

# Emerging Technologies for the Circular Economy

## Lecture 1: Introduction to the Circular Economy Part 1

Prof. Dr. Benjamin Leiding (Clausthal)  
M.Sc. Arne Bochem (Göttingen)  
M.Sc. Anant Sujatanagarjuna (Clausthal)

## License

- This work is licensed under a **Creative Commons Attribution-ShareAlike 4.0 International License**. To view a copy of this license, please refer to <https://creativecommons.org/licenses/by-sa/4.0/> .
- Updated versions of these slides will be available in our [Github repository](#).

# MOTIVATION

## Question 1

- How old are you?  
→ Type your response in the poll field.

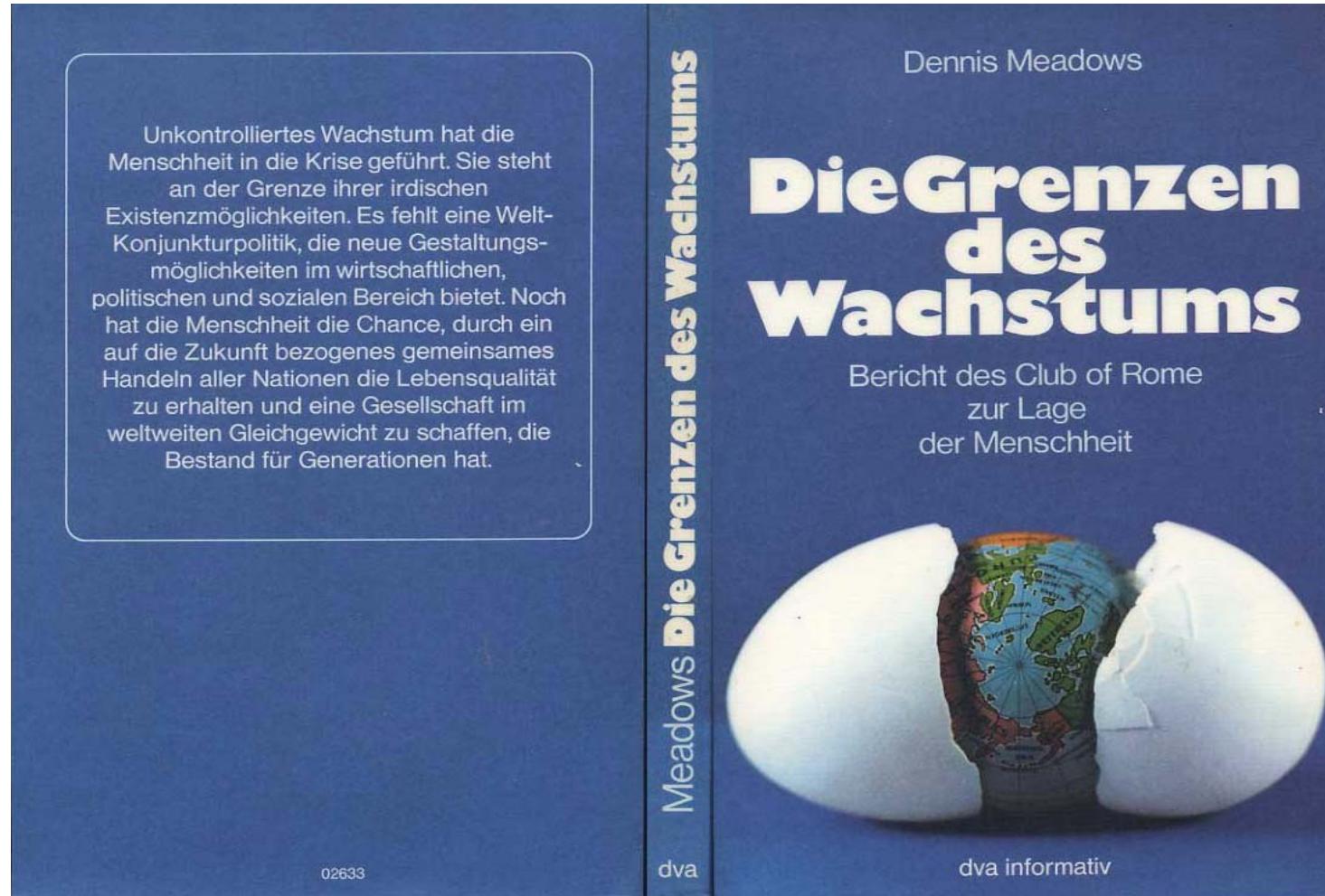
## Question 2

- Are you involved in any climate change or sustainability movement / organization / party / etc. - if yes, which one?
  - No? → Type “no”
  - Yes? → Type the name/abbreviation, e.g., “XR” (Extinction Rebellion), “FF” (Fridays for Future), etc.

