Emerging Skills Programme

Open Government Licence Guidelines

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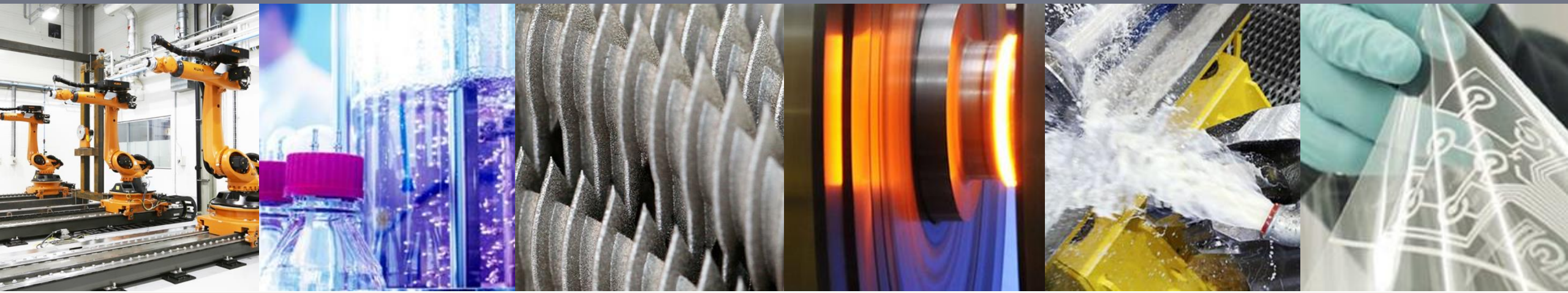

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Measuring sustainability at the design stage

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Pre-reading

- Design for Sustainability https://www.sustainablegoals.org.uk/design-for-sustainability/
- Life cycle initiative, *what is life cycle thinking?* https://www.lifecycleinitiative.org/starting-life-cycle-thinking/what-is-life-cycle-thinking/
- Introduction to the circular economy (spend some time clicking round on the website) https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview
- Design and the circular economy https://ellenmacarthurfoundation.org/articles/design-and-the-circular-economy
- Products in the circular economy https://circulareconomy.europa.eu/platform/sites/default/files/circular_by_design_-_products_in_the_circular_economy.pdf
- Sustainable Materials: with both eyes open (Chapters 1- 6) https://www.uselessgroup.org/publications/book/chapters

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Intended learning outcomes

- Understand how Design for Sustainability can be applied.
- Apply principles of life cycle thinking in product design.
- Understand the basics of Life Cycle Assessment (LCA).
- Understand some of the methodological challenges which arise from LCA.
- Read and interpret LCA studies.

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Subject areas covered in this section

- The role of sustainability and circularity in design.
- Design for sustainability approaches.
- Practical application of life cycle thinking.
- Application of the MET Matrix.
- Introduction to life cycle assessment (LCA).
- Application of LCA.
- Interpretation of LCA studies.
- Design exercise.

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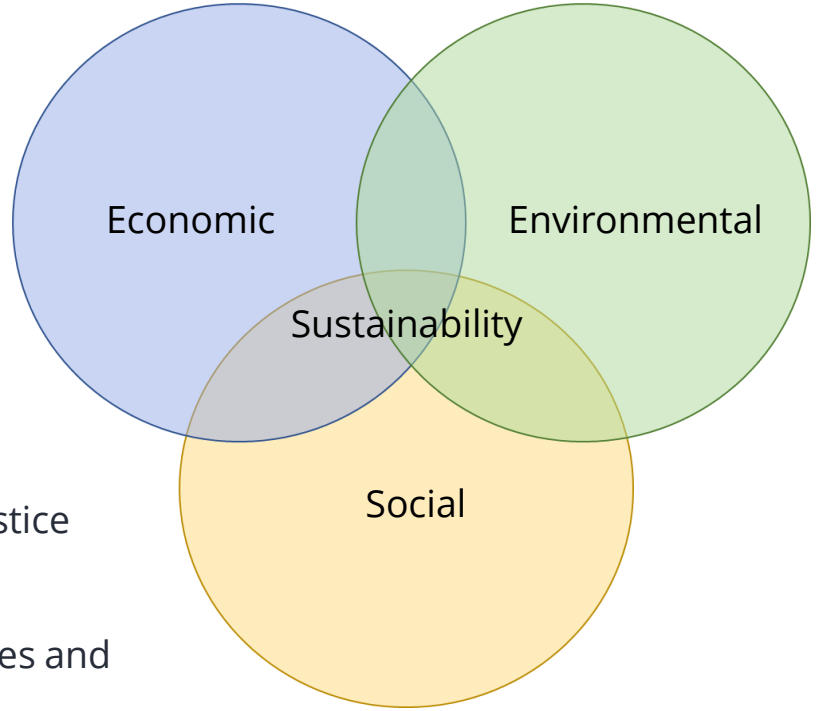
What is sustainability?

'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' – Brundtland Report 1987

Job creation
Profitability/Prosperity



Natural resource use
GHG emissions
Water quality
Ecosystem impacts

Environmental justice
Human health
Well-being
Access to resources and education

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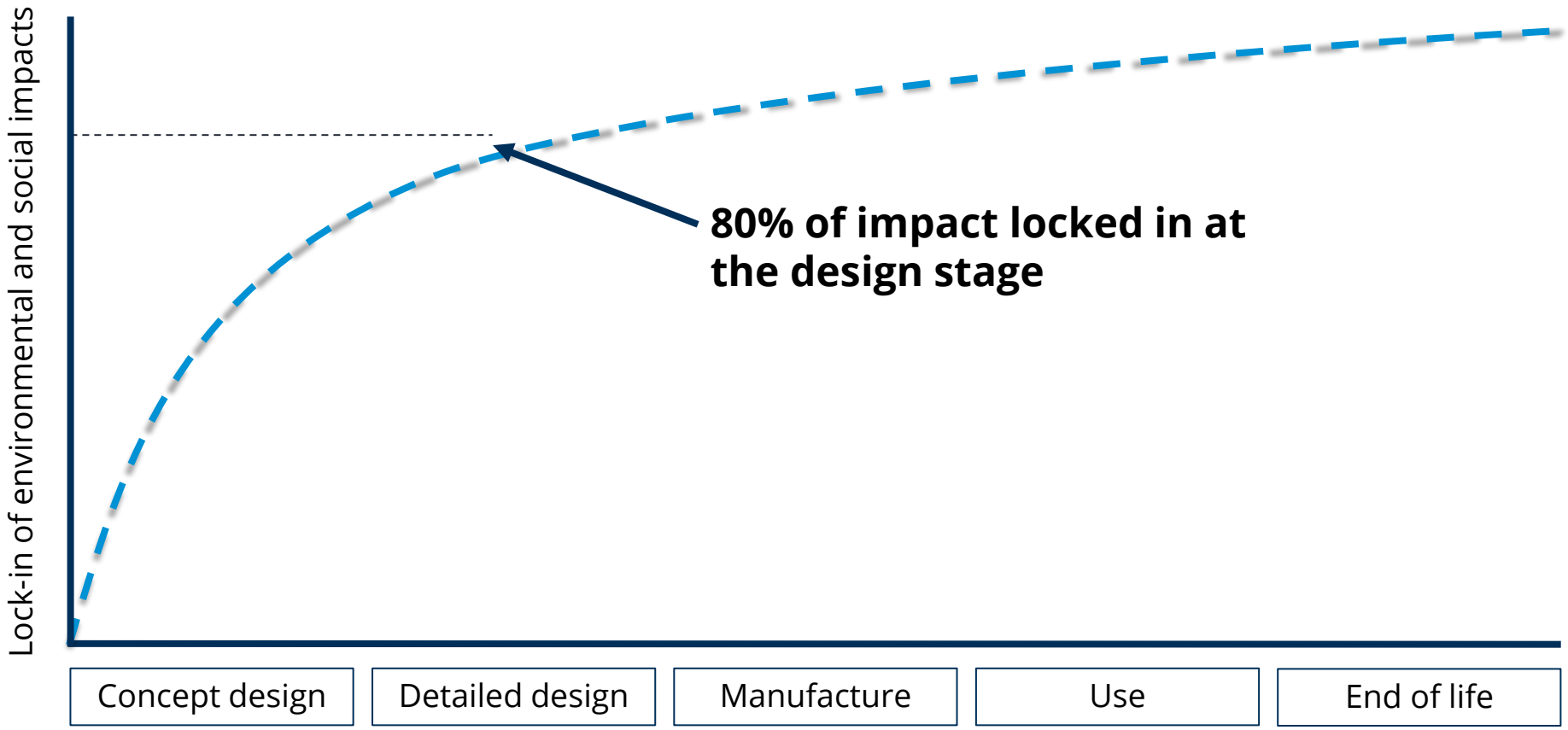
Why is sustainability important at the design stage?



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Why is sustainability important at the design stage?

- The majority of environmental and social impact is locked in by the decisions made within the design process.
- This significantly limits our options to reduce impact once the manufacturing process has begun.
- Design for sustainability (DfS) is more than just thinking about environmental impacts.
- It also encompasses elements of circularity, social impact and designing for social value.
- It is an umbrella term used in conjunction with Design for X strategies (i.e. Design for Environment, Design for End-of-life (Design for Recycling, Design for Reuse, Design for Remanufacture, Design for Disassembly), Design for Efficiency (material, energy etc.), Design for Cost).
- **What underpins all sustainability Design for X strategies is systems thinking and life cycle thinking.**

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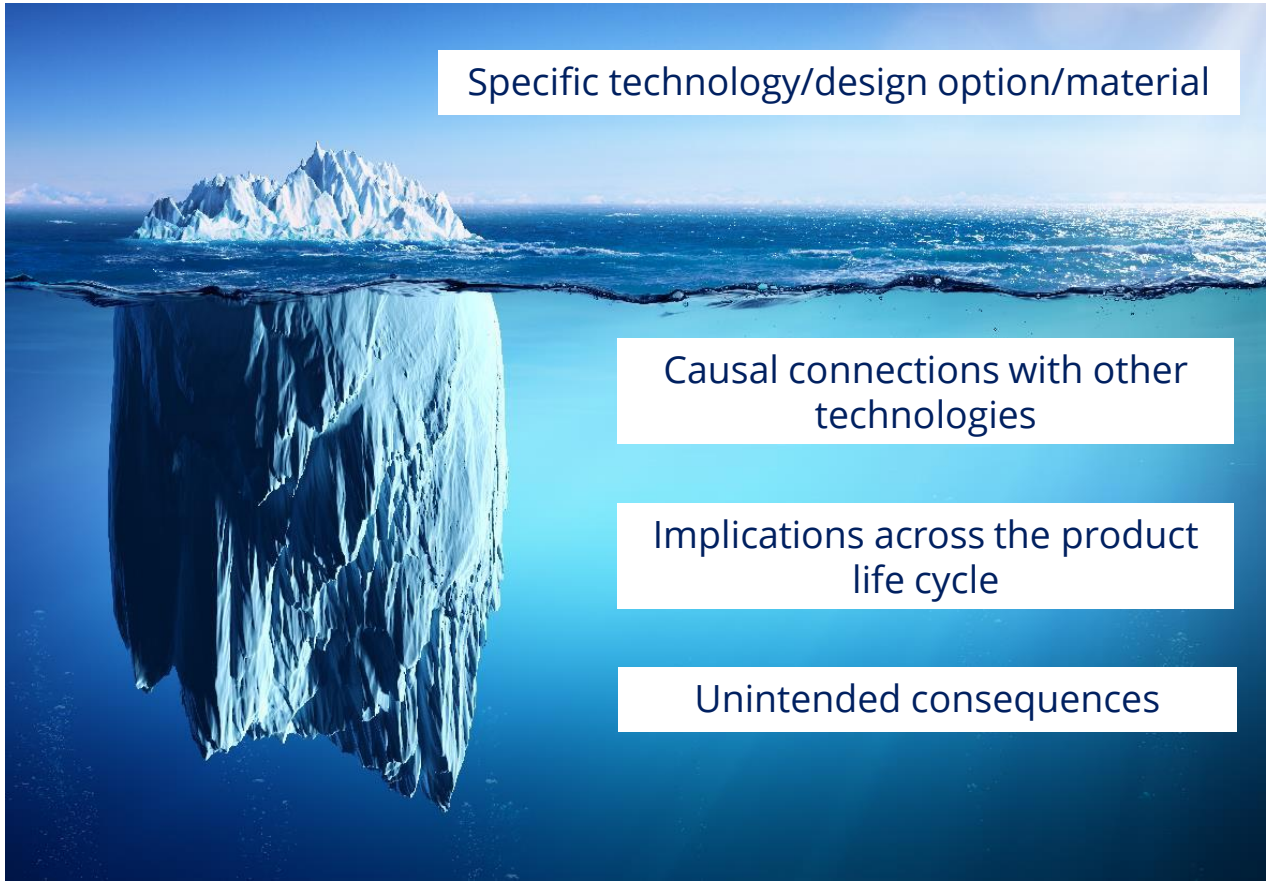
Thinking in systems



