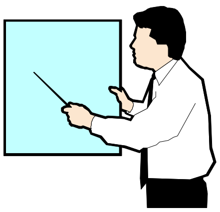
3 – BACKGROUND MATERIAL

3.1 Purpose of the textbook „Material flow analysis“



After having worked with this textbook you will be able to describe and illustrate any material flow occurring in a company and to write a systematic full documentation. You will be able to:

- Trace the flow of raw materials through the company;
- Retrace waste to the point where it is generated;
- Edit data in a decision-oriented way;
- Identify weaknesses in the production process;
- Set priorities for appropriate measures aimed at minimizing waste and emissions.

This will enable you to fulfil the waste documentation requirements within a company and to work out a detailed waste management concept. Furthermore, you will detect weak points in material utilization and define measures to minimize them.

3.2 What is a material flow analysis?

The so-called "material flow analysis" is a systematic approach aiming at:

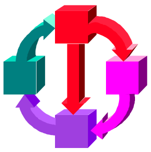
- Presenting an overview of the materials used in a company;
- Identifying the point of origin, the volumes as well as the causes of waste and emissions:
- Creating a basis for an evaluation and forecast of future developments;
- Defining strategies to improve the overall situation.

Waste and emission problems of a company arise at those points of production where materials are used, processed or treated. If a company wants to find a strategic solution to environmental problems, it is essential to capture the current material flows in a model in order to identify points of origin, volumes and causes of waste and emissions. Furthermore, in a material flow analysis the composition of the used substances is analysed, their economic value is estimated and possible future developments are forecast. The introduction of an information system will enable the management to retrace material flows within the company, to direct them and to guarantee that they are efficiently used.

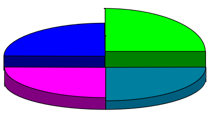
„A material flow analysis is a systematic reconstruction of the way a chemical element, a compound or a material takes through the natural and/or the economic cycle. A material flow analysis is generally based on the principle of physical balance". (German commission of inquiry "Schutz des Menschen und der Umwelt" – Protection of human life and the environment – of the Deutsche Bundestag, 1993)

Thus a material flow analysis can be compared to a geographical map which, instead of cities, roads or rivers, shows process steps and material flows. A graphical representation specifying origin, use and treatment of raw and process materials facilitates the rapid and easy interpretation of the information obtained from a material flow analysis.

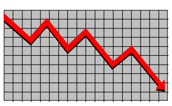
The following types of charts can be used for the graphical representation of a material flow analysis:



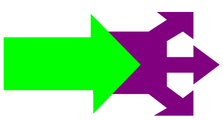
- **Flowcharts** representing material flows and process steps;



- **Pie charts and histograms** illustrating ratios and compositions;



- **Time-travel diagrams** showing time relations;

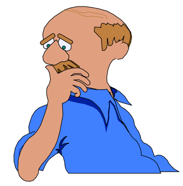


- **Sankey diagrams** visualizing material flows true to scale.

These charts and diagrams are widely used by large companies operating in the pulp and paper industry or in the chemical and petrochemical sectors. Why not use them for your own purposes?

3.3 How to carry out a material flow analysis

A complete material flow analysis comprises seven steps.



1. Define the objective of the material flow analysis and the parameters to be monitored.
2. Define the balance scope.
3. Define the balance period.
4. Identify and define process steps.
5. Draw the flowchart: material flows – qualitative approach.
6. Draw up balances: material flows – quantitative approach.
7. Interpret the results and draw conclusions.

Steps two to five are also called "system analysis". In the course of a system analysis, relevant system elements are identified and the relationship between them is established.

In the following, these steps are described in more detail.

1. Defining parameters

Which materials are to be traced?

One of the objectives of a material flow analysis is to retrace interesting flows of goods, certain chemical compounds or single elements through the company with regard to various criteria (costs, risks, safe disposal, volumes). It is important to decide right from the beginning, how exact this analysis has to be.

The best way of defining the objective is to start with a material flow analysis of the company as a whole. First of all, a global input/output analysis answers the following questions:

- What materials are used in the company?
- What quantities of materials are processed?
- What is their economic value?
- What quantities of waste and emissions are disposed of at the end of the production process?