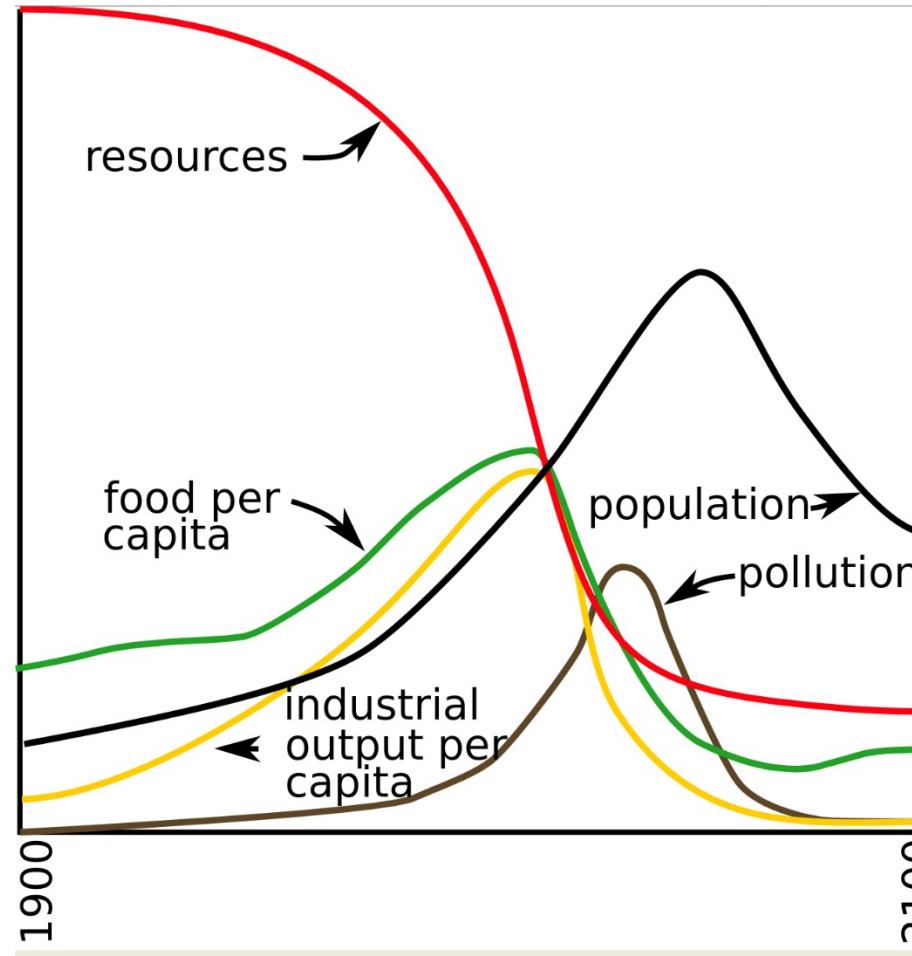
## Question 3

- Would you like to attend the lecture and Q&A live in Goslar?
  - Yes
  - No

# The Limits to Growth - 1972



# The Limits to Growth - World3 Standard Run

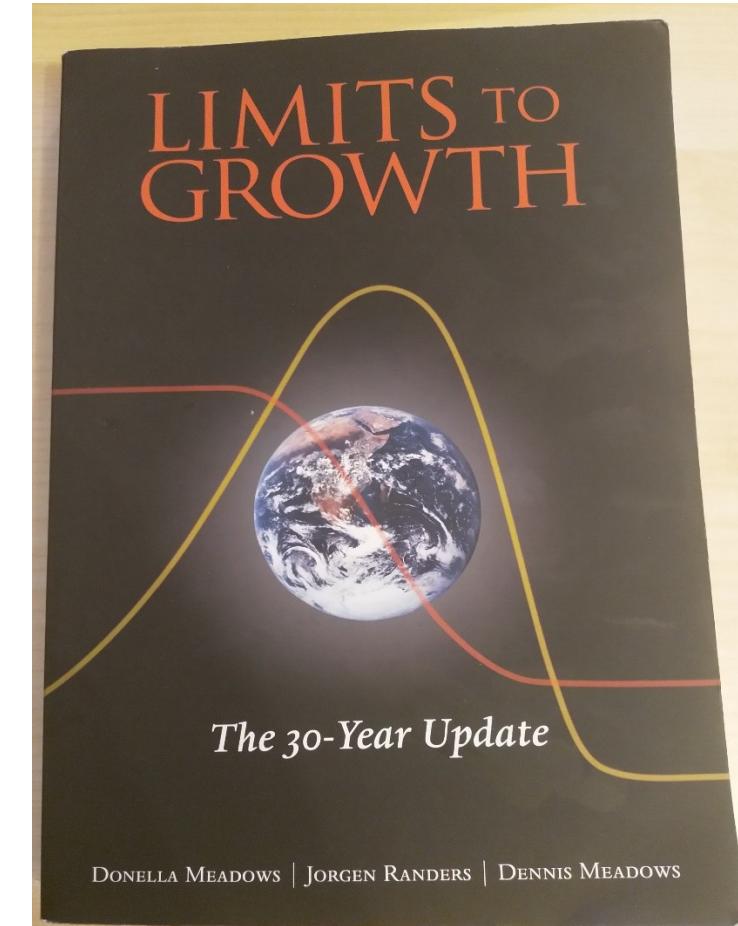
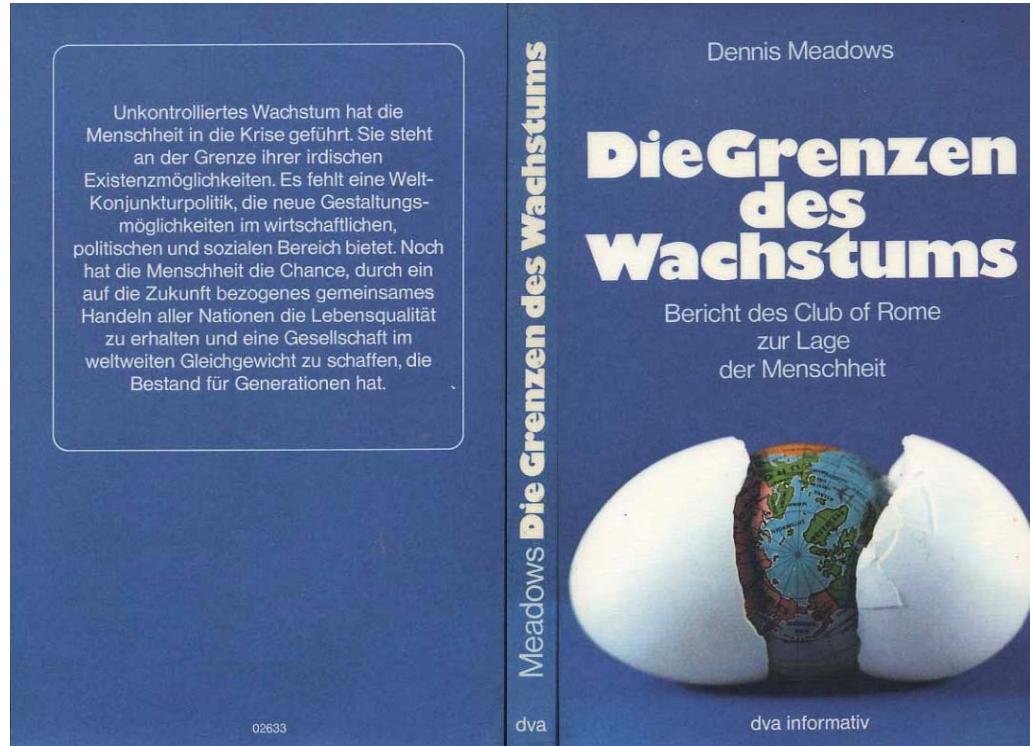


