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# AN INTRODUCTION TO LIFE CYCLE ASSESSMENT

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- Life cycle assessment (LCA) is a tool that calculates the potential environmental impacts of building materials, building elements and whole buildings.
- LCA is systematic and holistic, looking at production, use and disposal of any product.
- LCA can support design by showing the magnitude of environmental impacts and where they occur in the life cycle.

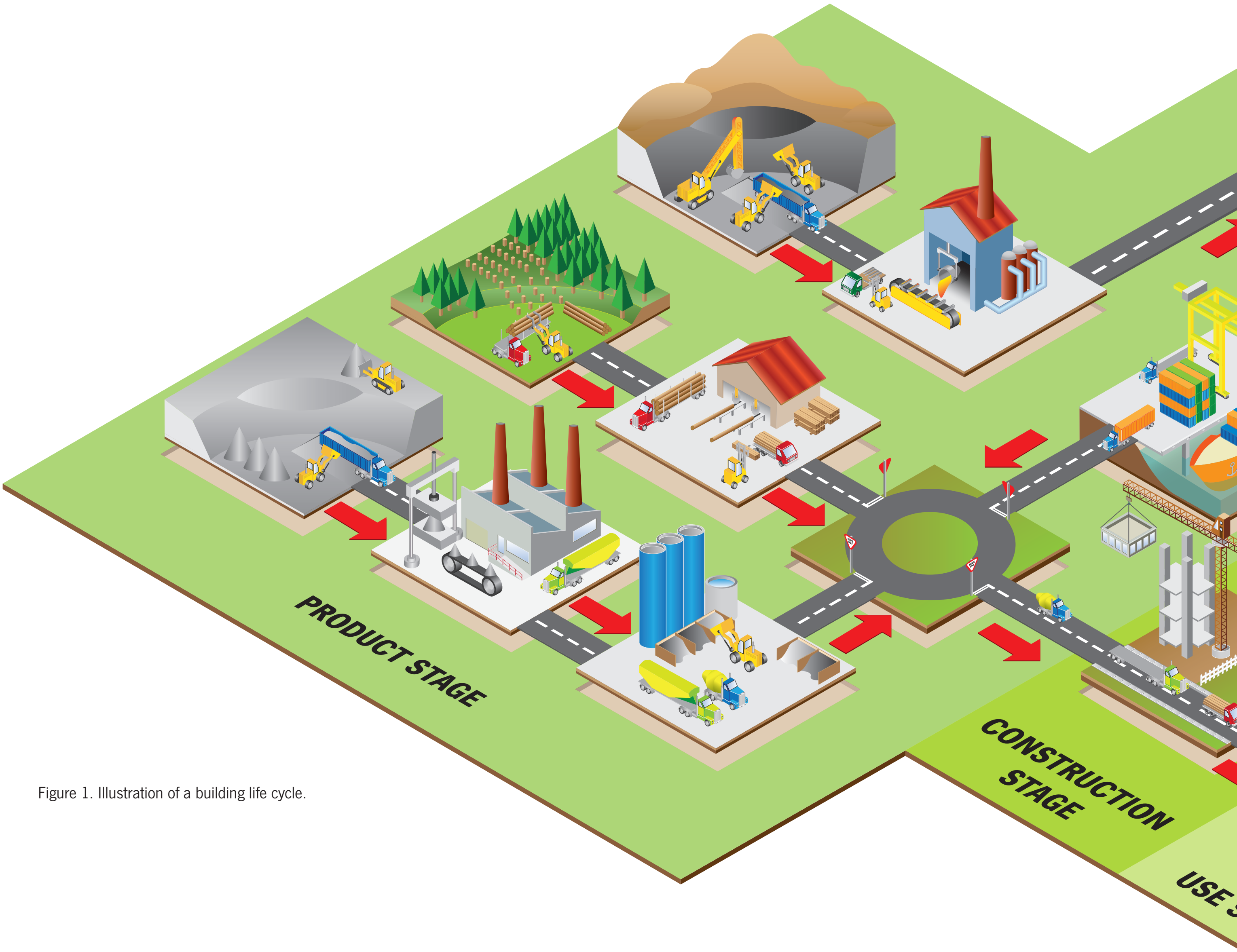



Figure 1. Illustration of a building life cycle.