Based on stock-keeping or accounting records, all raw and process materials as well as all energy sources are listed in terms of quantity and value. Products and emissions are listed using the same procedure. In this context we can speak of a material balance at company level. A more detailed analysis will primarily investigate expensive and ecologically problematic materials. For the definition of priorities, the identified material flows are then ranked according to their value and toxicity in the form of an ABC analysis.

Tip: Take the list you have drawn up during your work with Volume 1 containing the ten most expensive raw materials, the ten most hazardous materials and the ten most important types of waste occurring in a company. If any data are missing, estimate them and collect the exact data afterwards. Which of these materials do you want to retrace in detail? What is the most urgent problem? Rank the material flows according to their value and toxicity in the form of an ABC analysis. Later on, in a case study, we will trace the flow of water through a brewery.

2. The balance scope

Define the balance scope

The balance scope can either comprise the company as a whole or be limited to individual processes. Its definition depends once again on the objective of the analysis: first, the company as a whole is analysed. In order to identify possible points for intervention, processes have to be divided into single steps.

3. The balance period

Choose the balance period

Choosing a specific time span as balance period has proved successful. This may be a balance year, a month, a production batch or a week of production.

4. Identifying and defining production steps

Listing processes and procedures

5. In the next phase, processes are divided into steps and represented in a flowchart. This flowchart should be based either on activities or on equipment, on production units or on profit centres. As graphical elements *rectangles* are used to indicate production steps and *arrows* for material flows.

Drawing the flowchart

Flowcharts illustrate the production process

As a next step, all relevant data on material flows, such as components, values, volumes, data sources, ecological relevance, are represented in the flowchart. In the same way, all important data of process steps (or equipment) such as temperature and batch size have to be documented. These flowcharts can be used to draw up a waste management plan.

6. Balances

Observe the principle of conservation

When drawing up a balance, the principle of conservation of masses has to be observed. This applies both to the entire company and to the system elements defined as "production steps". In a stable system the mass input into an element has to be equivalent to the output. All raw and process materials input into a certain element have to leave it in the form of either a product or of waste or emissions. For this reason we have to calculate in mass units [kg].

7. Interpretation

Interpret the flowcharts and balance sheets

Finally, the flowchart is interpreted. The material paths (illustration of the exact point where waste is generated, establishment of relations between raw materials and waste) are retraced and key figures in the form of efficiency ratios (cost-efficiency ratio) and performance ratios (real efficiency compared to theoretically projected efficiency) are calculated for the company as a whole as well as for the individual production steps.

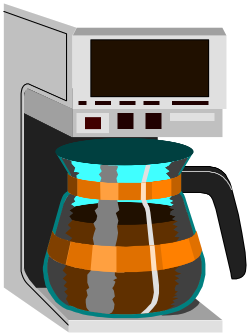
Tip: See also Volume 7 "Indicators and environmental controlling".

By comparing information on the real efficiency of processes to reference values weak points can be detected. They are ranked in order of priority and further analysed, inducing thus a discussion process within the company. These process data have to be updated on a regular basis in order to create an instrument for technical controlling and to document the development of material use and material flows.

Tip: Try to collect information on a particular problem material, machine or process: Do competitors also use this material? How much do they use compared to the examined company? Can the supplier provide a satisfying equivalent alternative?

The following strategies can lead to an improved material utilization:

- Good housekeeping in the sense of a thoughtful use and handling of raw and process materials (respect of product formulations, complete emptying of containers, sealing of leakages, etc.);
- Substitution of raw and process materials (by raw materials containing neither formaldehyde, nor heavy metals or chloride, etc.);
- Process modifications (automatic control, etc.);
- Product modifications;
- Internal recycling (closing of water circuits, recycling of valuable materials within the company, etc.)
- External recycling (recycling of scrap, composting biodegradable materials, etc.)



