Harnessing the eco-efficiencies in waste and emissions reduction

1. Introduction

Eco-Efficiency is about '*doing more with less*'. Eco-Efficiency is achieved through combined efforts to (i) reduce the consumption of natural resources; (ii) reduce the impact on nature (including humans); and (iii) enhance the product and service value.

While the previous module (Energy) and the next (Water) primarily focus on the first broad objective, this module also focuses on the second objective of reducing impacts on nature. The overarching aim is to reduce the dispersion of toxic materials into the environment during product manufacture, use or disposal.

This dual focus may create some difficulties in these introductory sections. Also, the wide spread of materials encompassed in "wastes and emissions" may introduce difficulties partly because of the different regulatory and management approaches to solid waste and emissions to water or air. However, the techniques for developing eco-efficiency opportunities presented in later sections are common to both aspects.

There is also a need to differentiate between general wastes and emissions, and those which can be regarded as 'toxics'. In the context of Eco-Efficiency and this presentation, the term '*toxics*' is used quite broadly as any harmful substance or material that can either directly or indirectly pose a threat to human health, nature or the function of eco-systems. This includes – but is not limited to –

- Poisonous substances: substances that are poisonous or produce poisonous substances during metabolic breakdown in the natural environment. The toxic effect could be on humans (for instance: mutagenic, carcinogenic, teratogenic, etc) and/or on flora and/or fauna (eco-toxicity).
- Hazardous materials: by their chemical, physical and/or biological nature these materials pose a hazard. This includes for instance corrosive, explosive or flammable materials, radioactive materials or infectious materials.
- Pollutants: substances that upon their release in the environment disturb environmental processes, which in turn then pose a health hazard to humans, flora and fauna, or interrupt the natural processes that provide ecosystem services (e.g. ability of the natural environment to provide fresh water, fresh air, food and stabilise climate). Pollutants are often classified in the environmental impact categories they contribute to: e.g. ozone depleting substances (contribute to the breakdown of stratospheric ozone), greenhouse gases (contribute to enhanced greenhouse effect), nutrients (contributing to eutrophication), organics (can create anaerobic conditions in the receiving environment), etc.

A key focus of waste and emissions management should be to ensure that toxic materials do not enter general waste streams where they can adversely affect options for eco-efficiency improvements such as recycling.

2. Context

On a per capita basis, each one of Perth's residents creates more than 1.4 tonnes of solid waste (rubbish) a year[1]. This includes general rubbish, recyclables and the waste we produce indirectly as commercial and industrial waste. It does not include sewage waste, crop residues or mine tailings. Almost all the waste we currently produce has the potential to be reused or recycled.

In the early colonial history of Australia relatively little waste was produced. There was very little excess packaging with most packaging being reused or refilled (e.g. glass milk bottles). Food scraps were either fed to livestock, or used as compost in the garden. Excess organic waste rotted away naturally. The only remaining rubbish included items that don't break down easily such as bones, metals and glass. Until the 1970's most of the waste that wasn't reused or given away was burnt in the backyard so landfill was not a big problem.

Today, urban populations have increased, lifestyles have changed, and people are producing much more waste. Manufacturing practices have become more efficient with improvements in technology so that it is often cheaper to buy a new product than fix a broken one. Often the product cannot be economically recycled. Many of the products we consume are contained in excess packaging or are sold in disposable containers. New hygiene requirements and concerns with air pollution caused by the incineration of more waste has led to landfill becoming the preferred disposal option. Initially most municipalities had relatively easy access to secluded large dump grounds, and there was very little energy, resources and costs involved in landfilling. This encouraged the 'use and throw' attitude that most Western Australians came to embrace. As a result the amount of rubbish going to landfill has increased exponentially.

At the same time, the old operational standards of landfills have become unacceptable as residential areas have come closer. There has been growing concern with odorous emissions, noise, ground water pollution, future remediation issues, greenhouse gas releases, and loss of resources.

Following is a breakdown of the types of waste streams that end up in landfill.[2]

Percentage of total waste that goes to landfill	
Domestic kerbside collection	25-35%
Green waste	15-25%
Inert (chemically inactive) waste	25-30%
Commercial and industrial waste	20-25%
Hazardous waste	Less than 5%
Liquid waste	1-2%

[1] Waste Wise WA website http://www.wastewise.wa.gov.au/pages/rubbish.asp#3

[2] ibid

Toxics use is widespread in industry. Some industries depend on large volume use of toxic materials for their core processes, such as use of sodium cyanide for gold extraction (estimated consumption in WA gold industry approximately 65,000 ton per annum) and use of chlorine for titanium dioxide refining (estimated consumption in WA pigment industry approximately 35,000 ton per annum). Herbicides, insecticides and fungicides are used in large quantities in all sectors of agriculture (typically in range of 1-2 kg/ha per annum for broadacre cropping). Other sectors use smaller amounts of toxic materials, such as heavy metal use in electroplating and electronics industries.

It is difficult to ascertain the total diversity and scale of toxics use in WA's industry. Some indication can be derived from emission estimates, such as these reported in the National Pollutant Inventory (NPI). Table 1 includes a few examples for WA from the NPI database (available at: www.npi.gov.au)

Table 1 Estimated annual quantities of pollutant emissions generated in WA

POLLUTANTS	ESTIMATED ANNUAL EMISSIONS
Total VOCs	24,000,000 t
Benzene & Toluene	7600 t
Hexane and Xylene	7400 t
Lead & compounds	660 t
Cyanide	610 t
PAH	240 t
Dichloromethane	102 t
Mercury and compounds	14 t

Pollutants generated from a process either enter the process as raw material or contaminant therein or are created in the process (by-product, product, intermediate) or are in a process auxiliary (including the processing equipment).

The need to tackle the problem of wastes and emissions using new technology and by changing the mindset of people is now widely accepted.

The laws of thermodynamics mean that all processes that use materials and energy will produce by-product streams that may be not be useable and eventually will have to be disposed of. However by understanding the processes and materials used to create the products, suitable designs can be developed to ensure efficient materials use, to use byproduct streams for other processes, and to repair damaged or defective products or disassemble them to their components without creating a waste stream. Although such product and process designs are most effective when incorporated at the inception of the manufacturing business, existing manufacturing processes can also benefit from waste reduction approaches.

