

Module 1 – Sustainability



Global Greenchem
Innovation & Network Program



Green Chemistry Toolkit



Center for Green Chemistry &
Green Engineering at Yale

What is Sustainability?



Sustainability is 'meeting the needs of the present without compromising the ability of future generations to meet their own needs.'

- Defined in 1987 by the United Nations Brundtland Commission



<https://www.un.org/en/academic-impact/sustainability>



What is Sustainability?



With sustainability definition in mind, some key circumstances are ascertained:

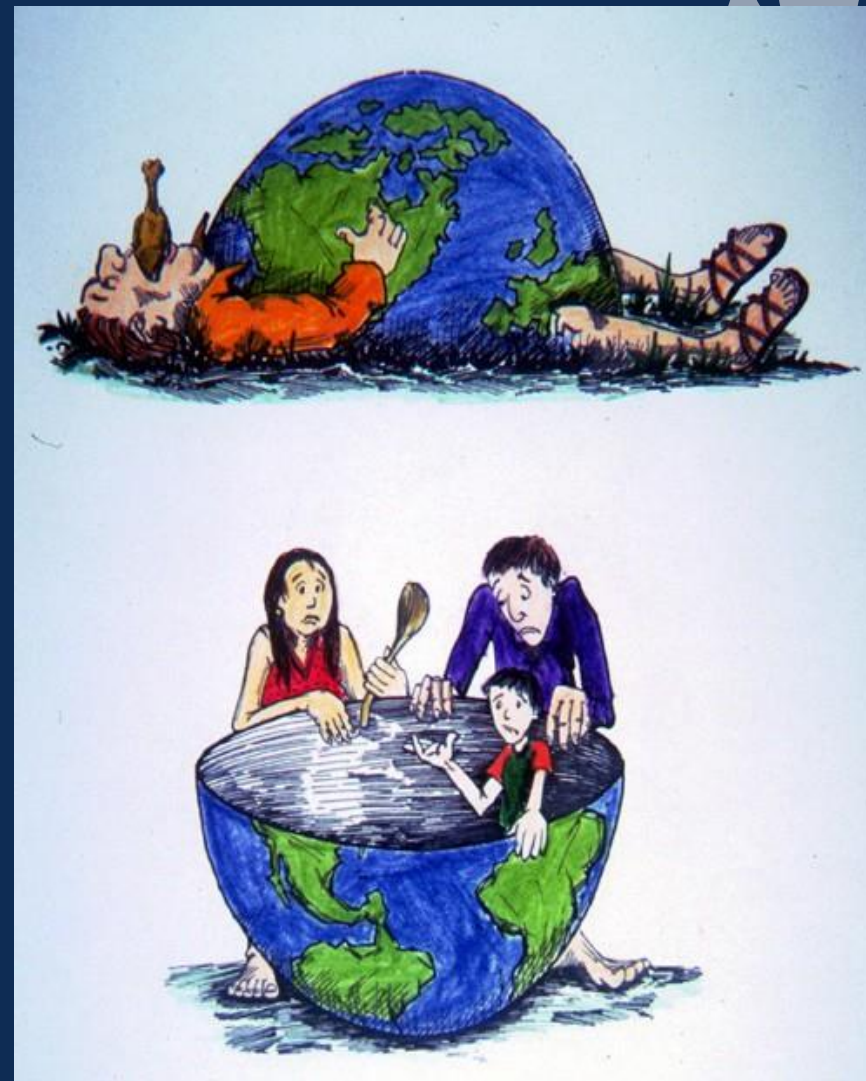
- Resources are finite
- Resources should be used conservatively
- Consideration of long-term developmental priorities
- Consideration of the consequences of resource use.

In simplest terms:
Sustainability is about the realization of human activity on planet earth that enables the same activity for future generations.



Sustainability

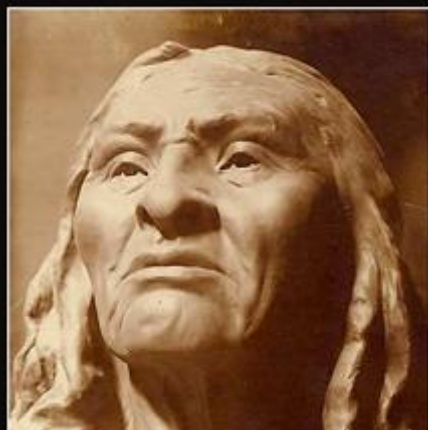
- We want to lead comfortable lives.
- AND**
- We need to ensure that future generations can also lead comfortable lives.



<https://www.slideserve.com/florence-vaughn/sustainable-development-a-geographic-perspective>



Sustainability



We do not inherit the earth from
our ancestors; we borrow it
from our children

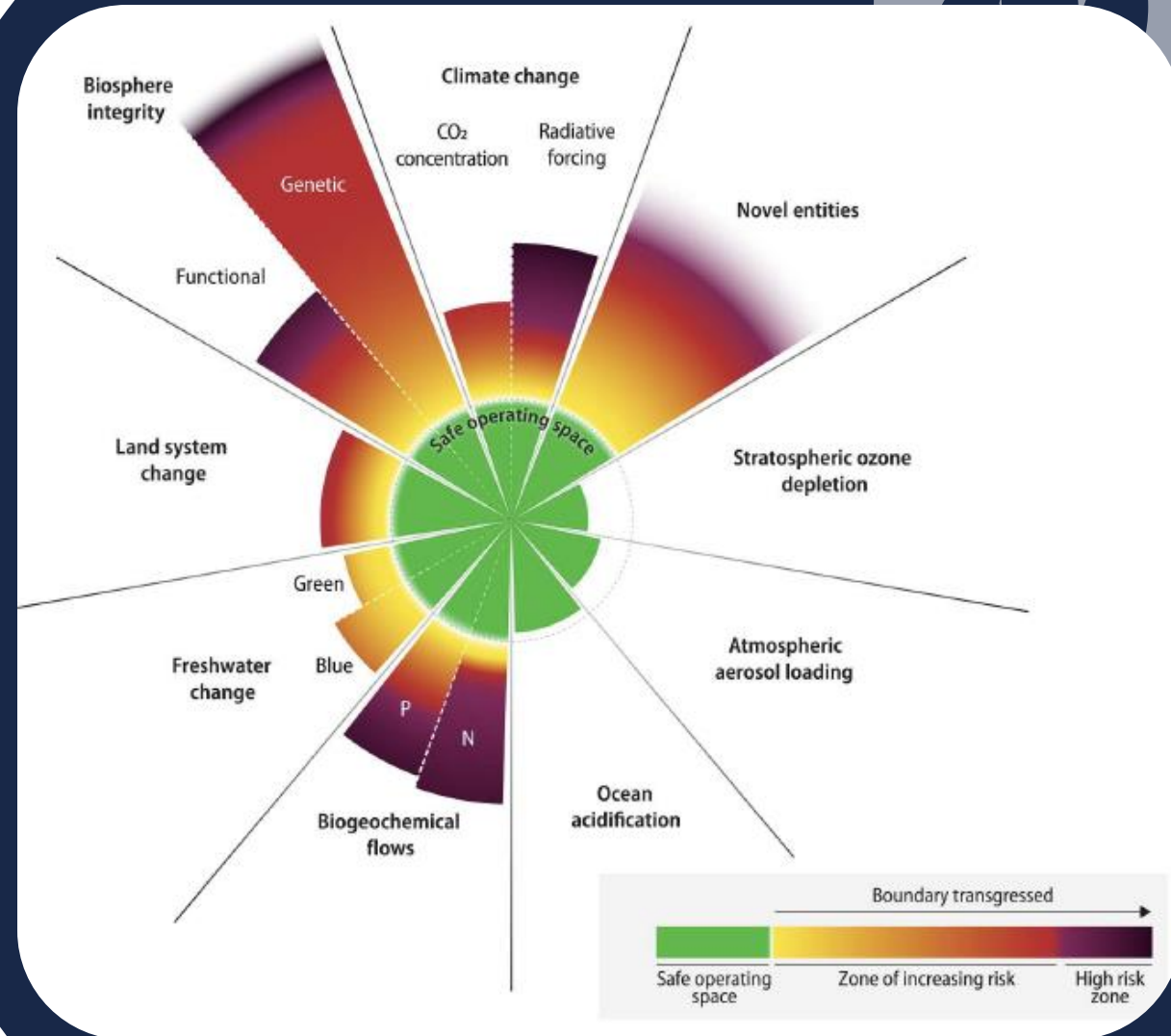
~ Chief Seattle

AZ QUOTES

<https://www.azquotes.com/quote/455413>



Planetary Boundaries



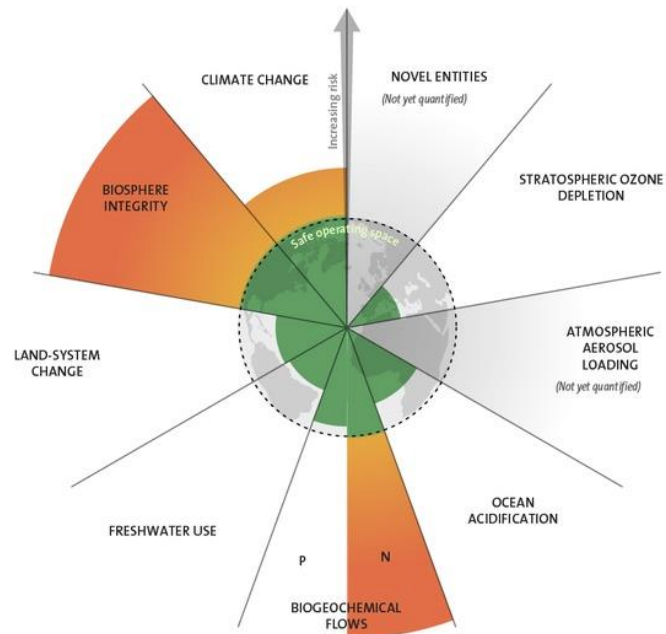
Katherine Richardson et al., Earth beyond six of nine planetary boundaries. *Sci. Adv.* 9, eadh2458 (2023).



