeneration (see Fig. 15). In practical terms, there are two common forms of industrial cogeneration.

50 Neusiedler paperstreet (2003): p. 22
51 Paprican (1999): p. 93

Steam Turbine

Boiler based systems burn fuel to generate high-pressure steam. A backpressure or extraction condensing steam turbine-generator produces electrical power and meets a process steam requirement (see Fig. 15). Boiler-based cogeneration has long been used in the pulp and paper industry.

Gas turbine

Gas turbine systems generate electrical power and use the exhaust heat to generate steam which meets a process requirement either directly or in combination with a steam turbine. These plants combine heat and power (see Fig. 16). These systems are still relatively uncommon in pulp and paper mills and tend to be owned and operated by independent power producers who deliver power and steam to the mill under long term contract.

The ideal fuel for gas turbines is natural gas. Because of its high hydrogen content, natural gas produces much less CO_2 than oil or coal and almost no SO_2 or particulate when burned. The boilers for steam generation in pulp and paper mills can also be burned by biomass. Biomass can be produced internally with the bark and other wood wastes, sludge from waste water treatment plants and spent cooking liquors.[52]

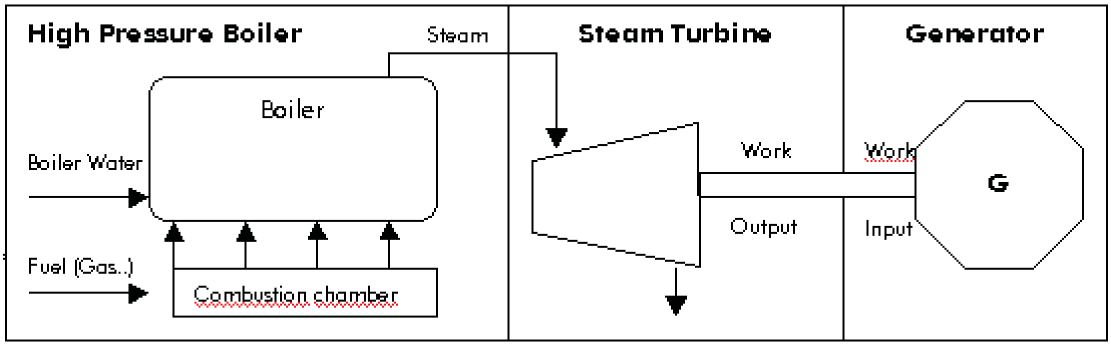

Fig. 15: Cogeneration plant

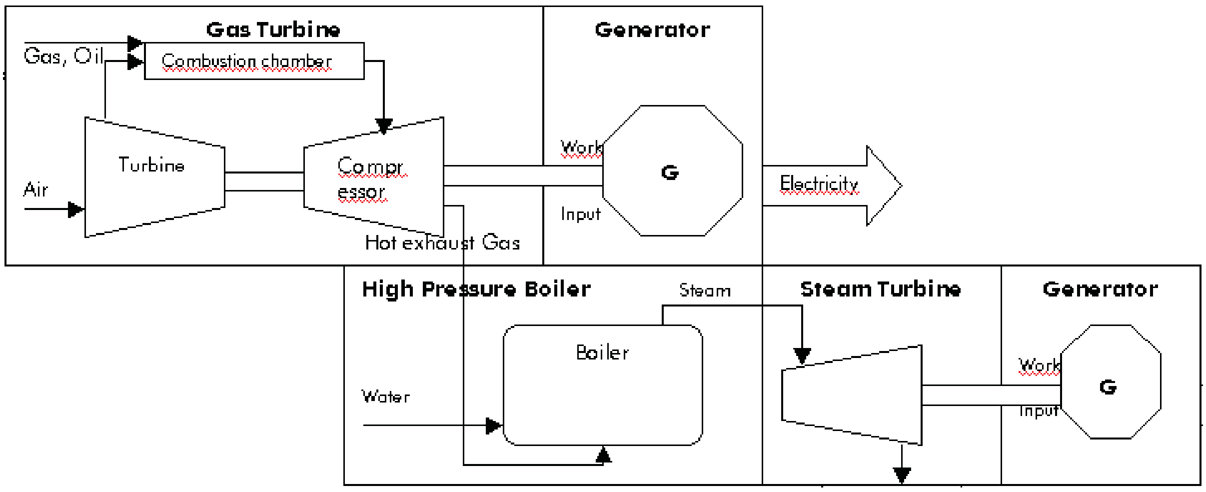

Fig. 16: CHP-Plant

52 Paprican (1999): p. 175

2.6 The principle of a paper machine

In the paper machine the paper is formed and most of the properties of the paper are determined. The paper machine is actually a large de-watering device consisting of a head box, a wire section, press section and dryer section. In our case we also defined the stock preparation as a part of the paper machine. In the literature the stock preparation is normally explained separately but the paper machine could not work without the stock preparation, so we decided to combine it with the paper machine.

Now the important parts of the paper machine will be explained. The explanation is based on a technical view.

Within the paper production we distinguish different unit operations:

2.6.1 Stock Preparation

Stock preparation is conducted to convert raw stock into finished stock (furnish) for the paper machine. The pulp is prepared for the paper machine including the blending of different pulps, dilution and the addition of chemicals. The raw stocks used are the various types of chemical pulp, mechanical pulp, and recovered paper and their mixtures. The quality of the finished stock essentially determines the properties of the paper produced (see Fig. 17). Primary fibre is a virgin fibre, so used for the first time in the form of a raw stock. All fibres recovered from de-inked and recycled papers are called secondary fibres.

Depending on the tree we differ between long fibres and short fibres. Each of them has special applications. The long fibres are a product of softwood. They enhance the resistance of the paper. Hard wood contains short fibres, which have many advantages in paper production like building up specific volume, opacity, softness and smoothness.

Note: Using only short fibres would decrease the resistance values, so a mixture of both types of fibres is common. The figure shows the three main indicators affecting the quality:

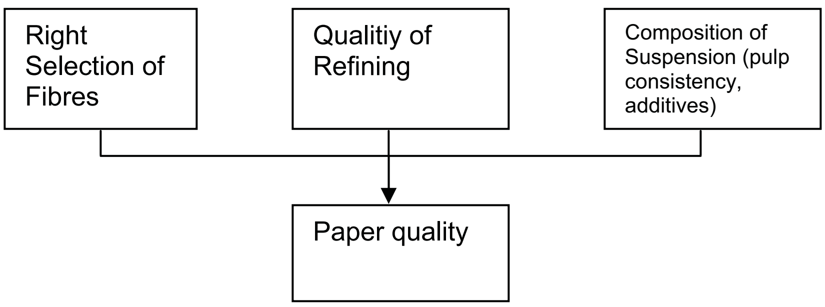

Fig. 17: Indicators for paper quality[53]

[53] cp. Papiertechnisches Seminar/ Stoffaufbereitung (2005): p.3

Choosing the indicators correctly will have positive effects on the attributes of the paper. These can be the physical or the optical attributes:

Physical attributes: resistance, thickness of paper…

Optical attributes: surface structure, formation, opacity…[54]

Raw Stock

Raw stock is available in the form of bales, loose material, or as suspension in case of integrated mills. Stock preparation consists of several process steps that are adapted to one another as fibre disintegration, cleaning, fibre modification and storage and mixing. These systems differ considerably depending on the raw stock used and on the quality of furnish required. For instance, in the case of pulp being pumped directly from the pulp mill, the slushing and deflaking stages are omitted.

Stock preparation is based on the removal of impurities, the conditioning of the strength properties of the fibres (refining) and the addition of chemicals to aid the process and affect the final quality of the paper sheet (resins, wet strength agents, colours, fillers). [55]

In non-integrated mills the fibres are received as dry pulp bales. They are hackled in a pulper to create a suspension that can be pumped. Then un-dissolved impurities are removed from the slurry by screens and cleaners. The cleaned suspension is settled in a tank and will then be milled in a refiner before it will be injected on the paper machine (see Fig. 18).

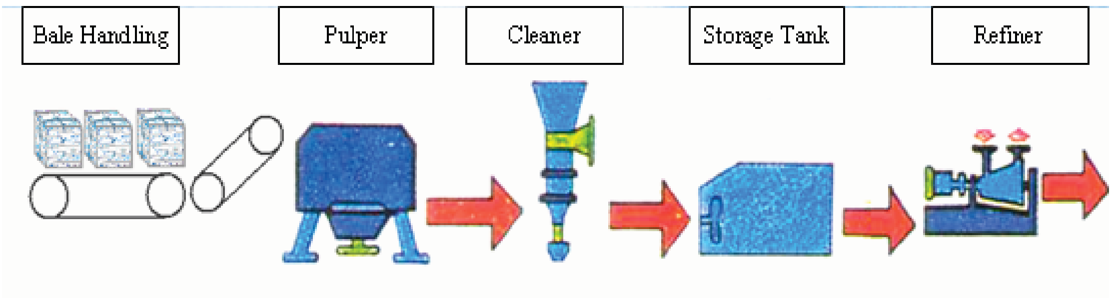

Fig. 18: Stock preperation[56]

The objective of screening is to remove interfering substances from the fibres. The fibre suspension is passed through a screen with apertures in the form of slots or round holes, and the impurities to be separated are rejected by the screen (see Fig. 19).

Cleaning is the separation of impurities from the fibre suspension in a centrifugal field. It is carried out in centrifugal cleaners (see Fig. 19). A distinction is made between heavy-particle and light-particle cleaners, depending on the purpose of separation. Heavy-particle cleaners have a wider diameter, so the velocity inside the cleaner is not that high and bigger particles can escape at the bottom. Most cleaners are multistage systems with up to five stages.

[54] Papiertechnisches Seminar/ Stoffaufbereitung (2005): p. 3
[55] IPPC (2000): p. 313
[56] Neusiedler Company Präsentation (2004)

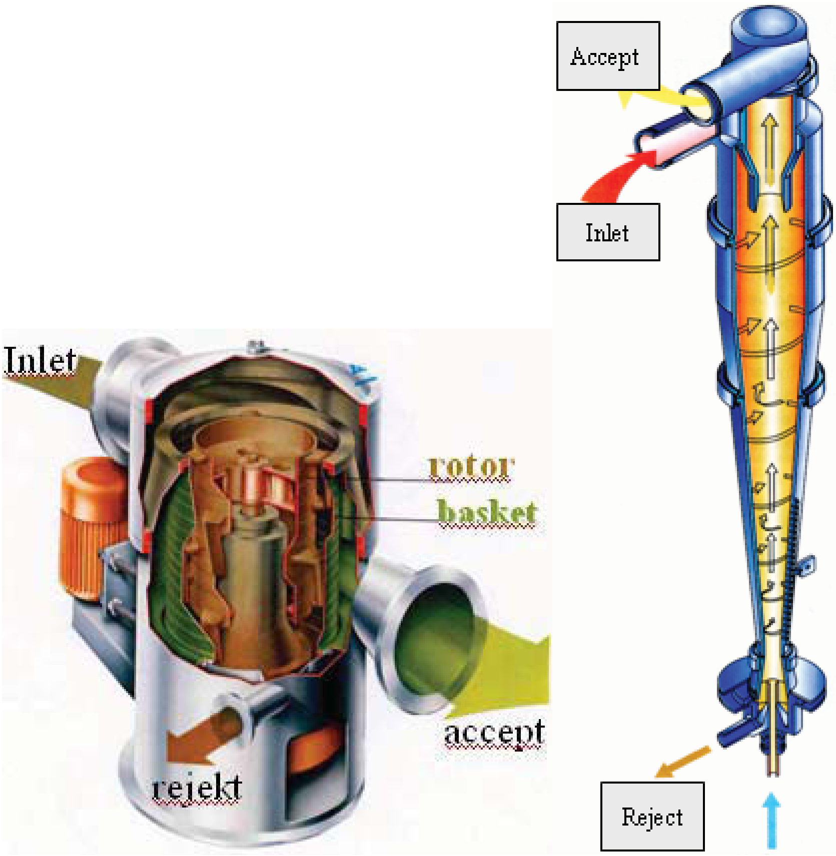

Fig. 19: Screen, Centrifugal Cleaner[57]

To improve the bonding ability of the individual fibres of the finished paper refining will be carried out. The refining has the purpose of conditioning the fibres to create the required properties of the finished product. Refining is carried out in conical refiners (see Fig. 20) or disc type refiners; those are equipped with a rotating disk that is pressed on a stator.

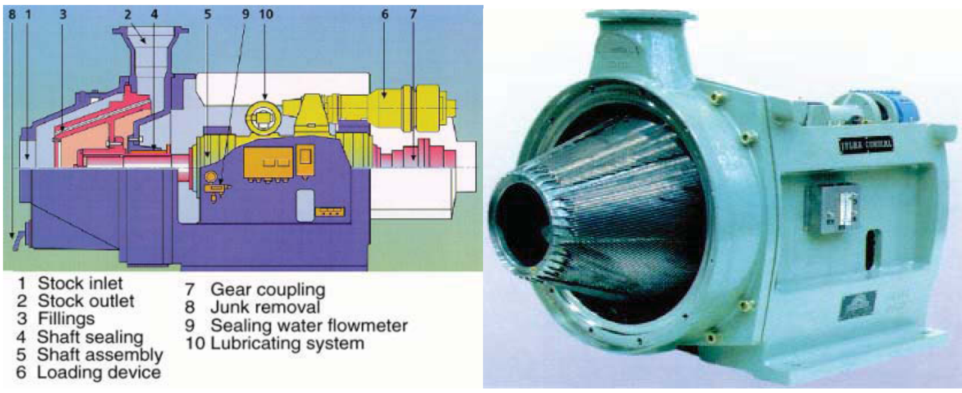

Fig. 20: Conical refiner

Sometimes stock preparation for a paper machine consists of several fibre lines, so in each line different raw stocks can be prepared.

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[57] Neusiedler Company Präsentation (2004)

Finally, the pulp is pumped to the storage chests or mixing chests (see Fig. 21). These chests serve as a buffer between the stock preparation and the actual paper machine, to promote process continuity. In the mixing chests, prepared stocks are mixed in proportions appropriate for producing a particular grade of paper, the required additives are added and the correct fibre consistency is adjusted.

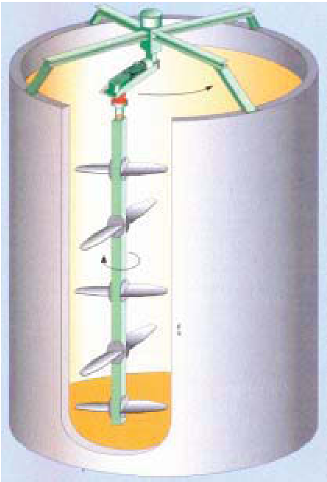


Fig. 21 storage chest

Broke system

The term "broke" refers to any formed paper from the beginning of the papermaking process to the finished product that is never shipped to the customer. Broke will exist in many forms and varying quantities and it will always be generated by the papermaking process.

The main goal of a broke system is to return the paper fibre back to the process with no disruption to the uniformity and quality of the stock flowing to the paper machine.

The amount of broke produced during papermaking is normally 5 - 20 % of the machine capacity. Wet broke is generated even during normal operation in the form of edge trimming at the wire section, and dry broke is produced in finishing operations.[58]

The broke pulps originating from the wet and dry ends of the paper machine are not identical in terms of their papermaking characteristics and so they have to be handled a bit different (Fig. 22).

58 IPPC (2000): p. 318

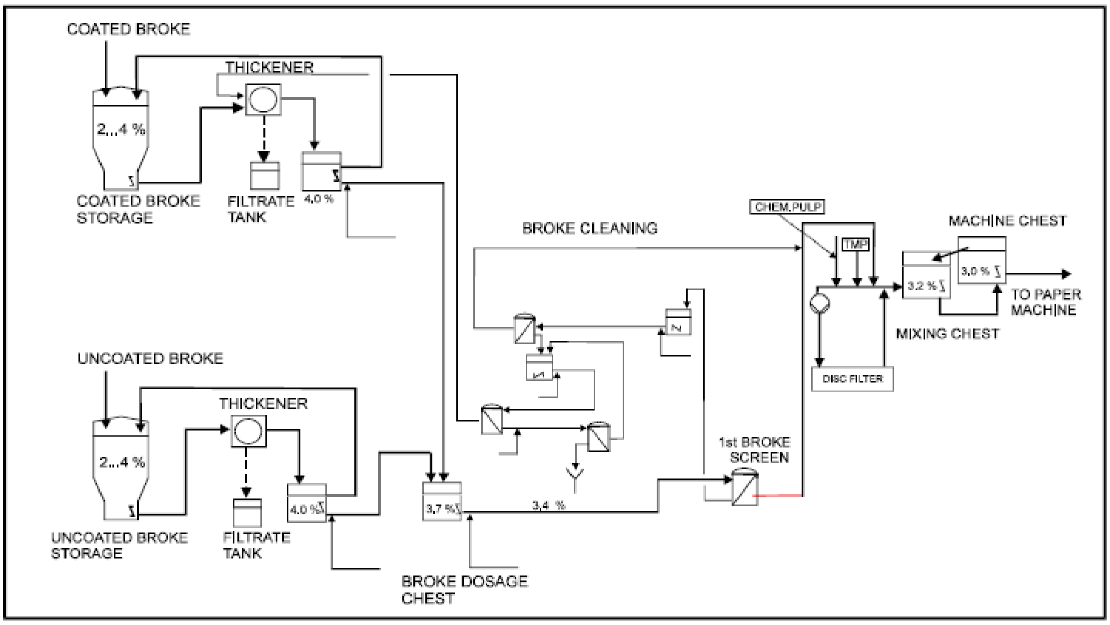


Fig. 22: Possible lay out of a broke system of a paper mill manufacturing coated paper. Uncoated and coated broke are stored in separate tanks[59]

Broke pulp is pumped from the storage towers to the thickeners where excess water is removed. Thicker broke is fed to the broke dosage chest, where the coated and uncoated broke are mixed together. After the broke dosage chest the broke is cleaned in several stages to minimise the waste broke which can not be re-circulated to the process. The cleaned broke is discharged to the main line mixing chest, from where the final papermaking furnish is pumped through additional cleaning to the paper machine. Finally the pulp is pumped to the storage chests or mixing chests.