Such a change requires the systematic introduction of manufacturing, materials usage and disposal management schemes according to the waste management hierarchy:

Eliminate or Prevent existing waste streams

Reduce the amount of waste being produced, particularly toxics; and reduce the consumption of material while giving preference to reusable or recyclable materials

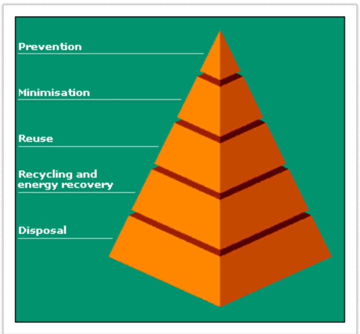
Reuse materials within the process or manufacturing system

Recycle materials that cannot be reused

Dispose of wastes with full awareness of and responsibility for the effects that the waste will create for future generations and the environment.

Make prevention the preferred option - Turn the Waste Pyramid on its head!

Let's go from this



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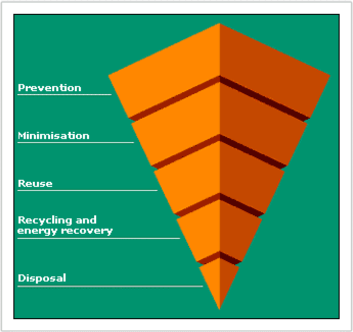

3. Where do businesses use excess material and how is waste created?

Waste creation and excessive materials usage are intrinsic process inefficiencies caused by poor product or manufacturing process design. The most important stage in adopting waste minimization is to identify the source of such wastes. Some of the areas where waste or excessive materials usage can be identified are from the following categories:

(a) Used packaging:

Packaging are materials that are use to hold, label, support and protect products or by-products so that they can be transferred to the next location or operation without damage. Some of the major types of packaging used in industry are made from:

Glass	Bottles used to hold corrosive and or volatile liquids, aseptic liquids or mixtures In the form of bottles to hold liquids containing or able leach gases.
Plastic	Containers or bags used to hold material products Labels used to designate products
Aluminium	Cans to hold gaseous liquids or aseptic liquids Fixtures, boxes or jigs to transport sensitive costly products
Steel	Cans to transport gaseous or volatile liquids, aseptic products Containers for pressurised products Fixtures or jigs to transport heavy parts
Wood	Boxes to hold heavy costly products or components Pallets used to transport heavy parts

(b) Unused by-products

In the production of various intended outputs a number of by-products are also manufactured. Depending on the costs and amount of by-products produced most of these by-products end up as waste simply because either no use can be associated with these materials or the potential users are inaccessible. These by-products may be in the form of:

- solid chemical mixtures
- hazardous chemicals
- off-cuts of resource materials
- cleaning wastes

(c) Accidents or unexpected damage caused by human errors, faulty or old equipment or natural causes

Damaged or broken equipment may contain valuable materials that can be recycled, or depending on the design may contain toxic components that need extra care in disposal.

(d) Poor product quality, poor product design, damaged or obsolete products

A well-designed manufacturing process, which produces no waste, is not adequate if the product is of a poor design, cannot be easily repaired, cannot be disassembled at the end of its life, or no provision is made for it to be returned to the supplier.

4. How much does waste cost?

A major reason why wastes are tolerated in industry is because the costs involved in their creation and disposal are hidden and usually incorporated as overhead costs.

Costs involved in materials use, waste creation and disposal need to be identified and incorporated as direct costs. Additionally, the total environmental costs associated with the production, transmission and final disposal of the materials; infrastructure costs; costs to society in terms of air pollution and greenhouse gases, costs of degradation of land and water resources, native flora and fauna; must be accounted for as well.

The direct costs could be indicated in the process map for the various steps in the process flow and the environmental cost could be indicated in the form of a simple Life Cycle Analysis chart.

Such accounting visibility can be the inspiration for action, with execution being through standard process and quality control techniques.

To find the true costs of materials use and waste disposal in your business, you need to consider the costs of:

- Materials as a resource (different to opportunity cost of a substitutable resource)
- Purchase
- Processing
- Disposal
- Productivity losses due to waste creation
- Infrastructure set-up and maintenance cost
- Utility maintenance cost
- Capital depreciation
- Environmental compliance cost
- Human health and land & water resources damage cost
- Environmental remediation, liabilities, etc

Toxics can cause additional costs in these categories, especially:

- Cost for safe storage and handling of toxics, including infrastructure (bunding, ventilation, etc), staff training, record keeping and personal protective equipment.
- On site treatment costs, for example, waste water treatment or air pollution control devices, and their safe operation.
- Licensing and permit costs, including management and administration of licensing conditions
- Insurance costs – in particular for workers compensation, fire/building, public liability

A mechanism for taking these costs into account is shown in **Worksheet A** in the appendix. This is used to list the main materials use and waste creating activities or processes in your company, infrastructure disposal, damaged or end of life product disposal costs.

From this study it is possible to identify the waste stream or materials that cost the most in terms of usage and disposal. This particular waste stream or material usage can then be targeted as the first item to apply cleaner production techniques to reduce or eliminate the waste stream.

5. Why reduce materials use and generation of waste and emissions?

Reducing the amount of materials used, particularly toxics, and reducing waste and emissions, will

- Reduce energy, bring resources cost down and increase product profitability
- Eliminate disposal costs
- Reduce fixed asset costs for equipment used to deal with waste and excessive material handling
- Reduce environmental risks involved in materials handling and waste disposal or discharge
- Enable less expenditure on meeting licence requirements
- Help foster a green image to both customers and the broader community which may be presented as a marketing opportunity
- Better interaction between suppliers and customers where packaging requirements and product end of life issues are concerned
- Simplify the process enabling easier control and a better working environment
- Product simplification
- Create valuable by-products to provide additional or alternative sources of revenue

With proper accounting, these factors can be kept in mind and used to design an opportunity checklist of actions that can be executed easily with short payback periods to convince management to take a proactive stance.

6. How to reduce the amount of materials used and reduce waste disposal?

Efficient materials use and waste disposal reduction can be implemented by the application of a systematic plan to eliminate or reduce the production of waste at the source. Waste material streams are perceived as an unwanted material resource. As such, efficient materials use is the incorporation of techniques and processes that ultimately either converts existing waste streams to economically viable ones or eliminates them at the source. Since defective products and products at the end of life are major waste streams, techniques, actions or design procedures that involve the ability to recover the resource from the final product completing the product life cycle loop form an integral part of the plan.

This action plan is set up using the following steps[3]:

- Assessing the scope or area of the business to apply the reduction plan
- Get commitment from management
- Process flow examination and data collection to find out where excess material and wastes are created

[3] 'Waste Minimisation, An Environmental Good Practice Guide for Industry' Environment Agency April 2001.

