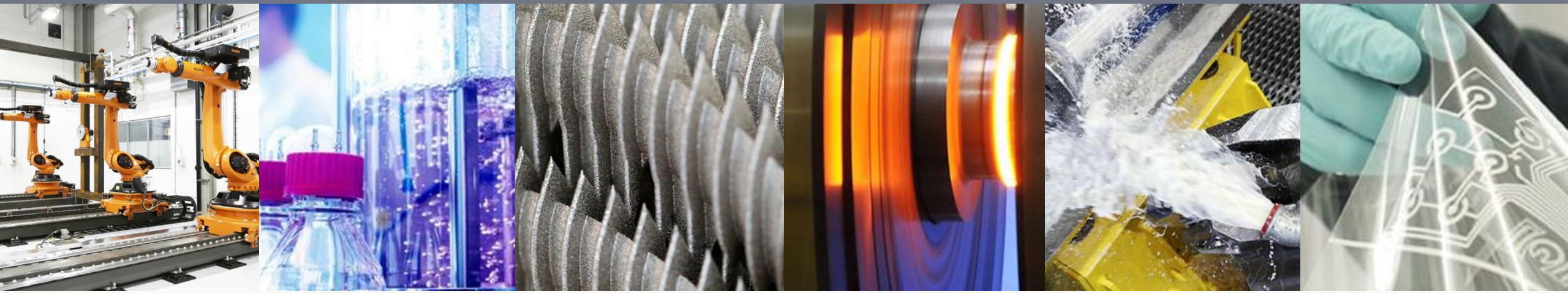
Emerging Skills Programme

Open Government Licence Guidelines

Emma Carroll-Walsh
Programme Exec
27/05/2021



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Basic Guidelines

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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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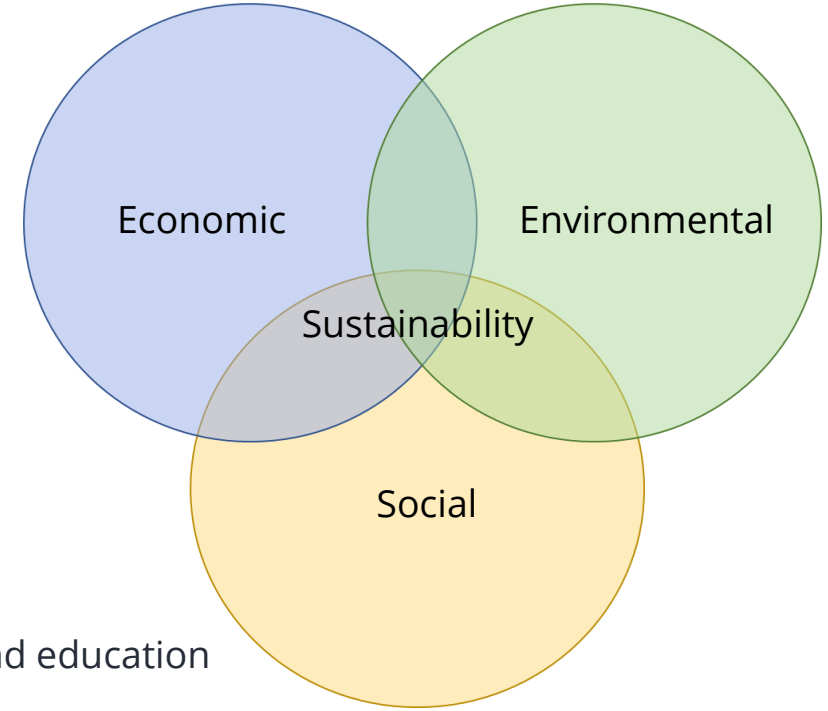
What is sustainability?

'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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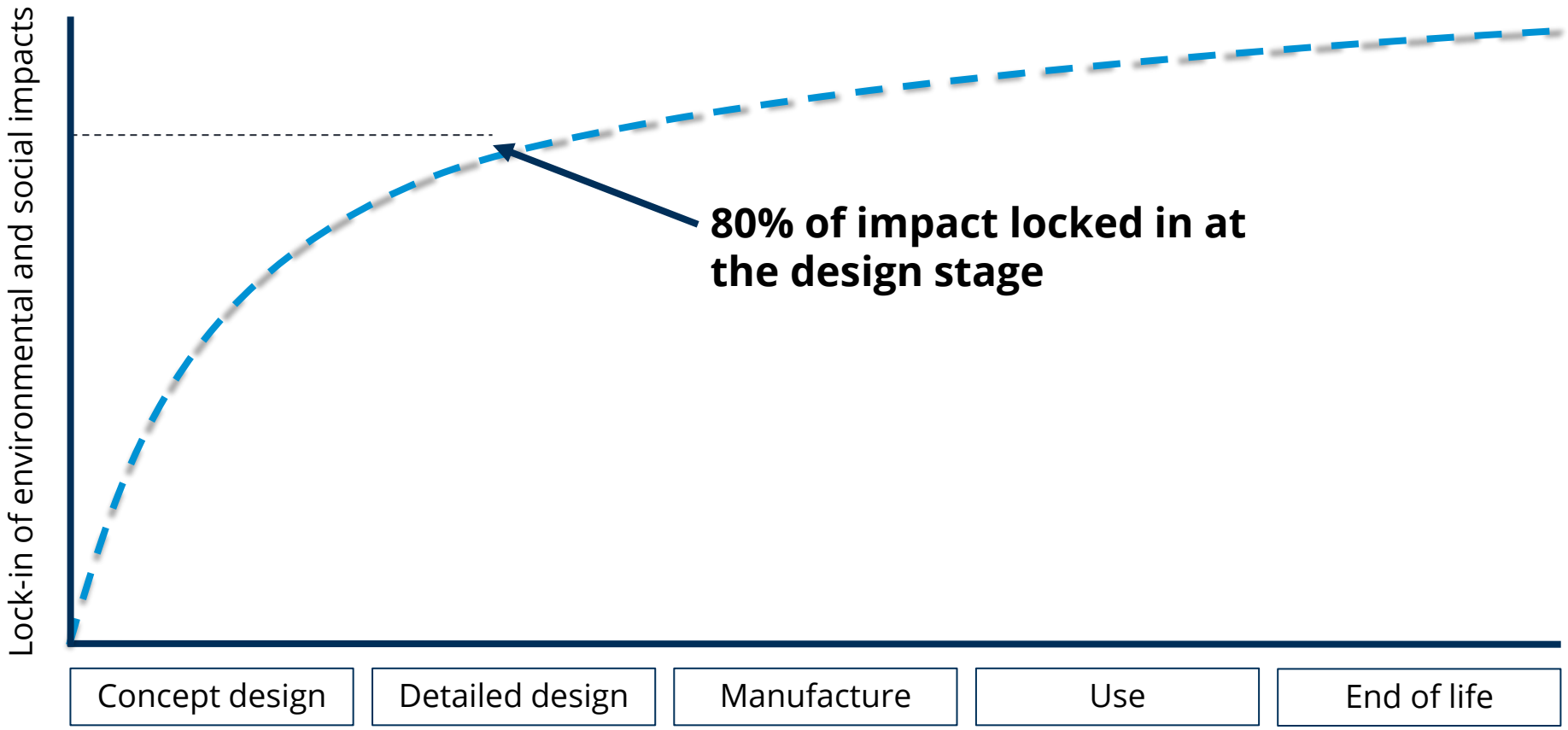
Why is sustainability important at the design stage?



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Why is sustainability important at the design stage?

- Majority of environmental & social impact locked in by decisions made within design process.
- Significantly limits our options to reduce impact once manufacturing process has begun.
- Design for sustainability (DfS) - more than just thinking about environmental impacts.
- Also encompasses elements of circularity, social impact & designing for social value.
- Umbrella term used with Design for X strategies (e.g. Design for Environment, Design for End-of-life).

- **Systems thinking & life cycle thinking underpin all sustainability Design for X strategies.**

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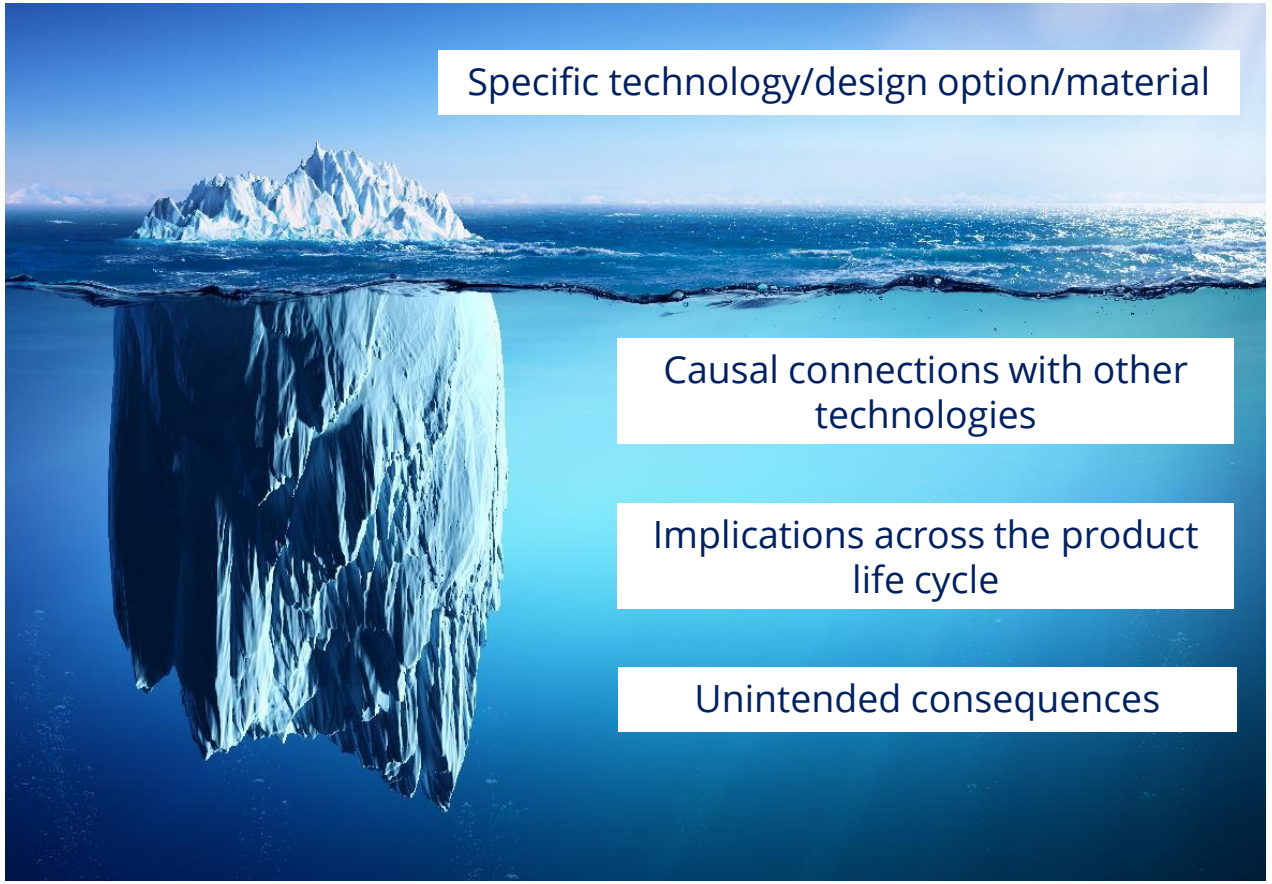
Thinking in systems



