



Design for Repairability



di:angewandte

Universität für angewandte Kunst Wien
University of Applied Arts Vienna

www.dieangewandte.at

Gastvortrag, 21.6.2022, FH Kufstein

Peter Knobloch – Institute of Design / Industrial Design 2, Computer Studio

peter.knobloch@uni-ak.ac.at

Contents

- Origin & intent of the lecture
- Ressource efficiency & circular economy
- Technical boundaries & pareto efficiency
- Potentials of closing, minimizing and extending
- Right to repair
- Design Considerations

Origin & intent of the lecture

Permanere & 100jährige Waschmaschine

Association for the Research and Development of Sustainable Products and Solutions

- **2013** Project idea
- **2017** First designs
- **2018** Founding of the association
- **2018** Funding aws impulse xs
- **2020** Funding aws Creative Impact



Photo: Clemens Fabry / Die Presse, f.l.t.r.: Bernhard Ranner, Billie Rehwald, Daniel Kloboucnik, Peter Knobloch

Umweltberatung & funding

- **2020** Approached by the Umweltberatung (Juli)
- **2020** Funding requested at VKS Verpackungskordinierungsstelle (October)
- **2021** Funding granted (January)



**DIE UMWELT
BERATUNG**

Syllabus / dates 2022S

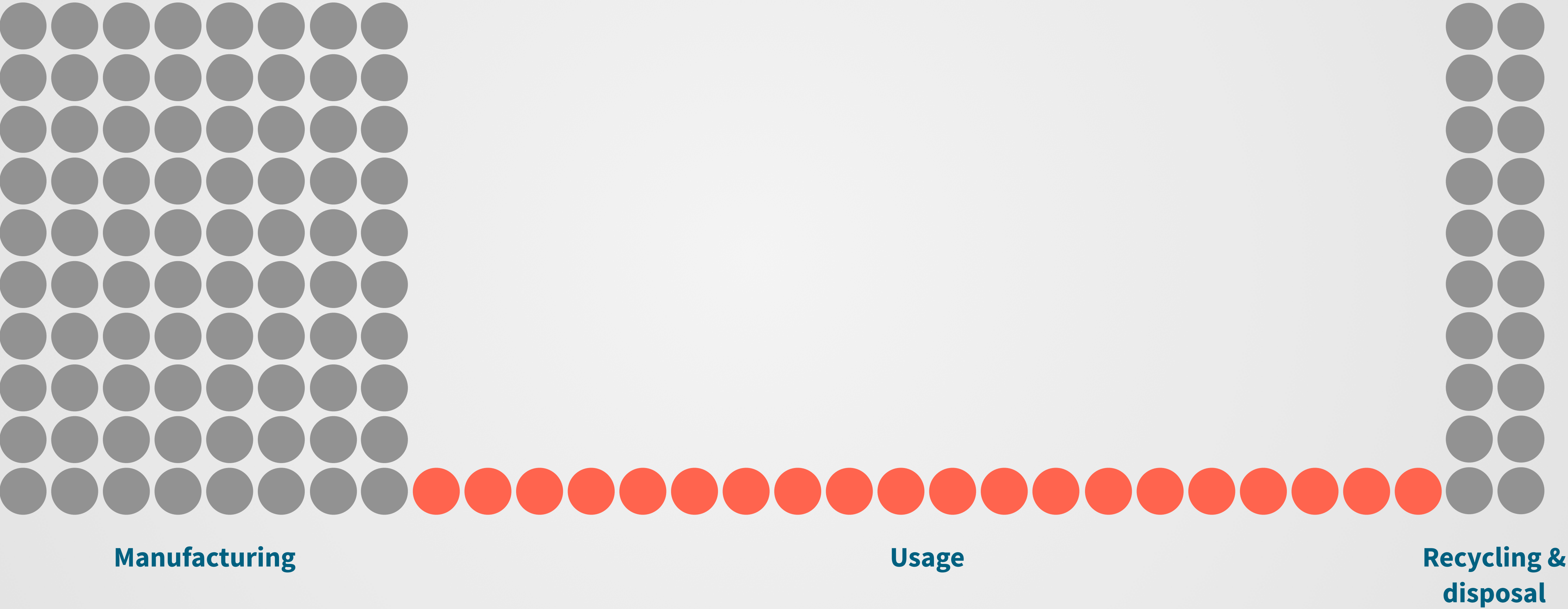
9 course dates, Wednesday 14:30–17:00 (lectures, 2.5h) / 14:00–17:00 or 14:30–17:30 (excursions & workshops 3.0h)

	09.03.	16.03.	17.03.	23.03.	30.03.	06.04.	27.04.	04.05.	11.05.	18.05.	25.05.
	Presence	Excursion	Online	Presence	Presence	Presence	Online	Workshop	Workshop	Presence	Online
14:00											
14:30											
15:00											
15:30		Excursion	Online							Guest	Guest
16:00	Lecture	RUSZ, DRZ, MA48	Event	Lecture	Lecture	Lecture	Guest	Workshop	Workshop	lecture	lecture
16:30							lecture	Group A: Bicycles (Lenkerbande)	Group B: Smartphones (Wir reparieren es)	Rainer Pamminger (Ecodesign, TU Wien)	Bernhard Stitzl (BSH Haushalts- geräte)
17:00											
17:30											

TBD to be determined (guest lecturer contacted but not confirmed yet)