- Determining the cost of the waste produced
- Examination of the data and prioritising based on all factors collected
- Brainstorming on possible actions to be taken guided by the 5 cleaner production techniques
- Perform feasibility studies on the possible actions and project financial analysis
- Implementation and data collection
- Set-up next action plan

Following are examples of how various organisations have reduced the amount of materials used and reduced waste according the 5 preventive Cleaner Production techniques of:

- Good housekeeping
- Input substitution
- Technology modification
- Product modification
- New use, re-use, recycle

PREVENTION PRACTICE	WASTE REDUCTION CASE STUDIES
Good Housekeeping	**CSR Timber Products** A methodical team approach was used to analyse the board production process to identify factors affecting product quality. From these identified factors, good housekeeping actions were implemented e.g. getting timber suppliers to provide appropriate species, and branded logs for collection; continually monitoring processes variables such as air gun pressure and pressed board thickness; and *reducing* the speed of the board machine. (With this last change, process consistency and quality improved and output actually rose by some 17% as a result). Gross reject rate from each stage of the process was recorded on a shift by shift basis by production personnel. As a result on the initiative, rejects reduced from an average 13.5% to an average 6% representing an annual saving of some $750,000. Since the primary cost to achieve this was in retraining the work force to operate as self-directed work teams and establishing the management systems, a payback period of 2 months was estimated.
Input Substitution	**Simcoa** Simcoa Operations Limited uses jarrah in the production of silicon at its smelter at Kemerton near Bunbury. In recent years in response to community pressure Simcoa has commenced a programme to substitute its use of jarrah from state forest logging operations with waste wood from mine sites.
Technology Modification	**Alcoa** Access to bauxite is the keystone of Alcoa's activities in Australia. Darling Range bauxite is a low-grade resource to which value is added through refining and smelting. Bauxite is defined as any ore in the lease which has a content of more than 27.5% aluminium oxide. As part of Alcoa's 2020 Global Environmental Strategy on Sustainable Development the following technological modifications have already been implemented: • The contamination of the refinery liquor stream by organic compounds is a major constraint on production. In the past , pockets of overburden were

	mined along with the bauxite. Research indicated that this was a significant source of organics. Mining practices were modified to carefully remove all overburden, thereby reducing organic inputs and subsequent waste. • Fine alumina is produced by uncontrolled precipitation and product breakdown during materials handling. It is captured in electrostatic precipitators in calcination. In the past, product quality specifications resulted in the recycling of over 200,000 tpa of fine alumina in three WA refineries. More than half of this was lost to residue. Technology and product modifications led to waste reduction refinements in precipitation control and calciner design, as well as reuse of some of the superfines as liquor burning feed medium, have significantly reduced the waste. After discussions with customers, some relaxation in the product specification further reduced the superfines recycle. Further improvements in calcination are planned.
Product Modification	**Inglewood** In 1994 Inglewood was the first company to use natural wood with features to make furniture. Previously these materials were considered defective but currently they are used and marketed as outdoor furniture with features. Since Inglewood are saw millers as well as furniture designers they were able to integrate technology in both operations so that designs could be created to suit the log. Instead of just producing and using square cut wood materials, curved pieces were cut out of curved material which was previously left to rot in the forest. Hence with the ability to maximise the usage of the valuable jarrah wood resource Inglewood has enjoyed a 500% growth in the last 9 years with 70% of their outdoor furniture made from feature grade jarrah.
New use, Re-use & Recycle	**Tiwest Rutile Recovery Plant** The aim of this initiative has been to recover synthetic rutile from process effluent. After chlorination, all metallic chlorides go to a sump and to the wastewater treatment plant. Overflow from the fluidised bed reactor is rich in unreacted synthetic rutile and petroleum coke but this went with the metal chlorides to effluent treatment. A new plant was installed and commissioned in 2000 to recover synthetic rutile from the effluent using hydrocyclones separating on particle size. The titanium-rich fraction is filtered on a belt filter, washed, dried in a fluidised bed drier and returned to the chlorinator with the normal input material. The titanium-poor fraction continues to the wastewater treatment plant.The rutile recovery plant was designed to recover up to 21,000 tonnes per annum of unreacted SR and coke (based on 180,000 tpa FPP) which equates to net savings of about $31,000 per day on an investment of $6m. At current pigment production rates, the recovery potential is about 53% of design potential. **Dale Alcock Homes Waste management** The company has undertaken a number of initiatives to reduce, reuse and recycle construction waste:It has teamed with a number of organisations to address the issue of how to deal with waste on an individual lot basis, instead of using landfill facilities. It has been trialing with a contractor to crush solid waste on site, such as roof tiles, waste bricks, masonry and concrete for use in driveways. It has been negotiating with local authorities to allow this material to be used instead of the crushed limestone currently used. Trials have covered sixty sites and included consideration of optimising use of crushers. For initial sites, a small crusher was provided for each site. In many situations a site crusher will not be economical or acceptable to neighbours and a central crusher is more suitable covering a few, or even many sites. Crushed material is then stockpiled for use where it is needed. Trucks hauling waste for crushing can then be used for delivery.

The reduction of toxics is covered in the following case studies.

