A Biosourced Janus molecule
for sustainable elastomeric nanocomposites

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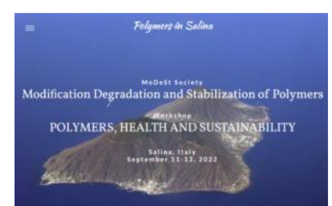
MoDeSt Society
Workshop Polymers Health and Sustainability
Salina, September 11-13



Outline of the Lecture

- ☞ Elastomers and Rubbers
- ☞ Rubbers and sustainability
- ☞ Focus on the main application of rubbers
- ☞ An example from ISCaMaP @Polimi

Elastomers and Rubbers

Elastomers and Rubbers

Elastomer

ελ

"A natural or synthetic polymer which at room temperature can be stretched repeatedly to at least twice its original length and which after removal of the tensile load will immediately and forcibly return to approximately its original length"

Compilation of ASTM Standards Definitions, sponsored by ASTM committee E8, ASTM, Philadelphia PA, 1976

Rubber

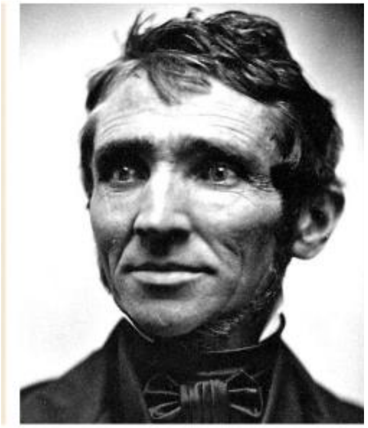
"Family of polymeric materials which are flexible and elastic. Rubber can be substantially deformed under stress, but recovers quickly to near its original shape when the stress is removed"

ISO 1382 (1982) "Rubber - Vocabulary"

Entropic elasticity

"There is probably no other inert substance
the properties of which excite in the human mind
an equal amount of curiosity, surprise and admiration.

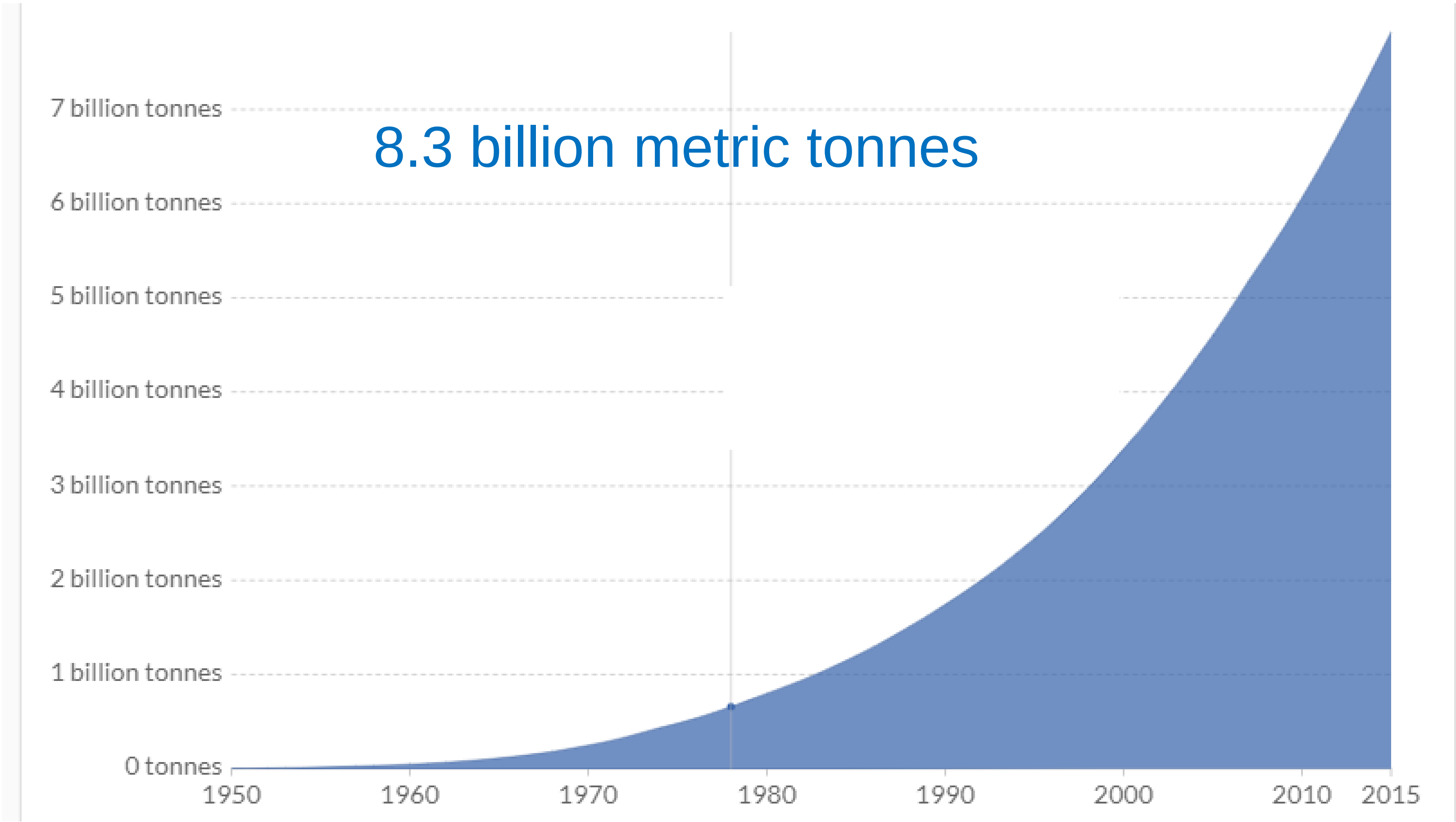
Who can examine and reflect upon this property of gum-elastic
without adoring the wisdom of the Creator?"