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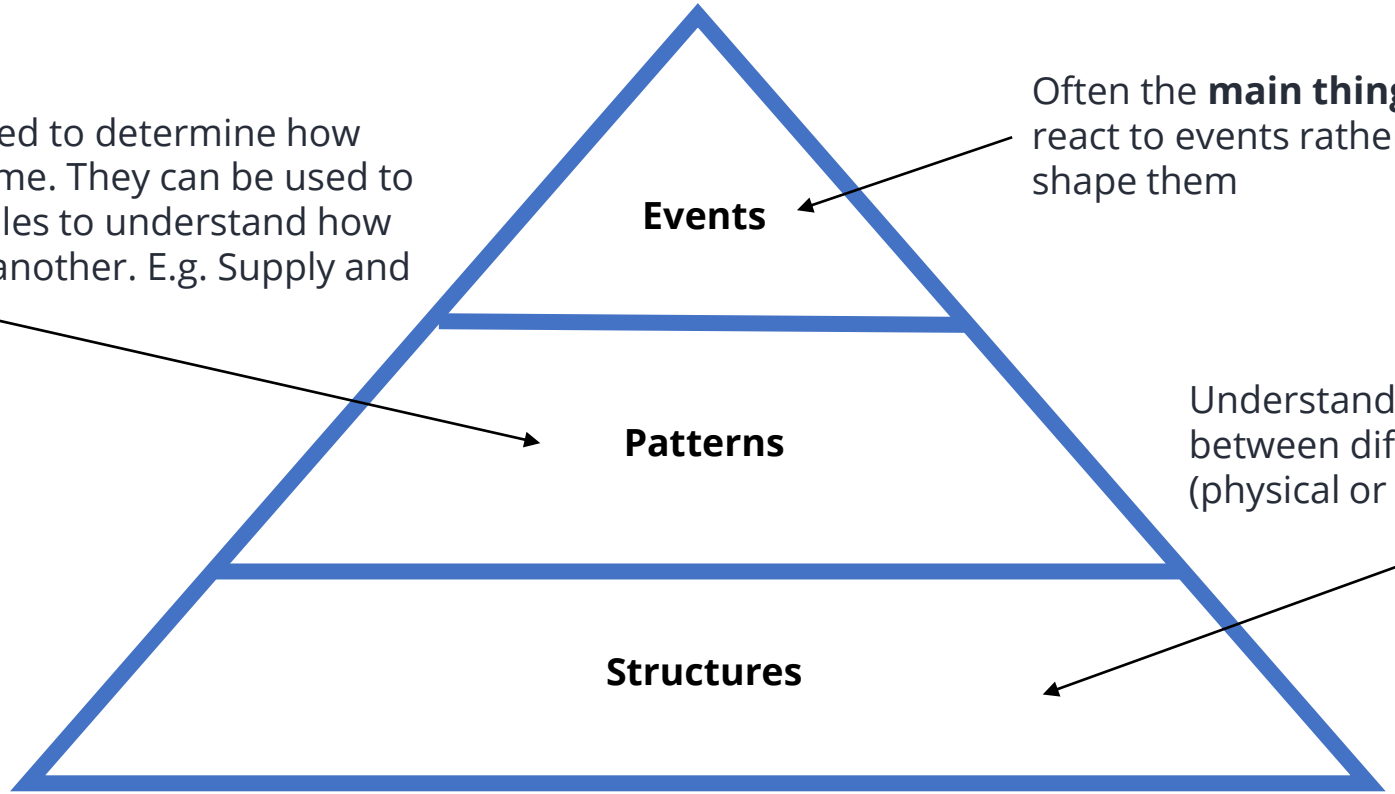
What is a system?

Set of complex interacting, interrelated or interdependent components which come together to form a unified whole.

Patterns are trends used to determine how variables change over time. They can be used to look at a range of variables to understand how they are related to one another. E.g. Supply and Demand curves



Often the **main thing we see**. We can only react to events rather than anticipate or shape them

Understanding **causal connections** between different components (physical or intangible components)

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Systems thinking

Systems thinking is a **transdisciplinary approach** characterised by a number of principles:

- Thinking in terms of the “big picture”.
- Balancing short-term and long-term perspectives.
- Recognising the dynamic and complex nature of systems.
- Taking into account measureable and non-measureable factors.
- We are all part of systems – we each influence those systems whilst simultaneously being influenced by them.

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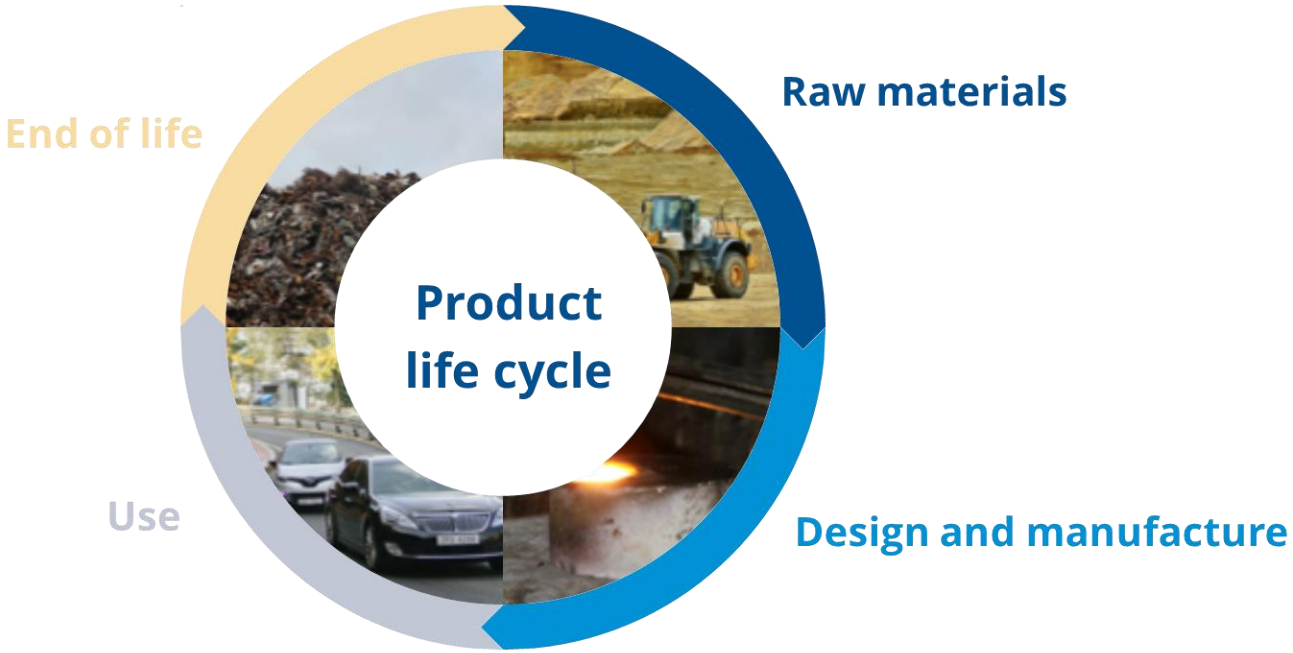
What is life cycle thinking?

Systems thinking and life cycle thinking are related concepts.

A product life cycle considers the flow of energy and resources that go into the product or process life cycle from raw materials production all the way through to end of life. This reflects part of the **product or process system.**



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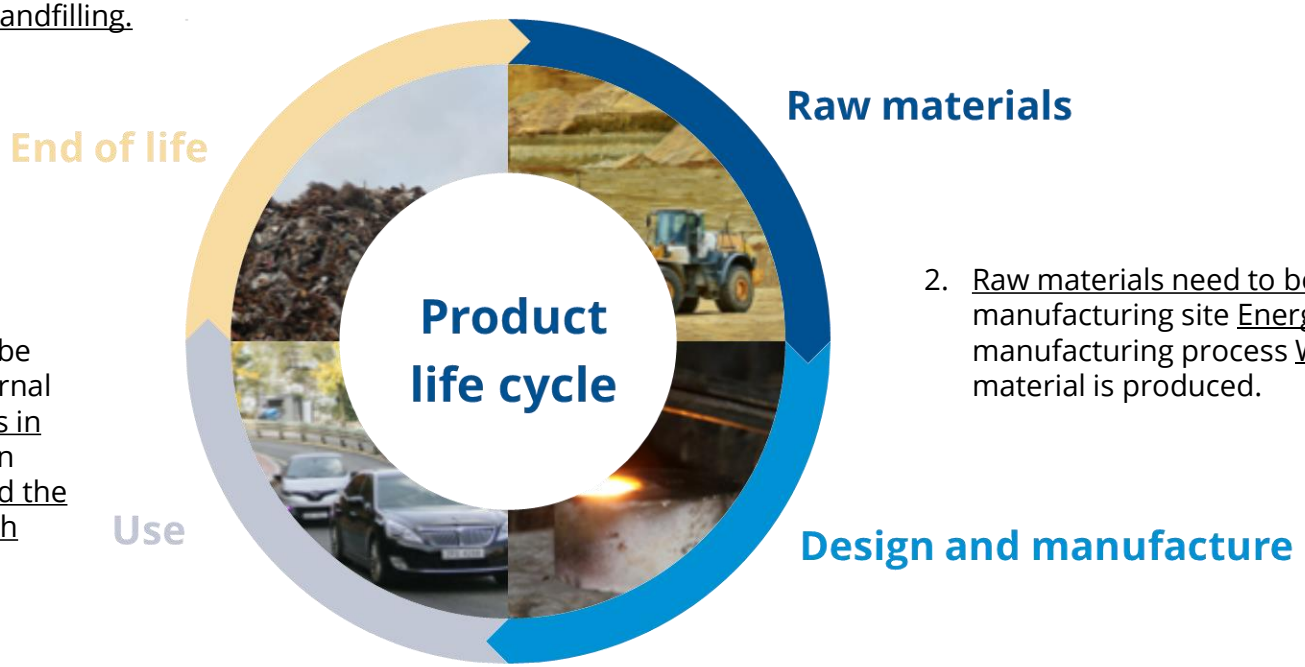
Life cycle thinking

E.g. – the production of a vehicle

1. Raw materials needed include steel, plastics, flame retardants, glass, rubber etc. Energy goes in to mining operations and raw materials transformation Waste/emissions out from mining operations and materials transformation.

4. Parts of the vehicle may be recycled (e.g. steel), whereas others may end up in landfill. There are energy inputs required for recycling and emissions associated with landfilling.



2. Raw materials need to be transported to the manufacturing site Energy goes into the manufacturing process Waste gases, and waste material is produced.

3. Vehicle is transported to a showroom to be sold through the use phase if it is an internal combustion engine vehicle then fuel goes in and tailpipe emissions come out. If it is an electric vehicle then electricity goes in and the source of that electricity is associated with emissions out.

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Life cycle thinking

- Value chains can be **highly complex and global** – e.g. cotton may be grown in Indonesia, dyed in China, transformed into garments in Africa before being brought and disposed of at end-of-life in Europe.
- Resource and energy flows result in a range of environmental, social, and economic impacts: climate change, ecotoxicity, human toxicity, resource use, water use, land use, impact on working conditions and worker H&S etc.
- Where potential environmental, social or economic impacts are concentrated within a value chain, these are called **'hotspots'.**
- It is important to understand not only where hotspots are, but the impact on these if changes are made to part of the life cycle. Life cycle thinking is important because it allows us to avoid **burden shifting** – reducing impact in one part of the life cycle only for it to increase in another part.
- An example of this might be the switch to electric vehicles reduces use phase impact from tailpipe emissions, however, this impact may be shifted to electricity production if this is heavily reliant on coal-fired powerstations.

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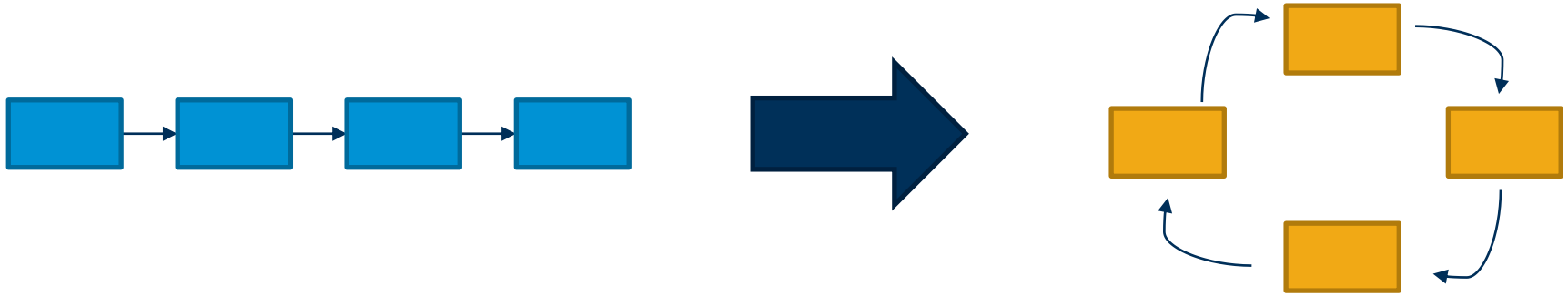
What is circularity?