Water circuits and fibre recovery

There are three process water circuits in a paper mill: the primary circuit, the secondary circuit, and the tertiary circuit. A scheme of the water circuits in a paper mill is shown in Fig. 23.

[59] source IPPC (2000): p. 353

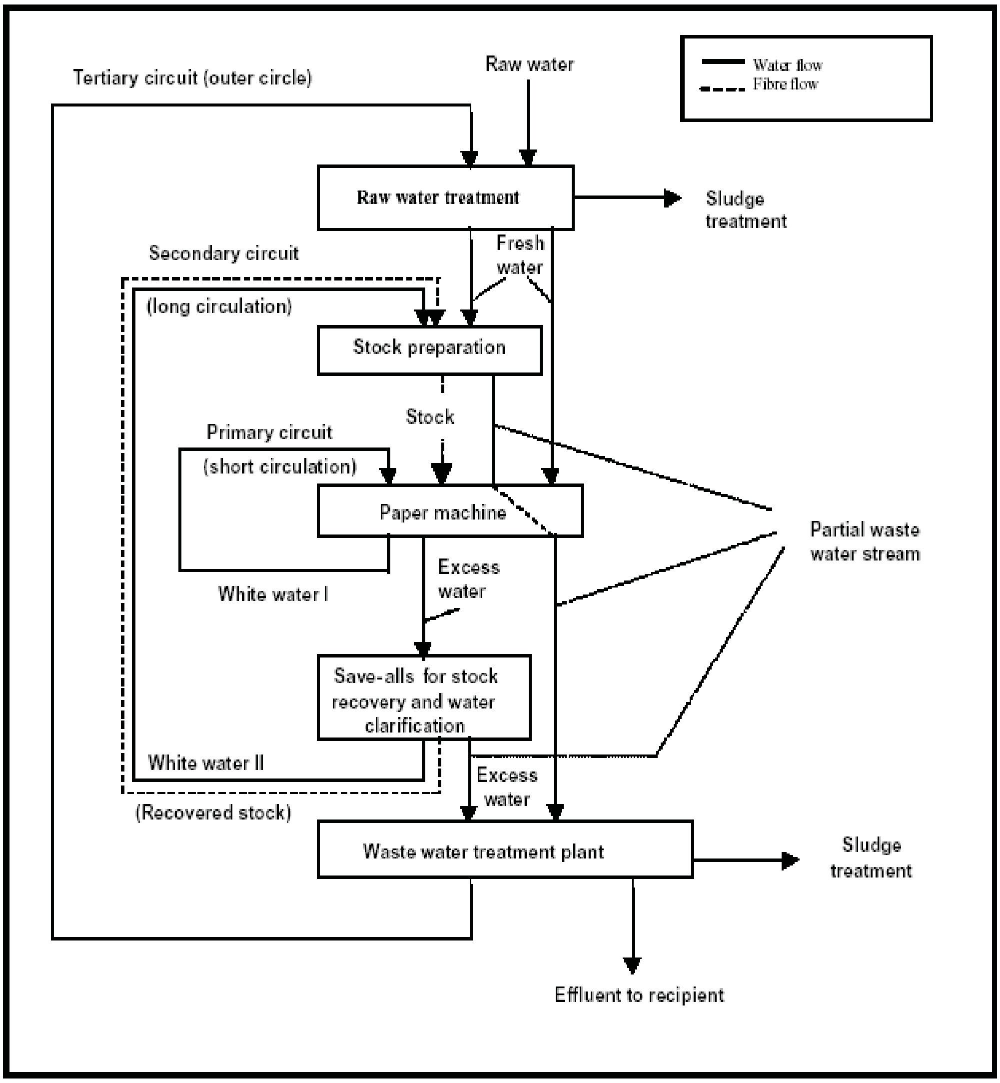


Fig. 23: Water and stock streams in a paper mill[60]

In the primary circuit (short circulation), the fibre, fines and filler-rich water obtained in the sheet-forming zone of the wire section (white water I) is recycled for stock dilution in the stock approach flow system. The primary circuit is maintained as closed as possible.

Excess water from the sheet-forming section, suction and press water, as well as cleaning water are called white water II and are circulated in the secondary circuit (long circulation). The white water draining from the wire is typically treated through a so called save-all. There are three possibilities how this water can be treated:

- Sedimentation plant
- Flotation plant or a
- Filtration unit as a drum or disc filter

This water is then called clarified water.

[60] source IPPC (2000): p. 351

At optimum conditions, the efficiency of flotation systems for solids removal is often almost 100% resulting in concentration of suspended solids of 10-50 mg/l (for virgin pulp). The consistency of the floated sludge is between 3 and 10%.

Flotation plants consist of a clarifying basin with sludge removal, aeration equipment for a partial stream of clarified water, and a dosing plant for the flotation chemicals. The advantage of flotation is that small-size colloidal material also can be removed.

The fibre stream that is recovered in save-alls is returned to the stock chest and the different quality waters are returned to different use relevant to their quality where it replaces fresh water.[61]

[61] IPPC (2000): p. 317, 318

2.6.2 Constant Section

The area between the mixing chest and the head box is called constant. The suspension will be cleaned.

High-speed paper machines require primary and secondary fan pumps. The primary fan pump supplies the primary cleaners; the secondary fan pump supplies the head-box. As with any pump, power consumption is a function of head and flow rate. Because fan pumps require large drive-motors, it is important that they are initially selected to operate in a high-efficiency range.

A deculator is important to remove free and bound air or small bubbles of air out of the suspension to improve sheet quality and machine run ability. It does this by exposing the stock to a vacuum close to the boiling point, and then spraying it through nozzles onto the solid surface of the vacuum chamber roof. The nozzle is designed to maximize the surface area of the droplets so as to break down fibre bundles and release gas bubbles. Vacuum pumps are generally required to remove air and non-condensed gases (NCG´s).

Then the suspension passes a screening system to reduce fibre loss. For printing and writing grades, there is a trend towards thin-stock slotted screening. Narrow slots reduce the hydraulic capacity of a screen, leading to increased screen size and power consumption. In addition, more stages of pressure screening are used in an effort to reduce fibre loss, further increasing power consumption and capital cost.

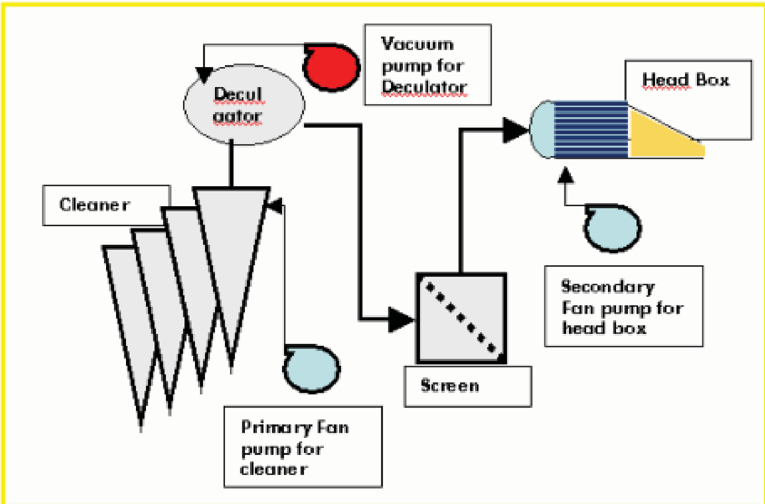


Fig. 24 constant section

2.6.3 Wire Section

The head box spreads the pulp in a homogeneous way over the whole screen (see Fig. 25). Under pressure the suspension flows on a single or between two infinite rotating wires. The system brings turbulence in the suspension which affects the quality of the sheet formation. With increasing speed of the PM the amount of suspension in the head box increases as well.

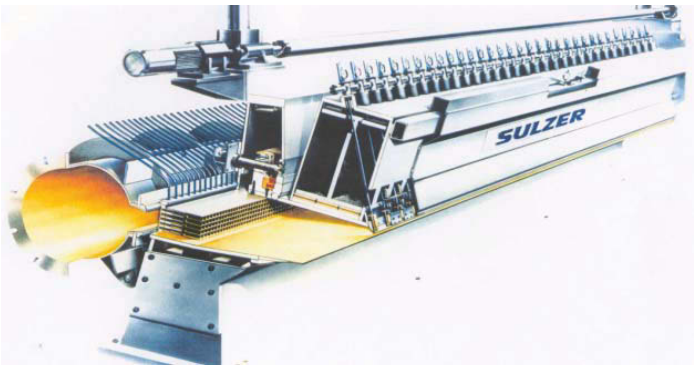


Fig. 25: Hydraulic head box[62]

We differ between three different types of machine configuration:

- Fourdrinier machine
- Gap former
- Hybrid former

On a Fourdrinier machine the sheet is formed onto a continuous screen onto which the suspension of fibres is introduced from the head box. The screen is a very fine felt where the fibres of the high diluted suspension will settle down while the white water will be rejected. The first roll in the wire section is the breast roll, followed by the forming board, foil boxes, low vacuum box, wet box, vacuum flat box and a couch roll, which powers the wire together with a wire turning roll (Fig. 26). The dewatering of the suspension and the felt is either done by gravity, which is regulated and enhanced by the foils, or vacuum.

Sometimes an Egoutteur is installed to enhance opacity on one side and to produce watermarking on the other side. The consistency of the sheet at the end of the forming section is about 20 % ds.

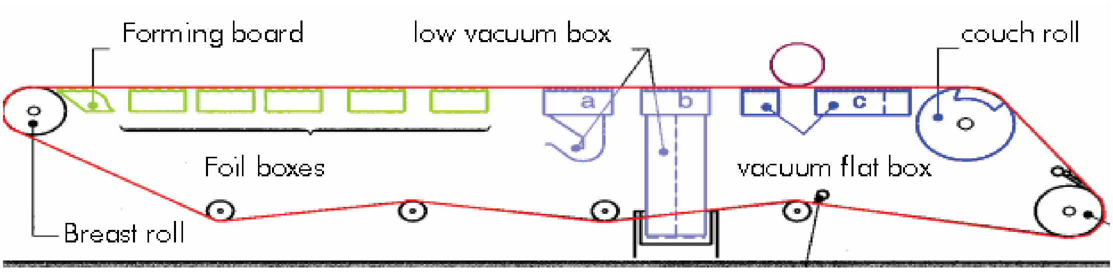


Fig. 26: Fourdrinier configuration[63]

[62] cp. Neusiedler Company Presentation (2004)
[63] Neusiedler company presentation (2004)

Recently twin wire formers have been used for the web formation and they have become state of the art design. In twin wire formers, the fibre suspension is led between two wires operating at the same speed. The suspension is drained at one side or at top and bottom side. This enables a similar surface structure on both sides. There are different types of twin wire formers:

A so called Gap former (see Fig. 27) will be mainly used for the production of office paper with high production speed.

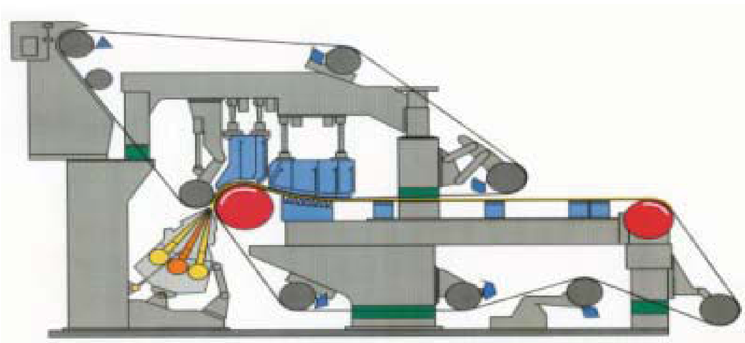


Fig. 27 Gap former[64]

Hybrid former are a combination of a Gap Former and a Fourdrinier machine. First the suspension is put on a single wire for a few meters and then a second wire will be placed. So we again have the effect of dewatering on top and on bottom. This increases the capacity of dewatering and the quality of the paper.

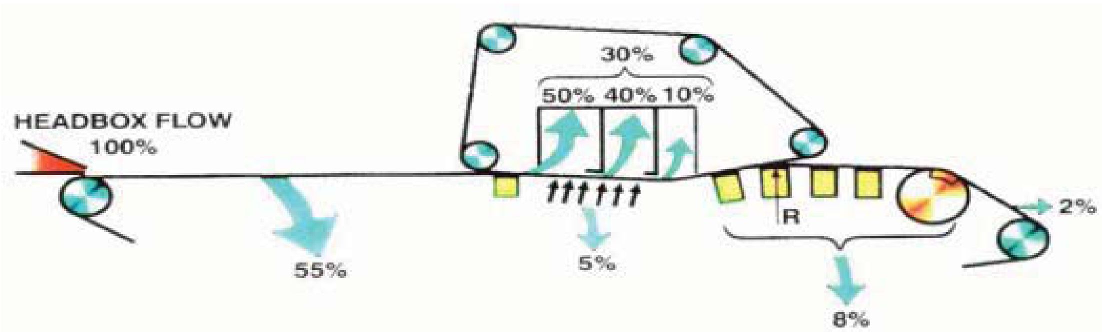


Fig. 28 Hybrid former[65]

[64] Neusiedler company presentation (2004)
[65] Neusiedler company presentation (2004)

Shower water system

During dewatering of the suspension, small fibres and additives remain in the wire. The cleaning of the wire is done by high pressure shower (20-40 bars) with needle-jet-nozzles. This should release the fibres and the stickies. Those will then be hosed down by flat-jet-nozzles (1-3 bars).

To remove the paper from the wire in case of a break, a shower is used, which injects the water in between the wire and the reverse roll. Because of the hydraulic pressure the paper falls directly into the couch pulper.

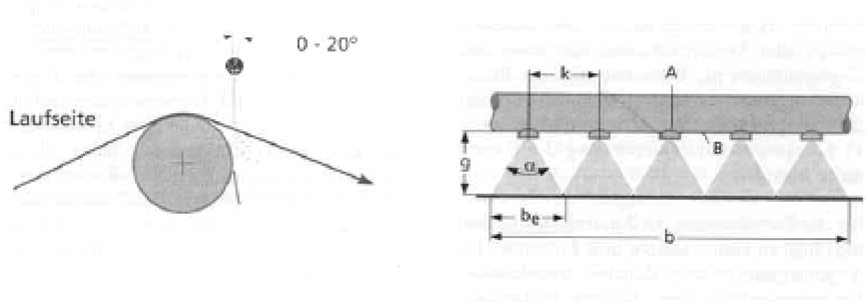


Fig. 29 needle jet nozzle and flat jet nozzles

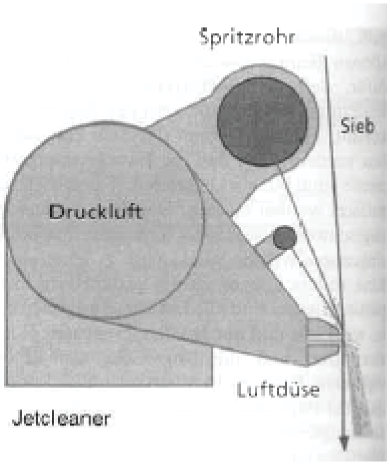


Fig. 30 Jetcleaner[66]

[66] Bos (1999): p. 254

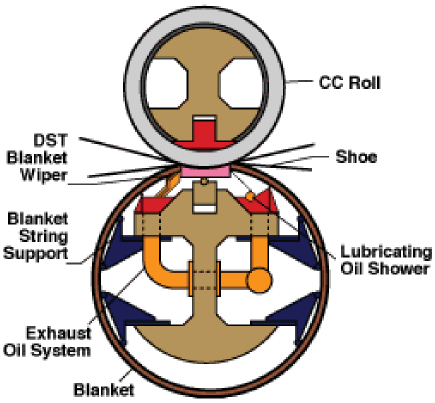
2.6.4 Press Section

At the press section the paper web together with the felt is pressed between hydraulic rolls. The water is absorbed by the felt because of the pressure between the press nips. This water is saved for a short time and then rejected.

The discharge of the water is done with the help of vacuum at so called suction presses, or mechanically with an extended nip press or shoe press (see Fig. 31). Depending on grade of paper, type of press section and speed, the stock consistency is increased to 40 – 52 % ds.

Shoe press

The dewatering ability has been improved. It differs from former roll presses, by substituting a wide nip for the lower roll of the shoe press and applying longer nip residence time. At the beginning, shoe presses were used for the production of paperboard grades, e.g., corrugated paper, but in recent years it has been widely used for paper grades, e.g., newspaper. Also, owing to the improvement of the closed type shoe press, the scattering of lubrication oil has been prevented and the shoe press can be used in the upper part of the roll, too.[67]



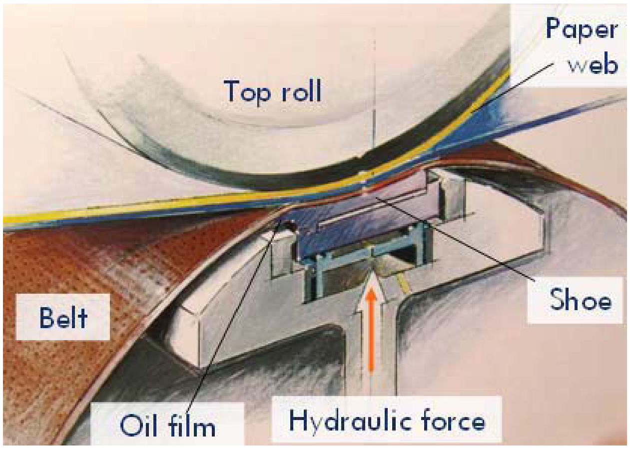


Fig. 31: Extended nip press or shoe press[68]

There are some other advantages of the shoe press in comparison to the suction press:

- more gentle dewatering because of long dwell time
- higher dewatering at a low specific pressure
- Low compression of the web.

