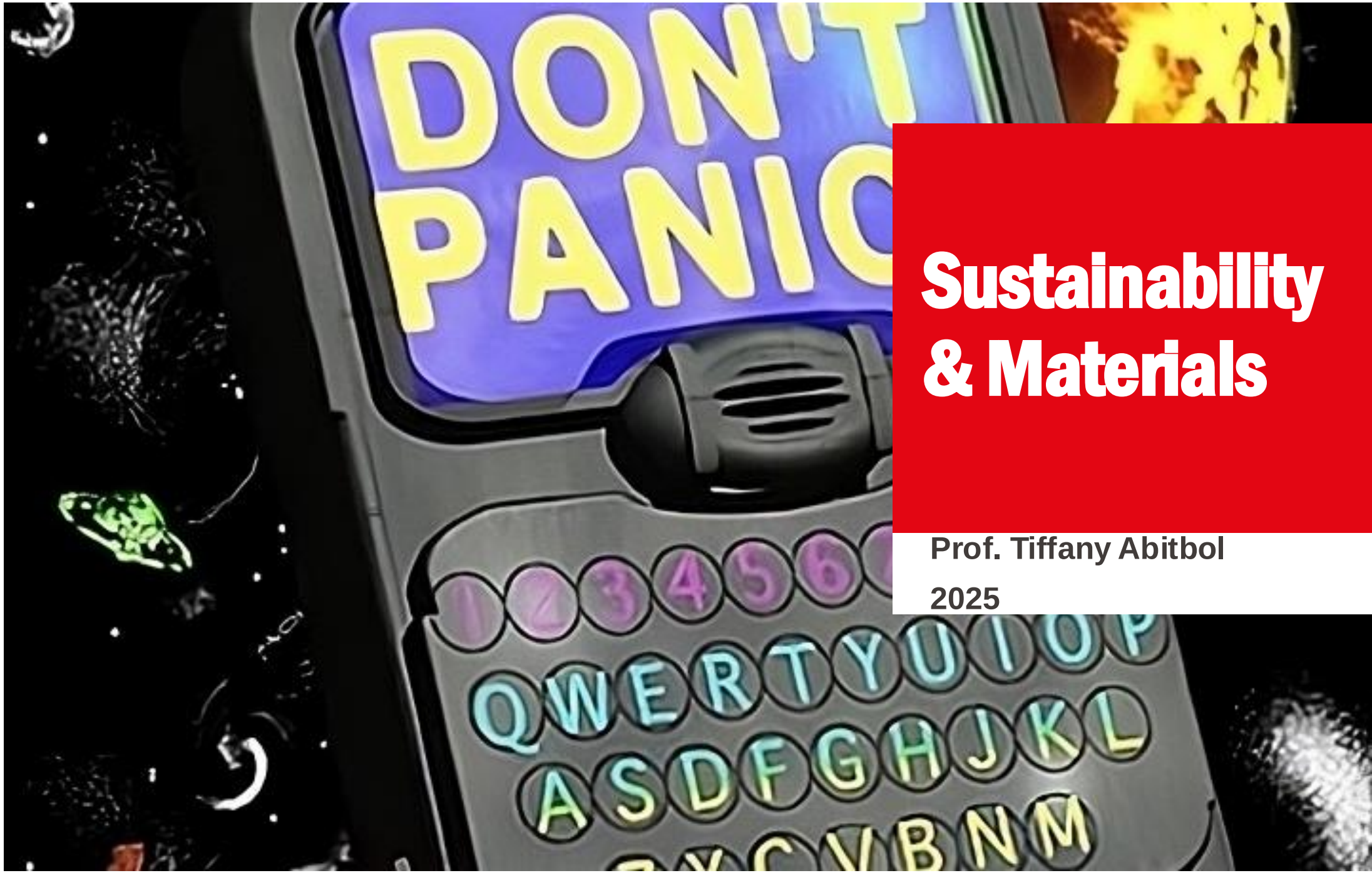


Sustainability & Materials

Prof. Tiffany Abitbol

2025

Group project - logistics

- Details on the Mar 6 Moodle
- Presentations will take place in the last 2 weeks of class
- Groups and schedules are already assigned – also posted on Moodle
- If you have a scheduling issue - switch slots with another group and please let us know
- Each group will get 30 minutes: 18 minutes for their presentation, 7 minutes for questions, & 5 minutes to fill in a peer-evaluation form
- Each group will need to present and to evaluate the presentation of 2 other groups (as indicated)
- We will provide you with a peer-evaluation rubric that must be handed in
- The presentation can be a classic slide show (timed) OR a video – your choice!
- The video/slides need to be handed in on the day of your presentation (on Mar 6 Moodle)

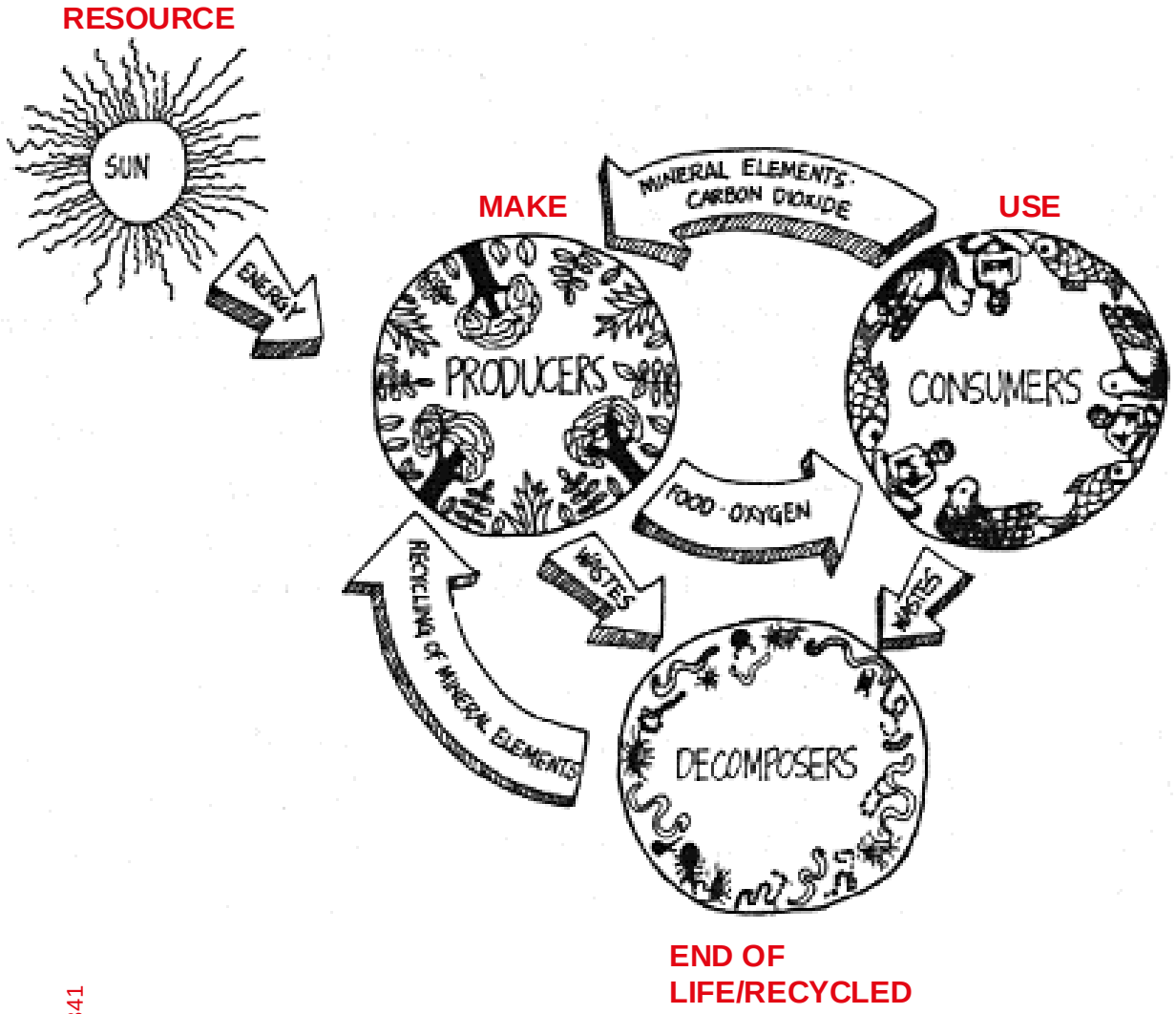
Group project - content

- Meet with your group (exercise time): brainstorm on topics at the intersection of “sustainability & materials” that you are passionate about; make a list

- Are there technologies that exist to address your topics? If so, pick one – this will be where you deep dive.

- Tell us why this technology is needed, why is it potentially disruptive, what it is, what’s its current TRL? Are there any bottlenecks to its implementation? What are the perceived ”hot spots” – does this tech address one problem only to create another elsewhere? Is it from a lab, a start-up, a more established company? Be critical, but also, we are looking for solutions! (more details on Moodle)

"The economics of nature"



- **Producers**/autotrophs – e.g., organisms capable of photosynthesis

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

- **Consumers**/heterotrophs – organisms that feed living organisms via aerobic respiration (nutrition is ingested and then digested)

- **Decomposers**/heterotrophs – feed mostly on dead organisms and plants (aerobic or aneorobic; nutrition is digested and then injested)

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Image from: The macroscope: A new world scientific system Hardcover – January 1, 1979
Link to book: The Macroscope

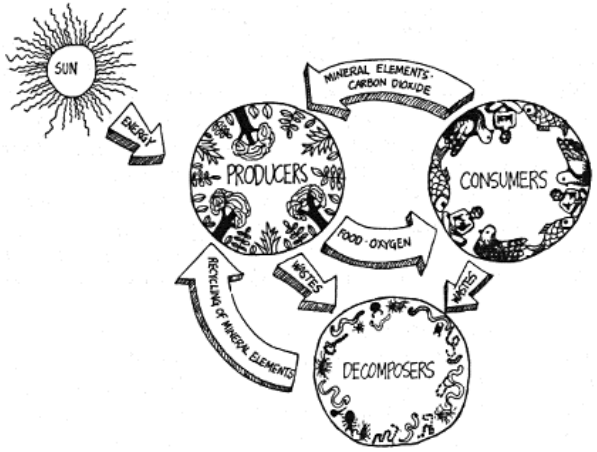
Nature is circular

"The environment is perceived as 'natural capital', a resource that we own, control and manipulate, something that is here for us, and us alone, not only to use up and pollute, but also to destroy. This is at the expense of other species that we co-exist with on this planet."

"The planet we live on is a circularly closed system. It has a boundary, the atmosphere. Matter circulates via atmospheric winds and oceanic currents and is continuously being recycled…What goes around comes around. Matter does not escape off the planet."

"Our present view of life is inadequate for humanity to live sustainably. At the core of this view lies our inherent problem. We perceive ourselves to be separate and independent from life. We do not see our inherent ***interconnectedness*** and ***interdependency*** with life.

