Manual on Material Flow Cost Accounting: ISO 14051

ASIAN PRODUCTIVITY ORGANIZATION

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FOREWORD

Material flow cost accounting (MFCA), developed in Germany in the late 1990s and since adopted widely in Japan, focuses on tracing waste, emissions, and nonproducts and can help boost an organization's economic and environmental performance. It is one of the major tools of environmental management accounting (EMA). EMA is a set of procedures used within enterprises for linking environmental considerations with economic objectives. Today, organizations cannot ignore the environmental aspects of their activities. Consequently, they seek management tools to link concern for the environment with their bottom lines. MFCA is a management tool that promotes the efficient use of materials more effectively, contributing to reductions in waste, emissions, and nonproducts. MFCA increases the transparency of material flow, which is a key to successful problem-solving and improvement. By solving problems, organizations can increase their resource productivity and reduce costs at the same time. This is in line with the Green Productivity (GP) concept and can be used to implement GP in organizations and factories. The Government of Japan is currently taking steps to enhance understanding of MFCA and to accelerate its widespread adoption. MFCA is already in place in more than 300 Japanese companies.

To standardize MFCA practices, a working group of the ISO Technical Committee ISO/TC 207, Environmental Management, developed ISO 14051, which complements the ISO 14000 family of environmental management system standards, including life cycle assessment (ISO 14040, ISO 14044) and environmental performance evaluation (ISO 14031). The standard was published in the second half of 2011. MFCA has been receiving increasing attention throughout the Asia-Pacific, including APO member countries, along with national environmental management concerns. The APO organized a series of training courses and workshops on MFCA starting from 2011 and offered a self-learning e-course in 2013.

This Manual on Material Flow Cost Accounting was prepared based on feedback from and needs of APO member countries. I hope that the publication will be useful to GP/MFCA practitioners and professionals while promoting sustainable development practices in the region.

Mari Amano
Secretary-General
Tokyo
September 2014

INTRODUCTION: GREEN PRODUCTIVITY AND MFCA

K. D. Bhardwaj
APO Senior Program Officer

Green Productivity (GP) was defined by a group of APO experts as "…a strategy for enhancing productivity and environmental performance for sustainable socioeconomic development. It is the application of appropriate productivity and environmental management tools, techniques, and technologies to reduce the environmental impact of an organization's activities, products, and services."

GP is not a new concept but has emerged gradually from the basic concept of productivity. GP integrates the productivity and environmental concepts to produce goods in cleaner, greener ways. This also ensures reduced environmental burden and input costs, along with improved quality and profitability. It is especially important for small-scale industries because it concentrates upon the preventive approach.

GP can be explained as adoption and implementation of environmentally sound processes, practices, and procedures to optimize the utilization of resources with minimum environmental impact. In other words, this concept focuses upon enhancing productivity without creating adverse environmental impacts. Seen from a different perspective, improvement of the environment should have beneficial rather than deleterious effects on the quantity and quality of products. Thus GP stresses optimum utilization of space, manpower, energy, and raw materials, i.e., all the factors of production. GP aims at overall socioeconomic development that leads to a sustained improvement in the quality of life.

NEED FOR GP

Conventional productivity improvement efforts focused on cost-effectiveness through cost reductions, and environmental protection focused on nonproductive end-of-pipe (EOP) solutions. With the growing awareness that quality, health, and safety aspects were involved in productivity improvement in addition to cost, a number of programs and techniques, like total quality maintenance and total productive maintenance for equipment maintenance, 5S for structured, systematic housekeeping, and kaizen for continual improvement were developed. Similarly, compared with conventional EOP treatment alone, pollution prevention is usually more cost-effective, often resulting in reduced energy and material usage and costs.

To some extent, productivity practices like preventive maintenance, good housekeeping, etc. reduce environmental burdens. However, productivity practices and pollution prevention programs alone cannot manage the total environment and sustain development. There is a need to integrate productivity improvement into pollution prevention and control programs for sustainability.

The need for a fundamental change by moving businesses toward resource efficiency and taking a holistic life-cycle view of products was recognized in the 1990s. Resource efficiency not only leads to conservation of natural resources but also results in improved productivity and environmental performance. Therefore, if development is to be sustainable, we must move beyond preventive approaches and ensure that both productivity improvement and environmental protection are achieved simultaneously. Recognizing this, the APO has integrated this approach into the concept of GP.

The goal of GP is to achieve higher levels of productivity to serve the needs of society and to protect and enhance the quality of environment both locally and globally. GP leads to gains in profitability through improvements in productivity and environmental performance. In other words, GP can improve the bottom line of every sector of society.

TRIPLE FOCUS OF GP

GP recognizes the importance of both the environment and development, and the concept of GP shows that for any development strategy to be sustainable it must have a focus on quality, profitability, and the environment. Quality is dictated by the voice of the customer for both goods and services. GP works at ensuring quality by promoting the use of newer, safer materials, increasing processing and production efficiency, and improving working conditions.

The intent of GP is thus to provide the consumer with more performance and value with the use of fewer resources, including energy, and the creation of less waste i.e., "doing more with less."

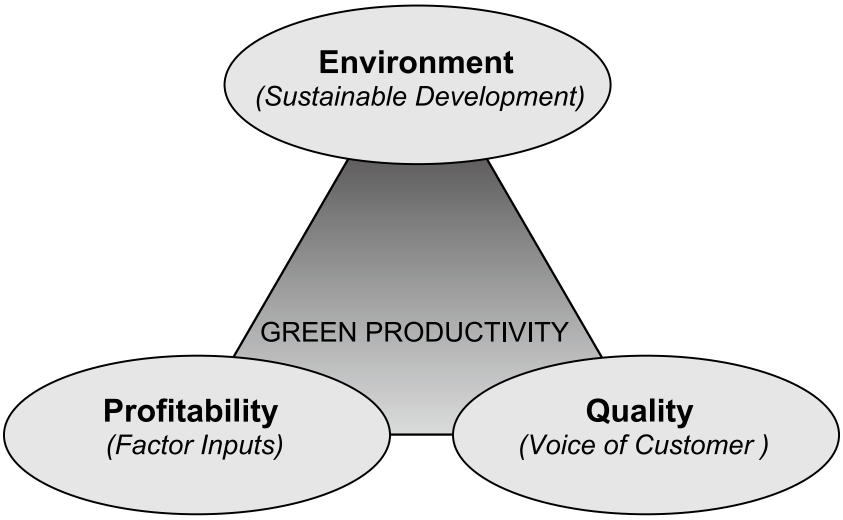

Figure 1: Triple Focus of GP

This makes sense both for the environment and for business. Natural resources are conserved, thereby reducing environmental degradation in many ways. The cost of production is also reduced, thereby ensuring profitability. Savings may also come from lower waste management costs or take the form of avoiding the cost of potential environmental liabilities.

BENEFITS OF GP

Implementation of the GP strategy will have both immediate and long-term benefits. The benefits accrue to producers as well as to consumers and include increased efficiency gains in resource use, lower costs of production, decreased costs of waste treatment and disposal, and better quality of products.

The adoption and practice of GP will also provide businesses with a competitive advantage. It will increase productivity growth rates in business, as a result of which market share and profitability increase. This shift toward integrating "the environment" and "productivity" enabled by GP has much greater implications for businesses, particularly in developing economies due to their technological and resource constraints. Opening of world markets and increased globalization have intensified the pressures on businesses, as they must meet international expectations. Workers will benefit from GP because it improves not only the workplace but also the health and safety of the labor force.

GP METHODOLOGY

The central element of the GP methodology is the examination and reevaluation of both production processes and products to reduce their environmental impacts and highlight ways to improve productivity and product quality. Implementing these options leads to another cycle of review and so promotes continuous improvement (see Fig. 2). The GP methodology revolves around the PDCA cycle. The six principle steps of the GP methodology are:

Step 1: Getting Started

The beginning of the GP process is marked by the formation of a GP team and a walk-through survey to gain baseline information and identify problem areas. At this stage, it is vital to get the support of senior management to ensure that adequate manpower and resources are available for successful GP implementation.

Step 2: Planning

Using the information gained in the walk-through survey along with a number of analytical tools such as material balance, benchmarking, eco-mapping, and Ishikawa diagrams, problems and their causes are identified and analyzed. Following this, objectives and targets are set to address the problem areas. Performance indicators are also identified.

Step 3: Generation and Evaluation of GP Options

This stage involves the development of options to meet the objectives and targets formulated in the planning stage. It involves both a review of pollution prevention and control procedures that have already been devised or implemented and the development of new options. Options are screened and prioritized in terms of their economic and technical feasibility and potential benefits. They are then synthesized into an implementation plan.

Step 4: Implementation of GP Options

The implementation of the selected GP options involves two steps: preparation and execution. Preparatory steps include training, awareness building, and competence development. They are followed by the installation of equipment and systems along with operator instruction and hands-on training.

Step 5: Monitoring and Review

Once the selected GP options have been implemented, it is vital to check whether they are producing the desired results. This involves monitoring the overall GP system to ensure that it is proceeding in the right direction and that targets are being achieved as per the implementation plan. Findings are reported for management review.

Step 6: Sustaining GP

In light of the findings of the GP evaluation, corrective actions can be taken to keep the GP program on target. In some cases, targets and objectives themselves will have to be modified. As the program progresses, a feedback system should be implemented so that new problems and challenges will be highlighted and dealt with. In this way, the GP cycle will loop back to the relevant step to implement a process of continuous improvement and ensure the continuing relevance and effectiveness of the GP process.