Circularity relates to the **Circular Economy**. This involves a move away from a traditional linear 'take, make, dispose' view of the world in which materials are extracted, turned into products and then discarded.

- There are many different ways to define and visualise the circular economy. One of the most popular recent frameworks for this was developed by the Ellen MacAurthur Foundation https://ellenmacarthurfoundation.org/circular-economy-diagram

- A circular economy offers a wide range of economic, social and environmental benefits. These can be achieved through:
  - Maximising the lifetime of products and materials and designing out waste.
  - Using recycled or natural materials.



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What is social value?

Understanding the wider social context of a product or service

- **Social value in the supply chain**
  - Responsible sourcing
  - Impact on health and safety
  - Impact on job creation?

- **Social value to product users**
  - Who are the users? Designing for gender/sex, understanding different types of user
  - Aesthetics, comfort level
  - Safety
  - Reliability
  - Additional indirect societal benefits.

- **Social value at end-of-life and beyond**
  - Durability
  - Life cycle benefits
  - Enabling services
  - Repairability/reusability/recyclability
  - Safety/impact.

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Design for Environment

Design for Environment (DfE) attempts to reduce the environmental impact of a product across its life cycle.

Elements you may consider in the design phase:

Materials down-selection

- Avoid use of hazardous or toxic materials.
- Avoid use of materials known to have a high energy content.
- Design in a way which minimises materials use and waste.
- Minimise the number of different types of materials you use.
- Design with natural materials or recycled materials.

Production

- Avoid using hazardous or toxic consumables or other materials required during manufacture.
- Avoid energy intensive processes or multiple process steps which require energy input.
- Optimise use of heat exchangers/other ways to utilise waste heat.
- Minimise manufacturing waste.
- Minimise energy use from production facility through efficient use of temperature controls/lighting/material storage etc.

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Design for Environment

Packaging and distribution

- Minimise long distance travel.
- Maximise how efficiently product can be transported.
- Minimise amount of packaging material and consider how packaging material choice can impact weight and environmental impact.
- Maximise amount of reusable packaging material is used.

Use

- Minimise energy consumption during use – lightweighting of materials, low energy using components, insulate heating elements.
- Increase lifetime by improving durability and reliability.
- Minimise consumables use during use phase.
- Design for easier maintenance and repair. This includes modular structure to aid upgrading components.
- Think about the needs of future users.
- Minimise degradation and emissions to the environment.

End of life

- Extend lifetime of product, enable reuse, remanufacture and recycling.
- Reduce use of toxic release during incineration or disposal.

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Design for Circularity (Durability, Reuse, Remanufacture, Disassembly, Recycling)

Design for Circularity (DfC) applies a more holistic view than DfE which is solely focused on minimising environmental impact across the life cycle. DfC can be materials selection choices like using recycled materials, all the way through to systems level change.

There is a link here with other circular economy concepts such as product-service design.

- Design for circularity (as a holistic approach to design)
- Design for life extension/durability
- Design for reuse
- Design for remanufacture
- Design for dissassembly,
- Design for recycling.

End of life focus <u>but</u> decision making on design impacts every stage of the life cycle.

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Design for Circularity - examples

- **Renault**
  - Repairable vehicles that are easy to dismantle and recover or recycle materials.
  - Renault Environment has a number of subsidiaries that collect, and repurpose, remanufacture or recycle end-of-life vehicles.
  - Working to close the loop completely through partnerships with various stakeholder (suppliers, local entities, scientists, and academics).
- **Fairphone**
  - Long-lasting design
    - With the average phone replaced every 18 months, consumer electronics are often viewed as being semi-disposable. Fairphone aims to combat this by making its phones modular and so easy to upgrade or repair.
  - Reuse and recycling
    - Every year millions of phones are thrown away. Fairphone sell spare parts and offer repair tutorials. The take back program supports the reuse and recycling of old phones, and Fairphone is also investing in research to determine the best way to recycle its phones by making them easier to dismantle.
  - Product as a service (PaaS)

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Design for Social Aspects

This may be referred to as social value centred design. As social impacts are a key pillar of sustainability, Design for Sustainability (DfS) should also aim to maximise social benefit and minimise negative social impact.

Social value may consider the following:

- Material county of origin/supplier
- H&S – exposure of workers to toxic materials, particulates, unsafe working practices; and exposure of consumers or waste processors at end of life
- Design for specific user groups
- Aesthetics
- Additional social benefits
- Safety at end of life
- Enabling additional services.

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Design for Social Aspects

Example of social value centred design:

<u>The BRE Dementia House</u>

Concept building refurbishment, however, principles can be applied towards new homes in the UK. Average cost of state care is £30,000-£40,0000 per year – the aim of this concept is to enable those suffering with dementia to stay in their homes as long as possible.

- Based on design for dementia principles:
  - Clear lines of sight and colour coded paths to guide people towards each specific room.
  - Increased natural light – helping people stay alert during the day and sleep better at night.
  - Noise reduction features to lower chances of stress.
  - Simple switches and heating controls with safety sensors in high risk areas such as the kitchen.
  - Upstairs is fitted out for more advanced stages of dementia.

https://www.bregroup.com/ipark/parks/england/buildings/dementia-friendly-home/approach/

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Avoiding sex and gender bias

Case study: Safety Footwear

- The design of safety footwear needs to be brought in line with advancements in other footwear industries.
- Improve comfort, fit, industry specific, safety.
- Equalise safety footwear offerings for women.

Slide content provided by D. Janson (University of Bath)

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Avoiding sex and gender bias

Case study: Safety Footwear

- A survey of safety footwear experiences was conducted with 632 people (102 women, 520 men).
- **Results**
  - Key elements respondents would change.

Women		Men	
Range	41%	Durability	25%
Fit	34%	Comfort	19%
Aesthetics	19%	Fit	13%
Weight	16%	Waterproof	12%
Comfort	9%	Toecap	10%

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Avoiding sex and gender bias

Case study: Safety Footwear

62% of women indicated that their safety footwear is not as comfortable as their "regular footwear". **83%** reported at least one area of discomfort.

45% of men indicated that their safety footwear is not as comfortable as their "regular footwear". **67%** reported at least one area of discomfort.

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D. Janson et al. (2021) https://doi.org/10.1016/j.apergo.2020.103333

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Avoiding sex and gender bias

Case study: Safety Footwear

Conclusions:

- Comfort and fit are really important to end users
- Needs to be improved!
- It's not just a problem for women
  - (Men tend to speak up less)
- Comfort and fit have safety and business impacts!

Slide content provided by D. Janson (University of Bath)
D. Janson et al. (2021) https://doi.org/10.1016/j.apergo.2020.103333

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Avoiding sex and gender bias

Case study: Personal Protective Equipment (PPE) in a pandemic

Background:

- Mainly anecdotal evidence.
- Face fitted masks are based on the anthropometrics of a “western average man”.
- In the NHS 79% of front line workers are women.

“This difference has made it impossible to create eyewear, helmets and facemasks that fit both groups well.”

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Avoiding sex and gender bias

Case study: Personal Protective Equipment (PPE) in a pandemic

- A survey of NHS PPE users was conducted (248 responses, 82% women).

Results

- **Gloves** – around three quarters reported fit being "just right"

Availability, irritation.

- **Aprons** – over half reported fit problems.
  - Men find them too small but equal amounts of men and women found them too large.
- **Surgical gowns** – over half of women reported too large.
  - Thumb holes, shortening, over-wrapping.
- **Surgical scrubs** – over half reported fit problems.

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Avoiding sex and gender bias

Case study: Personal Protective Equipment (PPE) in a pandemic

Results (continued):

- **Surgical masks** – too large for women.
  - Although a quarter said “just right” and a third of men.
  - Difficult to anchor – tape, devices.
  - Cause rubbing, chafing, bruising.
- **Face fitted masks** – around half found the fit “just right” (both women and men).
  - Fit test problems, brand variation.
  - Cause rubbing, chafing, bruising (around a third).
  - Fit vs comfort – tolerability.
- **Visors** – over half of women and a third of men experience fit problems.
  - Particularly short stature, large chested women.
- **Goggles / glasses** – around half fitted “just right”.
  - Women 3x more likely to report a large fit then men.

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Avoiding sex and gender bias

Case study: Personal Protective Equipment (PPE) in a pandemic

Unintended consequences:

- Hampering work (over half).
- Feeling safe (less than a third of women, half of men).
- Modifying PPE (over a third).
- Reduced cross-infection control.
- Physiological problems.
- Patient care.

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Avoiding sex and gender bias

Case study: Personal Protective Equipment (PPE) in a pandemic

Survey conclusions:

- There are clear sex differences across PPE design and provision.
- (Men are also disadvantaged by poor fit).
- But women are affected disproportionately.
- Safety is compromised as a result of PPE.

What can we do to improve things?

- Make sure PPE fits.
- Question women's or unisex fit.
- Consider hidden costs as well as total costs.
- Understand what PPE does work and why.

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Avoiding sex and gender bias

Summing up:

- Unisex fit is typically a ‘western man’s fit’ rather than truly unisex.
- This issue extends further than just PPE.
- **User insensitive design can compromise safety:**
  - This is more than just a gender/sex issue – what about different ethnicities or ‘non-averageness’?
- **A lack of appropriately fitting PPE affects users sense of belonging in the workplace** – in male-dominated environments women can be made to feel as though they don’t belong by being forced to dress in men’s PPE. Even in female dominated environments often women are not given PPE that fit correctly.

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Nature inspired design

- Often referred to as **Biomimicry.** This looks to natural for inspiration in the design process.

Examples:

- **Whales and wind turbines:** The bumps on a whales fin can significantly improve efficiency, reducing drag and increasing lift. Companies are now applying this to turbine blades, fans, and propellers.

- **The kingfisher and the Bullet train:** Bullet train made a loud boom as it exited tunnels due to build up of sound waves as they are pushed in front of the train. The shape of the kingfishers beak allows water to flow past rather than being pushed in front – applying this to the train reduced noise and also led to reduced air resistance.

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Product-service system level design

A product-service system (PSS) is a set of products and services that are combined. This is often in the form of a product-as-a-service model – leasing equipment/products rather than selling them. This may mean you can achieve a closed loop supply chain.

The benefits of this model from a sustainability perspective are the following:

- **Enhanced economic value**
  - Recovery of product returns, reduce sourcing costs, enter/create new markets.
- **Environmental and social value**
  - Reduce environmental impact, reduce risk, create employment opportunities or support local infrastructure development.
- **Customer value**
  - Aftersales service and maintenance to improve customer satisfaction. Leasing rather than owning model may enable access to better products.
- **Information value**
  - If you are taking back your product you can understand more about it e.g. wear and tear, this not only feeds into product design but also marketing and distribution as you can better understand customer needs e.g. why is the customer returning the product?

Schenkel et al., (2015) Creating integral value for stakeholders in closed loop supply chains

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Product-service system level design

PSS example: Philips

- Electronics company, also focused on healthcare (consumer and professional).
- Medical diagnostic equipment for hospitals.
- Move from 'take-make-disposal' model to 'take-make-return' in 4 returning loops: service, refurbish, parts recovery, recycle.

- **Customer value:** can use brand new equipment they might not be able to afford if brought.
- **Information value:** continued relationship with customer means you understand more about how it is used in service, how parts age or how different components behave.
- **Economic value:** recover product returns, sell additional services.
- **Environmental/social value:** Reduce material use and embodied energy, prolong product life with repairs.

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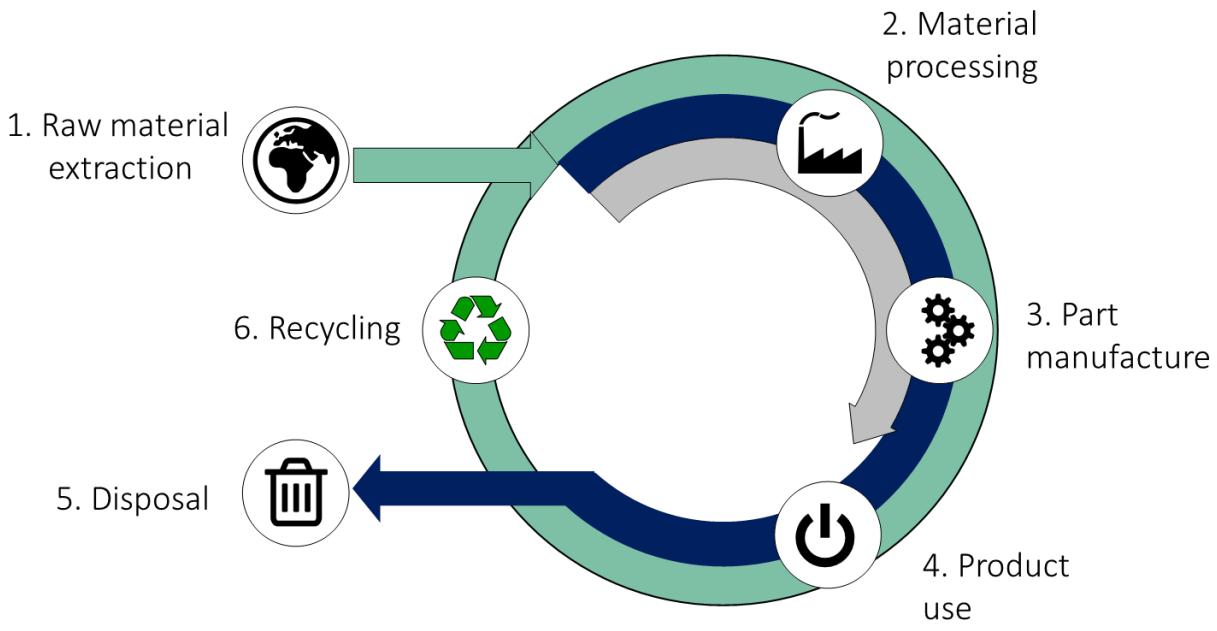
Life cycle thinking in design

- As part of the design process, along with considering some of the design principles discussed, it is also useful to consider the life cycle of the product you are designing.
- In the initial stages of design this might not need to be a *quantitative* analysis.