Planetary Boundaries

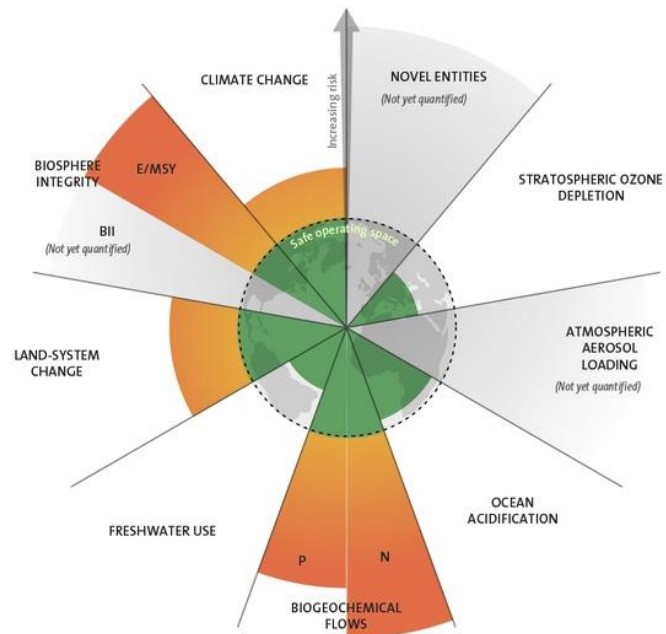


2009



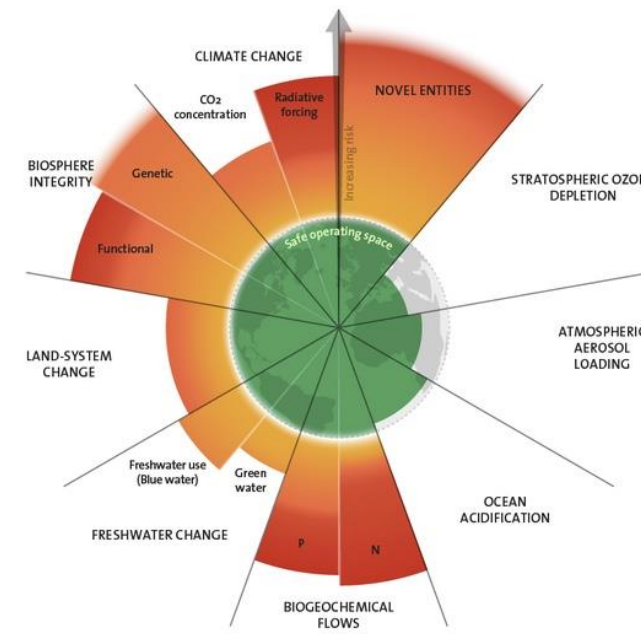
7 boundaries assessed,
3 crossed

2015



7 boundaries assessed,
4 crossed

2023

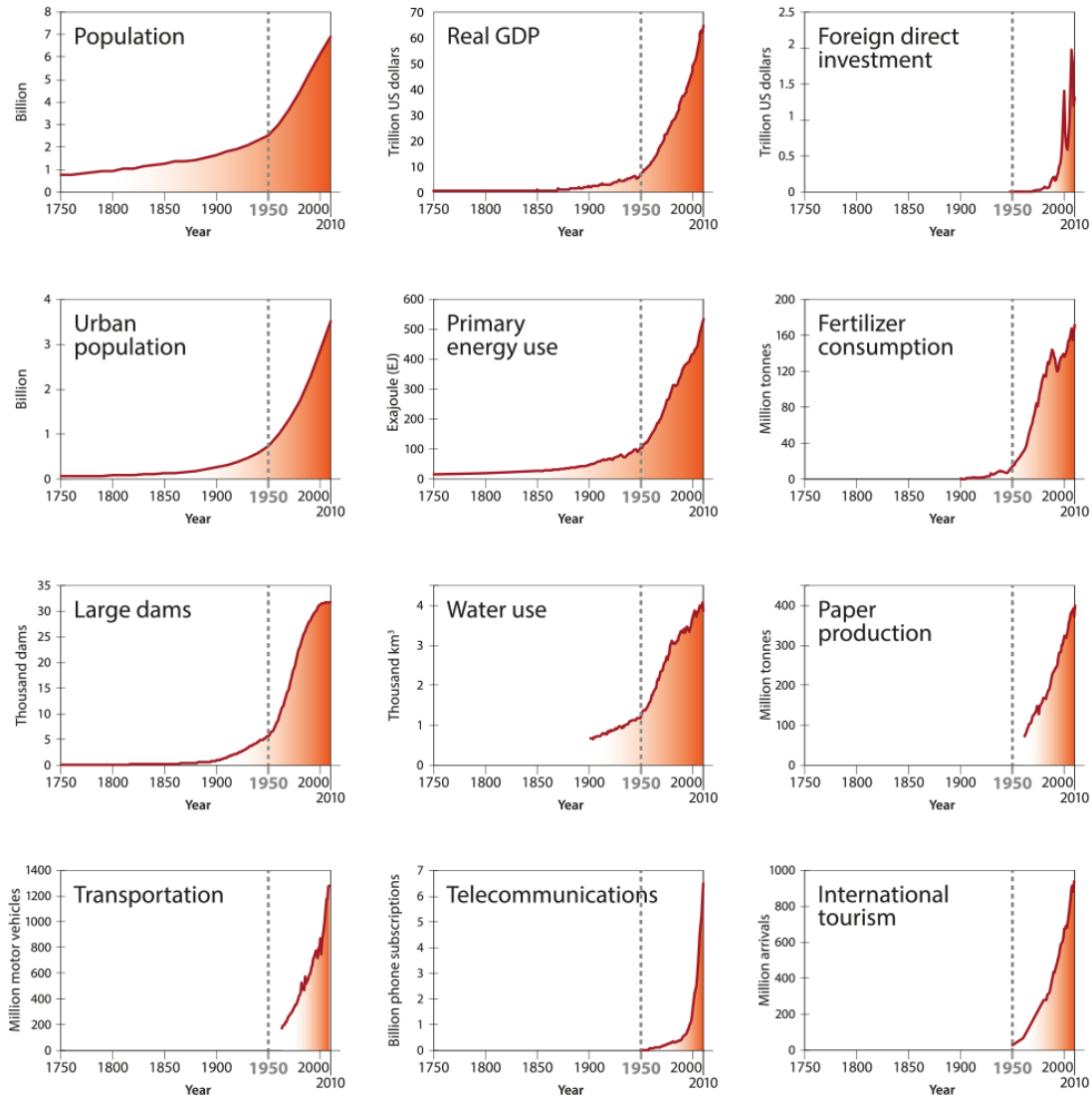


9 boundaries assessed,
6 crossed

<https://www.stockholmresilience.org/research/planetary-boundaries.html>



Socio-Economic Trends



- Pollution, contamination, and waste are increasing along with population.
- Society and corporations are encouraging increased customer demand, pushing consumption of life supporting resources further and further.
- Even as these resources presence declines, consumption of these resources is still rising.

Steffen et al., The Anthropocene Review 2015, 2(1), 81-98.



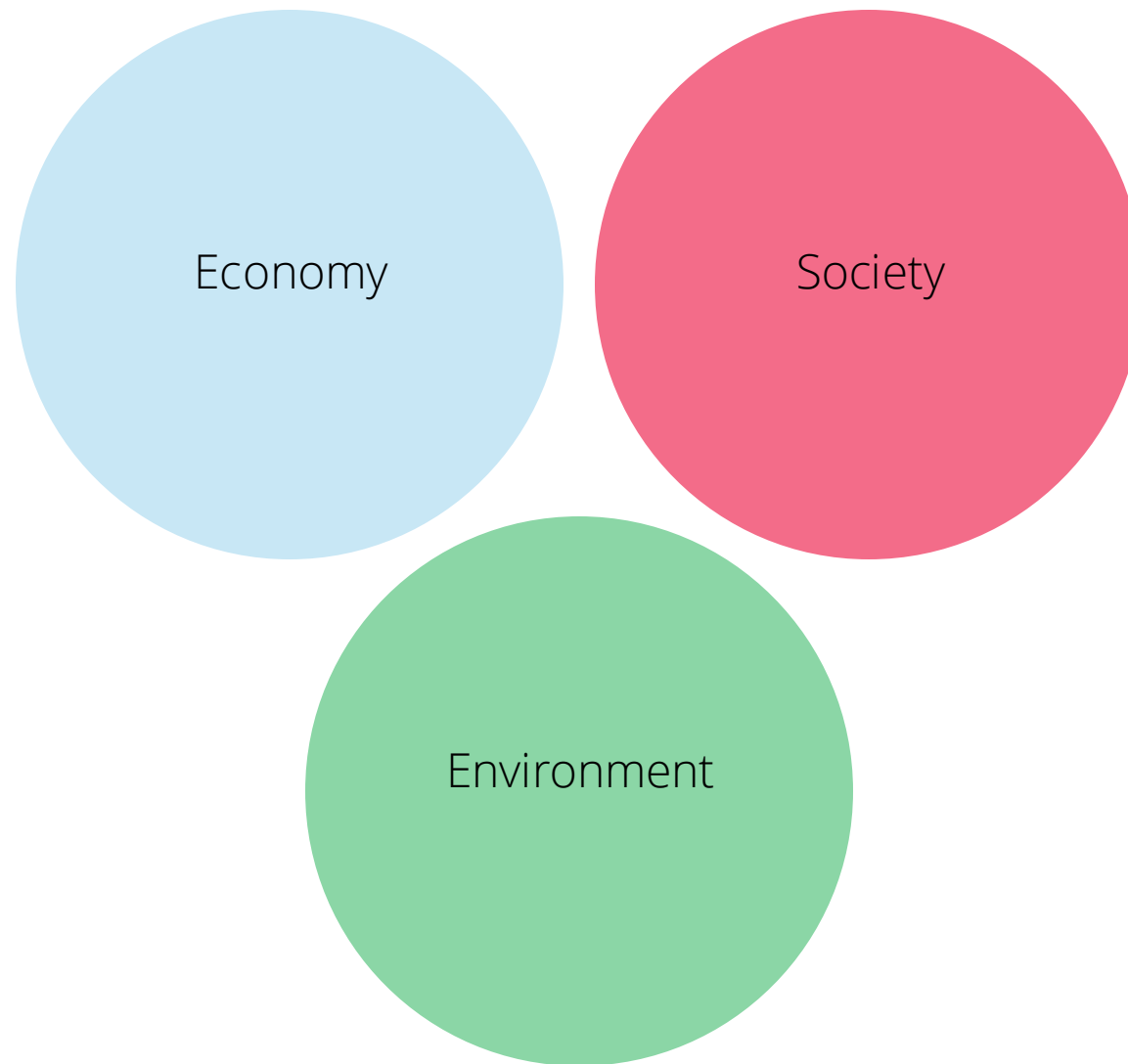
Where we **were!**



Economy, society, and the environment in the past:

- Society, economy, and the environment are viewed as separate.
- Community's problems are also viewed as isolated issues.
- Economic development councils try to create more jobs.
- Social needs are addressed by health care services and housing authorities.
- Environmental agencies try to prevent and correct pollution problems.





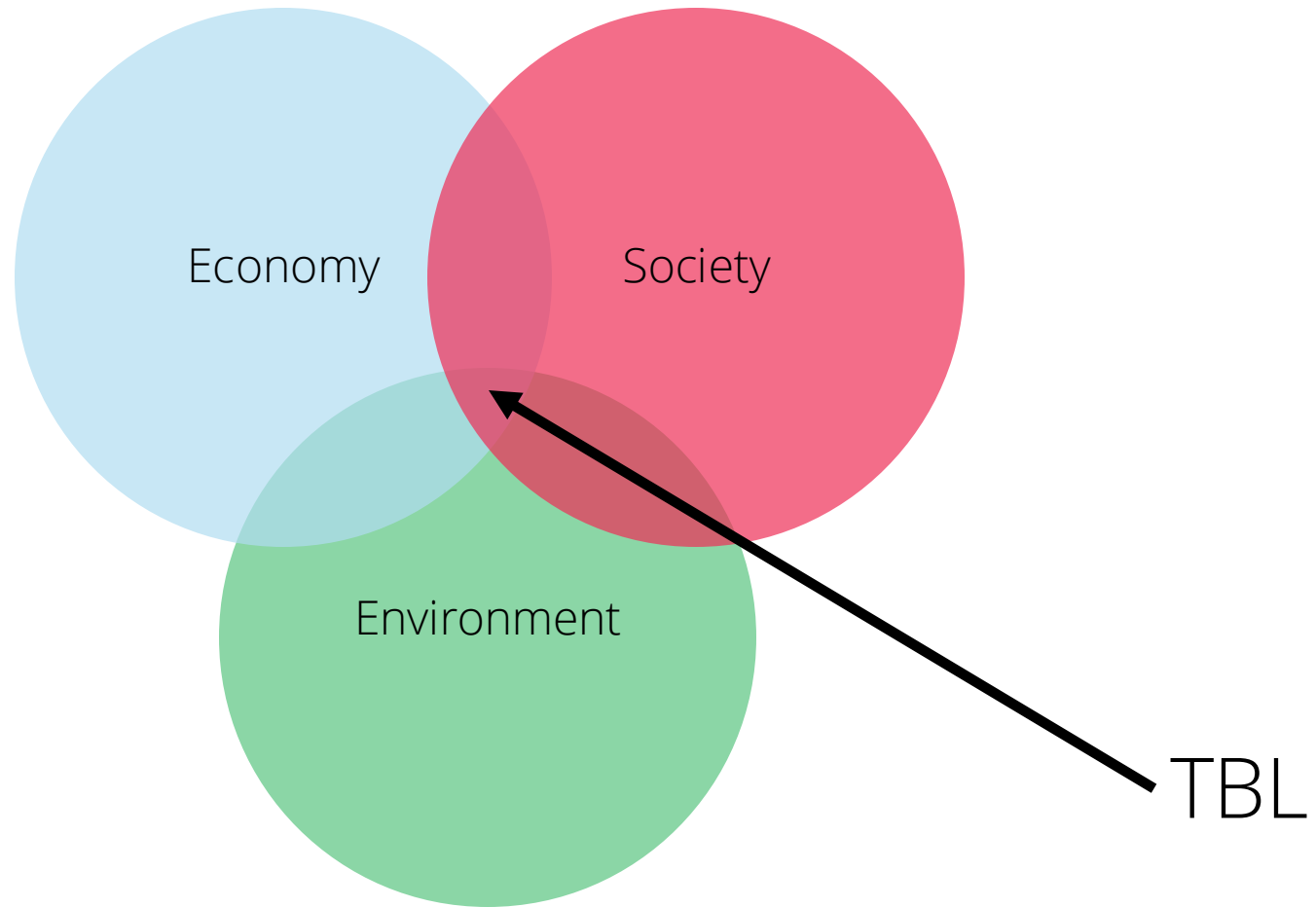
Where we **are!**



A current view: The *Triple Bottom Line (TBL)*

- Understanding and linking the three parts is key to sustainability.
- Sustainability is more than quality of life.
- A balance of society, economy, and the environment needs to be found.
- TBL measures the impact of an organization by looking at profitability and shareholder values through its social, financial, and environmental capital.
- Most major companies that include sustainability in their business plan use this model.