Charles Goodyear

Goodyear, C. "Gum elastic and its variation with a detailed account of its applications and uses" 1855, 1, New Haven

Cumulative global plastic production 1950 - 2015

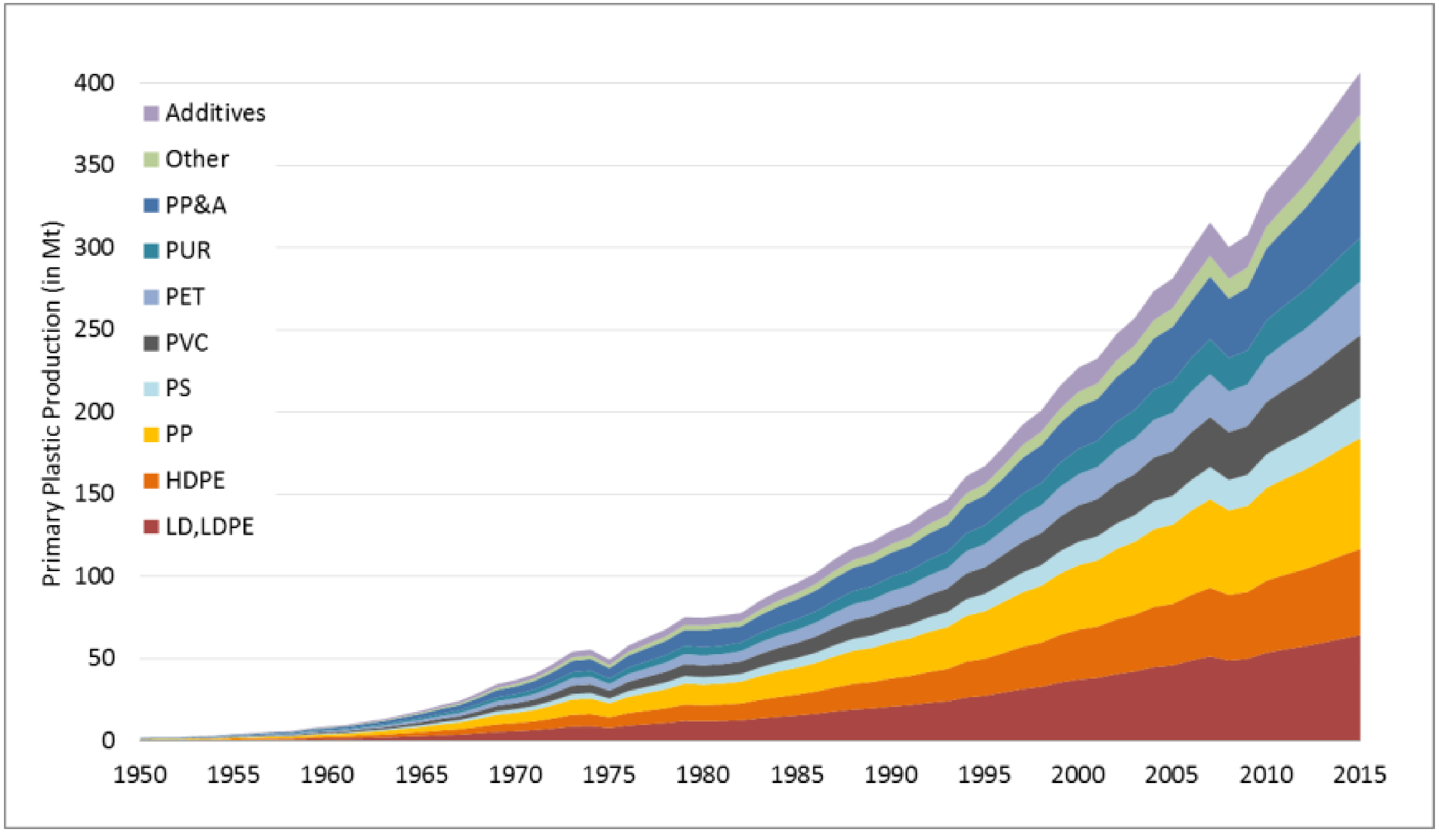


https://ourworldindata.org/plastic-pollution

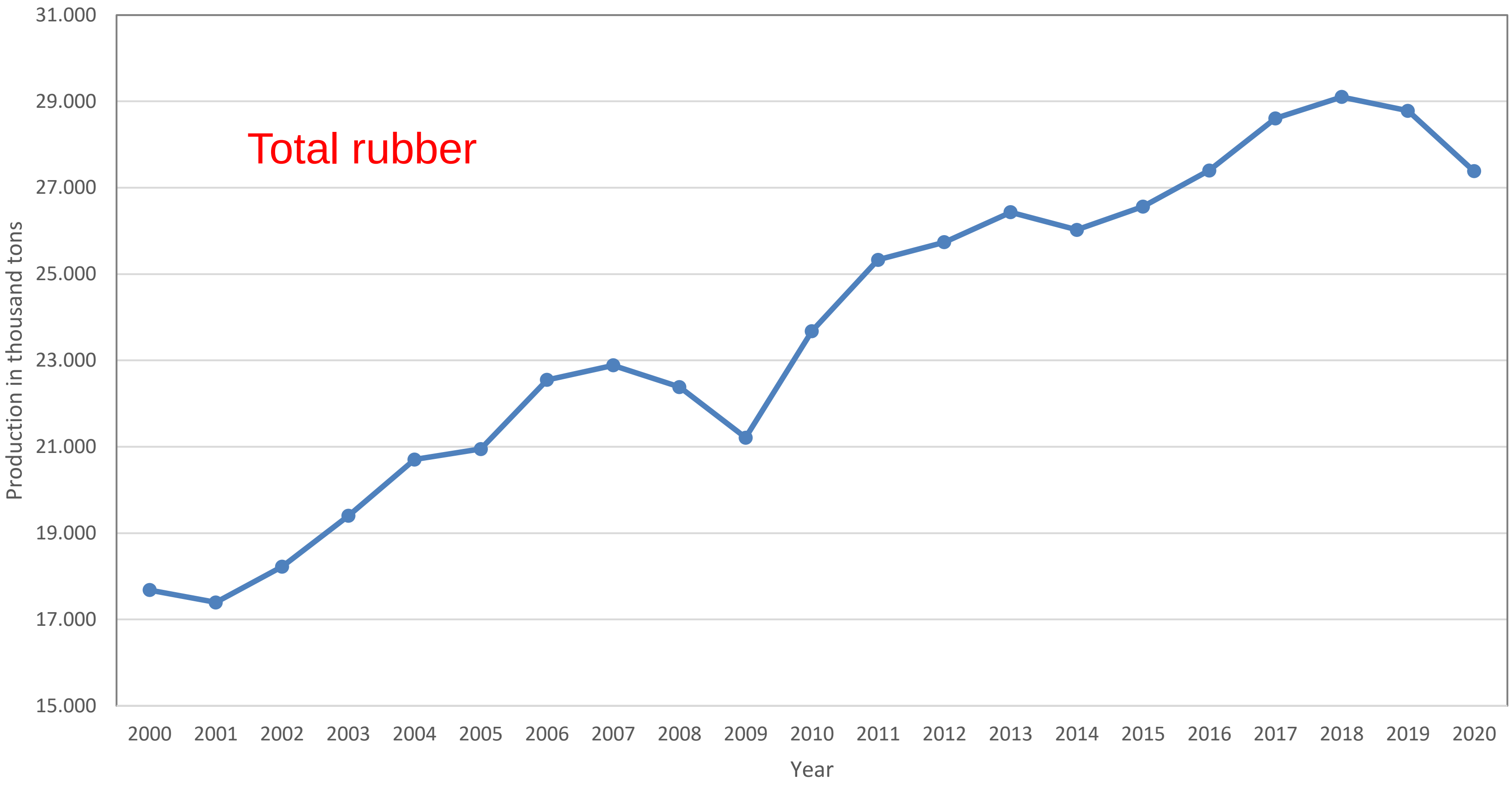
Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. Science Advances, 3(7), e1700782. Available at: http://advances.sciencemag.org/content/3/7/e1700782.

Cumulative global plastic production 1950 - 2015

By polymer type



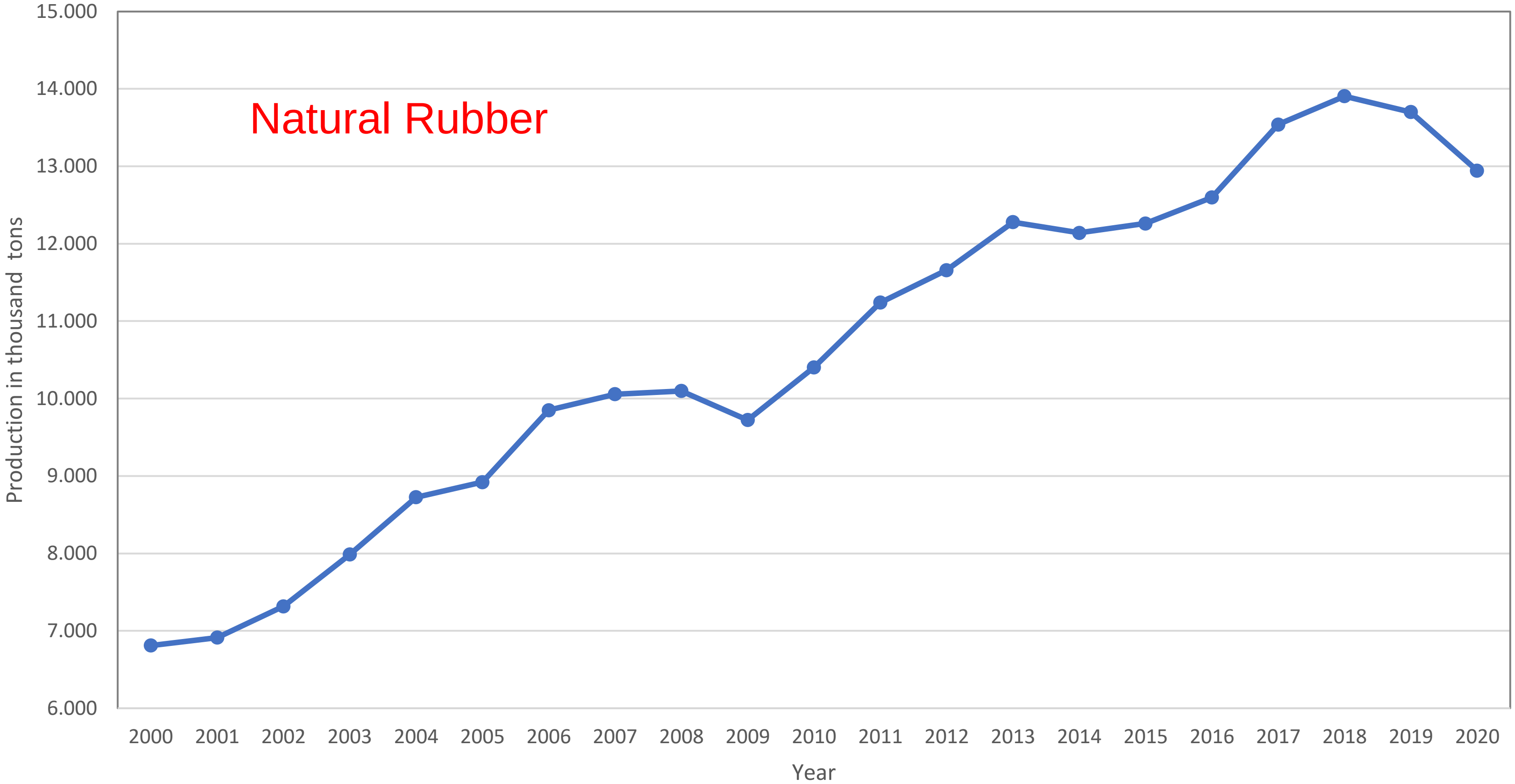
Production of rubber worldwide from 2000 to 2020 (in 1,000 metric tons)