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Life cycle thinking in practice

Wind turbine blades

- Blades are made from a range of materials and making these materials consumes large amounts of energy.
- The materials contribute to the blades strength, durability and weight. They also enable turbines to be built taller making them more efficient and able to harness more energy.
- Whilst it may not emit CO2 during life at end-of-life some materials do not have well defined waste management routes.
- Carbon payback can be used as a way of understanding the life cycle implications associated with different design or materials options.

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Life cycle thinking in practice

Electric vehicles

- Production of lithium-ion battery consumes large amounts of energy and lithium and cobalt mining have significant social and environmental impacts associated with them.
- Elimination of combustion emissions from use phase reduces environmental and human health impacts from air pollution. Reduces reliance on fossil fuels for energy.
- Environmental impact from use phase dependent on electricity grid mix.
- Cost to consumer is still high meaning few can afford to own an electric vehicle and charging infrastructure is limited.

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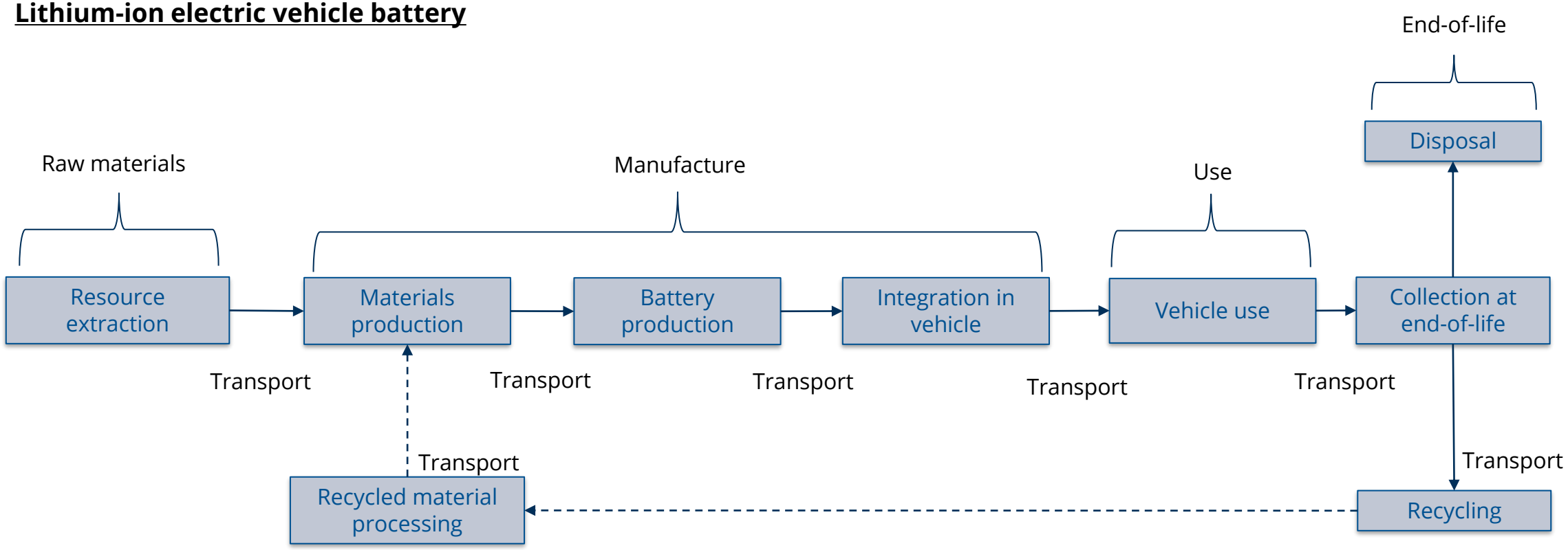
Life cycle thinking in practice

Lithium-ion electric vehicle battery



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The MET Matrix

We can use a MET matrix to qualitatively consider some of the life cycle impacts associated with particular product designs. At each stage in the life cycle environmental impact associated with materials use, energy use and toxicity is evaluated.

	Production	Manufacture and distribution	Use	End of Life
Materials				
Energy				
Toxicity				

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The MET Matrix

E.g. Basalt fibre reinforced polymer rebar for use in the construction industry to reinforce concrete.

	Production	Manufacture and distribution	Use	End of Life
Materials	Basalt fibre – predominately sourced from Ukraine can also be found in Iceland Epoxy resin Some processing chemicals and water	Water and Lubricating oil	Application as reinforcement within concrete	Material very difficult to separate from concrete at end-of-life (in contrast to steel rebar) Recycling limited to options for concrete
Energy	Energy input for extraction – potentially some similarities with glass fibre, energy input to washing melting and fibre forming Energy use transporting fibre and resin to manufacturing site	Energy use during pultrusion process	Operational impacts relating to maintenance of the structure rebar is used within rather than rebar itself	Energy use recovering and breaking up concrete
Toxicity	Resin – irritant and potential impact to aquatic organisms. Main climate impacts associated with Bisphenol A production Basalt – comparatively low impact from mining operations impact predominately from fibre extrusion at 1400-1600C	Environmental impact dominated by energy use (manufacture and transportation of final product), some potential impact from chemicals used during processing	Inert, corrosion resistant material	Material cannot be separated at end-of-life – potentially reduces overall recyclability of building materials used with more material going to landfill

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The MET Matrix

Exercise: Based on the example MET Matrix, have a go at creating your own one for a composite wind turbine blade.

What recommendations might you make based on this?

(60 minutes)

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The MET Matrix – example answers

	Production	Manufacture and distribution	Use	End of Life
Materials	Glass fibre, carbon fibre, epoxy, PVC, Gelcoat, Materials production is the biggest area of environmental impact in life cycle	Consumables – Peel ply, adhesive, mould release agent, PVC tubing, tacky tape, flow medium, putty, catalyst	Impact from concrete, steel etc. use for installation Impact from material use for blade maintenance through lifetime	Glass fibre can be recovered and coprocessed in a cement kiln, true fate of glass, carbon fibre, and plastics is often landfill Steel used can be recycled (usually @90%)
Energy	High energy intensity associated with epoxy, unless blade includes carbon fibre – this is the greatest contributor to energy intensity within the blade itself. Carbon fibre has an embodied energy of 200-1000 MJ/kg compared with epoxy at 76-137 MJ/kg and glass at 10-45 MJ/kg Energy impact from transport of materials	Resin Transfer Moulding (RTM) has an energy intensity of ~12 MJ/kg, vacuum assisted resin infusion has an energy intensity of ~10 MJ/kg Energy impact from transport	Energy intensity of steel highly dependent on recycled content and manufacturing method (blast furnace or EAF) After steel concrete has the next highest energy intensity	Energy use to recover and chop up blade ready for landfill or secondary application Some components may be appropriate for incineration and energy recovery
Toxicity	Epoxy resin – irritant and potential impact to aquatic organisms. Main climate impacts associated with Bisphenol A production Use of PVC foam – potential contribution to air and environmental pollution Impact from energy use (depending on geographical origin of material)	Impact from energy use (depending on location of manufacturing and regional grid mix) Uncertainty associated with recycling of waste materials from manufacture – how much is recycled and how much goes to landfill?	Environmental impact heavily dependent on geographical location of steel mill and forming location (e.g. India has a very high % of coal in its grid mix)	Impact from current highly linear process is that material's value is lost at EoL. Environmental impacts from landfill leachate

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The MET Matrix – example answers

- Materials use is associated with the largest amount of environmental impact.
- The composite materials used in wind turbine blades can have a high energy intensity (carbon>epoxy resin>glass fibres) and life cycle of blade is currently very linear with limited industrial scale technology to recover and recycle glass and carbon fibres.
- As a designer there are opportunities to look at:
  - Use of different materials which have a lower energy intensity or environmental impact.
  - Make material recovery and circularity easier by designing for disassembly and recovery at end-of-life/ and designing with recycled material content in mind from the outset (particularly important for materials like carbon fibre).
  - Think about the origin of materials – and how much geographical grid mix, local environmental standards, and transport may impact the overall environmental impact of materials and component choices.

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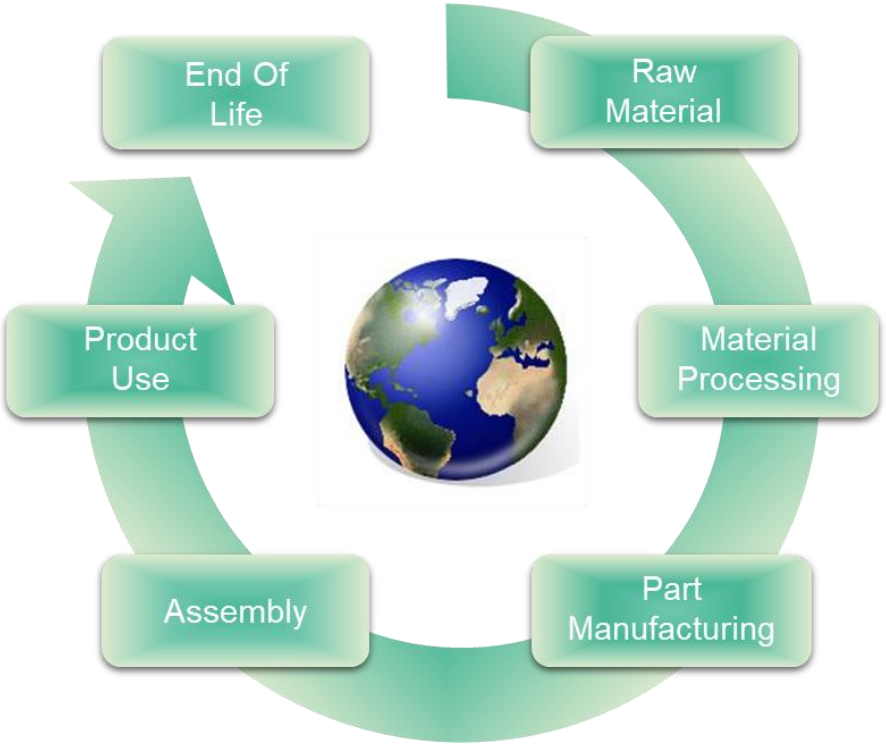
What is life cycle assessment (LCA)?

- **Life cycle assessment (LCA)** is an approach which quantifies the ecological and human health impacts of a product or system over its complete life cycle.
- Impacts are calculated based on mass and energy flows through the system.
- It is most commonly used to assess products.
- LCA has a specific methodology and set of standards (ISO 14040, ISO 14044).
- Using LCA you can assess a range of environmental impacts including:
  - Climate change
  - Ecotoxicity
  - Human toxicity
  - Eutrophication
  - Acidification
  - Resource use
  - Water use etc.



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Why LCA?

- To improve product design.
- To support internal sustainability efforts.

Internal drivers

- To support corporate reporting.
- To support development of environmental product declarations (EPDs), or other types of environmental declaration.

External drivers

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Types of environmental labelling

- **Type I - Ecolabel (ISO 14024)**
  - Seal or logo based on a specific set of criteria.
  - Third party grants license to use the label.
  - Criteria set with reference to product life cycle.
  - Less commonly seen in the UK.
  - Typically aimed at consumers.
  - Examples are: European Ecolabel, The Nordic Swan, Ecomark (Japan).

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Types of environmental labelling

- **Type II - Self declared environmental claims**
  - Non third party certified.
  - Claims made based on characteristics following general guiding principles.
  - Examples are recycled content or biodegradable.

- **Type III – Environmental declarations**
  - Quantitative indicators of environmental performance based on LCA for comparison of products fulfilling the same function.
  - Generally B2B or used in public procurement.
  - Examples are Environmental Product Declarations (EPDs).

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Types of questions LCA can answer…….

- Which is the most environmentally friendly option for a supermarket bag – paper, plastic or textile?
- From an environmental perspective should composites or steel be used to make a car body out of?
- Should a company target its own processes, its suppliers, its customers or waste management companies at end of life if it is to best reduce the environmental impact of its products?
- Are electric car more environmentally friendly that internal combustion engine vehicles? Which are the important parameters which decide this?