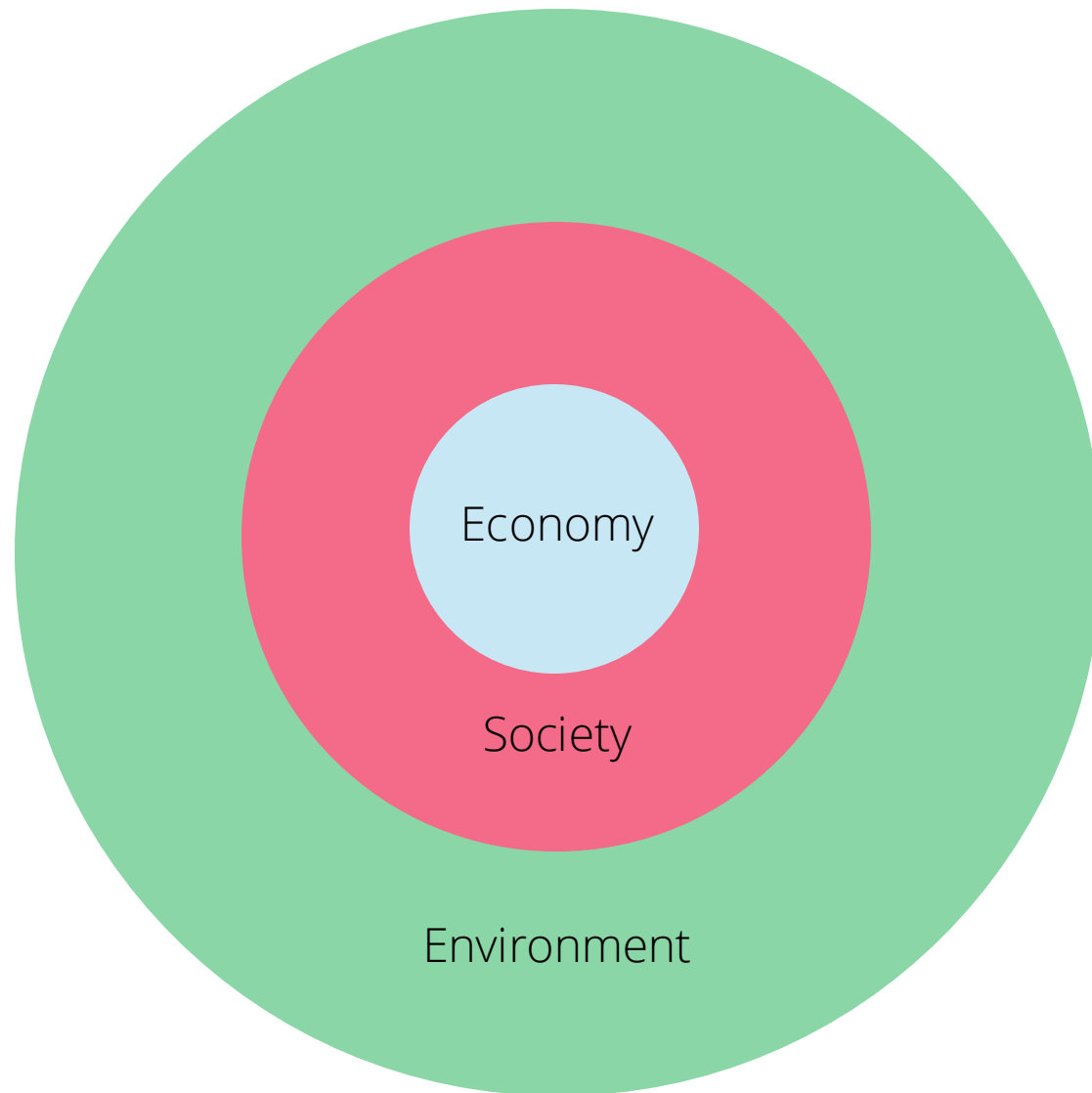
Where we need to be



An ideal scenario:

- Economy is entirely embedded in society since human economy requires interaction among people.
- Society is more than economy, and encompasses, friends and families, music and art, religion and ethics, which are not primarily based on the exchange of goods and services, i.e. the economy.
- Society forms part of the environment. Our basic requirements – air, food, and water – as well as the energy and raw materials for housing, transportation, products, and our economy depend on the environment.





The only question is:
Do we want to be there?



Let's talk about....



...what sustainability is **not**!

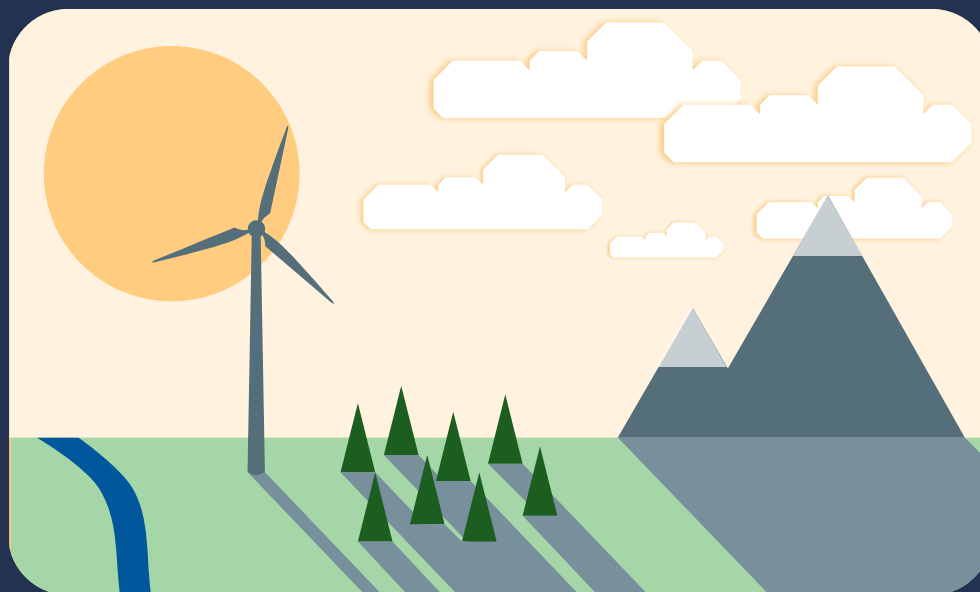
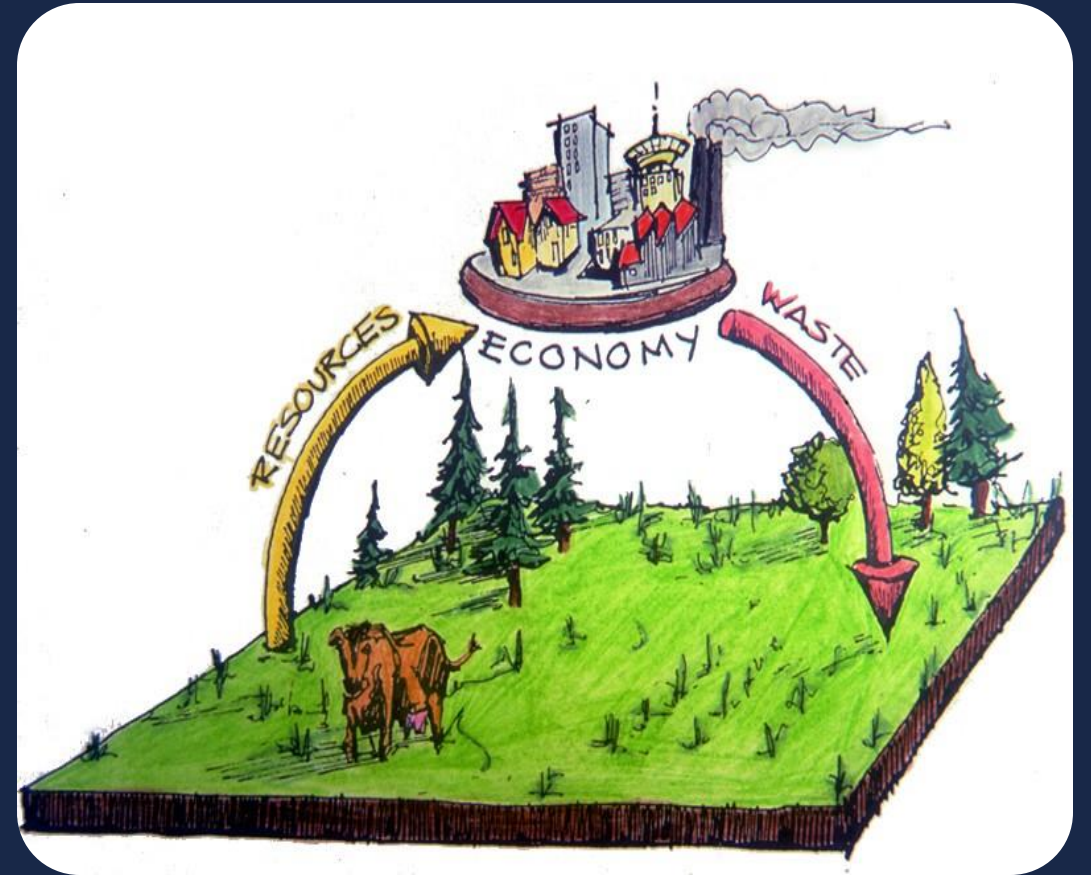


Image by [Marc Manhart](#) from [Pixabay](#)





...all about the environment.



<https://slideplayer.com/slide/13990221/>



All about the environment?



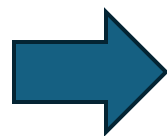
- Sustainability has transformed into an environmental term because the economy is **without any exception** driven by natural resources, although that might not be obvious in some cases.



All about the environment?



- Sustainability includes a wide range of social and economic development issues including poverty, hunger, health, education, climate change, water, sanitation, energy, and the environment.



- This requires everybody to get access to natural resources such as food, water, and energy - all of which come, one way or another, from the environment.
- Clearly, technology, healthcare, and political structures within a society are involved in sustainability.



Our sustainability blueprint



SUSTAINABLE DEVELOPMENT GOALS

17 GOALS TO TRANSFORM OUR WORLD



<https://www.un.org/sustainabledevelopment/sustainable-development-goals/>



Our sustainability blueprint



“The blueprint to achieve a better and more sustainable future for all.”

The goals are interconnected!



The challenges are interconnected too!



<https://www.un.org/sustainabledevelopment/sustainable-development-goals/>





**...sustainable and
green are the same.**



wildpixel via iStock



...sustainable and green are the same?

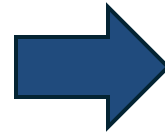
- “Green” concepts tend to focus on technologies/products causing less harm to human health and the environment
- In popular discourse it is often assumed that green = natural as opposed to artificial
- Yet natural may not always be sustainable
- Sustainability and green overlap since a sustainable solution must be able to preserve health and environment
- Sustainability adds the important idea of preserving resources for the next generation!



...sustainable and green are the same?



- GM crops: Is a society built on non-GM crops sustainable or not?



- Sustainability considers society, economy, and the environment: GM crops are important!



...sustainable and green

Both terms are often used outside of this context, without providing or considering metrics of their respective impact.

=> this is **Greenwashing**

<https://thesustainableagency.com/wp-content/uploads/2023/11/How-to-spot-greenwashing-infographic-min-1.png>



Green Chemistry Toolkit

How to spot greenwashing

@agencyakepa akepa

BADLY THOUGHT-OUT BIG GESTURES:

A classic one when an idea has come from a marketing team instead of experts.



MISLEADING NUMBERS AND PERCENTAGES

REBRANDING TO INCLUDE 'natural' PACKAGING

Products that change their look to apply the veneer of sustainability, but without actually changing anything.