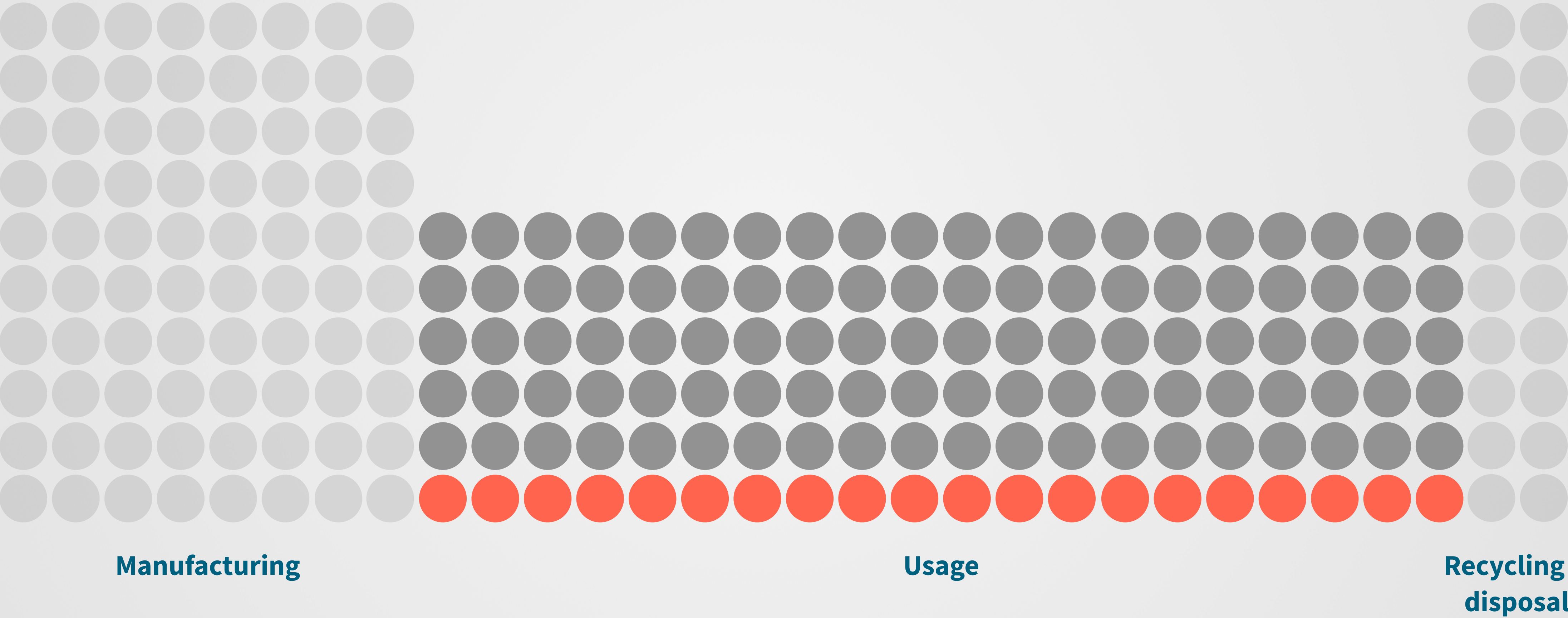
Ressource efficiency

Resource requirements



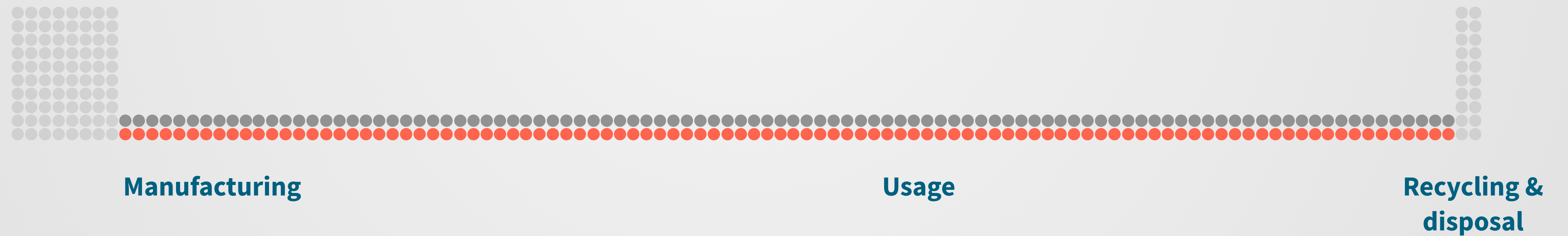
● „Grey“ resource requirements

Resource requirements



● „Grey“ resource requirements

Resource requirements



● „Grey“ resource requirements

Closing, minimizing & extending

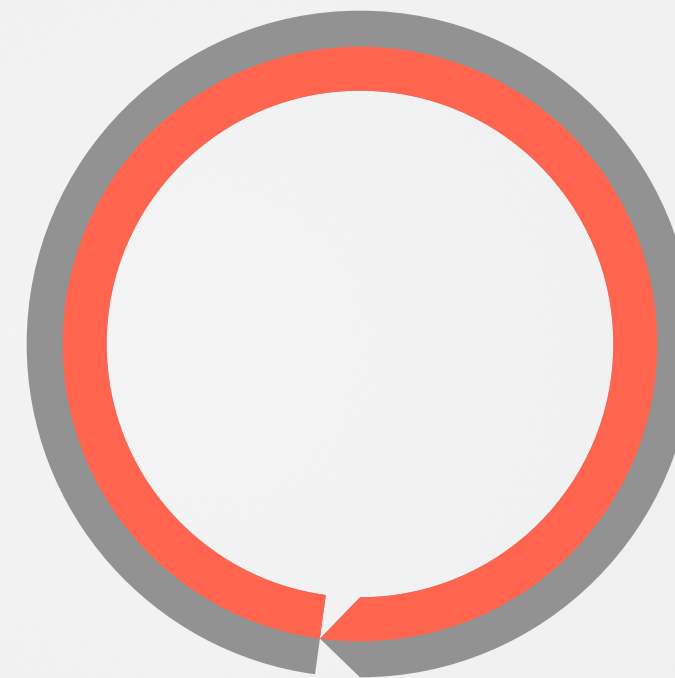
3 possibilities to improve resource efficiency



**Open
resource flow**
Trivial



**Closing
resource flow**
Challenging



**Minimizing
resource requirements**
Challenging



**Extending
life span**
Trivial

*Source: Own representation based on Walter R. Stahel: The Utilization-Focused Service Economy: Resource Efficiency and Product-Life Extension (National Academy Press **1994**)*

Circular economy

Spaceship earth

„The closed economy of the future might similarly be called the "spaceman" economy, in which the earth has become a single spaceship, without unlimited reservoirs of anything, either for extraction or for pollution, and in which, therefore, man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy.“

—Kenneth E. Boulding, The Economics of the Coming Spaceship Earth, 1966

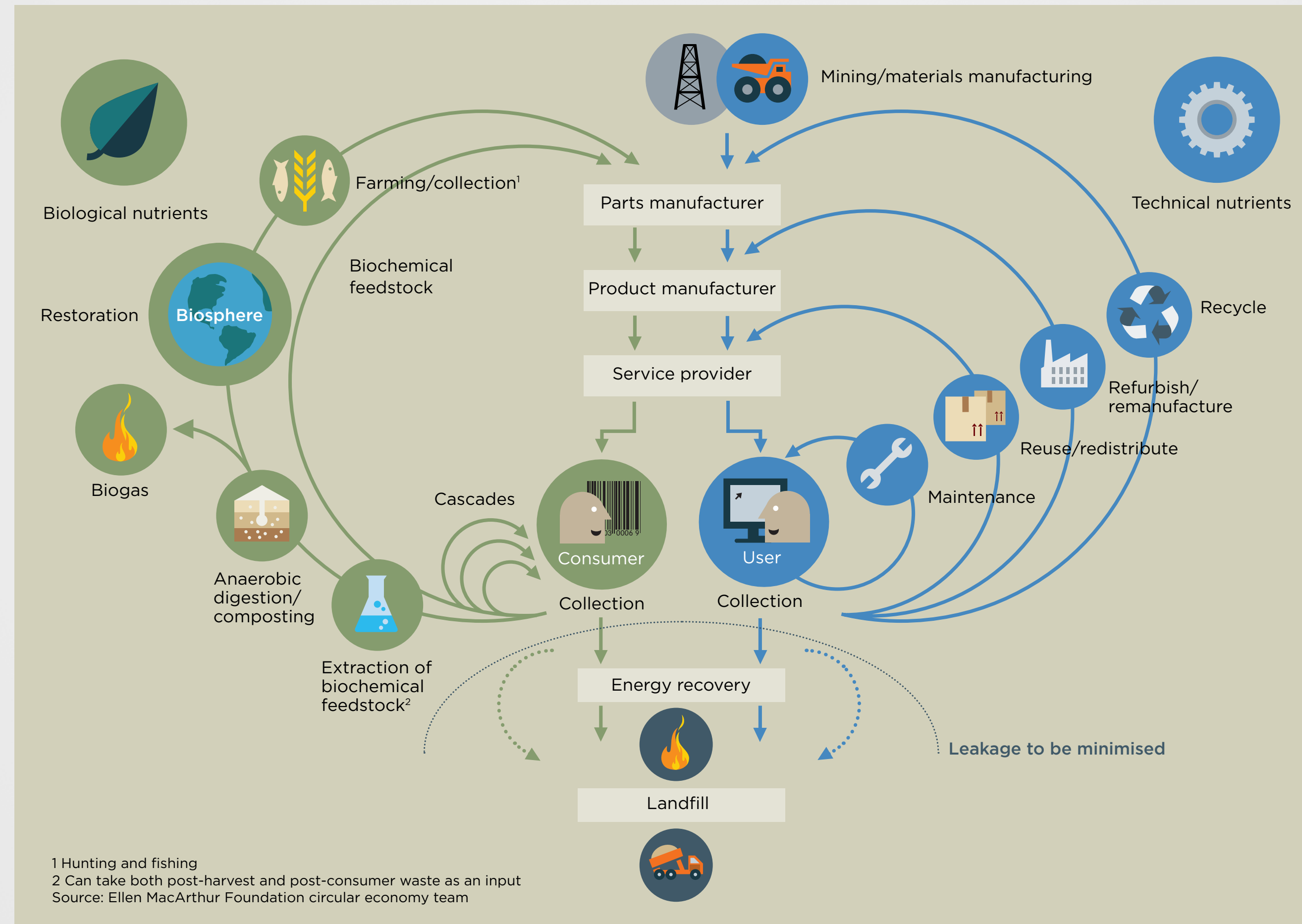
Waste hierarchy

„5 Rs“, Early origins can be found in the EU council directive 75/442/EEC in **1975**

- **Refuse**
- **Reduce**
- **Reuse**
- **Repurpose**
- **Recycle**

Towards the Circular Economy

„Butterfly Diagram“



Sustainable Development Goals

17 global goals set by the United Nations General Assembly (25.09.2015, New York)



EU action plan for the Circular Economy

Closing the loop - An EU action plan for the Circular Economy (2.12.2015, Brussels)