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Types of questions LCA can't answer…….

- Should we increase tax on old diesel cars to reduce the levels of particulate emissions – thereby reducing hospital spending on treating lung disease?
- Do current emissions from a specific factory lead to a pollutant concentration above regulatory levels?
- What is the impact on the local ecosystem health from installing a tidal turbine in the Bristol channel?

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History of LCA

- One of the first LCA studies was conducted by Coca Cola in the 1960s contrasting aluminum cans and glass bottles.
- Through the 1970s and 1980s LCAs were used by companies in an informal way to assess the environmental impacts of different products.
- In the 1990s LCAs were formalized with a specific framework developed by SETAC and ISO standards.
- In 2000s LCA information started to find its way into policy-making and public procurement.
- In 2010s LCAs have been used to inform energy policy, there is an increasing interest in social LCA, and development of the EU Product Environmental Footprint (PEF) looks to better enable comparability between product categories using Product Category Rules (PCRs).

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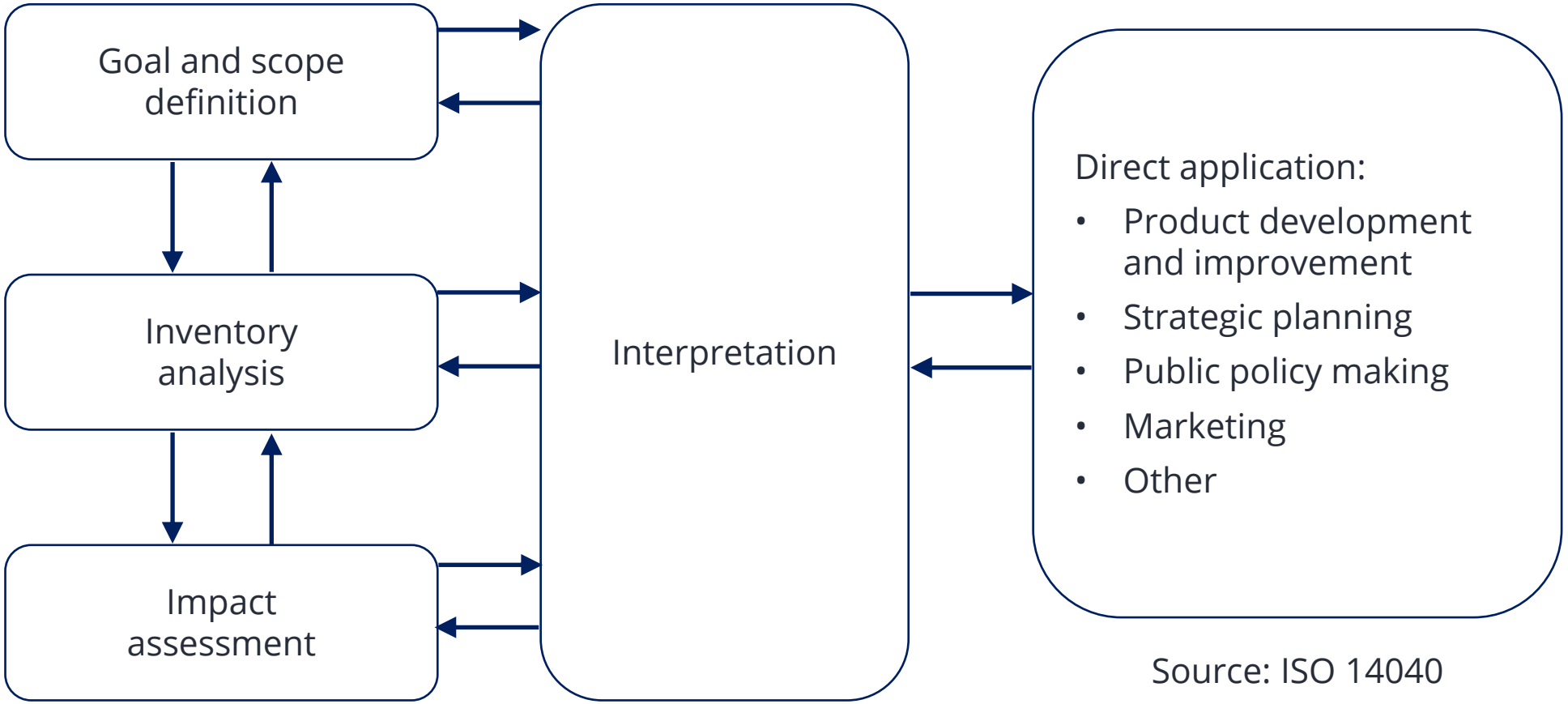
The structure of LCA



Source: ISO 14040

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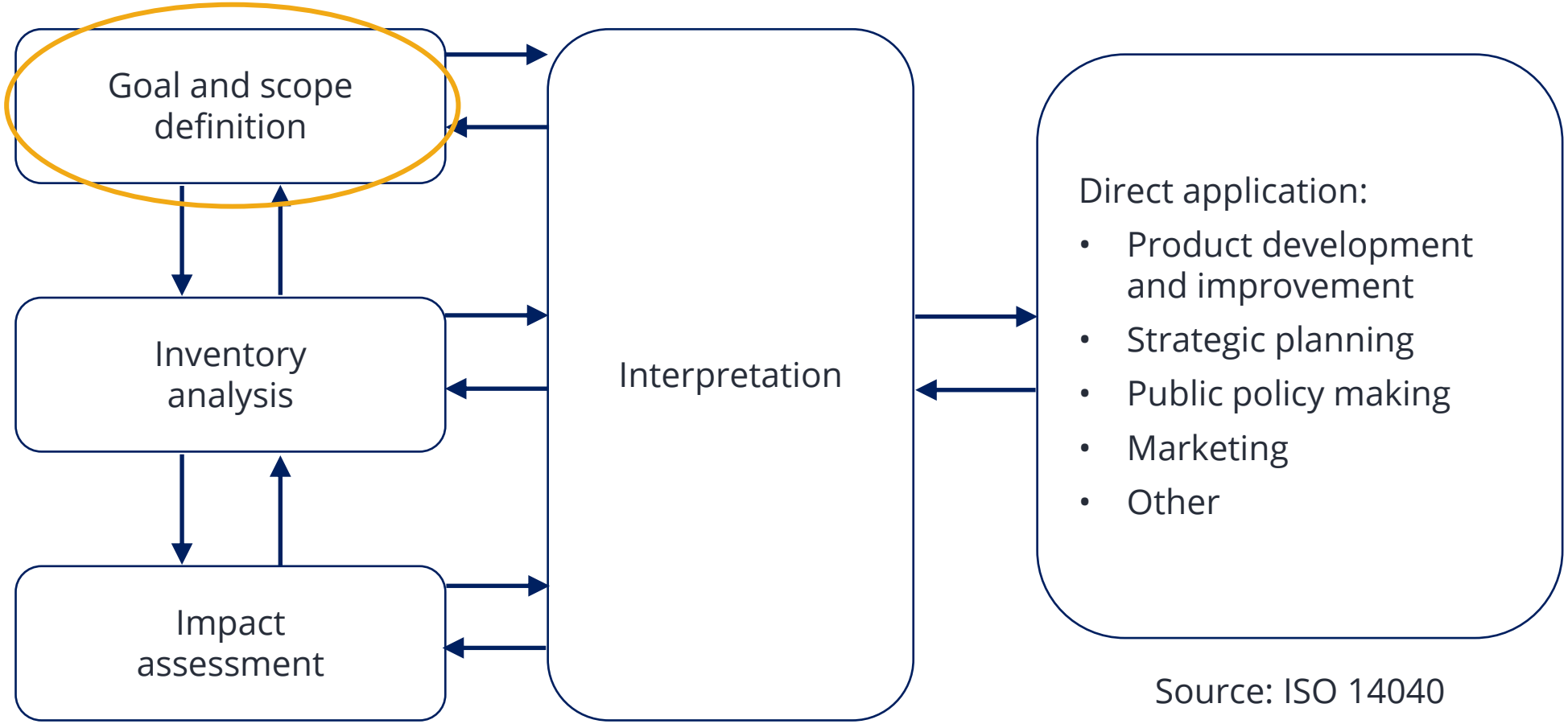
The structure of LCA



Source: ISO 14040

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Goal and scope definition

This is the first phase of an LCA and is key to helping plan out the LCA activity. This phase establishes the **aim** of the study, as well as it's **breadth and depth.**

A poorly defined goal and scope will impact the rest of the LCA. **The goal and scope definition can be split into 1. goal and purpose, and 2. Scope**

1. **Purpose of the study**

The purpose of an LCA is to compile and assess the potential environmental impacts associated with options for fulfilling a certain function. These can be:

- **Descriptive –** what environmental impacts can be assigned to a specific product

OR

- **Change orientated –** how does product/process/material A compare with B?

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Goal and scope definition

1. Goal definition

- What is the intended application of the study? – Product development? Marketing? Strategic planning?
- Which parties are involved? Who is the target audience?
- Why is LCA the right tool to solve this problem?
- **Under ISO 14044 any comparative assertions to be made public require third party critical review.**

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Goal and scope definition

2. Scope definition

- LCA level of detail
- What stages of the life cycle are covered?
- What processes are covered?
- What environmental impacts are being investigated?
- **Definition of the functional unit:**

The functional unit should (as far as possible) relate to the *functions* of the product system rather than to the physical product.

Example 1: “a mid-size 4-person vehicle driven in a semi-urban environment over 150,000km” not “one 4-person car”.

Example 2: “the lighting of a room over 1000 hours at 1250 lumens” not “one light bulb”.

If you are comparing two systems functional equivalence is key!!!!

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Goal and scope definition – short exercise

Can you think of an appropriate functional unit for the following:

- **Drinks container** (single use and a multi-use container).
- **Electricity generation** (wind and solar energy).

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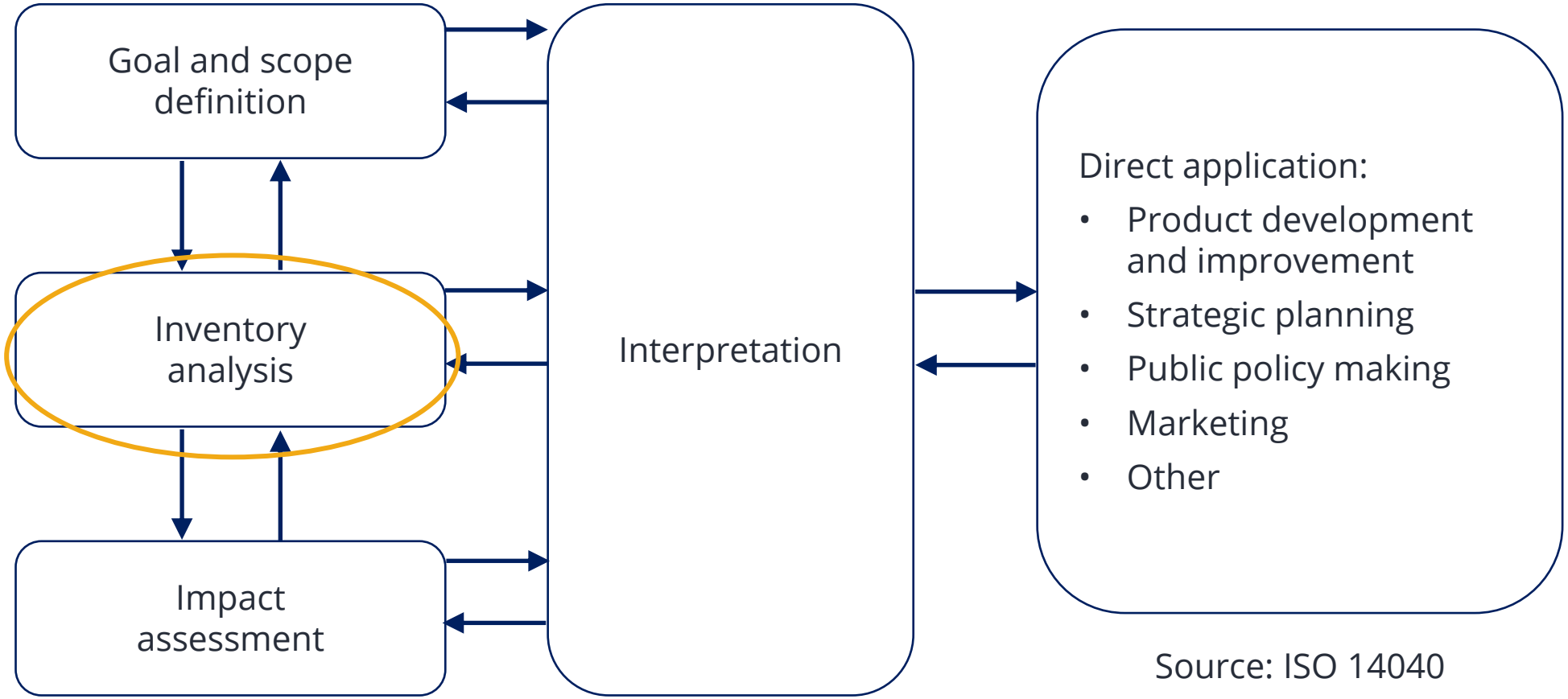
The structure of LCA



Source: ISO 14040

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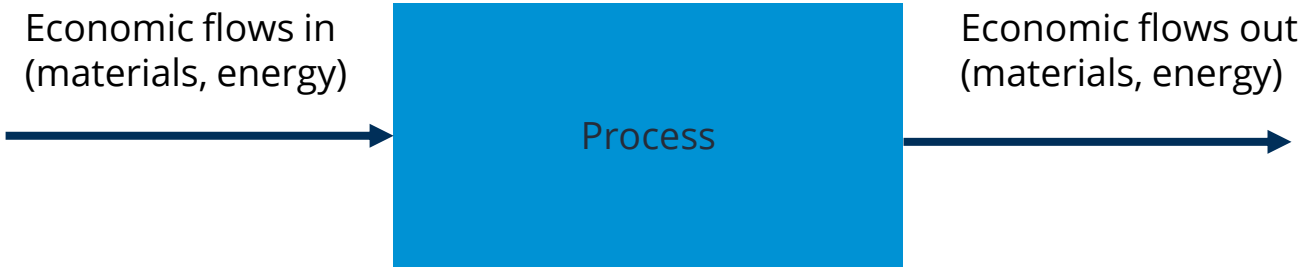
Life Cycle Inventory (LCI) Analysis

The LCI stage is a compilation and quantification of all the inputs and outputs associated with a product system across its life cycle.