This results in an increase in stock consistency of 5 to 8 % ds, which means that 25 to 40 % of steam can be saved in the drying section. A one percent absolute increase in dryness into the dryer section reduces its steam consumption by 4 to 5%. Existing press section performance can be enhanced by proper use of felt conditioning and steam showers.

[67] http://www.felt.co.jp/line_e/shoe.html
[68] source Neusiedler Presentation (2004)

2.6.5 Drying Section

By the time the sheet has left the press section the percentage of dry solids has reached the amount of 45 – 55%. The remaining imbibed water must be removed by evaporation. This is done by combined heat and mass transfer. Heat can be transferred to the sheet by conduction in steam-heated cylinder drying, convection and radiation in infrared (IR) drying.

Cylinder (Conduction) drying

The most widely used method for drying paper and board remains the use of steam-heated drying cylinders. The conventional drying process occurs in three phases.

In the warm-up zone, the sheet temperature is raised to the evaporation temperature of water, typically 80 to 90 °C. The rate at which this temperature is achieved is primarily dependent on the steam temperature used in the initial drying cylinders.

The constant drying rate zone represents the equilibrium condition where evaporation occurs at a constant sheet temperature. This zone is characterized by removal, primarily, of imbibed water. Heat transfer occurs at the dryer cylinder surface/web interface while the mass transfer of water vapour occurs primarily in the open draws between dryers.

The falling rate zone occurs once the sheet has reached about 85% dryness. The change is caused by the transition from removing water held by capillary forces near the surface of the sheet to water near the middle of the sheet, and the reduced diffusion rate of the water vapour to the surface. The zone is characterized by an increase in average sheet temperature and a lower drying rate.

Convection Drying

In convection drying, heat is transferred to the sheet by convection and driven by the temperature difference between the hot air and the sheet.

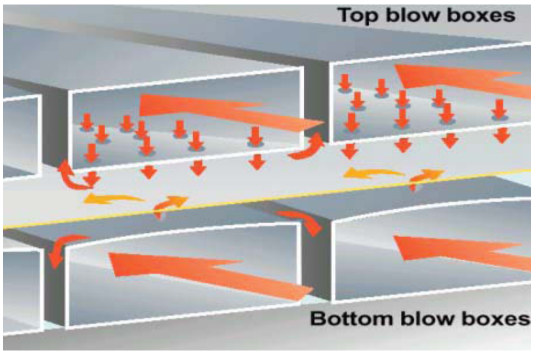


Fig. 32: Principle of blow boxes[69]

Infrared Drying (IR Drying)

In IR drying, heat is transferred in two ways, either by radiant heaters or by flames. Those two techniques need different energy sources. The radiant heaters are powered by electricity and the flames need gas to burn. Normally IR drying is an additional method to reach a higher rate in stock consistency and so it is often situated after the lime press or the surface application. [70]

Condensate Removal

Steam is fed to the dryer cylinder through a rotary joint in the dryer journal. Inside the shell, the steam condenses as it makes contact with the inside surface of the dryer and the developing layer of the condensate. A siphon removes the condensate. The next figure shows the three different types of siphons existing on the market.

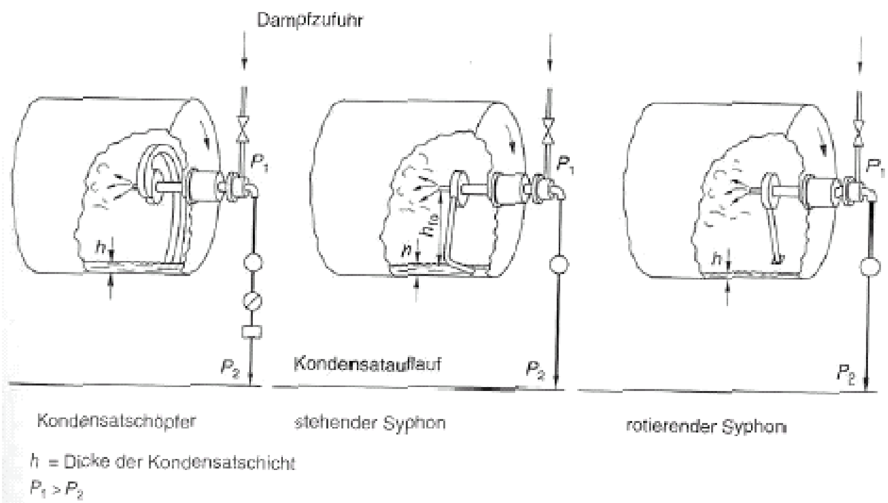


Fig. 33 Condensate removal[71]

[69] source Neusiedler Presentation (2004)
[70] Paprican (1999): p. 128 ff.
[71] source Bos (1999): p. 280

Rotary siphons allow a mixture of steam and condensate to flow up the pipe as a lighter two-phase mixture, at a lower differential pressure than that required to lift a solid column of condensate. The differential pressure required to force condensate up a rotary siphon pipe increases exponentially with dryer speed. Above 1000 m/min, stationary siphons are more common because they require much less differential pressure.

Dryer Hoods and Heat recovery

For economic reasons, all paper mills have installed heat recovery systems.
Typical applications are using either air-to-air heat exchangers or air-to-water heat exchangers both of plate design (some applications use also scrubbers). The former is mainly used for heating hood supply air and machine room ventilation air. The most common application for the latter is the heating of circulation water and process water respectively.

Fig. 34 shows a schematic picture of the drying and heat recovery section of a paper machine. In the first heat exchanger of the heat recovery system heat is recovered to incoming supply air. The next heat exchanger is for the heating of incoming fresh water. In some cases heat is also recovered to wire pit water to compensate for the heat losses in the wet end. The last heat exchanger is for circulation water. The circulation water is used to heat the incoming ventilation air. The supply air and shower water are heated to their final temperatures (90 – 95 °C and 45 - 60 °C respectively) using steam.

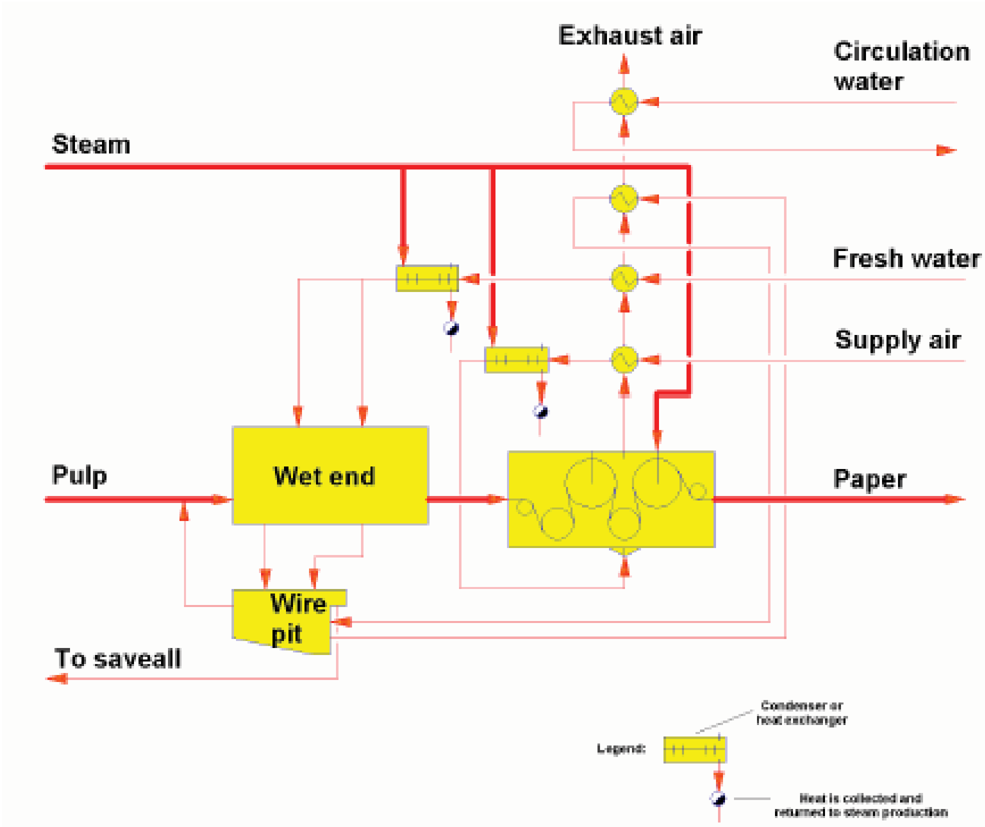


Fig. 34: Paper machine heat recovery system

Table 2 shows an example of heat flows in a typical large and modern paper machine. The production capacity of the machine is 240.120 t/a (667 t/d). The dry content of web entering dryer section is 44.5% and that of product 91%. The temperature of exhaust air is 82 °C and humidity 160 $g_{H_2O}/kg_{dry\ air}$. The values are for Scandinavian winter conditions. In warm climate the share of circulation water decreases or disappears and the exhaust to atmosphere correspondingly increases.[72]

Table 2: Example for heat recovery and heat losses of a paper machine with a production of 667 t/d[73]
Values are referring to Scandinavian winter conditions. In countries with warmer climate there is no need for heating of circulation water that is used for machine room heating

Locations for heat recovery	Destination of heat flow from the drying section [MW] and [MJ/t]	Distribution of heat [%]
Supply air	1.8 MW or 233 MJ/t	6
Wire pit water	3.6 MW or 466 MJ/t	11
Fresh water	5,5 MW or 712 MJ/t	19
Circulation water	8.0 MW or 1036 MJ/t	27
Exhaust to atmosphere	10.8 MW or 1399 MJ/t	37
Total (Exhaust air from hood)	29.7 MW or 3847 MJ/t	100

Sizing and starch station

Usually the drying section is divided in a pre- and an after drying section. Between those sections normally a size press or other surface applications are installed.

A size press is a section of the machine where starch and other chemicals are applied to the surface of the paper by dipping or spraying, with residual water being removed in a short after drying-section. Surface sizing has positive effects on inkjet suitability, surface strength, surface resistance and toner fixing. Two methods are common, a film press or a conventional press. The difference results in changes of lime consumption.

At the film press only a thin starch film is spread on the rolls (see Fig. 35).

At the conventional press the paper wire passes a lime bath. This has the disadvantage that the papers drying content is much lower than after of a film press.

72 IPPC (2000): p. 315 f.
73 cp. www.metsopaper.com

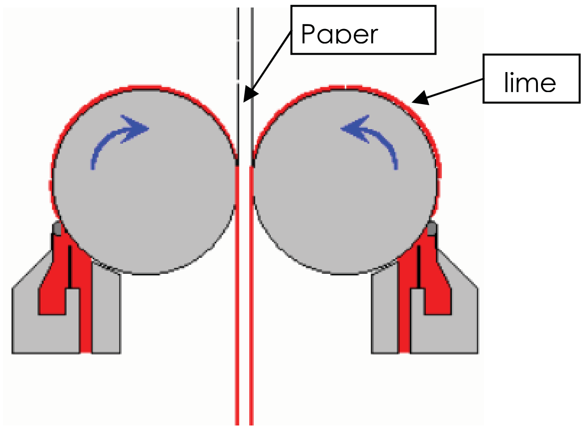


Fig. 35: Film press

Higher machine speeds and fewer breaks are possible with a film press; drying requires less energy because the applied size has higher solids content. Using a film press results in a reduced steam consumption of 10 % compared to a conventional press. The final papers consistency got to be a minimum of 95% ds.

Calendering

After the paper has crossed the drying section but before it is reeled it passes the calender. The objective of calendering is to produce a smooth paper surface that meets the printing and writing requirements for the intended use. In calendering, the web is fed through counteracting press rolls and in this process the surface roughness is influenced by the action of pressure and very often temperature. A machine calender consists of two or more chilled cast-iron rolls with very smooth surfaces that are arranged one on top of the other as shown in Fig. 36.

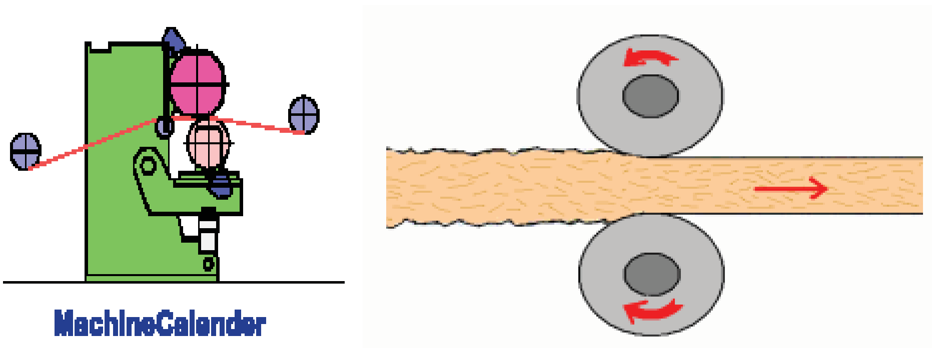


Fig. 36: Example of a machine calender[74]

The web is passed through the nips of these rolls (hard nips). Nowadays, calenders have a heated cast-iron roll combined with a roll with a soft plastic cover (soft nip). Two or more of these are arranged one behind the other. The rolls are heated internally with hot water, steam or heating oil.

The environmental impact of "super-calendering" is mainly the energy consumption needed for running the machine and heating the rolls.[75]

[74] www.metsopaper.com

Super calenders are mostly used offline – this means that the paper is already reeled from the paper machine and now injected into this calender.

Finally the paper will be rolled up on the so called pope-roller. Now a final consistency of about 90 – 95 % ds is reached.

In the following table some production data of the paper machines 5 & 6 in Hausmenning is given.

Table 3: Production data paper machines[76]

	Unit	PM5	PM6
Paper width	[m]	4,4	4,4
Paper speed	[m/min]	700	1.200
Yearly production	[t/y]	95.000	180.000
Daily production	[t/d]	300	500
Daily pulp used	[t/d]	235	390

[75] IPPC (2000): p. 322 f.
[76] cp. Neusiedler Paperstreet (2003)

2.7 Energy considerations mill and machine

The first step towards improving energy efficiency is to understand where energy is being consumed in the mill.

All mills should be able to produce a detailed "budget" of where energy is being "spent". The next step is to understand how energy consumption in one process area of the mill affects other areas. Many mills do not know how their energy is being allocated, or they implement an energy saving project in one area only to lose some or all of the saving in another area. For this reason it is important to detect energy insufficient production processes.

2.7.1 Energy demand

The annual primary energy consumption of the pulp and paper industry worldwide is estimated at 8 EJ (1990), of which 2.3 EJ are non-conventional energy, i.e. from wood waste and pulping chemicals.[77]

The pulp and paper industry is the fourth largest consumer of primary conventional energy in the industrial sector worldwide; its share of industrial energy consumption is about 4 %.[78] On the basis of the average specific energy consumption (SEC) per paper grade and a distribution of world paper production over paper grades, the global primary energy consumption of paper making excluding pulp making is estimated to be about 3,1 EJ[79] (see Table 4).

Table 4: Ranges in SEC_h and SEC_e and average values for SECs based on primary energy carriers[80]

Type of paper	SEC_h (GJ/mt of paper)	SEC_e (GJ/mt of paper)	Average SEC (GJ primary per mt of paper)[1]	Global production in 1992 (mt)	Estimated global primary energy consumption (EJ)
Newsprint	2,3-8,6	1,3-2,9	8,7	32	0,3
Printing(writing	2,9-8,6	1,9-3,2	15,4	71,4	1,1
Sanitary	2,6-7,0	2,4-3,6	16,9	14,5	0,2
Packaging	2,3-7,7	1,3-2,9	12,1	106,3	1,3
Other paper	5,0-7,0	1,3-1,8	9,5	21,3	0,2
TOTAL				245,4	3,1

[1] Assuming all heat is generated in boilers with an efficiency of 90%, and all electricity is generated in power plants with an efficiency of 33% [WEC, 1995]. The average SEC is based on the authors own judgement and includes production of heat and electricity from non-conventional fuels, like wood and chemicals.

[77] Farla et al., (1997): p. 25
[78] WEC (1995)
[79] Beer (1998): p. 77
[80] Nilsson (1996)

Table 5 shows the energy consumption of the different grades of paper but already split into heat and electricity energy. The high energy requirement for coated and surface-sized paper reflects the need to remove water from both the base sheet and the coating.

Table 5: Range of energy consumption by grade[81]

Paper Grade	Steam consumption	Gas consumption	Typical electrical consumption	
	(GJ/t)	(GJ/t)	(GJ/t)	(kWh/t)
Newsprint	3,4 – 5,5	-	1,2 – 2,3	420 – 630
Coated groundwood	5,1 – 5,6	-	2,0 – 2,9	550 – 820
Uncoated woodfree	4,3 – 7,2	-	2,0 – 2,4	550-670
Coated woodfree	3,7 – 7,7	-	1,6 – 3,2	440-900
Linerboard	3,4 – 8,8	-	1,8 – 2,4	515-660
Tissue	2,6 – 4,5	2,0 – 2,4	3,0 – 3,8	835-1050

You can see the values changed a little bit compared to the table above. This is due to the fact that this table is from another reference. As well the table covers the papermaking process from stock preparation to finishing, but never the less there are discrepancies.