<table>
<tr><th>PREVENTION PRACTICE</th><th>CASE STUDY</th></tr>
<tr><td>Good Housekeeping</td><td>Newmont Golden Grove Operations
Newmont Golden Grove operates two underground zinc/copper mines, 225 km east of Geraldton in the Murchison Region of Western Australia. The mines yield about 1.3 million tonnes of ore each year, which are processed on site to produce 100,000 tonnes of copper concentrate, and 150,000 tonnes of zinc concentrate. Pollution prevention measures taken on site included:
The construction of a $1.6 million shed to store concentrates which has prevented the annual loss of an estimated 1 000 tonnes of heavy metal sulphide concentrate valued at around $1M and prevented the contamination of surrounding bush-land.
Spillage containment structures in the mill which eliminated the need to hire four contract labourers previously dedicated to spillage clean up and decreased closure liabilities by ~ $1M and stopped creating more contaminated sites.
Improved hydrocarbon management and education programs in underground operations that have reduced oil contamination in discharge water by two thirds thus improving the quality of water discharged in the nearby lake. This is also the source of process water, and improvements in its quality have enhanced the metal recovery efficiencies of the processing plant.</td></tr>
<tr><td>Input Substitution</td><td>Environmental Printing Company
The Environmental Printing Company is located in Maylands in the northern suburbs of Perth, Western Australia. The main initiatives of the company have been to replace input materials with less harmful substitutes. This has been a continuing process over the years as technologies have developed and new materials have become available. Substitutions included:
Inks: Solvent-based inks were first substituted with vegetable (soya) oil-based inks in the early 1990s.
Cleaners: Citrus–based, solvent-free cleaners have been used for the past three years. Various types have been tried and in the past there have been problems of greasy residue leading to poor results and a lot of wasted paper. A new one has been found that cleans and dries without residue
Papers: 100%-recycled paper, oxygen bleached, is used for most purposes. Sugar cane roughage and hemp papers also used for some purposes. Virgin paper, cotton papers (cotton is heavily sprayed) and chlorine-bleached papers are avoided.
Although the financial benefits of the various initiatives were difficult to quantify, the working environment has improved greatly with improvements to the general health of the workers. Also the company has gained many “green” customers.</td></tr>
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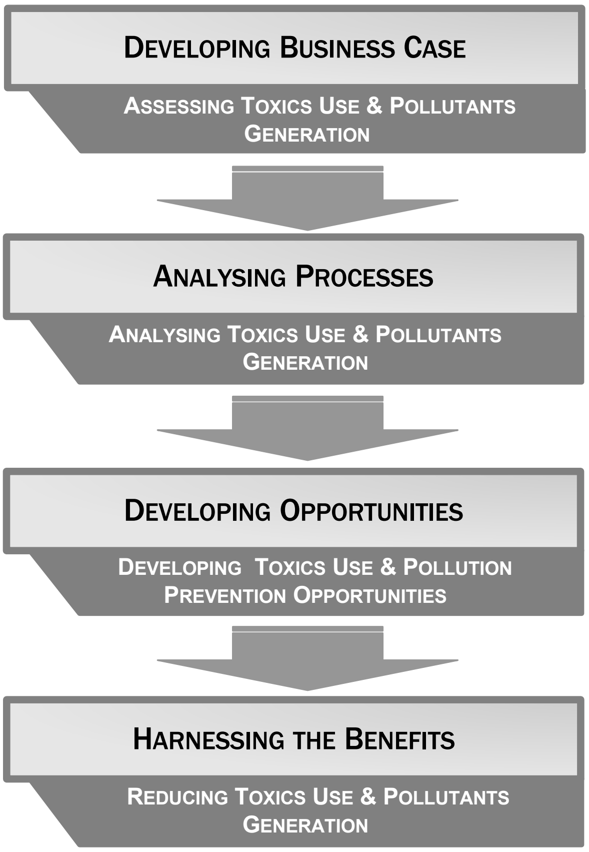
Technology Modification	**Herdsman Drycleaners** Herdsman Drycleaners (Churchlands) offers a retail dry-cleaning service and cleans some 2,600 garments/months. The drycleaning process involves washing in perchlorethylene (perc) and soaps to dissolve any grease and oil. The solvent is then removed and recycled in a still to recover the perc for reuse. This process also produces a liquid waste residue that has to be legally disposed of. Herdsman purchased a more-efficient dry-cleaning machine. The new machine has inbuilt energy efficiency mechanism and uses on average 17% less electricity to clean each garment. Comparing with the previous machine a 80% fall in perc consumption has been recorded. The improved still design has also reduced perc waste generation by 50%.
Product Modification	**Rohm and Haas** Fouling, the unwanted growth of plants and animals on a ship's surface, costs the shipping industry globally approximately $3 billion a year, largely from higher fuel consumption to overcome hydrodynamic drag. The main compounds used worldwide to control fouling are the organotin antifoulants, such as tributyltin oxide (TBTO). They are effective at preventing fouling, but have widespread environmental problems due to their persistence in the environment and the toxic effects they cause, including acute toxicity, bioaccumulation, decreased reproductive viability, and increased shell thickness in shellfish. Upon extensive screening Rohm and Haas Company identified 4,5-dichloro-2-n-octyl-4-isothiazolin-3-one (Sea-Nine(TM) anti-foulant) as preferred substitute. For TBTO, the bioaccumulation factor is as high as 10,000 X, while Sea-Nine(TM) antifoulant's bioaccumulation was essentially zero. Sea-Nine(TM) antifoulant has been sold worldwide and hundreds of ships have been painted with coatings containing it.
On-site Reuse & Recycle	**OneSteel – Kwinana Plant (OSK)** The OneSteel Kwinana (OSK) processes a range of tube and structural steel products. Employees identified the opportunity to recover powder coating and clean and recycle it on site. A recycling box was leased and fitted on the paint booth, to vacuum paint powders out of the booth back into the recycling chamber. The recycled paint powder is then put back through the paint gun device. The production processes were also addressed so only one paint colour is used for each batch, reducing cleaning costs and lost production time.

7. Becoming an eco-efficient business

The approach described herein facilitates problem solving and helps organisations to understand why and where materials and toxics are being used and where wastes and emissions originate. It employs some systems approach tools, such as process mapping, cause and effect diagrams and brainwriting to analyse the toxic/pollutant issue thoroughly and to determine the underlying root cause and generate possible improvements. It is advisable to use these tools in teams to ensure that the whole process and all opportunities are being covered, by the interaction and questioning within the team.

The following steps are covered:



DEVELOPING BUSINESS CASE

ASSESSING TOTAL MATERIAL USE & WASTE GENERATION

Process Mapping

It is impossible to improve your material use efficiency unless you have a good understanding of where materials are used, in what quantity and quality. That is why the first step of reviewing materials use efficiency for your organisation involves mapping of the process to show how materials are consumed and waste created.

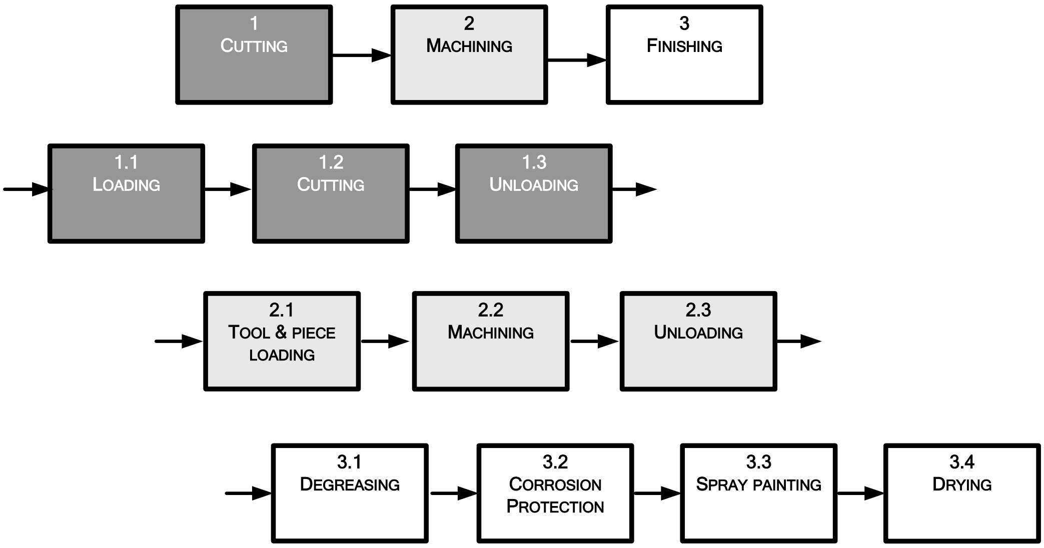
All the information of how, where and the quantities of materials used and waste created can be recorded and summarised on a single Process Map or Process Flow chart. This starts with classifying the business into various manufacturing or service steps, each step can then be analysed as a process flow of operations. All this information is then put on a diagram with the inputs and outputs of each operation shown. Next these inputs and outputs are quantified by conducting surveys or by installing real time measurement devices. The mass of the *input* materials is equal to the mass of the output products and by-products, which may also be in the form of a dissolved substance or gaseous components. These diagrams or charts can then be used to analyses the costs, causes and finally possible solutions to reduce materials use and waste.