Case study: Analysing the material flow of making coffee

The following case study illustrates the systematic approach of a material flow analysis by a simple example: we are going to look into the process of making coffee and the related material flows in order to:

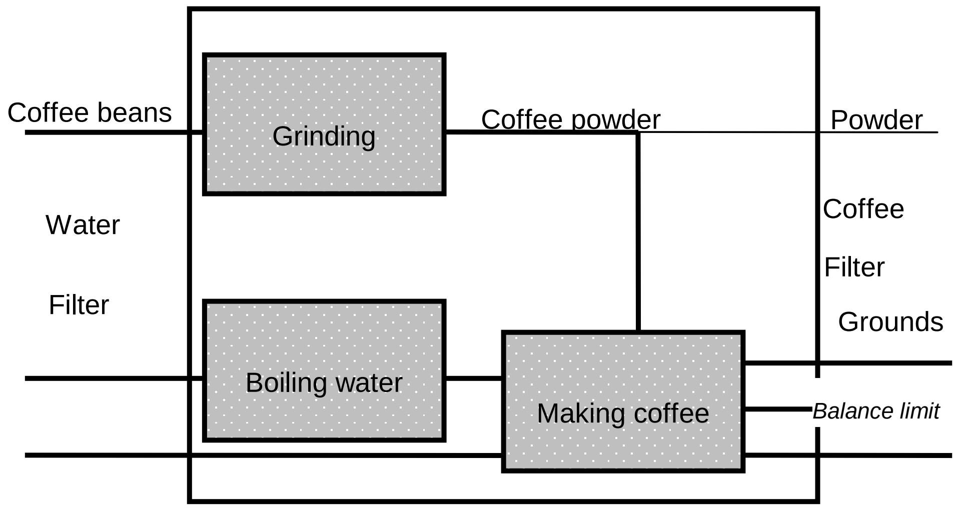
- Allocate the occurring wastes to individual process steps;
- Quantify the amount of waste produced;
- Define remedial measures.

Two cups of coffee are made. To do this, coffee beans are taken out of a storage box (in this case the packaging is not taken into account) and ground in a coffee grinder. A filter is put into the coffee machine to hold the coffee powder. Then the machine is filled with water and switched on. After about ten minutes the coffee is ready and can be poured into cups.

The necessary energy for the process and the waste heat produced are not taken into account. Likewise the steps of "filter production", "coffee purchasing", "coffee planting", "coffee roasting", "coffee packaging", "coffee storing", "water treatment", "drinking", "disposal of the filter" are omitted. The main goal of this analysis is to reduce the solid waste to be disposed of. The following list summarizes the individual steps.

1. **Parameters considered:** *material flows (coffee beans, water, filter); in this case, it is not necessary to go into further details;*
2. **Balance scope**: *the process steps of "making coffee" as well as all other relevant steps are grinding, boiling water and brewing;*
3. **Balance period**: *one brew as representative period comprising all relevant activities and materials in usual amounts;*
4. **Process steps**: *"making coffee", sub-sequences: coffee grinding, water boiling, brewing.*

5. Drawing a flowchart



6. Quantitative overview of the material flow:

Complete process	Material flow	Mass [g]	Costs [Cent]	Origin/destination
Input:	Coffee beans	10	51	Raw material
	Water	250	2	Raw material
	Filter	2	15	Process material
Output:	Coffee	220	256	Product
	Residual powder	1	0.02	Non-recyclable waste
	Used filter	7	1	Non-recyclable waste
	Coffee grounds	34	7	Non-recyclable waste
Balance				
	Input = Output	**262**		

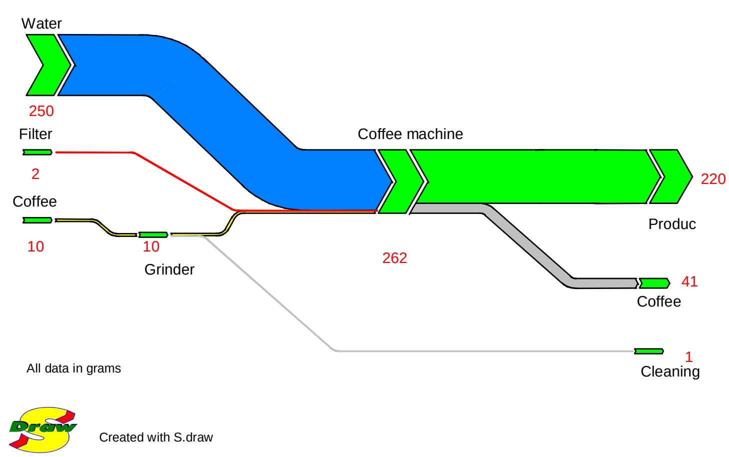
The data were collected by weighing and measuring as well as by an accounting analysis.