We are part of an ongoing circular flow of life, not separate and removed from it. The awareness of circularity is essential for understanding life. ***Without circularity and other essential life cycles, we do not exist***."

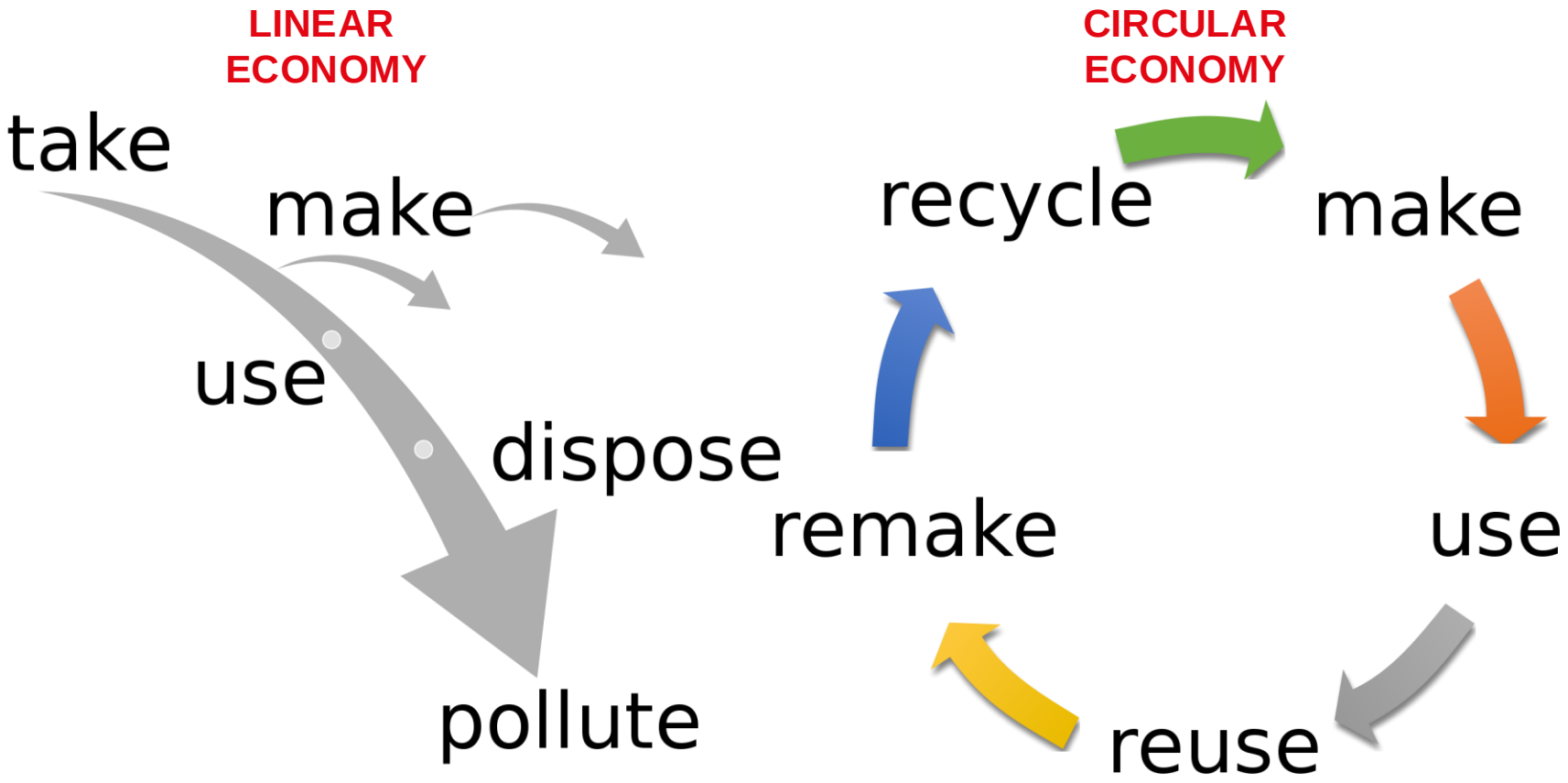


"This shift in worldview is not just environmentalism. It is not just about looking after the environment because we have to. It is literally an understanding of our co-existence on this planet, how ***we are systemically interconnected and mutually interdependent systems with the web of life***."

From: 'The Circularity of Life: An Essential Shift for Sustainability' by Jane Cull, 2016.
circularity-life

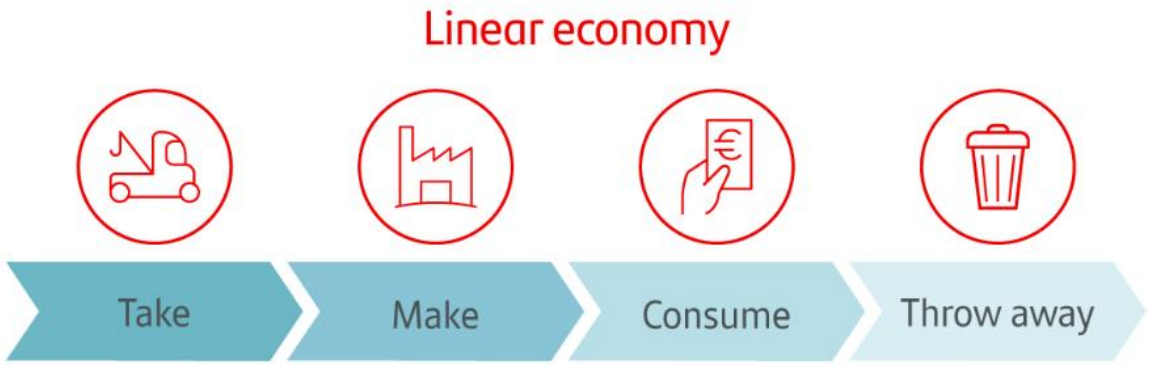
Linear vs. circular economies

Circular economy ideal



- *Implies recovery of materials at end of first life to use a resource*
- *Waste no longer exists*
- *Products recycled indefinitely*
- *No input of non-renewable resources*

Linear economy

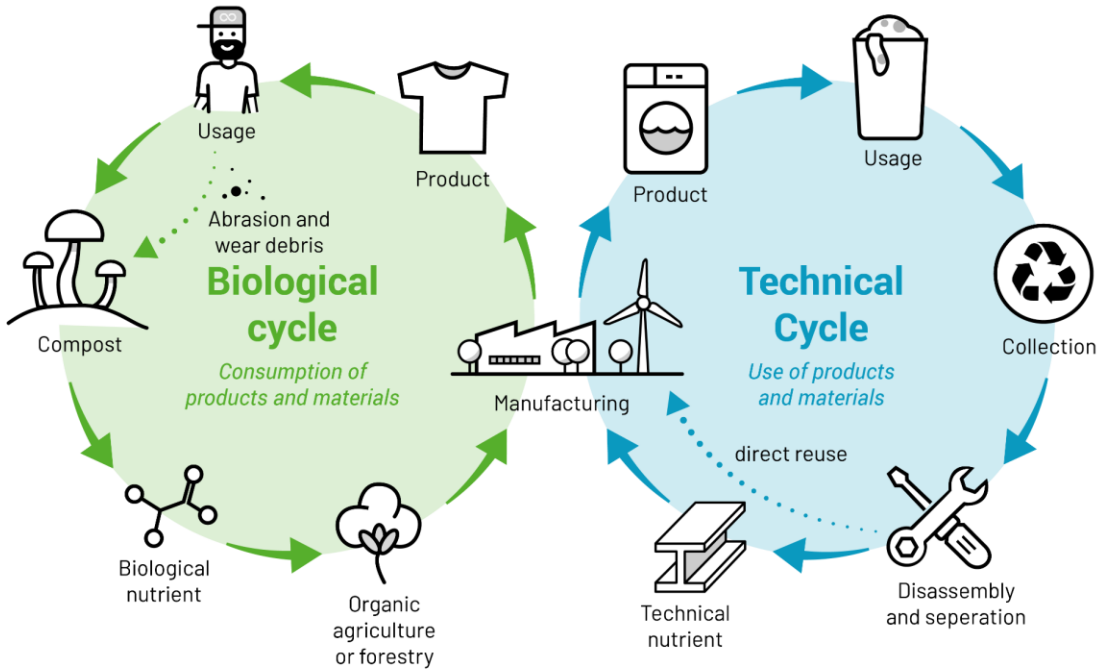


- *Traditional model*
- *“take, make, waste”*
- *Profit driven*
- *Products discarded at end of life*
- *Landfilling, incineration, pollution*
- *Unsustainable*
- *One direction – raw materials to waste*

Ellen Macarthur Foundation_Linear Economy
Linear and circular economies

CRADLE TO CRADLE

A concept by Michael Braungart and William McDonough



Cradle to Cradle concept by M. Braungart and W. McDonough

cradle

/ˈkreɪdl/

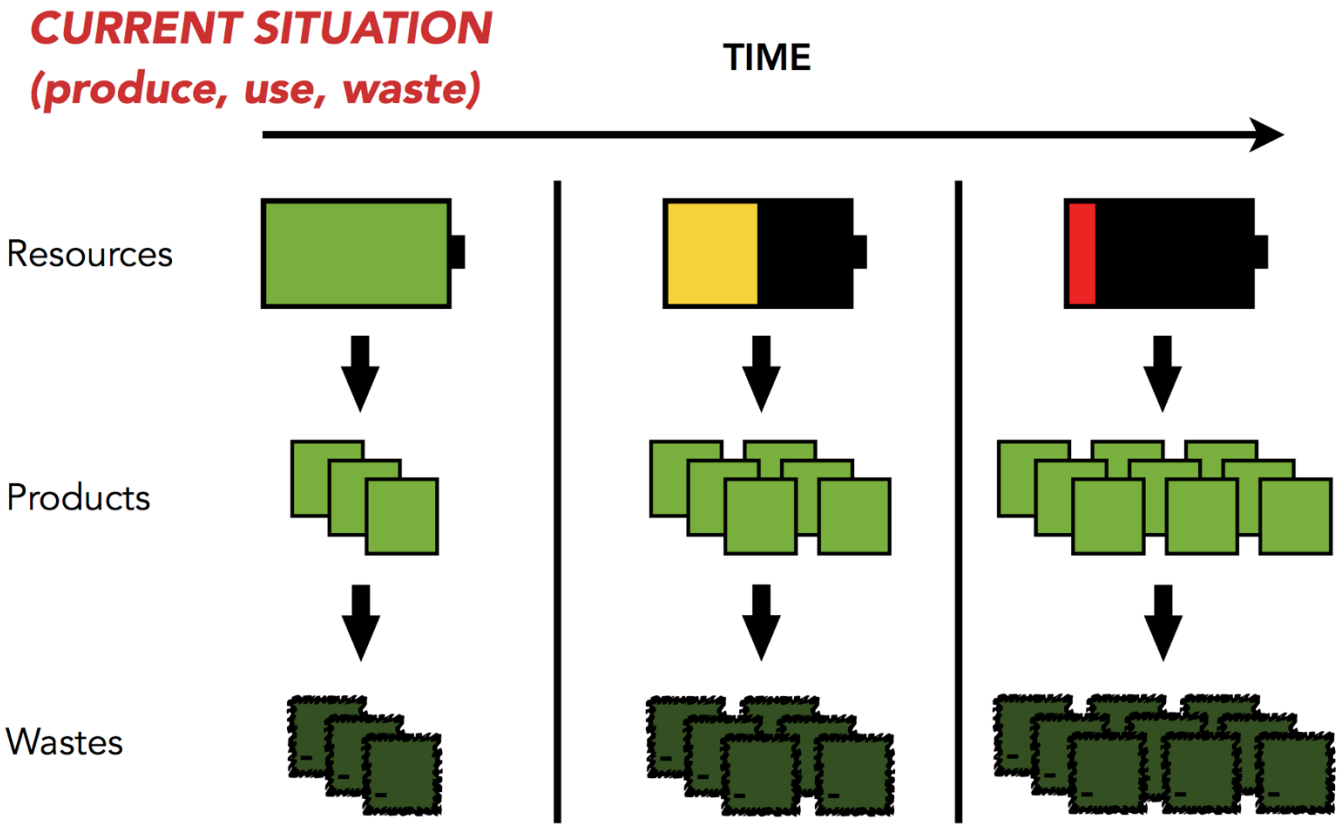
noun

1. a baby's bed or cot, typically one mounted on rockers.
   "the baby slept peacefully in its cradle"