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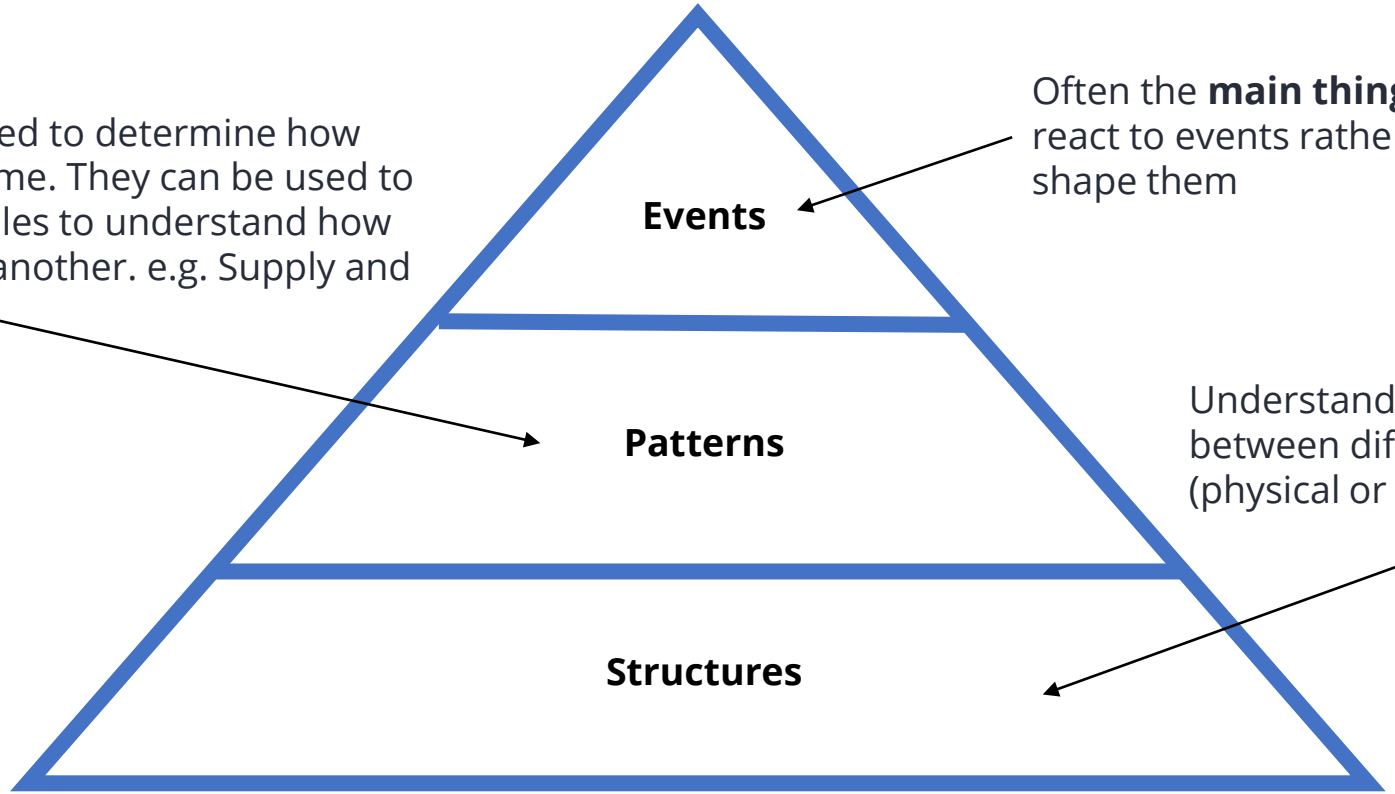
What is a system?

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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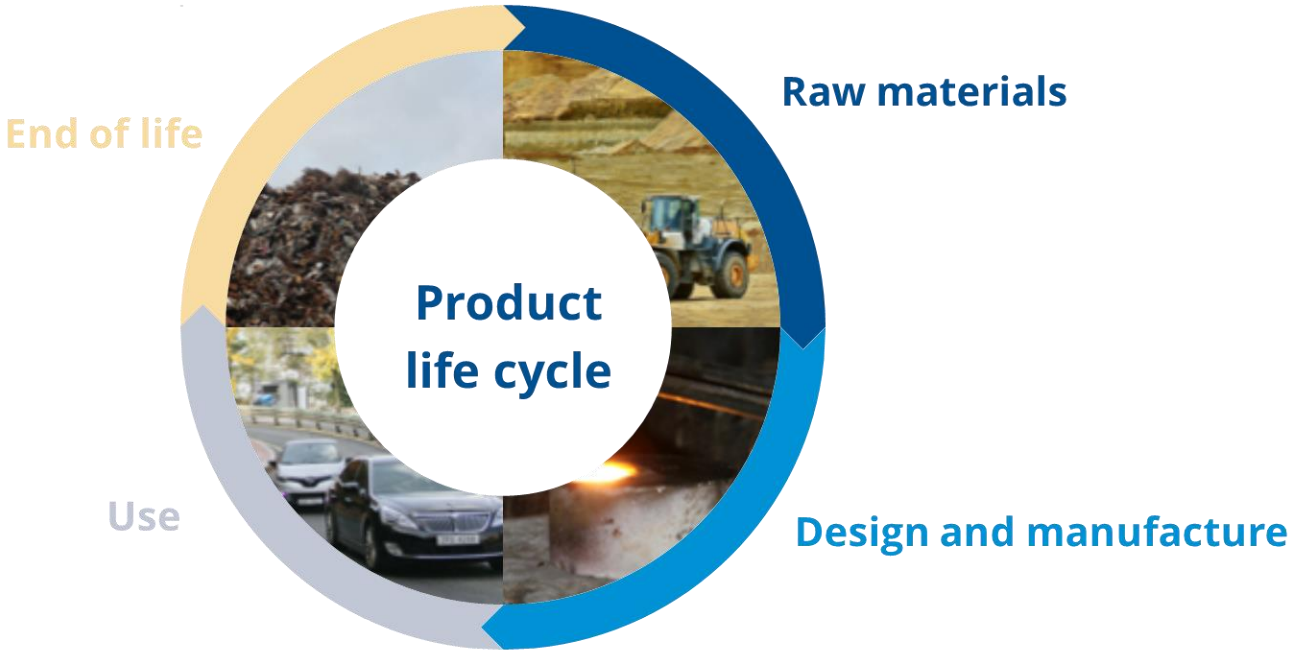
What is life cycle thinking?

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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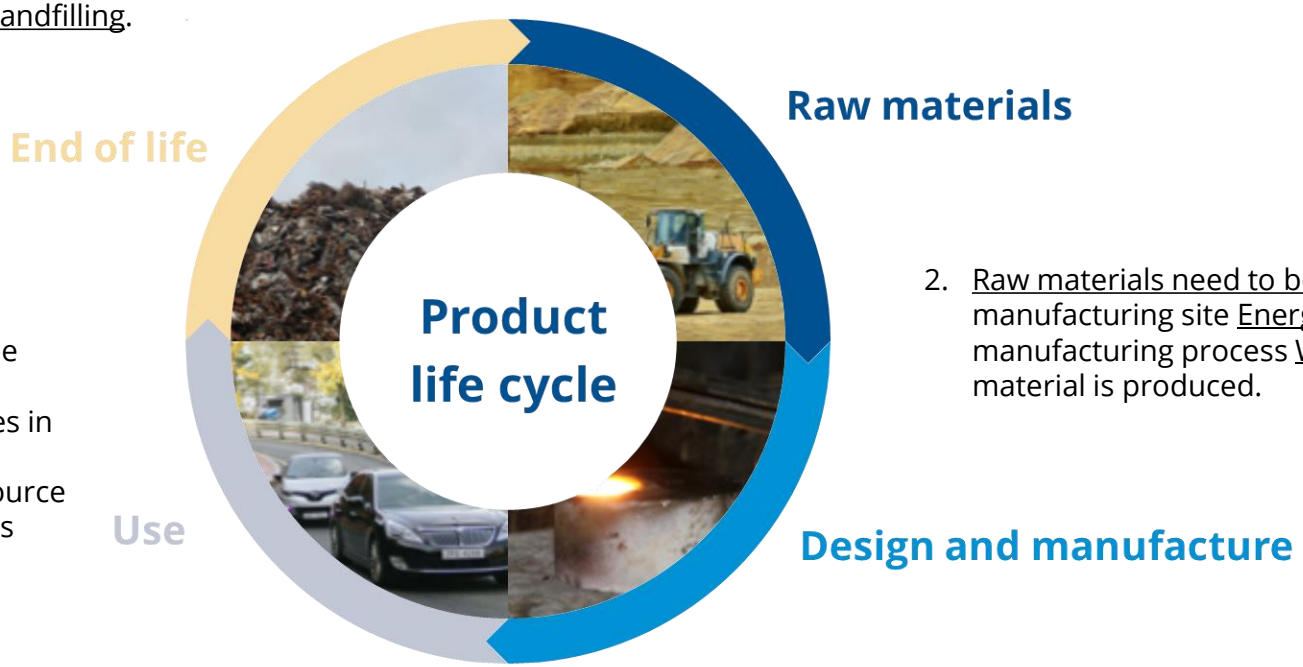
Life cycle thinking

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. 3. Vehicle transported to showroom to be sold through use phase:
- internal combustion engine vehicle fuel goes in & tailpipe emissions come out
- electric vehicle electricity goes in and the source of that electricity is associated with emissions out.

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Life cycle thinking

- Value chains - highly complex & 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 & energy flows result in environmental, social, & economic impacts: climate change, ecotoxicity, human toxicity, resource use, water use, land use, impact on working conditions and worker H&S, etc.
- ‘Hotspots’ where potential environmental, social or economic impacts are concentrated within value chain.
- Where are the hotspots? How do changes to part of life cycle impact hotspots? Life cycle thinking allows us to avoid burden shifting – reducing impact in one part of life cycle, but increase in another part.
- e.g. switch to electric vehicles reduces use phase impact from tailpipe emissions, but impact may shift to electricity production if heavily reliant on coal-fired power stations.