# The Limits to Growth - World3 Standard Run

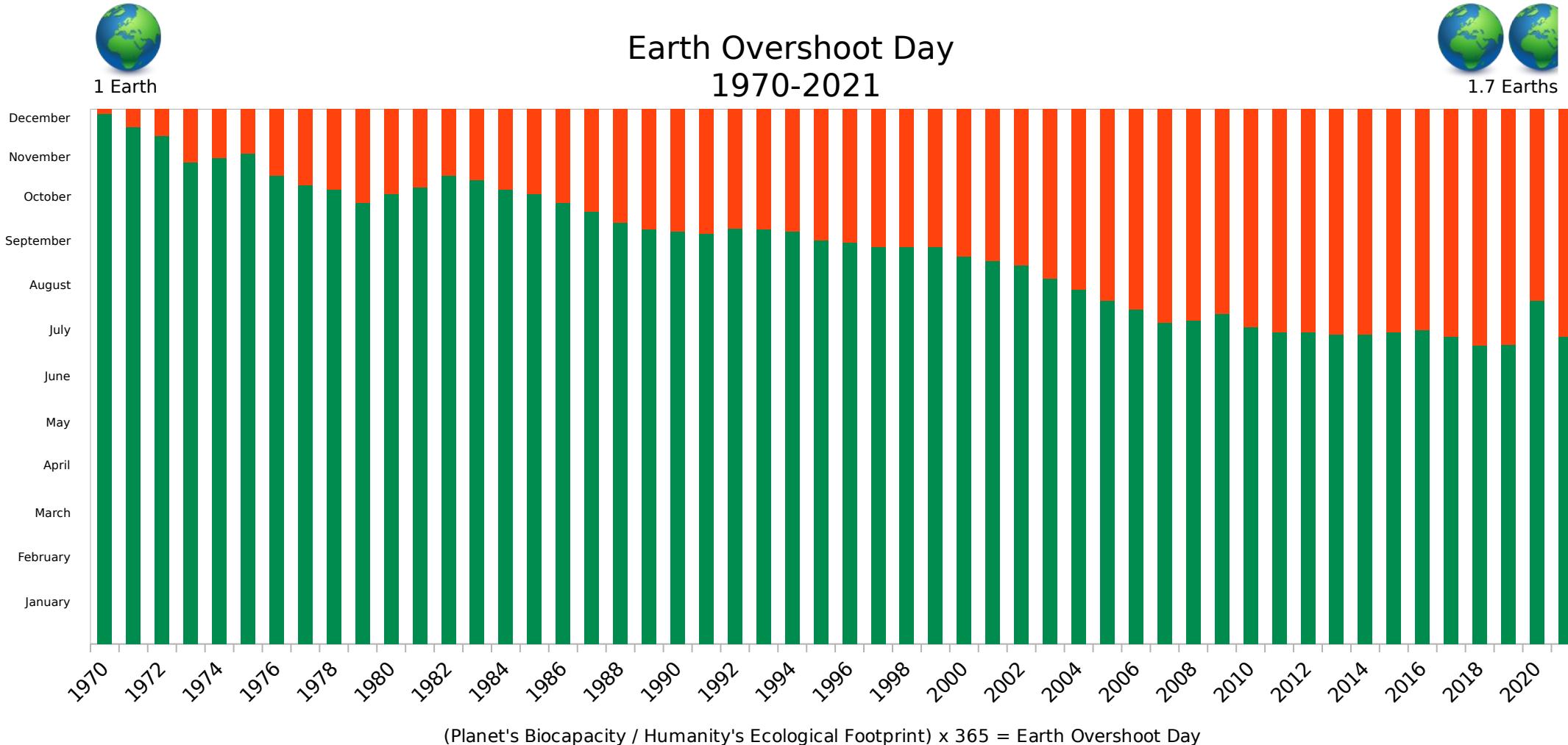


[Click Me](#)

# The Limits to Growth - 1972 / 2004



# We only have one planet - Resource Consumption



# We only have one planet - Environmental Pollution



1. "Landfill at Upernivik" by ulalume – <https://www.flickr.com/photos/96649248@N00/43867280734> – CC BY-NC-ND 2.0 (<https://creativecommons.org/licenses/by-nc-nd/2.0/>).
2. Christian Hüpfer – <https://flic.kr/p/aKXw2F> – CC BY-SA 2.0 (<https://creativecommons.org/licenses/by-sa/2.0/>).

# We only have one planet

## Environmental Pollution

- 3 of the 10 dirtiest european coal plants are located in Poland
- In which country/countries are the other 7 dirtiest coal plants located?



1. <https://ember-climate.org/insights/research/top-10-emitters-in-the-eu-ets-2021/>

2. John Englart – <https://www.flickr.com/photos/takver/11308053925/> – [CC BY-SA 2.0](#)

3. John Englart – <https://www.flickr.com/photos/takver/51658831095/> – [CC BY-SA 2.0](#)

# We only have one planet

## Environmental Pollution

- 3 of the 10 dirtiest European coal plants are located in Poland
- In which country/countries are the other 7 dirtiest coal plants located?
  - 7 of the 10 dirtiest European coal plants are located in **GERMANY**



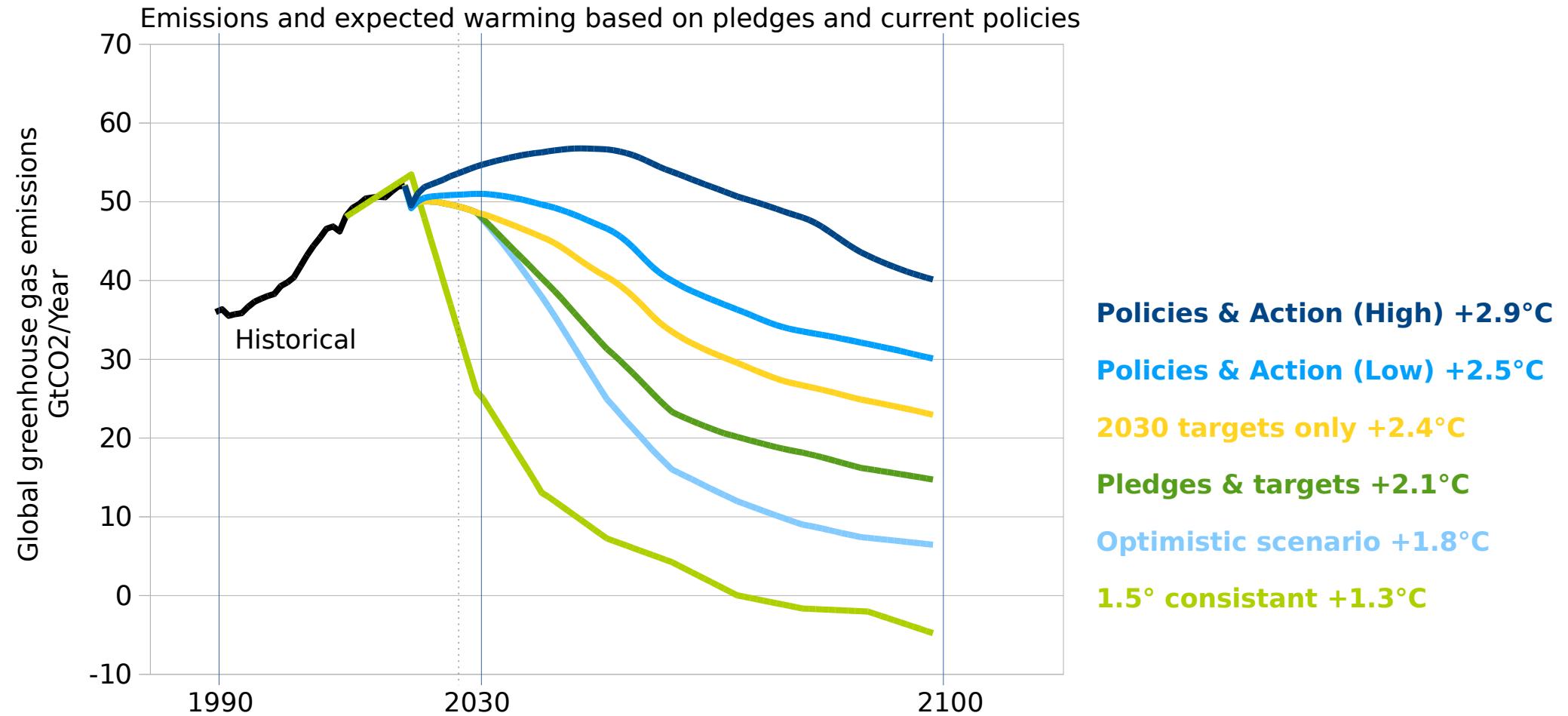
1. <https://ember-climate.org/insights/research/top-10-emitters-in-the-eu-ets-2021/>