## 1.0 INTRODUCTION

**1.0.1** Buildings and the way people use them consume a considerable quantity of resources and energy. The long lifetime of most buildings means that this impact can continue for many decades.

**1.0.2** Life cycle assessment (LCA) of buildings combines outputs of energy simulation models with information about materials (from a bill of quantities or a building information model) and shows results in terms of potential environmental impacts.

**1.0.3** LCA can therefore provide significant data for:

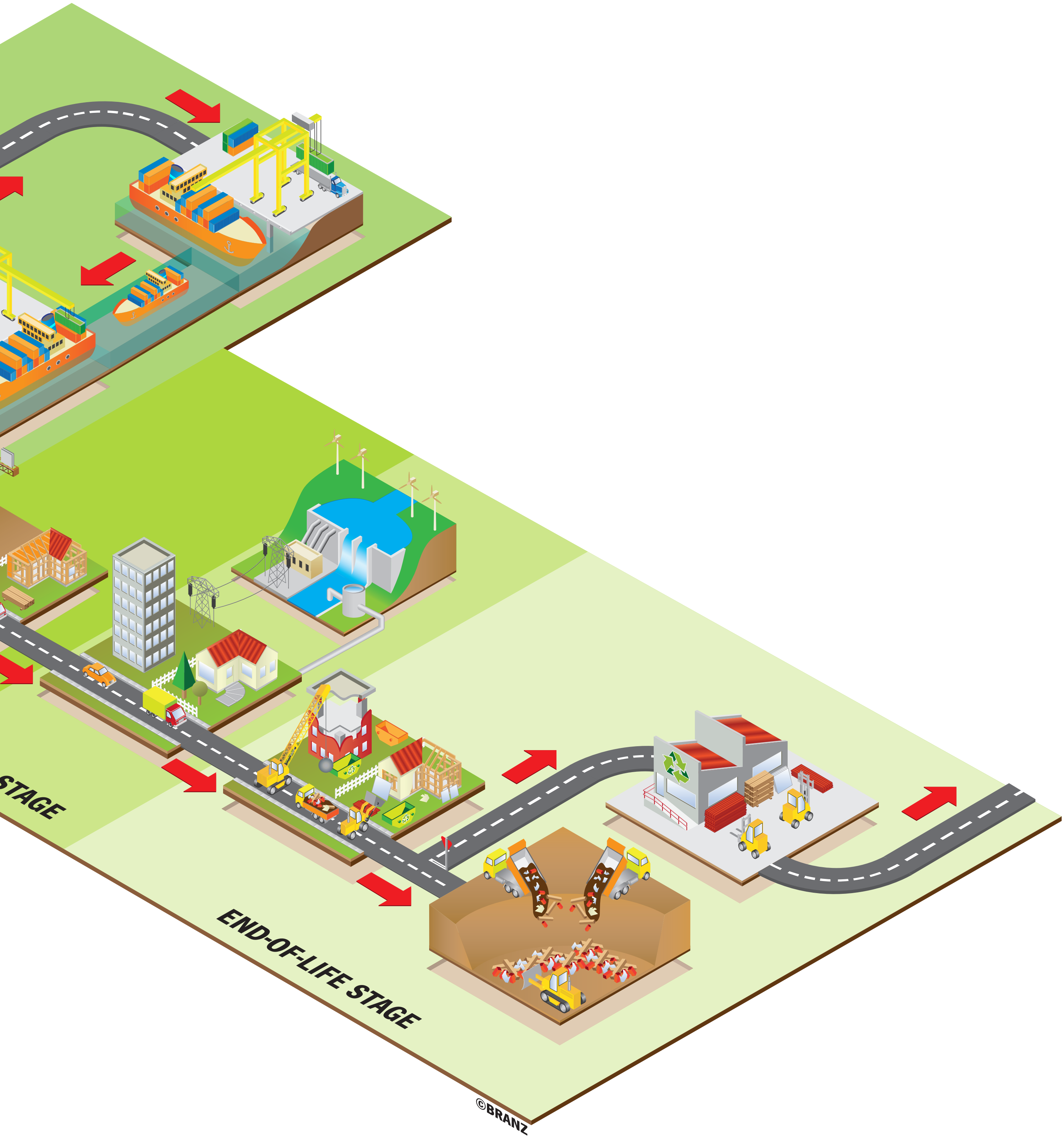
- designers – to understand the potential environmental impacts of different building design iterations and systems, such as form, type of structure, window-to-wall ratios, insulation levels or cladding alternatives
- product manufacturers – to understand the environmental impacts of what they produce and where they should focus their environmental improvements.