The process flow diagram
This is a graphical representation of the product system. In practice a simplified process flow often appears in the goal and scope definition as a way of graphically showing the scope of the study.



The process flow diagram does not include environmental information and tends not to include quantities.

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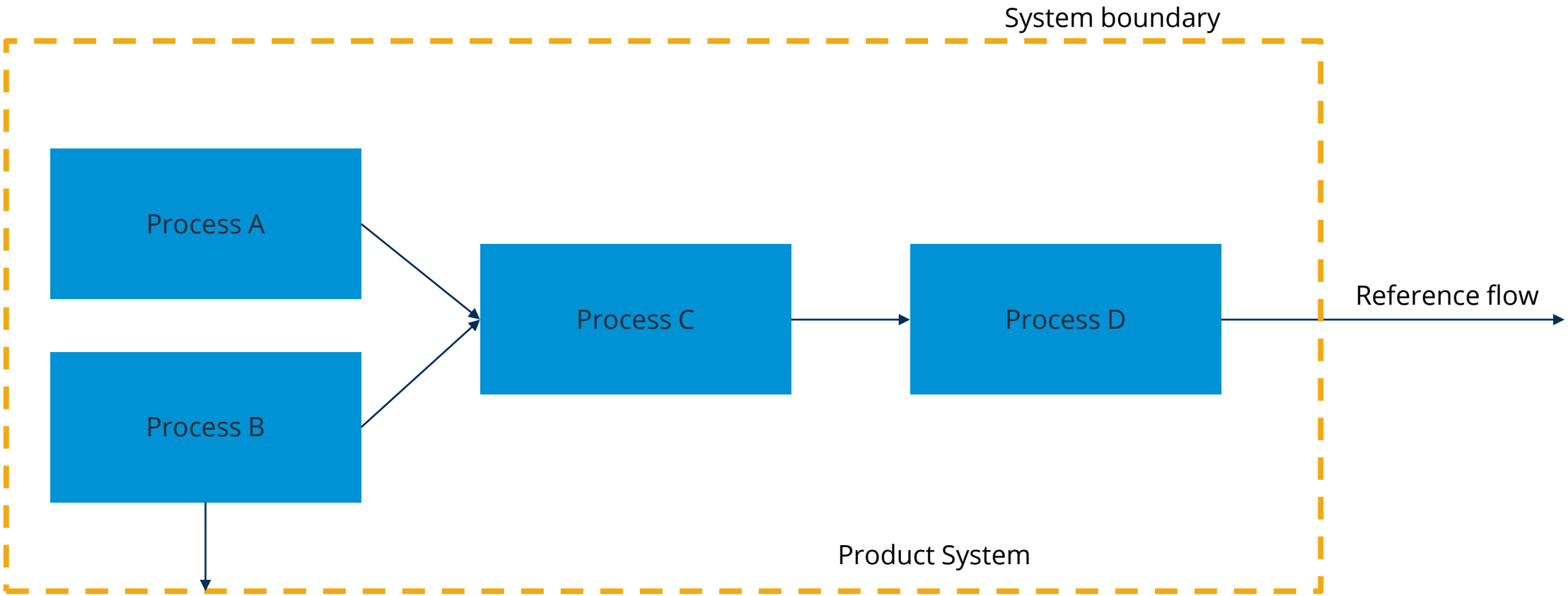
Life Cycle Inventory (LCI) Analysis



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Life Cycle Inventory (LCI) Analysis

- Inventory analysis can include data you collect yourself (primary data) or data from databases (secondary data).
- Data will include all (in scope) **mass and energy inputs** as well as **outputs, by-products and emissions.**
- Data can come from a variety of places making consistency/completeness challenging.
- Data quality can be assessed in terms of its precision, completeness, representativeness (temporal, geographical, technology), consistency, and reproducibility.

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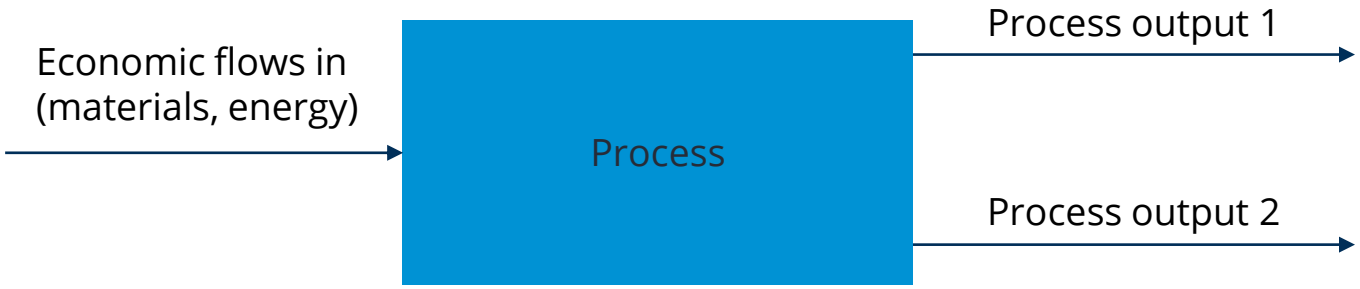
Multifunctionality and allocation

How do you assign impact between outputs 1 and 2?



- Some processes have more than 1 function – multifunctional processes.
- These functions might not just be physical outputs they might also be electricity or heat generation.
- Multifunctional processes can be the co-production of several flows (multi-output), combined waste processing (multi-input), or involve recycling (input-output).

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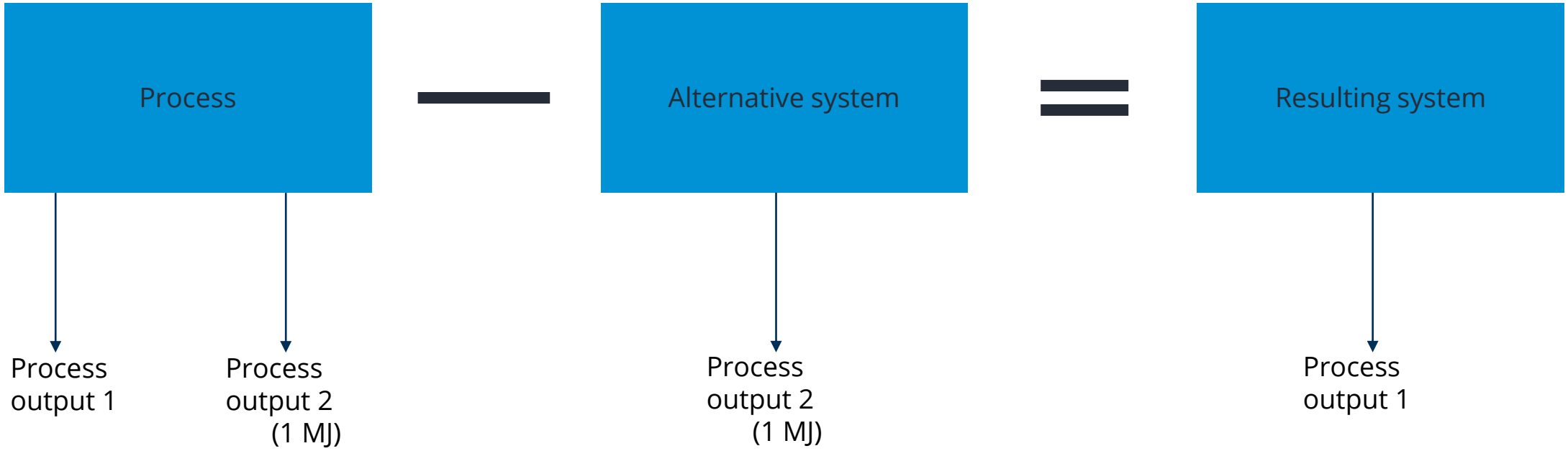
Multifunctionality and allocation

- Under ISO, allocation in multifunctional processes is advised to be dealt with in the following way:

System expansion



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Multifunctionality and allocation

Allocation based on physical relationships

Process output 1 = 10 kg

Process output 2 = 20 kg

Share of environmental impact
33%
66%

Allocation based on non - physical relationships

Process output 1 = £ 50/kg

Process output 2 = £ 10/kg

70%
30%

Allocation is a highly debated area of LCA methodology – as you can see results are highly sensitive to choices made!

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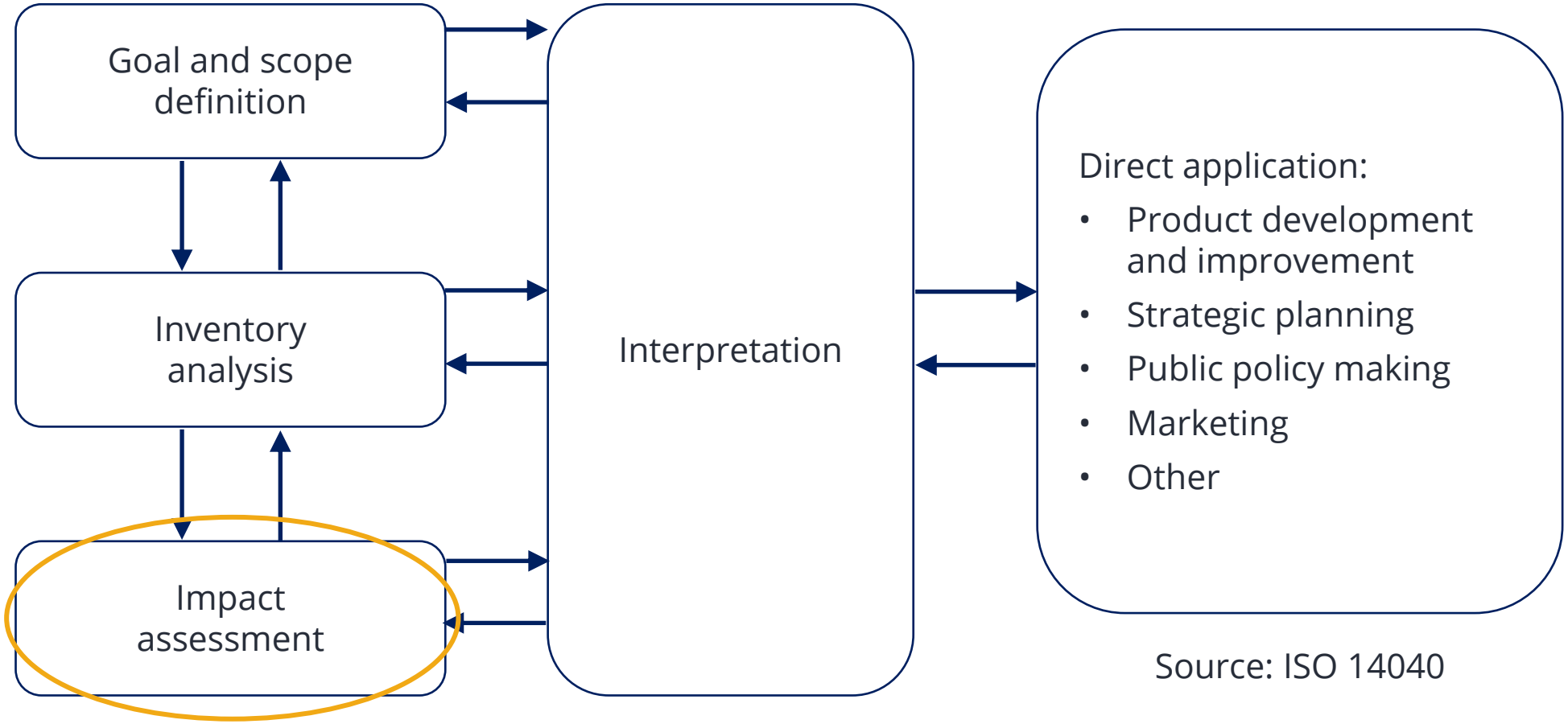
The structure of LCA