Where the review targets toxics and pollutants, you may need to browse through additional information sources to spot the toxics or pollutants to focus on, for example:

- Material Safety Data Sheets,
- Sector specific technical manuals or websites
- Operation manuals for your process equipment
- Environmental licence

Hierarchical ***process mapping*** uses boxes to depict the series of process steps through which the materials and other inputs are transformed into a product. It includes a set of several maps drawn to various levels of detail starting from a top-level map, providing a broad overview of the process and working down to second or third level maps, detailing the process. An illustrative hierarchical process map for a metal-working operation is presented in Figure 1. Boxes stand for the work steps and the arrows between represent the flow of materials from one step to another.

Figure 1: Hierarchical process map structure for an engineering workshop

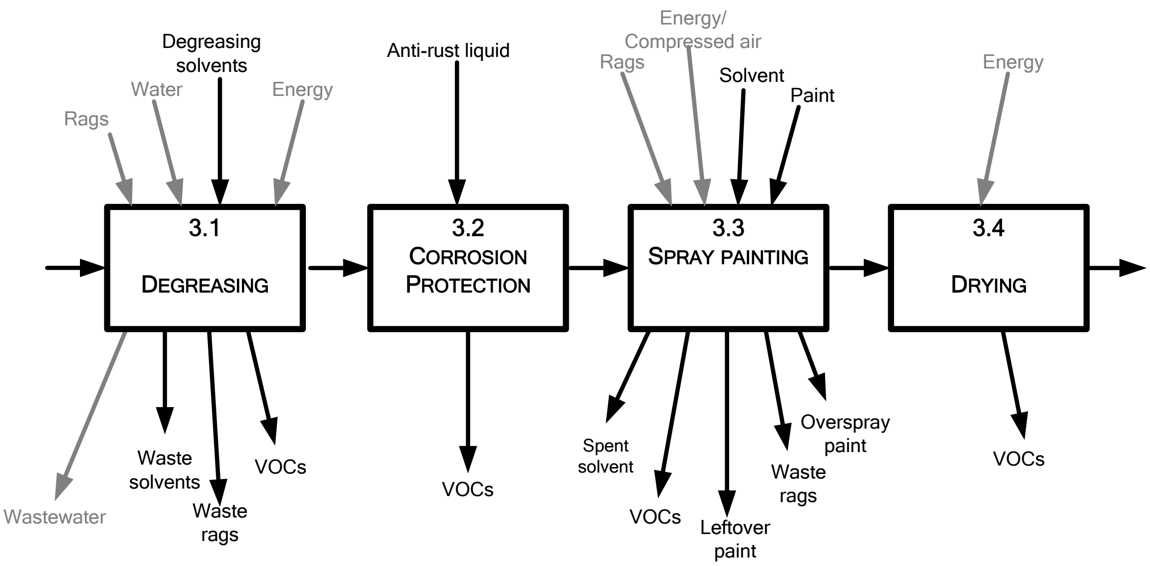


Process mapping typically reveals a number of areas where improvement can be made. Process maps at lower levels are often used to:

- Question the need for the usage of materials in the process wherever they occur and think of suitable alternative operating practices that can reduce or eliminate consumption.
- Map out areas where by-products are created and eliminate or find new applications for these products.
- Figure out where materials are wasted.
- Allocate the usage of materials and waste generated in a process to a particular activity allowing for *materials use and waste cost tracking* at every process step.
- Identify every process step that contributes to facility's waste as a result of materials use.
- Picture a new process before implementing it, including the possibility to calculate the difference in the activity based costs between operational scenarios.

Figure 2 illustrates how process mapping could be used as a template to account for toxics use and pollutants generation. Vertical arrows entering the work step boxes from above and leaving them from below indicate toxic and benign materials, and utility flows that are used by the process whilst vertical arrows leaving the boxes indicate wastes, emissions or by-products generated by the process.

Figure 2: Tracking for toxics use and pollutants generation in engineering workshop



Process mapping is generally used to illustrate all the materials, water and energy flows in an organisation, so for complex operations it may be necessary to use different colours or shading for different types of inputs and outputs, or to use separate diagrams.

The blank boxes in **Worksheet B** (see appendix) represent process steps. Start with the basic processes carried out in your business. Many of these processes have separate steps to them. Use the same worksheet to create more detailed second or third level maps if you need to describe complex process steps as in Figure 1.

When focusing on each individual process step it would be useful to develop a material and energy balance by quantifying the energy used and lost at each step. For that purpose use the boxes above and below and the energy flows to allocate energy consumption and the energy losses, if such information is available.

Process mapping will not only improve your understanding of how your business operates, but also gives you an understanding of the materials, waste quantities you use and loose and the expenditures you incur with every operating step. [4]

[4] Process mapping provides a foundation for all problem-solving activities in the modules of the series relating to Energy, Waste & Emissions, and Water.