**1.0.4** Internationally, LCA is increasingly finding application in the construction sector. LCA is now recognised in Green Star and other international building environmental rating tools.

**1.0.5** This bulletin provides an introduction to life cycle assessment, its applications and limitations.

## 2.0 WHAT IS LCA?

**2.0.1** Consideration of the life cycle is termed 'life cycle thinking' or a 'life cycle approach' and is a useful first step to better understand and map out the key processes and considerations during the life of a product. However, since this does not involve quantification, it is not LCA.




**2.0.2** LCA quantifies use of resources and energy and emissions to land, water and air that arise across the life of any product. A product may be as small as a nail or as large as a building, a service or even an organisation. The scope of analysis for an LCA begins at the point that resources are extracted from the earth (including exploration, land clearance and/or removal of overburden that may precede extraction) and finishes when emissions return to the environment.

**2.0.3** The separation between what is included in an LCA and the wider environment is termed the 'system boundary'. The choice of system boundary may have significant implications for an LCA's outputs and conclusions, so care must be taken when defining this. When conducting an LCA of a building, the system boundary is typically subdivided into the stages illustrated in Figure 1:

- Product stage – the manufacturing phase of a product, including extraction, transport to the

manufacturer, manufacturing and assembly. The boundary is typically the manufacturer's gate. This may also be termed 'cradle to gate' or 'embodied'.
- Construction stage – covers transport from the product stage to the construction site and installation at the construction site. Manufacture of product that becomes waste during construction and end-of-life routes for this waste are also included. Sometimes, 'embodied' additionally includes this stage.
- Use stage – this covers the building occupation phase, including use of energy and water. It also includes the maintenance and replacement of materials required during the service life of the building.
- End-of-life stage – covers demolition or deconstruction of the building, transport of materials and end-of-life routes, such as recycling or landfill.

**2.0.4** Only consideration of the whole life cycle provides a complete picture of environmental impacts. Studies addressing the whole life cycle can be termed 'cradle to grave'. However, depending on the goal of a study, consideration of only part of the life cycle may be appropriate. For example, an LCA that focuses only on product manufacture will show where significant environmental impacts occur in manufacture and the supply chain. However, an LCA with a cradle-to-grave boundary may reveal ways that a product may be improved that lead to lower life cycle environmental impacts. This could lead to changes in the design of the product, such as improved thermal performance, better durability, lower maintenance and ease of recycling.

# 3.0 A BRIEF HISTORY OF LCA

**3.0.1** The Coca Cola Company is credited with the first LCA-type investigation in 1969 when it considered alternatives to glass bottles.

**3.0.2** During the 1980s and 1990s, interest in using LCA for making environmental marketing claims grew but resulted in conflicting information due to differences in methods used. To address this, four ISO standards on LCA were published in the late 1990s. These were subsequently rationalised into two standards in 2006, ISO 14040:2006 *Environmental management – Life cycle assessment – Principles and framework* and ISO 14044:2006 *Environmental management – Life cycle assessment – Requirements and guidelines*. These standards provide core requirements and guidance for undertaking LCA work.

**3.0.3** In the early 2000s, it was recognised that buildings provide particular challenges when assessed using LCA. This is because buildings:
- are mostly bespoke, located in unique positions and often multi-functional, providing a mixture of spaces
- comprise myriad materials and products, which are frequently used in combination
- are long-lived, far longer than almost all other products.

**3.0.4** International standards began to emerge in the 2000s that specifically addressed the application of LCA to buildings and building products, such as:
- ISO 21929-1 *Sustainability in building construction - Sustainability indicators – Part 1: Framework for the development of indicators and a core set of indicators for buildings*
- ISO 21931-1 *Sustainability in building construction – Framework for methods of assessment of the environmental performance of construction works – Part 1: Buildings*
- ISO 21930 *Sustainability in building construction – Environmental declaration of building products.*

**3.0.5** Equivalent European standards have also been published, including:
- EN 15643-2 *Sustainability of construction works. Assessment of buildings. Framework for the assessment of environmental performance*
- EN 15978 *Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method*
- EN 15804 *Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products.*

# 4.0 STAGES OF AN ASSESSMENT

**4.0.1** There are four main stages in an LCA (Figure 2).

## 4.1 STAGE 1 – GOAL AND SCOPE DEFINITION

**4.1.1** During this first stage, the aims of the study are documented. This helps to define what is included in the study and what is excluded (the system boundary).