This is a good example to show that we always talk within a range of values and not of one true value. That's why it makes it difficult to benchmark paper mills on its total energy consumption.

The SEC of the paper-making process is hardly affected by whether the paper mill is integrated or not. The SEC is affected by the type of energy carrier (e.g. wood chips or natural gas) and the method of energy generation (e.g. black liquor recovery boiler or cogeneration plant). The specific heat consumption (SEC_h) and specific electricity consumption (SEC_e) differ considerably per type of paper, and even for one type of paper the range can be large.[82]

Wood for pulping represents the largest cost among material inputs to the pulp and paper industry, accounting for an average of 21% of total material and energy costs. The corresponding numbers for energy, wood pulp, and chemicals are 17%, 15% and 6%, respectively. It should be noted, however, that the industry uses about twice as much energy as indicated by these numbers since over half of total fuel and electricity use is self-generated (primarily from spent pulping liquors, wood residues, and bark) and thus does not appear in data on purchased energy costs.[83]

Energy is the third highest cost in the papermaking process, accounting for approximately 8% of turnover. This is inconsistent with the fact that less is published on specific energy requirement on process level than on water management for instance. Therefore, it is rather difficult to find qualified information on energy consumption related to different paper grades and product qualities, energy efficient technologies, and energy practices and usage within the European Paper Industry.

[81] Beer De (1998)
[82] Beer De (1998): p. 77
[83] Nilsson (1996)

The total demand for energy (consumption) in the form of heat (steam) and electric power for a non-integrated fine paper mill has been reported to consume:

Process heat: 8 GJ/t (2.222 kWh/t)
Electricity: 674 kWh/t.[84]

This means a consumption of 3 MWh electricity and steam/tonne product. When considering the primary energy demand for converting fossil fuels into power a total amount of 4 MWh/t of paper is needed.

The electricity consumption depends to a certain extent on the paper grade produced. The lowest values correspond to packaging paper or corrugated base paper that consumes about 500 kWh/t, whereas printing and writing paper account for about 700 - 800 kWh/t. The highest power demand, up to 5600 kWh/adt, is needed for some special paper grades. The power is mainly consumed by more intensive refining. More detailed information on electricity consumption is given further below.[85]

2.7.2 Electricity

Electric power in paper industry is mainly consumed for the operation of various motor drives and refining in stock preparation. The motors are used for running fans, pumps, compressors, stirrers, paper machines, presses, vacuum systems, various conveyors, etc.

Machine absolute operating efficiency

Within a given grade, there are large differences in energy utilization between machines. The absolute operating efficiency of the production line, which can range from the low 70s to low 90s, is a major contributor to these differences. The energy used to produce off-quality paper is the same as for sealable paper. The operating cost per tonne for a low-efficiency mill is therefore higher than for an efficient one and usually results from a combination of operating and quality issues[86] (see Table 6).

Table 6: Influence of machine efficiency on energy consumption[87]

Category of efficiency loss	Effect on energy efficiency
Frequent sheet breaks and long threading time	Recirculation of stock Pumps, fans, vacuum systems and machine drives in operation without production Steam venting Heat loss from white-water overflow
Frequent maintenance downtime – planned and unplanned	Long start-up times Large quantities of rejected production at start-up overloading the broke system Increased steam consumption to reach thermal equilibrium
High quantities of off-grade product	Excessive broke handling Countermeasures such as over-drying Roll rewinding

84 SEPA-report 4712-4 (1997)
85 IPPC (2000): p. 338
86 Paprican (1999): p. 120
87 cp. Paprican (1999): p. 120

In the following the consumption of electricity in paper mills is discussed in more detail to illuminate the technical background that builds the basis for improvements and the application of energy efficient technologies.

The total electrical energy consumption at paper mills is summarised in Table 7. All energy usage inside the paper mill starting from pulp storage towers (in integrated mills) ending at finishing operations is included in these figures. Non-integrated paper mills must have pulpers that increase specific power consumption a little (up to 60 kWh/t). Wastewater treatment is not included. It should be noted that the mill efficiency changes the figures. The lower the efficiency the higher the deviation from the dimensioning figures that refers to 100% efficiency.

The correction of the figures by the efficiency rate achieved plays a bigger role at old machines or multi-grade machines with a lot of grade changes.

Table 7: Typical electrical energy consumption at modern paper mills based on dimensioning capacity of paper machine [data from a supplier] [88]

Paper grade	Power consumption [kWh/t]
Newsprint	500 – 650
LWC paper	550 – 800
SC paper	550 – 700
Fine paper (uncoated)	500 – 650
Multiply board	≈ 680
Sack paper	≈ 850
Linerboard	≈ 550
Tissue	500 - 3000

All electric power inside the PM building is included and can be calculated from total electrical energy consumption divided by the dimensioning production of the machine

The total figures for power consumption of paper mills are composed of a number of energy consuming subsystems that are explained in the following.

Table 8: Typical specific energy consumption of the constant section[89]

Type of machine	Power consumption	Remarks
Fast machines (> 1300 m/min.)	80 – 120 kWh/t	Head box feed pump energy increases in the third power when PM speed increased
Slow machines	60 – 100 kWh/t	Slow machine may not have deaeration

Table 9: Typical specific energy consumption at the vacuum system (vacuum pumps) of the PM wire & press section[90]

Type of machine	Power consumption	Remarks
Fast machines (> 1300 m/min.)	70 – 110 kWh/t	Fast machines have bigger production; therefore specific power consumption is lower
Slower machines	80 – 120 kWh/t	

[88] source IPPC (2000): p. 341
[89] cp. IPPC (2001): p. 341
[90] cp. IPPC (2001): p. 341

Table 10: Typical specific energy consumption at the under machine pulpers of the PM broke system[91]

Position	Power consumption new machines	Power consumption old machines	Remarks
Couch pit	3 – 5 kWh/t	3 – 7 kWh/t	Older PMs (before the 90´s) typically had concrete vats or the tank shape was not optimised for slushing; technical development resulted in decrease of power consumption.
Wet broke - Press pulper	5 – 8 kWh/t	7 – 12 kWh/t	
Dry broke - dry end pulper	7 – 12 kWh/t	10 – 20 kWh/t	
Note: Under machines pulper are tanks under the PM where paper web is slushed with water. This pulper operates only during the web break			

Electricity demand - Broke system

For best energy efficiency, a machine making coated or sized grades should have separate wet- and dry-end broke surge tanks. After de-flaking, the broke are commonly combined before being screened in two stages with fine slotted screen baskets. The primary screen rejects are de-flaked in a second unit. Typically energy levels for de-flaking are 20 kWh/t (standard newsprint) and 40 kWh/t for light weight coated grades.[92]

In Hausmenning the finishing is done centralized for all paper. This means that the trimmings of the PM5 and PM6 will be handled together. It is important to consider this to allocate the energy use correctly.

Modern cleaners operate at different pressures of 100 kPa compared with 275 kPa for older designs, allowing for up to 65% reduction in pumping energy.[93]

Electricity demand - Refiner

For refining the electrical energy is primarily used to drive the rotor in the refiner. The energy usage varies by product with filter and blotting papers requiring least energy and tracing papers requiring the highest input. Typical power consumption is shown in Table 11.

Table 11: Typical specific energy consumption for new machines at the refiners per tonne of refined pulp[94]

Pulp grade	Power consumption
Long fibre (bleached)	100 – 200 kWh/t
Short fibre (bleached)	50 – 100 kWh/t
Long fibre (unbleached)	150 – 300 kWh/t
Short fibre (unbleached)	100 – 150 kWh/t

[91] cp. IPPC (2001): p. 341
[92] Paprican (1999): p. 124
[93] Paprican (1999): p. 122, 123
[94] cp. IPPC (2001): p. 342

Typical refining consistency is between 3.5 and 5%. The maximum energy input in a single refiner, depending on pulp type, varies between 30 and 100 kWh/t. If more than 100 kWh/t is needed, several refiners must be installed in series.[95]

The electrical energy used in refining as part of the papermaking process is usually in the range between 100 - 500 kWh/t for most papers but can be up to 3000 kWh/t for speciality papers. Thus for a non-integrated paper mill using chemical pulp, refining will represent the largest use of electrical energy (drying being the largest use of heat). Practically all of the energy input to this refining will be turned into heat and there is no option here for energy recovery although this heat generated contributes to the elevated temperature sought in the process.[96]

The potential for energy savings will be high in many cases. For example, many refiners are incorrectly sized or not well maintained and this results in a high no load power, which reduces refiner efficiency. Incorrect refiner fillings will cause an increased use of energy to achieve a given property. New refiners with enhanced efficiency can also save energy because of the very low no load power associated with this type of refiner.

[95] Paprican (1999): p. 122
[96] IPPC (2000): p. 313

Electricity demand – Stock Preperation

The PM6 in Hausmenning has three fibre lines. The top and the bottom line prepare the stock by short fibres. The middle line produces stock with long fibres. Originally this technique was created to use recycled paper in the middle line. This would mean that the top and bottom layer of the produced paper is of very good quality, as it consists of short fibre, and the intermediate layer is of minor quality. This should then result in a saving of expensive pulp and additionally save resources. The disadvantage of this technique lies in the fact that each fibre line does need its own refiners. So smaller but more refiners are used for the stock preparation at the PM6 and this results in a significantly higher electricity consumption for the stock preparation compared to the PM5.

Showing this example brings the difficulty of the energy benchmark. So it will be important to make some comments beside the values.

The stock preparation is a very energy intensive procedure. For the repulping, depending on the pulp type, 10 to 20 kWh/t of specific energy is applied. By slushing at 7% consistency instead of 4%, energy consumption can be halved or the production rate doubled.

Depending on the fibre type, deflaking requires 20 to 30 kWh/t at 4 to 5% consistency.[97]

Table 12: Typical specific energy consumption at the stock preparation and white water systems per tonne of paper (excluding refining, pulpers and approach flow system)[98]

Type of process	Power consumption	Remarks
White water system – fibre recovery	20 – 30 kWh/t	Water storage towers, chests, pumps
Broke system	40 – 60 kWh/t	Broke tower, broke screens, tanks, pumps
Mixing	10 – 15 kWh/t	Mixing chest, machine chest, pumps and agitators
Bale pulping (only for non-integrated mills)	25 – 40 kWh/t	Bale pulpers and conveyors, tanks and pumps
Pulp dosing (integrated)	5 – 10 kWh/t	Pulp line from storage to mixing chest; tanks, pumps
PM showers	5 - 10 kWh/t	PM showers water system consisting of pumps, filters, screens
Total electricity	70 – 120 kWh/t	Per tonne of product

[97] Paprican (1999): p. 121
[98] cp. IPPC (2001): p. 342

Electricity Demand – PM drive

Aside from the drive system, the primary energy requirements are for roll heating and calliper control. In soft calendering, up to 25% of the drive energy is converted to heat through roll deflection.[99]

Table 13: Typical specific energy consumption of PM drives

Type of process	Power consumption	Remarks
Paper machine drive	80 – 140 kWh/t	PM drives, former, press, dryer, sizer reel
Ventilation, PM	40 – 60 kWh/t	Hood air supply, hood air exhaust, air to runnability components, wet end ventilation, machine room ventilation, fans and pumps
Steam and condenser	5 – 10 kWh/t	Condensate and vacuum pumps
Lubrication & hydraulic pumps	15 – 40 kWh/t	Lubrication units and hydraulic pumps
Coaters	15 – 25 kWh/t	
Calender	100 – 120 kWh/t	
Winder	5 – 10 kWh/t	
Finishing	10 – 15 kWh/t	
Chemicals	5 – 50 kWh/t	Chemical mixers, feed pumps, screens

Nearly all electric power that is consumed is transferred to energy in form of mechanical work, and is finally transferred into heat. This heat may be useful in many cases, since the heat contributes in keeping the systems at required temperature levels.

Electric power consumption in many systems in a mill is quite constant and fairly independent of production levels, especially in mills where regulators are not extensively used. Low specific energy consumption may then be achieved by keeping an even and high production level. Amongst others, a minimum idle run of machines implies minimised electric power consumption.

[99] Smook G.A. (1989):

2.7.3 Heat (steam)

In the paper-making process heat is required mainly in the form of low-pressure steam. When heat and electricity are produced in a cogeneration plant, it is common to generate high pressure steam first, and let this expand to low pressure steam in a back pressure turbine to generate electricity.[100]

In papermaking paper drying is the most energy demanding stage during which the major amount of heat is consumed to evaporate water in the paper sheet. The influence of the consistency on the steam demand of the drying section is shown in Table 14. It can be seen that a 5% increase of the consistency at the start of the drying section can result in a 20% decrease in the energy requirement for drying.

Table 14: Minimum energy requirement for water evaporation from paper[101]

	(GJ/mt of paper)		(GJ/mt of water evaporated)
	Ingoing consistency (% ds)		
Minimum energy requirement for:	40%	45%	
Heating and evaporation water from 50°C to 100°C	3.25	2.63	2.46
Heating of fibres from 50°C to 100°C	0.07	0.07	0.07
Adsorption heat	0.02	0.02	0.02
Total	3.34	2.72	2.55

Pressing to a higher consistency (use of twin-wire and extended nip press) has resulted in somewhat lower moisture levels of the paper entering the drying section (this does not apply to tissue paper). In the case of surface sizing or coating the dried paper has to be dried again after adding surface glue or coatings to the paper web. Higher concentration and temperature of these chemicals result in reduced heat consumption.

So using a shoe press can result in a shorter drying section or higher machine speed. But on the other side the use of a shoe press needs a higher demand in electricity, so the electricity consumption in the press section will increase. But the demand of steam in the drying section will decrease. Taking into consideration that producing one GJ of steam needs many times the energy of producing one GJ of electricity brings an enormous advantage in energy saving.

100 Beer De (1998): p. 79
101 Beer De (1998): p. 82

Heat loss to the surroundings

The major part of heat losses with the humid exhaust air from the drying section is compensated by inlet dry air that has to be heated again. The heat requirements can be reduced by reducing the airflow through the drying section. This gives also a higher humidity of the outlet air, which increases the value of air as a source of secondary heat. Heat recovery through heat exchanger between the outlet humid air and the inlet dry air also reduces the heat consumption.

Energy Required for Drying

Much energy can be saved in the dryer hoods of most machines. Most of the drying energy supplied by the steam system leaves the hood as high-temperature air and water vapour. The high heat content of the hood exhaust is a prime candidate for recovery.

Unfortunately, few mills take full advantage of this recoverable energy. A survey of Canadian newsprint mills indicated that for those mills reporting heat recovery information, less than 16% of the drying heat was recovered. Under ideal conditions and with proper hood and heat recovery system design, 60 to 70% of the drying energy can be recovered for heating hood make-up air, glycol for building heating and process water.

Much of the energy introduced into the dryer section leaves with the hood´s exhaust air; only a small amount leaves with the condensate and the dry sheet. Therefore, controlling the exhaust volume is the key to limiting energy loss.[102]

Commonly used measures of drying performance include evaporation rate (kg water evaporated per unit area of dryer) and energy consumption per unit of product (kg steam per kg of product). However, the energy consumed per unit mass of water evaporated (GJ per tonne of water evaporated) is a better basis for comparative evaluation.

The theoretical minimum energy required to evaporate a kilogram of water in a conventional cylinder dryer section is about 1.24 kg of steam per kg of water, or about 2.8 GJ/t of water.[103]

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[102] Paprican(1999): p. 134
[103] Paprican (1999): p. 129

Conclusion

It should be noted that smaller mills often have higher specific energy consumption values and also higher water consumption than bigger mills. Reasons for differences in environmental performance between bigger and smaller paper mills are for instance:

Fresh water needed for continuously trimming the edges of the web is the same for wider and narrower machines. Thus, paper machines with a larger width use relatively less water for that purpose.

Bigger machine produce usually bulk grades. That means less changes of grades are necessary that cause higher water consumption and increase pollutant load when the system has to be washed.

The economies of scale facilitate investments in clean technology for bigger mills.

Bigger mills have more financial and human resources for research and development.

It can be concluded that improvement of the energy efficiency of paper making in the long term should be directed primarily at reducing the energy requirement for drying.[104]

[104] Beer De (1998): p. 83

2.8 Energy savings through energy efficient technologies

To summarise the possibilities for energy savings: the areas offering most direct opportunity for energy saving are refining, pressing and drying. However, once the "good housekeeping" changes have been made, drying is also the most capital intensive process to modify. Those offering smaller savings but also synergetic advantages are slushing, forming and size pressing.

Besides the selection of technologies the manner of operation (energy efficient practice) and the energy management in the mill is an important issue. Equipment is often not used at its optimum energy efficiency and with better management further savings can be achieved. The pinch method for optimisation of thermal integration of paper mills can be a beneficial tool to move towards energetically optimised processes.[105]

2.8.1 Energy Improvements in the Paper Mill

The following improvements are only a small range of the improvements possible. It should serve as an advice to show what is possible by using the best available technology.

Woodyard

The electrical demand for wood yard operation is roughly 10 - 20 kWh/adt. Steam demand is essentially zero.

Pneumatic chip conveying is still practised in some mills. Belt conveyor systems are now the preferred method of transport as they result in much less damage to the chips and are much more energy efficient. Belt conveyors consume roughly 0.5 Wh/t of wet wood per metre (Wh/t-m) for a horizontal run, and 5 Wh/t-m for a vertical run compared with 15 Wh/t-m for pneumatic conveyors.[106]

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105 IPPC (2000): p. 394
106 Nilsson (1996)

Buildings

This includes every building where people are working, researching or resting inside the area of the mill. For the buildings lightning and heating is an energy consumer as well as all the working tools like computers, printers….