MAKING THE PRODUCT PACKAGING GREEN

There are a few common tricks that you can watch out for to make it easy to spot greenwashing and dubious sustainability claims:

VAGUE 'GREEN-SOUNDING' LANGUAGE:

Look out for words that sound good at first but have no concrete meaning legally, like 'farm fresh' or 'conscious'.

IRRELEVANT CLAIMS:

Making a big noise about one tiny green attribute on an otherwise totally anti-green product.

At its core, greenwashing is all about misdirection.

SO WHAT SHOULD WE BE LOOKING OUT FOR TO KNOW IF A BRAND IS FOR REAL

Accountability

Ironically, truly sustainable brands are transparent about how they're affecting the environment.



Clear labeling

Sustainable products should include simple language labels about exactly what's in a product.

Accreditation

Don't just take brands' words for it. Look for companies that are audited or accredited by third parties.



Traceability

Some forward-thinking brands have been helping buyers track their products' sustainability using helpful tech.



When we do the **right** things **wrong!**



<https://kelseyannmo.wordpress.com/2013/06/03/fiji-every-drop-is-green/>

Discussion points:

- Transport efficiency
- What is water chemically
- Container
- ...



When we do the **right** things **wrong!**



<https://uccomm2004.wordpress.com>

Discussion points:

- Origin of molecules
- What is e.g. citric acid
- ...



When we do the **right** things **wrong!**



<https://businessofstory.com/is-your-sustainability-message-believable/>

Discussion points:

- Claim vs. proof
- Power of false marketing
- ...



When we do the **right** things **wrong!**



<https://www.braskem.com/>

Discussion points:

- Where do plastics come from
- Where do plastics go
- When is an improvement good
- ...





...sustainability is too expensive.



Image by [Satheesh Sankaran](#) from [Pixabay](#)



Sustainability and Expense



More sustainable ways of doing things usually cost less over the life-time of a product or service, and at scale.



<https://earth.org/solar-energy-facts/>

- Upfront costs might be offsetting: cost of innovation, implementation, training, redesign, all contribute to something chemists know as “activation energy barrier”. Economists might call it the barrier to “economy-of-scale”....

For additional reading on companies' visions:

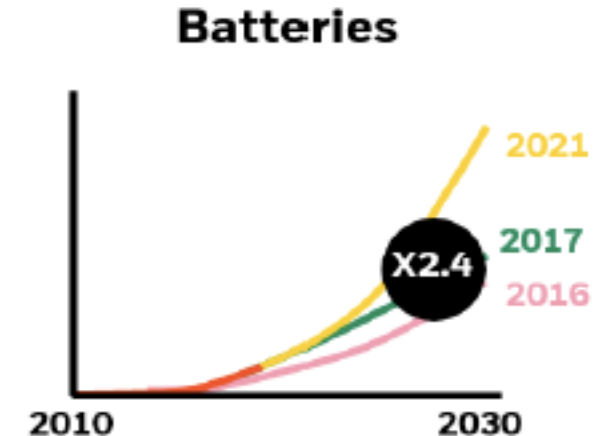
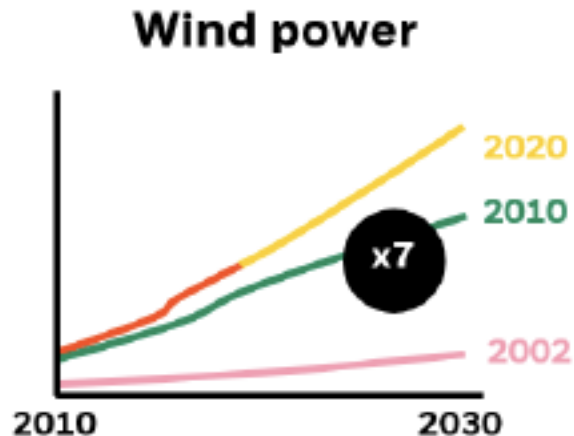
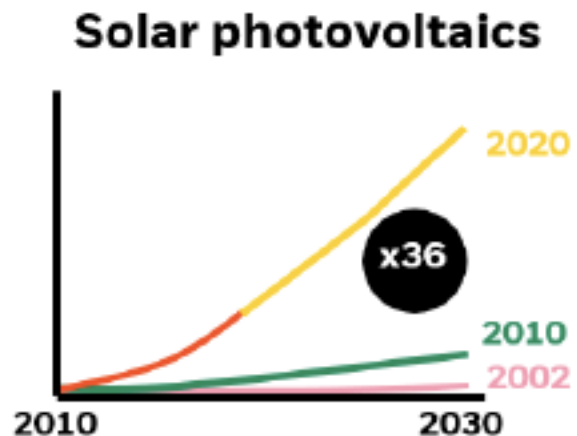
- <https://about.nike.com/en/impact-resources/chemistry-homepage>
- <https://www.unilever.com/brands/home-care/chemicals-sustainability/>



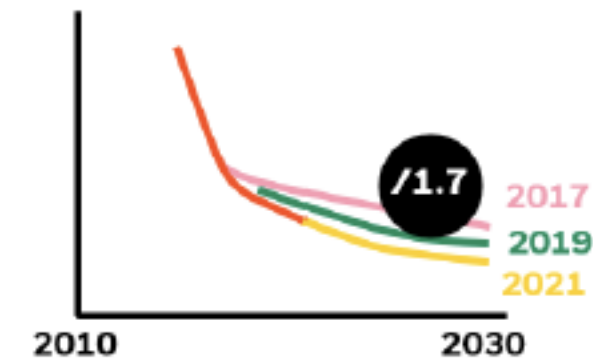
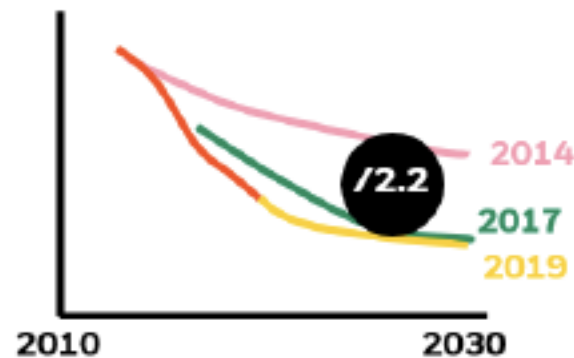
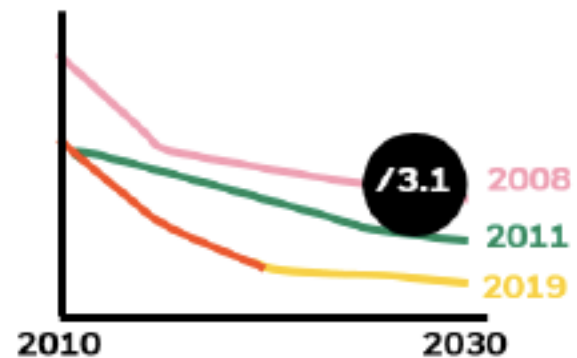
Example: Energy Sector



Capacity projections



Cost projections



BlackRock, IEA, BNEF, IRENA, BCG, 25/01/22. For illustrative purposes only.

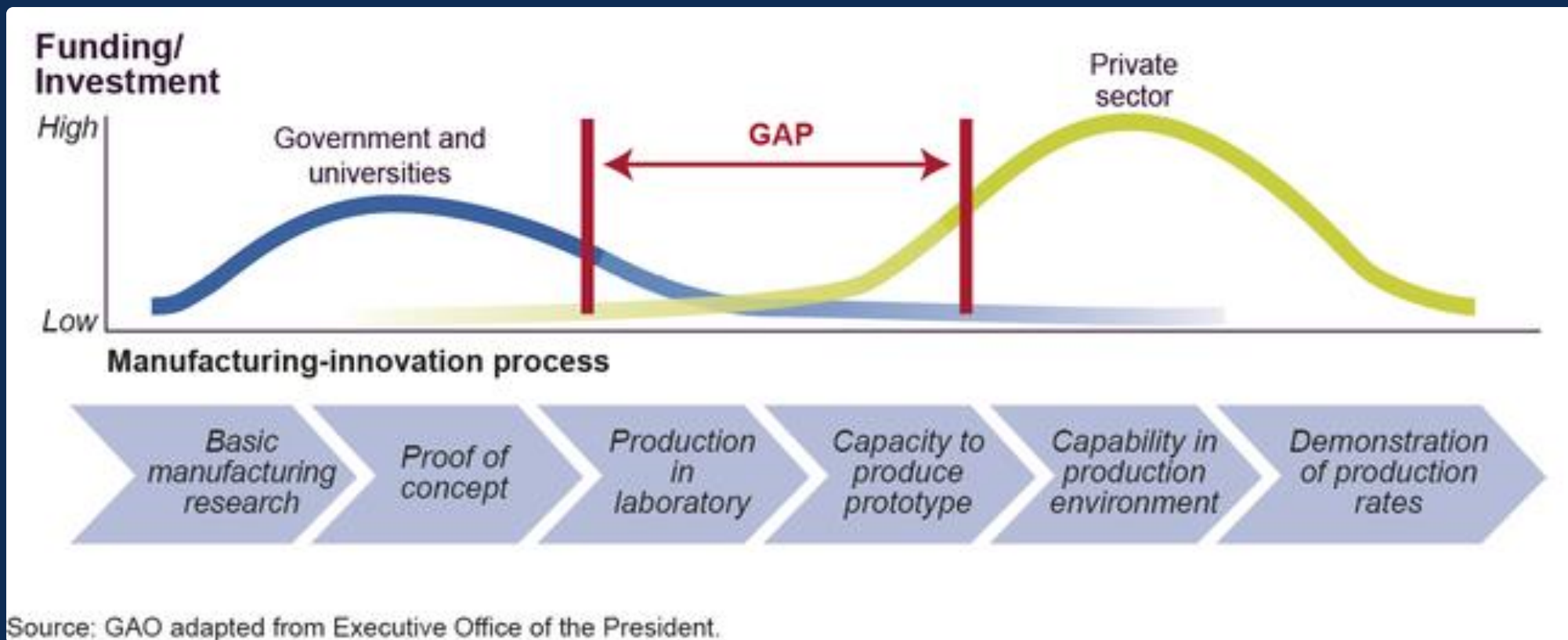
<https://www.dspim.com/media/pages/downloads/5d39fc8e9c-1723479190/dsp-world-energy-fund-presentation-july-23.pdf>



Innovation and Economies of Scale

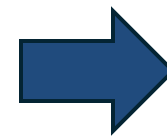
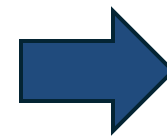
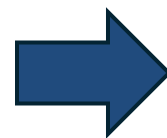


Developing new technologies always comes with risks and might entail upfront investments (and tremendous opportunity!).



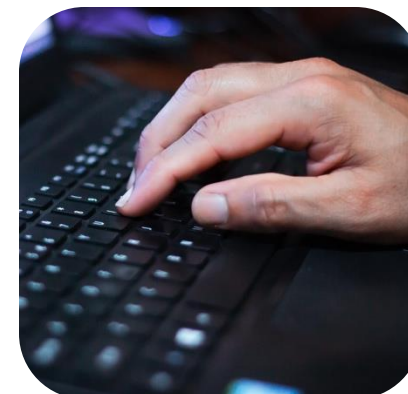
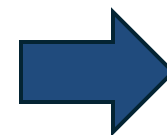
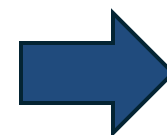
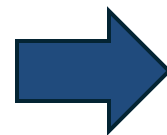
Examples

- Computers
- Cars
- EVs



Examples

- Batteries
- Solar Energy
- Internet





...lowering our
standard of living.



Standard of Living

['stan-dərd əv 'li-vɪŋ]

The material well being of the average person in a given population.

 Investopedia

Investopedia/NoNo Flores



Sustainability and Standard of Living



Innovations or breakthroughs usually don't start at 0, but rather substitute or improve existing products or processes to meet market demands (e.g. EVs, biopesticides, repellants, paints, etc.).



Sustainability and Standard of Living



Innovation plays a key role for sustainable living and is already a major economic engine (think about IoT, automatic irrigation systems, plant genetics, pharmaceuticals, SAFs etc.).



Sustainability and Standard of Living



And... if we are willing to adapt our standard of living even only slightly, it will make things much easier and much faster (think elimination of plastic bags, reusable water bottles, public transport, etc.)