Sub-sequence of making coffee	Material flow	Mass [g]
Input:	Coffee powder	9
	Water	250
	Filter	2
Output:	Coffee	220
	Used filter	7
	Coffee grounds	34
Balance		
	Input=Output	**261**

Similar balances should be drawn up for the other two sub-sequences.

In the following, all results of the material flow analysis are represented in a sankey diagram.

Sankey diagram



Description of the equipment used

Coffee grinder:

Type	COGRI I
Capacity	10 g
Power rating	50 W

Coffee machine (the water is boiled and the coffee is made in the same machine):

Type	COCO II
Capacity	8 cups
Power rating	500 W

The above data were taken from labels and/or the operating instructions.

7. Interpretation:

Generally speaking, it has to be stated that the existing coffee machine is badly used: the machine can produce 8 cups, but on average only 2 cups are made at the same time. Better utilization of the capacity could reduce the amount of disposable filters required.

During grinding and coffee brewing solid waste is produced: in the grinding step residual powder is left behind in the grinder and in the brewing step waste is generated in the form of a used coffee filter containing residual wet ground coffee. For several reasons (hygienic, practical reasons) this waste cannot be re-used. Altogether the solid waste generated amounts to 16% of the overall input, 70% of this waste, however, consist of water. The following strategies can reduce the waste to be disposed of:

a. Good housekeeping

Empty the coffee grinder completely. While the disposal costs for the solid waste avoided amount to only 0.02 cent, the value of the powder (purchasing costs!) adds up to 5 cents.

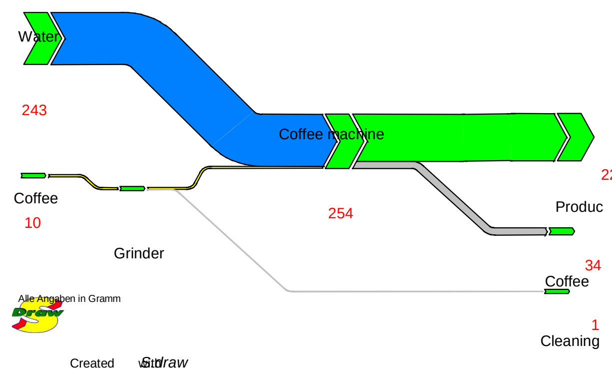
b. Other ways of disposal

Composting the used filter and coffee grounds: the same disposal costs are incurred. On the other hand, composting makes more sense than disposal as valuable material is externally recycled.

c. Changing process materials

Substituting the paper filter by a cleanable gold filter and composting the coffee grounds: using the goldfilter saves the costs for the paper filter and the disposal. The time needed to place the filter in the machine is not taken into account. The time for cleaning the filter is defined as equivalent to the time required to take the used paper filter out. The goldfilter is mechanically cleaned. At a price of € 46, the goldfilter is amortized after 90/0.32 = 281 processes of making coffee, i.e. within a year.

Sankey diagram



d. Minimizing the amount of raw materials used

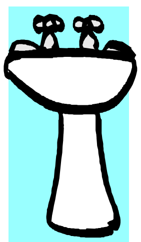
Drawing up a time-travel diagram in order to optimize coffee utilization: the quantities of coffee powder used for each brew are plotted in a diagram and compared to each other. If the variation among them or from the predefined reference amounts to more than 5%, for example, the causes of these variations have to be discussed in order to define appropriate remedial measures (e.g. using a measuring spoon). Furthermore, the indicator "coffee bean consumption per gram of finished coffee powder" is calculated. In our example this is 0.045g of coffee bean consumption per gram of finished coffee.

3.4 Material flow analysis for water

There are hardly any companies where water is not used in some way. Water is a precious commodity, which must not be wasted – and furthermore, it is not necessary to treat avoided wastewater.