- Cradle to Cradle approach (2010); also called “regenerative design”
- Biomimetic approach
- Materials viewed as nutrients circulating in a healthy metabolism
- Heavily influenced the development of the Circular Economy concept, especially visible in the Butterfly Diagram (see later slides)

Cradle2Cradle

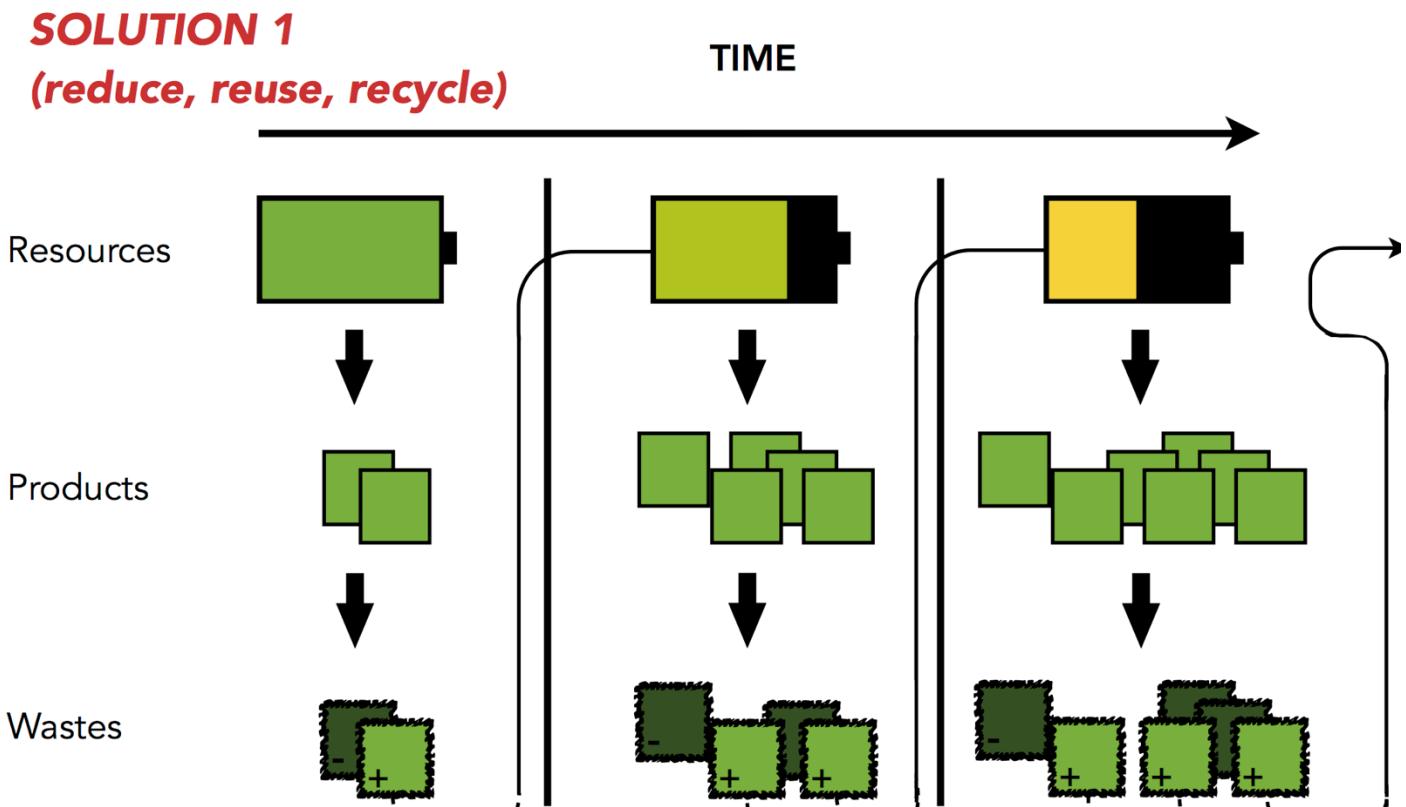
Clearly not a working model:



- The Earth's resources are being depleted.
- Population is increasing, which drives up production of goods.
- Increased production leads to increased waste.

[Cradle to Cradle Design aka Regenerative Design]

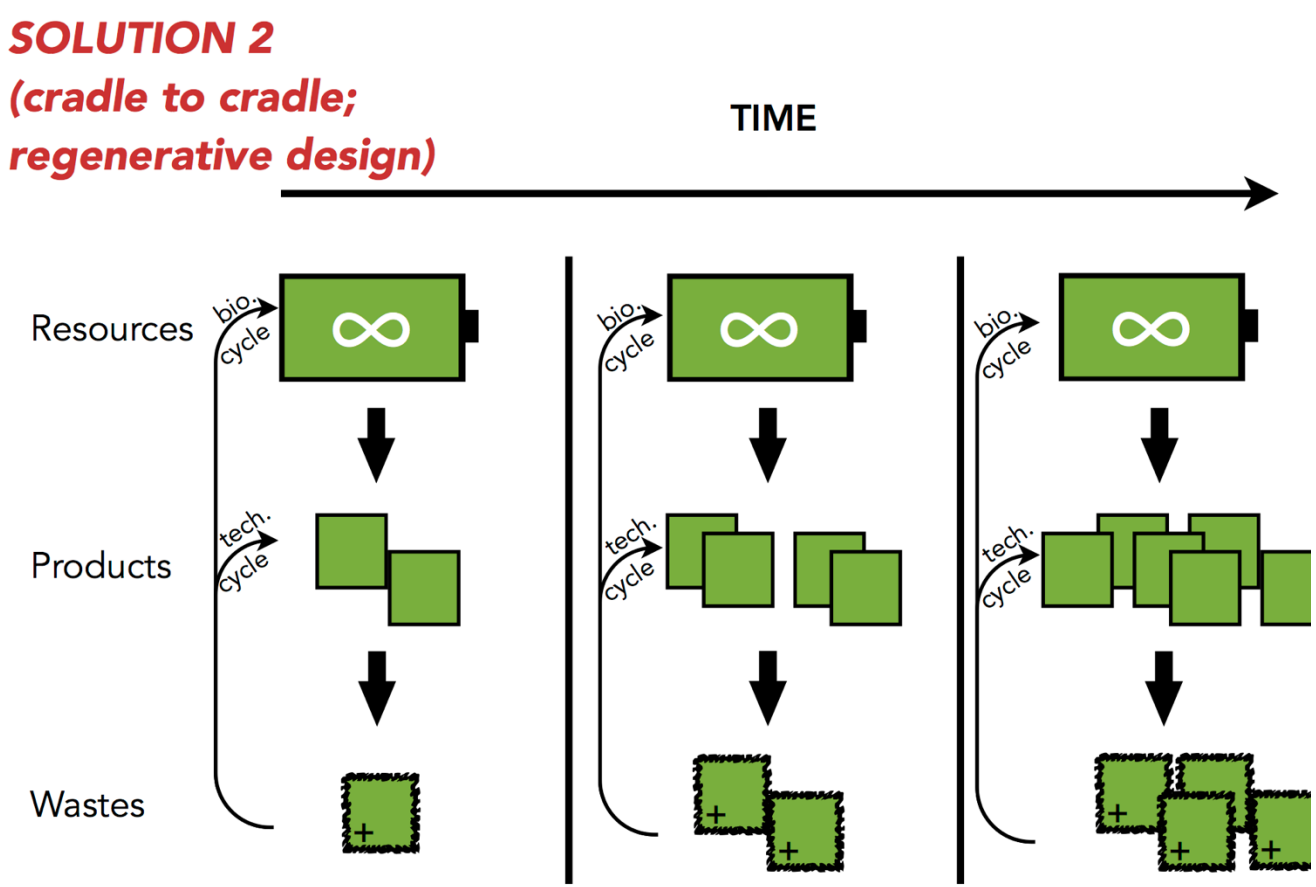
The problem with the 3R's:



Cradle to Cradle Design aka Regenerative Design

- Resources deplete, just more slowly (reduce production)
- Waste recycled for new products, but waste still grows
- It's just a matter of time before resources are totally depleted.

Cradle to cradle:



- Completely healthy for the Earth and its inhabitants
- All power comes from renewable sources only
  - Solar energy, wind power, water current
- Production only uses harmless technical or biological nutrients
  - T: Inorganic or synthetic materials that can be fully reclaimed
  - B: Organic matter that, when broken down, harms nothing
- Waste re-enters the system as a technical or biological resource
- Sample biological cycle
  - A tree is planted. It grows and is harvested, carved into a shovel handle, and a sapling is planted to replace it.
- Sample technical cycle
  - Old vehicles are dismantled. The metals are safely refined. The resulting metal is used to replace the outmoded cars.
- Cycles often combine for efficiency and better products

Cradle to Cradle Design aka Regenerative Design

How is the circular economy defined?

The circular economy is a system where materials never become waste and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling, and composting. The circular economy tackles climate change and other global challenges, like biodiversity loss, waste, and pollution, by decoupling economic activity from the consumption of finite resources.