Sustainability and Standard of Living



Conviction and Profit

“Innovative business models and products must work **financially**, or it won't matter how good they are ecologically and socially.”

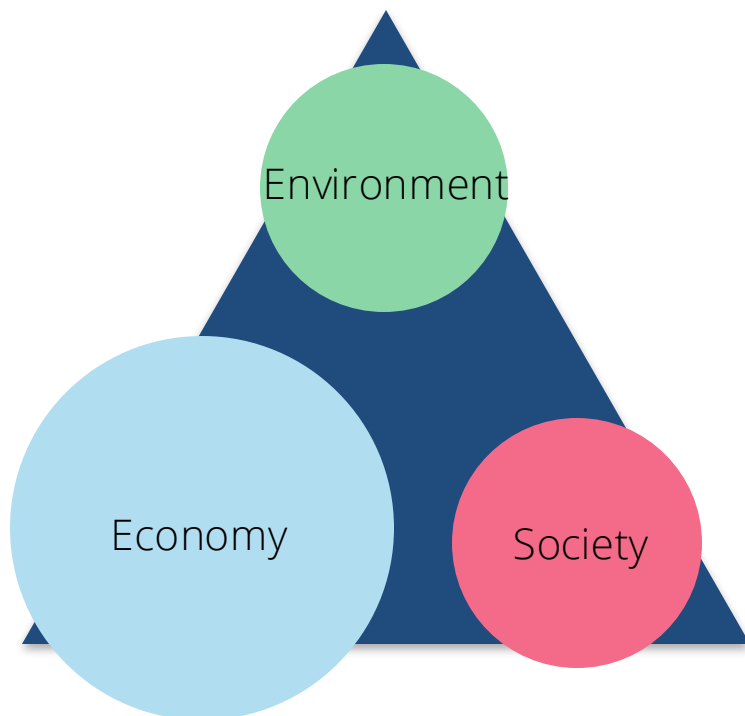
-Peter M. Senge



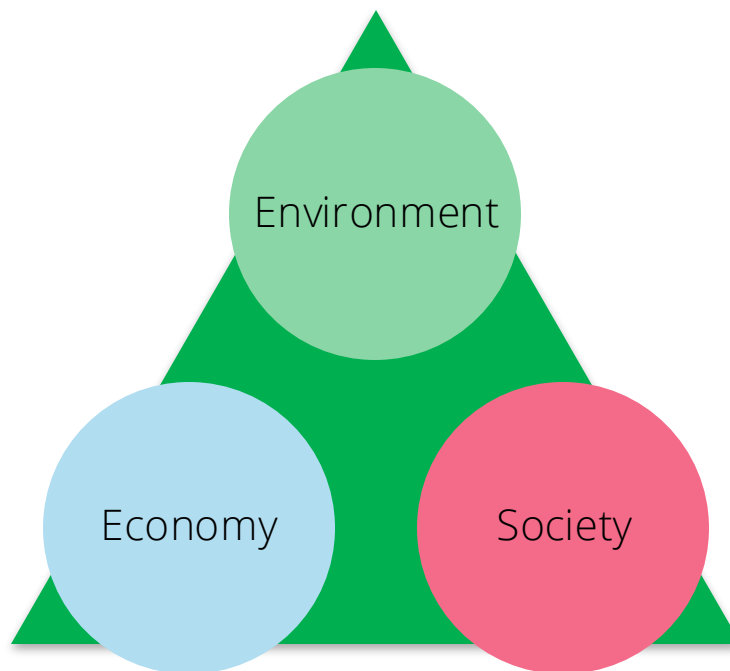
Sustainability and Standard of Living



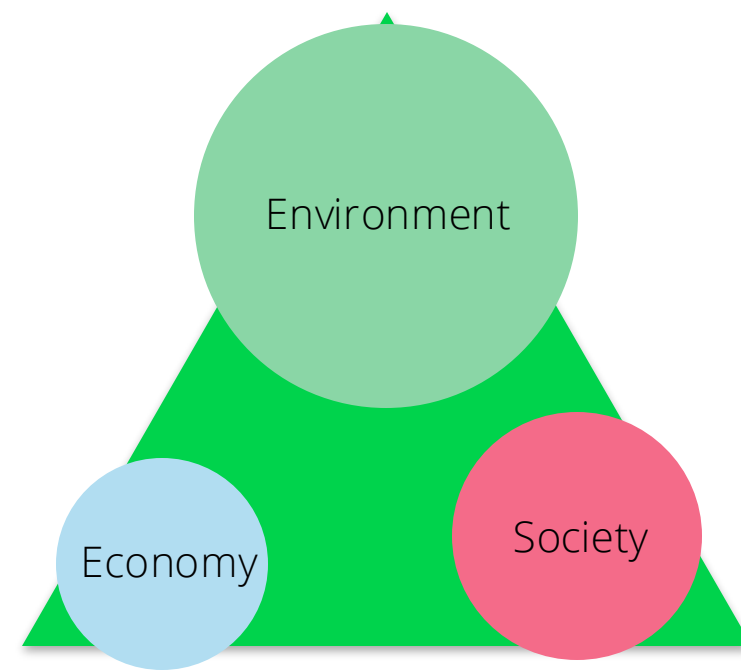
Focus on profit



Balance of profit and conviction



Focus on conviction





**...only driven through
consumer choices.**



Image by TaWiPoP from Pixabay



Sustainability, the Public, and Governments



- Grassroots movements and consumer choice are helpful and essential to initiate change, innovation, and demand.
- Ultimately national & international policies and reforms, such as curbing CO₂ emissions or chemical pollution, can only happen if central authorities initiate change.



Sustainability, the Public, and Governments



- Binding standards, environmental government regulations, and tax credits, are essential to drive change and innovation.

Participation and dedication of governments is a necessary component of societal, environmental, and technological sustainability and finally CHANGE!



Other Concepts of Sustainability



<https://medium.com/openforests/the-core-concept-of-sustainability-8facc0811f4f>



Circular Economy

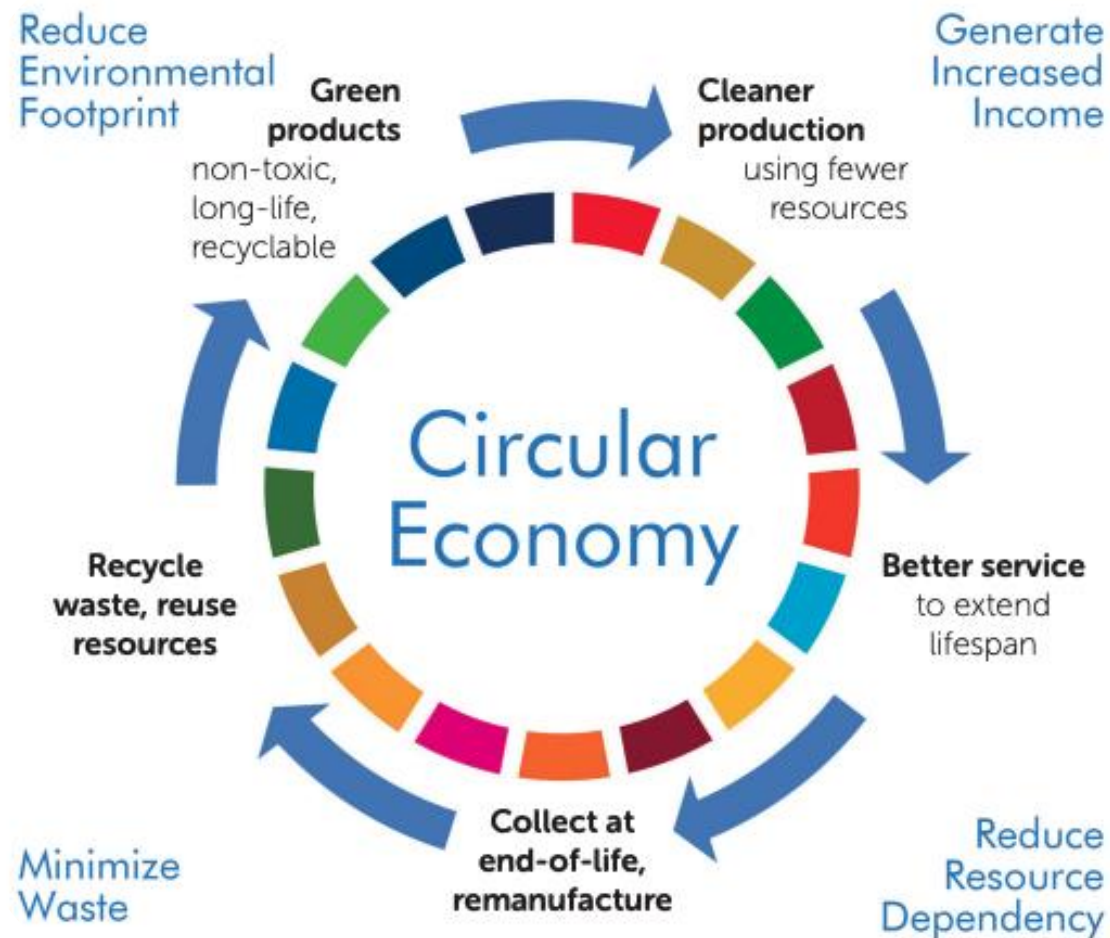


from: https://doi.org/10.1007/978-3-031-54664-8_19

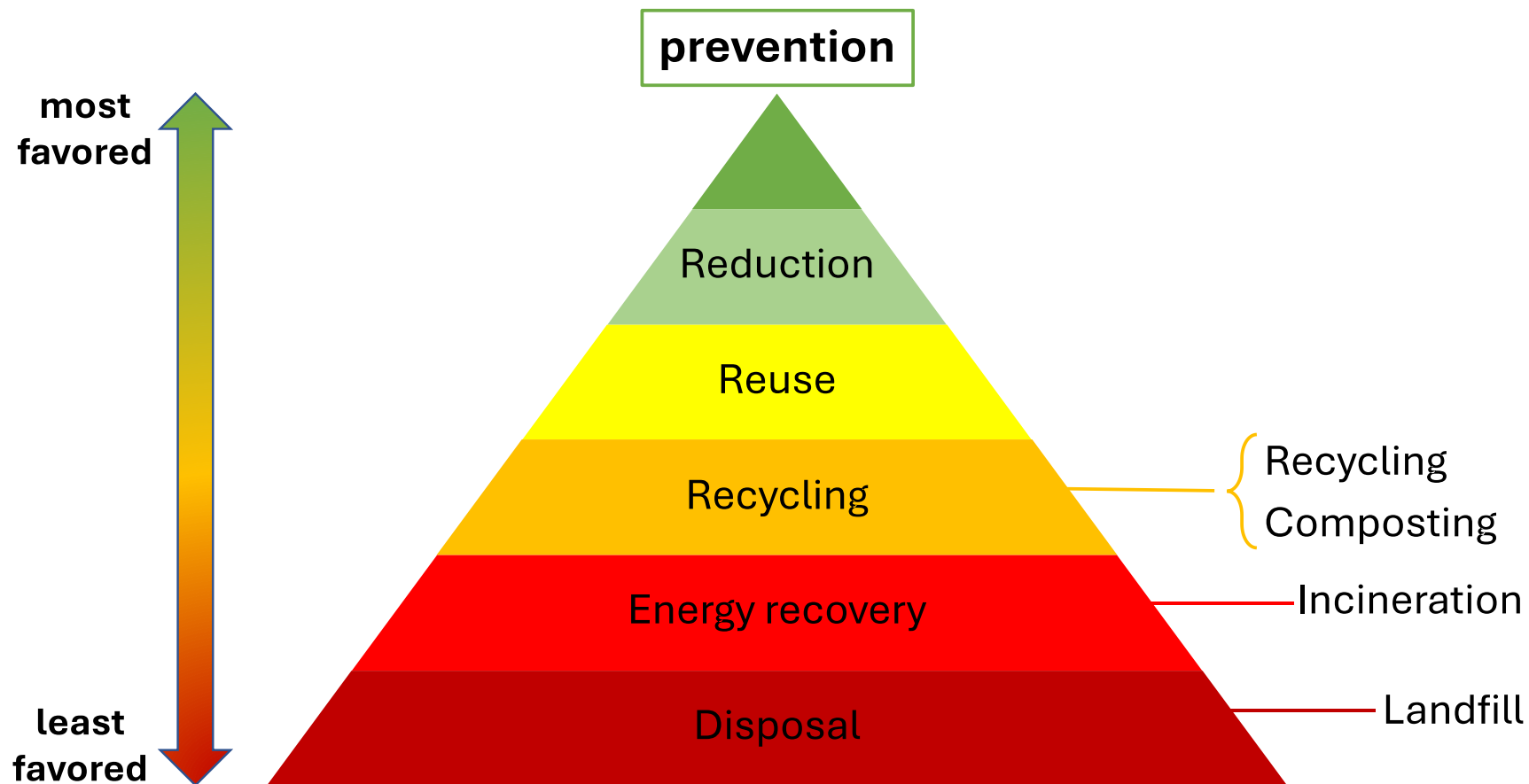




A circular economy is a model of resource production and consumption in any economy that involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products for as long as possible.