max: $29 \cdot 10^6$ metric tons

Source: Statista

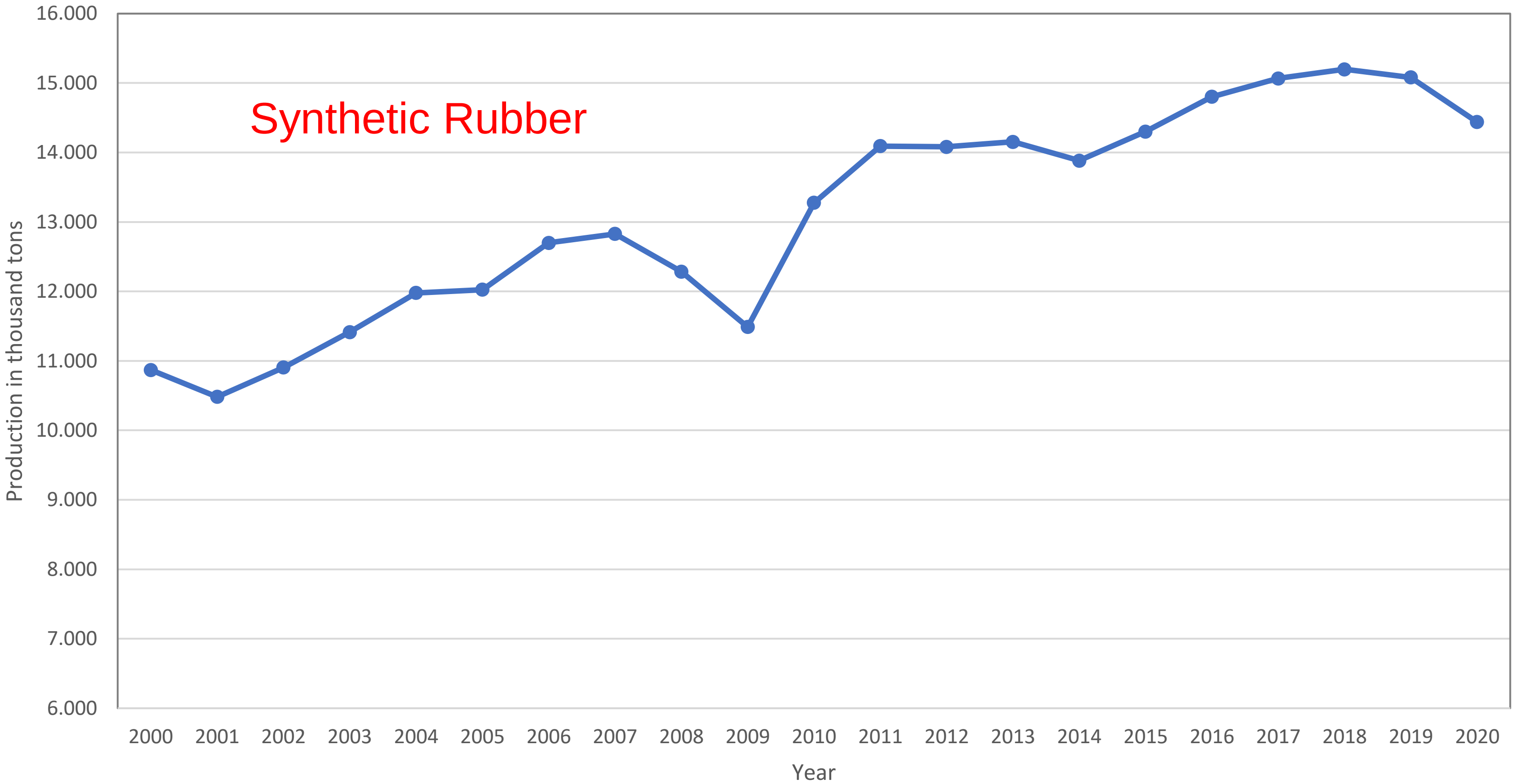
Natural rubber production worldwide from 2000 to 2020 (in 1,000 metric tons)



max: $14 \cdot 10^6$ metric tons

Source: Statista

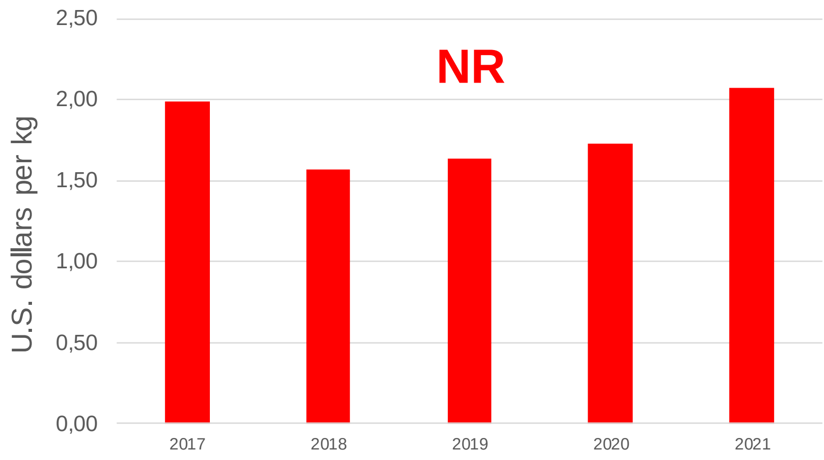
Synthetic rubber production worldwide from 2000 to 2020 (in 1,000 metric tons)