Direct quote from Ellen MacArthur Foundation

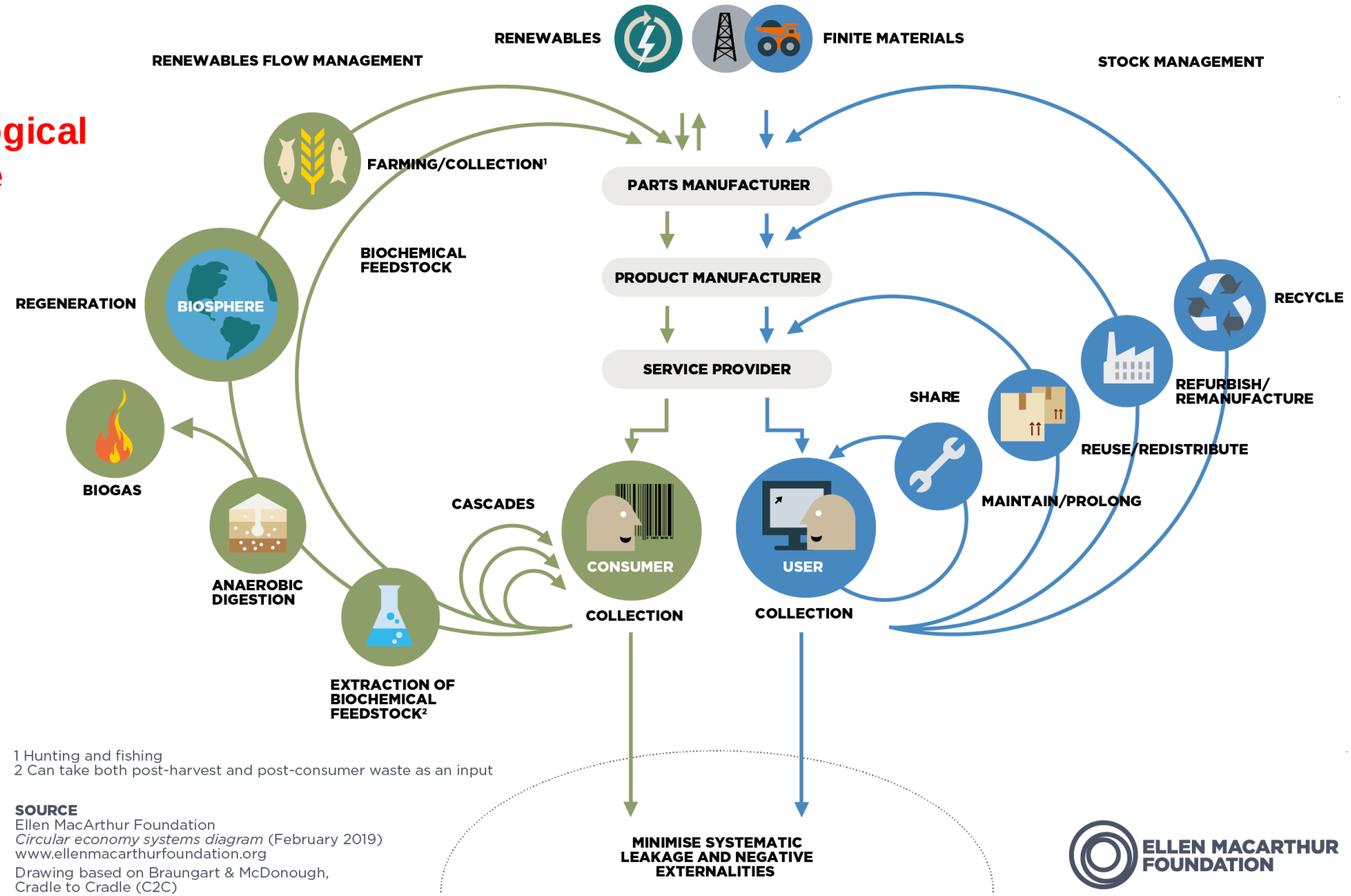
The circular economy is based on three principles, driven by design:

- **Eliminate waste and pollution**
- **Circulate products and materials (at their highest value)**
- **Regenerate nature**

Underpinned by a transition to renewable energy and materials, the circular economy is a resilient system that is good for business, people, and the environment.

How possible is zero waste?

Circular economy – Butterfly diagram

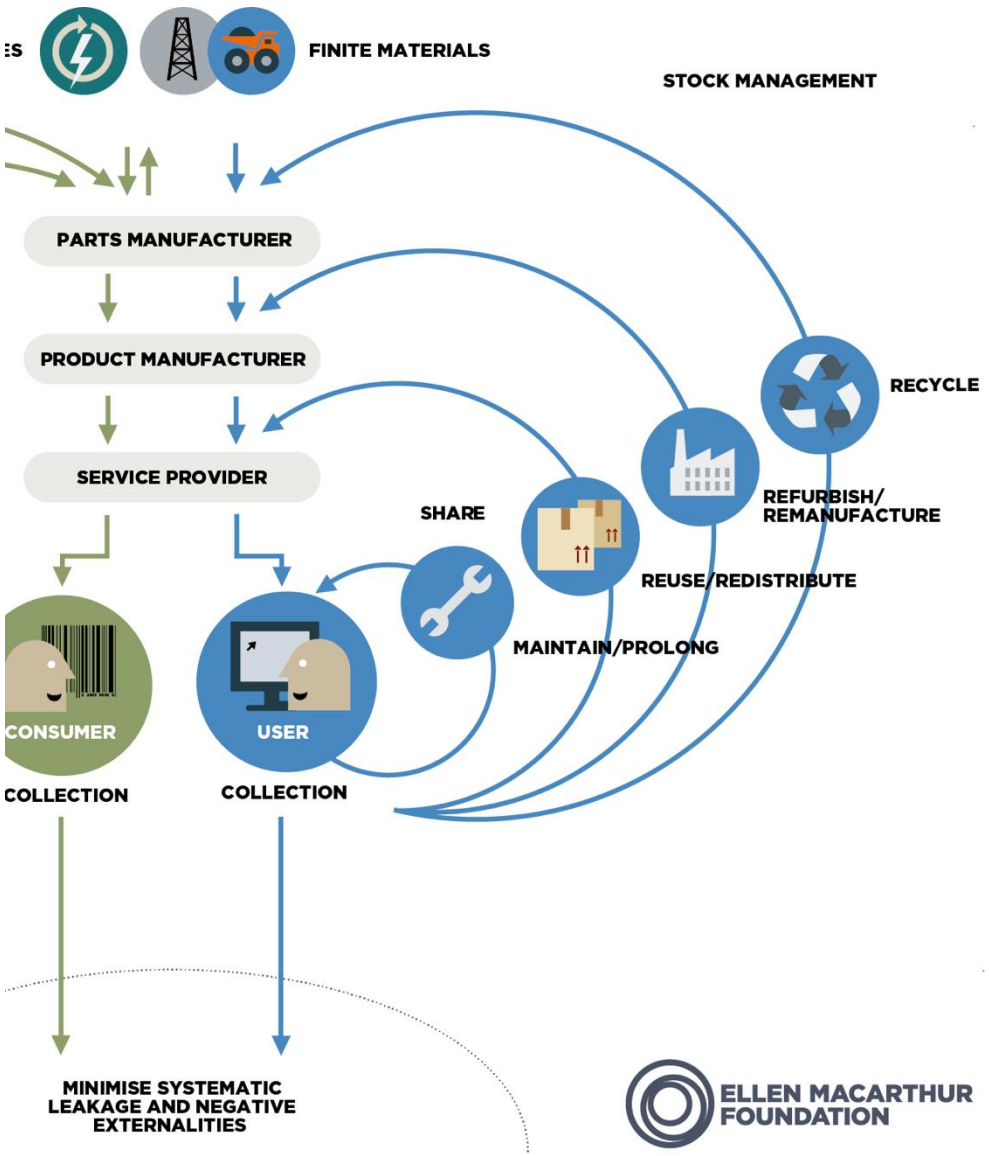


1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input

SOURCE
Ellen MacArthur Foundation
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough, Cradle to Cradle (C2C)

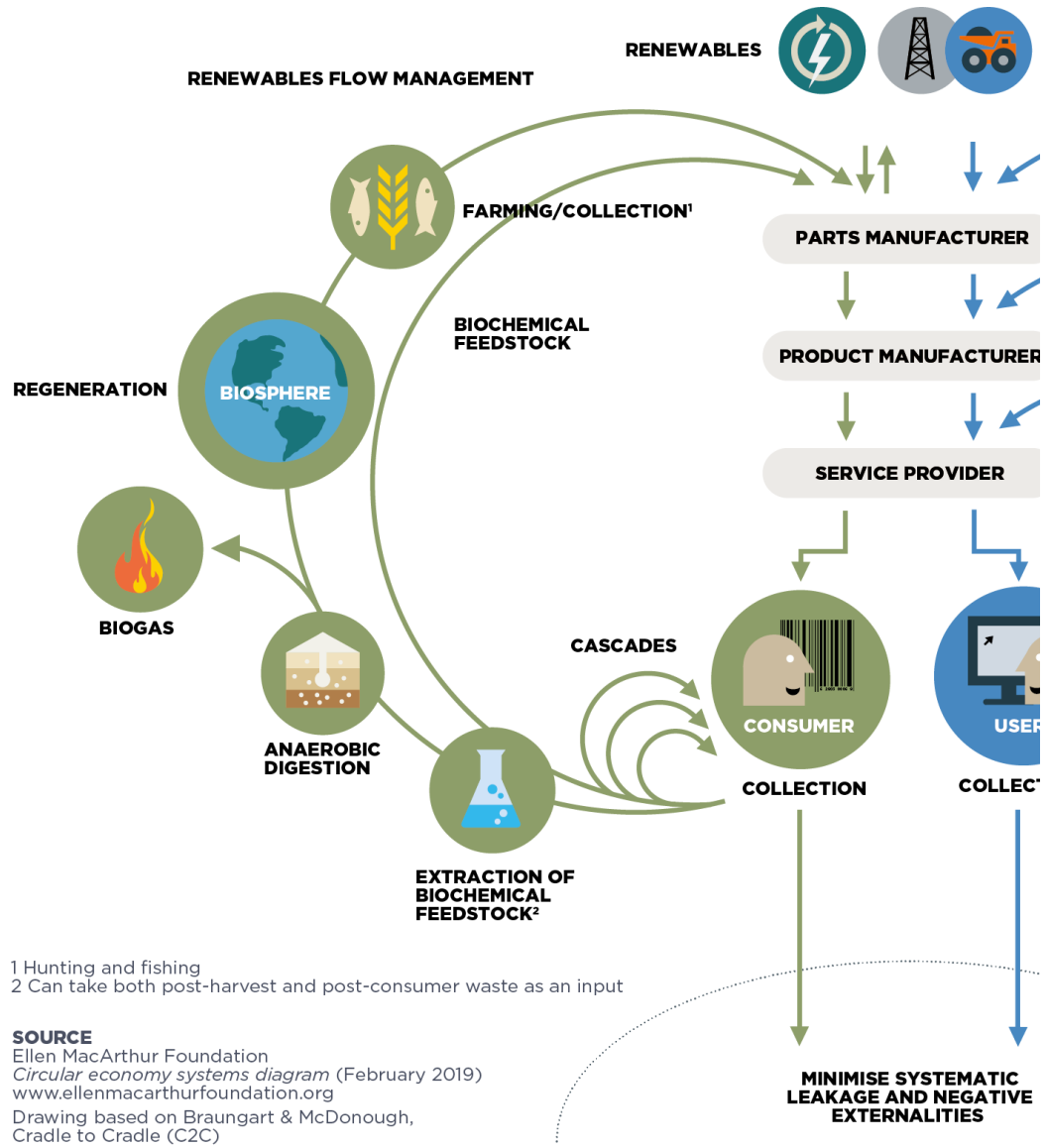
ELLEN MACARTHUR FOUNDATION

Circular economy – right wing



- Technical cycle
- How to keep non-renewable inputs circulating in the technical cycle
- Focuses on extending life of products and components and recovering and regenerating products and materials at end of life
- Strategies: share, maintain, reuse, refurbish, recycle (last option)