Brussels, 2.12.2015
COM(2015) 614 final

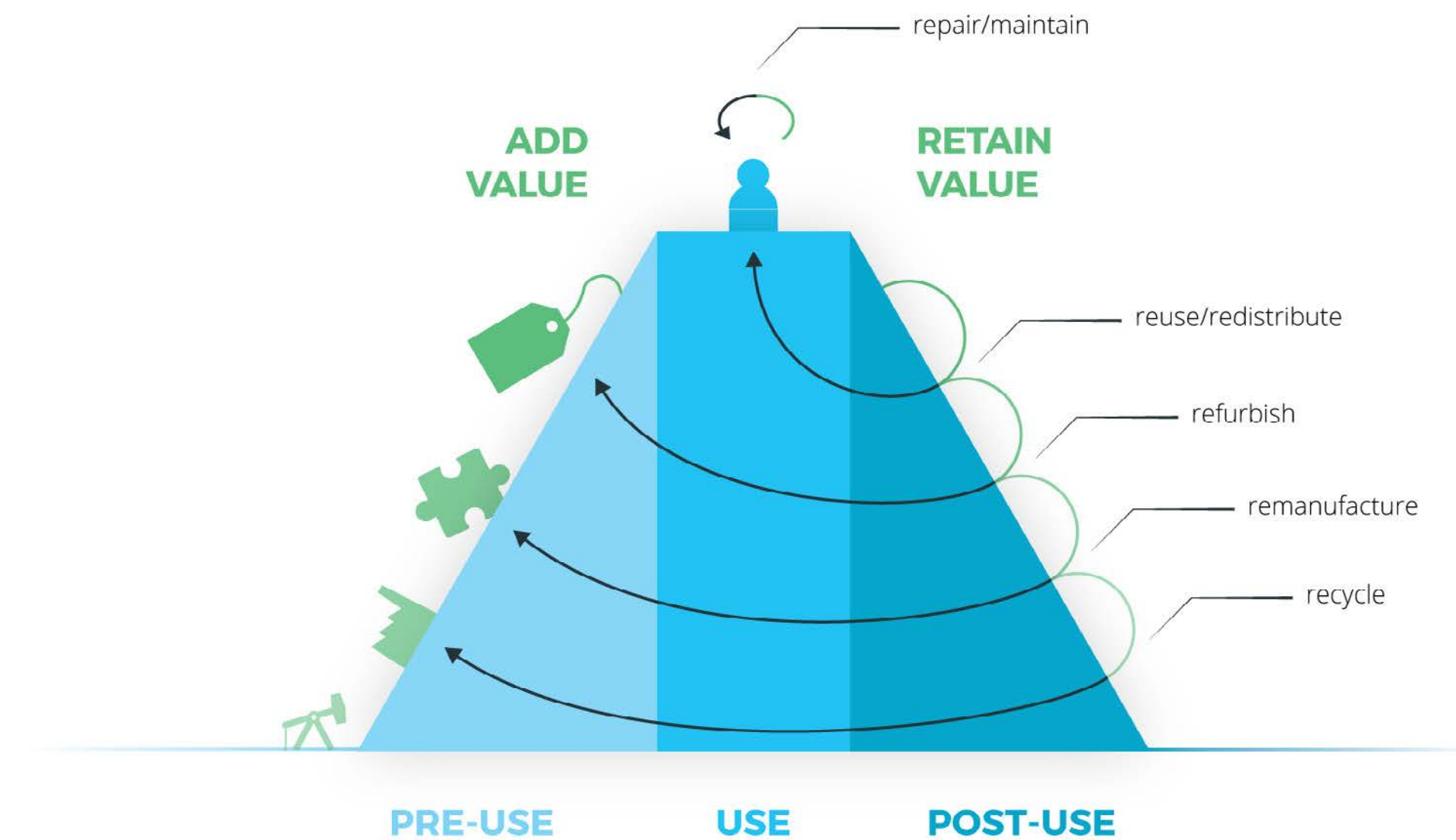
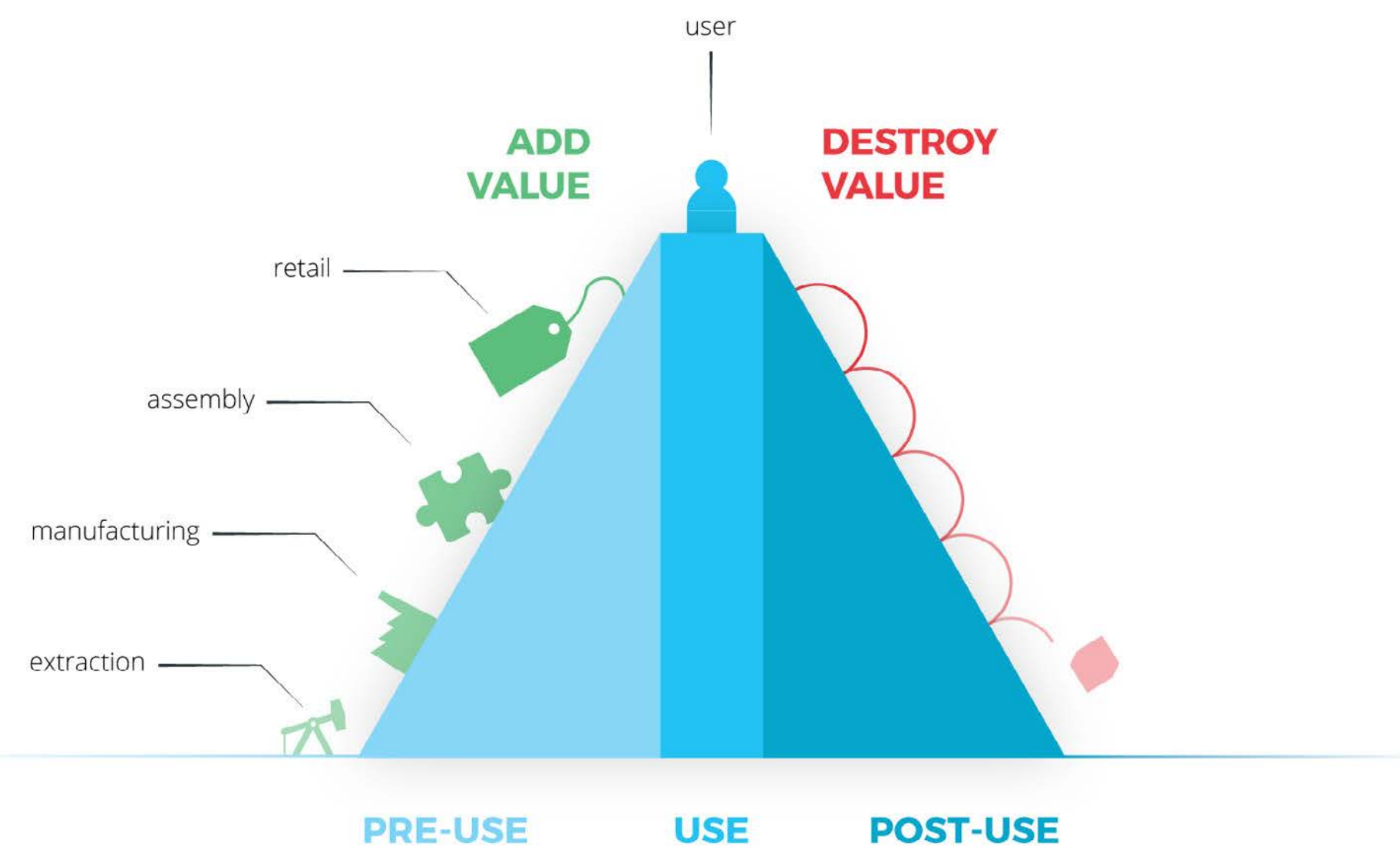
**COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN
PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL
COMMITTEE AND THE COMMITTEE OF THE REGIONS**