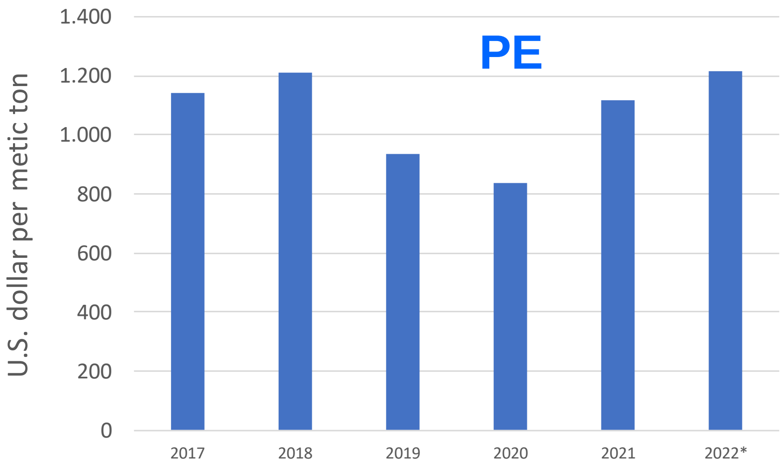


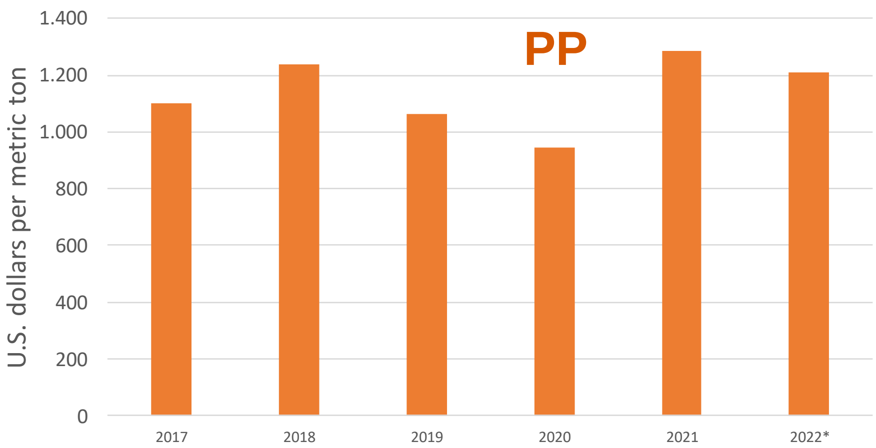
max: $15 \cdot 10^6$ metric tons

Source: Statista

Price from 2017 to 2021

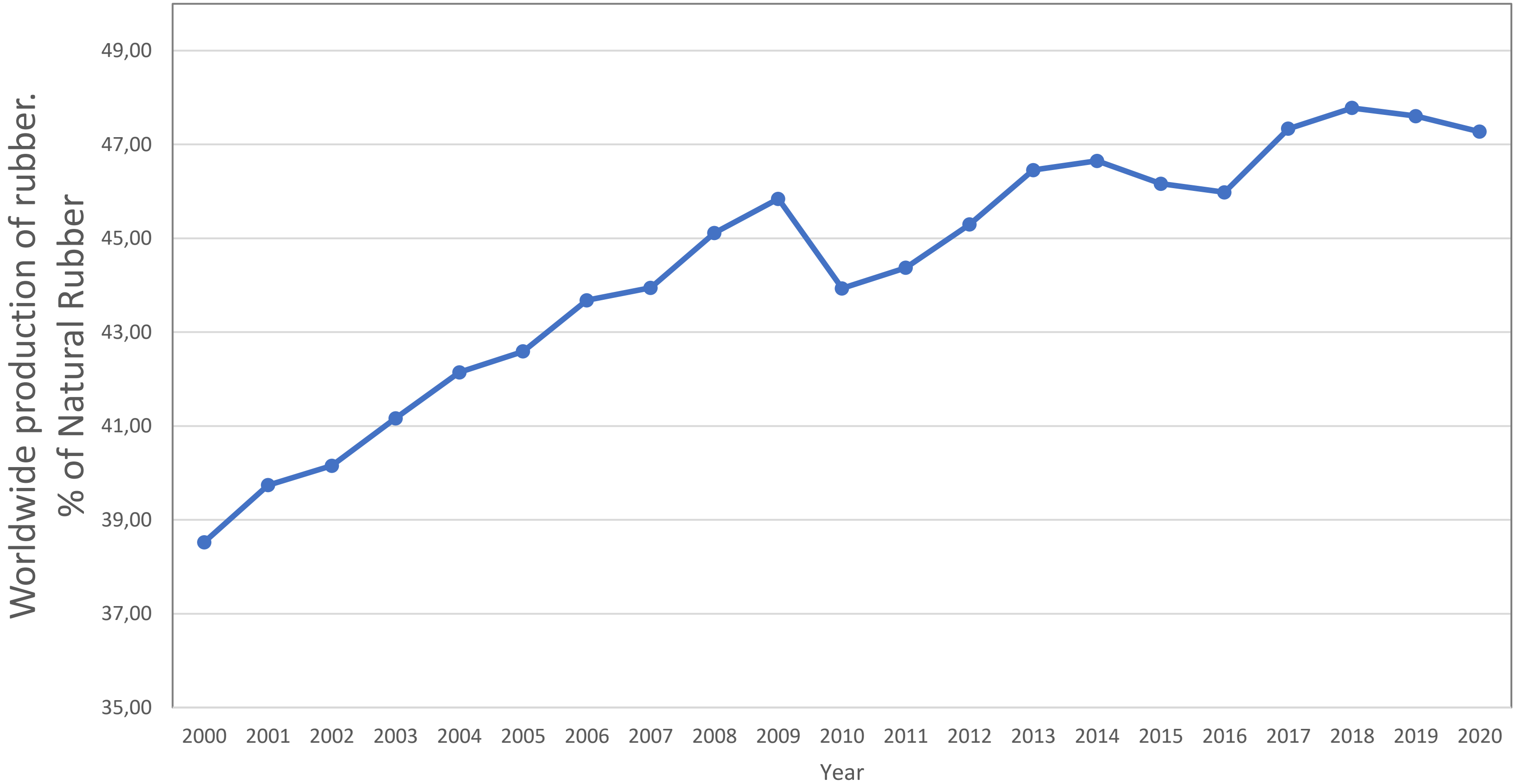






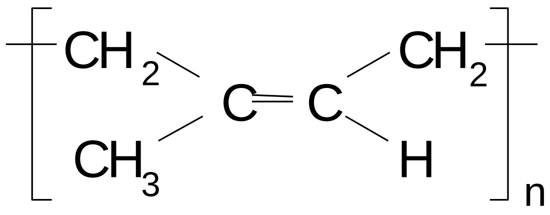
Source: Bloomberg; Krungsri Research

Relative amount of Natural Rubber



Source: Statista

Natural Rubber. Poly(1,4-cis-isoprene)