Water is valuable and expensive

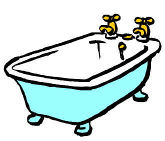
Operational water management is faced by considerable costs for the provision of fresh water and wastewater discharge as well as for the internal wastewater treatment. The costs for the discharge or disposal of water can vary from region to region and range – without any internal treatment – from € 0.5 to € 5 per m^3 (in some parts of Germany it is even more expensive).



The efficient use of water goes hand in hand with CP in terms of environmental protection and economy. By using water efficiently, especially by introducing CP measures for warm water production, considerable savings can be achieved. For this reason we have to focus on the issue "water" in a company and collect data by means of a material flow analysis.

Drawing up a water balance

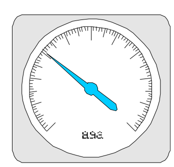
First a water balance is established determining the amount of water that is piped into the company (input from municipal water, wells, etc.). This amount has to leave the company again (output by discharge, contained in the product, evaporation, etc.). In the company itself, the different water consumers determine the overall water consumption.

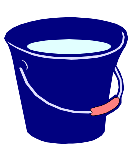


The objective of the water balance is to identify the streams or technical adjustments which have the potential to improve the water consumption in an ecological and economic way – improvements by reducing water consumption and/or the content of toxic materials in the water.

Compared to many other material flows, collecting data of water consumption is relatively easy because the following documents or tools are in most cases available:

- Annual payment to provider or to disposal companies;
- Water meter, water counter;
- Turbine wheel meter;
- Rotameter;
- Induction measuring instrument;
- Ultrasonic flow meter;
- Weir;
- Measuring at water consumers (stop watch, bucket);
- Estimating, calculating;
- Design specifications by manufactures of equipment;
- Indicators.





Example: According to literature, the reference value for the water consumption of a clerk is:

Administration building: 30 – 50 litres per day and employee (sanitary and cleaning water).

Water saving measures

Measures for minimizing water consumption can be classified according to the "tree of measures" (for further information, see also the textbook of Volume 1, chapter 1.5). Many of these measures are rather sophisticated, therefore we will not go into further details at this point. The feasibility of the measures has to be examined for each individual case.

- **Level 1: Measures at the source**
  - Dry-cleaning process;
  - Mechanical pre-cleaning;
  - Principles of reverse flow;
  - Cascade-use of waste;
  - Water saving fittings;
  - High-pressure cleaning appliance;
  - Discharge limiter;
  - Spring-loaded valves to interrupt water flow;
  - Reduction of harmful components in the wastewater;
  - Separation of wastewater streams;
  - Evaluation of data;
  - Use of process indicators;
  - Control engineering in view of water saving;
  - Use of rain water;
  - Selection of chemicals and purifiers in view of minimal water pollution;
  - Metering systems;
  - etc.
- **Level 2: Internal recycling**

Multiple use and reuse of water

Reuse for non-critical cleaning purposes, use of cascades, recovery by filter systems, closing water cycles, etc.

Carrying out a material flow analysis for water using the Worksheets

When carrying out a material flow analysis for water, first establish a water balance using Worksheets 3-1 and 3-2. Next measure, calculate, estimate, etc. the amounts of the most important water consumers (see above). If you have no important water consumers apart from sanitary water, you can also enter the percentage in the column with the heading "%".

For wastewater discharge, please state whether you discharge directly (into a river) or if you discharge indirectly into a sewer and then into an external public sewage plant. Furthermore, enter important constituents the company discharges (substances that are more polluting than sanitary water) as well as limit values from legislation. If the wastewater is pre-treated internally (oil separator, biological treatment, heavy metal precipitation), please describe this process briefly.

3.5 Information sources

System analysis for material flow

First of all, draw a flowchart using Worksheet 3-1. In order to carry out a material flow analysis for this case study, the following data are necessary:

- Type;
- Quantity;
- Value;
- Point of use or of generation.

As a next step, you have to determine this information for the company using Worksheet 3-2 (Water data sheet) and Worksheet 3-3 (Material tracing sheet) for any other material flows than water.

The numbering as well as the water consumers in Worksheets 3-2 and the materials in Worksheet 3-3 should correspond to the flows in the process flowchart (Worksheet 3-1).