2. John Englart – <https://www.flickr.com/photos/takver/11308053925/> – [CC BY-SA 2.0](#)

3. John Englart – <https://www.flickr.com/photos/takver/51658831095/> – [CC BY-SA 2.0](#)

# We only have one planet - Climate Change

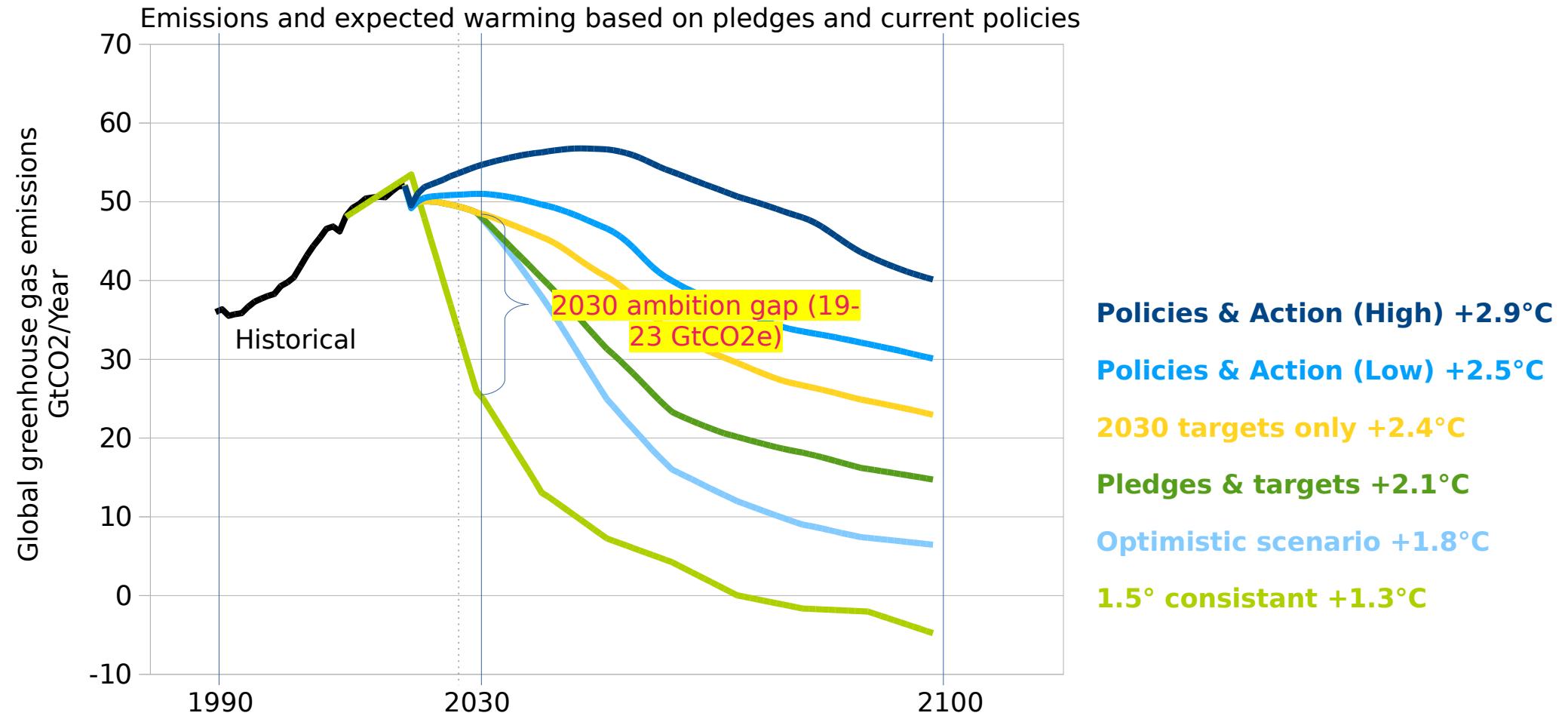
## 2100 Warming Predictions



Graph Recreated from [https://climateactiontracker.org/documents/999/CAT\\_2021-11\\_PublicData\\_EmissionsPathways.xlsx](https://climateactiontracker.org/documents/999/CAT_2021-11_PublicData_EmissionsPathways.xlsx)

# We only have one planet - Climate Change

## 2100 Warming Predictions



Graph Recreated from [https://climateactiontracker.org/documents/999/CAT\\_2021-11\\_PublicData\\_EmissionsPathways.xlsx](https://climateactiontracker.org/documents/999/CAT_2021-11_PublicData_EmissionsPathways.xlsx)

# We only have one planet - Health Impact of Climate Change

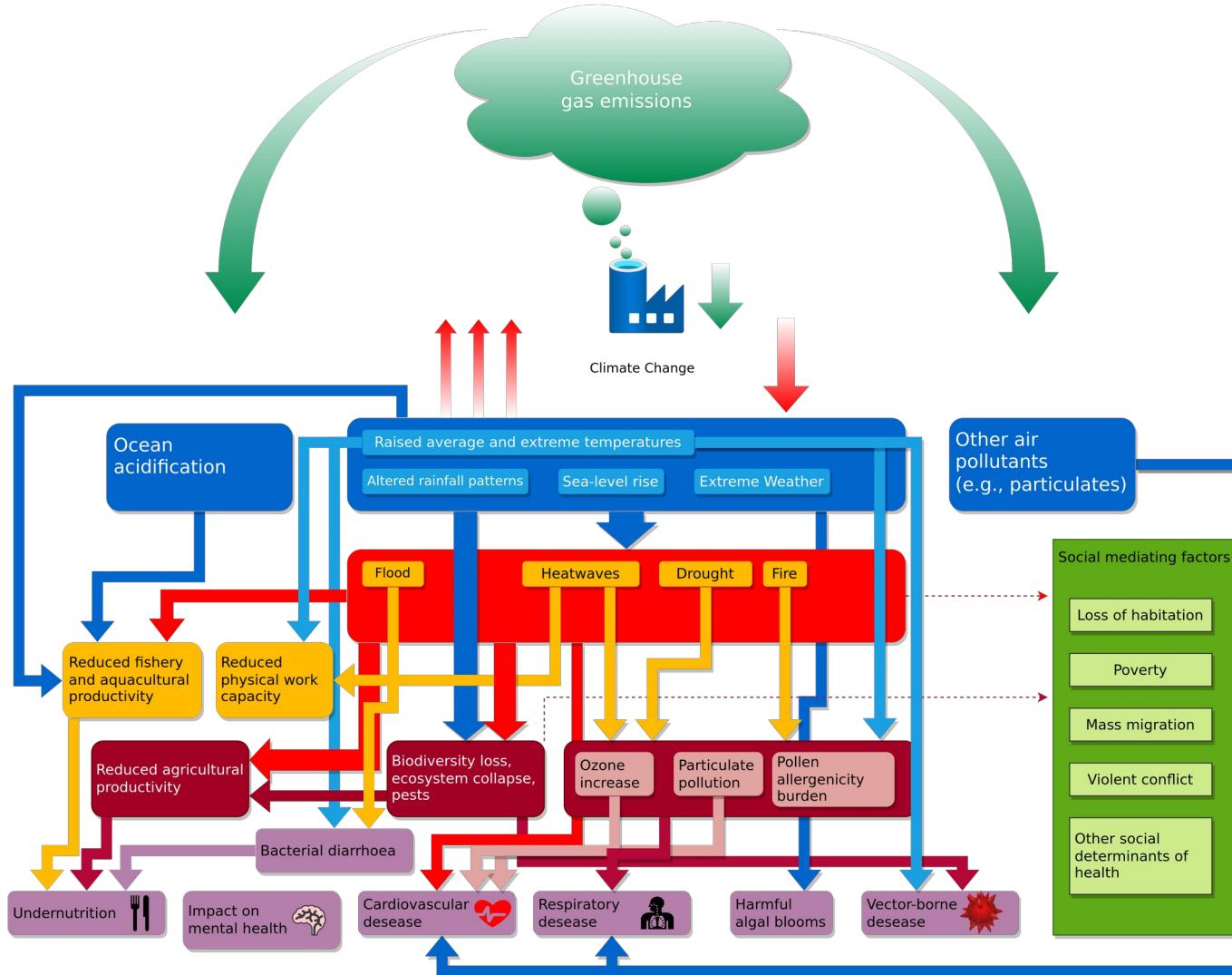


Figure adapted from: Watts, Nick, et al. (2017) – The Lancet Countdown: Tracking Progress on Health and Climate Change.

## 2019 UN Climate Action Summit in New York

*“change is coming, whether you like it or not”*

*Greta Thunberg*

[Click Me](#)

(start video at 1:50)

## 3 Key Challenges of the 21<sup>st</sup> Century

- 1) Climate change / Adaption to climate change
- 2) Environmental pollution
- 3) Dwindling non-renewable ressources

## Problem already solved?

**So we just reduce our CO<sub>2</sub> footprint and we are good?**

## Microsoft will be Carbon Negative by 2030

“By 2030 Microsoft will be carbon negative, and by 2050 Microsoft will remove from the environment all the carbon the company has emitted either directly or by electrical consumption since it was founded in 1975.”