ANALYSING PROCESSES

ANALYSING MATERIAL USE & WASTE GENERATION

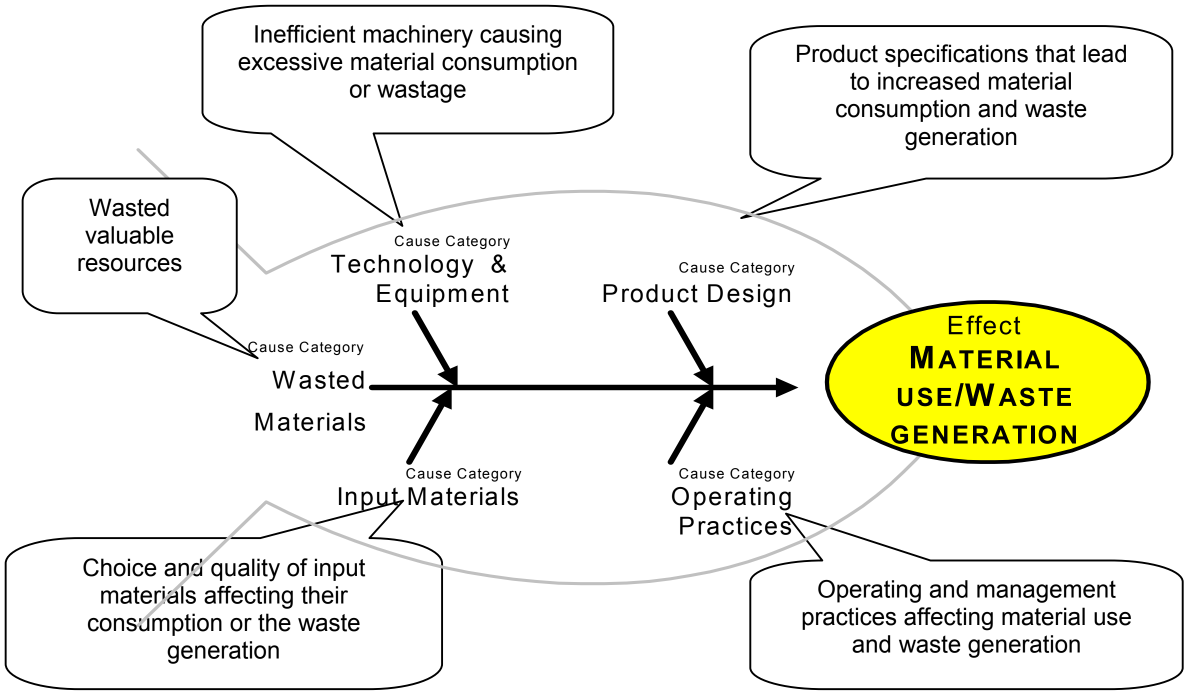
Cause Diagnosis

Cause-effect diagrams (also called fish-bone diagrams) are a well-known tool in quality and operational management. They can be applied to analyse any business process, to establish root causes for energy inefficiencies and quality deviations in that process, by investigating the impacts of materials, machine operations, and people, and develop customised solutions that alleviate the root causes identified. The major value of the *cause and effect diagram* is that it forces the team in charge of the process to analyse the root cause of a problem instead of simply acting on the first identified cause. It provides a graphical explanation to management and other parties for exactly what is contributing to the problem, considering different categories of potential causes, such as operating practices, input materials, technology and equipment, product design and wasted materials. A cause and effect diagram may often reveal multiple causes to a single problem. Root cause analysis can be an effective management tool for determining the true cause of resource use or loss in a process, facilitating effective corrective action, and preventing recurrence of the problem. Figure 3 provides an illustration of a cause-effect diagram.

The cause and effect analysis allows you to clarify the problem and identify possible root causes. The *effect* is the material uses or waste generation, while *causes* are any number of activities or conditions contributing to the waste generation. Use **Worksheet C** (see appendix) in a group and list all suggestions of possible causes of a problem.

After listing all possible causes in the fishbone diagram, you will need to select the most significant causes contributing to a particular material use efficiency issue. The Pareto principle, or 80/20 rule, suggest that 80% of the problems in a business comes from 20% of the possible causes. In other words 80% of the company's wastes and emissions can be attributed to 20% of the causes you have already identified.

Figure 3: Illustration of cause-effect diagram



Developing Opportunities

Developing Material Use Efficiency Opportunities

There are five prevention practices that can be applied to improve materials use efficiency listed in the table below. They correspond to the cause categories used to identify root causes for material use inefficiency (see Figure 4 below).

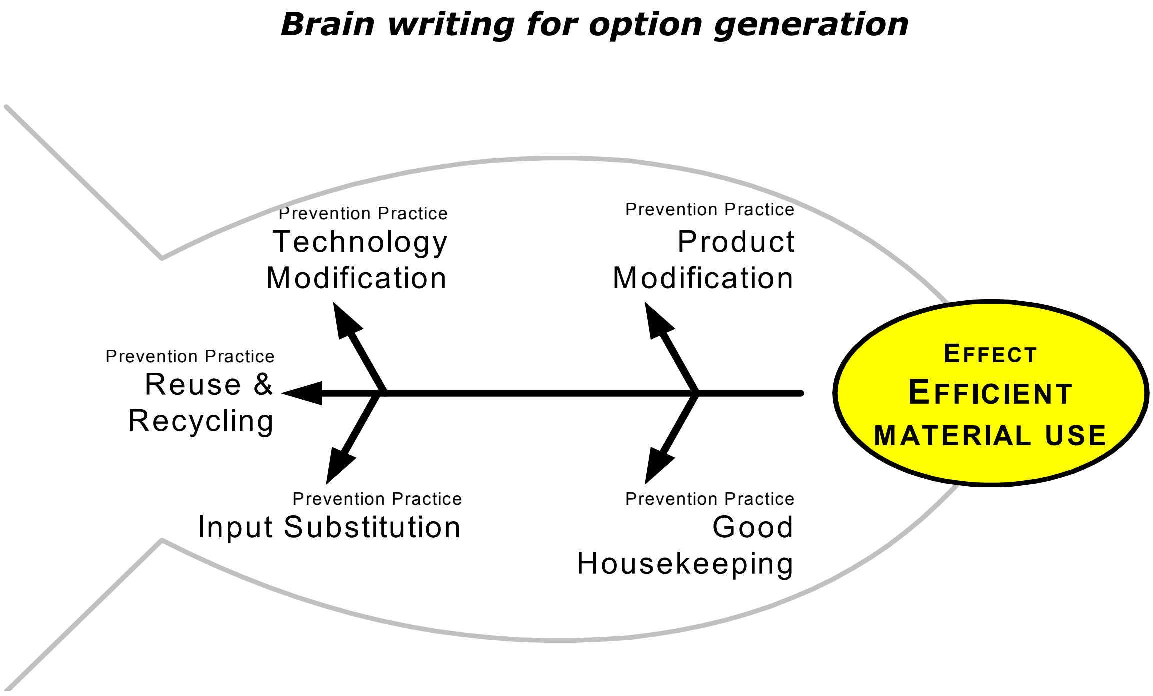
After mapping your process and becoming aware of all points where you are using or disposing materials, and after identifying the root causes for materials use inefficiency, the third step is to generate options that give answers to already identified problems.

Brain writing is a written form of brainstorming that allows the team members to generate materials efficiency improvement options. In a brainstorming session, the team lists all ideas/actions regarding the problem under review. Each member of the team receives a sheet of paper with materials use issue and the selected root causes clearly stated on the top of the sheet. Team members are asked to present all ideas for solving the problem, even those which at first glance seem impractical or unworkable.

The form used for the brain writing exercise is available in the appendix as **Worksheet D**.