**4.1.2** Another important consideration is the quantified functionality provided by the product being studied – this is called the functional unit. Guidance on functional unit definition is provided in ISO 14040:2006. When considering the life cycle, care needs to be taken to capture the function(s) that a product provides rather than just its mass or volume. Some examples of functional units are:
- provision of 5000 $m^2$ of conditioned office space meeting New Zealand Building Code requirements, and 100 car parking spaces over a 60-year life
- a roof system achieving an R-value of 4.1 $m^2K/W$ over a 100 $m^2$ area in a 60-year period.

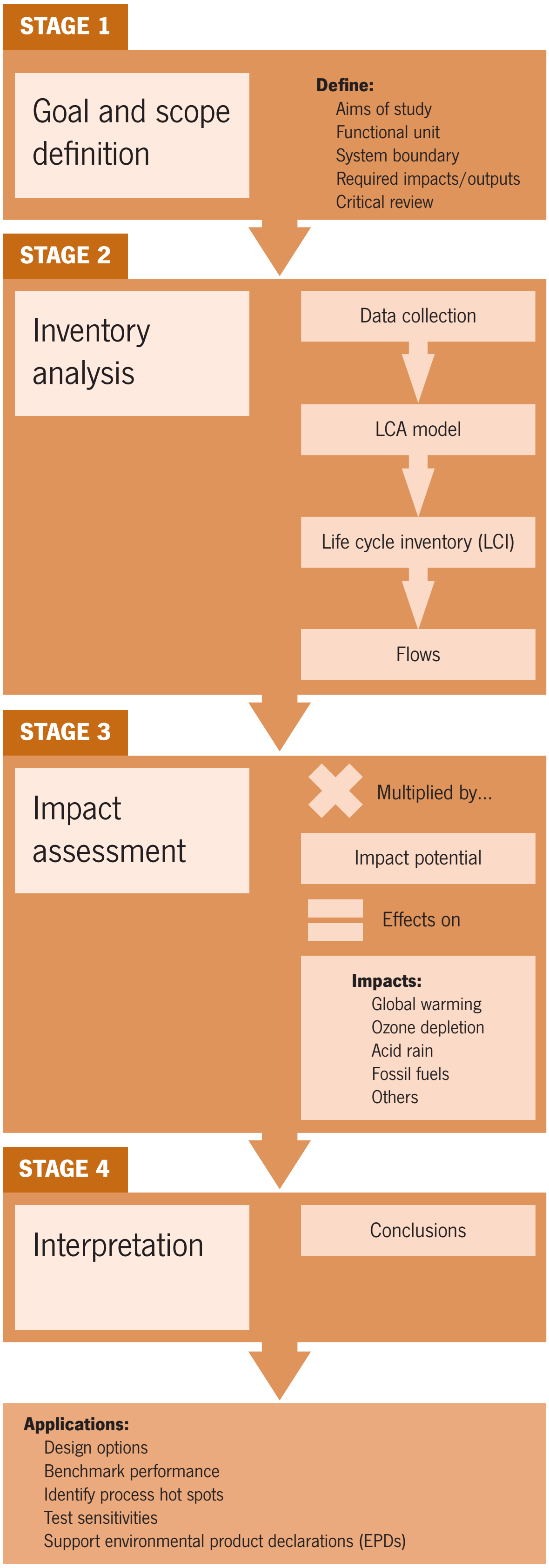



Figure 2. Stages of an LCA.

**4.1.3** Goal and scope definition also includes setting out the environmental impacts to be calculated and whether there will be a critical review of the study. If a critical review is to be included, its scope, who will undertake it and how it will be carried out should also be defined.