## Apple will be Carbon Neutral by 2030

July 2020

“Apple today unveiled its plan to become carbon neutral across its entire business, manufacturing supply chain, and product life cycle by 2030. The company is already carbon neutral today for its global corporate operations, and this new commitment means that by 2030, every Apple device sold will have net zero climate impact.”

## Polestar - 2030 Climate-neutral Car

“...we’re embarking on our greatest journey so far: challenging ourselves to create a climate-neutral car by 2030, by reducing emissions throughout supply chain and production.”

## Polestar - 2030 Climate-neutral Car

“...we’re embarking on our greatest journey so far: challenging ourselves to create a climate-neutral car by 2030, by reducing emissions throughout supply chain and production.”

“Relying on the current trend of offsetting by planting trees is not sustainable in the long run. It would mean using too much land, and the long-term carbon-storage capacity of forests and soils is not well known. Offsetting by planting trees also risks contributing to monocultures and loss of biodiversity. Additionally, there can be no guarantee that a forest won’t later be logged, devastated by a forest fire or altered by climate change.”

## Problem already solved?

**It is not only about CO2...**

# Greenwashing?

<b>Apple iPad Pro 11" 2018</b>	<ul style="list-style-type: none"><li>• Gobs of adhesive hold most everything in place, making all repairs more difficult.</li><li>• The battery is secured with both easier-to-remove stretch-release tabs and conventional, non-removable adhesive.</li><li>• The USB-C port is modular and can be independently replaced.</li></ul>
<b>Microsoft Surface Pro 6 2018</b>	<ul style="list-style-type: none"><li>• All repairs require first removing the display assembly—which is stubbornly glued in place, expensive, and prone to shattering.</li><li>• The battery is firmly glued in place, with its connector pinned under the motherboard—requiring near-total disassembly for service.</li><li>• Once upon a time, Surface Pro storage was removable—but not in this version.</li></ul>
<b>Apple iPad Air 3 2019</b>	<ul style="list-style-type: none"><li>• Battery replacement is possible, but still unnecessarily difficult.</li><li>• Gobs of adhesive hold many parts and cables in place, complicating all repairs.</li><li>• Many components are modular and can be replaced independently, but the Lightning port is soldered to the logic board.</li></ul>
<b>Apple iPad 7 2019</b>	<ul style="list-style-type: none"><li>• As with all iPads, a solid barrier of very strong adhesive hinders all repairs.</li><li>• The Lightning port, a common point of failure, is soldered to the logic board.</li><li>• More adhesive holds nearly everything else in place. Battery and logic board replacements are particularly obnoxious.</li></ul>
<b>Apple iPad Mini 5 2019</b>	<ul style="list-style-type: none"><li>• Battery replacement is possible, but still unnecessarily difficult.</li><li>• Gobs of adhesive hold many parts and cables in place, complicating all repairs.</li><li>• Removing the home button is tough, and will be required for display replacement if you want to keep Touch ID functionality.</li></ul>

## How much am I contributing to this mess?

- What is your *Ecological Footprint*?
  - How many planets do we need if everybody lives like you?
  - When is your personal *Overshoot Day*?
  - [Compute YOUR ecological footprint](https://www.footprintcalculator.org)



# Origins of the Carbon Footprint

# Origins of the Carbon Footprint

*"The first step to reducing your emissions is to know where you stand. Find out your #carbonfootprint with our new calculator & share your pledge today!"* - BP (British Petroleum)

## Who Emits CO2?

- 100 companies produced more than 70% of the world's greenhouse gas emissions between 1988 and 2017
- Guess who is on the list?

<https://www.theguardian.com/sustainable-business/2017/jul/10/100-fossil-fuel-companies-investors-responsible-71-global-emissions-cdp-study-climate-change>

## Who Emits CO2?

- 100 companies produced more than 70% of the world's greenhouse gas emissions between 1988 and 2017
- Guess who is on the list?

- 1) China (Coal) → 14.32%
- 2) Saudi Arabian Oil Company (Aramco) → 4.50%
- 3) Gazprom OAO → 3.91%
- 4) National Iranian Oil → 2.28%
- 5) ExxonMobil Corp → 1.98%
- 6) Coal India → 1.87%
- 7) Petroleos Mexicanos (Pemex) → 1.87%
- 8) Russia (Coal) → 1.86%
- 9) Royal Dutch Shell PLC → 1.67%
- 10) China National Petroleum Corp (CNPC) → 1.56%
- 11) **BP PLC → 1.53%**
- 12) Chevron Corp → 1.31%

## Who Emits CO2?

- 100 companies produced more than 70% of the world's greenhouse gas emissions between 1988 and 2017
- Guess who is on the list?

- 1) China (Coal) → 14.32%
- 2) Saudi Arabian Oil Company (Aramco) → 4.50%
- 3) Gazprom OAO → 3.91%
- 4) National Iranian Oil → 2.28%
- 5) ExxonMobil Corp → 1.98%
- 6) Coal India → 1.87%
- 7) Petroleos Mexicanos (Pemex) → 1.87%
- 8) Russia (Coal) → 1.86%
- 9) Royal Dutch Shell PLC → 1.67%
- 10) China National Petroleum Corp (CNPC) → 1.56%
- 11) **BP PLC → 1.53%**
- 12) Chevron Corp → 1.31%

Blaming individuals and denying any responsibility →  
great strategy!

<https://www.theguardian.com/sustainable-business/2017/jul/10/100-fossil-fuel-companies-investors-responsible-71-global-emissions-cdp-study-climate-change>

# Emotional Ecological Liabilities - Watson and Chomsky

# Emotional Ecological Liabilities - Watson and Chomsky





**What are you gonna tell you children?**

# What are you gonna tell you children?



*"I am afraid of losing my child  
to a resource war because of a  
climate collapse"*

# TU Clausthal - Research Profile

## About us

### Welcome to Clausthal University of Technology

TU Clausthal is a substantial producer of research and is exceptionally well connected both nationally and internationally. This is evidenced by its high volume of third-party resources and the many successful partnerships it maintains with universities, research institutions, and businesses in the region, across the country, and throughout the world. Around 80 professors, 4,000 students, and some 1,100 employees enjoy short distances between the places they need to be, one another's personal attention, and the varied landscapes of the Upper Harz amid sites of UNESCO World Heritage.

TU Clausthal is the most significant factor in the region's economy and its largest employer. There is close collaboration between the academic and private sectors, facilitating the journey from fundamental research to real-life applications. And the overarching theme across all this work is the **circular economy**. In comprehensively pursuing the principle of a resource-efficient, regenerative economic order, TU Clausthal is taking responsibility for the future. With climate change and digitalization under way, it aims to support the establishment of a sustainable society.

TU Clausthal's degree programs can often be found in the top tier of the CHE ranking. With approximately 40% of its students from outside Germany, representing more than 100 different countries, TU Clausthal is the epitome of internationalism. Alongside this cosmopolitanism, the cornerstones of the university's vision for the future comprise a pronounced focus on practical application, outstanding levels of attentive support for students, and the involvement of broader society.

TU Clausthal is divided into three faculties, 35 institutes, and six interdisciplinary research centers. Apart from its main location in Clausthal-Zellerfeld, the university has two additional sites, namely its Energy Campus in Goslar and the Drilling Simulator Celle – German Center for High Performance Drilling Technology and Automation.

Beyond that, students and employees enjoy the international atmosphere at Clausthal University of Technology, the extensive nature of the Harz Mountains and the over 60 different sports ranging from skiing to sailing and mountain biking offered by the Sports Institute.