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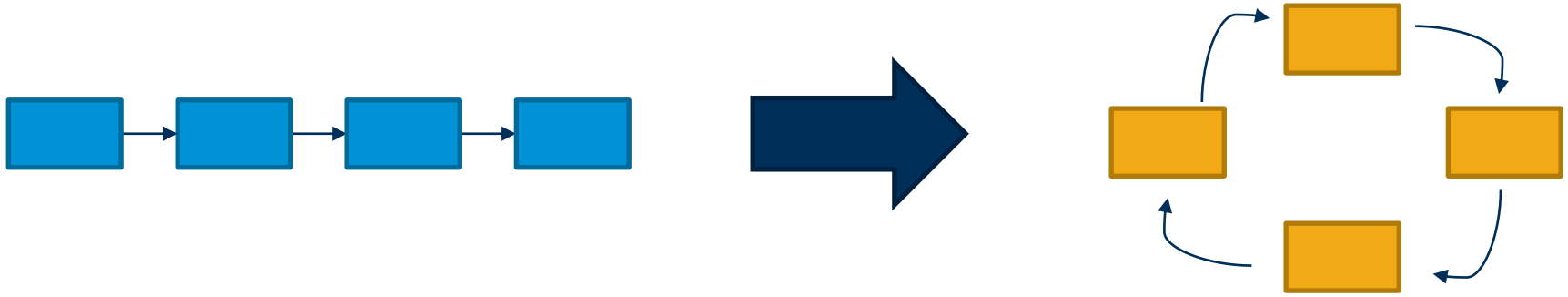
What is circularity?

Circular Economy - Move away from traditional linear 'take, make, dispose' view of the world (e.g. materials extracted, turned into products, then discarded).

- Many ways to define & visualise circular economy, e.g. popular recent framework developed by Ellen MacArthur Foundation https://ellenmacarthurfoundation.org/circular-economy-diagram

- Circular economy offers range of economic, social & environmental benefits, achieved through:
  - Maximising lifetime of products & materials & 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) - more holistic view than DfE (solely focused on minimising environmental impact across life cycle).

DfC affects materials selection choices: from recycled materials to systems level change.

Link with other circular economy concepts e.g. 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 disassembly,
- Design for recycling

End of life focus decision making on design impacts every stage of the life cycle.

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Design for Circularity - examples

- 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).

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Design for Social Aspects

- Long-lasting design
  - Average phone replaced every 18 months, consumer electronics often viewed as semi-disposable.
  - Fairphone aims to combat this - making phones modular - easy to upgrade or repair.

- Reuse and recycling
  - Every year millions of phones thrown away. Fairphone sell spare parts & offer repair tutorials. The take back program supports reuse & recycling of old phones.
  - Invests in research to find 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

Referred to as social value centred design.
Social impacts - key pillar of sustainability.
Design for Sustainability (DfS) should maximise social benefit & minimise negative social impact.

Social value may consider:

- 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: The BRE Dementia House

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

- Based on design for dementia principles:
  - Clear lines of sight & colour coded paths - guide people towards specific rooms.
  - Increased natural light – helping people stay alert during the day & sleep better at night.
  - Noise reduction features to lower chances of stress.
  - Simple switches & heating controls with safety sensors in high risk areas *e.g.* 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

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

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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!

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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: 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

- **Surgical masks** – too large for women
  - Although ¼ women said "just right" & 1/3 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 & provision.
- Men also disadvantaged by poor fit but women affected disproportionately.
- Safety 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 ‘western man’s fit’ rather than truly unisex.
- This issue extends further than just PPE.
- **User insensitive design can compromise safety**
  - More than just 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:

- Bumps on whale's fin can significantly improve efficiency, reducing drag and increasing lift.
- Companies now applying this to turbine blades, fans, & propellers.

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Nature inspired design

The kingfisher and the Bullet train:

- Bullet train made loud boom as it exited tunnels.
- Build up of sound waves as they are pushed in front of train.
- Shape of kingfisher's 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 (PPS) level design

PSS - combination of products & services (often as product-as-a-service model – leasing equipment/products not selling them).

May achieve closed loop supply chain.

Sustainability benefits of model:

- **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 & maintenance to improve customer satisfaction.
  - Leasing rather than owning model may enable access to better products.
- **Information value**
  - Recovering product aids understanding (*e.g.* wear & tear).
  - Feeds into product design, marketing & distribution.
  - Better understanding of 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 consumer & professional healthcare.
- Medical diagnostic equipment for hospitals.
- Move from 'take-make-disposal' model to 'take-make-return'.
- 4 returning loops: service, refurbish, parts recovery, recycle.

- **Customer value:** can use brand new equipment - might not be able to afford to purchase.
- **Information value:** continued relationship with customer - better understanding of 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 & embodied energy, prolong product life with repairs.

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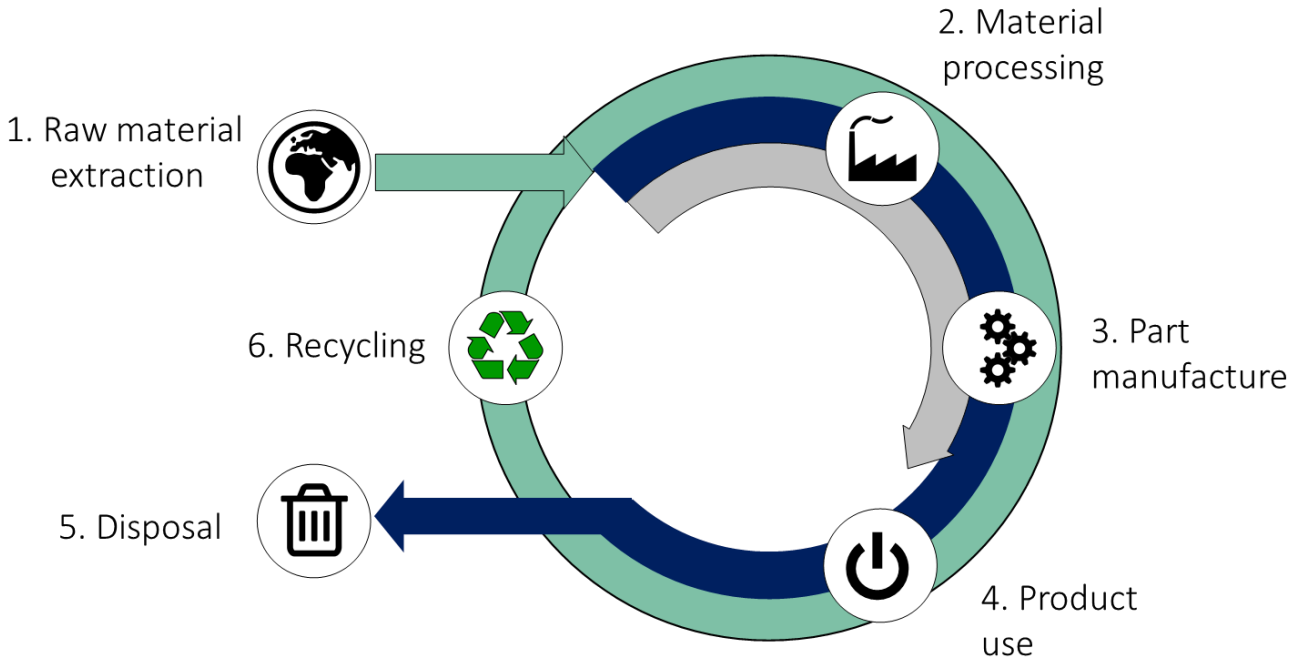
Life cycle thinking in design

- During design process, consider design principles & also useful to consider life cycle of product.
- Initial stages of design might not need to be *quantitative* analysis.



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Life cycle thinking in practice

Wind turbine blades

- Blades made from range of materials - manufacturing consumes much energy.
- Materials contribute to blade's strength, durability & weight.
- Enable turbines to be built taller - more efficient & able to harness more energy.
- Does not emit CO_2 during life, but some materials have no well defined waste management routes.
- Carbon payback - 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

- Lithium-ion battery production: consumes large amounts of energy.
- Lithium & cobalt mining: significant social & 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 still high - few can afford to own electric vehicle & charging infrastructure limited.

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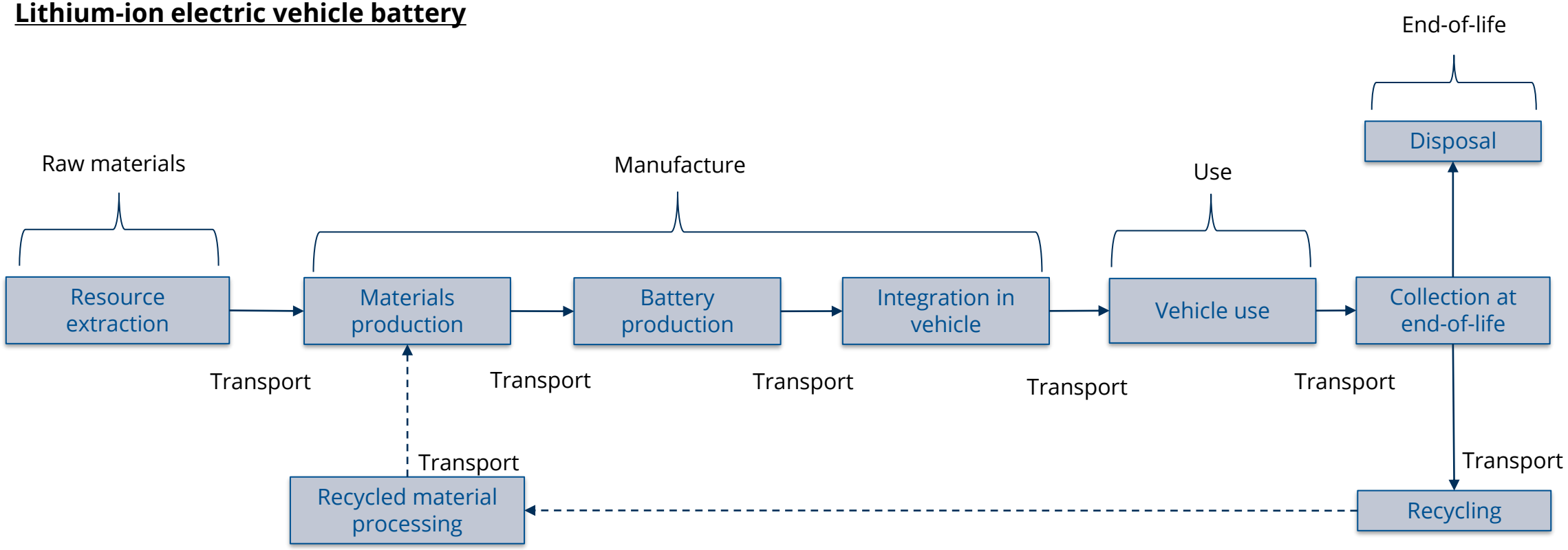
Life cycle thinking in practice

Lithium-ion electric vehicle battery



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The MET Matrix

- Use MET matrix - qualitatively consider life cycle impacts associated with product designs.
- Environmental impacts (materials use, energy use & toxicity) evaluated at each stage in life cycle.