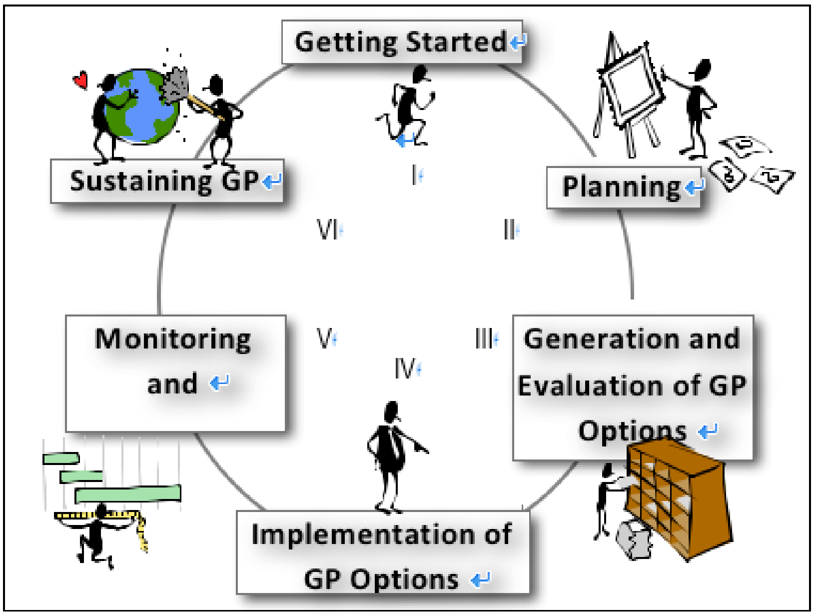

Figure 2: GP Methodology

GREEN PRODUCTIVITY AND MATERIAL FLOW COST ACCOUNTING

MFCA, developed in Germany in the late 1990s and since adopted widely in Japan, focuses on tracing waste, emissions, and nonproducts and can help boost an organization's economic and environmental performance. It is one of the major tools of environmental management accounting (EMA). EMA is a set of procedures used within corporations and other organizations for linking environmental considerations with economic objectives. Today, organizations cannot ignore the environmental aspects of their activities. Consequently, they seek management tools to link concern for the environment with economic considerations.

MFCA is a management tool that increases the transparency of material flow, which is a key to successful problem solving and improvement. By solving problems, organizations can increase their resource productivity and reduce costs at the same time. This is in line with the GP concept and can be used to implement GP in organizations and factories.

BASIC MANUAL ON MATERIAL FLOW COST ACCOUNTING (ISO 14051)

This manual was prepared to provide basic knowledge and understanding of material flow cost accounting (MFCA). It intends to be a manual that is comprehensive, up to date, and consistent with ISO 14051. It is recognized that:

- This manual is not intended to be the one and only manual on learning and applying MFCA.
- Learning levels and progress depend on the individual's learning abilities and exposures to the subject matter.
- Gaining practical experience through project implementation after formal training will greatly increase the speed and level of competency.
- Sole reliance on the manual is not advisable.
- Measuring, analyzing, and applying practical solutions to problems are subject to local conditions where MFCA is practiced and applied.

MODULE 1: GENERAL CONCEPT OF MFCA

WHAT IS MFCA?

MFCA is one of the major tools for environmental management accounting and promotes increased transparency of material use practices through the development of a material flow model that traces and quantifies the flows and stocks of materials within an organization in physical and monetary units.

It is a method of environmental management accounting that simultaneously achieves "reduced environmental impacts" and "improved business efficiency." MFCA is applicable to all industries that use materials and energy, of any type and scale, with or without environmental management systems in place (Clause 1, ISO 14051:2011). It can be seen as one alternative for organizations to consider environmental matters, including material scarcity, climate change, and increasingly stringent environmental regulations for any business decision and achieve sustainable development.

The method was originally developed in Germany and has been further developed in Japan. The inclusion of MFCA in the International Organization for Standardization (ISO) was an initiative from Japan. ISO 14051 was issued in 2011.

MFCA measures the flow and stock of all materials in the manufacturing process in both monetary and physical terms. The materials include raw materials, parts, and components. MFCA analysis provides an equivalent comparison of costs associated with products and costs associated with material losses, for example, waste, air emissions, wastewater, etc. In many cases, an organization is unaware of the full extent of the actual cost of material losses because data on material losses and the associated costs are often difficult to extract from conventional information, accounting, and environmental management systems. In this way, MFCA enables organizations to identify material use and their flows within a production process and assign costs to all of these materials.

Organizations are required to consider the environmental impact of their operations in every phase of said operations. Recycling, reusing, and reducing have been actively promoted in recent years and recycling has especially gained support among organizations trying to reduce the consumption of raw materials and their environmental impact. Although waste recycling is an effective measure for resource use, it is not always cost-effective as substantial inputs of energy and other expenses are often required. From an MFCA perspective, it is essential to reduce waste generation itself to increase resource use and cost efficiency.

MFCA identifies quantities of each material and its costs (including material, processing, and waste treatment costs). This enables us to look at each of the sources of waste generation in a separate way and identify improvement opportunities that could lead to the reduction of waste generation itself.

Using this information, organizations can identify the costs of losses caused by waste and other emissions, as well as defective products, and calculate the quantities and resources used in each process and the costs associated with these processes. MFCA acts as a strong motivation for organizations to reduce waste and material inputs, leading to cost reductions and increased productivity.

Reduction of waste generation leads to enhanced environmental performance in manufacturing processes by highlighting the importance of reducing inputs of raw materials. Hence, MFCA becomes a tool that allows organizations to establish a link between the need to reduce resource procurement in order to increase process efficiency of the operations and the need to reduce environmental impact at the same time. Therefore, MFCA serves not only as a tool for environmental purposes but also as a general management tool that helps organizations find ways to reduce their environmental impact while increasing profitability through cost reductions (Clause 4, ISO 14051:2011).

While MFCA is primarily designed for use within a single facility or organization, the approach can be extended to multiple organizations within the supply chain, enabling them to develop an integrated approach for more efficient use of materials and energy.

MODULE 2: CHARACTERISTICS OF MFCA

DIFFERENCE BETWEEN MFCA AND CONVENTIONAL COST ACCOUNTING (Clause A.1, ISO 14051:2011)

MFCA represents a different way of management accounting. In conventional cost accounting, the data are used to determine whether the incurred costs are recovered from sales. It does not require determining whether material is transformed into products, or disposed of as waste. In conventional cost accounting, even if waste is recognized in terms of quantity, the costs to produce "material losses" are included as part of the total output cost. On the other hand, MFCA, as explained before, focuses on identifying and differentiating between the costs associated with "products" and "material losses." In this way material loss is evaluated as an economic loss, which encourages the management to search for ways to reduce material losses and improve business efficiency.

Table 1. Difference between MFCA and conventional cost accounting.
MFCA calculates the associated with the material losses. (Unit: USD)

MFCA		Conventional accounting	
Sales	15,000,000	Sales	15,000,000
Product cost	3,000,000	Cost of sales	4,500,000
Material loss cost	1,500,000	N/A	N/A
Gross profit	10,500,000	Gross profit	10,500,000
Selling, general, and administrative expenses*	8,000,000	Selling, general, and administrative expenses*	8,000,000
Operating profit	2,500,000	Operating profit	2,500,000

The differences between MFCA and conventional cost accounting do not mean that MFCA cannot be applied to any organization that uses materials and energy. In other words, MFCA does not demand any specific requirement in regard to the type of product, service, size, structure, or location. In addition, MFCA can be expanded to multiple organizations belonging to the supply chain. This will enable the organizations to identify even more opportunities for material reduction as well as higher energy efficiency.

Wider MFCA scope than that for a single entity is especially helpful because waste generation in an organization is occasionally derived from materials provided by a supplier or demanded by customers/consumers (Clause A, ISO 14051:2011).

MODULE 3: ISO 14051: SCOPE, TERMS, AND DEFINITIONS

TERMS AND BASIC CONCEPTS
(Clause 3, ISO 14051:2011)

MFCA is constituted by three main elements, as shown in Figure 1:

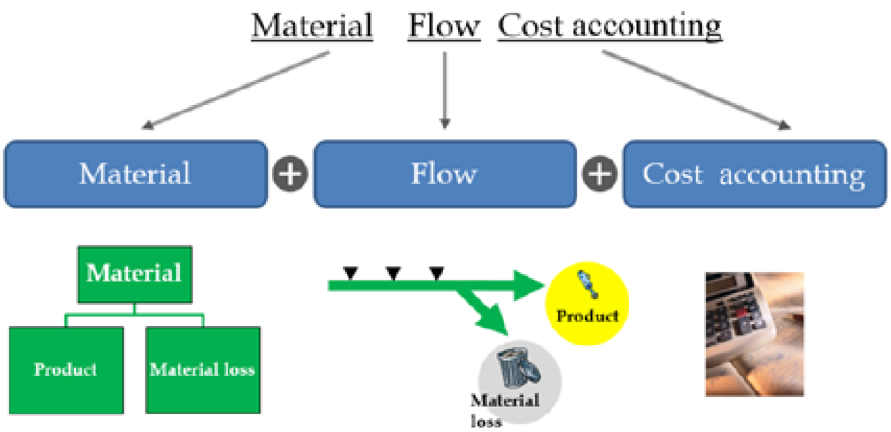

Figure 1. Main elements of MFCA. Each element is described below.