Almost 100% cis - 1,4- poly-isoprene

hevea brasiliensis

partenium argentatum

taraxacum kok-saghyz

Why Natural Rubber is such a great material?

Low Tg: - 64°C

Chain mobility

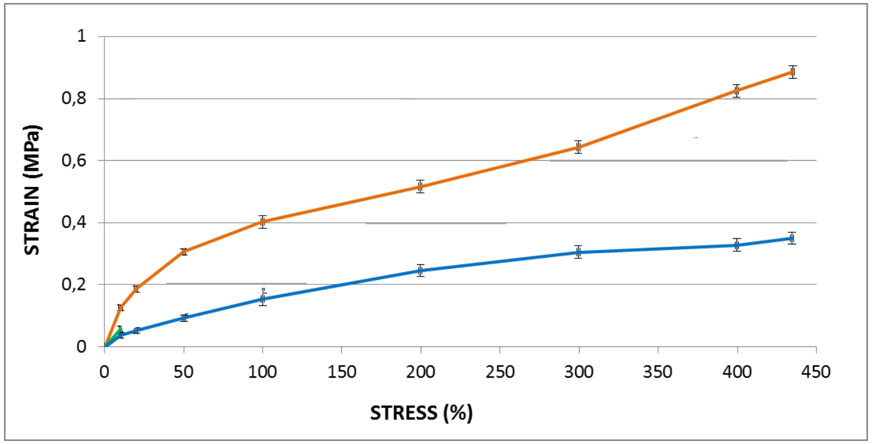
Good behavior at low T

Steric purity: 1,4-cis

Molecular order: enough to crystallize under stretching

↓

Strain Induced Crystallization (SIC)



Taraxacum

Why Natural Rubber is such a great material?

High tensile strength

High Elasticity

High resilience

Low hysteresis

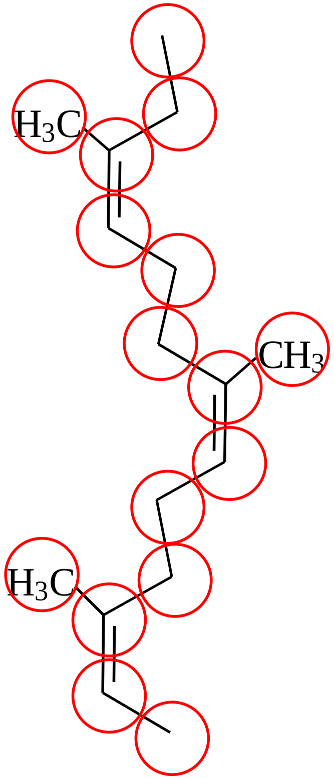
Low heat build up

The best building tack

High dynamic fatigue resistance

High tear and abrasion resistance

NR. The Strain Induced Crystallization (SIC). The traditional interpretation



SIC has been prevailingly explained

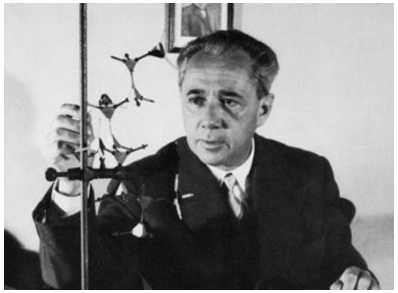
with the high stereoregularity of poly(isoprene) chains:

1,4-cis units close to 100%

Brock, M. J., & Hackathorn, M. J. *Rubber Chemistry and Technology,* **1972,** *45,* 1303-1314.

Burfield, D. R., & Tanaka, Y. *Polymer,* **1987,** *28*, 907-910.

Eng, A.H., Ong, E. L. in: Hevea *Natural Rubber Handbook of elastomers Eds., CRC Press,* **2000**, 29-60.



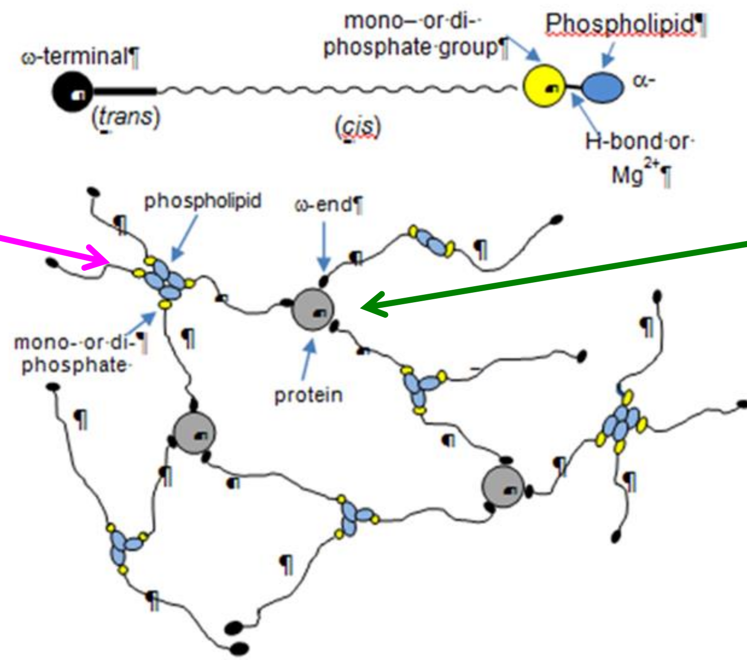
Small melting entropy per statistical segment
was reported to be an important factor
for controlling the crystallization of the rubber network

Corradini, P. In: *J. Polym. Sci., Polym. Symp.*, **1975,** *50*, 327-344. Wiley Subscription Services, Inc.