Closing the loop - An EU action plan for the Circular Economy

<https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0614>

Master circular business with the value hill

Elisa Achterberg, Jeroen Hinfelaar, Nancy Bocken 2016



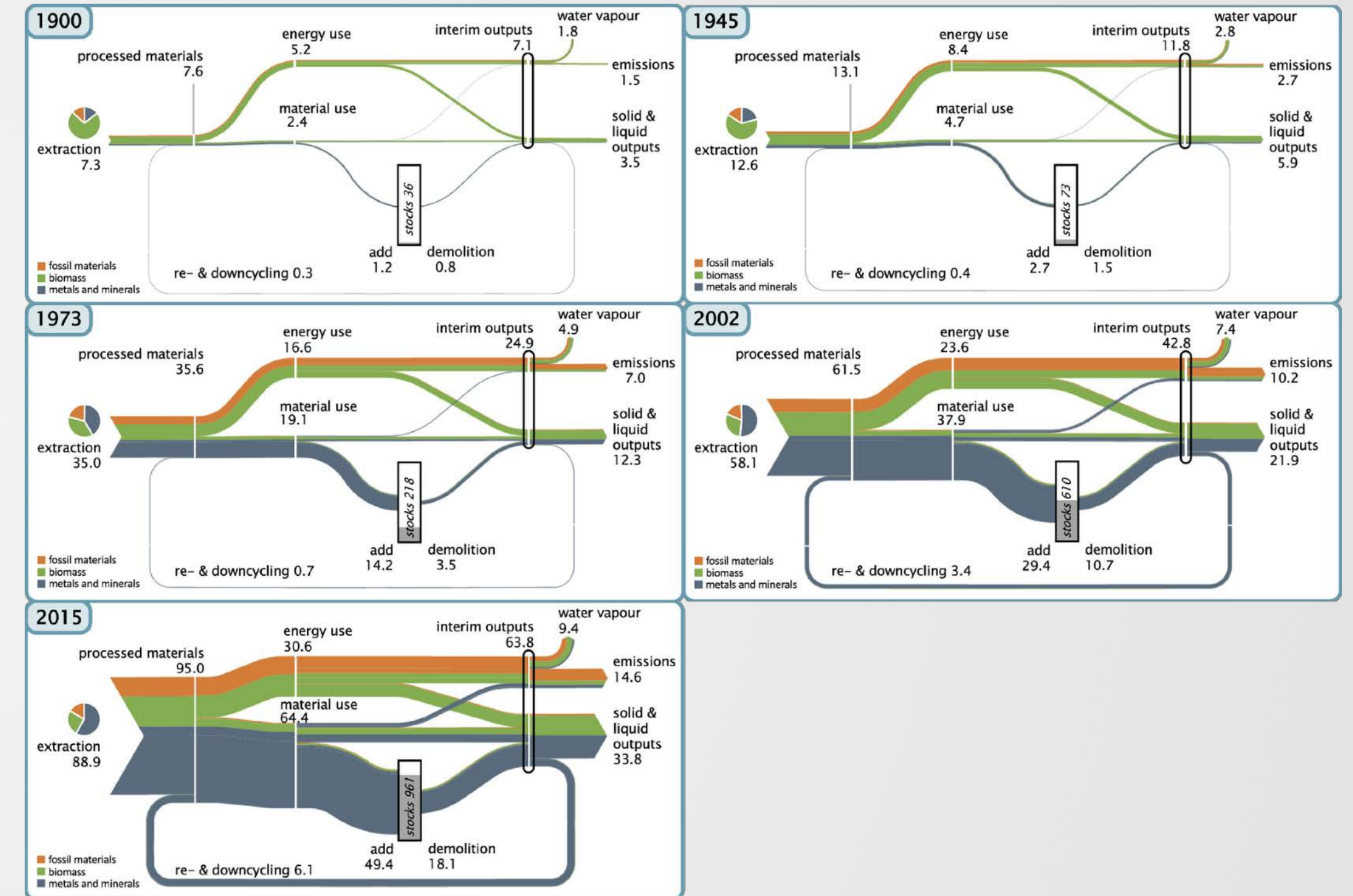
<https://hetgroenebrein.nl/wp-content/uploads/2017/08/finance-white-paper-20160923.pdf>

Growing resource requirements

Growing resource requirements

Over the last century resource requirements have risen substantially. During the period from 1900 to 2015

- the amount of processed materials surged from 7.6 to 95.0 Gt/yr (12.5×)
- the output of materials rose from 7.1 to 63.8 Gt/yr (9×)
- the relative amount of biomass within the composition declined from 70% to 40% (0.6×)
- the absolute amount of biomass extract rose to 23 Gt/yr (4×)



Global socioeconomic flows of fossil materials, biomass, metals and (non-metallic) minerals through the global economy between 1900 and 2015 (rearranged representation)

Technical boundaries

Technical boundaries

Examples

→ Specific heat capacity of water

$$c_{water} = 4,182 \frac{kJ}{kg \cdot K}$$

→ Chemical reaction of octane



→ Standard enthalpy of a reaction

$$\begin{aligned} & - 1mol \cdot (-249,90 \text{ kJ/mol}) + 8mol \cdot (-393,51 \text{ kJ/mol}) \\ & + 9mol \cdot (-241,82 \text{ kJ/mol}) = -5074,56 \text{ kJ} \end{aligned}$$

→ Carnot-efficiency

$$\eta_{Carnot} = 1 - \frac{T_c}{T_h}$$

Specific heat capacity of water

Technical boundaries

Energy requirement for Heating up
1 Liter of water by **1 degree** celsius:

= 1.16 Watt-hours

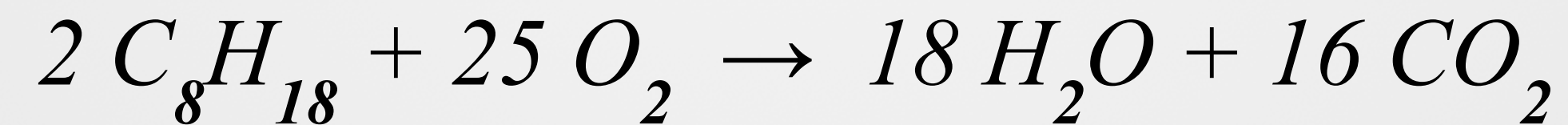
$$c_{wasser} = 4,182 \frac{kJ}{kg \cdot K}$$

Chemical reaction of octane

Technical boundaries

Amount of CO₂ emitted by combusting
1 Liter (= 0.77 kg) of octane or gasoline:

= 2.32 kg



Standard enthalpy of a reaction

Technical boundaries

Energy released during the combustion
of octane or gasoline:

$$= -5074,56 \text{ kJ}$$

$$- 1\text{mol} \cdot (-249,90 \text{ kJ/mol}) + 8\text{mol} \cdot (-393,51 \text{ kJ/mol}) + 9\text{mol} \cdot (-241,82 \text{ kJ/mol}) = -5074,56 \text{ kJ}$$

Carnot-efficiency

Technical boundaries

Theoretical efficiency of a gasoline burning engine
at 300 K ambient and 550 K combustion temperature:

= 45 %

$$\eta_{Carnot} = 1 - \frac{T_c}{T_h}$$

Pareto efficiency

1937: Bendix Home Laundry

First automatic washing machine

Source: automaticwasher.org



Sinner's circle

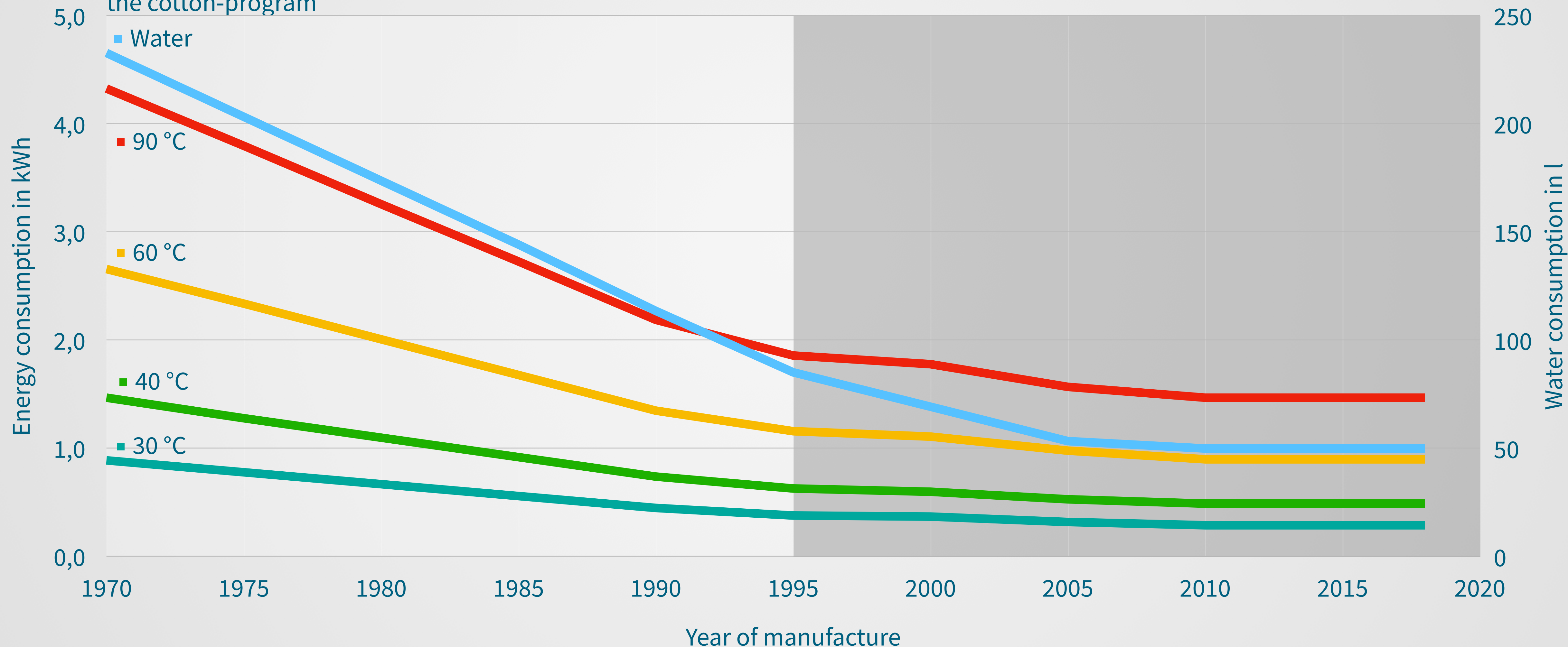
Herbert Sinner, tenside chemist at Henkel (* 1900 in Chemnitz, † 1988 in Hilden)