## 4.2 STAGE 2 – INVENTORY ANALYSIS

**4.2.1** This is the stage when data is collected for processes within the system boundary. For example, for a manufacturing operation making product A, this would typically include the following inputs:

- Energy used in manufacture, in what form (for example, electricity, heat, steam) and how derived (electricity from the grid, combustion of natural gas). For fuels brought to site, such as coal or wood pellets, the distance and method used for transport would be included.
- Materials used, either directly in product A or as consumables in the process. This will typically include the distance and method used to transport materials to the site, including amounts and types of packaging used (for example, plastic film).
- Water use, including where derived (for example, reticulated network, on-site rainwater collection and storage).

**4.2.2** It would also include outputs from the process of making product A, such as:

- Production of any co-products (byproducts or intermediate products) made in addition to product A. Where co-products are not included in the system boundary, care needs to be taken about how materials and energy used in manufacture, and generation of wastes and emissions, are divided between product A and co-products.
- Production of wastes and the end-of-life routes these follow, including transport to recycling or recovery facilities and/or landfill.
- Measured emissions to air, water and soil, arising from the process – for example, carbon dioxide from flue gases and phosphate to river from wastewater discharges.

**4.2.3** In an LCA model, each of these inputs and outputs is listed, together with the quantities required to make one unit of product A. Examples of inputs could include 64 kWh of medium voltage grid electricity, 5 $m^3$ of water from the reticulated network and 0.5 kg plastic film, but normally there will be many more.

**4.2.4** The environmental inputs and outputs associated with the supply of each of these need to be reflected. To do this, data is added to the LCA model that reflect the inputs and outputs arising from production of (typically) one unit of each. For example, 1 kWh of medium voltage grid electricity supplied, 1 $m^3$

| Grid electricity generation and distribution | |
|---|---|
| **INPUTS** | |
| Coal in ground | 0.05 kg |
| Gas in ground | 0.03 kg |
| *Other inputs* | |
| **OUTPUTS** | |
| **Grid electricity (medium voltage)** | **1 kWh** |
| Carbon dioxide to air | 0.16 kg |
| Phosphate to water | 0.02 kg |
| *Other outputs* | |

| Water treatment and distribution | |
|---|---|
| **INPUTS** | |
| Water (river) | 1,003 kg |
| Sand in ground | 0.0001 kg |
| *Other inputs* | |
| **OUTPUTS** | |
| **Water, reticulated** | **1 $m^3$** |
| Carbon dioxide to air | 0.04 kg |
| Phosphate to water | 0.005 kg |
| *Other outputs* | |

| Plastic film manufacture | |
|---|---|
| **INPUTS** | |
| Oil in ground | 1.3 kg |
| Gas in ground | 0.05 kg |
| *Other inputs* | |
| **OUTPUTS** | |
| **Plastic film** | **1 kg** |
| Carbon dioxide to air | 0.2 kg |
| Phosphate to water | 0.1 kg |
| *Other outputs* | |

| Manufacture of product A | |
|---|---|
| **INPUTS** | |
| Plastic film | 0.5 kg |
| Water, reticulated | 5 $m^3$ |
| Grid electricity (medium voltage) | 64 kWh |
| *Other inputs* | |
| **OUTPUTS** | |
| **Product A** | **1 unit** |
| Carbon dioxide to air | 0.3 kg |
| Phosphate to water | 0.1 kg |
| *Other outputs* | |

| Life cycle inventory for product A | | |
|---|---|---|
| **INPUTS** | | **Basis** |
| Coal in ground | 3.2 kg | 64 kWh x 0.05 kg/kWh |
| Oil in ground | 0.65 kg | 0.5 kg x 1.3 kg/kg |
| Gas in ground | 1.945 kg | [64 kWh x 0.03 kg/kWh] + [0.5 kg x 0.05 kg/kg] |
| Sand in ground | 0.0005 kg | 5 $m^3$ x 0.0001 kg/$m^3$ |
| Water (river) | 5,015 kg | 5 $m^3$ x 1003 kg/$m^3$ |
| *Other inputs* | | |
| **OUTPUTS** | | |
| **Product A** | **1 unit** | **1 unit** |
| Carbon dioxide to air | 10.84 kg | [0.3 kg] + [64 kWh x 0.16 kg/kWh] + [5 $m^3$ x 0.04 kg/$m^3$] + [0.5 kg x 0.2 kg/kg] |
| Phosphate to water | 1.455 kg | [0.1 kg] + [64 kWh x 0.02 kg/kWh] + [5 $m^3$ x 0.005 kg/$m^3$] + [0.5 kg x 0.1 kg/kg] |
| *Other outputs* | | |

Figure 3. Example of how a life cycle inventory for product A is generated.

of water supplied and 1 kg of plastic film supplied. By linking this supply data to the respective demand data to make product A, the inputs and outputs are scaled according to the demand. Figure 3 illustrates the process. The numbers shown are randomly generated for illustration purposes only.