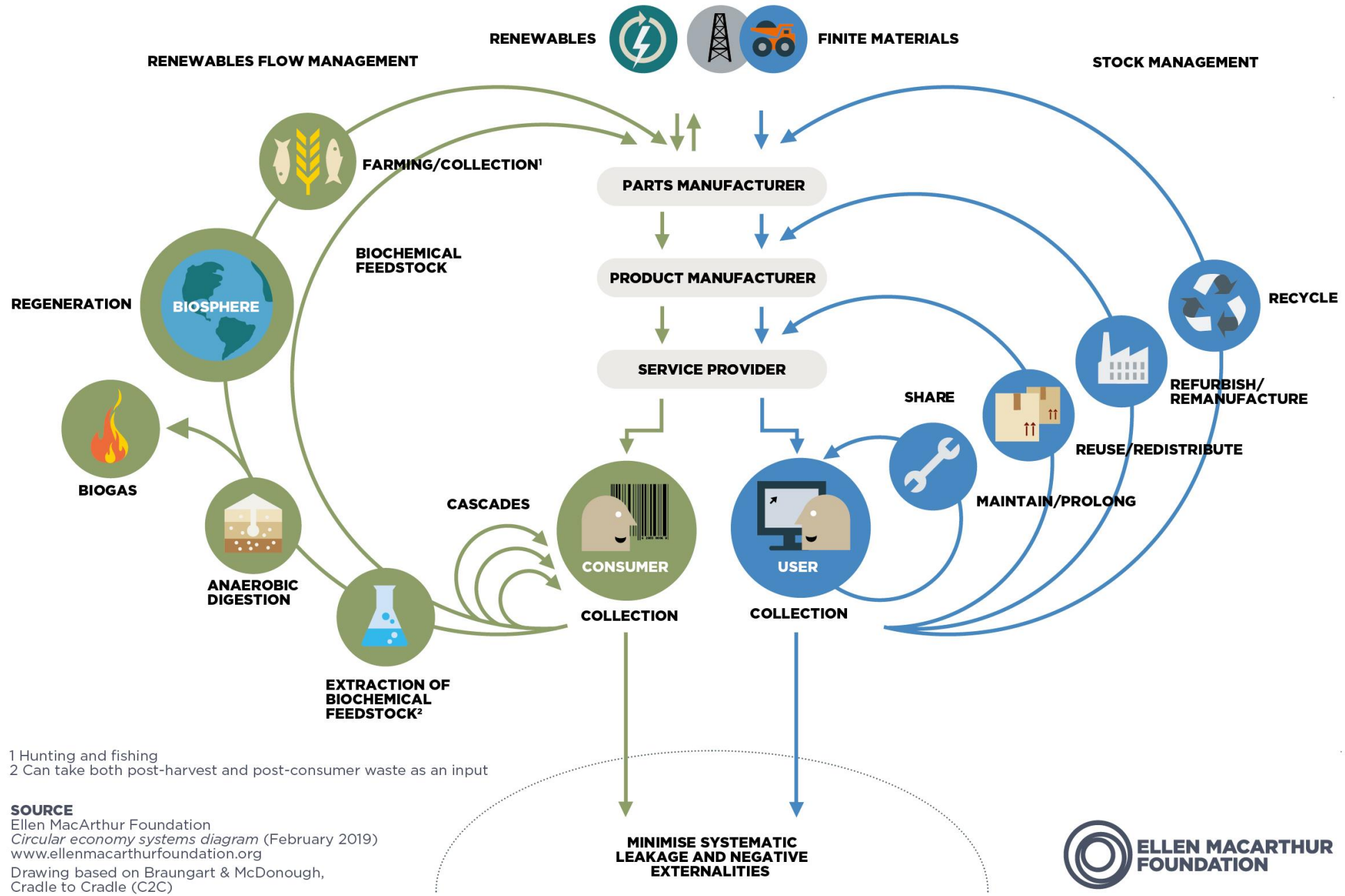


When waste is not waste



Relearning from nature and Relearning from our own past!





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)



Analyzing circular economy

Advantages:

- Conserves Resources
- Benefits the Environment
- Economic Opportunities
- Enhances Resilience
- Brings Social Benefits

Disadvantages:

- Complex to implement
- Limited Solutions Exist
- Harder to Scale
- Limits Technology and Design
- Requires Change of Mindsets



Circular Economy needs thorough analysis



- Should we apply circular economy everywhere?

Some loops should not be closed!

Inherently toxic materials (aka legacy materials) need to be removed from our increasingly complex systems.

The graphic features a large red 'X' over a background image of two children running in a field. Text elements include: 'PFAS' in large blue letters; a yellow box with 'CAN CAUSE SEVERE ILLNESSES' in blue; a list of health effects: 'PFAS can cause: cancers, lower birth weight, liver damage, thyroid disease, high cholesterol, and fertility issues'; and a yellow box at the bottom with 'IT'S TIME TO PHASE OUT PFAS' in dark blue. A chemical structure is visible in the top right corner.

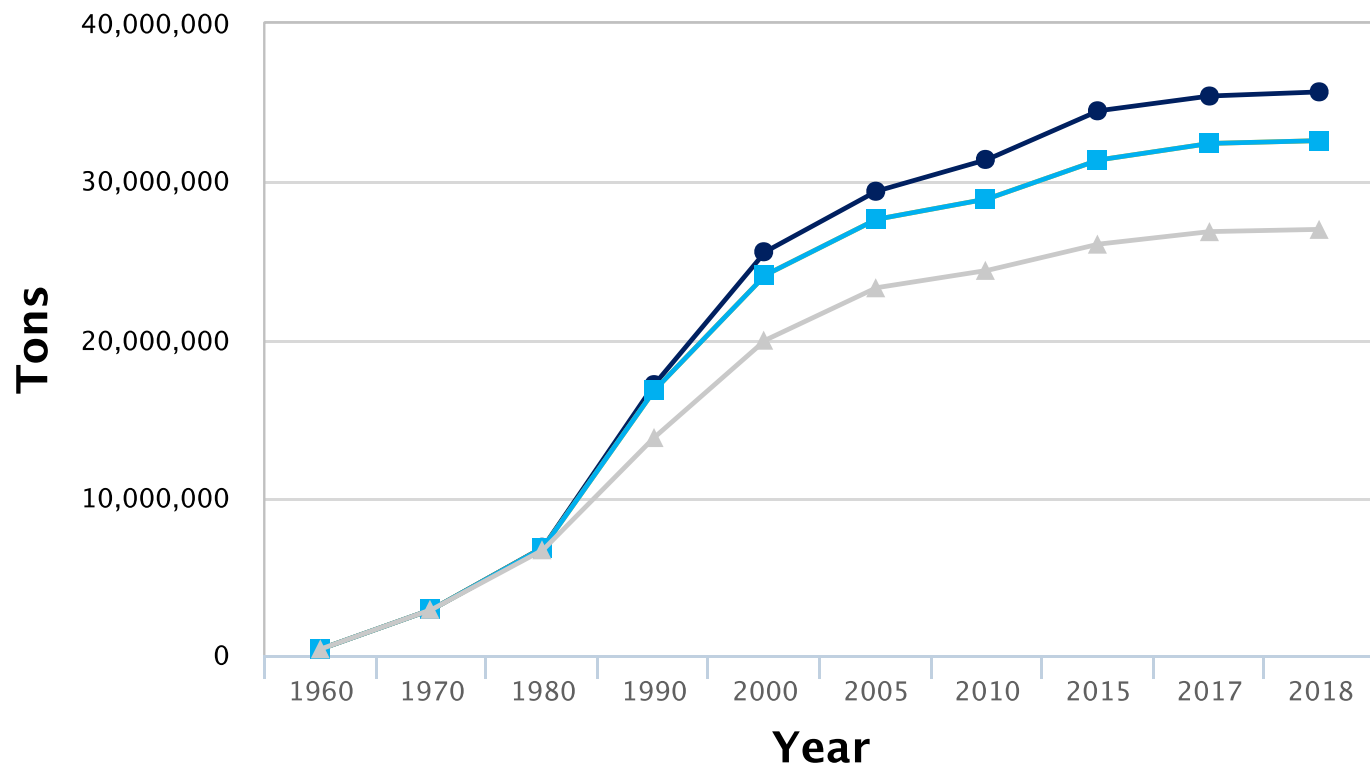
<https://oeconline.org/pfas/>



Circular Economy and Recycling



Plastics Waste Management: 1960–2018



Click on legend items below to customize items displayed in the chart

Recycled **Combed** **Combustion with Energy Recovery**
Landfilled

If recycling systems or supply chains would be adequate, even single use plastics could be sustainable...

<https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data>

For additional reading:

- <https://www.un.org/en/chronicle/article/ecology-recycling>



Circular Economy and Recycling



The problem is, that we have too many different plastics which make an efficient recycling very difficult.

 PET	 HDPE	 PVC	 LDPE	 PP	 PS	 OTHER
POLYETHYLENE TEREPHTHALATE	HIGH-DENSITY POLYETHYLENE	POLYVINYL CHLORIDE	LOW-DENSITY POLYETHYLENE	POLYPROPYLENE	POLYSTYRENE	OTHER
WATER BOTTLES; JARS; CAPS	SHAMPOO BOTTLES; GROCEY BAGS	CLEANING PRODUCTS; SHEETINGS	BREAD BAGS; PLASTIC FILMS	YOGURT CUPS; STRAWS; HANGERS	TAKE-AWAY AND HARD PACKAGING; TOYS	BABY BOTTLES; NYLON; CDS
						

<https://www.plasticsforchange.org/blog/different-types-of-plastic>



Design Problems drive our Impact: Life-Cycle-Assessment

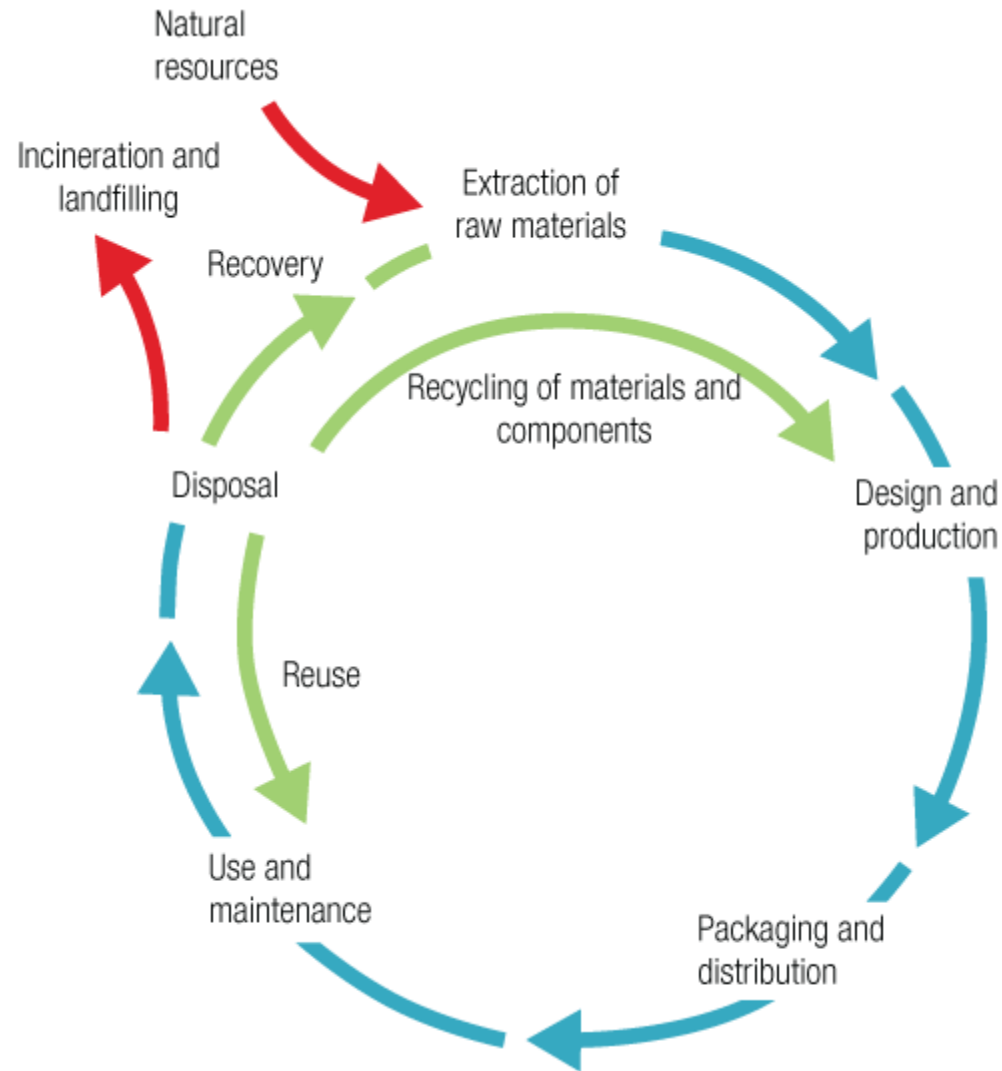


from <https://lca-center.dk>

“Cradle-to-Shelf”
“Cradle-to-Grave”
“Cradle-to-Cradle”



Life-Cycle-Assessment: Measuring Impact



Life-Cycle-Assessment: Measuring Impact



- **Life Cycle Assessment** (LCA) is a methodological internationally standardized method. It quantifies all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues that are associated with any goods or services.