Lighting efficiency varies with lamp wattage and type. A large mill can require 800 to 1000 kW of lighting so any reduction in consumption can represent a useful saving. Modern lighting systems based on high pressure sodium lamps can reduce electricity costs by 50-80% relative to systems with mercury vapour lamps.

Cylinder drying steam and condensate systems

Steam venting: this major source of heat loss results from poorly designed and controlled steam and condensate systems in particular improperly sized or applied siphons. Rotary siphons should not be used at high speeds (>1000 m/min) because the required differential pressure and low through flow rate becomes too large.

Most systems are designed to dump steam either to a vacuum condenser or to atmosphere to maintain differential pressure.

In many mills, the vacuum pump is oversized and pulls steam from the top of the condenser. If properly sized, the condenser will create adequate vacuum for the system.[107]

[107] Paprican (1999): p. 133

2.9 BAT for paper mills

For paper mills the following techniques are considered as BAT. The following list of BAT is not considered exhaustive and any other technique or combination of techniques achieving the same (or better) performance can also be considered; such techniques may be under development or an emerging technique or already available but not described in this document. If not stated otherwise, the data refer to yearly average values.

2.9.1 General measures

- Training, education and motivation of staff and operators. Paper mills are operated by people. Therefore, training of staff can be a very cost-effective way of reducing water consumption and discharges of harmful substances as for instance accidental releases of chemicals.

- Process control optimisation. To be able to reduce different pollutants simultaneously and to maintain low emissions, improved process control and measurement are required.

- To maintain the efficiency of the technical units of paper mills and the associated abatement techniques at a high level, sufficient maintenance has to be ensured.

- Environmental management system which clearly defines the responsibilities for environmentally relevant aspects in a mill. It raises awareness and includes goals and measures, process and job instructions, check lists and other relevant documentation.[108]

2.9.2 Energy saving measures

In general in this sector BAT is considered to be the use of energy efficient technologies. A lot of options for energy saving in many stages within the manufacturing process are available. Usually these measures are linked with investments to replace, rebuild or upgrade process equipment. Because of economies of scale, smaller mills are less able to invest in new energy efficient technologies. It should be noticed that energy saving measures are mostly not applied only for energy saving. Production efficiency, improvement of product quality and reduction of overall costs is the most important basis for investments. Energy saving technologies can therefore be regarded as techniques that are incorporated into many other aspects of papermaking.

In order to reduce the consumption of steam and power a number of measures are available:

- Implementation of a system for monitoring energy usage and performance. Based on reliable energy performance information appropriate action can be taken. Energy management includes setting, controlling, reviewing and revising energy performance targets.

[108] source IPPC (2000): p. 403

- More effective dewatering of the paper web in the press section of the paper machine by using wide nip (shoe) pressing technologies (this does not apply to tissue mills).

- Use of energy efficient technologies as e.g. high consistency slushing, best practice refining, twin wire forming, optimised vacuum systems, speed adjustable drives for fans and pumps, high efficiency electric motors, well sizing of electric motors, steam condensate recovery, increasing size press solids or exhaust air heat recovery systems. For some of these techniques implementation may only be possible at a rebuild or when a replacement of equipment is planned anyhow.

- Reduction of direct use of steam by careful process integration by using pinch analysis.[109]

In many European countries, information on energy balances of paper mills is poorly available in public. Different reporting schemes, if any, for energy consumption are used. Energy demand also depends on the product quality (especially in tissue mills) and partly on local conditions. Therefore, it is difficult to present energy consumption values associated with the use of BAT.

The ranges of energy consumption of paper mills shown in Table 15 should only be taken as an indication about the approximate need of process heat and power at energy efficient paper mills.

Table 15: Indication for energy consumption associated with the use of BAT for different types of paper production per tonne of product[110]

Type of mill	Process heat consumption (net) in GJ/t	Power consumption (net) in MWh/t
Non-integrated uncoated fine paper	7.0 - 7.5	0.6 - 0.7
Non-integrated coated fine paper	7.0 - 8 0.	7 - 0.9
Non-integrated tissue mill	5.5 – 7.5[1)]	0.6 - 1.1
Notes: [1)] In tissue mills the energy consumption depends mainly on drying system used. Through air drying and creping consume significant additional process heat up to 25 GJ/t [according to ETF]		

It should be noted that steam consumption may be between 10% and 25% higher depending on the size of the mill. Electricity consumption may be between 5% and 20% higher depending on the size of the mill. The degree of refining has also a significant effect on the electricity demand.

[109] source IPPC (2000): p. 411
[110] source IPPC (2000): p. 411

3 Empirical Part

As you can see there is already a lot of information existing in the literature regarding to energy consumption of paper mills. This is good and important for a benchmark. But now there has to be gathered correct values of a Mondi Paper Mill to compare them with the values in the literature.

This was done by creating a model paper mill with the target to contain all important installations of the different mills within Mondi BP. This means that the mill should contain all departments and operations that can occur in either an integrated or a non integrated mill.

3.1 The Model Paper Mill

The model paper mill is an integrated paper mill, which means that the pulp and paper production takes place at the same location. Knowing that some of the Mondi paper mills are not integrated, this scenario is valid too.

The figure below shows the levels the model mill is split in.

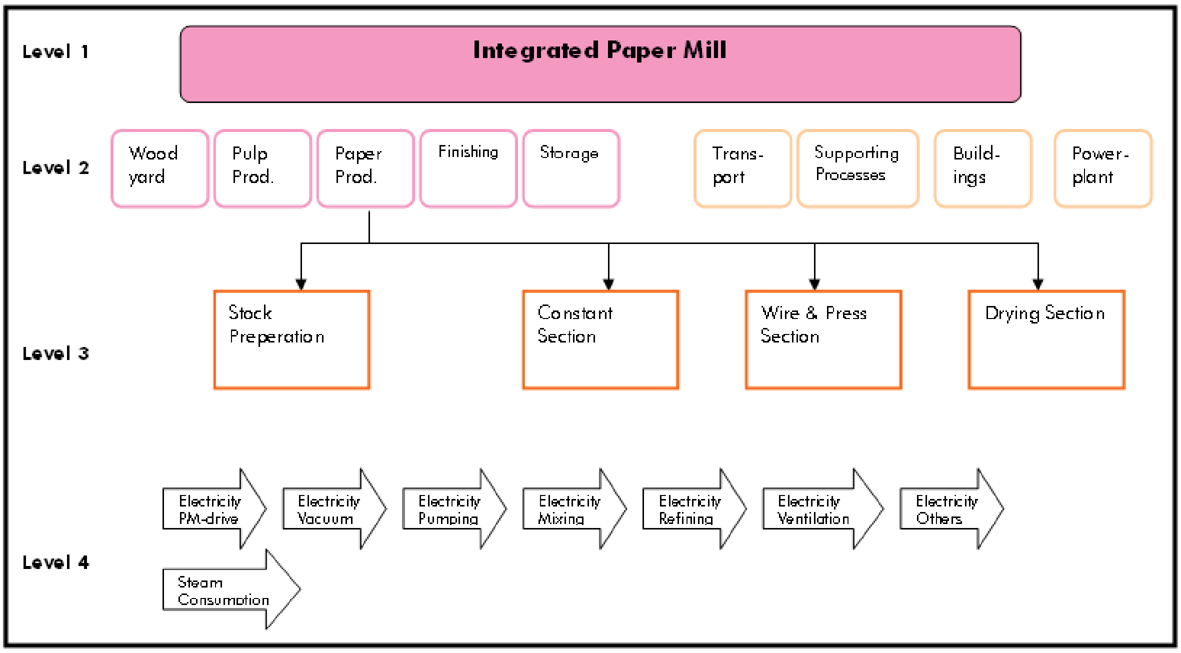


Fig. 37: Model Paper Mill

The mill was broke down into four levels.

3.1.1 Level 1 – Mill Level

Level one gives an Input/Output consideration of the system (see Fig. 38). From the left to the right you see the energy In and Output. The material flow is figured from top to bottom. The processes inside the system are of low interest at this stage – therefore the other levels have been established.

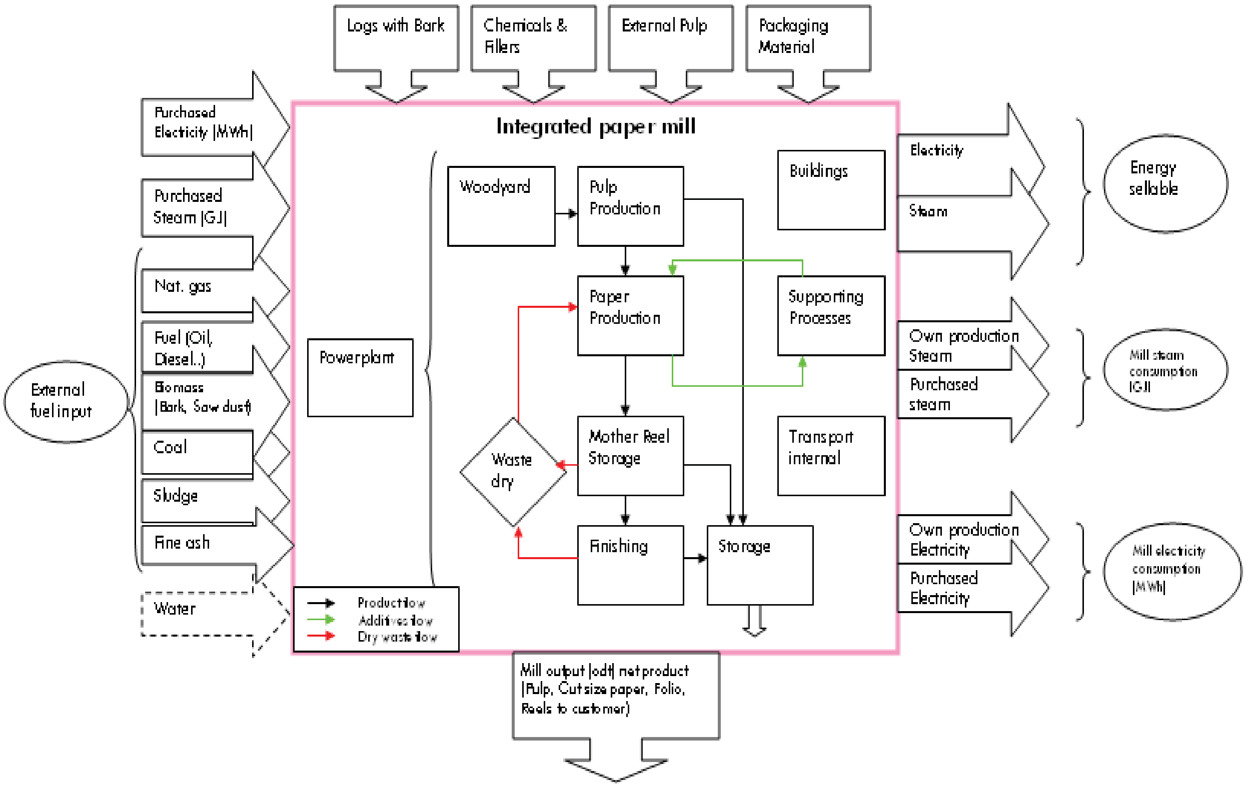


Fig. 38: Energy Input – Output of an integrated paper mill

On the basis of the material flow you can follow the way from the wood to the finished paper and find out which transmutation happens in each section. It is signed by arrows from top to bottom (see Fig. 39).

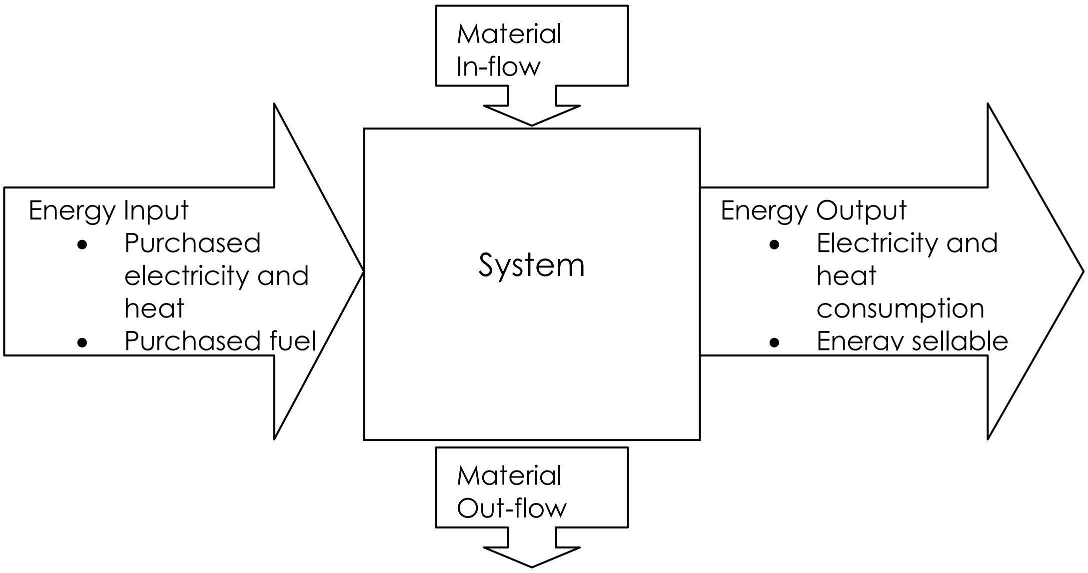


Fig. 39: Sample of an element of the model papermill

This figure is a practical tool to build up the energy balance of the mill in a graphical way.

The energy Input is divided into two main groups. One group is purchased energy (electricity and steam). The other group is purchased fuel for energy self production. This contains types like:

- Natural gas
- Oil
- Coal
- Biomass
- Sludge
- Fine Ash…

The energy Output is divided into energy that was consumed in the mill and energy that is able to sell. This differentiation is important for the calculation of the key data.

3.1.2 Level 2 – Operating Departments

Level two shows the different operating departments of the model PM. Nine departments have been:

- Wood-Yard
- Pulp-Production
- Paper-Production
- Power-Plant
- Finishing
- Storage
- Buildings
- Transport
- Supporting Processes

But for this diploma thesis eight of the nine areas will stay as a black box, which means that no further detailed observation is done. This is called the Input/Output-consideration of a system.

The paper production is chosen for further observation (Fig. 40). It is the main energy user of a paper mill besides the pulp production, so the energy savings potential is quite high. Consequentially we decided to go more into detail here. This means that the paper machine will be a structure orientated consideration of a system.

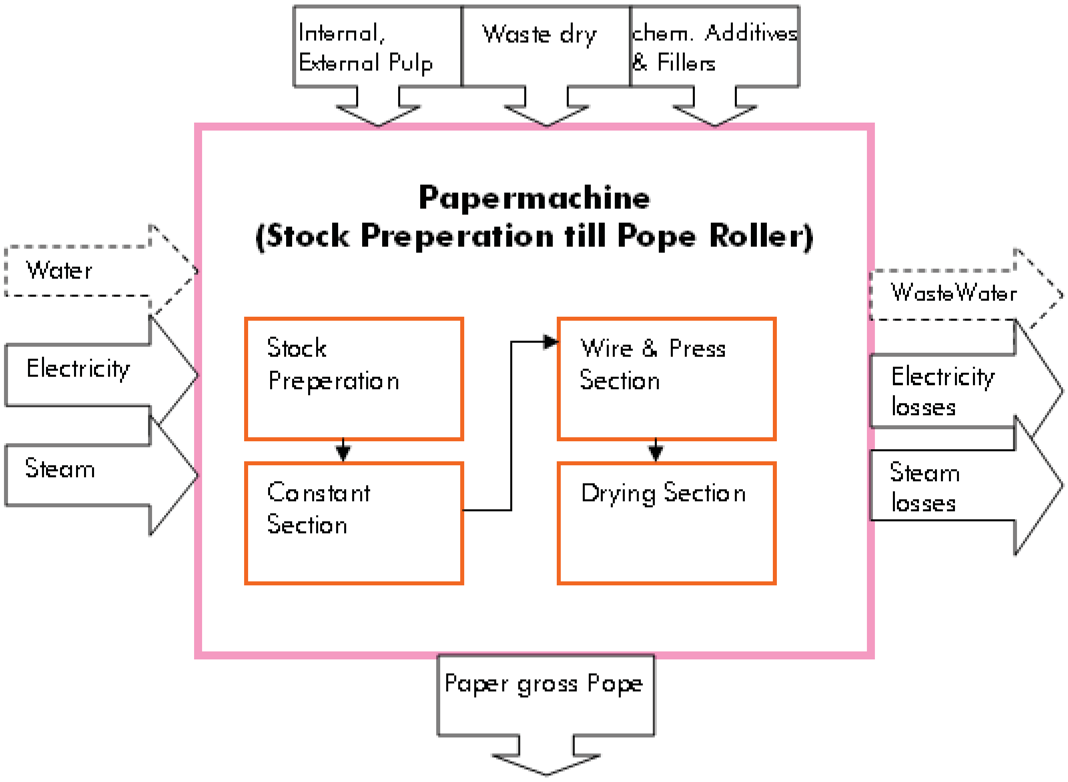


Fig. 40: Energy Input-Output of a paper machine

In case of the paper machine four elements were defined to describe the system:

- Stock preparation
- Constant Section
- Wire & Press Section
- Drying Section

Criteria for splitting:

The sections were split on a technical and a logical basis. It took long discussions to define the boarders of the sections. The sections should make sense in a technical way and be valid for benchmarking. Of course different machines or installations can be used in these groups but the main body will be the same for each PM.