1. Material

Material refers to any raw material, auxiliary material, component, catalyzer, or part that is used to manufacture a product. Any material that does not become part of the final product is considered material loss. In any process, waste and resource loss occur in different steps of the process, including:

- Material loss during processing, defective products, impurities
- Materials remaining in manufacturing equipment following set-ups
- Auxiliary materials such as solvents, detergents to wash equipment, water
- Raw material that becomes unusable for any reason

2. Flow

MFCA traces all input materials that flow through production processes and measures products and material loss (waste) in physical units using the following equation:

Input = Products + Material loss (waste)

The starting point of MFCA is to measure the amount of material losses based on mass balance. The concept is illustrated in Figure 2. In this case, the amount of the material loss (30 tons) is calculated based on the amount of total input and products in a selected part of a process in which the inputs and outputs are quantified. This part of the process is defined as a quantity center in MFCA (i.e., Material loss = Input - Products), as Figure 2 shows.

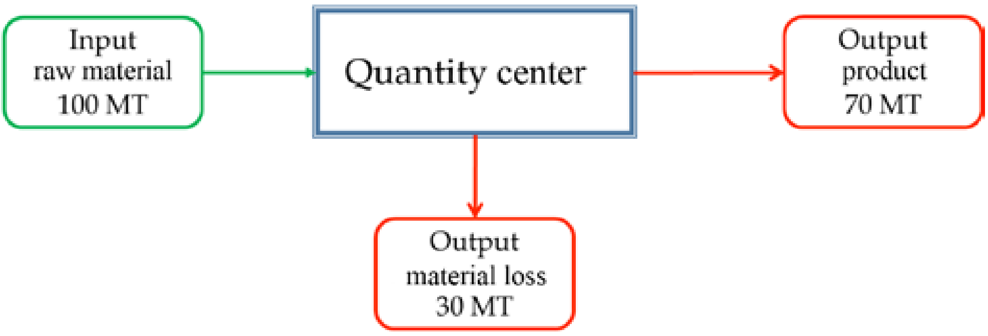

Figure 2. Concept of material balance.

Decision-making in organizations typically involves financial considerations. MFCA supports this point by assigning a monetary value to material losses. In detail, MFCA allows organizations to see material losses as "products" rather than "waste" even though they are not marketable. This indicates that costs for both products and material losses are calculated in an equivalent manner. Therefore, all costs caused by and/or associated with the material flows entering and leaving a quantity center must be quantified and assigned or allocated to those material flows (Clauses 3.14, 3.16, 5.2, ISO 14051:2011).

3. Cost Accounting

Under MFCA, the flows and stocks of materials within an organization are traced and quantified in physical units (e.g., mass, volume) and then assigned an associated cost. Under MFCA, four types of costs are quantified: material costs, system costs, energy costs, and waste management costs. Each cost is defined as follows:

- Material cost: cost for a substance that goes through a quantity center (measurement unit of input and output for MFCA analysis). Typically, the purchase cost is used as the material cost.
- Energy cost: cost for energy sources such as electricity, fuels, steam, heat, compressed air.
- System cost: cost incurred in the course of in-house handling of the material flows, excluding material cost, energy cost, and waste management cost.
- Waste management cost: cost for handling material losses.

Following identification of a physical unit for material flow data, material costs, energy costs, and system costs are subsequently assigned or allocated to quantity center outputs (i.e., products and material losses) based on the proportion of the material input that flows into product and material loss. For example, as illustrated in Figure 3, of the 100 tons of material used, 70 tons flow into product and 30 tons flow into material loss. Thus, the material distribution percentages of 70% and 30% are used to allocate energy and system costs to the product and material loss, respectively. In this example, the material distribution percentage based on mass is used to allocate these costs. On the other hand, in Figure 3, all waste management costs of $100,000 are attributed to material loss, since the costs are caused solely by material losses. In the final analysis, the total cost of material losses in this example is $520,000. This cost is not separated but included in the cost of the product in conventional costing; the cost for material loss is not considered except in MFCA.

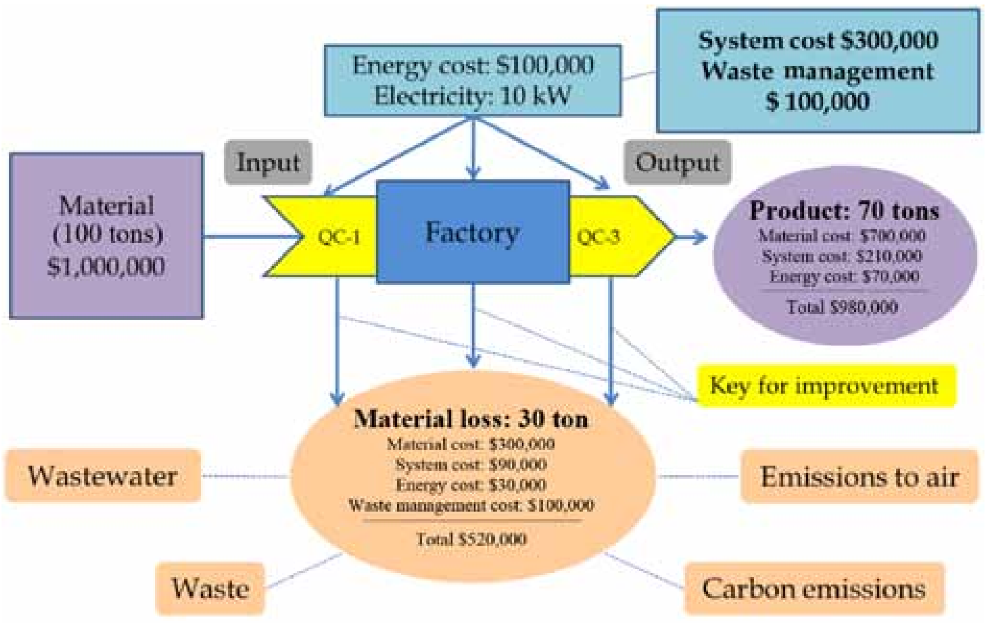

Figure 3. MFCA evaluation in monetary units.

The resulting cost of the material loss can become an incentive for organizations and managers to reduce operation costs by reducing material losses. Therefore, it can be said that MFCA can help organizations simultaneously achieve financial benefits and control of material losses (i.e., more effective resource use) (Clause 5.3, ISO 14051:2011).

PRINCIPLES OF MFCA
(Clause 4.2, ISO 14051:2011)

MFCA can be used to increase the transparency of material flows and energy use, along with the associated costs and environmental impacts, and to support organizational decisions through information obtained through MFCA. This can be achieved by following the four core principles of MFCA methodology.

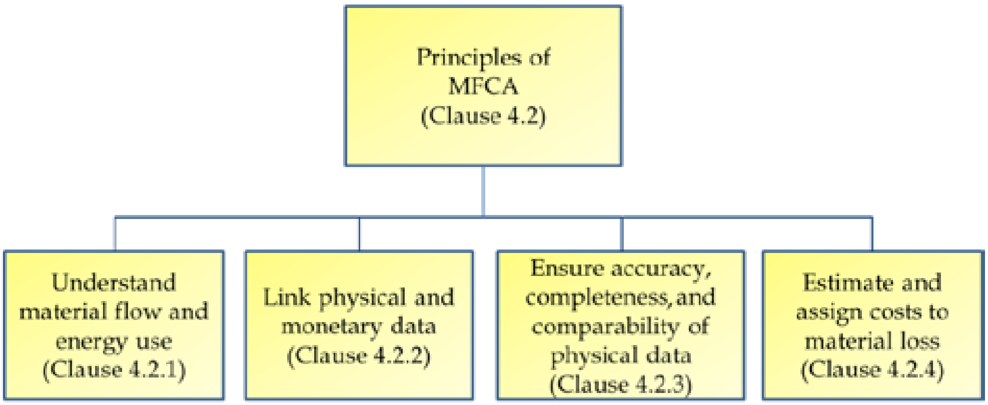

Figure 4. Principles of MFCA.

1. Understand material flow and energy use
The flow of all materials and energy use for each quantity center should be traced to understand how materials are used and transformed along the whole process.

2. Link physical and monetary data
Through MFCA, the environmental-related decision-making process can be linked to financial information via the material flow model, which provides a better understanding of the real costs of material and energy use and results in an improved decision-making process.

3. Ensure accuracy, completeness, and comparability of physical data
MFCA requires that all data be verified and that all inputs and outputs be identified and quantified. It is recommended that all data be converted to a common unit. Using accurate and complete data is critical to identify the cause and source of any gap between inputs and outputs.

4. Estimate and assign costs to material losses
Real costs should be assigned to all material losses and products. When exact information is not available, the cost allocation should be as accurate and practical as possible. In MFCA, the information on costs attributed to material losses represents one of the main incentives for process improvement.

MODULE 5: ISO 14051: FUNDAMENTAL ELEMENTS OF MFCA

FUNDAMENTAL ELEMENTS OF MFCA (Clause 5, ISO 14051:2011)

MFCA brings about both environmental and cost-reduction impacts on the organization. In order to apply MFCA to an organization effectively, the concepts of quantity center, material balance, cost calculation, and material flow model shown in Figure 5 need to be incorporated.

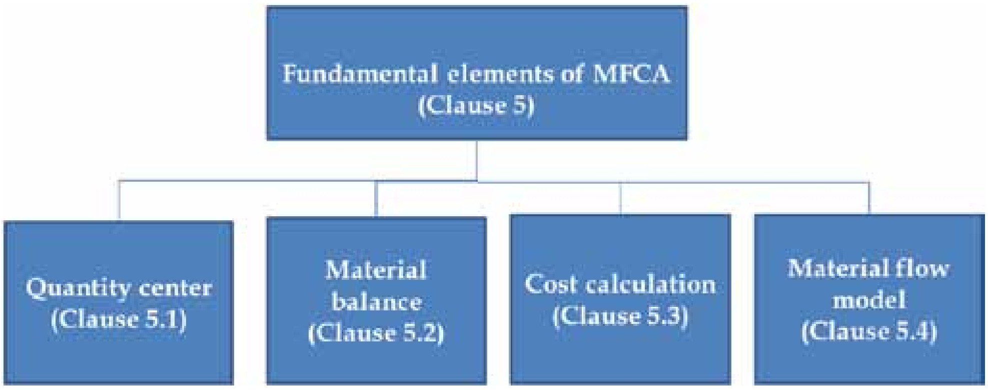

Figure 5. Fundamental elements of MFCA.