Professor Dr. rer. nat. Joachim Schachtner  
President of Clausthal University of Technology

#### ADDITIONAL INFORMATIONEN

[Our Vision at TU Clausthal](#)

Facts

## TU Clausthal's research profile

Our research, teaching, and technology transfer are all part of the interdisciplinary endeavor to tackle the great challenge facing our society: to safeguard the sustainable supply of resources and advance the transformation of our energy system under the onset of climate change. The spotlight is on systemic approaches to the creation of a circular economy.

Next to its narrow definition as an economic order that minimizes waste, the circular economy also encompasses renewable energy and digital management of the whole system. Digitalization has special significance, since it is the only means by which industrial processes designed for the linear system can be successfully transformed to suit a circular one. The problem-solving work is grounded in the academic disciplines of mathematics and computer science, natural sciences, engineering, business, and economics. Additionally, combining knowledge of materials with understanding of processes is one of TU Clausthal's key capabilities, which radiates into all its research areas. The university has organized the totality of its research activities into four areas:

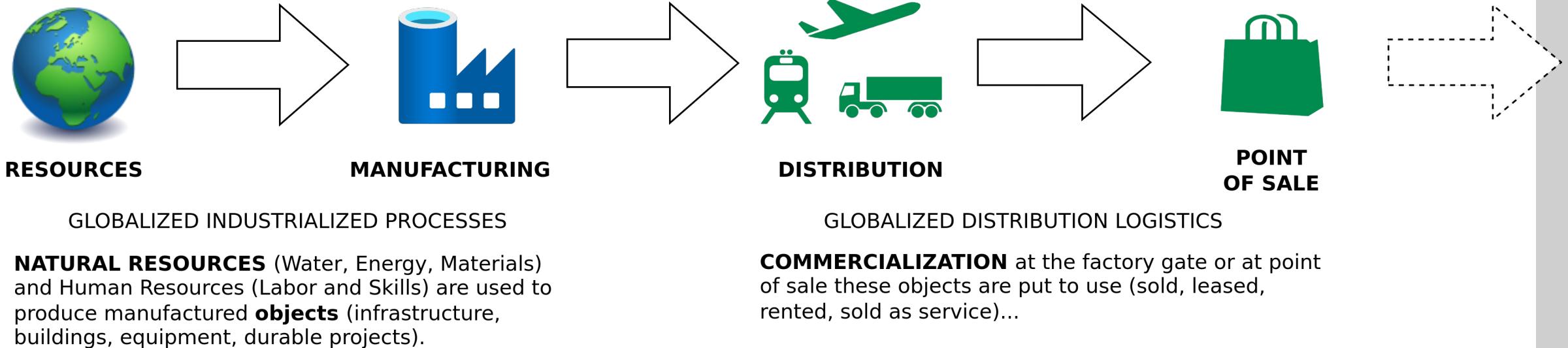
1. Sustainable Energy Systems
2. Raw-Materials Supply and Resource Efficiency
3. New Materials and Processes for Competitive Products
4. Digitalization for a Sustainable Society

Under the umbrella of the circular economy, interdisciplinary and closely dovetailed study is engaged in within and across the research areas. The six research centers at TU Clausthal provide an ideal platform for this in practice. The research areas and the focused, consistent work on their continuous strategic development form the basis of our university's outstanding visibility on the national and international stage.

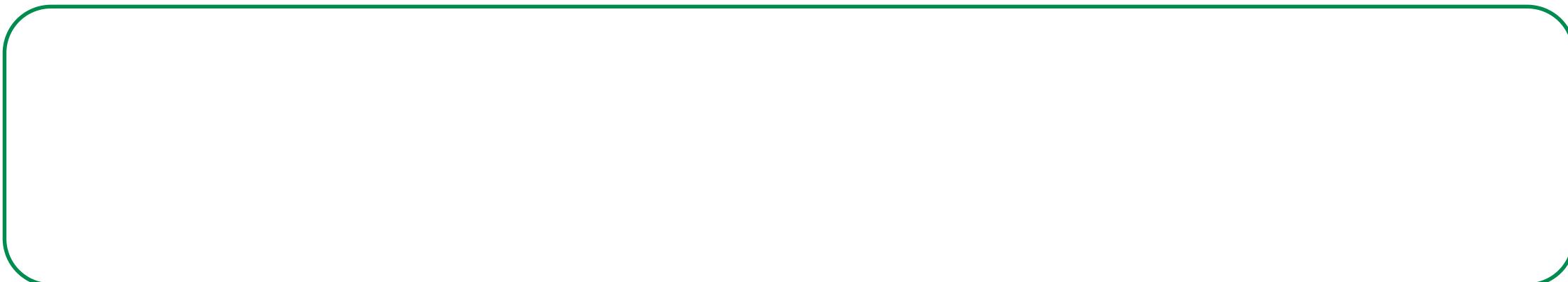
The holistic view inherent in the circular economy addresses not only technological but also behavioral and economic issues. The three dimensions of sustainability – environmental, social, and economic – are essential to the transition of our energy and raw-materials systems and to the necessary transformation of society. For that to succeed, public approval of the proposed technological solutions and sustainable business models is indispensable. This aspect is actively included in the processes of research and technology-transfer as well as teaching at TU Clausthal.