4 principle factors determine the success of a wash

- Chemicals
- Mechanical power
- Temperature
- Time

Approaching technical boundaries

Average energy- and water consumption of washing machines by year of manufacture between 1970 – 2018 with 5kg load using the cotton-program



Source: Own representation based on IKW: Nachhaltigkeit in der Wasch-, Pflege- und Reinigungsmittelbranche in Deutschland (2019)

**The potentials of closing,
minimizing & extending**

Closing resource flow

Recycling potentials

Overview of different material groups theoretical recycling potentials

	Compostable	Recycleable	Downcycleable	Incineration	Landfill
Renewable					
wood, cotton, wool	■ ■	■ ■	■ ■ ■	■ ■ ■	■ ■ ■
Not renewable					
metal, glass		■ ■ ■	■ ■ ■		■ ■ ■
plastics	■	■ ■	■ ■ ■	■ ■ ■	■ ■ ■
compound materials				■ ■ ■	■ ■ ■
ceramics, concrete					■ ■ ■

Minimizing resource requirements

Thinkstep 2018

What is Sustainability?

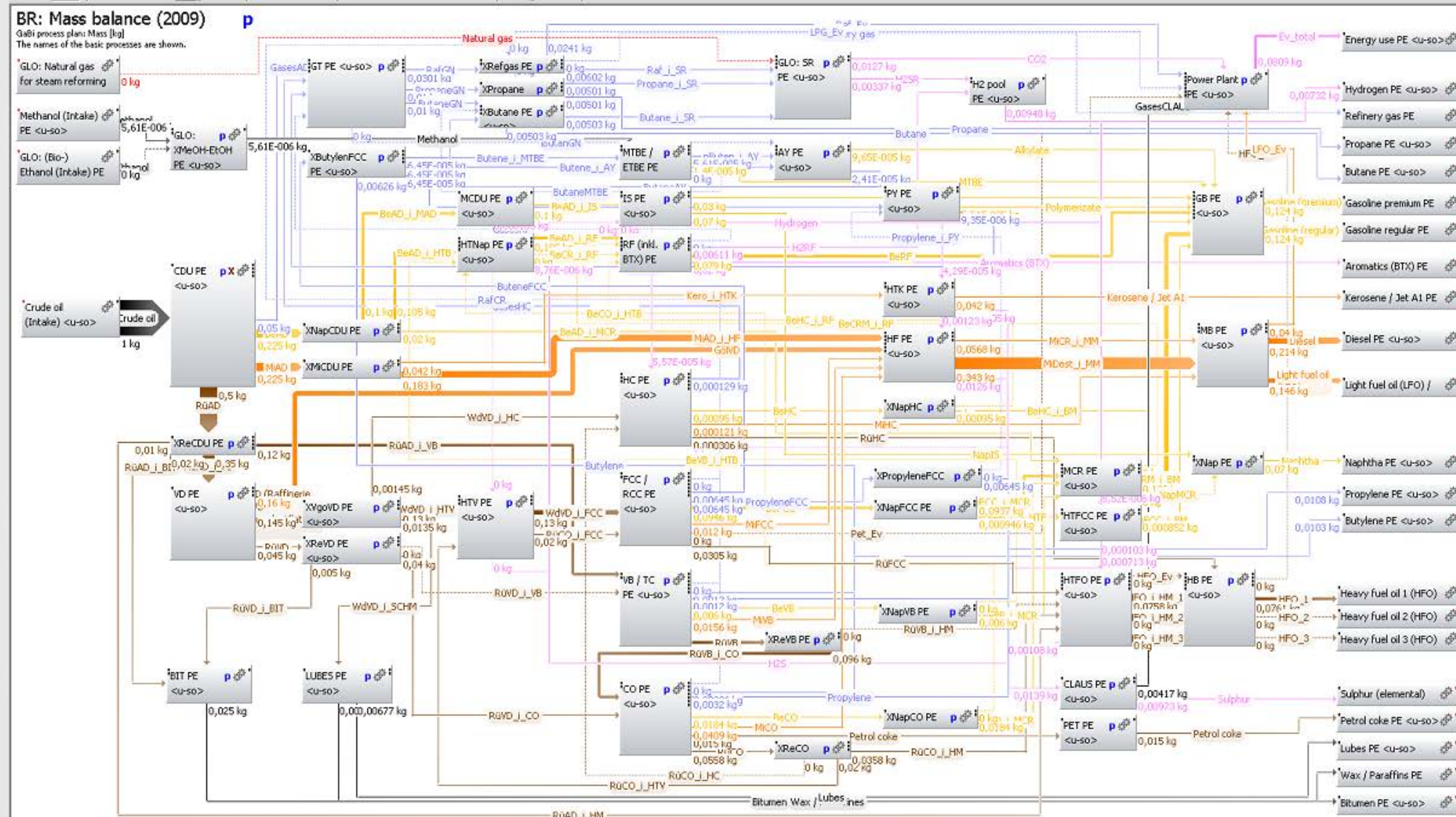
The fascinating Life of Cheese – How understanding the life cycle of your product or company allows you to make the right decisions.
(Dauer 3:24)

thinkstep

<https://www.youtube.com/watch?v=XmFmXyChufs>

LCA Software

E.g. GaBi – Ganzheitliche Bilanzierung (engl. ‚*holistic accounting*‘)



<https://gabi.sphera.com/international/software/gabi-universities/>

Extending the service life

Design criteria

For long lasting products

MTBF

Maintenance

Repair

EOL

Mean time between failure:

- **Material quality**
- **Dimensioning**
- **Failure tolerance**

Maintenance & repair:

- **Accessibility**
- **Unambiguity**
- **Documentation**
- **Licencing**

Repair:

- **Standard components**
- **Manufacturing process**
- **Independence**
- **Adaptability**

End of life:

- **Patina-ability**
- **Recyclability**
- **Disposal**

Material quality

Example: electrolytic capacitor 33 μ F, 160 V

- 2.000 vs. 20.000 h
- 18 ct vs. 28 ct

→56% higher purchasing cost
→900% higher life time

Value.	Case Size	Life Time (hrs)
	$\phi D \leq 8$	1000
	$\phi D \geq 10$	2000
0 250 350 400 450 (120Hz)		

Value.	Case Size	Life Time (hrs)
	6.3×11, 8×9, 10×9	12000
	8×11.5, 10×12.5	15000
10×16, 10×20 $\phi D \geq 12.5$		20000

Manufacturing processes – lot sizes

To enable the subsequent production of spare parts

Required:

Manufacturing processes that are economically applicable even in small quantities, e.g.

- CNC milling
- CNC laser cutting
- CNC punching & nibbling
- CNC bending
- All 3D printing processes

Additionally possible:

Manufacturing processes that require costly tool making, e.g.