Fundamental Element 1: Quantity center (Clause 5.1, ISO 14051:2011)
A quantity center is typically one or multiple unit process(es). The center is the point at which the material balance will be calculated both in physical and monetary units. One quantity center can include either a single process or multiple processes, depending on the amount of the material losses identified at the unit of production.

Furthermore, the quantity centers within the MFCA boundary can be based on existing production management information, cost center records, and other existing information. Generally, quantity centers are established in all processes where relevant material losses or system costs, such as energy for transport, oil, or air pressure leakages, are identified, then the appropriate process is selected as an additional quantity center and its inputs and outputs are determined. Typical examples of quantity centers include points where materials are stocked and/or transformed, such as storage, production units, waste management, and shipping/receiving points.

Once the inputs and outputs have been identified for each quantity center, they can be used to connect the quantity centers within the boundary so that data from the quantity centers can be linked and evaluated across the entire system within the scope. It is important that material balance be ensured to evaluate material efficiency in physical and monetary units. The concept of material balance is described in the following section, Fundamental Element 2: Material balance.

Fundamental Element 2: Material balance (Clause 5.2, ISO 14051:2011)
In MFCA, all material that goes into and leaves the quantity center should be balanced. Thus, to account for all the materials targeted in the MFCA analysis, the material input and output need to be confirmed, while comparing the quantities of material inputs to outputs and changes in the inventory to identify any data gaps. The missing materials or other data gaps can lead organizations to identify missing points which result in areas of improvement.

As an example, Figure 6 shows a general material balance around a quantity center. In this example, a total of 145 kg of material enters the quantity center with an inventory of 35 kg. Over the time period for analysis, the raw material is distributed between product (120 kg), material loss (40 kg), and inventory (20 kg).

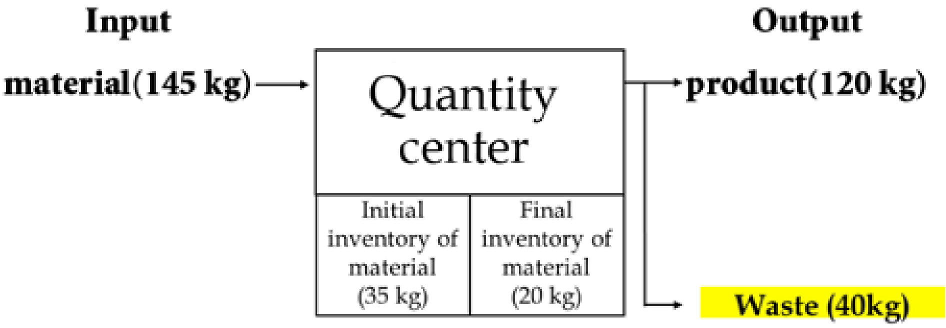

Figure 6. Example of material balance in a quantity center.

For each quantity center, the amounts of inputs and outputs should be quantified in physical units. All physical units should be convertible to a single standardized unit (e.g., mass) so that material balances can be conducted for each quantity center. It is preferable to use existing on-site basic units for production management.

A material balance requires that the total amount of outputs (i.e., products and material losses) be equal to the total amount of inputs, taking into account any inventory changes within the quantity center. Ideally, all materials within the MFCA boundary should be traced and quantified. However, in reality, materials that have minimal environmental or financial significance can be excluded.

Fundamental Element 3: Cost Calculation (Clause 5.3, ISO 14051:2011)
During the decision-making process, financial considerations are often included. Through MFCA, the material balance of inputs and outputs is linked to monetary units by assigning and/or allocating costs to all products and material losses. MFCA considers four types of cost, all of which are allocated to both products and material losses:

- Material costs;
- Energy costs;
- System costs; and
- Waste management costs.

Figure 7 shows an example of cost calculation based on the material balance at one quantity center in which the total costs of the quantity center are allocated to the outputs based on the proportion of inputs that becomes a product and the proportion that becomes part of the material losses.

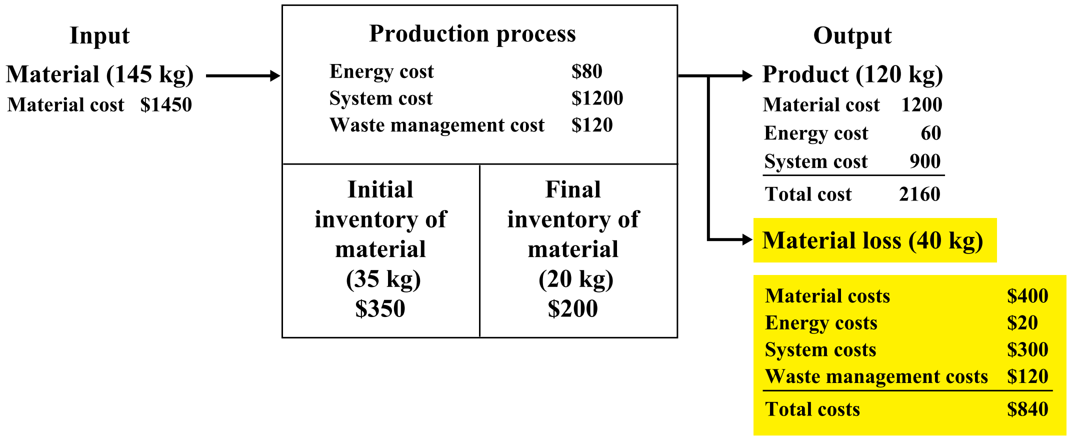

Figure 7. Example of cost calculation in a quantity center.

Fundamental Element 4: Material Flow Model (Clause 5.2, ISO 14051:2011)
It refers to the visual representation of the process that shows all the quantity centers in which the materials are transformed, stocked, or used, as well as the flow of these materials within the system boundary. Figure 8 shows an example of a material flow model.

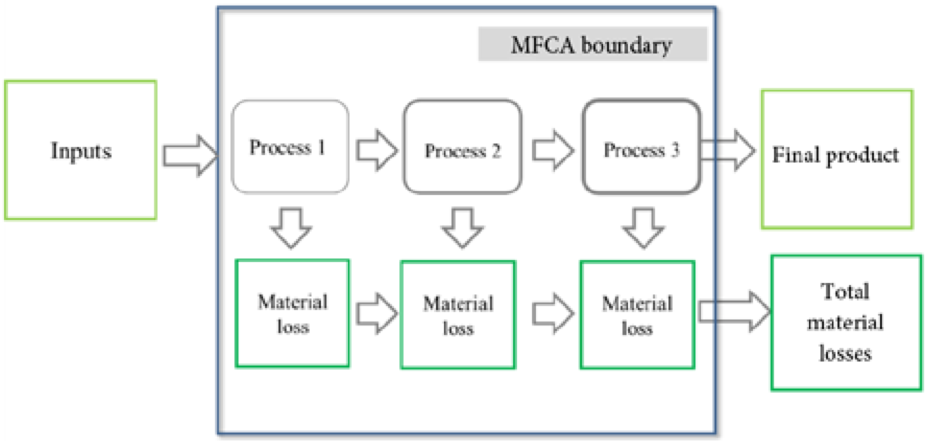

Figure 8. Example of a material flow model for a process within the MFCA boundary.

MODULE 6: ISO 14051: MFCA IMPLEMENTATION STEPS

To facilitate implementation, ISO 14051 proposes several MFCA implementation steps as delineated below. The level of detail and complexity of the analysis will depend on the size of the organization, nature of the organization's activities and products, number of processes, and quantity centers chosen for analysis, among other factors. These conditions make MFCA a flexible tool that can be applied in a wide range of organizations, regardless of size or the existence of an environmental management system (EMS). In fact, the implementation process of MFCA is considered to move more smoothly and faster if the organization has an existing EMS as it is probable that material- and waste-related data EW already being collected for analysis.

Furthermore, MFCA can be easily integrated into other EMS as it incorporates the Plan-Do-Check-Act (PDCA) continual improvement cycle, which is a common approach in many EMS. MFCA can provide additional information in each of the stages of the PDCA cycle and enhance the existing EMS. For example, the use of MFCA allows the organization to include financial considerations in setting objectives and targets. The knowledge of potential environmental impacts and financial impacts can enhance the quality of the evaluation, providing useful information for an organization's decision-making.

IMPLEMENTATION STEP 1: ENGAGING MANAGEMENT AND DETERMINING ROLES AND RESPONSIBILITIES (Clause 6.2, 6.3, ISO 14051:2011)

Successful projects usually start with support from the company's management; MFCA is not an exception. If the company management understands the benefits of MFCA and its usefulness in achieving an organization's environmental and financial targets, it is easier to gain commitment from the whole organization. In order to be effectively implemented, it is highly recommended that top management take the lead in MFCA implementation by assigning roles and responsibilities, including setting up an MFCA project implementation team, providing resources, monitoring progress, reviewing results, and deciding on improvement measures based on the MFCA results.

In general terms, management should be engaged in all phases of MFCA implementation and it is recommended that MFCA projects start with aggressive support from management, followed by a bottom-up approach on-site, as shown in Figure 9.