	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 & water	Water & 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	Operational impacts relating to maintenance of the structure rebar is used within rather than rebar itself	Energy use recovering & breaking up concrete
Toxicity	Resin – irritant & 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 & 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 More material going to landfill

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The MET Matrix

Exercise: Based on the example MET Matrix, try and create one of your own 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 associated with largest environmental impact.

- Composite materials used in wind turbine blades can have high energy intensity (carbon > epoxy resin > glass fibres) and life cycle of blade currently very linear with limited industrial scale technology to recover & recycle glass & carbon fibres.

- Designers have opportunities to:
  - Use different materials with lower energy intensity or environmental impact.
  - Make material recovery & circularity easier by designing for disassembly & recovery at end-of-life/ and designing with recycled material content in mind from the outset (particularly important for materials like carbon fibre).
  - Consider origin of materials –how much geographical grid mix, local environmental standards, transport may impact overall environmental impact of materials & component choices.

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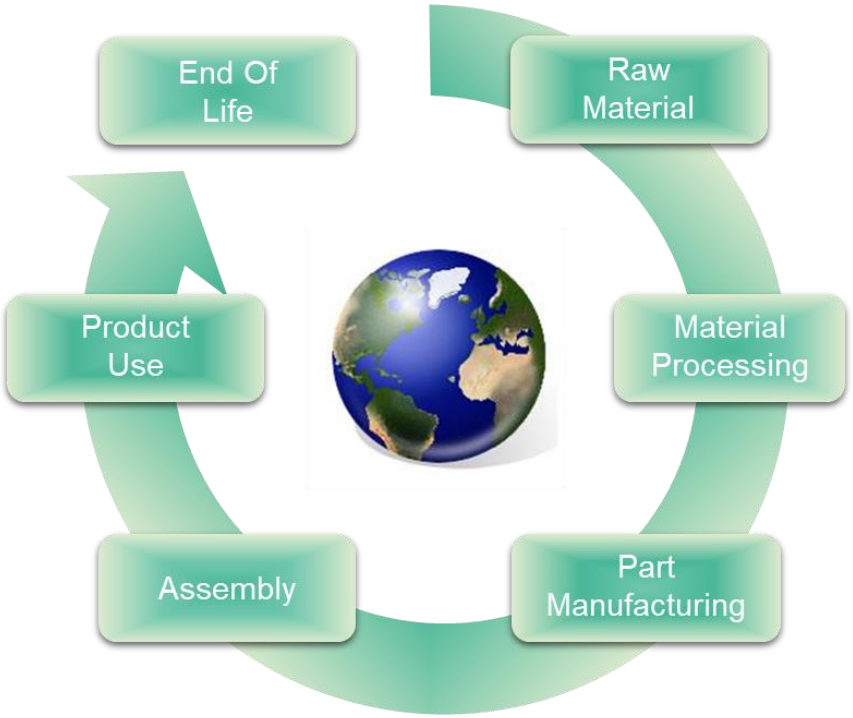
What is life cycle assessment (LCA)?

- Approach which quantifies ecological & human health impacts of product or system over complete life cycle.
- Impacts calculated on mass & energy flows through system.
- Most commonly used to assess products.
- LCA has specific methodology & standards (ISO 14040, ISO 14044).
- Using LCA you can assess environmental impacts including:
  - Climate change
  - Ecotoxicity
  - Human toxicity
  - Eutrophication
  - Acidification
  - Resource use
  - Water use, *etc.*



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Why Perform 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 specific set of criteria.
  - Third party grants license to use label.
  - Criteria set with reference to product life cycle.
  - Less commonly seen in UK.
  - Typically aimed at consumers.
  - Examples are: European Ecolabel, The Nordic Swan, Ecomark (Japan).

  - http://www.ecogloballabel.org/download/GLOBAL_ECO_LABELS_LISTESI.pdf

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Types of environmental labelling

- **Type II - Self declared environmental claims (ISO 14021)**
  - Non third party certified.
  - Claims made based on characteristics following general guiding principles.
  - Examples are recycled content or biodegradable.

https://www.oecd.org/env/policy-persectives-environmental-labelling-and-information-schemes.pdf

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Types of environmental labelling

- **Type III – Environmental declarations (ISO 14025)**
  - 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).

https://www.oecd.org/env/policy-persectives-environmental-labelling-and-information-schemes.pdf

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Types of questions LCA can answer…….

- Which is the most environmentally friendly option for supermarket bag – paper, plastic or textile?
- From an environmental perspective should car bodies be made of composites or steel?
- To best reduce environmental impact of its products, should a company target:
  - its own processes,
  - its suppliers,
  - its customers, or
  - waste management companies at end of life?
- Are electric cars more environmentally friendly than 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

- **1960s** - One of first LCA studies conducted by Coca Cola contrasting aluminium cans & glass bottles.
- **1970s & 1980s** - LCAs used by companies informally to assess environmental impacts of different products.
- **1990s** - LCAs formalized with specific framework developed by SETAC & ISO standards.
- **2000s** - LCA information started to find its way into policy-making & public procurement.
- **2010s** - LCAs used to inform energy policy, increasing interest in social LCA & development of EU Product Environmental Footprint (PEF).
- PEF - enables comparability between product categories using Product Category Rules (PCRs).

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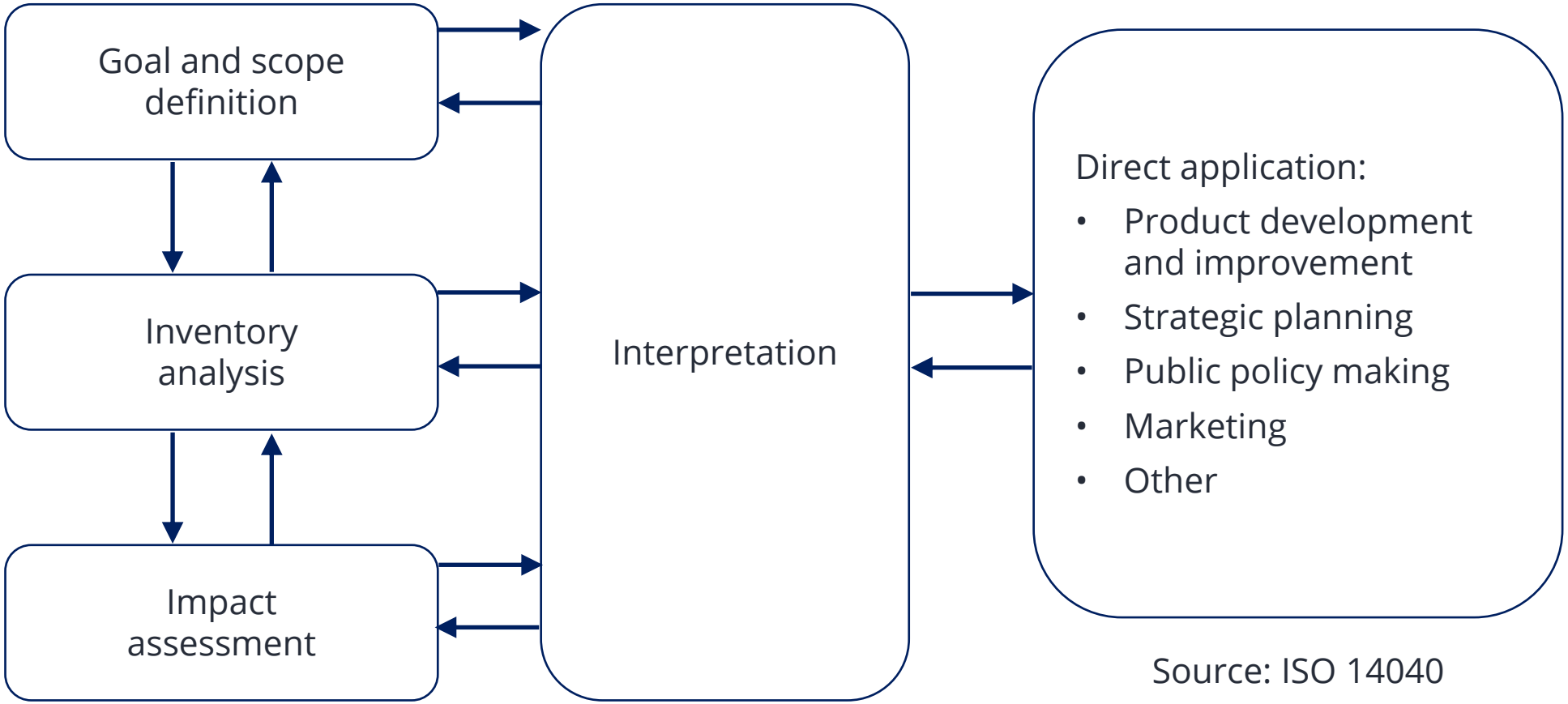
The structure of LCA