- Injection moulding
- Punching
- Deep drawing of sheet metal

DIN SPEC 3105-1 & 2

Open Source Hardware – Requirements for Technical Documentation & Peer-Certification (Submitted 2019)

DIN SPEC 3105-1

Draft 0.7

Open-Source-Hardware – Anforderungen an die Technische
Dokumentation; Text auf Englisch

Open Source Hardware – Requirements for Technical
Documentation; Text in English

3105-2

- Peer-Zertifizierung; Text auf Englisch
Peer-Certification; Text in English

<http://blog.oshpark.com/2020/01/11/open-source-hardware-in-industry-meet-din-spec-3105/>

Right to repair

Right to repair

- **Reparatur- und Service-Zentrum (R.U.S.Z.)** <https://rusz.at>
- **iFixit** <https://www.ifixit.com/Right-to-Repair>
- **repair.org** <https://www.repair.org>
- **Right to repair Europe** <https://repair.eu>
- **Anstiftung** <https://anstiftung.de>
- ...

Service life & maintainability

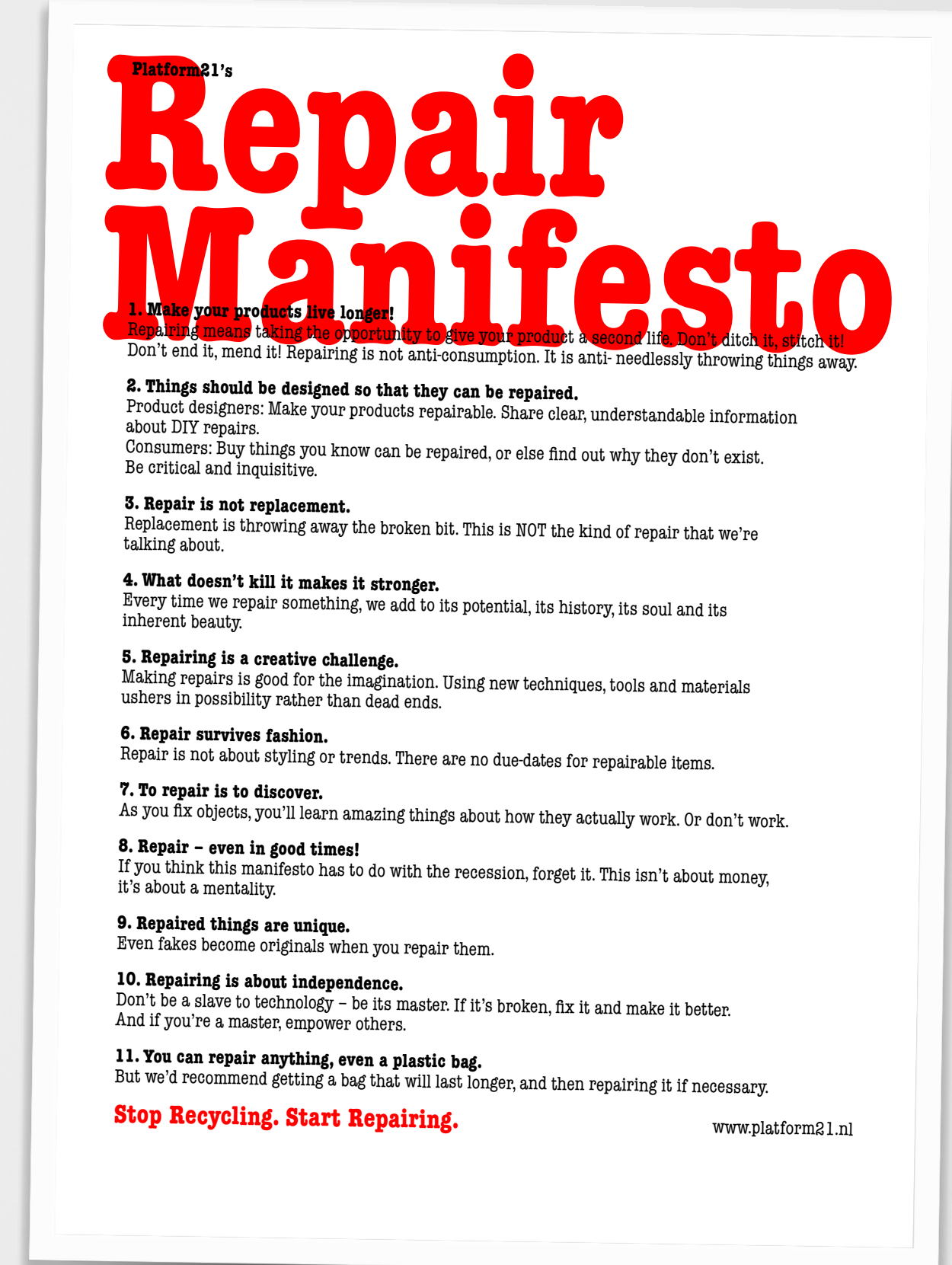
Designed to be repaired?



www.ifixit.com



makezine.com



www.platform21.nl

Service life & maintainability

ON-Rule 192102:2014

ICS 03.080.10;
13.020.50;
13.030.50



ONR 192102

*Gütezeichen für langlebige,
reparaturfreundlich konstruierte
elektrische und elektronische Geräte*

*Label of excellence for durable, repair-friendly designed electrical and electronic
appliances*

*Marque de qualité pour les durables, faciles à réparer les appareils électriques et
électroniques*



R.U.S.Z & BMLFUW

Service life & maintainability

DIN EN 45554:2020

DEUTSCHE NORM		Oktober 2020
	DIN EN 45554	DIN
ICS 13.030.50		
Allgemeine Verfahren zur Bewertung der Reparatur-, Wiederverwend- und Upgradebarkeit energieverbrauchsrelevanter Produkte; Deutsche Fassung EN 45554:2020 General methods for the assessment of the ability to repair, reuse and upgrade energy-related products; German version EN 45554:2020 Méthodes générales pour l'évaluation de la capacité de réparation, réutilisation et amélioration des produits liés à l'énergie; Version allemande EN 45554:2020		