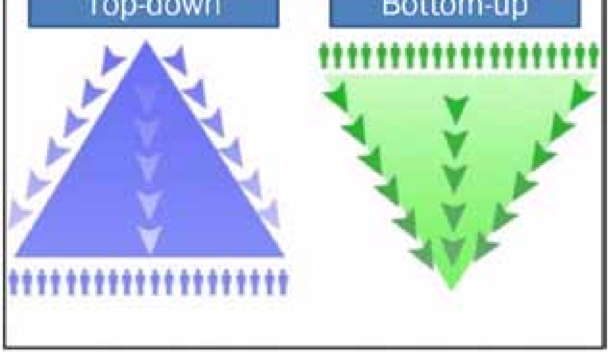

Figure 9. Top-down and bottom-up approach.

In addition, successful implementation of MFCA requires collaboration between different departments within the organization. The reason why collaboration is needed is because different sources of information are required to complete MFCA analysis. Through engagement of the company management in the MFCA implementation process, the required expertise can be determined and the correct flow of information between all areas involved can be facilitated. The following are typical examples of expertise that are needed for successful implementation of MFCA:

- Operational expertise on the flow of input materials and energy use throughout the target process;
- Technical expertise on material-related implications of processes, including combustion and other chemical reactions;
- Quality control expertise on various issues, such as frequency of product rejects, causes, as well as rework activities, maintenance, and other quality assurance data;
- Environmental expertise on environmental impacts; and
- Accounting expertise on cost accounting data.

IMPLEMENTATION STEP 2: SCOPE AND BOUNDARY OF THE PROCESS AND ESTABLISHING A MATERIAL FLOW MODEL (Clauses 6.4, 6.5, ISO 14051:2011)

Based on collected material flow data, the MFCA boundary needs to be specified to understand clearly the scale of MFCA activity. During implementation, it is usually recommended to focus on specific products or processes at the beginning and then expanding implementation to other products. By implementing MFCA in steps, the analysis is simplified and better results can be achieved.

The boundary can be limited to a single process, multiple processes, an entire facility, or a supply chain. It is recommended that the process or processes that are chosen for initial implementation be the ones with potentially significant environmental and economic impacts. After specifying the boundary, the process should be classified in quantity centers using process information and procurement records. In MFCA, the quantity center is the part of the process in which inputs and outputs are quantified. In most cases, quantity centers represent parts of the process in which materials are transformed. If the material flow between two processes is the source of significant material loss, the flow can be classified as a separate material flow.

After determining the boundary and quantity centers, a time period for MFCA data collection needs to be specified. While MFCA does not indicate the period during which data must be collected for analysis, it should be sufficiently long to allow meaningful data to be collected and to minimize the impact of any significant process variation that can affect the reliability and usability of the data, such as seasonal fluctuations. Several historical MFCA projects indicate that the appropriate data collection period can be as short as a month, with a half-year or a year of data collection being the most common.

In MFCA, production, recycling, and other systems are represented by visual models that illustrate MFCA boundary and multiple quantity centers where materials are stocked, used, or transformed, as well as the movements of materials between those quantity centers.

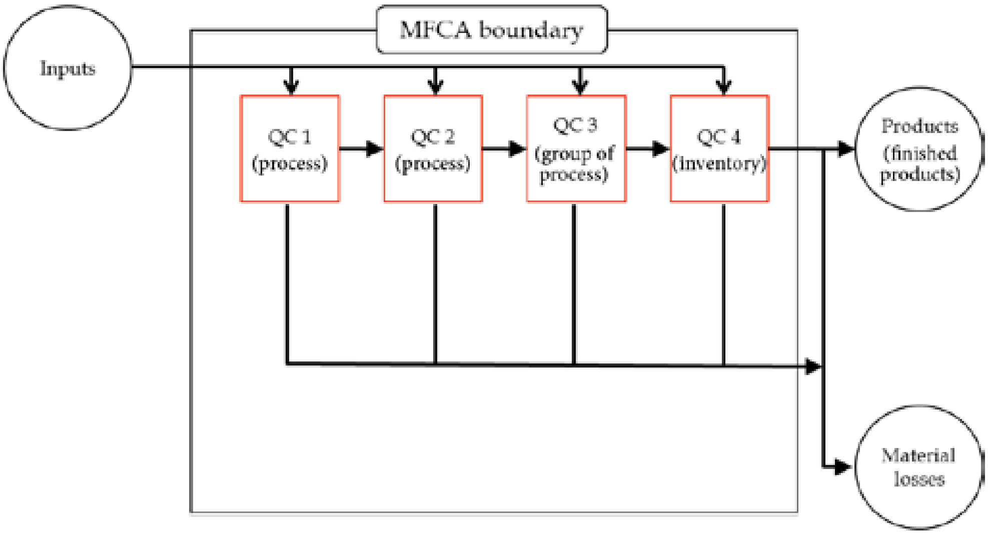

Figure 10. Material flow model for a process within the MFCA boundary.

Figure 10 shows a general material flow system. The material flow model is useful to provide an overview of an entire process and to identify the points where material losses occur. Products include finished products from the entire system, intermediate products, and material inputs to other quantity centers. For each quantity center, material balance-based verification should be conducted to understand material-related efficiency. The material flow model is not necessarily visualized by computer; the model can be made on paper and with Post-It Notes for discussion among project members.

IMPLEMENTATION STEP 3: COST ALLOCATION (Clauses 5.3, 6.8, ISO 14051:2011)

MFCA divides costs into the following categories:

- Material cost: cost for a substance that enters and/or leaves a quantity center
- Energy cost: cost for electricity, fuel, steam, heat, and compressed air
- System cost: Cost of labor, cost of depreciation and maintenance, and cost of transport
- Waste management cost: cost of handling waste generated in a quantity center

Material costs, energy costs, and system costs are assigned or allocated to either products or material losses at each quantity center based on the proportion of the material input that flows into product and material loss. The material costs for each input and output flow are quantified by multiplying the physical amount of the material flow by the unit cost of the material over the time period chosen for the analysis. When quantifying the material costs for products and material losses, the material costs associated with any changes in material inventory within the quantity center should also be quantified. In contrast to material, energy, and system costs that are assigned to products and material losses proportionally, 100% of the waste management costs are attributed to material loss, since the costs represent the costs of managing this material loss.

In most cases, costs such as energy costs, system costs, and waste management costs are only available for an entire process or facility, and allocating or attributing these costs to each specific product and material loss is challenging. If costs for each quantity center are unknown and difficult to calculate or estimate, it is possible to distribute the total respective costs of the specific processes to the quantity centers and subsequently allocate them to products and material losses, following the next simple steps:

1. Allocation of overall (e.g., process-wide, facility-wide) costs to each quantity center; and
2. Allocation of costs to products and material losses

Each organization will need to decide the allocation criteria that best fits its needs and the scope of the project. Accordingly, during each allocation step, an appropriate allocation criterion should be selected. The criterion chosen should reflect the costs being allocated as closely to the real process as possible.

When process-wide or facility-wide costs are being allocated to quantity centers, machine hours, production volume, number of employees, labor hours, number of jobs performed, or floor space can be considered as appropriate examples of allocation criteria. For the second step, allocation of costs in a quantity center to products and material losses, it is common to allocate costs based on the material distribution percentage. In other words, costs follow the same ratio as the material balance in physical units.

Once costs have been allocated to all inputs, the cost analysis should be incorporated to the material flow analysis. By doing so, the output from one quantity center becomes the input of the following quantity center. The material cost that enters a quantity center should reflect the combination of the material costs, energy costs, and system costs from the previous quantity center. Carryover cost items can be expressed separately as material cost, energy cost, and system cost.

IMPLEMENTATION STEP 4: INTERPRETING AND COMMUNICATING MFCA RESULTS (Clauses 6.9, 6.10, ISO 14051:2011)

MFCA implementation provides information such as material loss throughout the process, the use of materials that do not become products, overall costs, and energy and system costs associated with the material loss. This information brings about multiple impacts by increasing the awareness of the company's operations. Managers who are aware of the costs associated with material losses can then identify opportunities to increase efficiency in material use and improve business performance.

Through the identification of MFCA issues that lead to material losses, organizations have a chance to identify the resulting economic loss, which is usually overlooked when relying solely on conventional cost accounting.

While most organizations monitor the yield rate associated with the materials used in the process, the general scope of such monitoring only covers the main materials, processes, or losses in many cases. They often control the main materials without monitoring the amounts of use or loss in auxiliary or operating materials. On-site operators may see materials being lost, whereas managers of the manufacturing, production engineering, and product design departments are not aware of such losses. This happens because the organization's conventional management practices only focus on the handling of waste when there are costs associated with its management. In such cases, MFCA helps organizations highlight uncontrolled material losses.

The physical and monetary quantification of the material flow can be summarized in a format that is suitable for further interpretation, for example, in a material flow cost matrix. The data should first be summarized for each quantity center separately. Table 2 illustrates a format of the summary of the MFCA data for a quantity center.

Table 2. Example of a material flow cost matrix for a quantity center.

Cost	Material	Energy	System	Waste management	Total
Product	Amount (65%)	Amount (65%)	Amount (65%)	N/A	Total product (60%)
Material loss	Amount (35%)	Amount (35%)	Amount (35%)	Amount (100%)	Total material loss (40%)
Total	Amount (100%)	Amount (100%)	Amount (100%)	Amount (100%)	Total (100%)

In general, the review and interpretation of summarized data will allow the organization to identify quantity centers with material losses that have a significant environmental or financial impact. These quantity centers can be analyzed in more detail (i.e., root cause for sources of material loss). Data from individual quantity centers can also be aggregated for the entire target process being analyzed.