3.1.3 Level 3 – Paper Machine Sections

Now the sections will be explained and its borders will be defined. So the different energy consumptions can be allocated correctly as already mentioned in the general rules of benchmark.

Stock preparation

The stock preparation includes the broke system and the fibre recovery. It starts with the slushing of the pulp bales and ends at the mixing chest.

Note:

Integrated paper mill: There is sometimes no bale pulping because the pulp is directly pumped into the chests in liquid phase.

The broke system consists of the dry and wet broke of the machine. It includes the pulper for the wet broke (couch pulper, press pulper), the pulper at speed sizer and the pulper at pope roller.

The other dry broke that occurs at finishing is not included. It will be considered at the finishing system.

Depending on the type of fibre recovery, it includes different filters to separate the fibres from the white water and pumps to transport the suspension.

Chemical additives are not considered in the stock preparation, because they are normally done centrally for all machines.

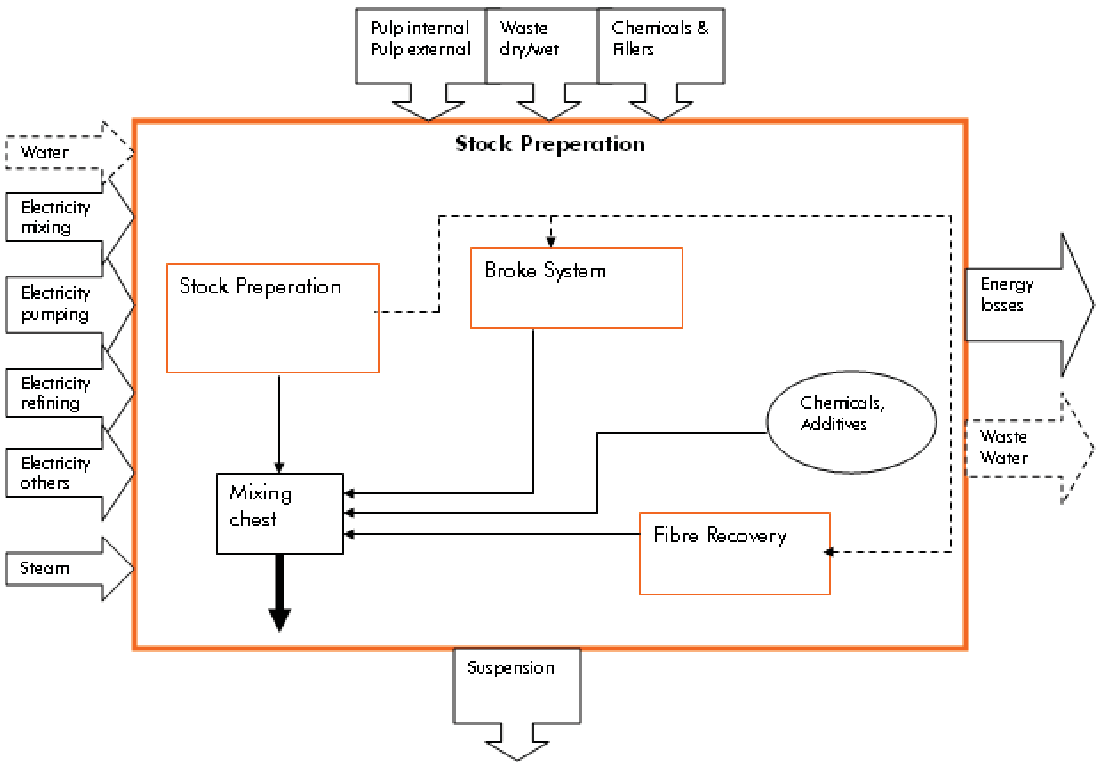


Fig. 41: Input – Output of the Stock Preparation

Constant Section

The area between the mixing chest and the head box is called constant (Fig. 42). It includes the fan pumps for the cleaners. It includes the vacuum pumps for the deculator, which is important to remove air or small bubbles of air out of the suspension.

Normally the suspension will then be screened. Then pumps will be used to handle the requested amount of suspension for the head box and to guarantee a sufficient pumping pressure.

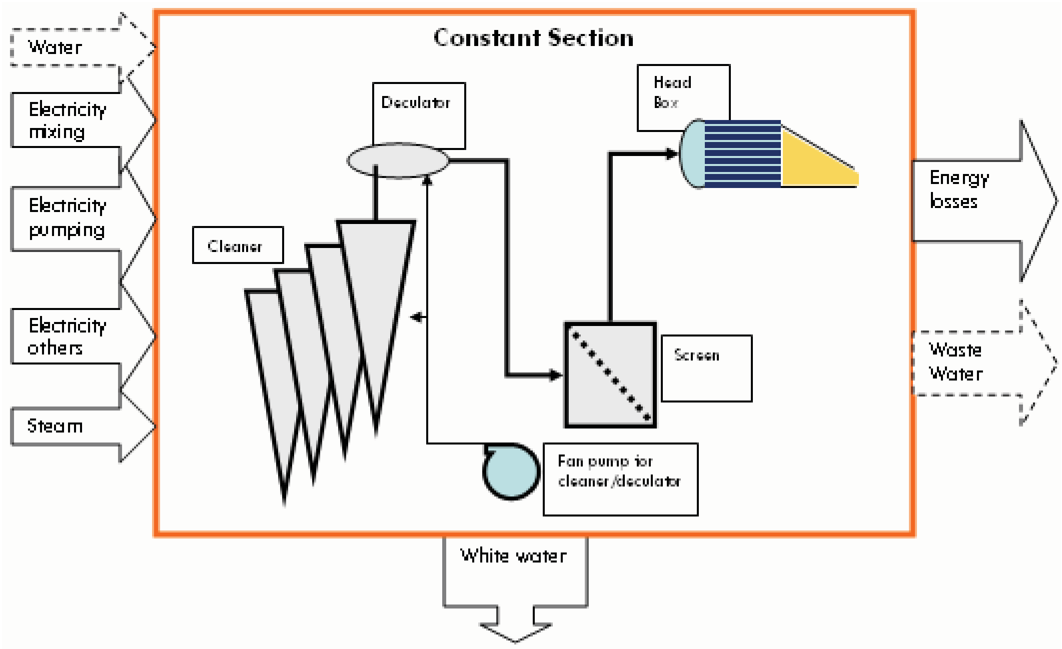


Fig. 42: Input – Output at the Constant Section

Wire & Press Section

At the Wire Section the main electricity consumer is the shower water system. This includes the hot water tank and diverse pumps to transport the filtrate and the water.

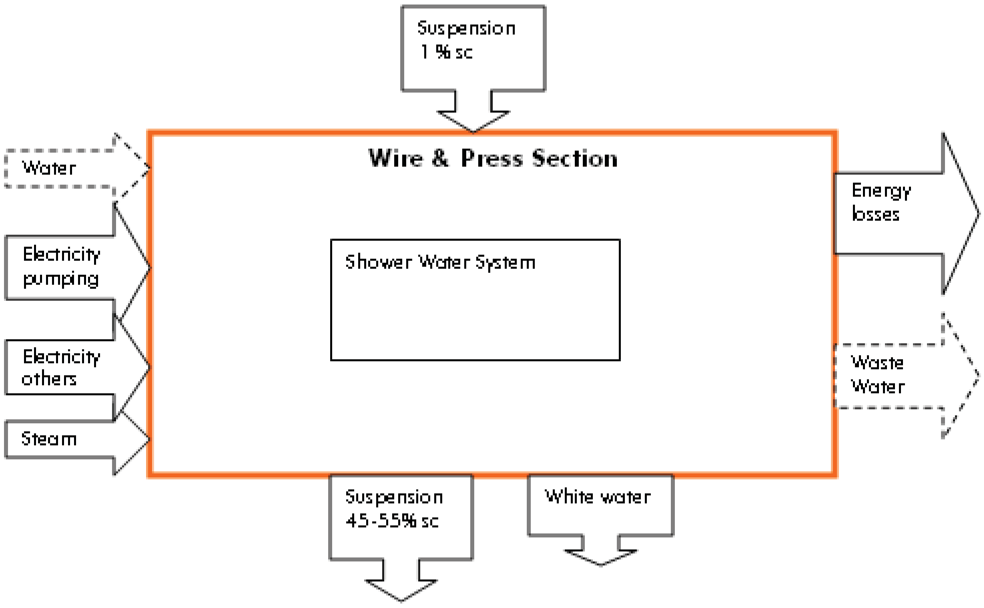


Fig. 43: Input – Output at the Wire & Press Section

Drying Section

In the Drying Section the energy consumption for the heat recovery is important. Then we also have to consider the power for sizing, for the shower water and condensate system and for the calendering.

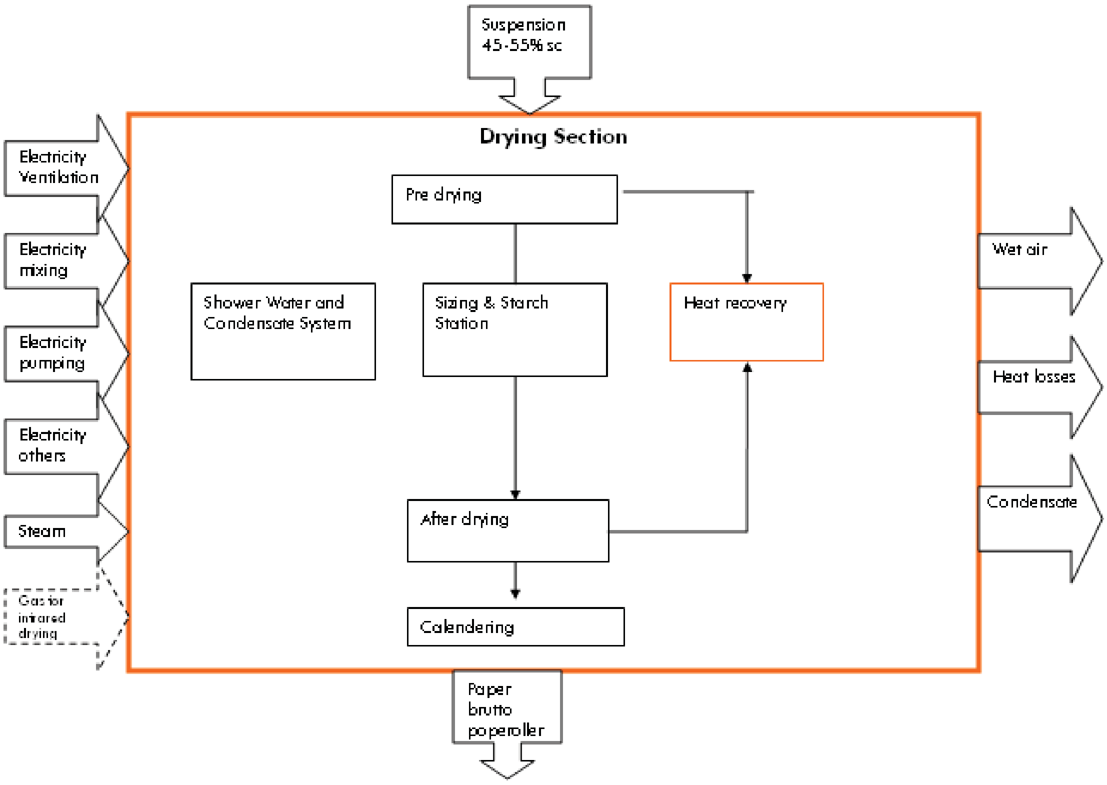


Fig. 44: Input – Output at the Drying Section

In the future the other eight operating departments will be analysed similar. An important factor in the planning phase was to create a module-wise structure. So you can work on every module separately. This has the advantage that you can already start with a detailed benchmarking for the paper production process without analysing the other departments. This saves time and whenever another module is analysed it can be attached to the block.

The future target is a detailed observed and analysed paper mill.

3.1.4 Level 4 – Groups of Energy

Finally the very top down few defines the different groups of energy. Here the different groups of electricity are listed:

Electricity PM-drive	Electricity vacuum	Electricity ventilation	Electricity refining	Electricity pumping	Electricity mixing	Electricity others

- Electricity PM-drive includes all drive motors used to keep the paper running*.
- The electricity for vacuum is mainly used at the constant section and the wire & press section*.
- Electricity for ventilation will basically be used for heat recovery – Drying Section
- Electricity refining is used at the refiner and deflaker at the stock preparation.
- Electricity for pumping is used everywhere, where pumps are installed.
- Electricity for mixing is used at the chests.
- Any electricity user that does not fit in the fields above will be listed in the field "others".

*) The Electricity for PM-drive and Vacuum is measured centrally, so it is not allocated to one of the four PM-Sections. In the sheet there are separate fields to put in the values for those two data.

The steam consumption is mostly known for the whole paper machine. There is a splitting according the sections of the paper machine, but mostly the separate consumptions are not known, beside the fact that most of the steam is used in the drying section. So it will be asked as a total value for each paper machine.

Restrictions about the model paper mill that is given here:

Any kind of water treatment (besides fibre recovery) is neglected at the moment.
Any kind of chemical and filler treatment is neglected.
This benchmark is only valid for office paper production.
It is valid for integrated and non integrated paper mills but it has to be marked.
Pressurized Air is neglected.

3.2 Input form

The model paper mill sheets were developed to fill in the important energy data for further evaluation. The mill data sheet was developed on the basis of level one, which means that here the overall mill data will be asked. The paper machine sheet is created to evaluate the data of a paper machine from level two down to level four.

3.2.1 Mill Data Sheet

The data blocks are:

- own production energy
- external purchased energy input
- external purchased fuel input
- revenues of energy sold

As you can see the amounts of unit and also the costs per unit are asked. The data based period can be done monthly, as the energy manager already have to do a monthly report of their energy consumption.

For the "own production energy" it is important to say that it is based on the net value (see Table 16). This means that the gross own production has to be subtracted by the auxiliary power of the plant and the losses of the turbines and the boilers. Here fore it is important to know that each turbine needs energy to run and that during energy production losses due to friction occur.

For the "external purchased fuel input" the "net calorific value" is of high interest, which is given in GJ/unit (see Table 16).

The input boxes are marked yellow but not all boxes will get an input. This depends on the mill configuration. For example a non integrated mill will never produce steam from recovery boiler, because the recovery boiler is fired by the liquor that is produced at the pulp production. As there is no pulp production in a non integrated mill – there will be no liquor.

It was one important target of the thesis to evaluate a sheet that is valid for all mills of the Mondi BP Group, so all possible types of fuel had to be listed. The required data should already be known by each energy officer.

The white boxes will be calculated automatically out of the input data.

Table 16: Mill Data Sheet

Mill Data Sheet

Name of mill:	

Integratred paper mill Y/N:		Type of paper:	

	Mechanical pulp	Kraft (sulphate) pulp	sulphite pulp
Type of pulp production (X):			

Data based period:	

paper saleable: [t]	

Own production energy (net)			
	Amount of units	Cost per unit [€]	Total Cost [€]
Electricity from Steam turbine [MWh]			-
Electricity from Gas turbine [MWh]			
Electricity from Hydro [MWh]			-
Total [MWh]	-		-
Steam from Recovery Boiler [GJ]			-
Steam from Energy Boiler [GJ]			-
Total [GJ]	**-**		**-**

External purchased energy input			
	Amount of units	Cost per unit [€]	Total Cost [€]
Electricity [MWh]			-
Steam [GJ]			-
Purchased Energy (electricity + steam)			-

External purchased fuel input					
	Amount of units	Cost per unit [€]	net calorific value [MJ/unit]	Total Cost [€]	Energy amount [GJ]
Natural gas [Nm³]				-	-
District heating [MWh]				-	-
Fuel Oil [t]				-	-
Coal [t]				-	-
Biomass (bark, saw dust,...) [t] atro				-	-
Sludge [t] atro				-	-
Fine Ash [t]				-	-
waste and others [t]				-	-
Purchased fuel				-	-

Revenues of energy sold			
	Amount of unit	Revenue per unit [€]	Total revenue [€]
Electricity [MWh]	-		-
Steam [GJ]			-
Others [GJ]			-
Energy sold			-

total energy costs	-

Mill steam consumption [GJ]	Mill electricity consumption [MWh]	specific steam consumption [GJ/t]	specific electricity consumption [MWh/t]	Specific costs/ ton of paper [€/t]
-	**-**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**

3.2.2 Paper Machine Sheet

The paper machine sheet needs to be fed with information from the paper machine. Besides energy consumption values also machine configuration data are asked (see Table 17). This sheet is rather detailed and so most energy officers do not have information in such detail. The next chapter explains a way to get the values required.

Detailed information is important for specialists to define problem areas. With the configuration data they can better explain the reason for it.

Example:
Using an extended nip press (shoe press) at the press section will serve in a steam reduction of the drying section because of a higher stock consistency after the press. But on the other side the electricity consumption at the press section will be higher with a shoe press than without. So someone is asking why the press section at PM6 does need more specific electricity than the press section at PM5, you can have a look at the configuration data and understand the reason.

The sheet is divided in the four main sections already explained and defined with its borders. The main input data are marked yellow and with this data further calculation will be done.

Consumers that are served by a separate transformer can simply be read of by meter reading. This is very common for the PM-drive, so this field is marked orange.