# THE LINEAR (INDUSTRIAL) ECONOMY

# The Linear (Industrial) Economy



## Linear Economy - Definition



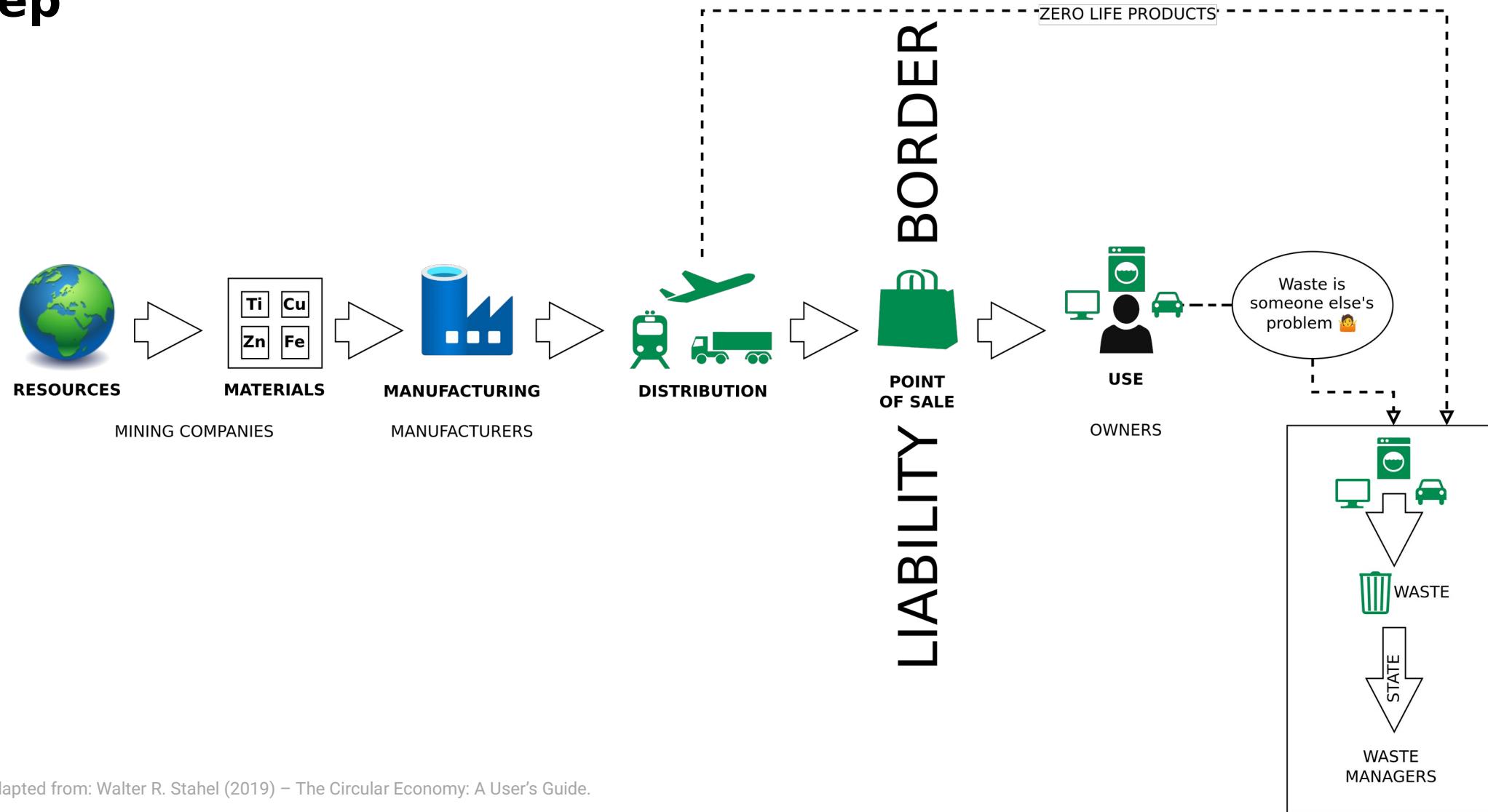
## Linear Economy - Definition

“Take – Make – Dispose”

## Linear Industrial Economy - Definition

“Its objectives are to maintain value (not to create value added), to optimise stock management (not flows) and to increase the efficiency of using goods (not of producing goods)”

# The Linear (Industrial) Economy - Waste Management as last Step



# Horrible Waste Management - Example 1



# Horrible Waste Management - Example 1



## Horrible Waste Management - Example 1

→ 2 generations profited from cheap nuclear energy

## Horrible Waste Management - Example 1

- 2 generations profited from cheap nuclear energy
- 40,000 generation will have to live with the waste

## Horrible Waste Management - Example 2



"Pollution Plastique" by Mouenthias is licensed with CC BY-SA 4.0. To view a copy of this license, visit <https://creativecommons.org/licenses/by-sa/4.0/>

## Horrible Waste Management - Example 2

- We are consuming about 2000 tiny pieces of plastic every week.



"Pollution Plastique" by Mouenthias is licensed with CC BY-SA 4.0. To view a copy of this license, visit <https://creativecommons.org/licenses/by-sa/4.0/>

Wijnand de Wit and Nathan Bigaud for the WWF (2019) – No Plastic in Nature: Assessing Plastic Ingestion from Nature to People.

## Horrible Waste Management - Example 2

- We are consuming about 2000 tiny pieces of plastic every week.
- That is a credit card every week!
- That's approximately 21 grams a month, or just over 250 grams a year.



"Pollution Plastique" by Mouenthias is licensed with CC BY-SA 4.0. To view a copy of this license, visit <https://creativecommons.org/licenses/by-sa/4.0/>

Wijnand de Wit and Nathan Bigaud for the WWF (2019) – No Plastic in Nature: Assessing Plastic Ingestion from Nature to People.

# Horrible Waste Management - Example 2

## Global Flows of Plastic Packaging Materials in 2013

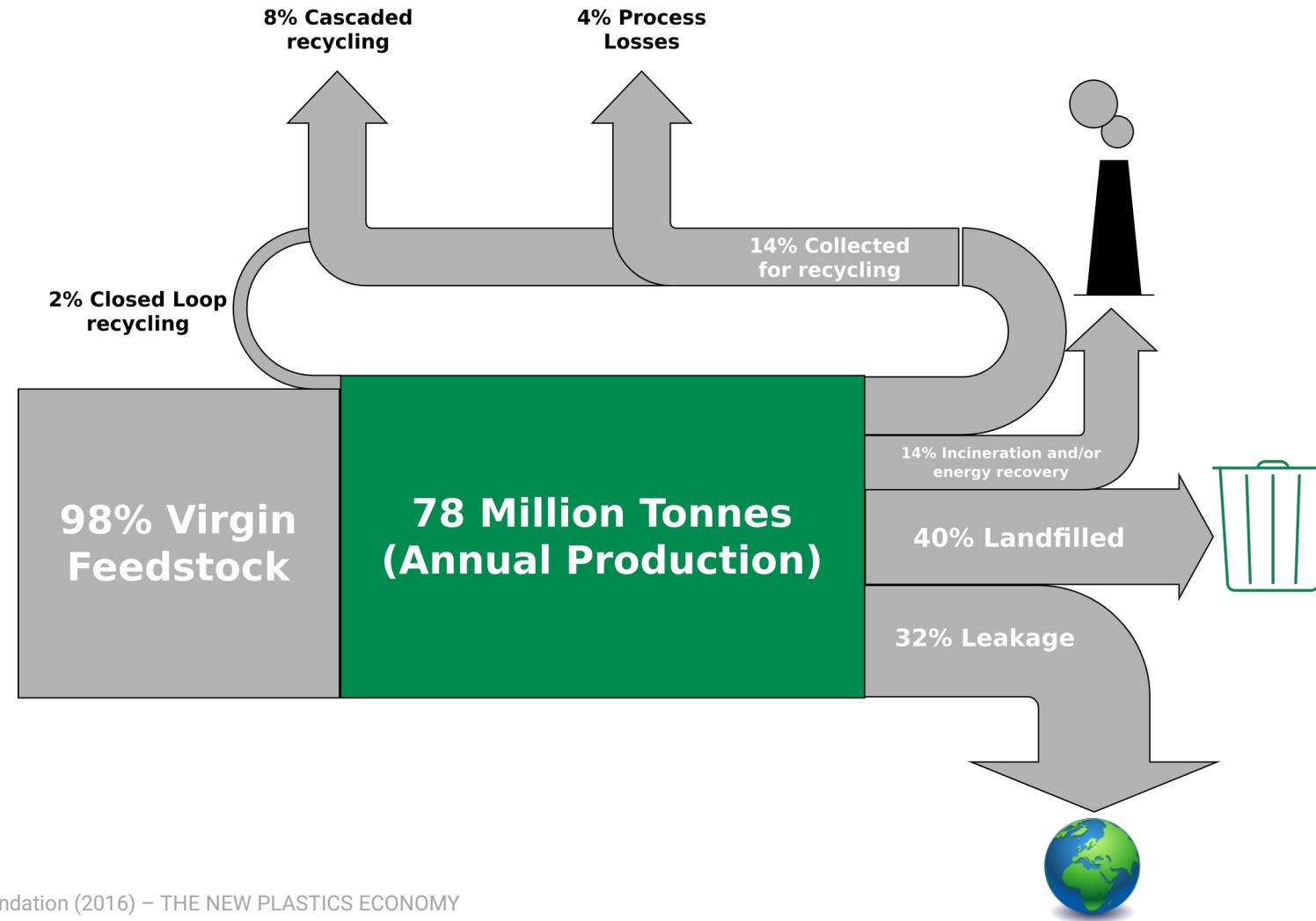


Figure adapted from: Ellen MacArthur Foundation (2016) – THE NEW PLASTICS ECONOMY

# Horrible Waste Management - Example 2

## Global Flows of Plastic Packaging Materials in 2013

- In 2050, there will be more plastic than fish in the ocean (by weight)