Circular economy – left wing



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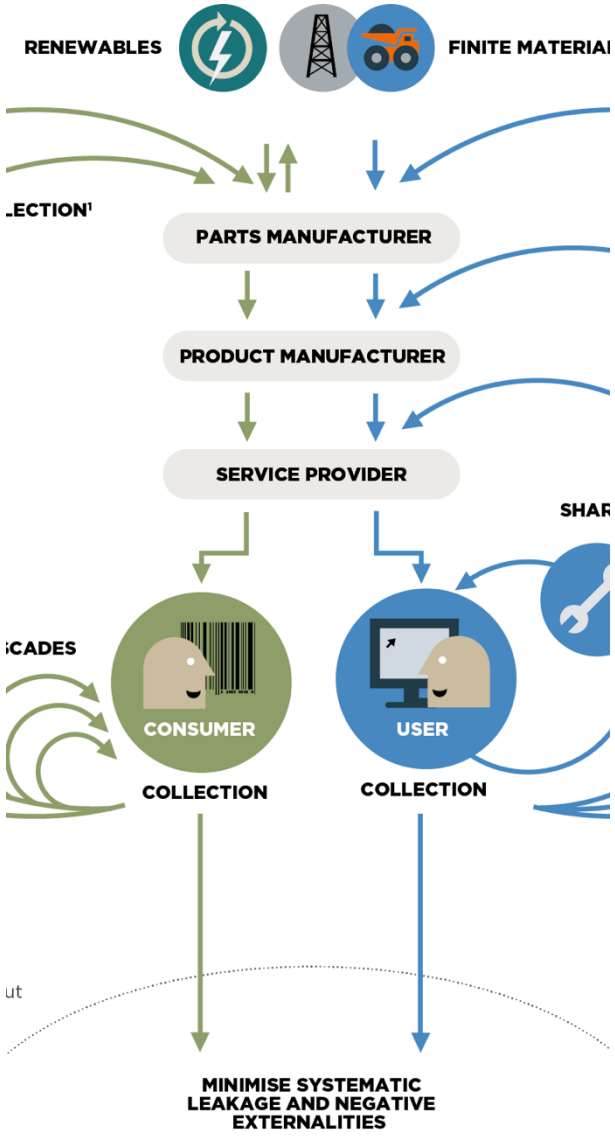
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough, Cradle to Cradle (C2C)

- Biological cycle
- How to integrate organic materials (food, wood, natural fibers…) back into nature
- Farming & collection: natural resources are grown and harvested for food, textiles, and biodegradable products
- Processing & consumption: biological materials are used by industries and consumed by humans and animals
- Cascades (reuse): before decomposition, these biological materials can be repurposed
- Eventually, digestion back to nature (biogas or regeneration); biogas exits the circle but produces CO_2 that can be up taken by new plants, etc.,

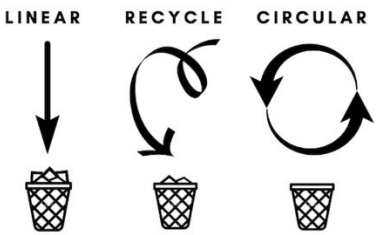
Circular economy – center



- User/consumer at the center
- Underlines the important to design products with user in mind
- Products must be durable and maintainable while also fulfilling the needs of users – here is where the **product designer** comes in!
- **Consumer/industry/government** also have a role with end of life… who is responsible for the collection needed to recirculate materials?
- Can industry balance the needs of the consumers and the environment, while still making money?
- *How does this all work? How is it "policed" and policied? (out of our scope but interesting to consider)*

Principles of “good design” from Dieter Rams in the.1970s:

Linear<Recycle<<Circular



1. Good design is innovative
2. Good design makes a product useful
3. Good design is aesthetic
4. Good design makes a product understandable
5. Good design is unobtrusive
6. Good design is honest
7. Good design is long-lasting
8. Good design is thorough down to the last detail
9. Good design is environmentally-friendly
10. Good design is as little design as possible

Can you identify good vs. bad design?

- a-circular-mindset-in-a-linear-economy
- design-and-the-circular-economy

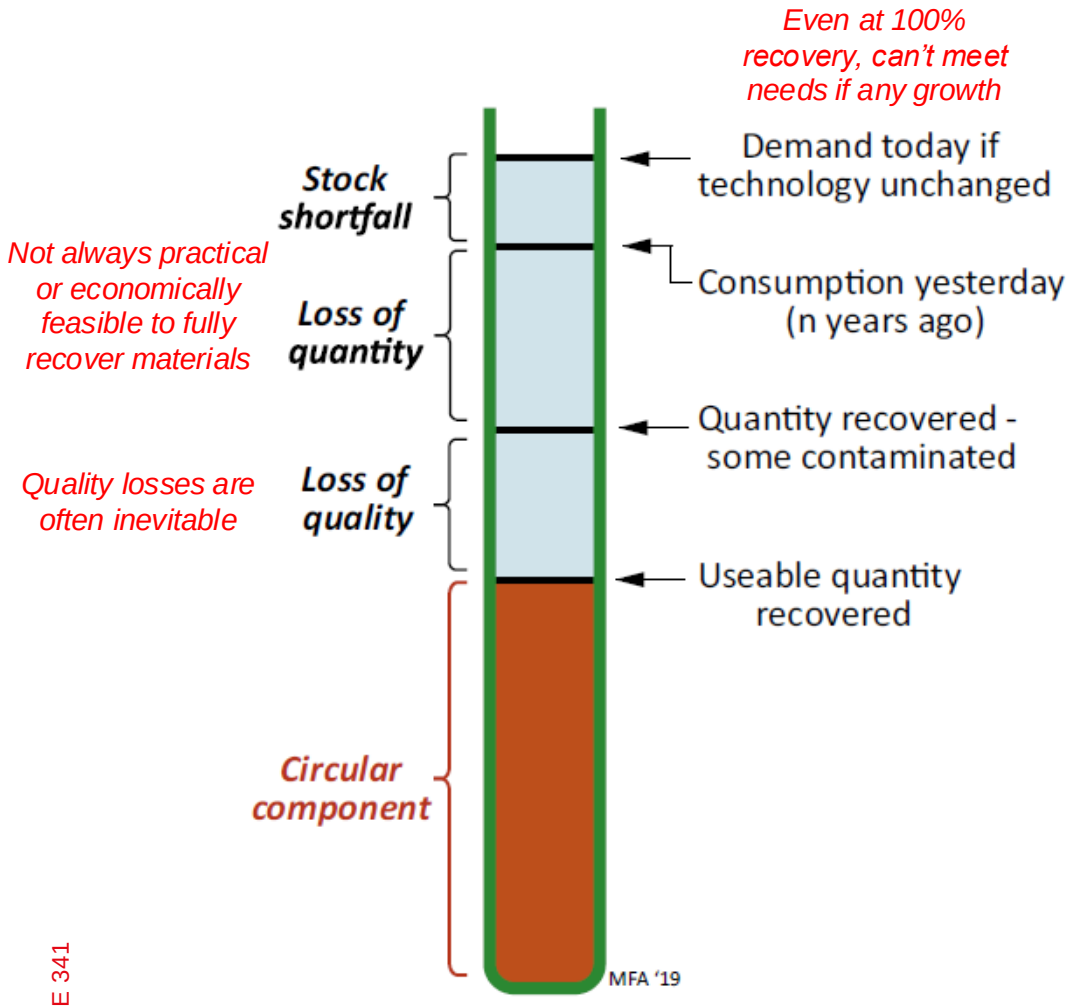
https://repair.eu/

Consumer rights

We are people, we are repairers, we are sustainability activists, we are community.

How circular can we get? Moving into reality

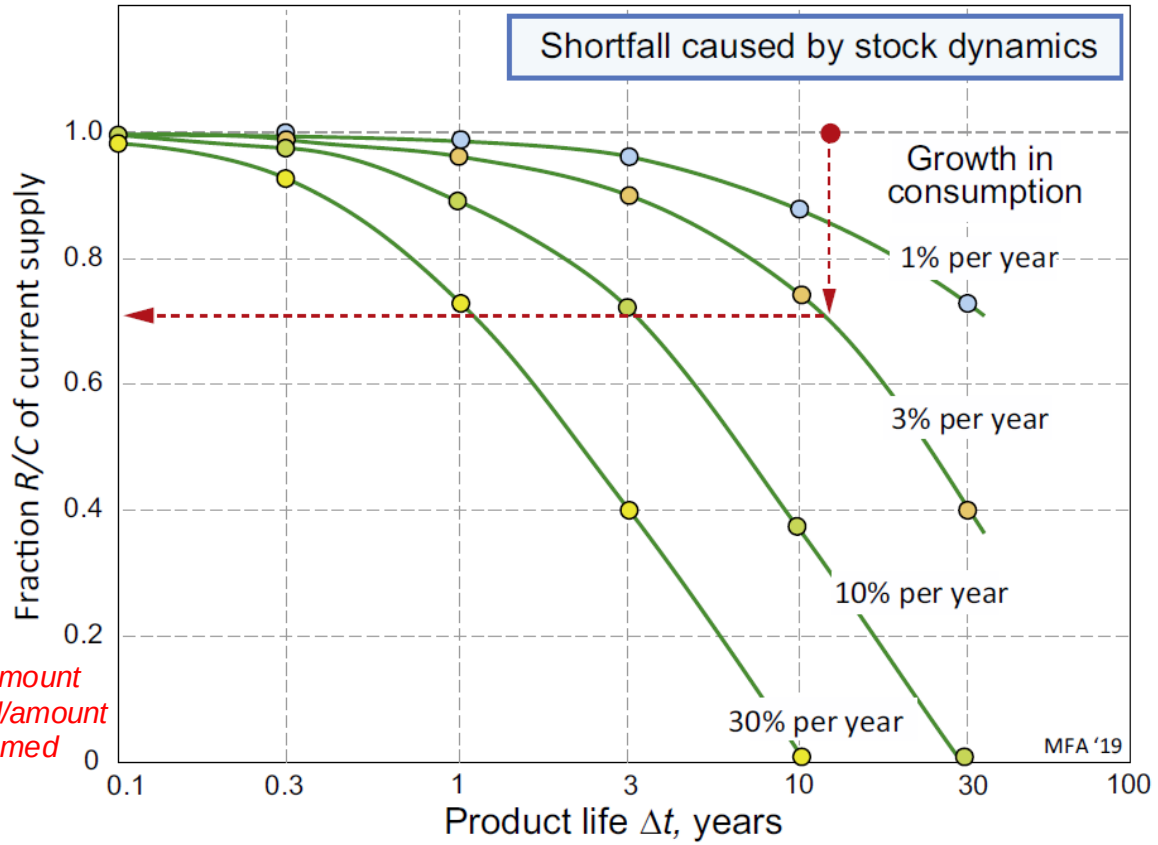
Within a given product:



From: Materials and the Environment, Michael F. Ashby, Copyright 2021 Elsevier, Chapter 13.