Source: ISO 14040

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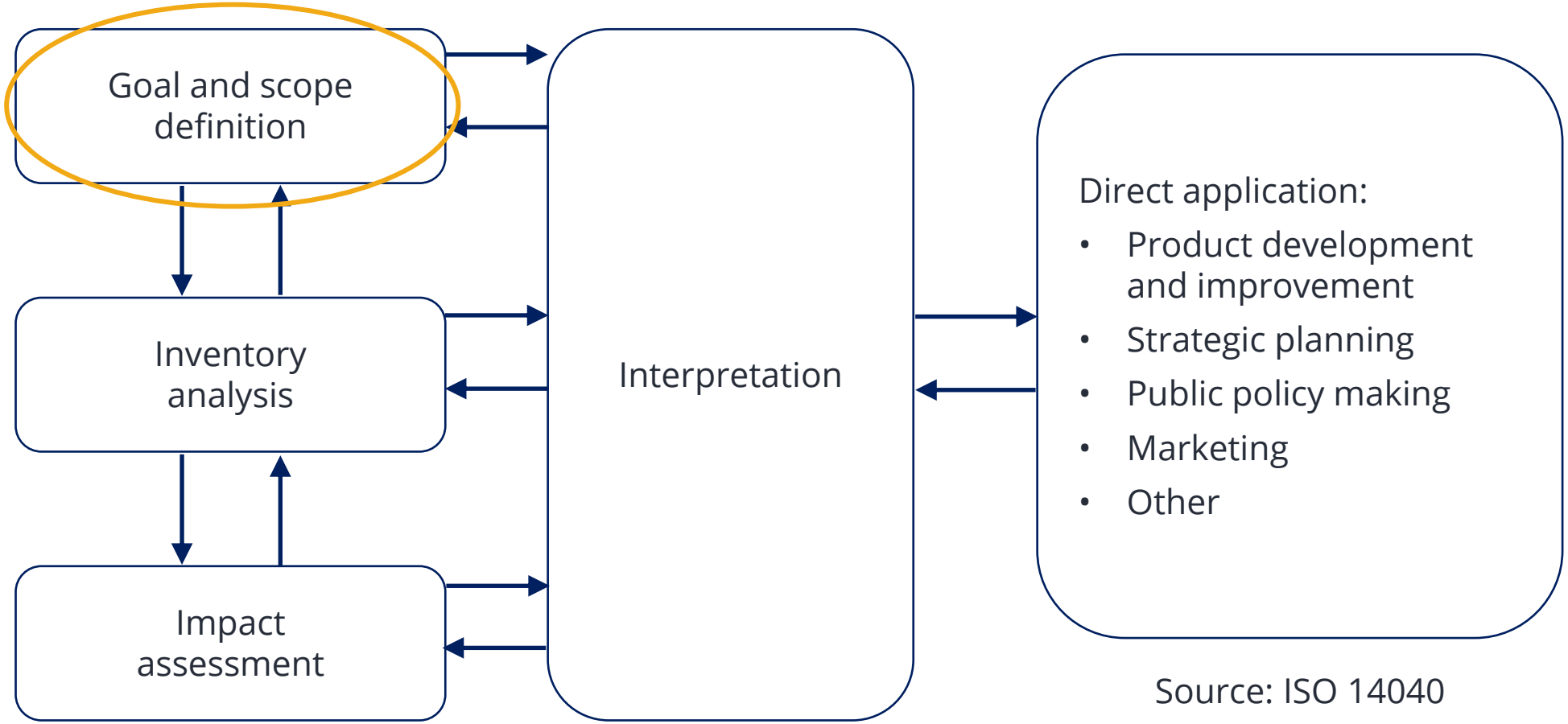
The structure of LCA



Source: ISO 14040

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Goal and scope definition

First phase of an LCA and key to helping plan out LCA activity.

This phase establishes the **aim** of the study, and its **breadth & depth.**

Poorly defined goal and scope will impact the rest of LCA.

The goal and scope definition can be split into 1. goal and purpose, and 2. Scope

1. Purpose of the study

Purpose of an LCA to compile & assess potential environmental impacts associated with options for fulfilling a certain function. These can be:

- **Descriptive –** which environmental impacts can be assigned to 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 life cycle are covered?
- What processes are covered?
- What environmental impacts are being investigated?

- **Definition of the functional unit:**

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

Example 1: “a mid-size 4-person vehicle driven in a semi-urban environment over 150,000 km” 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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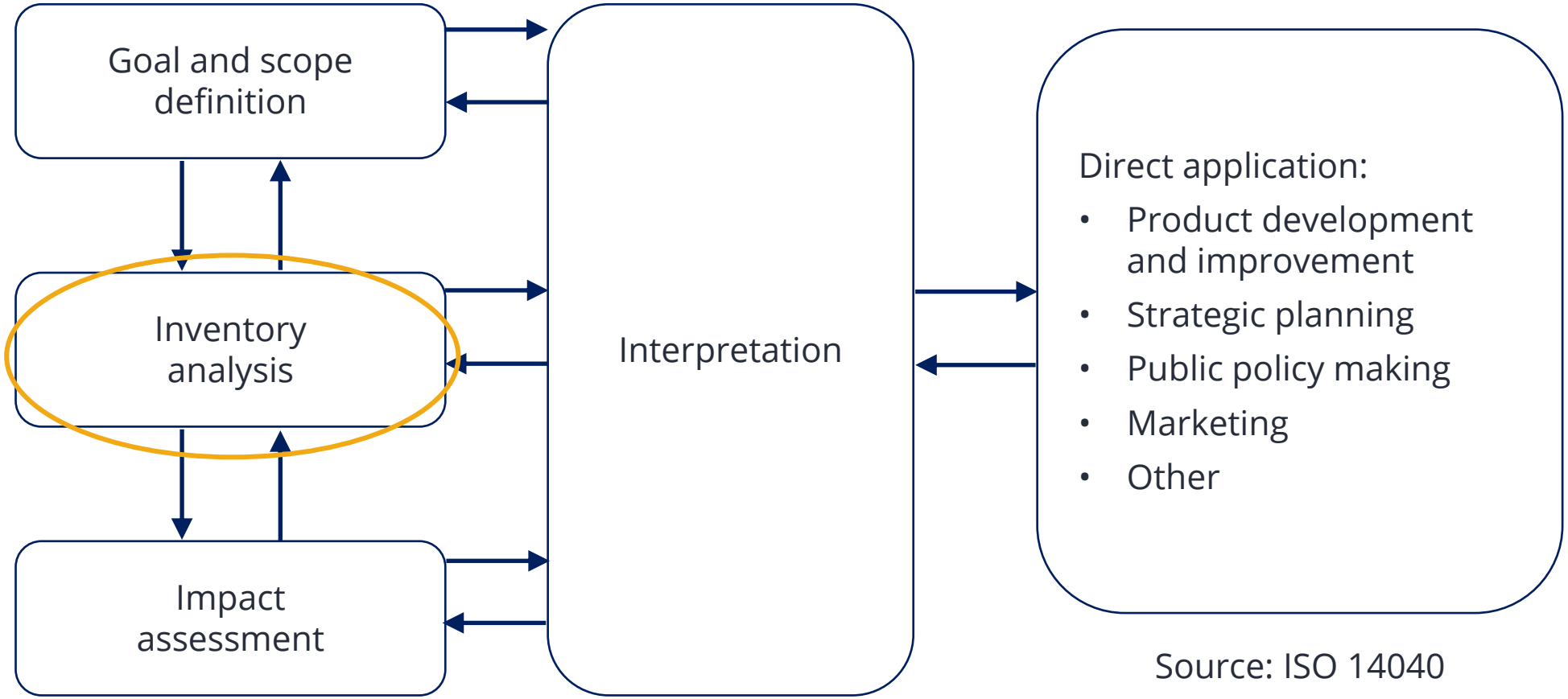
The structure of LCA



Source: ISO 14040

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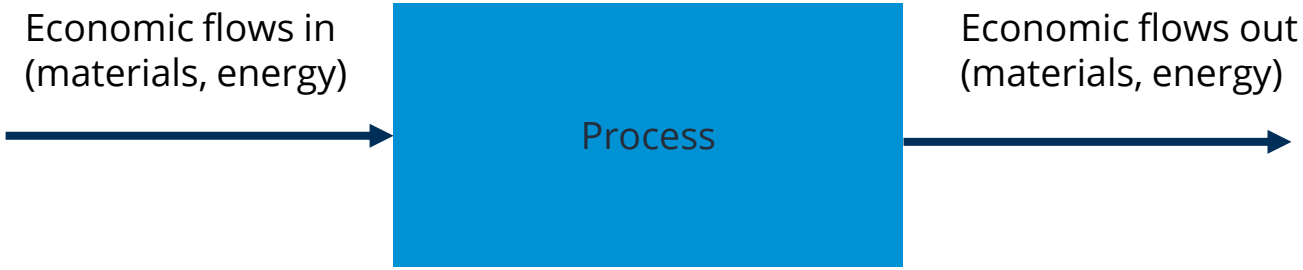
Life Cycle Inventory (LCI) Analysis

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

The process flow diagram

Graphical representation of product system.

Simplified process flow often appears in goal & scope definition to show graphically scope of study.



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

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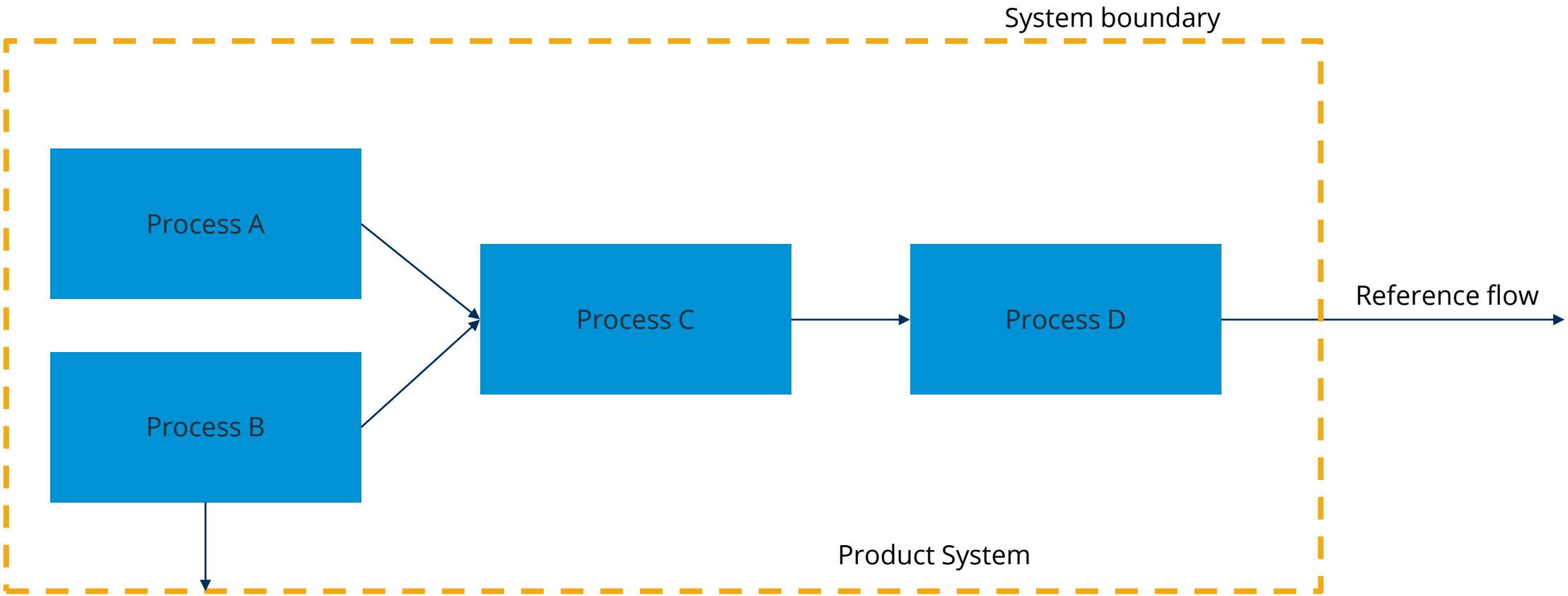
Life Cycle Inventory (LCI) Analysis



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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 & emissions.**
- Data can come from variety of places making consistency/completeness challenging.
- Data quality assessed in terms of precision, completeness, representativeness (temporal, geographical, technology), consistency, & reproducibility.