The options on each sheet should be discussed within the group to eliminate impossible ones and to arrive at a comprehensive list containing all ideas. If an idea appears repeatedly with small variations, all variations of the idea need to be included.

Figure 4: Five prevention practices



Examples of common techniques for improving eco-efficiency

Prevention Practice	Materials use Efficiency Examples	Pollution Prevention Examples	Toxics Use Reduction Examples
Good Housekeeping: Involves improving operating and maintenance practices and procedures, as well as education and awareness training to reduce the use of energy and minimise waste creation.	Staff training on materials use efficiency Separation and arrangement of materials used, to prevent cross contamination Proper classification and labelling of the various materials used Scheduled monitoring and purchasing of materials to maintain a good inventory control Maintaining separate handling of different waste types Segregation of wastes for disposal	Dry clean up and recovery of spilled materials from process areas Develop and implement system of periodic review and adjustment of standard operating procedures Introduce preventative maintenance practices	Staff training on safe storage and handling of toxics First-In-First-Out inventory management Policy and procedures in place for review of new toxics for use in company Proper classification and labelling of the various toxic materials used and ready-access to up-to-date MSDSs
Input Substitution: Inputs to the production process are replaced by environmentally preferred inputs, such as renewable or less toxic materials.	Use reusable or recyclable materials instead of disposable materials If available, replace existing process chemistry or unit operation with one requiring less or no materials Replace the materials or consumables to that which require less resources Replacing materials with those from sustainable sources	Substitute process auxiliary with one that has longer service life (e.g. coolant, oil, degreaser)	Eliminate toxic auxiliaries from product formulation Replace toxic with less toxic or better degradable alternative Replace process chemistry or unit operation with one requiring less or alternative non-toxic materials Use high purity ingredients with minimum contamination levels

Technology Modification: Involves improved process automation, process optimisation, equipment redesign and process substitution.	Modify processes to reduce the types or quantity of materials required Change process so by-products are made valuable Incorporate new equipment that can accept recycled or reused materials Modify equipment for efficient material transfer between operations	Improve process instrumentation to reduce frequency and duration of abnormal process conditions that cause pollutants of concern Adopt catalytic process options	Modify process chemistry and process design to avoid use of toxics as raw material and/or generation of toxic intermediates and by-products ('green chemistry') Close and seal process equipment to reduce dissipative losses of toxics Redesign processes to operate a milder conditions (e.g. ambient temperature and pressure) to reduce risk for accidental releases
Product Modification: Redesign product to reduce the environmental impact of its manufacturing, use or disposal.	Investigate product re-design so that it can be made from recyclable, reusable materials that come from less resources intensive processes Modify products to that which require less resources to produce Create products that are easily reusable or recyclable Design packaging to be reusable or recyclable and or made as a useful product Design products that are resources efficient when used	Modify products to ones that use emission-less processes Design products that use material derived from processes that use less toxic materials	Eliminate toxics from product formulation (e.g. water based paints and inks) Design products for quick and complete breakdown into un-harmful substances in the environment Investigate the introduction of alternative products to replace existing ones that use toxic material or generate emissions Investigate product re-design so that it can be made from non-toxic materials
Reuse & Recycle: Involves simple reuse of material and resources, or involves some reprocessing before use. It also includes finding new uses for by-products	Reuse all packaging Recycle or reuse damaged products Find new uses for by-products Incorporate by-products into processes or product	Cascading use of process auxiliaries	Use toxics in closed loop process configurations

HARNESSING THE BENEFITS

REALISING MATERIAL USE EFFICIENCY

During the brain writing step a comprehensive list of improvement ideas is generated. The next step is to determine how to work with the information to select a feasible list of efficiency options that would lead to reduced materials use and waste generation.

Once a list of possible solutions is generated it will be necessary to identify those that can result in the most benefits for the lowest cost. You will need to identify which are the impractical ideas; the ideas that need more information before being considered; and ideas that can be implemented without much effort and expense.

To do this a prioritisation tool known as *Bubble up/Bubble down* is used for ranking statements or ideas from a long list of possibilities and putting them in an orderly sequence. For evaluating and ranking the alternatives a number of decisive factors need to be considered such as:

- Cost
- Ease of implementation
- Effectiveness
- Risk of liability

The team examines only two alternatives at a time and decides which one is best based on criteria mentioned above and any other criteria that are specific for the business. The better of the two options is moved to the top of the list. The second option is compared with the third on the list and the better of those options is moved up and compared with the first. If it is better than the first it bubbles up to the top of the list, if not, stays in second position. This process is continued until all of the options are rank ordered.

Options that bubble up to the top are usually those that strike the best balance between effectiveness (i.e. material resources conservation potential), expected feasibility (economical and technical) and ease of implementation. Options that fall in the middle are usually at first sight less effective in preventing losses but they might require further investigation and a feasibility study. The options at the bottom of the list typically require major equipment changes or serious capital investment, with doubtful material use efficiency gains.

Monitoring

After selecting all feasible material use efficiency options it is advisable that you monitor and evaluate the progress and results achieved by their implementation. To accomplish that the following tasks need to be considered:

- Prepare *Material use Efficiency Implementation Plan* - the selected options are organised according to their implementation date and responsible person for carrying out each one.
- Implement the easiest and cheapest material use efficiency options to generate quick savings for a start.

Monitor and report material use efficiency progress – use simple indicators to monitor progress and keep staff, management and other stakeholders informed.

Additional Information

TOXICS USE REDUCTION

- Toxics Use Reduction Institute http://www.turi.org/
- Minnesota Technical Assistance Program - http://www.mntap.umn.edu/

POLLUTION PREVENTION

- Cleaner Technologies Substitutes Assessment, A Methodology and Resource Guide - http://www.epa.gov/dfe/pubs/tools/ctsa/index.htm
- Pollution Prevention Information Resource for Industry Sectors (**P2IRIS**) - http://www.p2gems.org/
- Enviro$ense - repository for pollution prevention, compliance assurance, and enforcement information and data bases - http://es.epa.gov/

GREEN CHEMISTRY

- American Chemical Society, Green chemistry institute - http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=greenchemistryinstitute%5Cindex.html
- USEPA Green Chemistry Mission - http://www.epa.gov/greenchemistry/index.html
- Centre for Green Chemistry, Monash University - http://web.chem.monash.edu.au/greenchem/

SECTOR RESOURCES

- Online Solvent Alternatives Guide - http://sage.rti.org/
- Coatings Guide - http://cage.rti.org/

Appendix – Worksheets

Worksheet A: Calculating Materials and Waste Costs

Material Use Costs

Resource /Raw material	Quantity/ Volume	Cost	Annual Cost	Estimated % Reduction	Estimated Cost Reduction
raw material 1					
raw material 2					
raw material 3					
raw material 4					
raw material 5					
raw material 6					
		TOTAL			