- Current demand may be greater than past consumption – so even if we could recover all past product (you can't), there is still "stock shortfall" that needs to be met with new resources
- Loss of quantity addresses that it's not feasible to recover everything – maybe the product is still in use! We need new resources again to address this shortfall.
- Loss of quality addresses that even if you recover a products some of it will have a very poor quality such that it can't be reused in the same product – another shortfall requiring fresh materials
- Finally, we have a circular component, which represents the part that is recovered and can be used to make the same product again – How does this fraction change for given product?

How circular can we get?



R/C – amount recovered/amount consumed

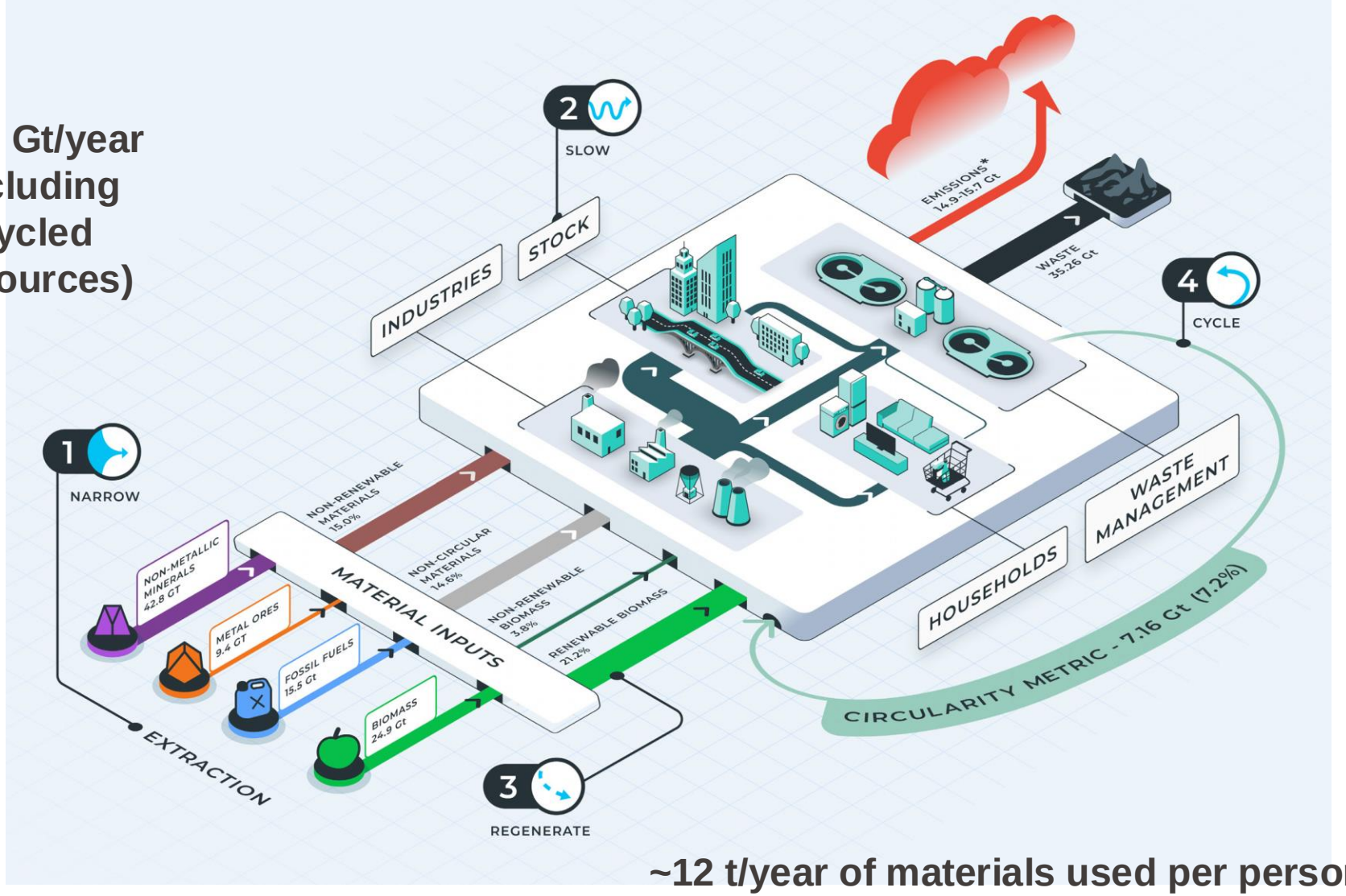
Longer product lifetimes, take materials out of circulation! → *Even at low 1% growth and 100% recovery, we can't be fully circular due to materials tied up in products , so virgin inputs are needed to meet demands*

- R/C is amount of product recovered divided by the amount consumed
- Graph starts at R/C = 1, assuming full recovery (fully circular)
- Graph looks what happens in this scenario when there is a growth in consumption
- In all cases, even low 1% growth, we see a shortfall (R/C < 1) that needs to be met with fresh material inputs
- The magnitude of the shortfall is determined by the *lifetime of the material that takes materials out of circulation* and *growth in consumption that demands more material inputs*

From: Materials and the Environment, Michael F. Ashby, Copyright 2021 Elsevier, Chapter 13.

How circular are we?

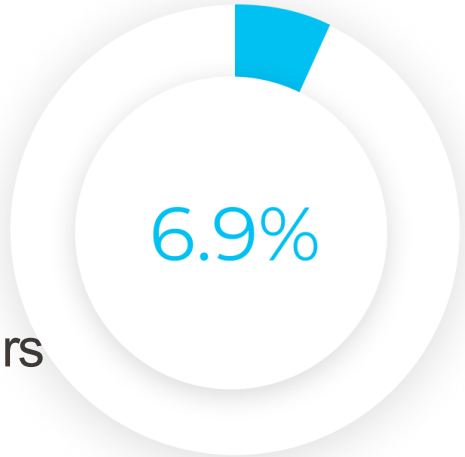
100 Gt/year (including recycled resources)



~12 t/year of materials used per person

- "Over the past six years alone, the global economy has extracted and used almost as many materials as over the course of the entire 20th century, finds the Circularity Gap Report 2023"
- Global economy is only 7.2% circular; >90% of materials are wasted, lost, or unavailable (tied up in long lasting products)

How circular is Switzerland?



- The good: decarbonized electricity, one of the world's best recyclers of municipal solid waste, ambitious climate targets
- The less good: very high consumption: **19 tonnes** of virgin materials per person per year - higher than European average of **17.8** and global average of **11. 9**
- Only 6.9% of resources are cycled back into the economy with >90% of the materials used coming from virgin resources
- Relies heavily on imports; with high consumption tied to overextraction in other parts of the world… that's just business, right?

https://www.circularity-gap.world/switzerland

Possible end of life scenarios

https://www.epa.gov/sm

How is recycling viewed from a circular economy perspective?

- Recycling begins at the end, the ‘get rid’ stage of the product’s life, whereas circular economy starts at the beginning of the life, asking how we can design to prevent waste and pollution in the first place? (We don’t always have recycling infrastructure in place…)

- So circular economy strategies address potential issues at the source

- Although recycling is important, it should be considered as part of a bigger picture, since most of the environmental impacts of products are attributed to the decisions made at the design stage

- “*In a properly built circular economy, one should rather focus on avoiding the recycling stage at all costs. It may sound straightforward, but preventing waste from being created in the first place is the only realistic strategy*.”

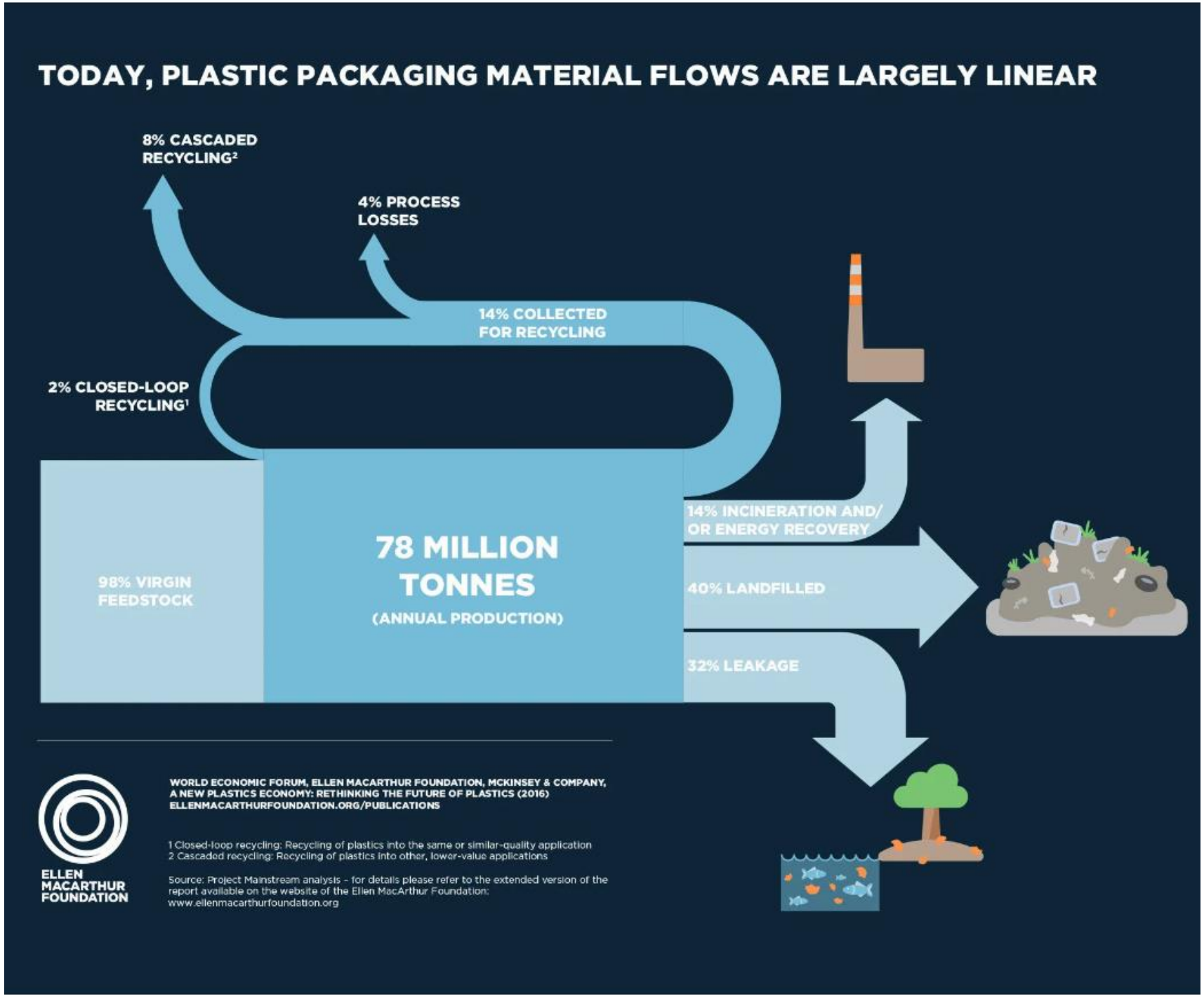
- World Economic Forum

Recycling and the Circular Economy

Looking at plastics recycling

- Currently mostly linear
- 2% in closed loop - used to make the same product, e.g., PET bottles