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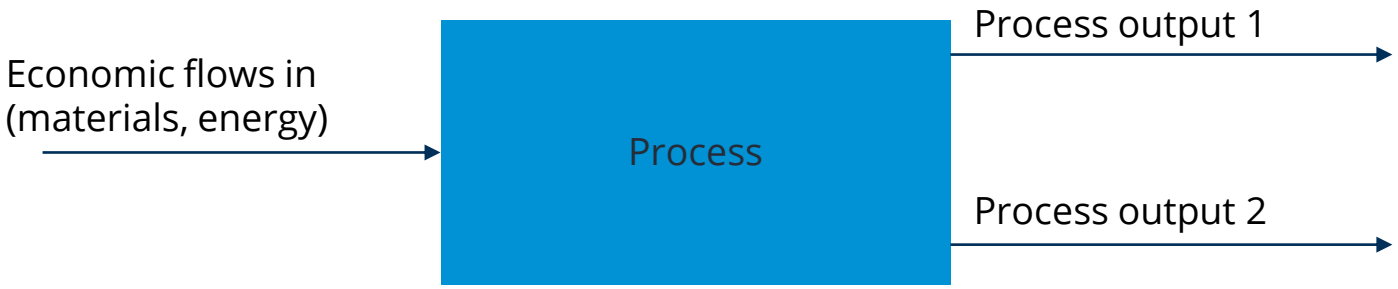
Multifunctionality and allocation

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 - might be electricity or heat generation.
- Multifunctional processes can be co-production of several flows (multi-output), combined waste processing (multi-input), or involve recycling (input-output).

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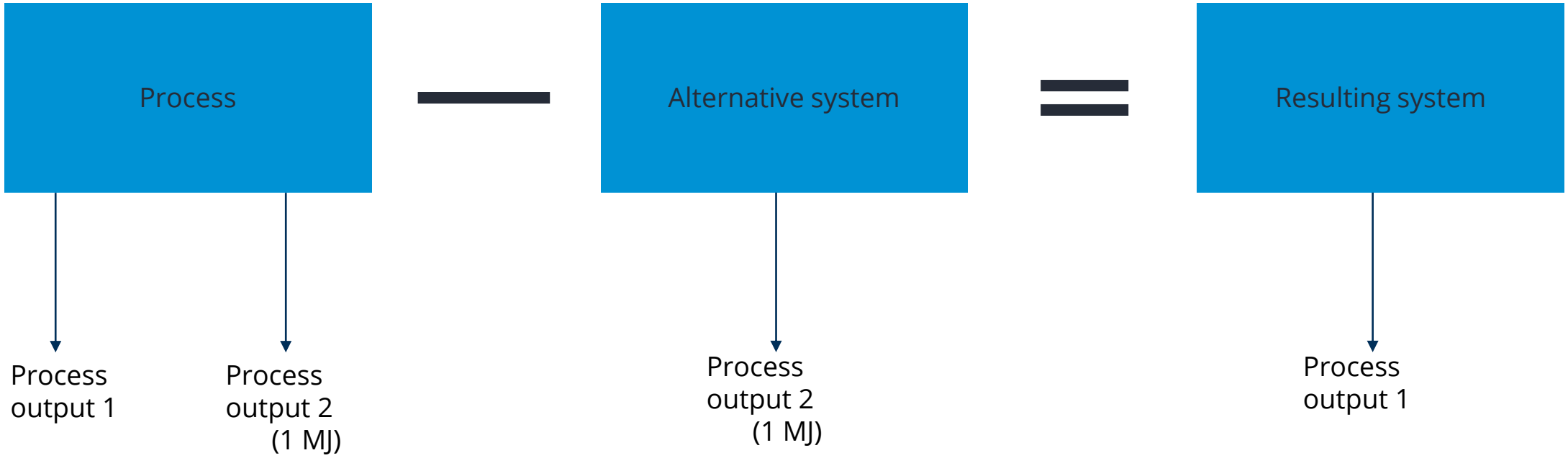
Multifunctionality and allocation

- 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

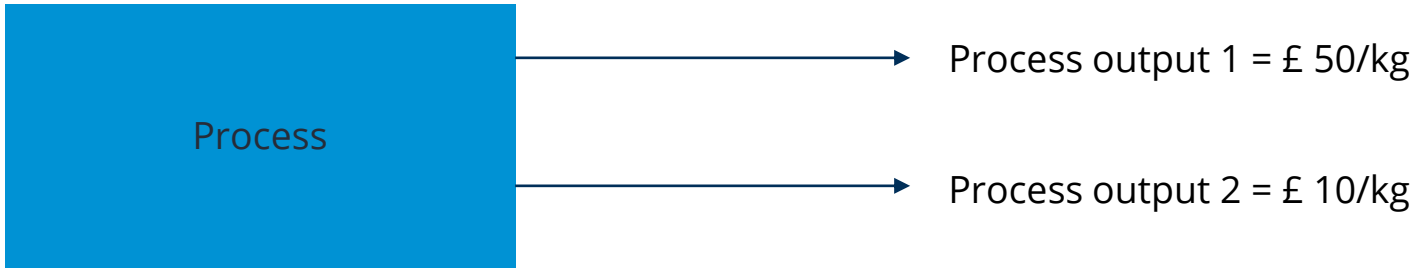
Allocation based on physical relationships

Share of environmental impact

33%

66%

Allocation based on non - physical relationships



70%

30%

Allocation - highly debated area of LCA methodology – results highly sensitive to choices made!

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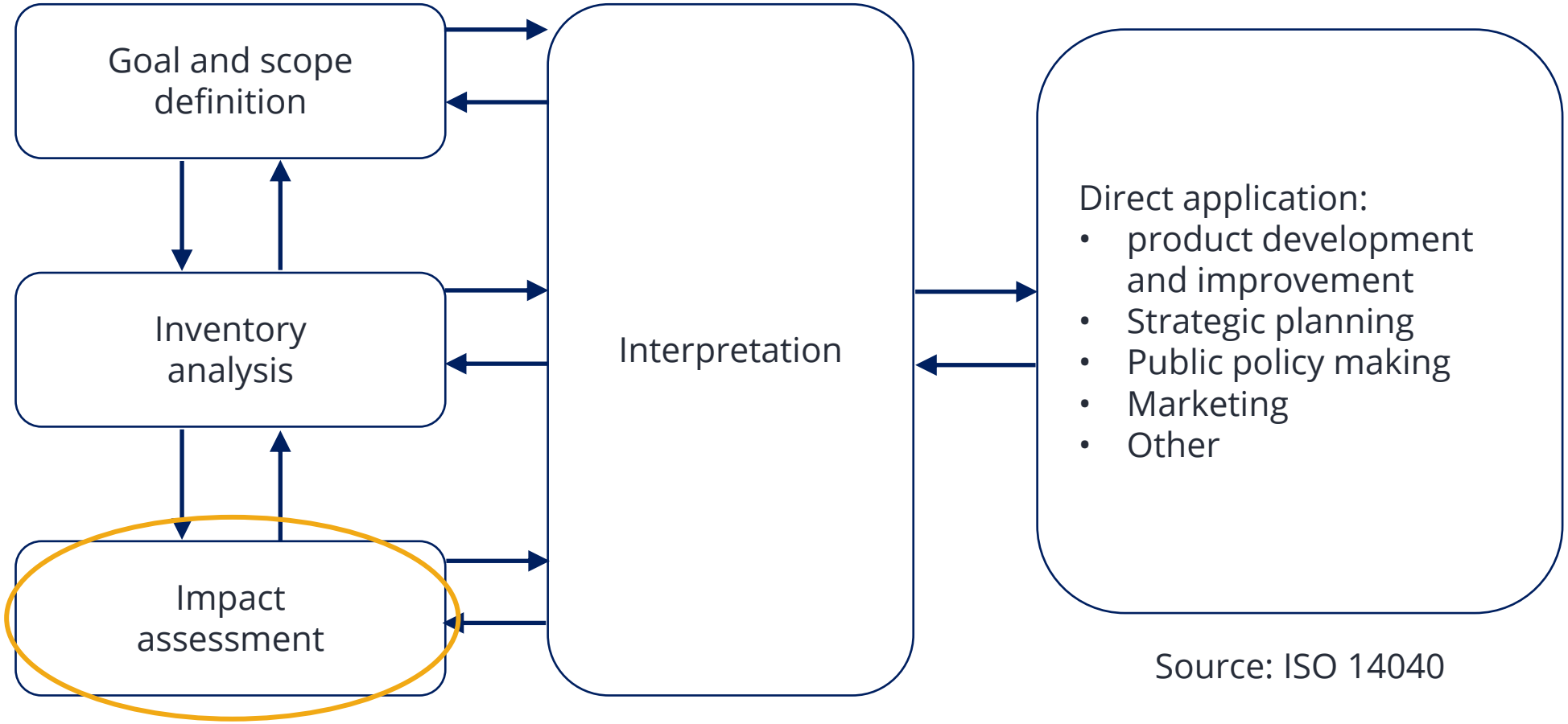
The structure of LCA



Source: ISO 14040

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Life cycle impact assessment (LCIA)

Once all materials and energy data have been compiled for process model, next step is life cycle impact assessment (LCIA). Comprises two stages:

Classification - data in inventory are assigned to environmental impact categories, then

Characterization, where emissions are directly compared and added together.

In next example Global Warming Potential (GWP) measures climate change based on radiative forcing for a mass unit of greenhouse gas (GHG).

Carbon dioxide has characterization factor of 1 all GHGs compared to this (hence units of CO_2 equivalents).

Methane has characterization factor of 25 - has 25 times greater impact on radiative forcing than CO_2.