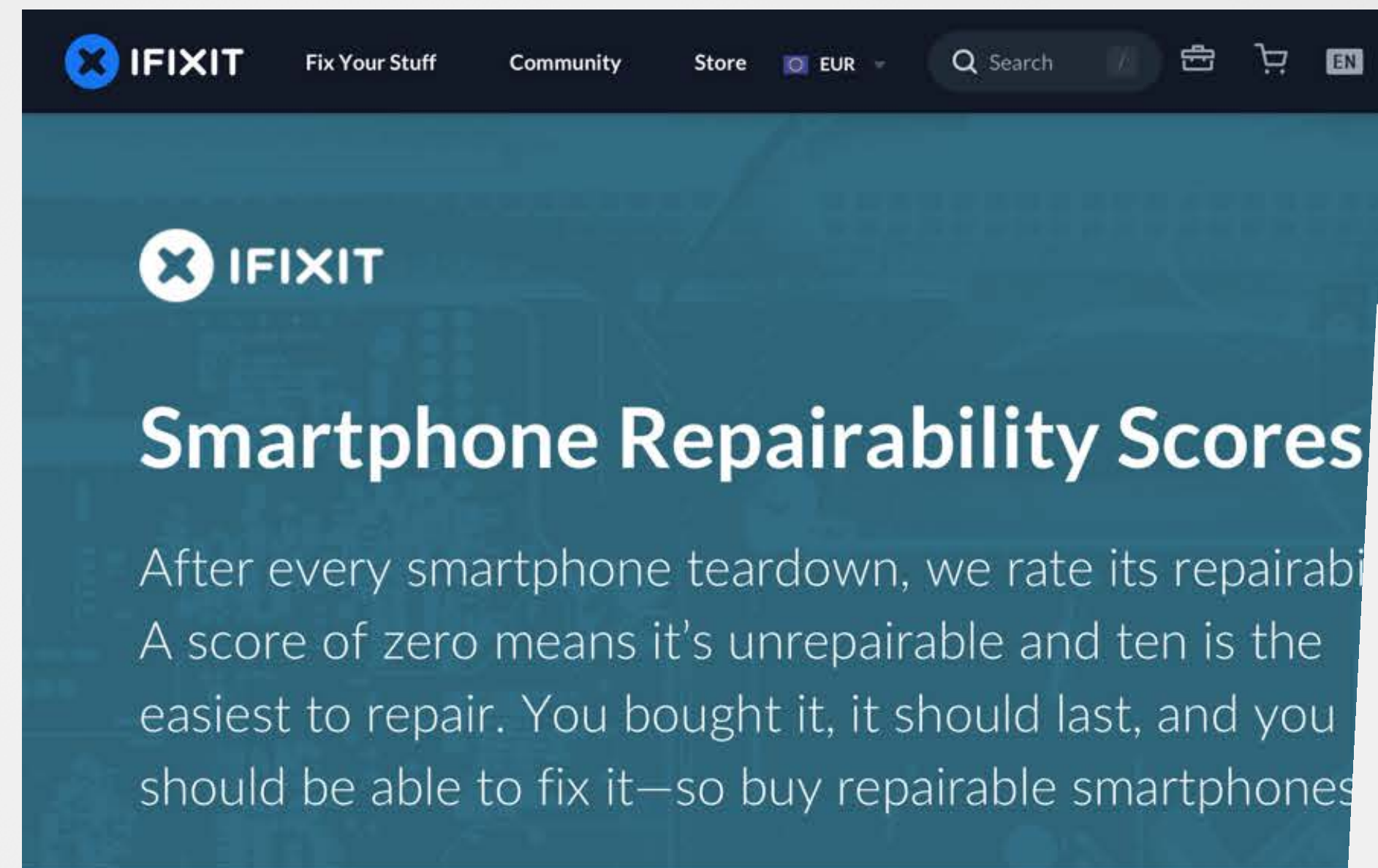
iFixit's repairability scores

<https://www.ifixit.com/smartphone-repairability>

3 device categories:

- Smartphones
- Tablets
- Laptops

Devices scored*: **229** since 2007

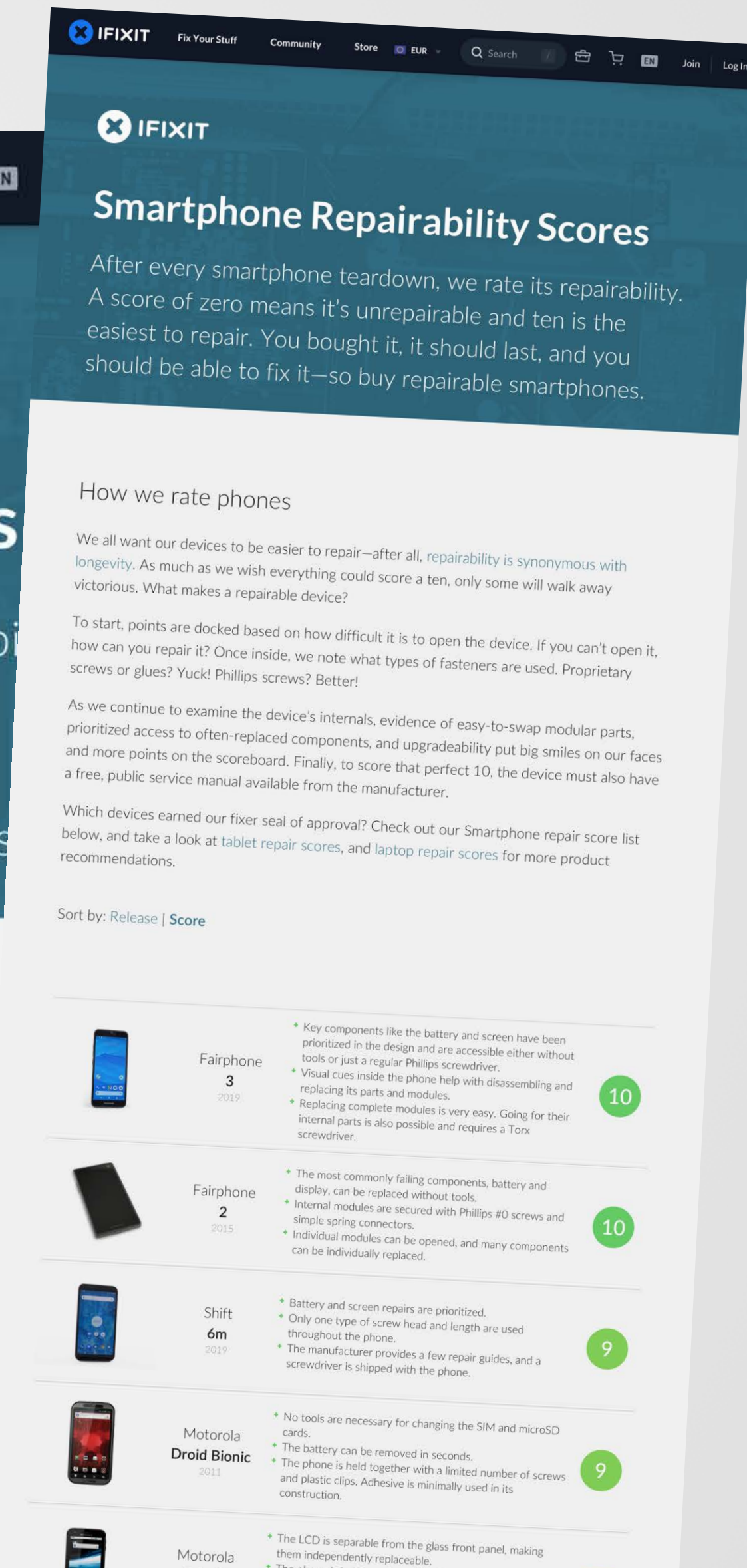


How we rate phones

We all want our devices to be easier to repair—after all, repairability is synonymous with longevity. As much as we wish everything could score a ten, only some will walk away victorious. What makes a repairable device?

To start, points are docked based on how difficult it is to open the device. If you can't how can you repair it? Once inside, we note what types of fasteners are used. Proprietary screws or glues? Yuck! Phillips screws? Better!

As we continue to examine the device's internals, evidence of easy-to-swap modular



France's repairability index

<https://www.indicereparabilite.fr>

5 device categories:

- Washing machines
- Smartphones
- Laptops
- TV sets
- Lawn mowers

Devices scored*: **1.192** since 2021

* As of November 2021



EU Regulations, directives, etc.

Types of legislation

■ Regulations <i>Verordnungen</i>	A "regulation" is a binding legislative act . It must be applied in its entirety across the EU.
■ Directives <i>Richtlinien</i>	A "directive" is a legislative act that sets out a goal that all EU countries must achieve . However, it is up to the individual countries to devise their own laws on how to reach these goals.
■ Decisions <i>Beschlüsse</i>	A "decision" is binding on those to whom it is addressed (e.g. an EU country or an individual company) and is directly applicable.
■ Recommendations <i>Empfehlungen</i>	A "recommendation" is not binding .
■ Opinions <i>Stellungnahmen</i>	An "opinion" is an instrument that allows the institutions to make a statement in a non-binding fashion , in other words without imposing any legal obligation on those to whom it is addressed.

Selected directives

Directives regarding waste, energy efficiency and hazardous substances

Directive	Date issued	Short name	Topic	Status	Current version
<u>2000/53/EG</u>	2000.09.18		End-of life vehicles	In force	2020.03.06
<u>2002/95/EG</u>	2003.01.27	RoHS 1	<u>R</u> estriction <u>o</u> f the use of certain <u>h</u> azardous <u>s</u> ubstances in electrical and electronic equipment	Repealed	2011/65/EU
<u>2002/96/EG</u>	2003.01.07	WEEE	<u>W</u> aste <u>e</u> lectrical and <u>e</u> lectronic <u>e</u> quipment	Repealed	2012/19/EU
<u>2005/32/EG</u>	2005.07.06	EuP	Ecodesign requirements for <u>e</u> nergy- <u>u</u> sing <u>p</u> roducts	Repealed	2009/125/EC
<u>2008/98/EG</u>	2008.11.19		Waste and repealing certain Directives	In force	2018.07.05
<u>2009/125/EG</u>	2009.10.21	ErP	Establishing a framework for the setting of ecodesign requirements for energy-related products	In force	2012.12.04
<u>2011/65/EU</u>	2011.06.08	RoHS 2	<u>R</u> estriction <u>o</u> f the use of certain <u>h</u> azardous <u>s</u> ubstances in electrical and electronic equipment	In force	2021.11.01
<u>2012/19/EU</u>	2012.07.04	WEEE	Waste electrical and electronic equipment	In force	2012.12.04

https://european-union.europa.eu/institutions-law-budget/law/types-legislation_en