- Life Cycle Assessment considers a **product's full life cycle**: from the extraction of resources, through production, use, and recycling, up to the disposal of remaining waste.

Online Tools for LCA (and many more):

- <https://www.openlca.org/>
- <https://www.greenncap.com/lca-tool/>



Life-Cycle-Assessment: Measuring Impact



Two attributes make LCA distinct and useful as an analytical tool:

- Whole system considerations of the total product life-cycle can be considered and incorporated in the analysis.
- Presentations of tradeoffs among multiple environmental issues are possible.

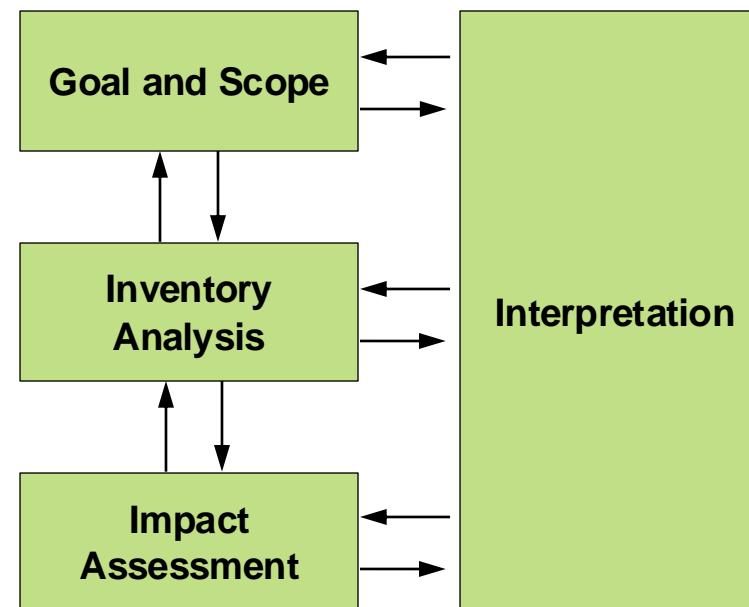
LCA is **quantitative** (only limited by data and knowledge availability).



The Steps of an LCA



- **Goal and Scope - (ISO 14040)**
Definition of the assessments purpose
- **Inventory Analysis - (ISO 14041)** -
What are the energy, raw materials, emissions, and wastes? What data is needed?
- **Impact Assessment - (ISO 14042)** -
Assess environmental impacts identified in the life-cycle inventory.
- **Interpretation - (ISO 14043)** Identify opportunities to reduce the environmental impacts by modification of the life-cycle inventory.



<https://www.iso.org/standard/37456.html>



What does this mean?



1. Select a functional unit and a scope

- making 1 kg of aniline
- washing one window
- cradle to gate
- cradle to grave

2. Select one or more impacts

- Acidification
- Ozone depletion
- Smog formation
- Global warming
- Human toxicity
-
- Ecotoxicity
- Eutrophication
- Resource depletion
- Water consumption
- Land usage
-

3. Make an inventory for each option

- all material & energy inputs
- all material & energy outputs

4. Calculate impacts for each option

P = potential for harm per gram of compound
(relative to a reference compound)

$$I = \text{impact} = P \times m$$

5. Compare the options & choose the greenest



Life-Cycle-Assessment: Measuring Impact



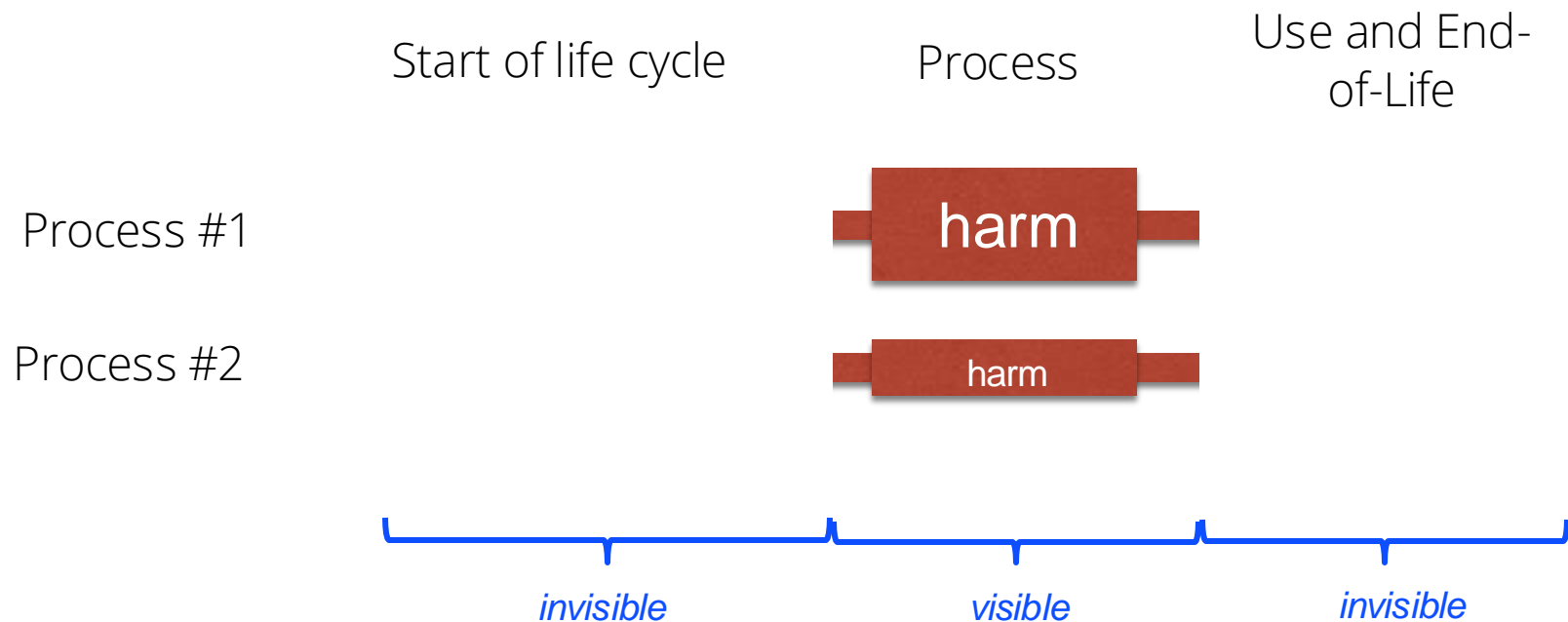
It is important to make an LCA unbiased, because:

- The entity interested in the LCA can define how the system is really considered, how many factors come into play, and which environmental issues play a role in the study.
- Presentations need to be planned and conducted in good faith.

LCA is quantitative so the datasources are critical and should be independent.



Why should we care?

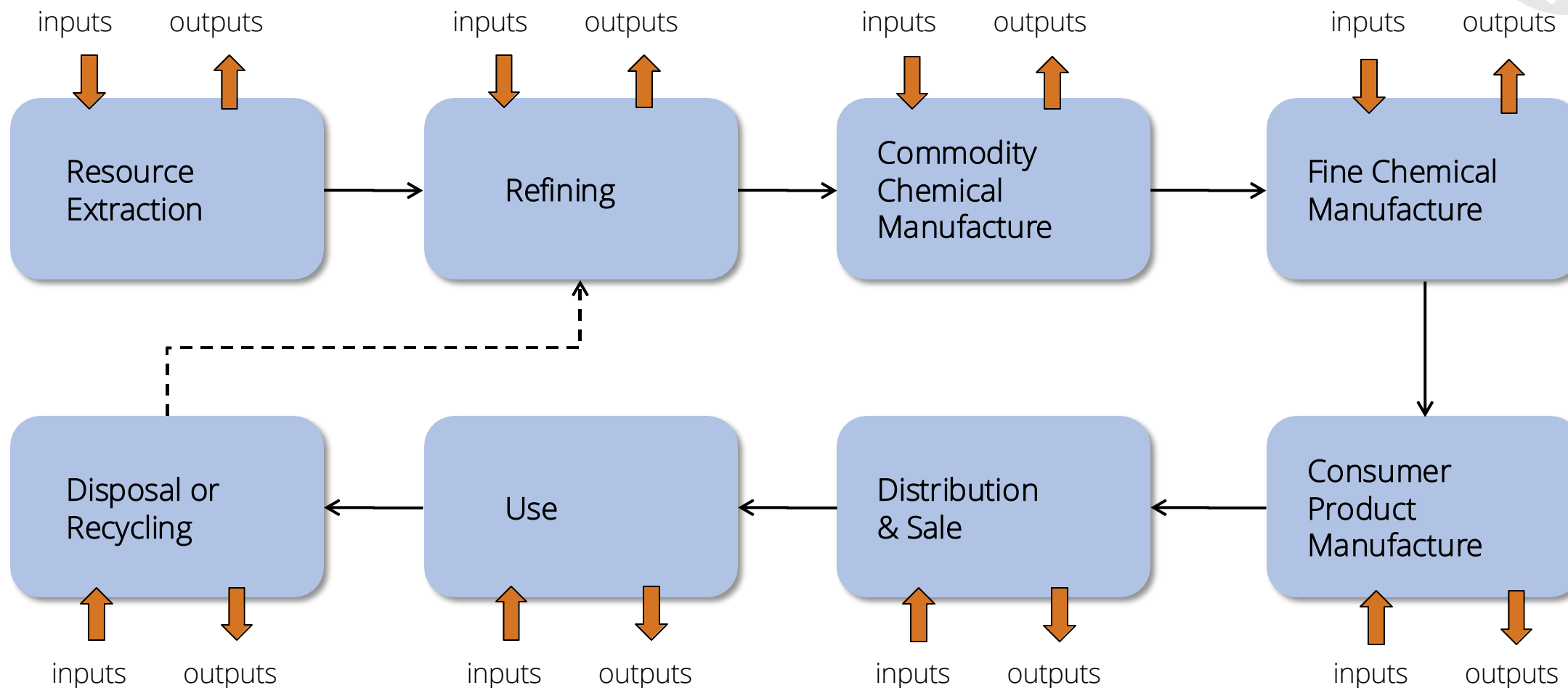


Harm is only visible to the **company** if it occurs on their property.

Products causing most of their harm before or after the process stage appear to be greener than they actually are.