**4.2.5** At the end of this stage, a life cycle inventory (LCI) is produced, which lists all the inputs (resources that need to be extracted from the earth and other resources such as recycled materials, water, land) and outputs (emissions to air, water and soil) that cross the system boundary. These are called 'flows'. The LCI can be further analysed by process and life cycle stage.

## 4.3 STAGE 3 – IMPACT ASSESSMENT

**4.3.1** Since the LCI is detailed and can be difficult to communicate, it is common to move to the third stage of LCA, impact assessment. This provides an understanding of how LCI flows contribute to environmental impacts.

**4.3.2** First, flows relevant to a specific environmental impact of interest are identified. For example, carbon dioxide, methane, nitrous oxide and hydrochlorofluorocarbons (HCFCs), among other emissions, contribute to climate change and are therefore classified to the impact 'global warming'. Flows may contribute to more than one impact. For example, HCFCs also contribute to the impact 'stratospheric ozone depletion'.

**4.3.3** Once flows have been classified, they are characterised. Each classified flow is multiplied by an 'impact potential', which quantifies how significantly the flow contributes to an impact, relative to a reference flow. For example, carbon dioxide is the reference flow for calculating a global warming impact and has a global warming potential (GWP) of 1. Methane has a GWP of 25, meaning that 1 kg of methane emitted to the atmosphere makes the same contribution to climate change as emitting 25 kg of carbon dioxide.

**4.3.4** By multiplying the quantity of each contributing flow from the LCI by the relevant impact potential, a total potential impact is calculated. This can be broken down by life cycle stage and process.

**4.3.5** Examples of environmental impacts that can be calculated using LCA:

- **Global warming (greenhouse effect)**: Human society's part in climate change is caused by the emission of greenhouse gases and other activities influencing their atmospheric concentration. Greenhouse gases absorb infrared radiation from the earth.
- **Stratospheric ozone depletion (ozone hole)**: Stratospheric ozone is vital for life because it hinders harmful solar ultraviolet UV-B radiation from penetrating to the lower levels of the atmosphere. Stratospheric ozone depletion occurs if the rate of ozone destruction is increased due to emissions of ozone-depleting substances, which persist in the atmosphere. This can lead to higher UV-B radiation reaching the surface of the earth, increasing the risk of skin cancer, cataracts, premature ageing and suppression of the immune system.
- **Acidification of land and water (acid rain)**: When emitted to the atmosphere, acidifying pollutants such as sulphur dioxide, nitrogen oxides and ammonia may remain in the air for days and can be dispersed and carried over long distances by winds. They can cause damaging effects far from the source of emission. Acidification can occur when the capacity of the soil or water bodies to neutralise acidifying atmospheric deposition declines. The effects include acidification of freshwater systems resulting in the loss of fisheries, impoverishment of soils, damage to forests and vegetation and corrosion of buildings, cultural monuments and materials.
- **Tropospheric ozone creation/photochemical oxidant formation (smog)**: This addresses the potential impacts from formation of ground-level ozone and other reactive oxygen compounds as a result of emissions of volatile organic compounds (VOCs) and carbon monoxide, for example. Health effects may include irritation of the respiratory system, reduced lung function, aggravation of asthma and inflammation and damage to the lung lining.
- **Abiotic resource depletion**: This provides a measure of resource scarcity by considering resources based on availability. Methods for defining availability vary and are normally considered at a global level, not taking into account differences that may arise locally.

**4.3.6** Other environmental impacts that may be calculated include water scarcity, toxicity to human health and the environment, respiratory effects and ionising radiation.

**4.3.7** It is important to recognise that LCA calculates *potential* impacts. Using the results of an LCA to reduce these potential impacts lowers the risk of actual impacts occurring in the environment, which is further complicated by the sensitivity of the receiving environment and presence of other emissions in the vicinity. For example, sulphur dioxide emissions from cars, buses and trucks in a city are more likely to cause air acidification than emissions of sulphur dioxide by ships at sea. Cities contain other emitters of sulphur dioxide, and the density of population in a city means greater sensitivity compared to the same emissions in the middle of the Pacific Ocean.