Water balance in m³

As we have mentioned before, balances are usually made out in mass units (kg, t, g), because in this way it is easier to compare the mass input to the corresponding mass output. Therefore, the flows in the material tracing sheet should be stated in mass units. For the water balance, however, we use m³ (1 m³ = 1 000 litres), because this is the most widely used unit of water measurement.

The data required for a material flow analysis can be obtained from different sources such as EDP, routine measurements, individual measurements, information from the production department, documentation of equipment, but also by calculating or estimating. These data sources are listed in the footer of Worksheets 3-2 and 3-3.

Data on the input of raw and process materials are available from the accounts department or the logistics department. Data concerning process flows are available from the computer department (e.g. production planning and control), from the foremen or workshop masters themselves, from job planning or production records. If all these sources do not permit the collection of the necessary data on quantities and values you will have to carry out own measurements or else rely on estimates.

Output data are usually detailed on control sheets. Thus the flow of a certain material can be retraced from the point of entry into the company following its way through diverse processes to the point of output. Ideally you will be able to draw up a coherent material balance: input has to be equivalent to output. The same applies to detailed balances and individual process steps.

A good estimate is always preferable to having no balance at all. An estimate with an accuracy of 80 – 90% is usually sufficient.

3.6 Material flow analysis in SMEs (small and medium-sized enterprises)

Typical problems

There are many problems you can face when establishing a detailed material flow analysis in an SME:

- No process control system;
- No measuring instruments;
- Not enough time and personnel;
- Not enough knowledge about material flow balances;
- Little insight into necessities – the benefit of a material flow analysis;
- The costs are not proportional to the benefits;
- No typical production companies;
- High inaccuracy.

Recommendations:

Awareness and recom-mendations

- Carry out the material flow analysis in steps.
- An estimate is better than doing nothing at all.
- Even with estimates it is possible to improve.
- 80 – 90% of accuracy is sufficient.
- Use simple measuring instruments.
- Use indicators (see also Volume 9 – Environmental controlling).
- If necessary, contact the supplier or plant manufacturer.

- It is not essential to follow the instructions or procedures in great detail, a creative approach is often helpful.
- Even by simply working with the balances you can sometimes achieve improvements.

It is important to translate the results into the language of the respective target group (monetary units, kg, pictures, comparisons, etc.).

3.7 The use of data sheets and EDP programmes

Before handing over worksheets and checklists to plant personnel, check if they are suitable for this particular case and adapt them, if necessary. If the data collection sheets are transmitted to a technician for completion, make sure that he is informed about the important points.

Tip: Make sure that you fully understand the worksheets of this volume! Make sure that you fully understand the checklists for waste avoidance in Volume 1!

Today PC and spreadsheet programs, such as MS-Excel, are standard equipment in every office. They can also be very helpful for data administration and for the development of graphical analyses and presentations.

TIPS

Tips and questions for a material flow analysis

Tip/question/measure	
Make sure that you fully understand the individual steps of the material flow analysis (Chapter 3.2).	☐
Discuss with the environmental team which materials should be included in a detailed material flow analysis (possible criteria are: volume, costs, toxicology, etc.).	☐
Obtain the data about costs of these materials from the accounts department.	☐
Make a list of the tasks or process steps where the materials you have chosen are used.	☐
Record the waste generated by each step or task. Then weigh the waste generated at the respective location every day during a week.	☐
Use the weight shown on the invoice of the disposal company as information.	☐
Ask the water supplier for a discarded water meter which you can still use in a company.	☐
Ask the water supplier to measure the water flow rate.	☐
Check the use of rainwater.	☐
Check the criteria for the water bill (according to the real consumption, to the size of the company area, to the amount of sanitary facilities, etc.). Check also to which extent you can avoid water costs (especially if the costs do not depend on the amount you consume but on the amount of sanitary facilities, etc.).	☐
Metering water consumers is very simple and effective. Examples: the water flow rate for hand wash basins should not be more than 6 – 8 l/min; for showers not more than 12 l/min, otherwise build in water saving fittings.	☐
Examine the average cleaning time and procedures and the water used for cleaning.	☐
If you buy new equipment, always take into account the water consumption indicator.	☐
Read the meters every morning and evening from Monday to Friday to check, if water is consumed after finishing-time (e.g. due to leaks or open valves, etc.).	☐