Table 17: PM-sheet

Name of mill:			Paper machine:	
data based period:(mm.yy)				

Paper production gross pope: [t]	
Paper production net rewinder: [t]	
Paper production after finishing: [t]	

dry solid content after headbox	%	
dry solid content after press	%	
dry solid content before sizing	%	
dry solid content after sizing	%	
dry solid content before pope	%	
filler content	%	
Speed PM	[m/min]	
grade	[g/m²]	
effective runtime	days	

Stock Preparation

Number of fibre lines:	

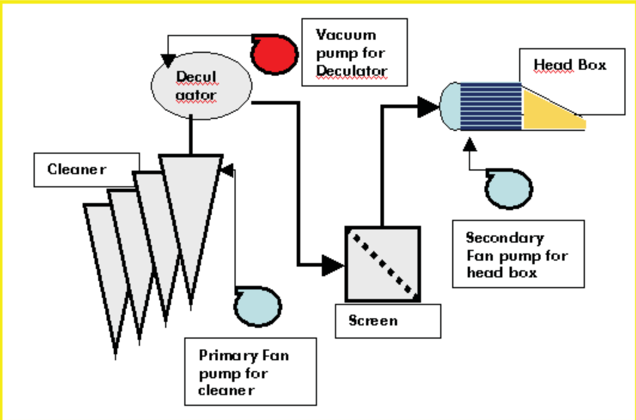
REFINER	Steep cone refiner (Steilkegel)	Disk type refiner	Others
Type of refiner:			
nr. of refiner:			

Broke system	process depending contactor	intervall contactor	continous running	nr. of agitators
couch pulper (x)				
press pulper (x)				
pulper at winder (x)				
pulper at size press (x)				
other pulper (x)				

Fibre recovery	
nr. of disk filter	

	Electricity pumping [MWh]	Electricity mixing [MWh]	Electricity refining/deflaking [MWh]	Electricity others [MWh]	Thermal energy [GJ]
stock preperation					
Broke system					
Fibre recovery					
Total Stock preparation	**0,00**	**0,00**	**0,00**	**0,00**	**0,000**

Constant Section



vacuum and drive is asked separately!!

	Electricity pumping [MWh]	Electricity mixing [MWh]	Electricity others [MWh]	Thermal energy [GJ]
Constant part				

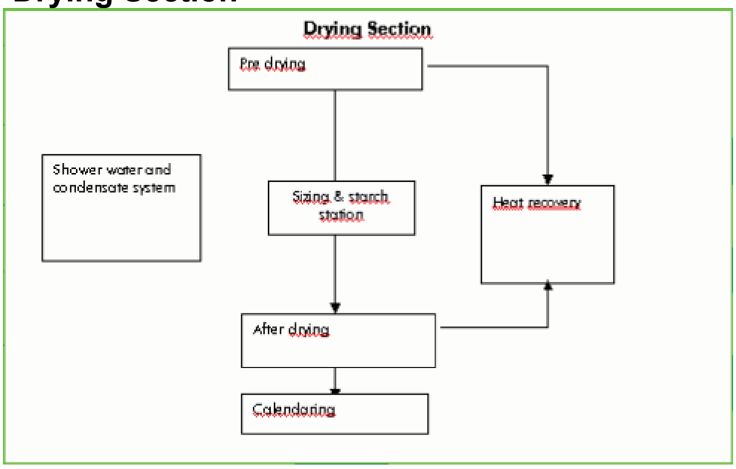
Wire & Press Section

	Fourdrinier	Hybrid Former	Gap Former
Type of paper machine configuration:(X)			
Shoe press Y/N			
Conventional press Y/N			
Number of press nips:			

vacuum and drive is asked separately!!

Wire & Press Section	Electricity pumping [MWh]	Electricity others [MWh]	Thermal energy [GJ]

Drying Section



	fresh air capacity	exhaust air dew point [C°]	exhaust air temperature [C°]	ind. air temp. below cylinders [C°]
heat recovery				

	Number of cylinders for contact drying	Number of vacuum cylinders (no steam)	Infrared drying gas heated Y/N	Infrared drying electrical heated Y/N
Pre - drying				
After - drying				

drying group	standard wire (x)	spiral wire (x)	aero plus wire (x)	slalom configuration (x)	standard configuration (top,down) (x)
1					
2					
3					
4					
5					
6					

	film press	conventional press	coater
Type of size press:(X)			

materials for doctors	steel	carbon	others (brass, plastics)
doctors drying section (X)			

Calender Y/N	Soft nip Y/N	Number of nips:	Calender online Y/N

	Electricity pumping [MWh]	Electricity mixing [MWh]	Electricity ventilation [MWh]	Electricity others [MWh]	Thermal energy [GJ]
Heat recovery - pre drying					
Heat recovery - after-drying					
shower water and condensate system (hood, hall-heating)					
sizing and starch station					
calendering					
others					
total drying section	**0,00**	**0,00**	**0,00**	**0,00**	

Whole Paper Machine

	Electricity PM-drive [MWh]	Electricity Vacuum [MWh]
total consumption PM		

3.3 Energy Data gathering for Paper Machine

For data gathering the PM6 in Hausmenning was chosen to be observed. Of course many data already exist by the local energy officer. But there hasn't been a splitting into the different groups of energy before.

For practical reasons it was required to figure out all energy consumers within the paper machine with a minimum installed power. For the PM6 we defined a minimum installed value of 18.5 kW. The consumers had than to be allocated correctly to the defined sections and the effective power had to be measured.

Normally smaller consumers will be installed together on one transformer. It can happen for example that one pump that serves the stock preparation is on the same transformer as a pump for the sizing and this was to figure out now.

This was done with the help of R&I schema. The R&I schema is an engineering drawing of the sections where all electricity consumers, mostly pumps, are figured. So we marked the important ones. In the case of the PM6 it was the schema of:

- Stock preparation – short fibre
- Stock preparation – long fibre
- Broke system
- Fibre recovery
- Constant section
- Injection water system
- Heat recovery
- Speed sizer
- Steam and condensate system
- Vacuum system
- Central lubrication drying section
- Central lubrication press section

The data was then put into an Excel sheet with information of the section, subsection, electricity group and motor number. An example is given as
Table 18. For the electricity group the following abbreviations are valid. (p=pumping, m=mixing, v=ventilation, vac=vacuum, r=refining, o=others). The motor number was important to gather further information.

Table 18: List of motors – step one

Section	sub-section/trafo nr.	electricity group	Motor number
stock preperation	stock	m	m6100
stock preperation	stock	p	m6527
stock preperation	stock	p	m6528
stock preperation	stock	r	m6530

The data of the R&I schema were allocated to the sections as following:

Table 19: List of R&I schema allocated to the PM-sections

R&I Schema	Section	Sub-Section
Stock preparation – short fibre	Stock preparation	Stock preparation – short fibre
Stock preparation – long fibre	"	Stock preparation – long fibre
Broke system	"	Broke system
Fibre recovery	"	Fibre recovery
Constant section	Constant Section	Constant section
Injection water system	Drying Section	Drying Section
Central lubrication	"	Central lubrication
Heat recovery	Wire & Press Section	Heat recovery
Speed sizer	"	Speed sizer
Steam and condensate system	"	Steam and condensate system
Central lubrication	"	Central lubrication

According to the motor number the nominal power, the nominal current, the place of backup and the type of connection was to found out (see
Table 20). Especially the type of connection is important, because it makes a difference in calculation if a motor has a "Bucked-Brigade-Device" or a Delta connection. This information was gathered out of a software called API-Pro, where each paper machine within the Mondi Group is saved.

Table 20: List of motors after checked by API-Pro

motor number	P_n (kw)	I_n (A)	Place of backup (eg: MCC1/203/F5)	Delta connection X	I_m (A)
m6004	18,5	41,6	TRAFO3 NV6800-SPEED SIZER _06D03	S	35

Now the list contained about 250 positions and so some restrictions had to be done. As already mentioned only motors with a nominal power of minimum 18.5 kW were considered and on the other side some motors just served as a reserve so they were neglected either. After executing these restrictions the list was reduced to about 150 positions.

To calculate the effective power an electrician had to measure the active current during action of each consumer. Because of little time the electrician only measured each connection once. As some machines have changing electricity consumption with different paper grades, it would be better to measure each connection two or more times and then evaluate an average value out of these measurements. Unfortunately this was not possible.

As the motor list exists now, additional measurements can be done at any time.

Note: in case of a delta connection the $I_{measured}$ values had to be multiplied with the factor 1.7 to have the correct measured data.

The next step is to define the Cosφ: The apparent output (kVA) is given by active power (kW), that produces energy and idle power (kVAr), which is produced by inductive users. The idle power reduces the net capacity and causes needless losses. The power factor Cosφ is defined by the ratio of P (kW)/S (kVA).

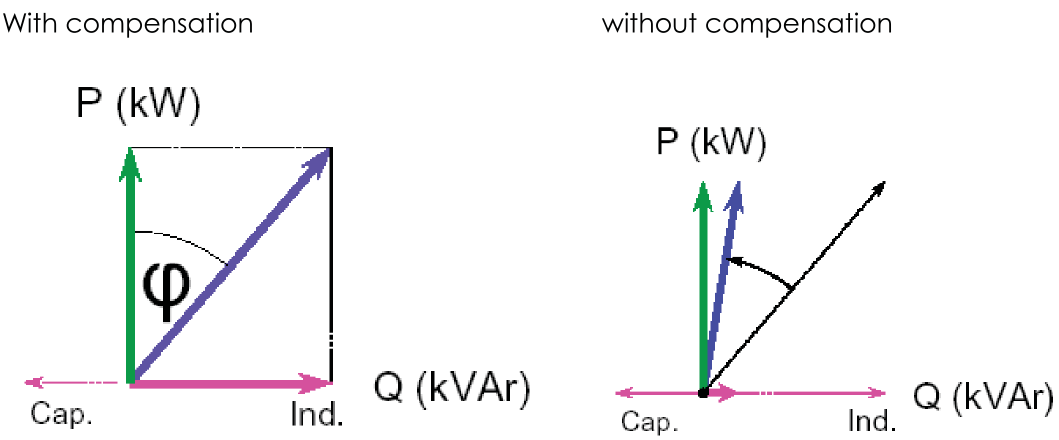


Fig. 45: Cos phi by coordinate system[111]

Now the evaluation of Cosφ according to Table 21 was possible. It is based on long experience and the average values for such machines. "Normally each machine has got its specific Cosφ but it would be much more complicated and so it is not worth it."[112]

Example: Motor m6004 (see
Table 20). The given motor has a nominal current of 41.6 [A] and an active current of 35 [A]. Dividing the measured value by the nominal value gives us the delta I.

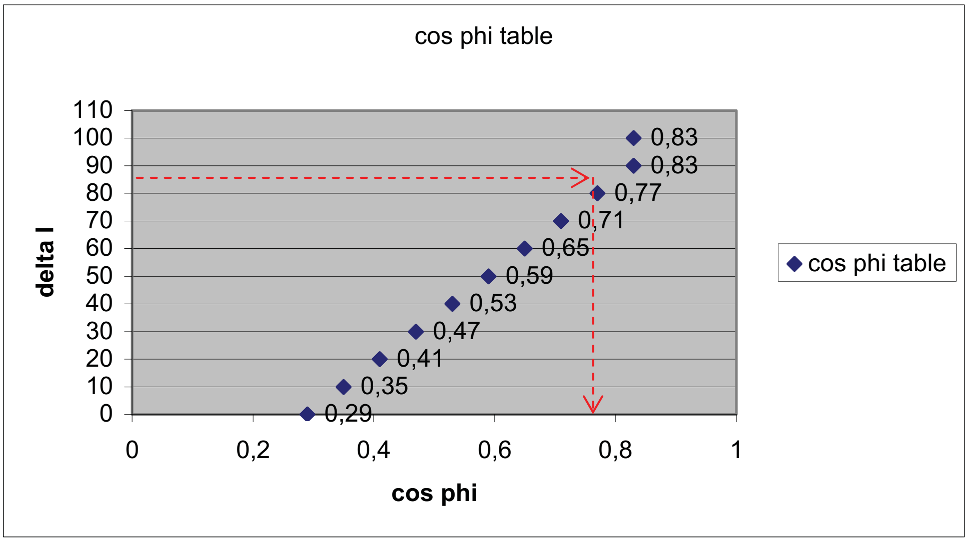
$$\Delta I = \frac{I_{measured}}{I_{nominal}} = \frac{35}{41,6} * 100 = 84,13[A]$$

The just calculated ΔI can now be set in into the graph and the corresponding Cosφ can be read of. In the example the Cosφ value for a ΔI of 84.13 will be 0.77. There is always

[111] wwwex.physik.uni-ulm.de/lehre/gk1-2005-2006
[112] Oberleitner A., MBPAT

a range of ΔI to have the same Cosφ. Here every ΔI between 76 and 85 has a Cosφ of 0.77. The next lower range is from 66 to 75.

Table 21: Cos phi evaluation[113]



This procedure was done for every energy consumer in the list. Now the active capacity P_a (W) could be calculated according to the given formula:

$$P_a = \sqrt{3} * U * I_m * \cos\varphi * c$$

Where c is a correction factor due to losses and U is the voltage [V]. The correction factor of c = 0.9 and a nominal voltage of 400 [V] is assumed.

In the example the P_m of motor m6004 has about 16.784 [W]

In case of a direct current machine the calculation is simpler, but here we consider the actual voltage!

$$P_a = U * I_m$$

For comparison we have to use the resulting kWh`s.

$$P_a * 24 * 31 / 1000 = e[kWh]$$

The machines do hardly run 24 hours a day and 356 days a year. The energy cost calculation of a paper machine is done every month, so to compare these values correctly we had to multiply the measured capacity P_m by 24 hours and 31 days (test was done in December) to get Watt hours [Wh]. Dividing by 1000 gives us the required [kWh].

In example: m6004; P_a= 12.488 [kWh]

Finally a table with all important information was established and so it was possible to sum up all required data and fill it in the appropriate paper machine sheet.

113 source Oberleitner A., MBPAT

With the function of "Auto Filter" it is quite easy to figure out data of the same groups.

Example: Find out the refining energy at the stock preparation. Open the section "stock preparation" and activate the filter for "electricity group" by choosing "r" for refining – then all electricity consumers using refining energy at the stock preparation are listed.

With this procedure it was possible to fill out the complete "paper machine sheet".

3.4 Creation of an Result Sheet

All this data input is useless without evaluation. There the data will be calculated automatically. Corresponding to the model paper mill I divided the results in four levels.

These results will be automatically calculated out of the "Mill Data Sheet" and the "Paper Machine Sheet".

Fig. 46 should serve as an assistance to show the way of the energy. It should support the understanding of the calculations.

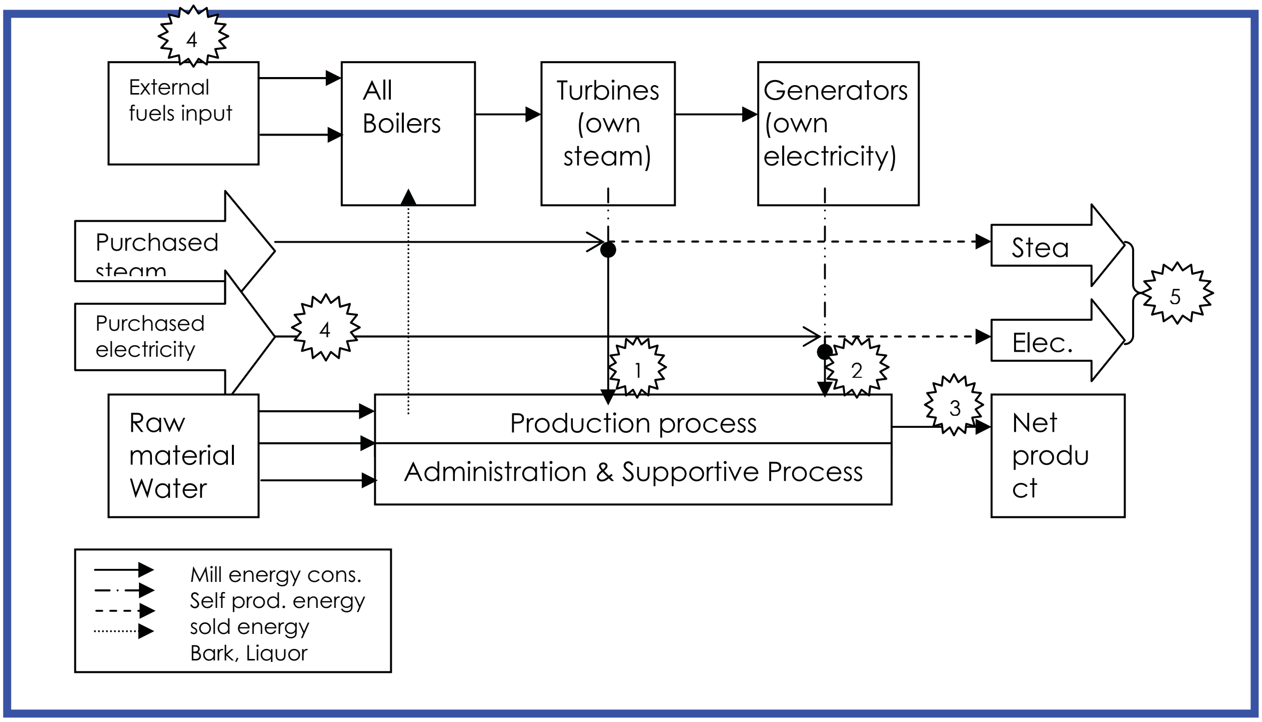


Fig. 46: Benchmarking on Mill Level

The numbers in the figure explain the following data:

- Mill steam consumption in [GJ]
- Mill electricity consumption in [MWh]
- Mill paper output in [adt] net product
- Fuel cost and purchased energy in [€]
- Revenues from sold energy in [€]

These data are asked in the "mill data sheet". So the following key data corresponding for the mill-benchmark can be calculated. The formulas are given below.