Cradle-to-Grave LCA Process

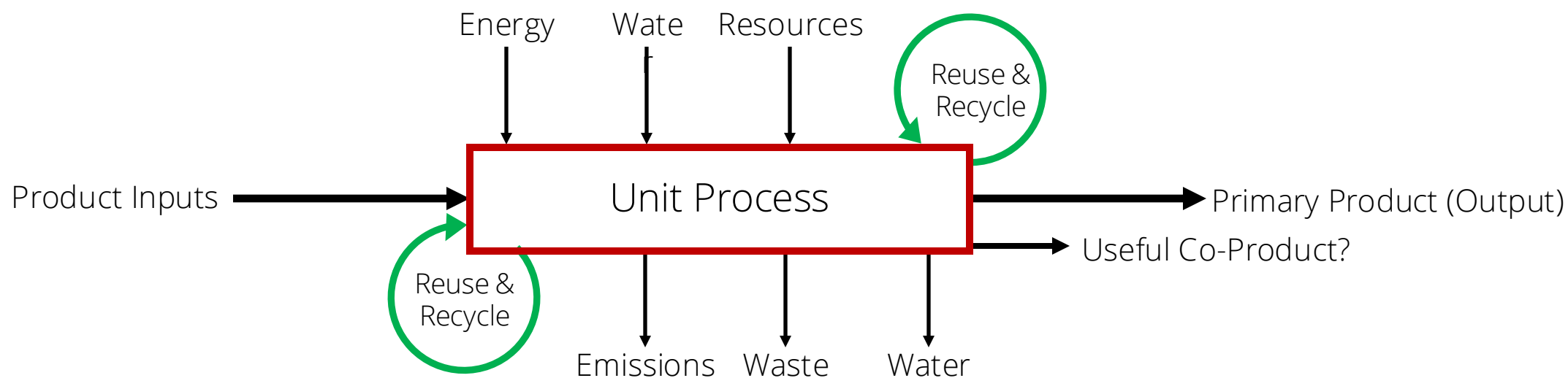


Individual units of an LCA

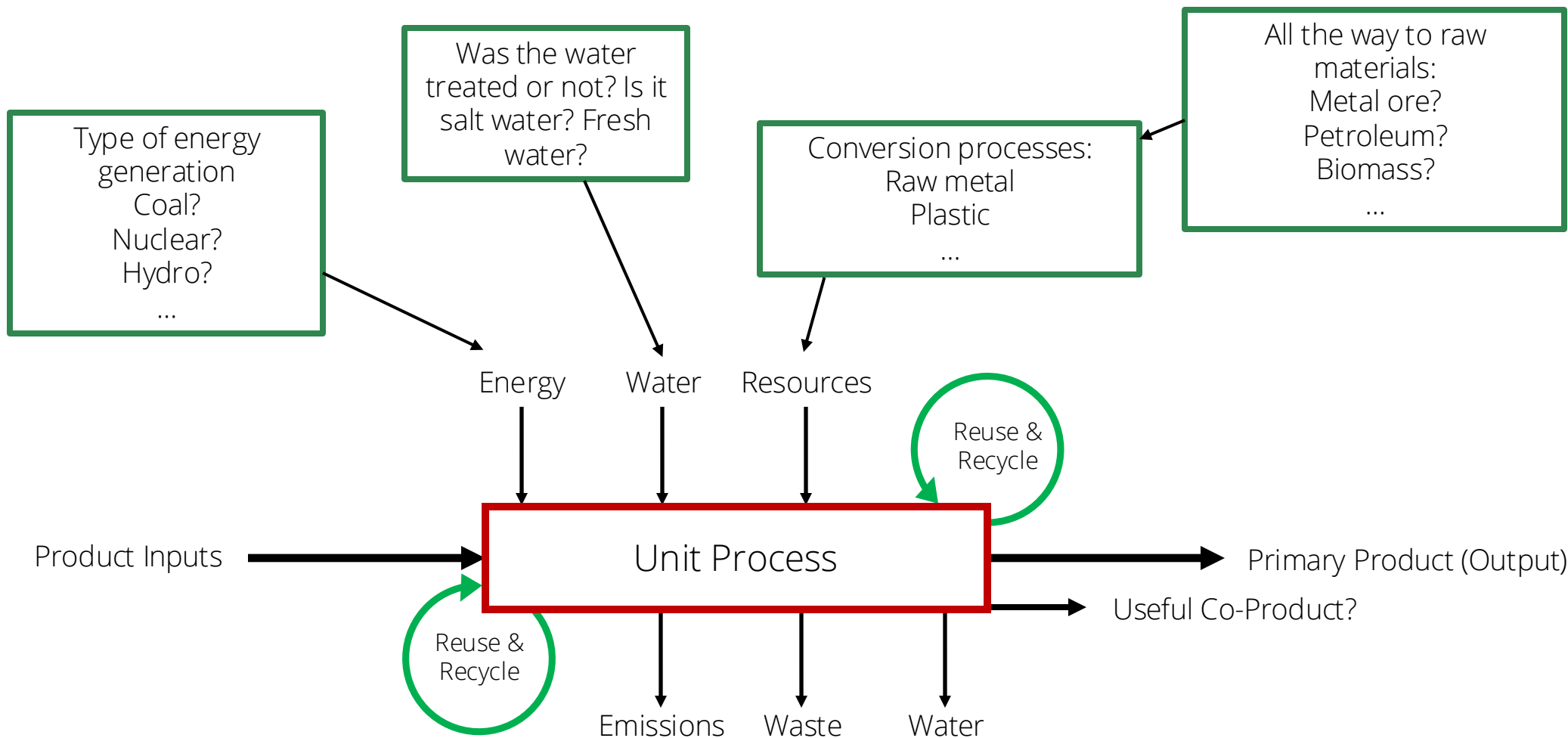


Each process is subdivided into the **unit processes**: a detailed input/output analysis is conducted.

Unit processes: Smallest element in the life cycle inventory analysis for which input, and output data are quantified and available.



Individual units of an LCA



Case Study: Plastic or Paper Bag?



Which is greener:
A plastic or a paper shopping bag?

An example:



Image by Anja from Pixabay



Image by Matthias Böckel from Pixabay



Case Study: Plastic or Paper Bag?



Table 1. The environmental impact of grocery bags for one month's shopping (483 items) in the UK.

1. Functional unit

2. Options



Option	global warming	acidification	smog formation	eutrophication	human toxicity	freshwater aquatic toxicity	resource depletion
paper	5.5	38	2.0	5.0	3.3	150	27
plastic	2.1	13	0.7	0.9	0.3	84	24
units	kg CO ₂ eq	g SO ₂ eq	g C ₂ H ₄ eq	g PO ₄ eq	kg DCB eq	g DCB eq	g Sb eq

Things to look for right away.

3. The impacts

4. The missing impacts

Edwards and Fry, Life cycle assessment of supermarket carrier bags, SC030148, Environment Agency, Bristol, UK, 2011.





Case Study: Plastic or Paper Bag?

Table 1. The environmental impact of grocery bags for one month's shopping (483 items) in the UK

Option	global warming	acidification	smog formation	eutrophication	human toxicity	freshwater aquatic toxicity	resource depletion	persistence
paper	5.5	38	2.0	5.0	3.3	150	27	
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units	kg CO ₂ eq	g SO ₂ eq	g C ₂ H ₄ eq	g PO ₄ eq	kg DCB eq	g DCB eq	g Sb eq	



1. Compare numbers within a column. Small numbers are good.

2. Include qualitative impacts in your decision

3. Never compare numbers between columns.

Edwards and Fry, Life cycle assessment of supermarket carrier bags, SC030148, Environment Agency, Bristol, UK, 2011.

Three rules about interpreting the table.



Case Study: Plastic or Paper Bag?



Table 1. The environmental impact of grocery bags for one month's shopping (483 items) in the UK.

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Which is greener?

Can we invent a new option that would be even better?

Edwards and Fry, Life cycle assessment of supermarket carrier bags, SC030148, Environment Agency, Bristol, UK, 2011.



Case Study: Styrofoam or Popcorn?



Has Styrofoam or Popcorn less environmental impact for packaging purposes?

The importance of function:



<https://www.thermalshipping.com/styrofoam-ban-impact/>



Image by Teresa Wilde from Pixabay



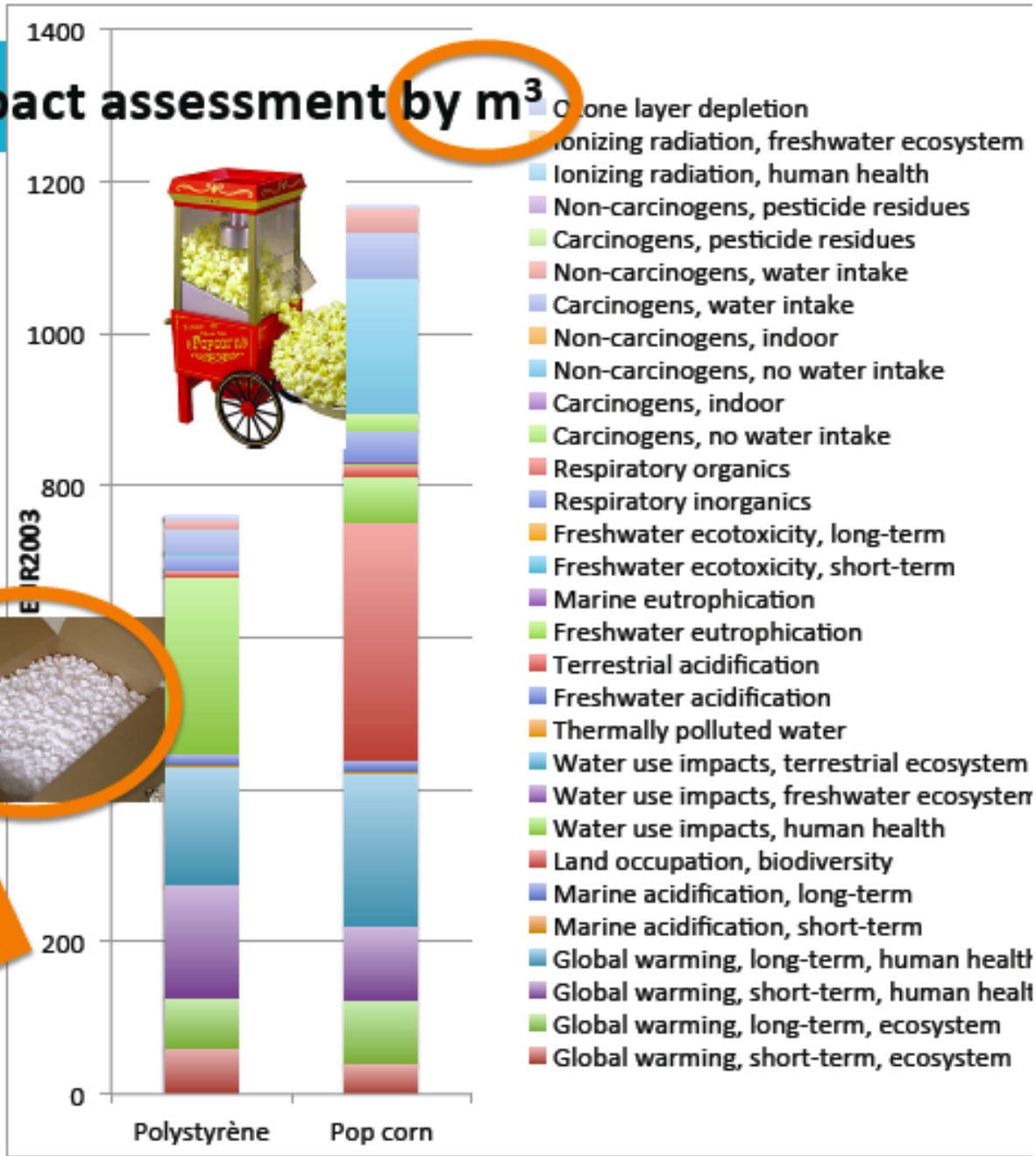
Comparative impact assessment by m³



The relevant function unit here is the volume!

It's essential to define well the functional unit for validity of conclusions!

Conclusions ?



And: Should we use food as a material?

In summary



Sustainability concepts and solution are powerful and, if used correctly, can have a profound impact.

- Definition of Sustainability
- Planetary Boundaries
- Socio-Economic Trends
- What is Sustainability not (and there are many myths)
- Circular Economy
- Life-Cycle-Assessment (LCA)





Yale School of
the Environment



Center for Green Chemistry &
Green Engineering at Yale

Advance Science

Catalyze
Implementation

Prepare the next
generation

Raise Awareness

Thank You!

For questions, please reach out:

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<https://greenchemistry.yale.edu/>



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