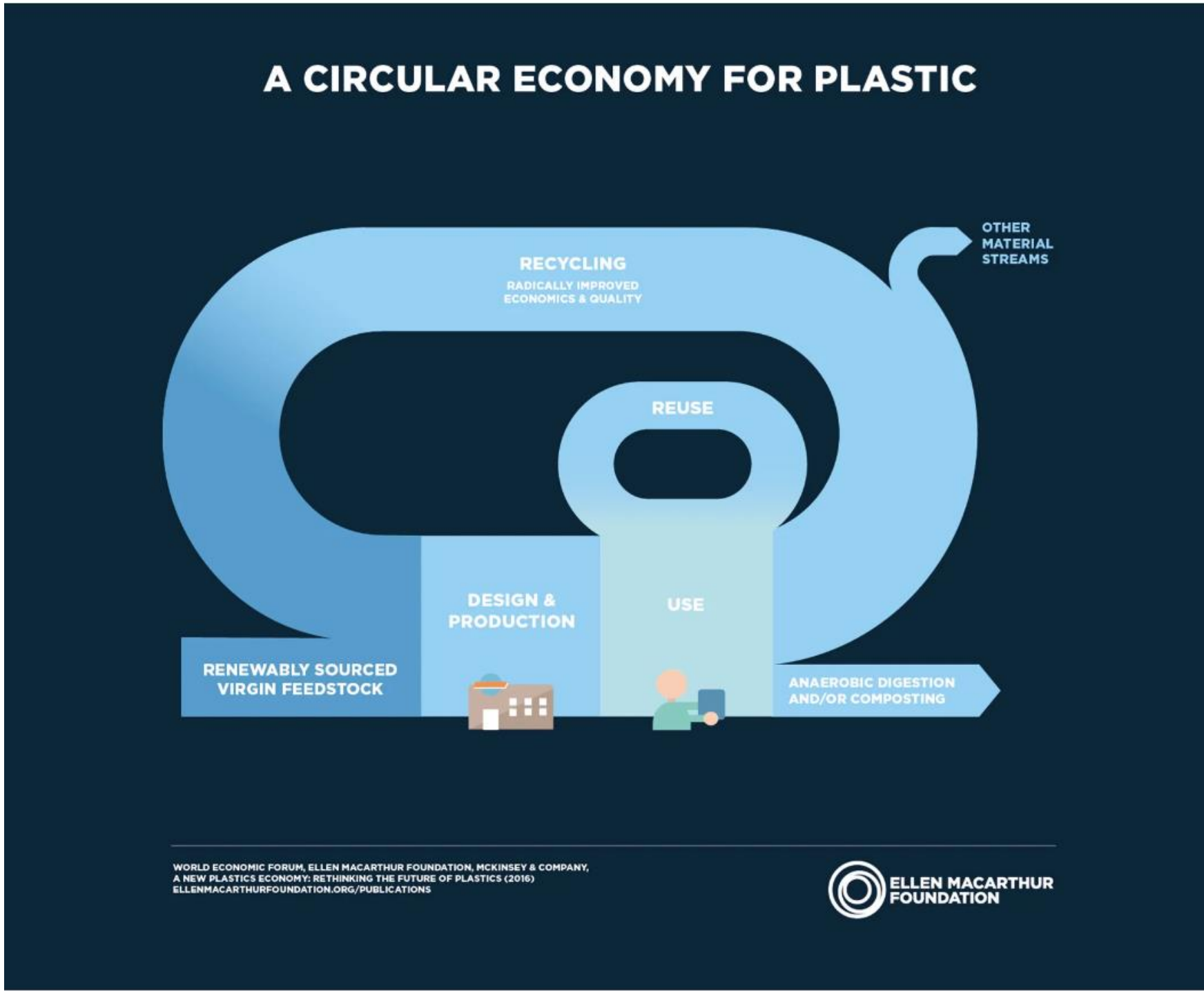
[Plastics and the circular economy]



What could be?

- Circular vision for plastics
- Circulate all plastics to keep them in economy and out of environment; landfill, incineration, waste-to-energy not considered long term solutions
- Renewable feedstocks
- Reuse, recycle, compost
- *Requires a major shift! Infrastructure, materials…*

Plastics and the circular economy



Recycling – the lingo

- Mechanical – physically break apart & reform (shred, melt, reform)
- Chemical – chemically break down into basic molecular units, like monomers (depolymerize)
- Closed-loop
- Open-loop
- Downcycling
- Upcycling
- Cascading: when the above technologies are applied sequentially to retain materials at the highest level of quality and economic and environmental value for as long as possible (see slide 27 on plastics)

Closed-loop

- The product is reprocessed into the same type of product, e.g., Al cans, glass bottles, PET bottles, paper
- Closed loop is mostly mechanical but can also be chemical, e.g., chemically break down a polyester fabric into monomers to create new fibers/textiles
- Benefits – new material is as good as old (no loss in material properties), no virgin inputs needed, less waste generated (materials kept in circulation)
- Glass and metal can be infinitely recycled in this way, whereas the same is not true of plastic and paper, whose properties deteriorate over time
- If you can add some virgin inputs to make the same product with the same properties, then it is still closed-loop but not perfectly circular

BOTTLE-TO-BOTTLE RECYCLING

On average, new glass bottles for food and beverages contain 33% recycled glass—and manufacturers can use as much as

100% RECYCLED GLASS

FACT

Glass bottles are **100% and endlessly recyclable** in a closed loop system

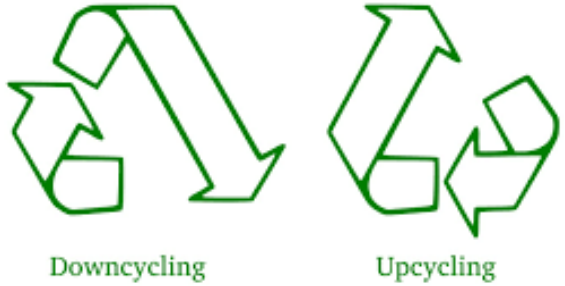
From recycling bin to store shelf in as little as

30 DAYS

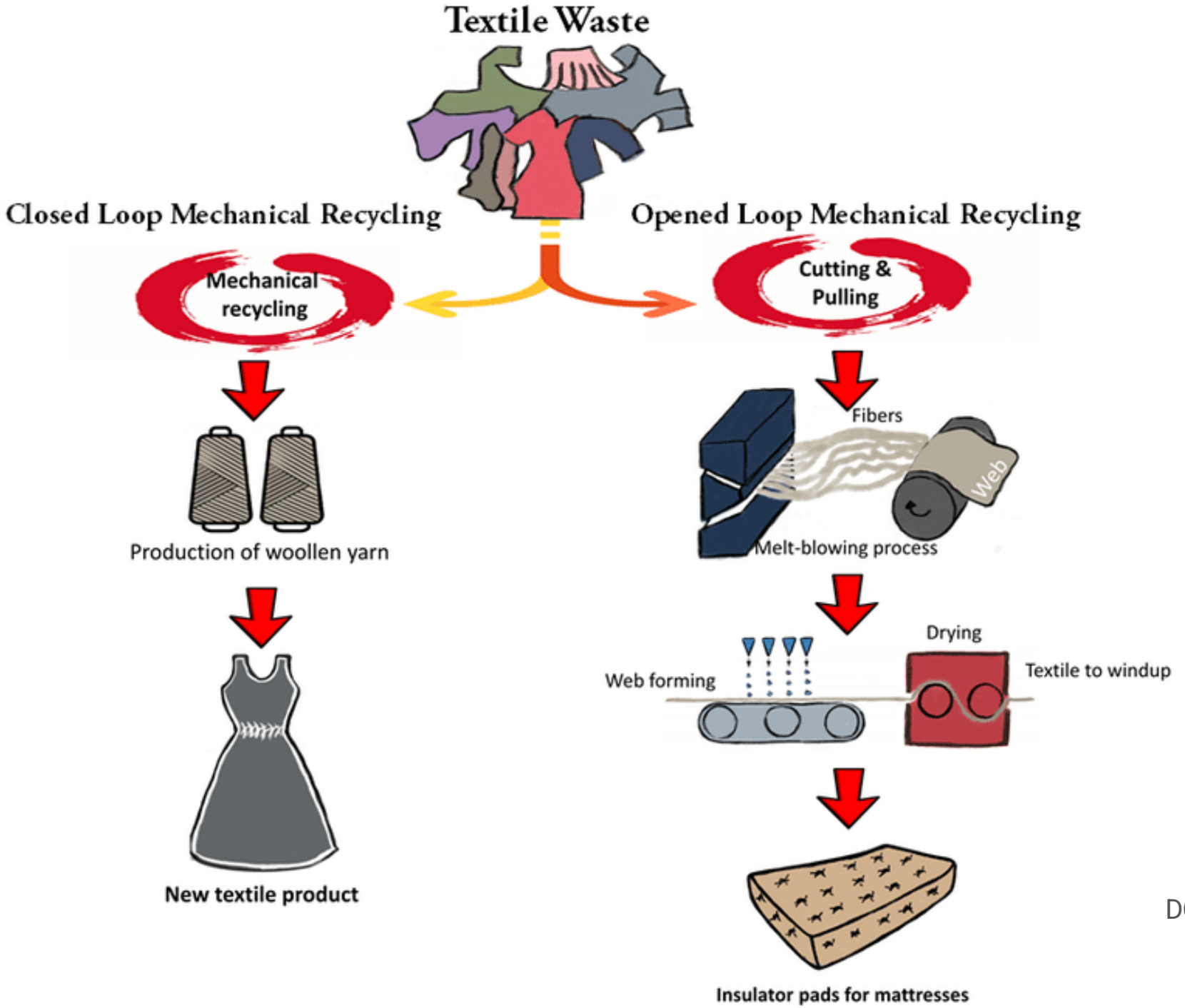
UPGRADETOGLASS.COM

glass packaging institute

Open-loop



- Usually mechanical, can also be chemical
- Here, the recycling approach addresses the loss of properties that happens to some materials with processing & recycling
- E.g., the properties of paper fibers and plastics will eventually deteriorate over time
- In open-loop, you literally open the loop and now use this somewhat degraded material to make a different product , e.g., turn a plastic bottle into clothing,
- Can be upcycled or downcycled, but most commonly downcycled
- Benefits – extend lifespan of the material/reduce waste (at least in the moment)
- Drawbacks: Waste still generated if new product is not recyclable, delays the problem since still rely on virgin inputs for initial product, e.g., if we still have a demand for bottles, turning them into clothing is not helpful