Allegra, G., & Bruzzone, M. *Macromolecules,* **1983,** *16*, 1167-1170.

NR. The Strain Induced Crystallization (SIC). The new interpretation

phospholipidic
α terminals,
containing
fatty acid ester groups



dimethylallyl groups
modified with proteins
as ω terminal

☞ branch-points are formed, by hydrogen bond, ionic bond or through the formation of micelles.

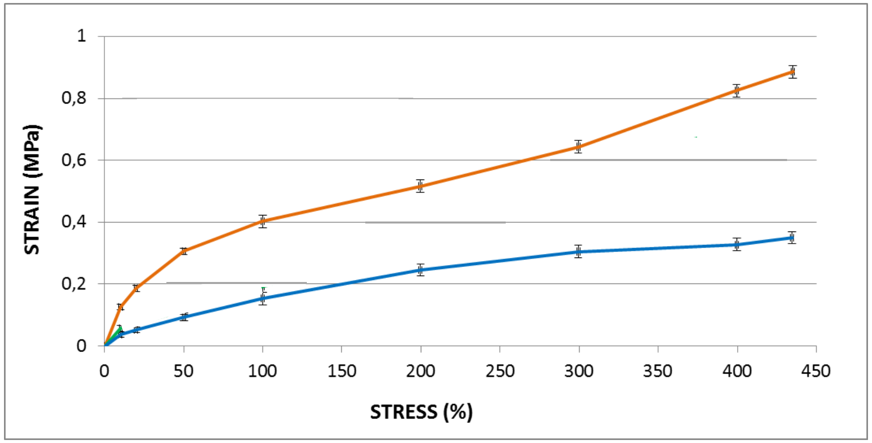
☞ Linked and free saturated fatty acids: nucleating effect
Free unsaturated fatty acids: plasticizers

Kakubo, T., Matsuura, A., Kawahara, S., & Tanaka, Y. *RCT,* **1998,** *71*, 70-75.

Tanaka, Y., & Tarachiwin . *RCT*, **2009**, *82*, 283-314

Why Natural Rubber is such a great material?

Strain Induced Crystallization (SIC)

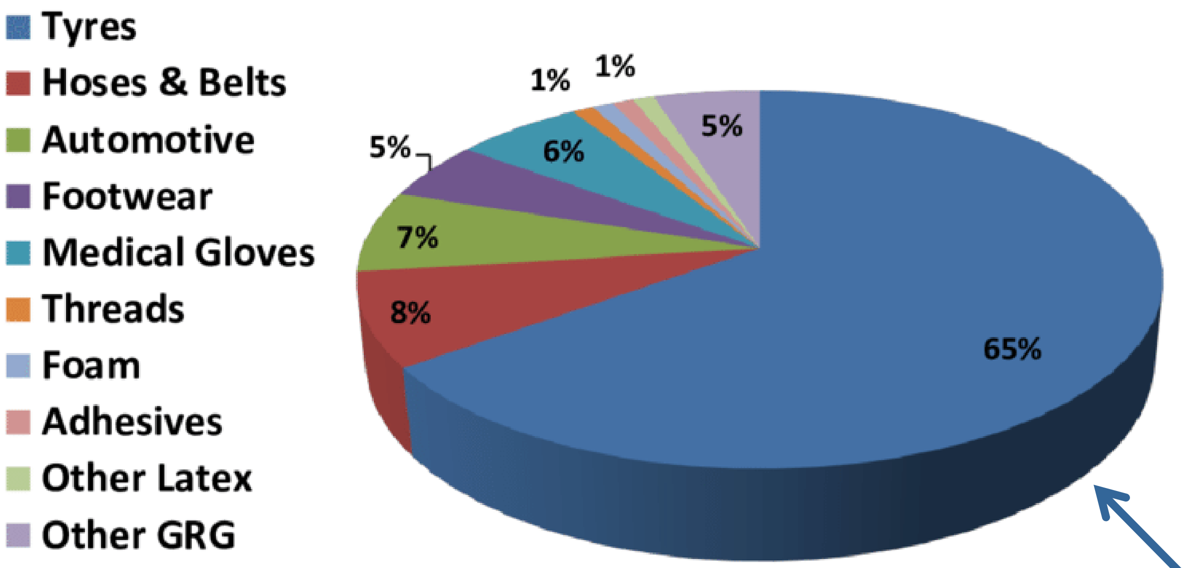


Taraxacum

Taraxacum
without chain end crosslinks

Musto, S., Barbera, V., Maggio, M., Mauro, M., Guerra, G., & Galimberti, M. (2016). Crystallinity and crystalline phase orientation of poly (1, 4-cis-isoprene) from Hevea brasiliensis and Taraxacum kok-saghyz. *Polymers for Advanced Technologies*, *27*(8), 1082-1090.