Source: ISO 14040

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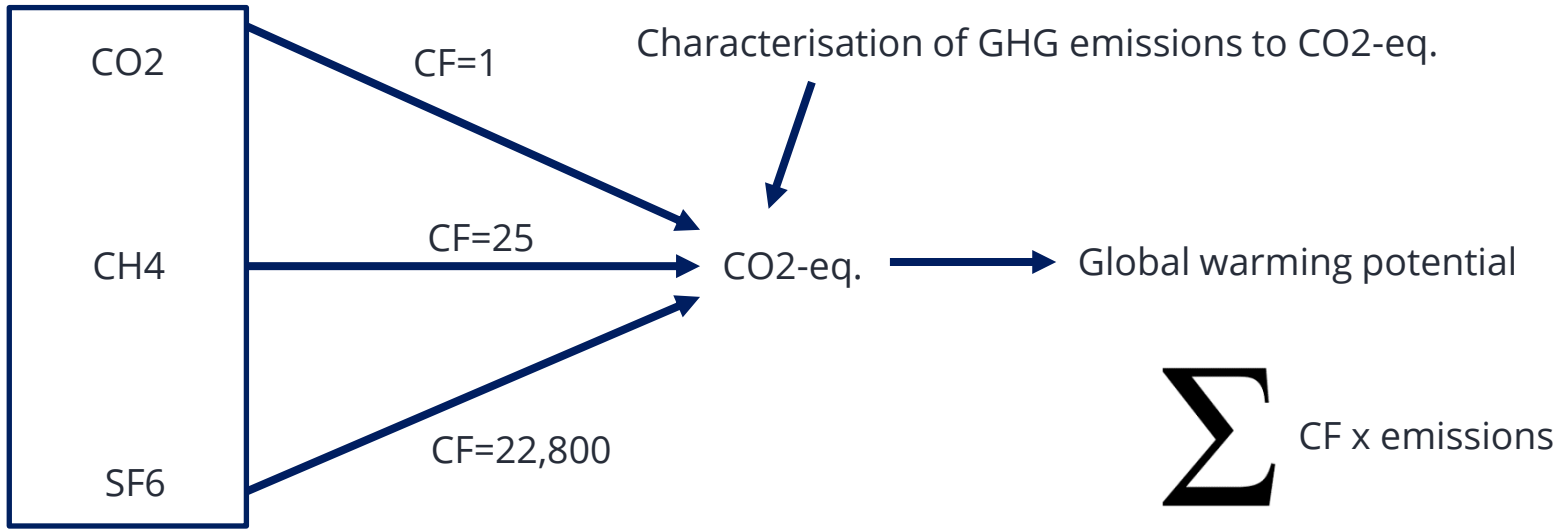
Life cycle impact assessment (LCIA)

Once all the materials and energy data has been compiled for the process model, the next step is life cycle impact assessment (LCIA). This forms two stages: **classification**, where data in the inventory is assigned to the environmental impact categories and then **characterization**, where emissions are directly compared and added together.

In the example below Global Warming Potential (GWP) is a measure for climate change based on radiative forcing for a mass unit of greenhouse gas (GHG). Here carbon dioxide has a characterization factor of 1 with all GHGs are equivalent to this (hence units of CO2 equivalents). Methane has a characterization factor of 25 indicating it has a 25 times greater impact on radiative forcing than CO2.



e.g. if I have 3kg of carbon dioxide and 2kg of methane then total GWP will be:

(3 x 1) + (2 x 25) = 53 kg CO2-eq.

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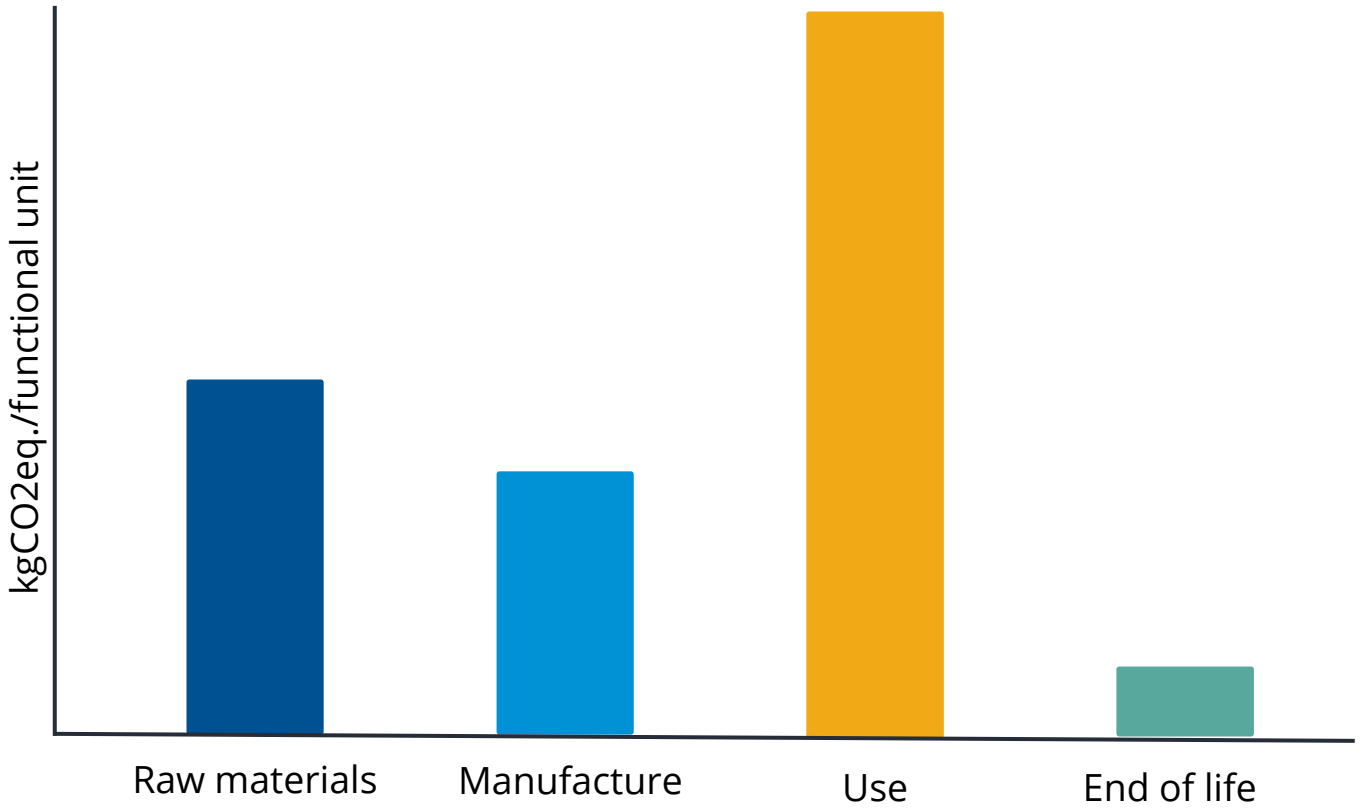
Life cycle impact assessment (LCIA)

- The results of life cycle impact assessment enable you to see where impact is concentrated in the life cycle.
- It can also help identify key processes within each life cycle stage contributing to environmental impact.
- Focus of result dependent on what was set out in goal and scope definition.



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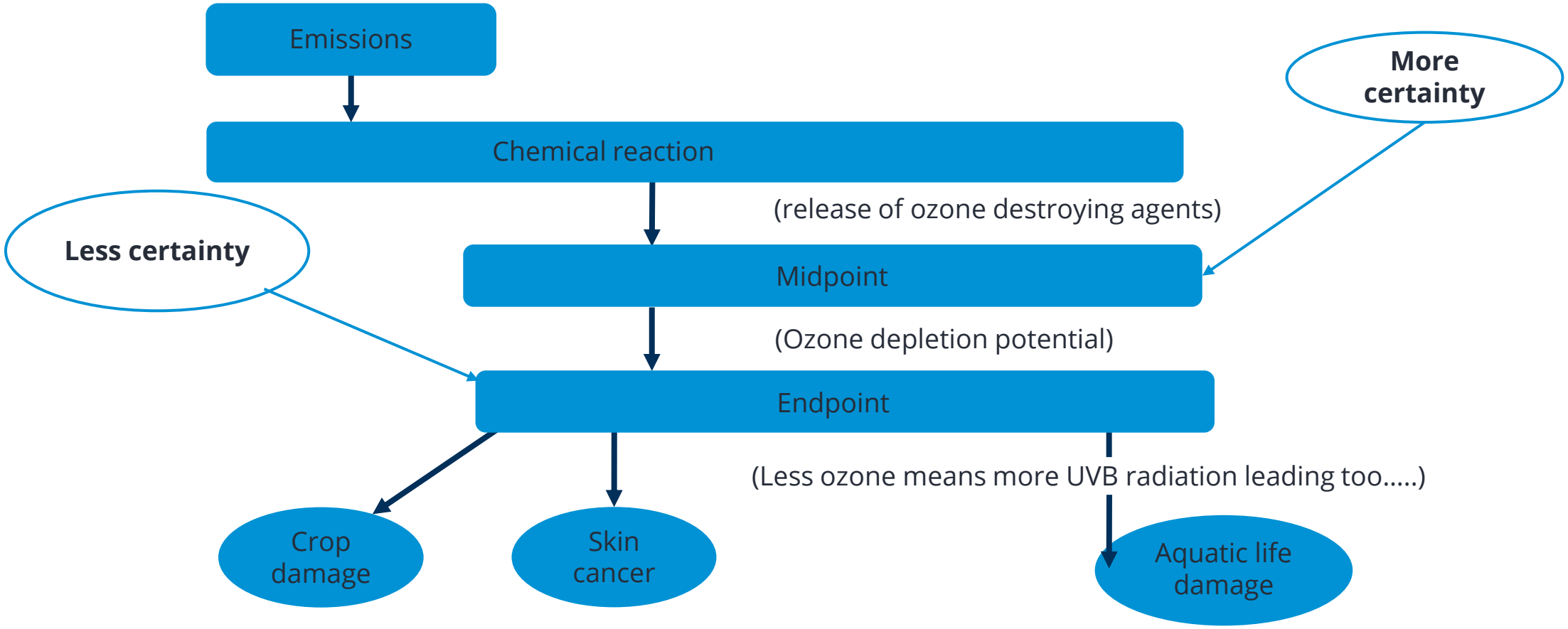
Midpoint vs. Endpoint modelling



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Normalisation

- Used to relate calculated environmental burden to the relative burden in its surroundings.
- Helps put results in context against a reference point:

i.e $Ni = Si/Ai/yr$

i = impact category
Ni = normalised result
Si = product system before normalisation
Ai = results of reference area

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Interpretation

Overall steps for interpretation are defined in ISO 14044:

1. Should identify the significant issues based on the inventory and assessment phases of the LCA.
2. The interpretation should conduct these checks:
    - Completeness check - Is relevant data present?
    - Sensitivity check - How sensitive are the LCA results to an assumption?
    - (To test: make a change to the assumption and recalculate the LCA results.)
    - Consistency check - Did the LCA abide by the stated goals and scope.
3. Include conclusions, limitations and recommendations.