After the MFCA analysis is completed, the results should be communicated to all relevant stakeholders. In addition, management can use MFCA information to support many different types of decisions aimed at improving both environmental and financial performance. Communicating the results to the organization's employees can be useful in explaining any process or organizational changes and gain full commitment from all members of the organization (Clauses 6.9, 6.10, ISO 14051:2011).

IMPLEMENTATION STEP 5: IMPROVING PRODUCTION PRACTICES AND REDUCING MATERIAL LOSS THROUGH MFCA RESULTS (Clause 6.11, ISO 14051:2011)

Once MFCA analysis has assisted an organization to understand the magnitude, consequences, and drivers of material use and loss, the organization may review the MFCA data and seek opportunities to improve environmental and financial performance. The measures taken to achieve these improvements can include substitution of materials; modification of processes, production lines, or products; and intensified research and development activities related to material and energy efficiency.

MFCA data can be used to support the cost-benefit analysis of proposed measures, both those requiring additional investment and those requiring little or no initial investment (e.g., process standardization, process improvement).

Additionally, MFCA implementation can also be used as an opportunity to pursue improvements in the organization's accounting and information systems. After implementing MFCA for the first time, organizations can identify ways to access more systematized data for all future projects to avoid some manual data collection and analysis. This can facilitate further implementation of MFCA, and system improvements can be pursued. Possible system improvements that are discovered during MFCA implementation must be noted and included in the overall analysis.

By applying MFCA, financial costs such as processing and material losses are identified. In many cases, the scale of the identified costs is more significant than previously assumed. At the same time, MFCA presents an ultimate target for engineers: "the zero material loss cost," which can encourage the organization to make a breakthrough in the recognition of the necessity for improvement. The typical losses identified by MFCA include the following:

1. Waste treatment cost for material loss;
2. Procurement cost for material losses sold to external recycling contractors;
3. System cost for material losses (labor, depreciation, fuel, utility and other costs);
4. System cost required for internal recycling of materials; and
5. Material and system costs for in-stock products, work-in-progress materials, materials that were disposed of due to a switch to a newer model, deterioration of quality, or for aging stock.

Through MFCA implementation in several companies of different industries and sizes, it has been found that only a few companies control auxiliary materials on a corporate basis. Auxiliary and operating materials are often managed on a process or equipment basis, and the quantities of materials input (and loss) for each model are rarely accounted for. In some cases, such quantities are managed in the unit of production lot. The overall waste treatment cost is generally managed on a factory basis by waste type. However, some companies identify such cost by material type, product model, and process type.

Furthermore, companies are often unaware of losses associated with recyclable waste because such waste is reused as resources and sometimes sold as valuable material to external recyclers.

MFCA CASE EXAMPLE: NITTO DENKO CORPORATION

This case example shows actual implementation of MFCA in accordance with the implementation steps described in the previous section.

Nitto Denko Corporation (hereafter "Nitto") is a leading Japanese diversified materials manufacturer that provides a wide range of products including tapes, vinyl, LCDs, insulation, and reverse osmosis membranes. Nitto was the first model company that introduced MFCA with the support of the Japanese Ministry of Economy, Trade and Industry (METI) in the early 2000s.

Step 1: Engaging Management and Determining Roles and Responsibilities (Clause 6.2, 6.3, ISO 14051:2011)

Nitto has always been committed to enhancing efficiency and minimizing the environmental impacts of its operations. As a part of environmental management activities, Nitto found that its environmental accounting system was not fully representative of the total environmental impact costs of operations. The reason was that only environmental conservation costs were being considered, and some costs associated with environmental impacts remained hidden. Figure 11 shows that the environmental conservation costs used for conventional environmental accounting only represented 1.6% of total sales in 2005. However, other costs, such as energy consumption costs associated with environmental impacts are usually allocated to production costs. In the case of Nitto, these costs represented around 13.6% of total sales, which is significantly higher than the environmental conservation costs (1.6%).

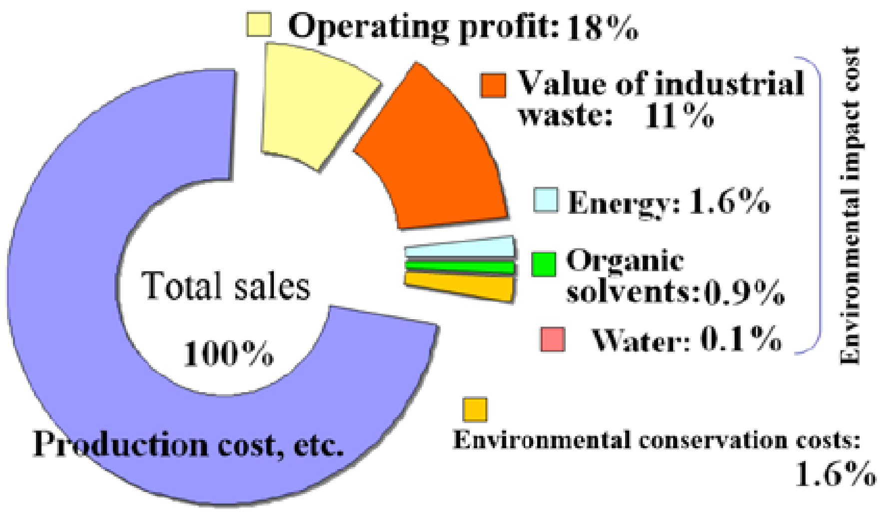

Figure 11. Composition of total sales (nonconsolidated basis, FY 2005). Source: Nitto Denko Corporation.

At the time, the company was looking for alternatives for its existing conventional environmental accounting, when METI introduced MFCA to Nitto. At the initial phase of the project, top management (CEO of the company) showed strong interest in and commitment to the project. One of the reasons for the strong CEO commitment was in understanding the importance of the *"mottainai"* concept. *Mottainai* is a traditional Japanese concept that conveys a sense of regret about waste from any activity. For example, Japanese say *mottainai* when they witness waste, and therefore people make more effort to avoid it.

For full implementation of the project, the CEO designated a main key person in the field of the sustainability management as team leader. The implementation team leader was in charge of providing basic training to people at the manufacturing site and guide MFCA implementation for the target process. Actual implementation activities are described in the following sections.

Step 2: Scope and Boundary of the Process and Establishing a Material Flow Model (Clauses 6.4, 6.5, ISO 14051:2011)
During the target product selection process, Nitto decided to focus on a product that showed an upward trend in the market, its production lines generated a high amount of material losses, and had production lines that consumed substantial amounts of energy in the manufacturing process. Based on these criteria, the adhesive tape used in electronics produced at the Toyohashi Plant was selected as the target product for MFCA implementation.

The adhesive tape consists of a three-layered structure composed of a base material, an adhesive compound, and a separator. Its manufacturing process starts from creating the adhesive compound. Sheets are then created by coating the base material and separator with the adhesive compound. This sheet is cut to the correct length and width based on product specifications and shipped as finished adhesive tape. Losses in the length and width directions are incurred in the cutting process.

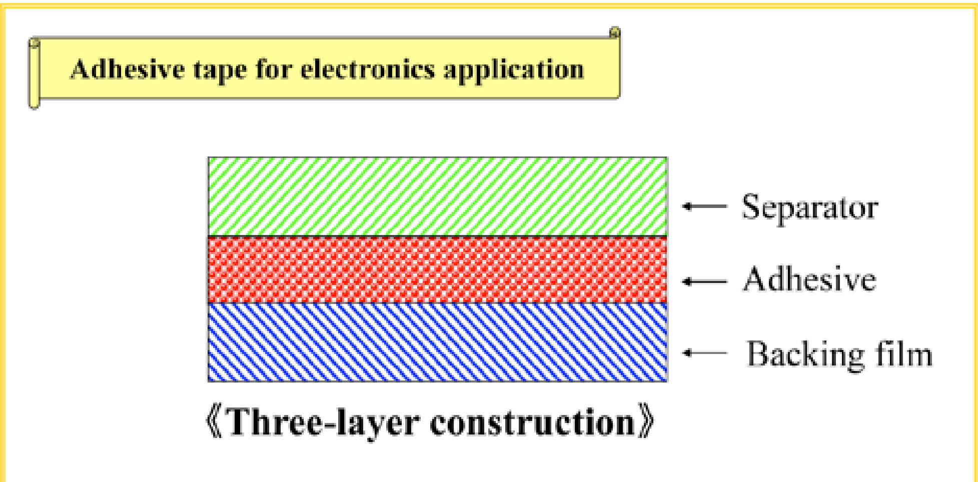

Figure 12. Applicable product.
Source: Nitto Denko Corporation.

As a first step, month-long data were collected for MFCA analysis. However, recommended MFCA implementation should follow the PDCA continual cycle, and therefore three-month and six-month data were collected and analyzed.

Determination of Quantity Centers (Clause 6.5 and 6.7, ISO 14051:2011)
After selecting the target product, as suggested by the MFCA implementation steps, quantity centers of the process were decided. Quantity centers should be established based on loss analysis and process analysis and not purely for data collection. In the MFCA methodology, one quantity center should usually be set up per production process. In this process, Nitto identified some benefits in integrating several processes into one quantity center from the perspective of the "man-hour"-"accuracy" balance.

Using the process flow from the adhesive tape production as shown in Figure 13, the MFCA implementation team decided to divide the process into five quantity centers:

1. dissolution/batch blending process;
2. coating/drying process;
3. store process;
4. slitting process; and
5. inspection/packing process.