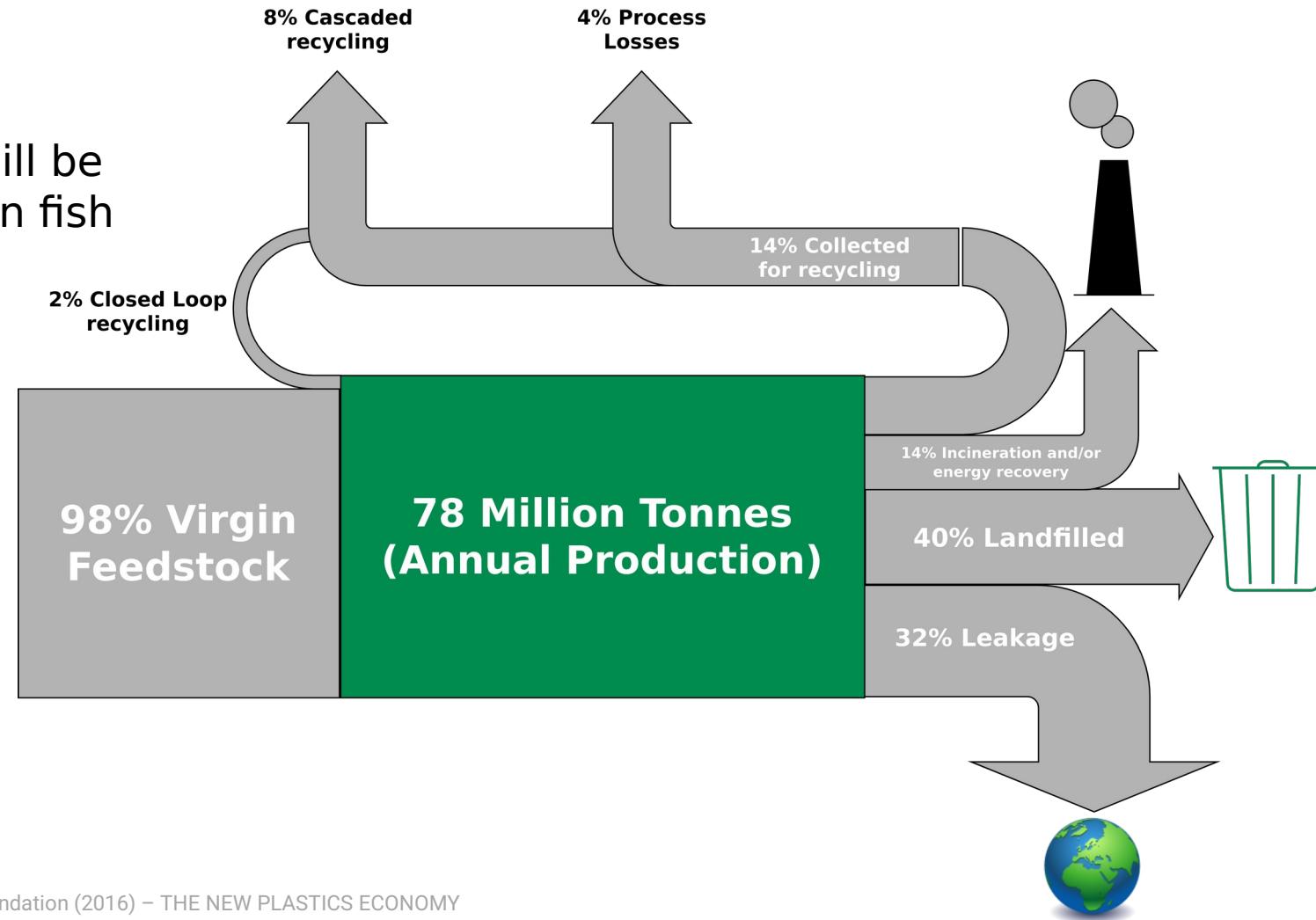


Figure adapted from: Ellen MacArthur Foundation (2016) – THE NEW PLASTICS ECONOMY

# The Limits to Recycling

- Recycling often requires a lot of energy
- Some materials cannot be recycled at all (yet)
- Impurities are challenging
- Often requires a lot of manual labor
- Recycled material often with lower quality than input material
- False sense of safety!

**I am not saying you should stop recycling!**

# The Limits to Recycling

- Recycling often requires a lot of energy
- Some materials cannot be recycled at all (yet)
- Impurities are challenging
- Often requires a lot of manual labor
- Recycled material often with lower quality than input material
- False sense of safety!

**I am not saying you should stop recycling!**

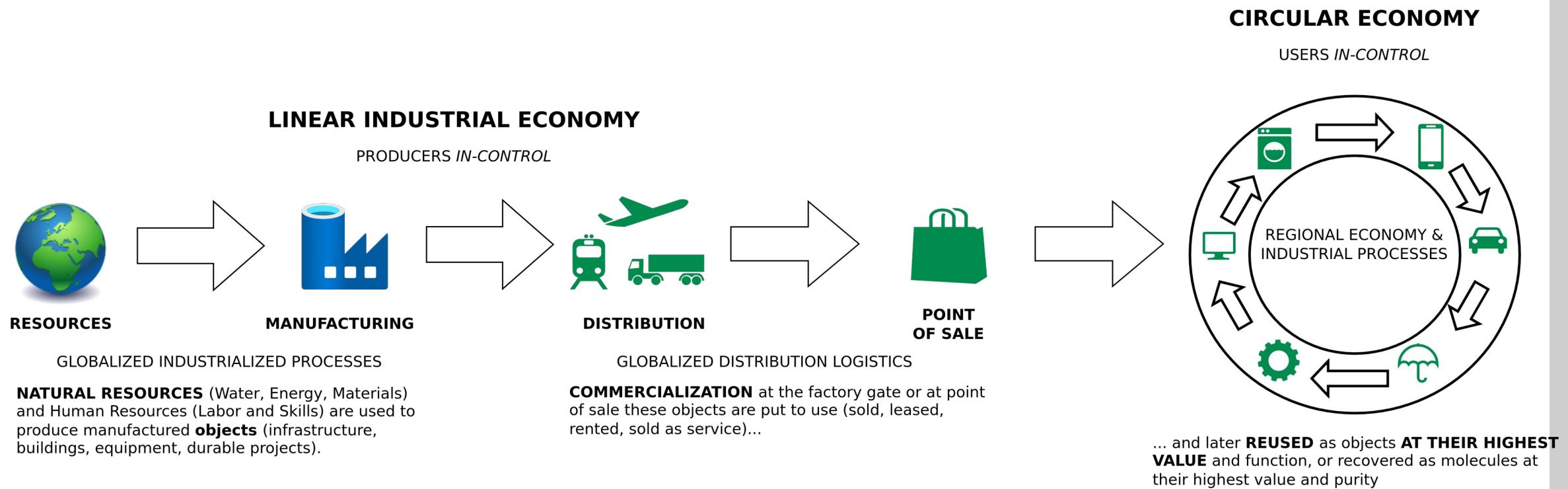
→ Recycling is great but it is better to make sure that we do not have to recycle anything.  
→ Buying less (e.g., only the essentials) is way more effective.

*"We buy things we don't need, to impress people we don't like." -  
Tyler Durden / Chuck Palahniuk*

# Waste Management

**Waste = Inefficiency**

# The Linear (Industrial) Economy



# Emerging Technologies for the Circular Economy

## Lecture 2: Introduction to the Circular Economy Part 2

Dr. Benjamin Leiding (Clausthal)  
M.Sc. Arne Bochem (Göttingen)

# Questions?