### 4.4 STAGE 4 – INTERPRETATION

**4.4.1** The fourth stage of LCA – interpretation – is where conclusions are drawn from the study findings, bearing in mind the goal and scope, the quality of data used and any assumptions that have been made. Sensitivity analysis is useful for testing significance of uncertainties in the study and how these may affect conclusions.

## 5.0 APPLICATIONS AND BENEFITS

**5.0.1** LCA is primarily used for the following purposes:

- Provide scientifically-based information that does not lead to problem shifting. LCA calculates multiple environmental impacts typically over the life cycle, thereby reducing the risk that a preferred option merely shifts impacts from one stage of the life cycle to another or from one medium to another. For example, a focus on embodied impacts would show additional environmental impacts from incorporation of insulation or solar shading in a building. It is only when these features are considered across the life cycle that the environmental benefits of incorporating them in a building can be quantified through savings in energy and the environmental impacts associated with its generation and distribution.
- Compare options such as designs, materials choices, logistics arrangements, different patterns of use, and end-of-life routes for waste. Some companies use LCA to inform strategic investment decisions and to understand the environmental risks associated with each option and what mitigation measures may be necessary. Some governments have used LCA to ensure legislation decisions are based on science and will lead to an environmental benefit.
- Benchmark environmental performance in order to make comparisons – for example, between alternative building elements such as structures or claddings or different buildings in a property portfolio. Construction product manufacturers may benchmark different plants or years of production. Establishing and using benchmarks can show opportunities for reducing resource and energy use and for target setting.
- Identify specific processes or stages of the life cycle that significantly contribute to one or more environmental impacts. Understanding where these hot spots are and what is causing them allows focused research and development on areas that yield bigger environmental gains.
- Test sensitivities in the life cycle to understand whether specific changes are likely to lead to significant additional environmental impacts or savings.
- Provide robust information to support marketing to customers – for example, by developing Type III environmental declarations or environmental product declarations (EPDs). The Australasian EPD® Programme was launched in New Zealand and Australia in 2014 and provides a platform for registration of EPDs.

## 6.0 LIMITATIONS

**6.0.1** LCA usually needs a lot of data. Collecting this can be time and resource intensive. There may be limits on data availability and applicability, which may have implications for achievement of the goals set out for the study.

**6.0.2** There is currently a lack of publicly available New Zealand data that can be used in LCAs. Ultimately, data gaps or use of data that is not entirely representative of the processes being modelled will impact on the accuracy of results and conclusions that can be drawn.

**6.0.3** There are environmental impacts that LCA does not yet cover adequately, although research is ongoing in many of these areas. Examples include biodiversity and emissions to indoor air. LCA also does not calculate costs, although it can be linked to another technique called life cycle costing (LCC).

**6.0.4** LCA generates lots of information, making communication of results a challenge. For example, a designer may be faced with LCA outputs for two products – product A has lower climate change and resource depletion impacts, while product B has lower eutrophication, air acidification and human toxicity impacts. Which is the better option environmentally? There are ways to deal with these situations, such as through normalisation and weighting of calculated environmental impacts. These have the effect of condensing multiple outputs to one number or rating.

**6.0.5** LCA sets boundaries around what is included in the study and what is excluded. There may therefore need to be some iteration, adding time and cost, to ensure that processes excluded from the study would not materially contribute to calculated environmental impacts, were they to be included.

**6.0.6** Other methods, such as hybrid LCA, take account of wider impacts than would be traditionally considered in an LCA. An example is the environmental impacts associated with supporting services needed by product manufacturers, such as banking, insurance and marketing. These other methods are not covered in this bulletin.

## 7.0 FURTHER INFORMATION

**BRANZ**
A range of BRANZ resources on the application of LCA to building design in New Zealand are available on the BRANZ website. Search ‘LCA’ at www.branzfind.nz

**OTHER**
Australian Life Cycle Assessment Society (ALCAS)
www.alcas.asn.au

Life Cycle Association of New Zealand (LCANZ)
www.lcanz.org.nz

New Zealand Life Cycle Management Centre
www.lcm.org.nz

The Australasian EPD® Programme
www.epd-australasia.com

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