After the quantity centers were selected, Nitto collected data for verification of the amount of inputs and outputs in physical units by doing a material balance.

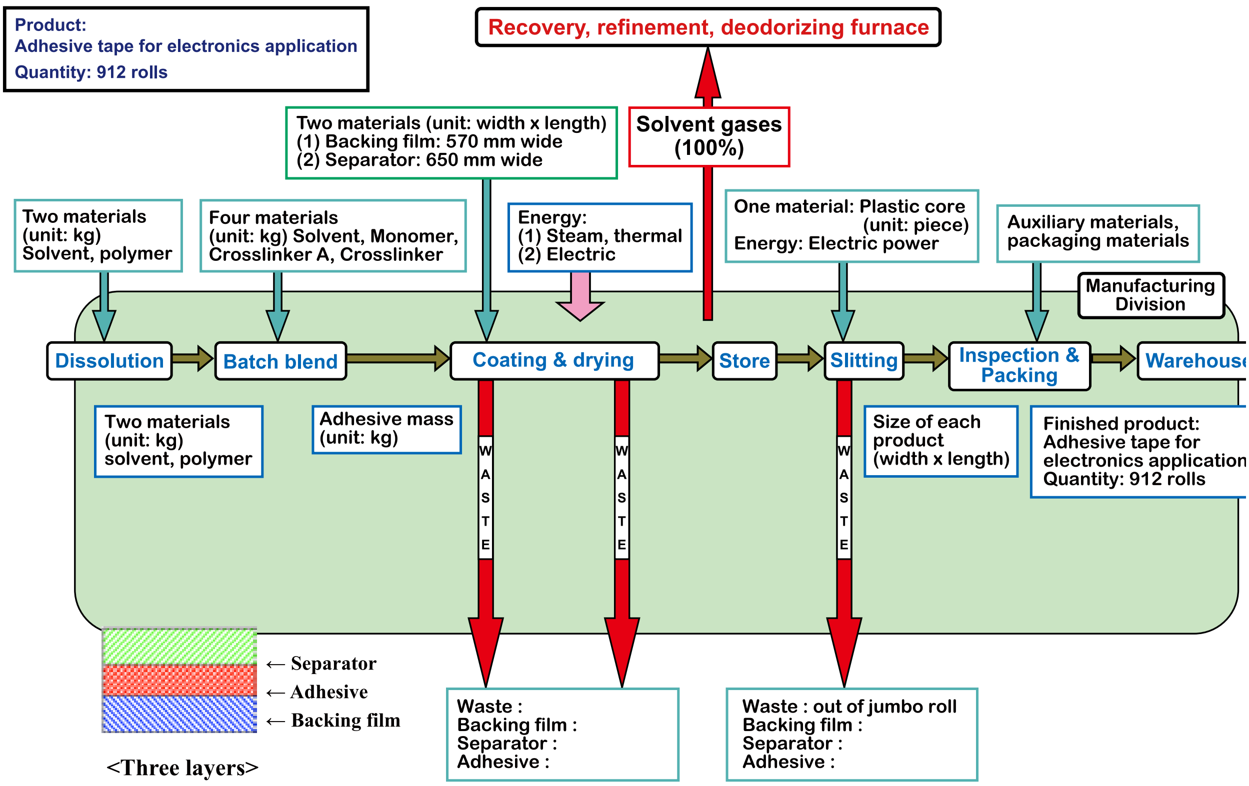

Figure 13. Material flow model.
Source: Nitto Denko Corporation.

Step 3: Cost Allocation (Clause 5.3, 6.8, ISO 14051:2011)
Costs were classified into four cost elements: 1) material costs, 2) energy costs (separate from material costs), 3) system costs, and 4) waste disposal costs (delivery/disposal costs). To determine material costs, the physical amount of input materials in each quantity center was multiplied by their unit costs. Material cost flows were tracked through each quantity center, as shown in Figure 14.

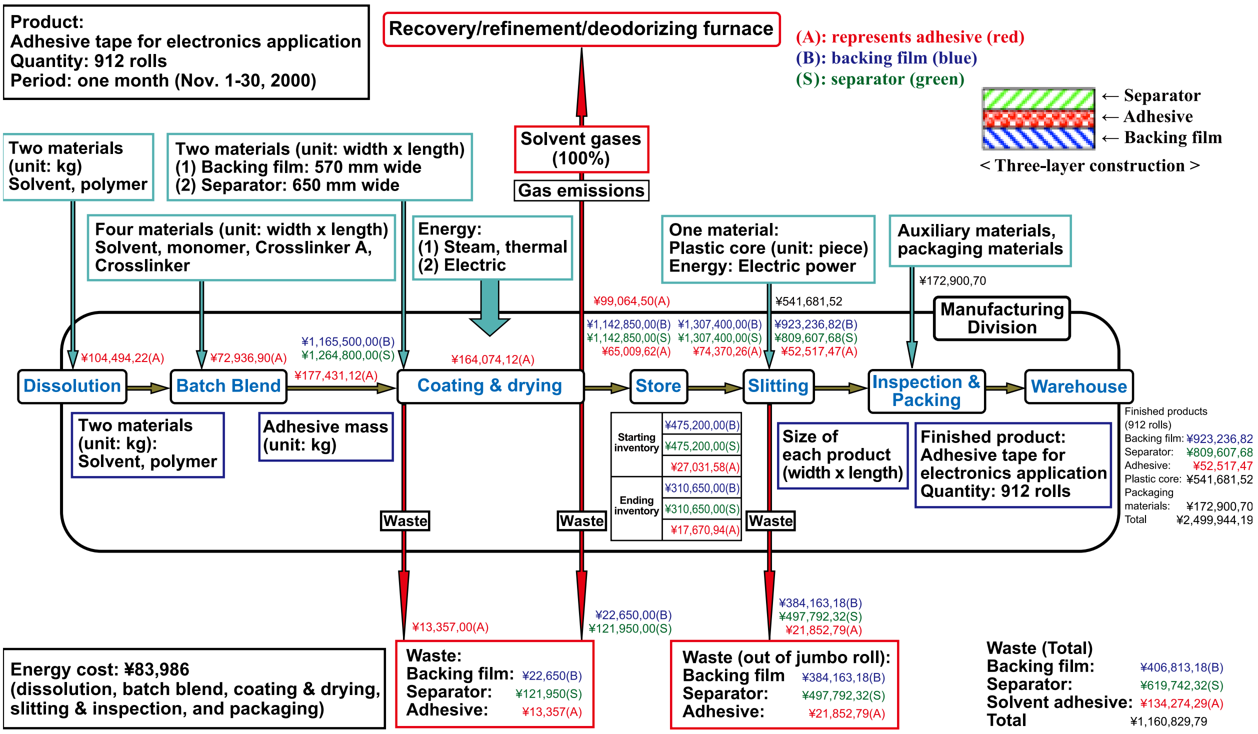

Figure 14. Material flow model with data.
Source: Nitto Denko Corporation.

Collection of energy costs, system costs, and disposal costs
Once material costs were identified and allocated to each material, energy costs, system costs, and disposal costs for each quantity center were collected. Some of the information is only available for the complete process and had to be allocated to each material following the criteria shown in Table 3.

Table 3. Allocation bases.

Cost elements	Allocation base	Allocation type
Energy (electricity)	Consumption	B
Energy (fuel)	Consumption	B
Labor (regular employees)	Man-hours	A
Labor (part-timers)	Man-hours	A
Depreciation (straight-line method)	Operating time	B
Maintenance	Expenditure	C
Tools and implements	Expenditure	C

A:Allocation based on real data.
B:Allocation based on monthly data (as accurate as possible).
C:Apportionment based on monthly data.

Source: Nitto Denko Corporation.

All collected costs are allocated to products and to material losses following the material flow obtained through the material balance. In this process, Nitto decided to allocate energy costs and system costs based on the product/material loss ratio in physical units. Following the MFCA methodology, all disposal costs were allocated to material loss rather than using the allocation based on the proportion of material that becomes product and material loss, as used for energy and system costs.

Step 4: Interpreting and Communicating MFCA Results
(Clauses 6.9, 6.10, ISO 14051:2011)
After collecting all data in physical and monetary units and making the material balance of the quantity center, the implementation team prepared a material flow cost matrix in which all costs were classified as part of the products or material losses. The main purpose of the matrix is to provide the results of the MFCA analysis in a format that can be easily interpreted by the entire organization.

For the selected process, the proportion of positive products to negative products was 67.17% to 32.83%, as shown in Table 4.

Table 4. Flow cost matrix. Period: from November 1 to 30, 2000 (unit: yen).

Cost	Material	Energy	System	Disposal	Total
Positive products	2,499,944 (68.29%)	57,354 (68.29%)	480,200 (68.29%)	NA	3,037,498 (67.17%)
Negative products	1,160,830 (31.71%)	26,632 (31.71%)	222,978 (31.71%)	74,030 (100%)	1,484,470 (32.83%)
Total	3,660,774 (100%)	83,986 (100%)	703,178 (100%)	74,030 (100%)	4,521,968 100%

Source: Nitto Denko Corporation.

Material flow profit-and-loss statement
In addition to the material flow cost matrix, Nitto used the results from the MFCA analysis to create a new profit-and-loss (PL) statement based on MFCA. Table 5 compares material flow PL with conventional PL in which *material flow PL* refers to the profit-and-loss statement using MFCA and *conventional PL* refers to the profit-and-loss statement used by Nitto before MFCA implementation.

Table 5. Comparison of profit-and-loss statements.
Period: from November 1 to 30, 2000 (unit: yen).