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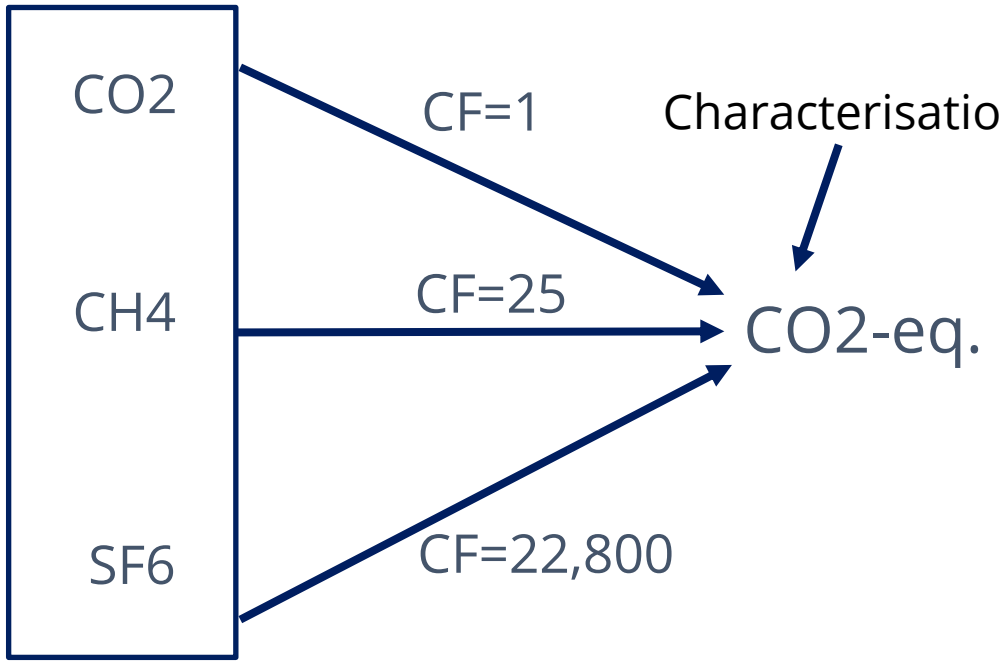
Life cycle impact assessment (LCIA)



Characterisation of GHG emissions to CO_2-eq.

Global warming potential

e.g. if I have 3 kg of CO_2 & 2 kg of CH_4 then total GWP will be:

(3 x 1) + (2 x 25) = 53 kg CO_2 -eq.

$$\sum \text{CF x emissions}$$

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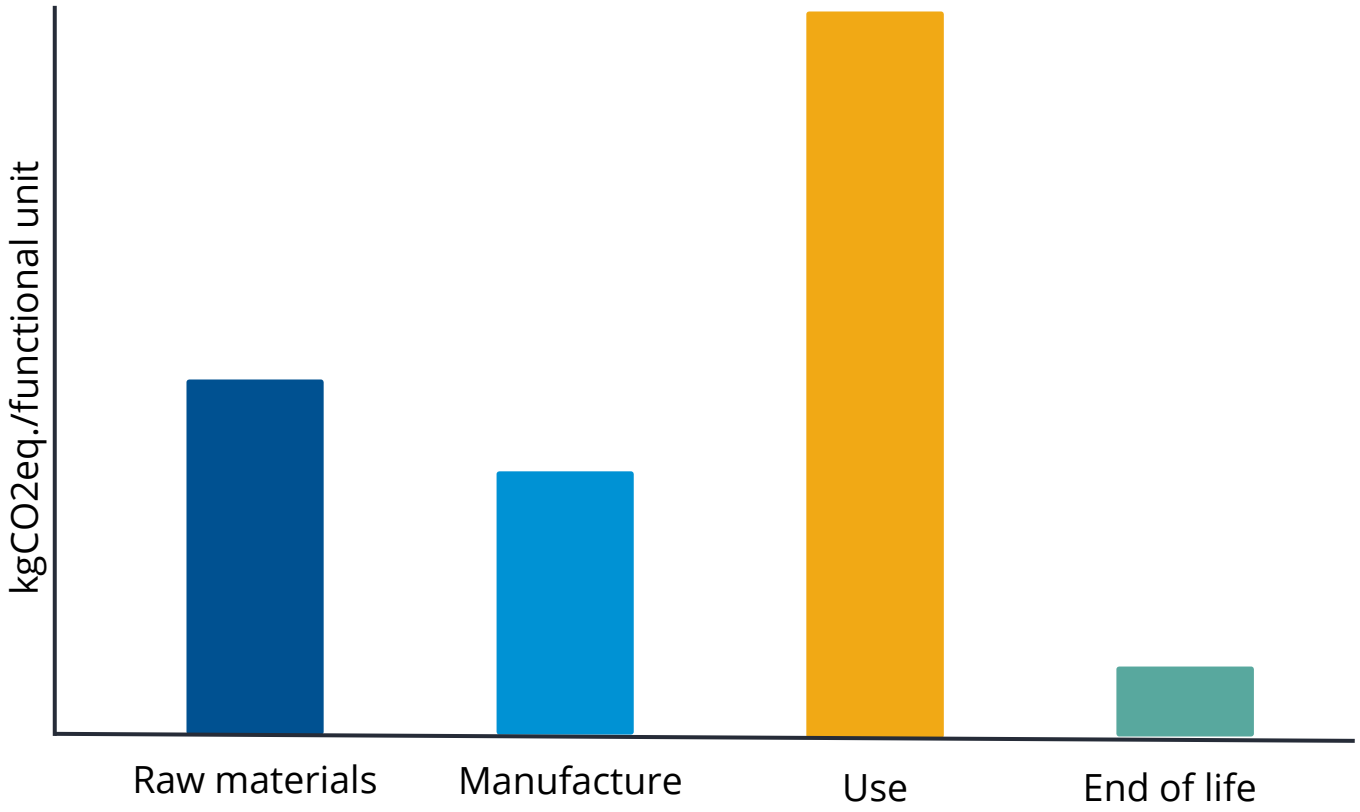
Life cycle impact assessment (LCIA)

- Results of LCIA identify where impact is concentrated in life cycle.
- Also helps to 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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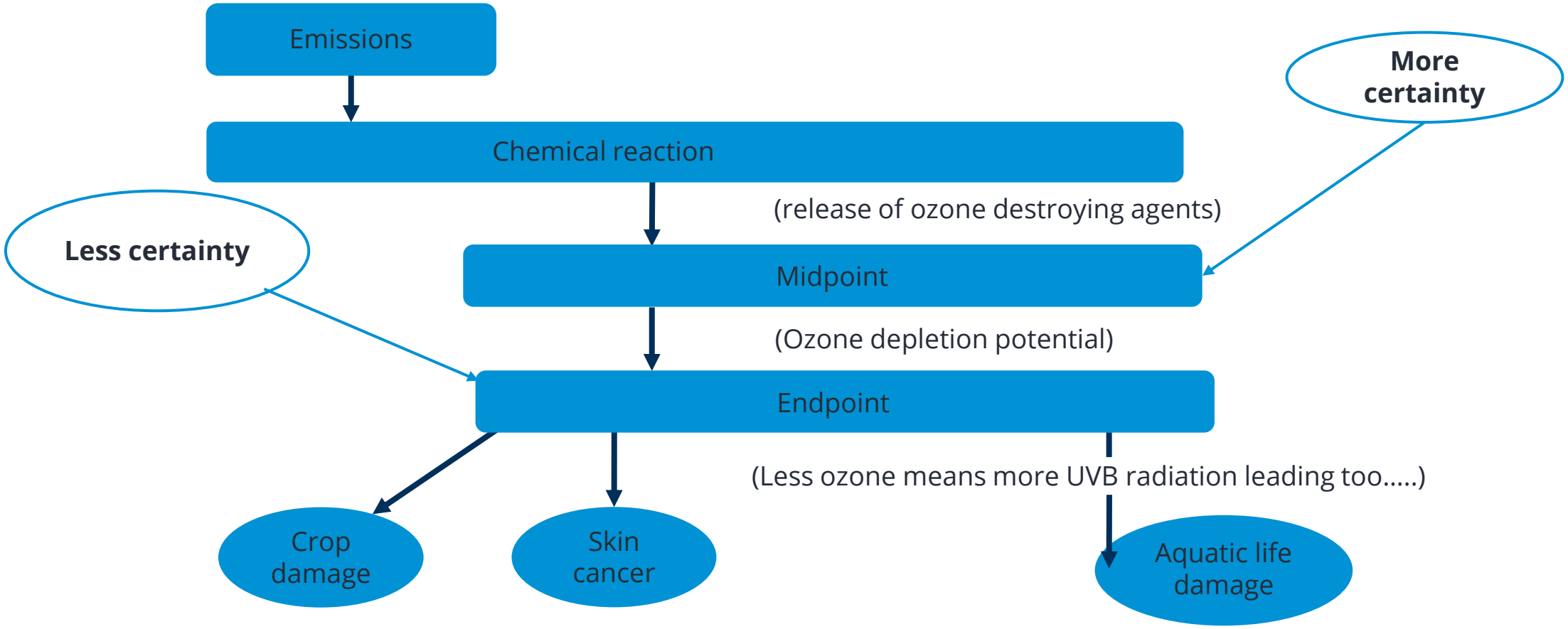
Midpoint vs. Endpoint modelling



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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 significant issues based on inventory and assessment phases of the LCA.

2. Interpretation should conduct these checks:

- Completeness check - are relevant data present?
- Sensitivity check - How sensitive are LCA results to an assumption?
- (To test: make a change to the assumption and recalculate LCA results.)
- Consistency check - Did the LCA abide by stated goals & 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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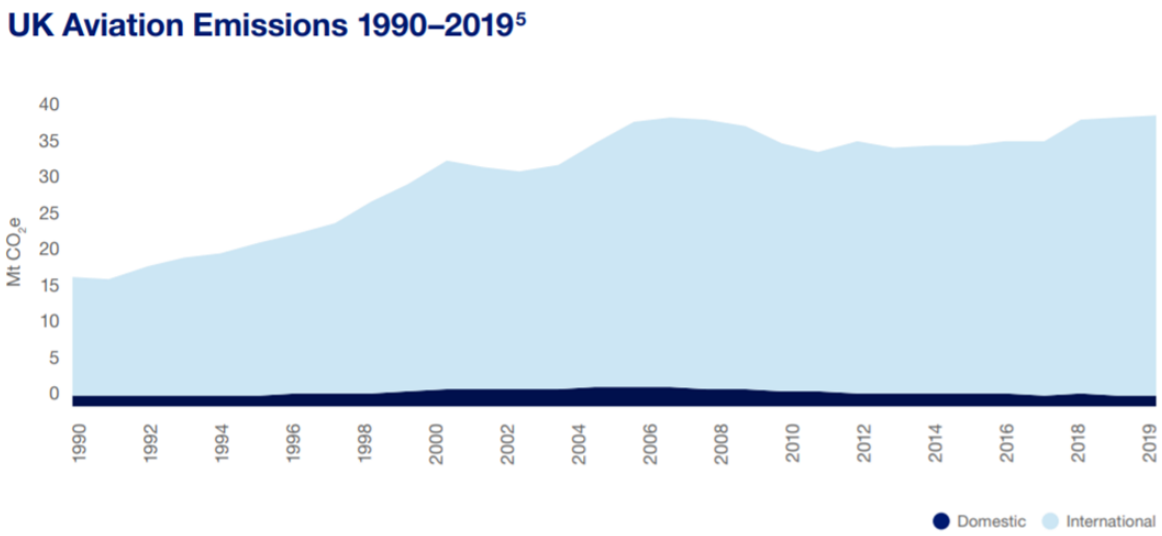
Sustainability in the aviation industry