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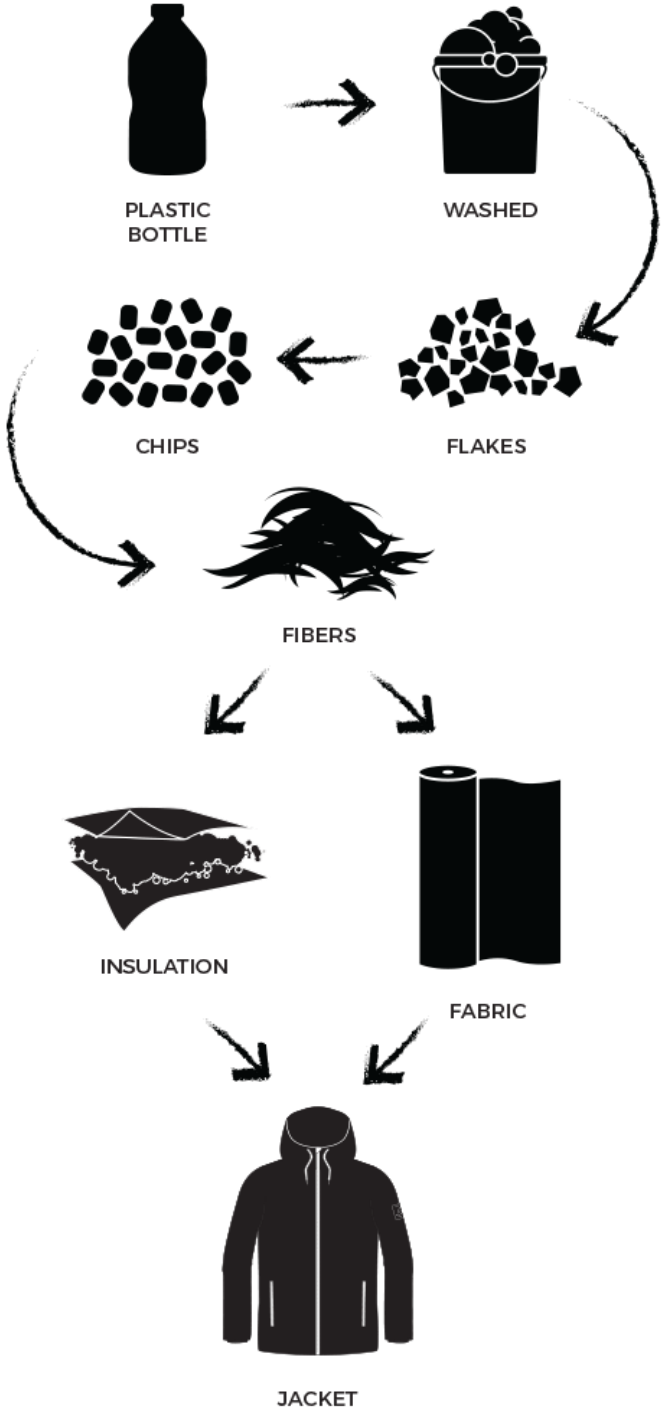


A more extreme example – bottle to clothing (downcycling)

It’s not like we don’t need bottles anymore

So now we have diverted or upcycled bottles into clothing – a product that may be more difficult to recycle than actual bottles…

Is this a good solution to a resource management problem? What do you think?

If poor quality bottles that are unsuitable for classic recycling are used, perhaps upcycling is OK? We still have a stock shortfall, but we move toward circularity…

Upcycling vs. downcycling

Examples of downcycling (loses value)

- Bottle to clothes grade
- Office paper to newspaper
- Glass bottles into construction aggregate

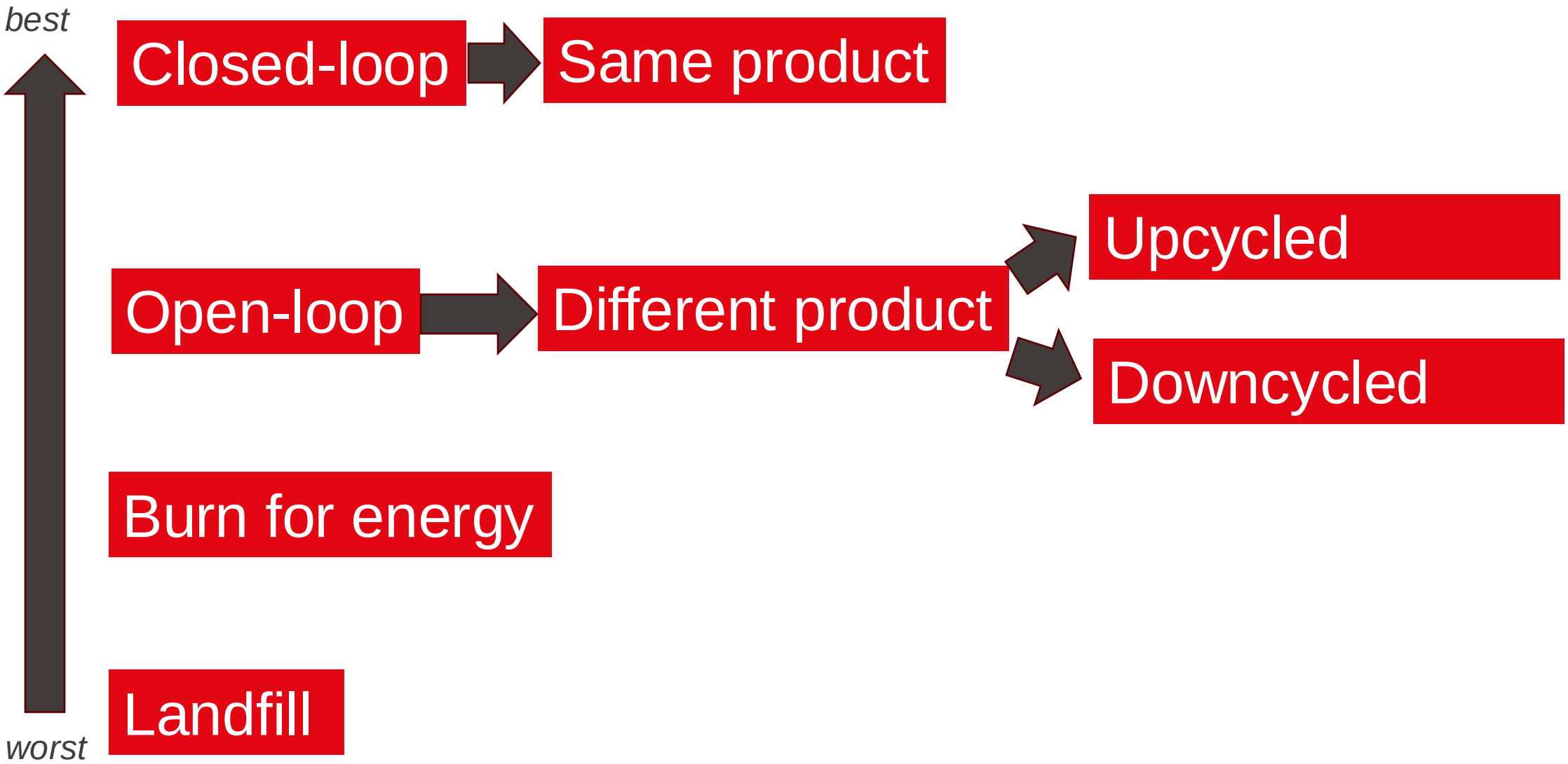
Key: Materials are made weaker or mixed with other materials; recyclability in future is inherently limited

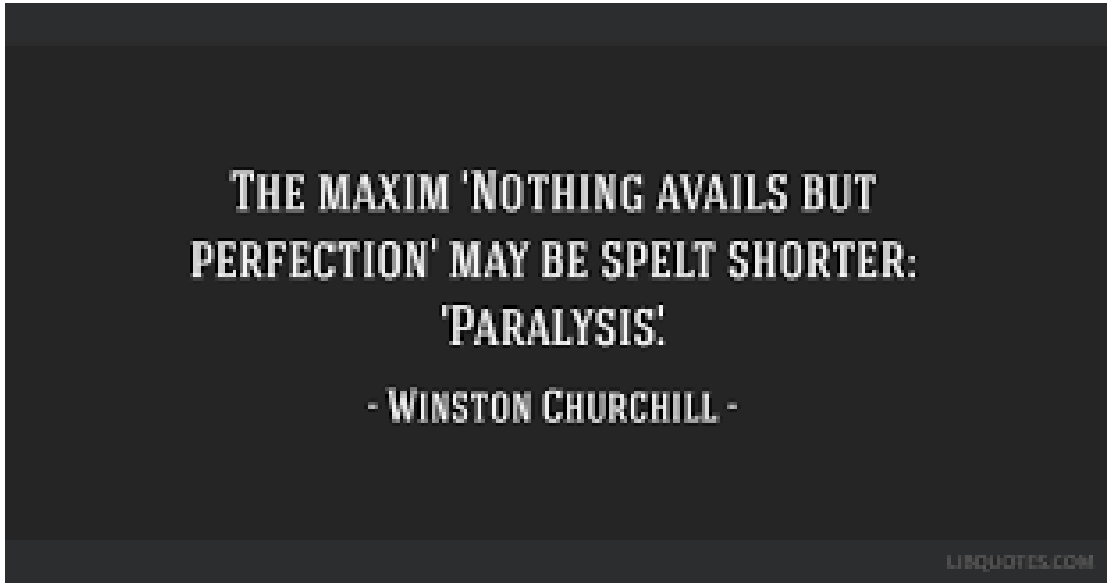
Examples of upcycling (adds value)

- Found wood converted to furniture
- Old bike parts to art
- Used fabric to arts & crafts pieces

Key: New materials are more functional, have artistic value, and are longer lasting compared to the original

Recycling summary





Maybe good words to consider in the context of this course?

Take aways

- Linear and circular economy
- How circular can we get? Are there limitations?
- Recycling – closed-loop
- Upcycling, downcycling – open-loop
- Next week: Metrics for assessing sustainability… **If we don’t know where we are, then how can we improve?**