Specific steam consumption = $\frac{total\_steam_{mill}}{paper_{saleable}}\left[\frac{GJ}{t}\right]$

Specific electricity consumption = $\frac{total\_electricity_{mill}}{paper_{saleable}}\left[\frac{MWh}{t}\right]$

Specific steam costs/ton paper = $\frac{\cos t_{ownsteam} + \cos t_{purchasedsteam} - revenues_{soldsteam}}{paper_{saleable}} \left[\frac{€}{t}\right]$

Specific electricity costs/ton paper =
$$\frac{\cos t_{own\_elec} + \cos t_{purchased\_elec.} - revenues_{sold\_elec.}}{paper_{saleable}} \left[\frac{€}{t}\right]$$

Specific energy costs/ton paper =
$$\frac{\cos t_{ownenergy} + \cos t_{purchasedenergy} - revenues_{soldenergy}}{paper_{saleable}} \left[\frac{€}{t}\right]$$

Evaporation Efficiency [%] = $\frac{energy\_for\_evaporation\_[GJ]}{energy\_fuel\_puchased\_[GJ]}$

Energy for evaporation [GJ] = $\frac{evaporation\_in\_process_{yearly}}{electricity_{own\_production} * 3,6}$

Yearly Evaporation in process [GJ/year] = $total\_evaporation * 2,4 * 12$

Total Evaporation [tH_2O] = relative Evaporation * paper gross pope [t]

Relative Evaporation [%] = $1 * (\frac{dsc_{before\_pope}}{dsc_{after\_sizing}} - 1) + (\frac{dsc_{before\_sizing}}{dsc_{after\_press}} - 1) * 0,95$

The calculation of the specific costs is only able on direct cost basis at the moment. The calculation on total cost basis in not jet defined. This means that there is no clear definition of the total costs belonging to amortisation of the power plant and so on.

If you are interested in the results of the paper machine then you can get into more detail. This means that you look at the next level.

Level two is created for a paper machine benchmark. There fore the following key data were developed:

Specific steam consumption = $\frac{steam_{PM}}{paper_{gross\_pope}} \left[\frac{GJ}{t}\right]$

Specific electricity consumption = $\frac{electricity_{PM}}{paper_{gross\_pope}} \left[\frac{kWh}{t}\right]$

Level three and four are more detailed calculations. Here it is possible to compare the four main sections of a paper machine on its specific electricity and thermal energy consumption (see Table 22). Or it is also possible to compare the machines on the basis of the different types of electricity.

So for example you can shortly find out the difference in "Electricity Vacuum" between PM5 and PM6.

For the required data input you have to follow the steps described in the previous chapter ("energy data gathering for Paper Machine"), because data such detailed are not available right away.

Table 22: Result sheet

Final results for the energy benchmark of a paper mill:

name of mill	-
data based period	Jänner 00

level 1 - paper mill

	[GJ/t]	specific steam costs [€/t]
steam cons./ton paper saleable	#DIV/0!	#DIV/0!
	[MWh/t]	specific electricity costs [€/t]
electricity cons./ton paper saleable	#DIV/0!	#DIV/0!

Specific costs/ ton of paper [€/t]	Evaporation Efficiency %
#DIV/0!	#DIV/0!

level 2 - paper machines

PM	-	-
spec.elec.cons./ton gross pope [MWh/t]	#DIV/0!	#DIV/0!
spec.steam cons./ton gross pope [GJ/t]	#DIV/0!	#DIV/0!

	PM	-	-	total
dry solid content after headbox	%	0	0	
dry solid content after press	%	0	0	
dry solid content before sizing	%	0	0	
dry solid content after sizing	%	0	0	
dry solid content before pope	%	0	0	
filler content	%	0	0	
Speed PM	[m/min]	0	0	
grade	[g/m²]	0	0	
rel. Evaporation	[%]	#DIV/0!	#DIV/0!	
tons paper gross pope	[t]	#DIV/0!	#DIV/0!	
total Evaporation	[tH2O]	#DIV/0!	#DIV/0!	#DIV/0!
yearly evaporation in process	[GJ/year]	#DIV/0!	#DIV/0!	#DIV/0!
required energy for evaporatio	[GJ]	#DIV/0!	#DIV/0!	#DIV/0!
Evaporation Efficiency %	%			#DIV/0!

own production electricity
-

effective runtime of PM	days
-	0
-	0

level 3/4 - PM

	Electricity pumping [MWh]	Electricity mixing [MWh]	Electricity ventilation [MWh]	Electricity refining/deflaking [MWh]	Electricity others [MWh]	Electricity PM-drive [MWh]	Electricity Vacuum [MWh]	Total Electricity [MWh]	Specific Electricity [MWh/t]	Thermal energy [GJ]	specific thermal energy GJ/t
Stock Preparation	-	-		-	-			-	#DIV/0!	-	#DIV/0!
Constant Section	-	-			-	-		-	#DIV/0!	-	#DIV/0!
Wire & Press Section	-				-	-	-	-	#DIV/0!	-	#DIV/0!
Drying Section	-	-	-		-			-	#DIV/0!	-	#DIV/0!
Others								-	#DIV/0!		#DIV/0!
Total	-	-	-	-	-	-	-	-	#DIV/0!	-	#DIV/0!
Total in percent	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!			#DIV/0!

specific values are based on ton gross pope

3.5 Summary and conclusion

Generally it is to say that a benchmark of paper machines is complicated as there is no machine like the other. Many paper machines are dozens of years old and only components are replaced by better ones during this time. It is seldom to build a complete new mill (Greenfield mill), as there is already a mill existing.

So we have to live with the fact that the benchmark of mills and paper machines is afflicted with some problems.

The most important and time consuming point in my thesis was to define clear borders of the sections of a paper machine. Therefore the creation of a model paper mill was necessary to break down a mill into different levels. For these levels I could then consider and list all installations that can occur.

Based on this standard a consistent input and further more a consistent evaluation of the energy consumption is possible. The evaluated data coincide quite well with the data of the energy officer. But we have to consider that I only could compare the results at level one and two as there was no more detailed information till now. And in the literature there is only little data based on level three and four. But I calculated the results of level two on the basis of the results of level three and four and so we can assume that all important energy consumers are considered in my project. Otherwise my results would not match with the present data.

I think it would be a good approach to execute my procedure and benchmark at every mill within the Mondi BP group. It is a quite complex way to get to the energy data but doing it once is a good tool for detailed observation concerning energy consumption.

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Attachment – test run PM6:

Here the results of the test run at the PM6 are given. Note that the data based period for the mill was the year 2005 and the data based period for the PM6 was December 2005!

Mill Data Sheet PM6

Name of mill:	**mbpat**

Integratred paper mill Y/N:	n	Type of paper:	**ucwf**

	Mechanical pulp	Kraft (sulphate) pulp	sulphite pulp
Type of pulp production (X):			

Data based period:	2005

paper saleable: [t]	263.013

Own production energy (net)			
	Amount of units	Cost per unit [€]	Total Cost [€]
Electricity from Steam turbine [MWh]	96.818	31,50	3.049.767
Electricity from Gas turbine [MWh]			
Electricity from Hydro [MWh]			-
Total [MWh]	**96.818**		**3.049.767**
Steam from Recovery Boiler [GJ]			-
Steam from Energy Boiler [GJ]	1.725.645	4,30	7.420.274
Total [GJ]	**1.725.645**		**7.420.274**

External purchased energy input

	Amount of units	Cost per unit [€]	Total Cost [€]
Electricity [MWh]	84.900	39,60	3.362.040
Steam [GJ]			-
Purchased Energy (electricity + steam)			3.362.040

External purchased fuel input					
	Amount of units	Cost per unit [€]	net calorific value [MJ/unit]	Total Cost [€]	Energy amount [GJ]
Natural gas [Nm³]	54.300.000	0,14	36	7.602.000	1.954.800
District heating [MWh]				-	-
Fuel Oil [t]				-	-
Coal [t]				-	-
Biomass (bark, saw dust,...) [t] atro				-	-
Sludge [t] atro				-	-
Fine Ash [t]				-	-
waste and others [t]				-	-
Purchased fuel				7.602.000	1.954.800

Revenues of energy sold			
	Amount of unit	Revenue per unit [€]	Total revenue [€]
Electricity [MWh]	-		-
Steam [GJ]	32.400	1,00	32.400
Others [GJ]			-
Energy sold			32.400

total energy costs	13.799.681

Mill steam consumption [GJ]	Mill electricity consumption [MWh]	specific steam consumption [GJ/t]	specific electricity consumption [MWh/t]	Specific costs/ ton of paper [€/t]
1.693.245,00	**181.718,00**	**6,44**	**0,69**	**52,47**

Attachment 1: Mill Data Sheet – Mondi BP Hausmenning

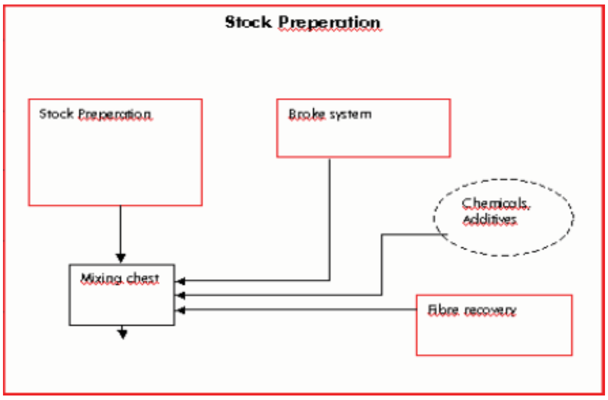
PM Data Sheet PM6

Name of mill:	**mbpat**	Paper machine:	**pm6**
data based period:(mm.yy)	may06		

Paper production gross pope: [t]	16.387,7
Paper production net rewinder: [t]	15.650,6
Paper production after finishing: [t]	14.868,0

dry solid content after headbox	%	1
dry solid content after press	%	52
dry solid content before sizing	%	98
dry solid content after sizing	%	66
dry solid content before pope	%	95
filler content	%	
Speed PM	[m/min]	1200
grade	[g/m²]	80
effective runtime	days	

Stock Preperation



Number of fibre lines:	3

REFINER	Steep cone refiner (Steilkegel)	Flat cone refiner (Flachkegel)	Disk type refiner	Others	nr. of refiner
Type of refiner:					
nr. of refiner:		8			

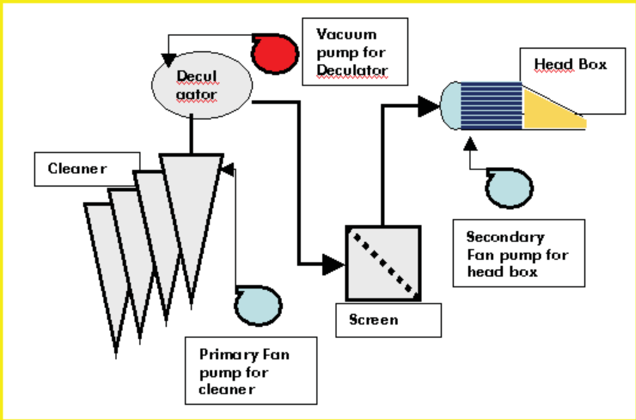
Broke system	after run contactor	tearing contactor	continous running	nr. of pulper
couch pulper (x)	x			2
press pulper (x)	x			2
pulper at winder (x)			x	2
pulper at speed sizer (x)			x	2
other pulper (x)				

	Sedimentation	Filtration	Flotation
type of fibre recovery (X)		x	

the values for the orange fields should be read off by the meter reading

	Electricity pumping [MWh]	Electricity mixing [MWh]	Electricity refining/deflaking [MWh]	Electricity others [MWh]	Thermal energy [GJ]
stock preperation	168,06	330,93	1767,54	16,77	
Broke system	38,48	280,90		36,79	
Fibre recovery	131,49				
Total Stock preparation	**338,03**	**611,83**	**1767,54**	**53,56**	**0,00**

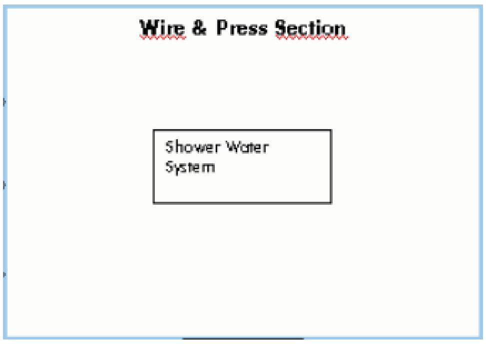
Constant Section



no vacuum and no drive - it is asked seperately!!

	Electricity pumping [MWh]	Electricity mixing [MWh]	Electricity others [MWh]	Thermal energy [GJ]
Constant part	1093,24	120,91		

Wire & Press Section



	Fourdrinier	Hybrid Former	Gap Former
Type of paper machine configuration:(X)			x
Shoe press Y/N	y		
Conventional press Y/N	y		
Number of press nips:	3		

no vacuum and no drive - it is asked seperately!!

Wire & Press Section	Electricity pumping [MWh]	Electricity others [MWh]	Thermal energy [GJ]
Shower water system	199,10	76,54	

Drying Section

	fresh air capacity	exhaust air dew point [C°]	exhaust air temperature [C°]	ind. air temp. below cylinders [C°]
heat recovery				

	Number of cylinders for contact drying	Number of vacuum cylinders (no steam)	Infrared drying gas heated Y/N	Infrared drying electrical heated Y/N
Pre - drying	40		n	n
After - drying	13		n	n

nr. of drying groups	standard wire	spiral wire	aero plus wire
slalom configuration		8	
standard configuration (top,down)			

	film press	conventional press	coater
Type of size press:(X)	x		

materials for doctors	steel	carbon	others (brass, plastics)
doctors drying section (X)	x	x	x

	Calender Y/N	Soft nip Y/N	Number of nips:	Calender online Y/N
Type of calender	y	n	1	y

	Electricity pumping [MWh]	Electricity mixing [MWh]	Electricity ventilation [MWh]	Electricity others [MWh]	Thermal energy [GJ]
Heat recovery - pre drying			323,14		
Heat recovery - after-drying			135,23		
shower water and condensate system (hood, hall-heating)	13,17			12,49	
sizing and starch station	2,61				
calendering					
others					
total drying section	**15,79**	**0,00**	**458,37**	**12,49**	**65.531,00**

	Electricity PM-drive [MWh]	Electricity Vacuum [MWh]
total consumption PM	1.937,30	1.143,55

Final results - test run PM6

Here you see the final results for the paper mill and the PM 6 in Hausmenning.(see Table 24) Comparing to literature you will see that this mill is working quite good (see Table 23). As the total demand for energy consumption in the form of heat (steam) and electric power for a non-integrated fine paper mill has been reported to consume:

Table 23: Mill energy consumption – compared to literature[114]

		Hausmenning	Literature
Process heat	GJ/t	6,44	8
Electric Power	kWh/t	690	674[*)]

[*)] this data does not yet take into account the losses when transferring the energy of fossil fuels into electricity. When converting purchased electricity into primary energy consumption, energy yield of the electricity generating companies of 36.75%, can be assumed. In this case an electricity consumption of 674 [kWh/t] corresponds to 1852 [kWh/t] primary energy (e.g. coal).

[114] SEPA-report 4712-4, (1997)

Table 24: Final results PM6

Final results for the energy benchmark of a paper mill:

name of mill	mbpat
data based period	may06

level 1 - paper mill

	[GJ/t]	specific steam costs[€/t]
steam cons./ton paper saleable	6,44	28,09
	[MWh/t]	specific electricity costs[€/t]
electricity cons./ton paper saleable	0,69	24,38

Specific costs/ ton of paper [€/t]	Evaporation Efficiency %
52,47	**68,28%**

level 2 - paper machines

PM	pm6	pm5
spec.elec.cons./ton gross pope [MWh/t]	0,45	0,29
spec. steam cons./ton gross pope [GJ/t]	4,00	5,77

	PM	pm6	pm5	total	
dry solid content after headbox	%	1	1		
dry solid content after press	%	52%	44,00%		
dry solid content before sizing	%	98%	98,50%		
dry solid content after sizing	%	72%	66,30%		
dry solid content before pope	%	95%	95,30%		
filler content	%				
Speed PM	[m/min]	1200	700		
grade	[g/m²]	80	60-100		
rel. Evaporation	[%]	116%	161%		
tons paper gross pope	[t]	16.387,72	9.441,01		348.544,80
total Evaporation	[tH2O]	19.006,95	15.238,83	34.245,79	
yearly evaporation in process	[GJ/year]	547.400,27	438.878,34	986.278,61	
required energy for evaporati	[GJ]	895.945,07	787.423,14	1.334.823,41	
Evaporation Efficiency %	%			68,28%	

level 3/4 - PM6

	Electricity pumping [MWh]	Electricity mixing [MWh]	Electricity ventilation [MWh]	Electricity refining/deflaking [MWh]	Electricity others [MWh]	Electricity PM-drive [MWh]	Electricity Vacuum [MWh]	Total Electricity [MWh]	Specific Electricity [MWh/t]	Thermal energy [GJ]	specific thermal energy GJ/t
Stock Preperation	338,03	611,83		1.767,54	53,56			2.770,95	0,17	-	-
Constant Section	1.093,24	120,91			-	894,74		2.108,89	0,13	-	-
Wire & Press Section	199,10				76,54	894,74	1.143,55	2.313,92	0,14	-	-
Drying Section	15,79	-	458,37		12,49			486,65	0,03	65.531,00	4,00
Others								-	-		-
Total	1.646,15	732,74	458,37	1.767,54	142,58	1.789,48	1.143,55	7.432,66	0,45	65.531,00	4,00
Total in percent	22,15%	9,86%	6,17%	23,78%	1,92%	24,08%	15,39%	100,00%			3,45

specific values are based on ton gross pope