- UK aviation committed to achieving net zero by 2050 & 78% reduction in emissions by 2035.
- UK Government has established **Jet Zero Council** to focus the sector on developing UK capabilities in net zero & zero emission technologies.
- Includes funding for sustainable aviation fuels & 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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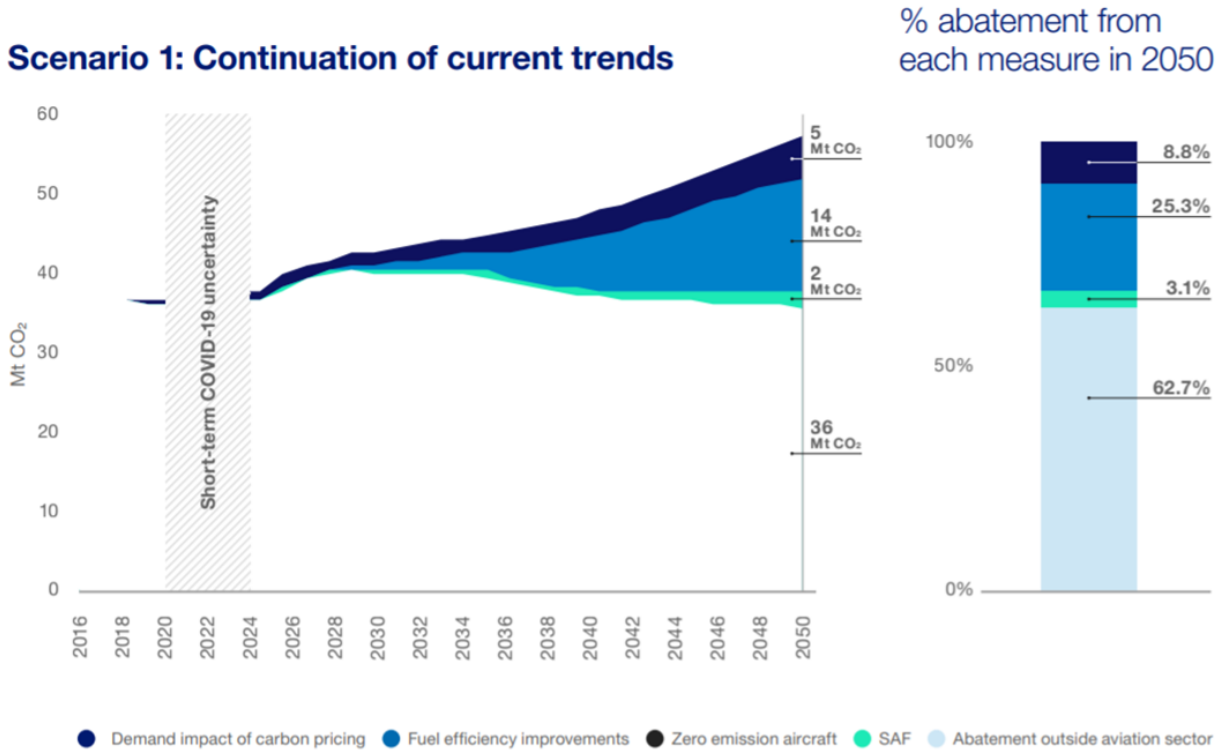
Sustainability in the aviation industry



- Range of scenarios suggested within Jet Zero Strategy consultation published 2021.
- 4 Scenarios suggested from 1 (continuation of current trends) to 4 (high ambition with breakthrough on zero emission aircraft).
- **Scenario 1:**
- Continuation of current trends.
- 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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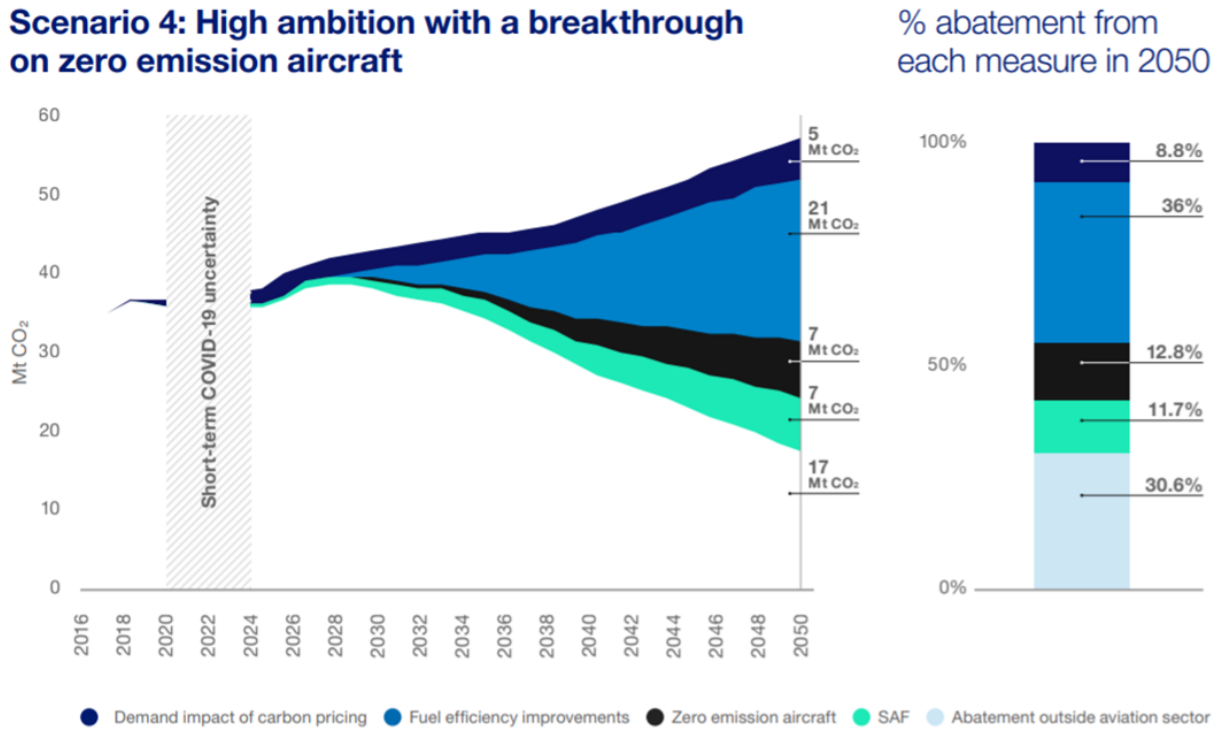
Sustainability in the aviation industry



- **Scenario 4:**
- Assumes higher ambition with breakthrough on zero emission aircraft.
- Greater contribution from:
  fuel efficiency improvements,
  zero emission aircraft,
  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 *e.g.* greener technologies, improving operations & phasing out old aircraft.
  - Knock on benefits to UK economy & reducing impacts from noise pollution.
  - Improve efficiency of conventional aircraft - changes to engines, wings, structures & other systems.
  - Reduce impact at airports - use of connected autonomous vehicles & taxiing with single engine.
  - Reduction in aircraft weight - material choice or efficiencies gained from matching fuel & water requirements with passenger load.

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Sustainability in the aviation industry

- **Sustainable aviation fuel**
  - Sustainable aviation fuel (SAF) seen as key element to meeting net zero targets.
  - Fuels are ‘drop-in’ option – can be blended into fossil-based aviation fuel in existing aircraft.
  - SAF can be produced from:
    - Biomass or biogenic waste, *e.g.* cooking oil
    - Non-biogenic waste *e.g.* unrecyclable plastics or waste fossil gases from industry
    - CO_2 and green hydrogen.

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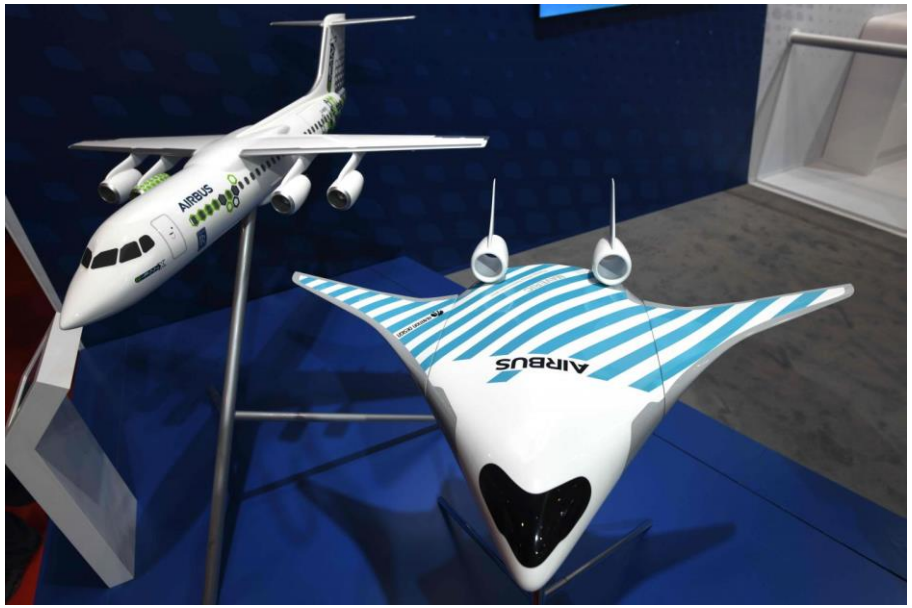
Sustainability in the aviation industry

- **Zero emission flight**
  - Comes from deployment of hydrogen-electric & battery-electric aircraft.
  - Small-scale electric aircraft have already been demonstrated and could form part of domestic fleet in 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 materials production of materials used through to solving challenges at end-of-life.
- It also requires more **resource efficient** & **circular approach** to how the industry operates.
- It requires range of interventions – from materials to technology to influencing consumer behaviour.

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Design Exercise

- **From design perspective how can you improve the sustainability of the aviation sector?**
- Considering the following:
  - Life cycle implications of any improvement (you could use a MET Matrix to do this).
  - Role that circular economy plays.
  - Roles of social impact & consumer behaviour.
  - Use of LCA data 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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