10 new ecodesign regulations

1. October 2019

- C(2019) 2120 – ecodesign for **household refrigerators** and annexes
- C(2019) 2121 – ecodesign for **light sources** and annexes
- C(2019) 2122 – ecodesign for **electronic displays** and annexes
- C(2019) 2123 – ecodesign for **dishwashers** and annexes
- C(2019) 2124 – ecodesign for **washing machines** and **washer-driers** and annexes
- C(2019) 2125 – ecodesign for **motors** and annexes
- C(2019) 2126 – ecodesign for **external power supplies** and annexes
- C(2019) 2127 – ecodesign for **refrigerators with a direct sales function** and annexes
- C(2019) 5380 – ecodesign for **power transformers** and annexes
- C(2019) 6843 – ecodesign for **welding equipment** and annexes

<https://ec.europa.eu/energy/en/regulation-laying-down-ecodesign-requirements-1-october-2019>

10 new ecodesign regulations

1. October 2019

- Estimated final energy savings of **167 TWh per year** by 2030
- Estimated reduction of over 46 million tonnes of **CO₂** equivalent
- European households save on average **150 EUR** per year
- Six of the product groups that are subject to new and revised ecodesign requirements, are also covered by **new energy labelling** rules

Design Considerations

System of units

System of units

Preferred system of units: International System of Units (**SI**)

There are currently three main measurement systems in use worldwide:

- International System of Units (SI)
- US Customary System (UCS)
- Imperial System of Units

All but 3 countries adopted the International System of Units as their official system, i.e. 94,9% of the global population (only the United States of America, Myanmar, and Liberia use the UCS).

https://en.wikipedia.org/wiki/International_System_of_Units

System of units

Preferred system of units: International System of Units (SI)

There are a few noteworthy differences between the SI, UCS and the imperial system of units:

- Only the SI covers **all 7 base units** (time, length, mass, electric current, thermodynamic temperature, amount of substance, and luminous intensity)
- The SI is **decimalised** (e.g. 1.000 mm = 1 m, 1.000 m = 1 km, etc) while the other two use a mix of multipliers (12 inch = 1 foot, 3 foot = 1 yard, 1.760 yards = 1 mile, etc.)
- Since 2019 all of the SI's 7 base units are **defined by fundamental constants of nature**

All other units are defined on those 7 base units (e.g. speed = $\text{m} \cdot \text{s}^{-1}$, voltage = $\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-3} \cdot \text{A}^{-1}$, etc.).

https://en.wikipedia.org/wiki/International_System_of_Units

Standards

Standards

Preferred standard: **ISO / IEC**

- Standards are defined by standard defining organisation (SDO), vary in their scope (e.g. national, regional, international) and are voluntary.
- The world largest developers of international standards are the **International Organization for Standardization (ISO)** and **International Electrotechnical Commission (IEC)**. The ISO and the IEC are an independent, non-governmental organisations, headquartered in Geneva, Switzerland and have 165 (ISO) / 89 (IEC) member countries.

https://en.wikipedia.org/wiki/International_Organization_for_Standardization, https://en.wikipedia.org/wiki/International_Electrotechnical_Commission

Standards

Preferred standard: **ISO / IEC**

- Examples for SDO's with a *national scope* are the American National Standards Institute (ANSI), Austrian Standards Institute (A.S.I., formerly Österreichisches Normungsinstitut ÖNORM), Deutsches Institut für Normung e.V. (DIN, English: German Institute for Standardisation).
- Examples for SDO's with a *regional scope* are Comité Européen de Normalisation (CEN, English: European Committee for Standardization) and Comité Européen de Normalisation Électrotechnique (CENELEC, English: European Committee for Electrotechnical Standardization).

https://en.wikipedia.org/wiki/International_Organization_for_Standardization, https://en.wikipedia.org/wiki/International_Electrotechnical_Commission

Standards

Preferred standard: **ISO / IEC**

In case for very common standards like e.g. screws, equivalent standards are issued by several SDO's.

E.g. equivalent standards for Hexagon socket head cap screws

- International: ISO 4762
- National: DIN EN ISO 4762 (German), ~DIN 912 (German, withdrawn), ~CSN 021143 (Spanish), ~PN 82302 (Polish), ~UNI 5931 (Italian)

https://en.wikipedia.org/wiki/International_Organization_for_Standardization, https://en.wikipedia.org/wiki/International_Electrotechnical_Commission

Joining

Joining

Several features for joints are important to improve the maintain- and repairability of a product:

- ability for assembly, disassembly and reassembly
- availability in small lot sizes
- durability

On the other hand not so important features are

- higher speeds during assembly
- lower purchasing costs

Screw joints

Screw joints

The anatomy of a screw consists of several features:

- type and size of helical thread,
- screw head shapes,
- screw drives,
- material,
- grade, and
- dimensions

Screw joints – *Type and size of thread*

Since the International System of Units is the preferred one the type and size of helical thread should be **metric**.

Screw joints – *head shapes*

Common screw head shapes, without taking into account sub-variants such as flat or raised countersunk head shapes and special types such as eyebolts are:

		Hexagon	None	Cylinder	Rounded	Countersunk
		<i>Sechskant</i>	<i>Stift</i>	<i>Zylinder</i>	<i>Linsenkopf</i>	<i>Senkkopf</i>
DIN EN ISO	e.g.	4014	4026	4762	7045	10642
<i>DIN</i>	<i>e.g.</i>	<i>931</i>	<i>913</i>	<i>912</i>	<i>7985</i>	<i>7991</i>

The *preferred* variety can be reduced to **hexagon**, **cylinder**, and **countersunk**.

Screw joints – *drives*

Common screw drives and their different practical qualities are:

		Hexagon	Slotted	Cross recessed	Cross recessed	Hexagon socket	Hexa-lobular
		<i>Aussen-sechskant</i>	<i>Schlitz</i>	<i>Kreuzschlitz Typ H aka. 'Phillips'</i>	<i>Kreuzschlitz Typ Z aka. 'Pozidriv'</i>	<i>Innen-sechskant</i>	<i>Innen-sechsrund aka. 'Torx'</i>
	ISO e.g.	4014	1580	7046	7046	4762	14579
	DIN e.g.	931	85	965	965	912	—
Driver self centering		n/a	no	yes	yes	no	no
Driver can slide out		no	radially	axially	no	no	no
Driver can stay in place		yes/no	no	no	no	yes	yes
Wrong driver sizes can be used		no	yes	yes	yes	no	no
Driver can wear out drive		yes	yes	yes	yes	no	no
Driver can be used at an angle		no	no	no	no	yes	no
Highest torque transmission		no	no	no	no	no	yes

The preferred drives are **hexagon** and **hexagon socket**.

Screw joints – *materials*

Typical materials are steel (plain or zinc plated), stainless steel, and plastic (e.g. Nylon), with **zinc plated steel** being the *preferred* choice, since it is the most readily available one and having good durability for most applications.

Screw joints – *grades*

The most common grade is **8.8** for screws and **8** for nuts and thus they are the *preferred* ones.

Screw joints – *dimensions*

The **variants** of e.g. ISO 4762 screws (cylinder head, hexagon sockets) from M1.6 (the smallest available helical thread size) until M12 and the available lengths is **114**.

By reducing the selection to

- M3 and upwards and the
- lengths to 5, 10 to 60 in steps of 10,
- and 60 to 120 in steps of 20

the variety of preferred sizes can be reduced to 40%.

[illegible]

Screw joints – *tool sizes*

The required tool sizes for the preferred screw variants are:

ISO	DIN									
Wrench sizes				5.5	7	8	10	13	17	19
4032	934	Hexagon regular nuts		M3	M4	M5	M6	M8	M10	M12
4014	931	Hexagon head bolts		M3	M4	M5	M6	M8	M10	M12
Key sizes			2	2.5	3	4	5	6	8	10
4762	912	Hexagon socket head cap screws		M3	M4	M5	M6	M8	M10	M12
10642	7991	Hexagon socket countersunk head	M3	M4	M5	M6	M8	M10	M12	

Since some tool manufacturers offer double open-end wrenches and (ratcheting) double ring-end wrenches in the dimensions 7+8, 10+13, and 17+19 the **number of wrenches can be cut down to 6** covering the dimensions from M3 to M12 for hexagon nuts and bolts.

Thank You!

Repair costs

Acquisition & repair costs

Costs for ...		Acquisition	Repair
<i>Manufacturing</i>	Design optimized exclusively for assembly	↓	↑
<i>Labor</i>	Manufacturing often in low-wage country with eventually relaxed environmental policies, Repair at regional wages	↓	↑
<i>Spare parts</i>	Spare parts have to be pre-financed, storage costs have to be paid, additional logistics costs have to be covered		↑