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Online LCA resources

- ILCD Handbook for LCA - https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN.pdf
- LCA MOOCs on places like Coursera or directly through Universities like MIT.
- Industrial Ecology Freiburg - http://www.teaching.industrialecology.uni-freiburg.de/ - would highly recommend this ranges from introductory level all the way through to advanced.
- Other open teaching material - https://ilca.es/teaching-materials/open-teaching-material/ https://www.lifecycleinitiative.org/resources/training/

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Online LCA resources

- LCA networks: Imperial LCA network https://www.imperial.ac.uk/life-cycle-network/about-us/, International Life Cycle Academy https://ilca.es/, Forum for Sustainability through Life Cycle Innovation (FSLCI) https://fslci.org/, International Society for Industrial Ecology https://www.is4ie.org/

- Global Life Cycle Data network (GLAD) (a good source to search for inventory data) https://www.globallcadataaccess.org/

- LCA discussion list for Simapro (covers range of LCA methodological questions posed by the community – not limited to discussion specifically about Simapro) https://support.simapro.com/articles/Article/LCA-Discussion-List

- ETH Zurich LCA Discussion Forum (access event details and recordings of previous events) https://video.ethz.ch/events/lca/2021/spring/77th.html

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Sustainability in design exercise – sustainable aviation

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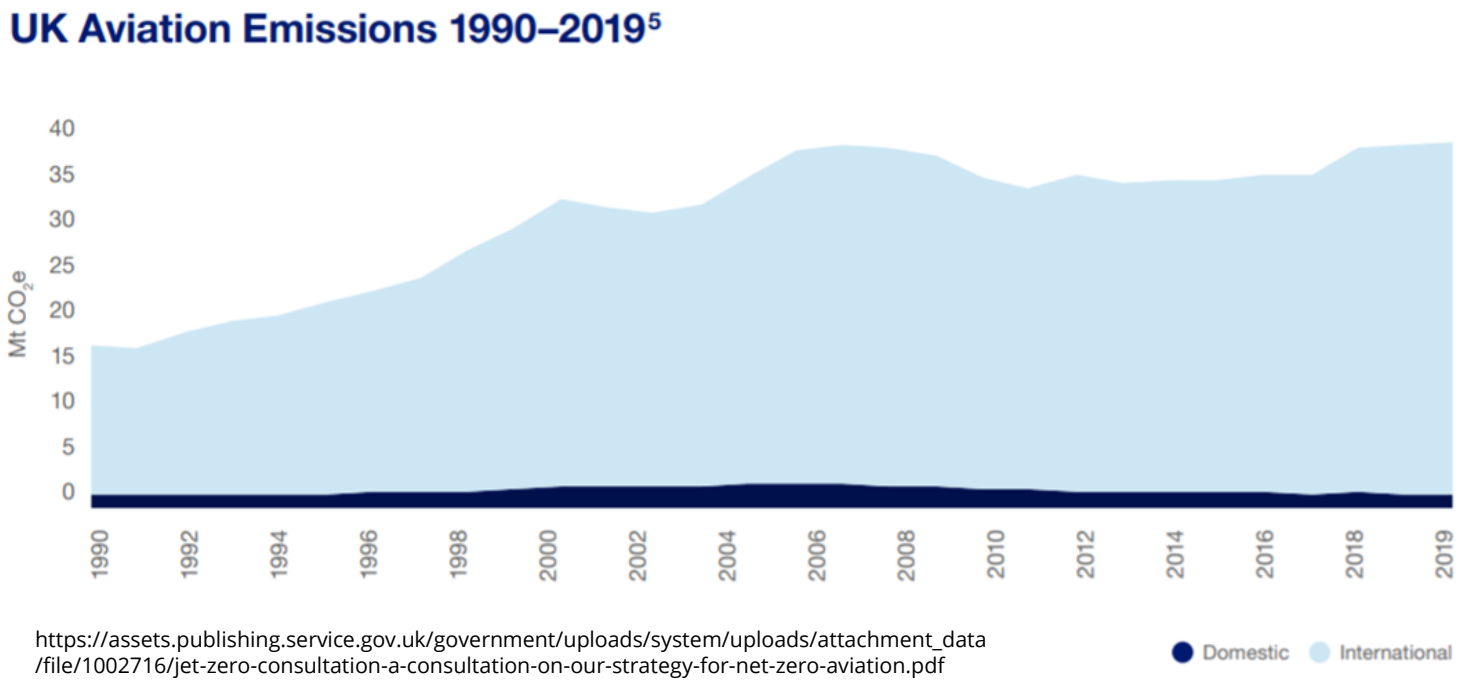
Sustainability in the aviation industry

- UK aviation has committed to achieving net zero by 2050 and a 78% reduction in emissions by 2035.
- UK Government has established the **Jet Zero Council** to focus the sector on developing UK capabilities in net zero and zero emission technologies – this includes funding for sustainable aviation fuels and zero emission flight infrastructure.



https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1002716/jet-zero-consultation-a-consultation-on-our-strategy-for-net-zero-aviation.pdf

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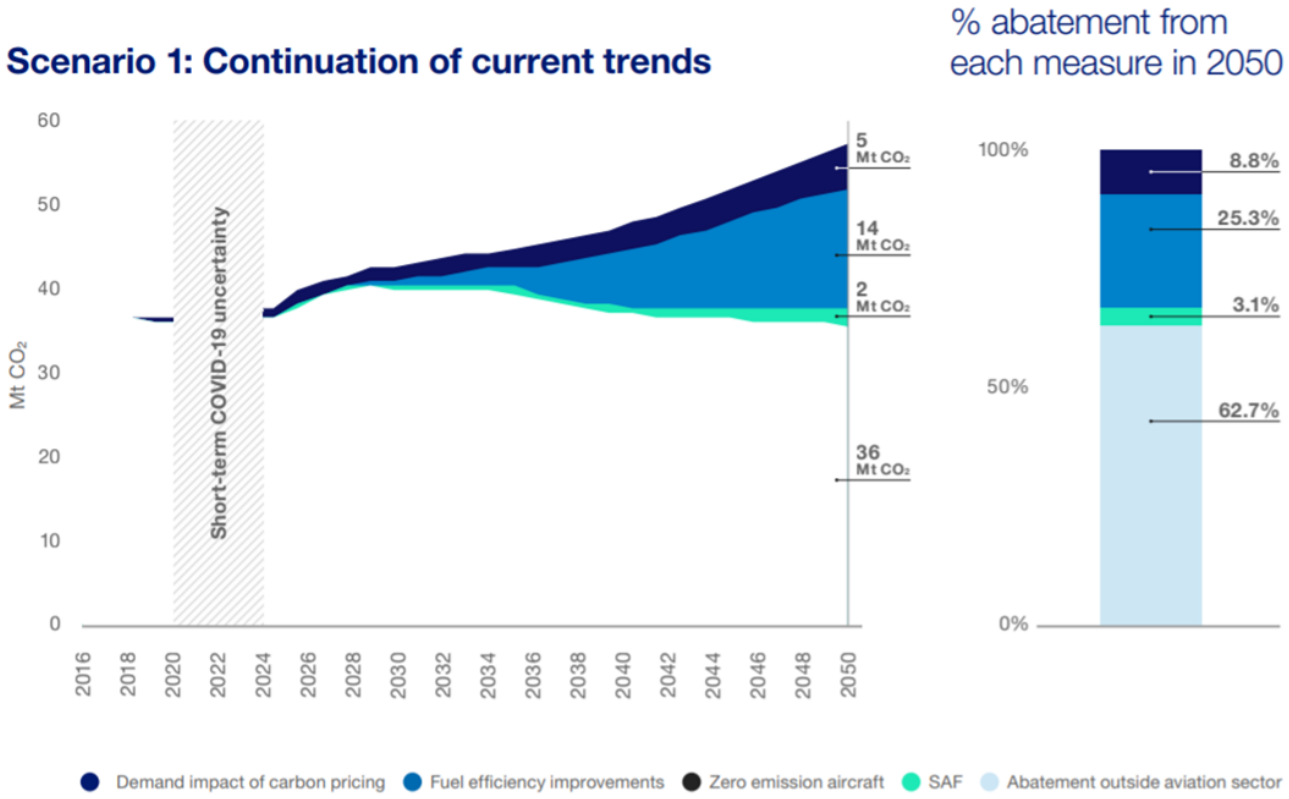
Sustainability in the aviation industry



- A range of scenarios are suggested within the UK Government's Jet Zero Strategy consultation published in 2021.
- 4 Scenarios were suggested from 1 (continuation of current trends) to 4 (high ambition with breakthrough on zero emission aircraft).
- **Scenario 1:** continuation of current trends and reflects highest dependency on abatement coming from outside aviation sector.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1002716/jet-zero-consultation-a-consultation-on-our-strategy-for-net-zero-aviation.pdf

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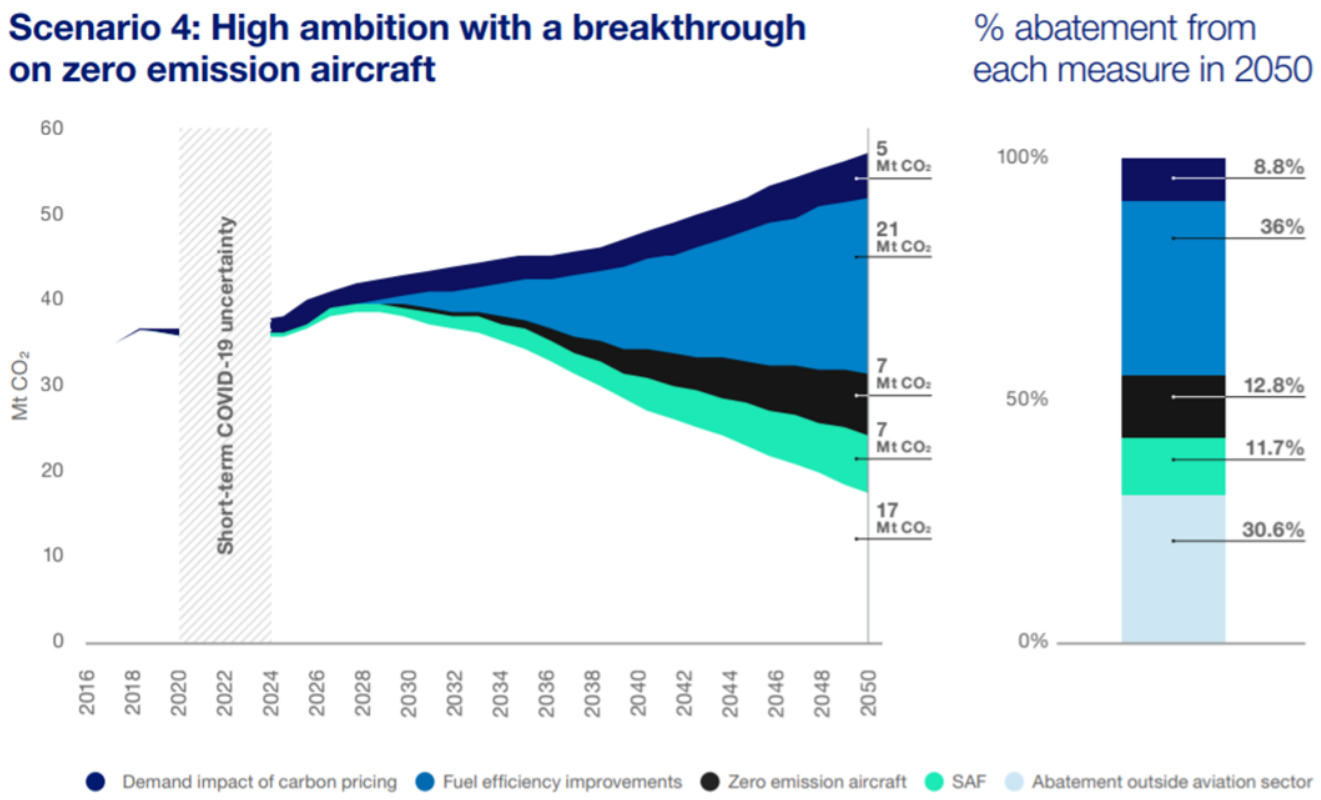
Sustainability in the aviation industry



- **Scenario 4:** Assumes higher ambition with breakthrough on zero emission aircraft.
- Greater contribution from fuel efficiency improvements as well as zero emission aircraft and sustainable aviation fuels.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1002716/jet-zero-consultation-a-consultation-on-our-strategy-for-net-zero-aviation.pdf

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Sustainability in the aviation industry

- **System efficiencies**
  - Improvements in efficiency of aircraft as well as how airports operate.
  - Improvements in efficiency include greener technologies, improving operations and phasing out old aircraft.
  - Knock on benefits to UK economy and reducing impacts from noise pollution.
  - Efficiency of conventional aircraft can be improved through changes to engines, wings, structures and other systems.
  - Impact at airports can be reduced through use of connected autonomous vehicles and use of a single engine whilst taxiing.
  - Reduction in aircraft weight can be achieved through material choice or efficiencies gained from matching fuel and water requirements with passenger load.

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Sustainability in the aviation industry

- **Sustainable aviation fuel**
  - Sustainable aviation fuel (SAF) is seen as a key element to meeting net zero targets.
  - These fuels are a ‘drop-in’ option with can be blended into fossil-based aviation fuel in existing aircraft.
  - SAF can be produced from:
    - Biomass or biogenic waste like cooking oil.
    - Non-biogenic waste like unrecyclable plastics or waste fossil gases from industry.
    - CO2 and green hydrogen.

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Sustainability in the aviation industry

- **Zero emission flight**
  - This comes from deployment of hydrogen-electric and battery-electric aircraft.
  - Small-scale electric aircraft have already been demonstrated and could form part of a domestic fleet in the next decade.
  - There are a number of ongoing research programmes looking to scale up this technology.

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Sustainability in the aviation industry

- Designing for a more sustainable aviation industry requires a **systems perspective.**
- It requires us to think about every stage of the life cycle - from the production of the materials used the way through to solving challenges at end-of-life.
- It also requires a more **resource efficient** and **circular approach** to how the industry operates.
- It requires a range of interventions – from materials to technology to influencing consumer behaviour.

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Design Exercise

- **From a design perspective how can you improve the sustainability of the aviation sector?** Considering the following:
  - The life cycle implications of any improvement (you may wish to use a MET Matrix to do this).
  - The role the circular economy has to play.
  - The role of social impact and consumer behaviour.
  - Use of life cycle assessment data as a way to evaluate environmental impact associated with new designs.
- Because this is a very large topic you may wish to **focus in on one area** of the sector, one specific technology or efficiency improvement (keeping in mind how this may be connected with wider aspects).

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