Waste Costs

Waste	Quantity/ Volume	Disposal costs	Treatment costs[1]	Handling costs[2]	System costs[3]	Fees, permits, licences	Hidden costs (estimate)			Annual cost
							Material	Energy	Labour	
non-product output 1										
Non-prduct output 2										
Non-Product output 3										
General waste										
Paper waste										
Packaging waste: • Cardboard										
• wood Pallets										
• Plastic wste										
									TOTAL	

1 - include labour, materials; 2 - include storage, sorting, transfer; 3 – pro rata monitoring, reporting, maintaining EMS

Worksheet B: Material Use Process Map

MATERIAL INPUTS

Type	Qty/Vol	Characteristics
•		
•		
•		
•		

#

MATERIAL OUTPUTS

Type	Qty/Vol	Characteristics
•		
•		
•		
•		

MATERIAL INPUTS

Type	Qty/Vol	Characteristics
•		
•		
•		
•		

#

MATERIAL OUTPUTS

Type	Qty/Vol	Characteristics
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•		
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MATERIAL INPUTS

Type	Qty/Vol	Characteristics
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MATERIAL OUTPUTS

Type	Qty/Vol	Characteristics
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MATERIAL INPUTS

Type	Qty/Vol	Characteristics
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MATERIAL OUTPUTS

Type	Qty/Vol	Characteristics
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MATERIAL INPUTS

Type	Qty/Vol	Characteristics
•		
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•		
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MATERIAL OUTPUTS

Type	Qty/Vol	Characteristics
•		
•		
•		
•		

LEGEND

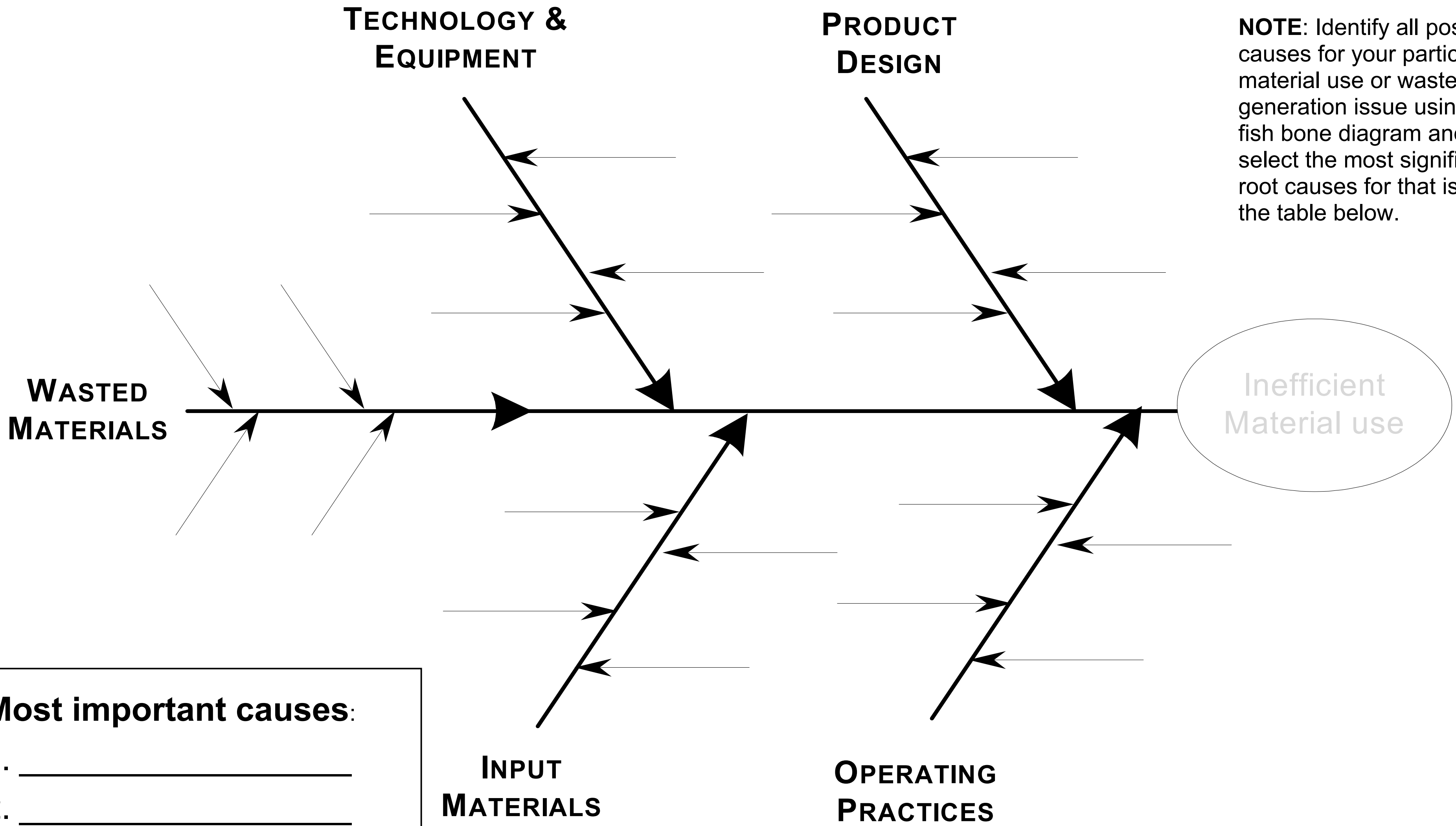
Types of **input materials** are: raw materials, ancillary materials, consumables and packaging

Characteristics such as: grade, composition, etc.

Type of **output materials** could be: defective products, by-products, waste; packaging, unused or expired materials, defective inputs materials, materials to be recycled or reused and general waste

Characteristics such as: composition, hazardous class, liquid or solid, , method of disposal, etc.

Worksheet C: Materials Use / Waste Generation Fishbone Diagram



NOTE: Identify all possible causes for your particular material use or waste generation issue using the fish bone diagram and then select the most significant root causes for that issue in the table below.

Most important causes:

1. ______________________
2. ______________________
3. ______________________
4. ______________________
5. ______________________

Developed by WASIG in partnership with Department of Industry and Resources of WA

Worksheet D - Brainwriting

Material use Inefficiency / Waste Generation Issue (Environmental Impact) Considered: ____________________________________ ____________________________________ ____________________________________	Root Causes: ____________________________________ ____________________________________ ____________________________________ ____________________________________
Potential Solutions	
1.	2.
3.	4.
5.	6.
7.	8.
9.	10.
11.	12.