Material flow P/L (unit: yen)		Material flow P/L (unit: yen)	
Sales*	15,000,000	Sales*	15,000,000
Cost of positive products	3,037,498	Cost of sales	4,521,968
Cost of negative products	1,484,470	N/A	N/A
Gross profit	10,478,032	Gross profit	10,478,032
Selling, general, and administrative expenses*	8,000,000	Selling, general, and administrative expenses*	8,000,000
Operating profit	2,478,032	Operating profit	2,478,032

*Provisional figure.
Source: Nitto Denko Corporation.

Under material flow PL, the cost of goods sold (cost of positive products) and the cost of waste (cost of negative products) were calculated as ¥3,037,498 and ¥1,484,670, respectively. Assuming that total sales were ¥15,000,000 and sales and administrative costs were ¥8,000,000, the operating income was ¥2,478,032.

In the material flow PL, a clear distinction between the cost of positive and negative products was seen. Nitto was able to identify the real costs of the negative products and work on strategies to increase its profits by reducing the cost of negative products. The material flow PL was used by the implementation team as a tool to stimulate the rest of the organization to consider how to convert the cost of negative products into profits and to direct their attention to continuous improvement.

Under conventional cost accounting, all costs were allocated to the final product. Conventional cost accounting considers that only finished (non-defective) products have the capacity to recover the cost of goods that were used. Costs associated with material loss, such as unused materials, are usually included under the production costs. Through the conventional cost accounting, costs for the material loss remain hidden and cannot be fully understood. Conversely, MFCA provides information not only on the costs associated with the final product but also with the material loss. The difference between MFCA-based PL and conventional PL is shown in Table 5.

Step 5: Improving Production Practices and Reducing Material Loss through MFCA Results (Clause 6.11, ISO 14051:2011)

Through MFCA, Nitto was able to recognize its material losses and the costs associated with these losses accurately. This information became an incentive for Nitto to improve the material productivity of this manufacturing line. Thus, the implementation team decided to set up its kaizen plan on the basis of a cost/benefit analysis using the physical and cost data under MFCA. Figure 15 shows the cost of negative products broken down by factor, and countermeasures were subsequently planned and implemented.

Cost of positive products (products) :
cost of negative products (material losses) = 67% : 33%

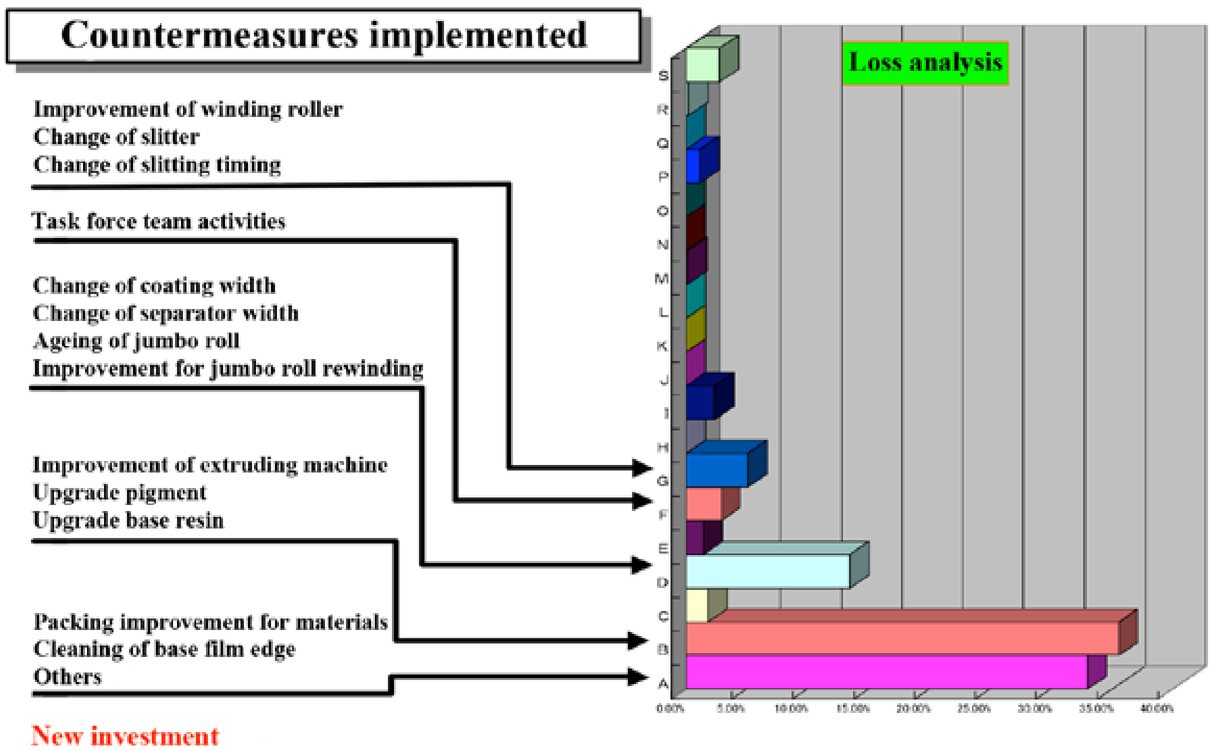

Figure 15. Loss analysis.
Source: Nitto Denko Corporation.

Capital investment decisions
Nitto conducted an assessment of its capital investments amid the implementation of these measures and decided on an additional ¥700 million capital investment. The results of the implementation of improvement measures are shown in Table 6.

The proportion of positive products increased by 10%. There was, however, much room for improvement and the company decided to introduce a continuous MFCA analysis in this process. Improvement targets are updated on a yearly basis.

Table 6. Implementation results: Improvement of material productivity through MFCA by Nitto (cost basis).

	2001	2004	2013 (target)
Positive products	67%	78% (+11%)	90% (+23%)
Negative products	33%	22% (-11%)	10% (-23%)
Total	100%	100%	100%

Source: Nitto Denko Corporation.

Outcome of MFCA implementation
After completing the project, Nitto recognized the potential of MFCA as a management tool. In particular, Nitto recognized the following points:

1. MFCA can support the pursuit of company-wide goals.
2. It is necessary to convert physical and monetary data units into a standardized unit along their flow.
3. It pursues the flow of materials, energy, and system costs in a process from start to finish.
4. MFCA can help clarify losses in terms of cost and enables managers to set clear targets for improvement.
5. MFCA provides a way to identify potential cost reductions and positive impacts on the environment.
6. MFCA contributes to increased material productivity and strengthened competitiveness.
7. MFCA provides relevant, useful information for equipment investment appraisal and design for the environment.

In MFCA, processing costs and indirect costs that are included in waste, such as system costs, are also taken into account. This enables companies to clarify the costs associated with emissions as waste. In other words, there are no losses that are ignored as in conventional cost accounting and all losses are within the scope targeted for improvement.

Material flow data, which recognize the quantity and cost of waste via each quantity center, provide a clear picture of the issues and bottlenecks in the manufacturing process. By settling such issues and converting the flow of negative products into positive products, companies can simultaneously achieve a reduction in environmental impact and an increase in profit.

This also enables companies to recognize that the cost of waste will vary depending on where it is generated, even if the total quantity of waste remains constant. From this point of view, companies can comprehend which manufacturing processes most need improvement or reform, and it becomes possible to estimate a pertinent investment amount and secure funds for such investments.

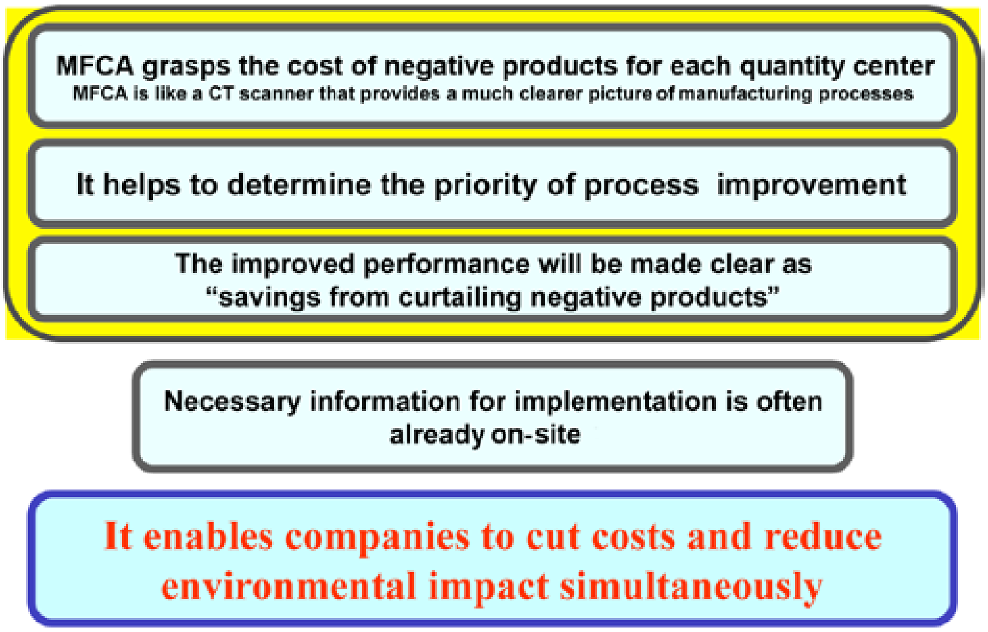

Figure 16. Implementation summary.
Source: Nitto Denko Corporation.

Figure 16 shows the summary of the implementation of MFCA and how Nitto was able to identify material losses that served as valuable information for capital investment decisions and achieving lower costs and fewer environmental impacts.

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