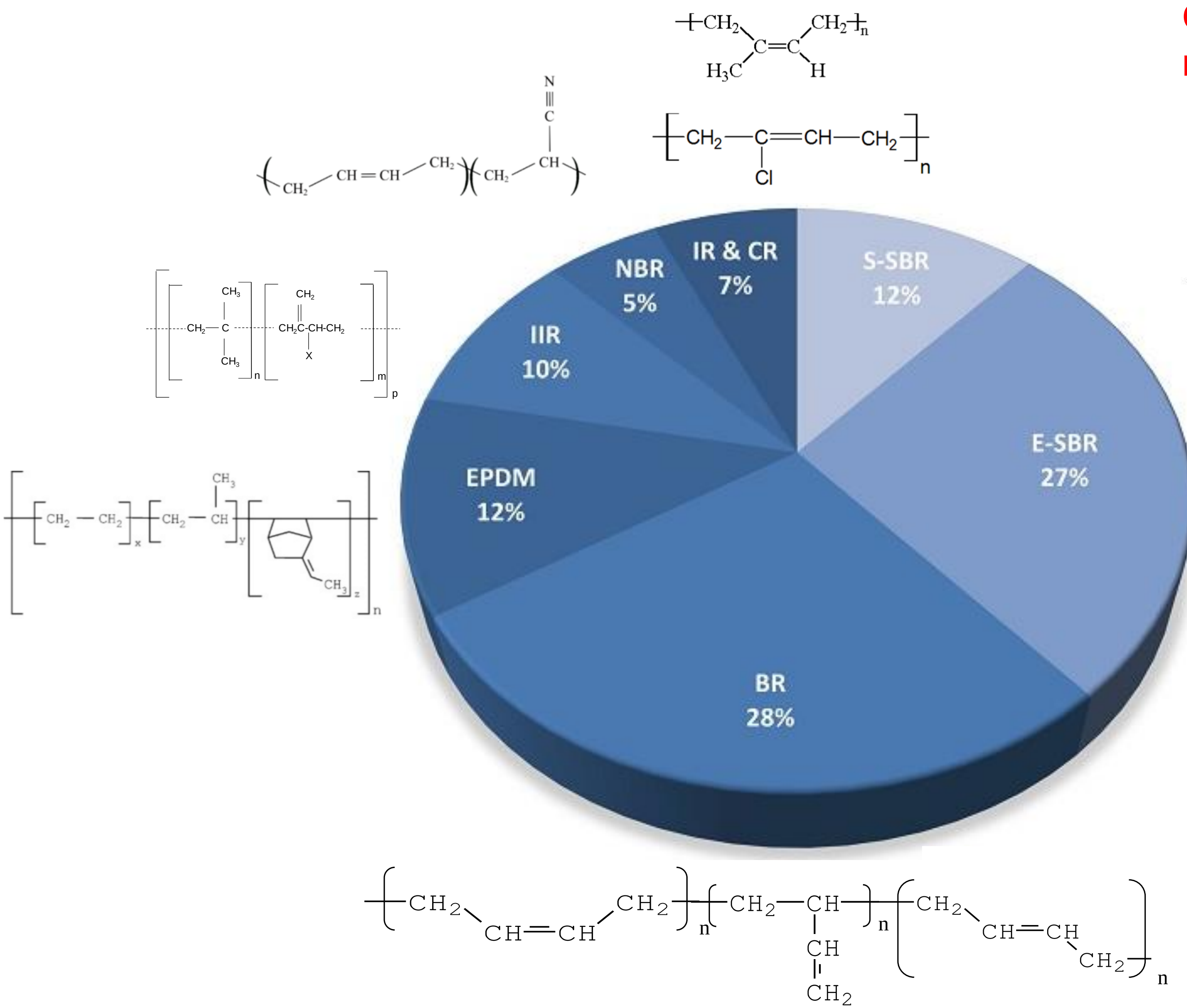
NR. World Applications

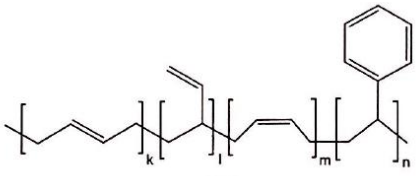


Blengini et al. Assessment of the Methodology for Establishing the EU List of Critical Raw Materials. 2017

Global demand for synthetic elastomers. 2020

Global production:
max: 15 · 10^6 metric tons





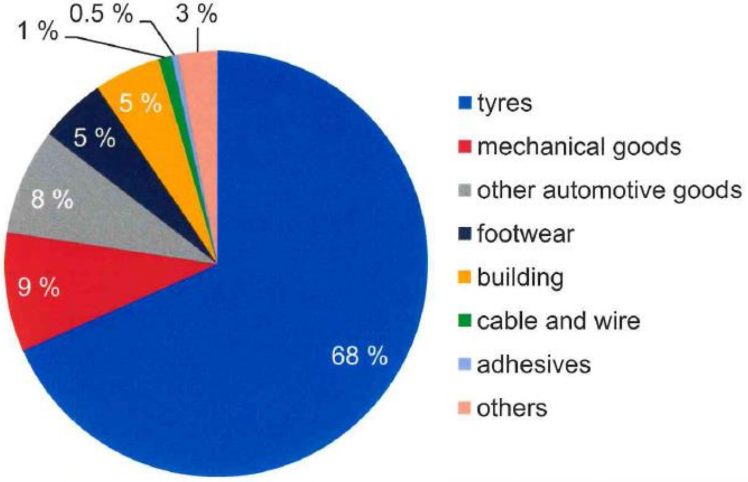
https://www.ceresana.com/en/market-studies/plastics/synthetic-rubber/

Unsaturated rubbers. BR, SBR. Main applications

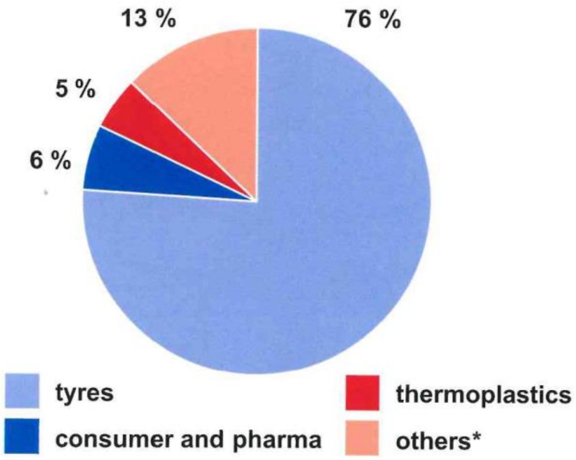
https://www.youtube.com/watch?v=c-JKYRSzu0s

1942
The speech of F.D. Roosevelt

E-SBR



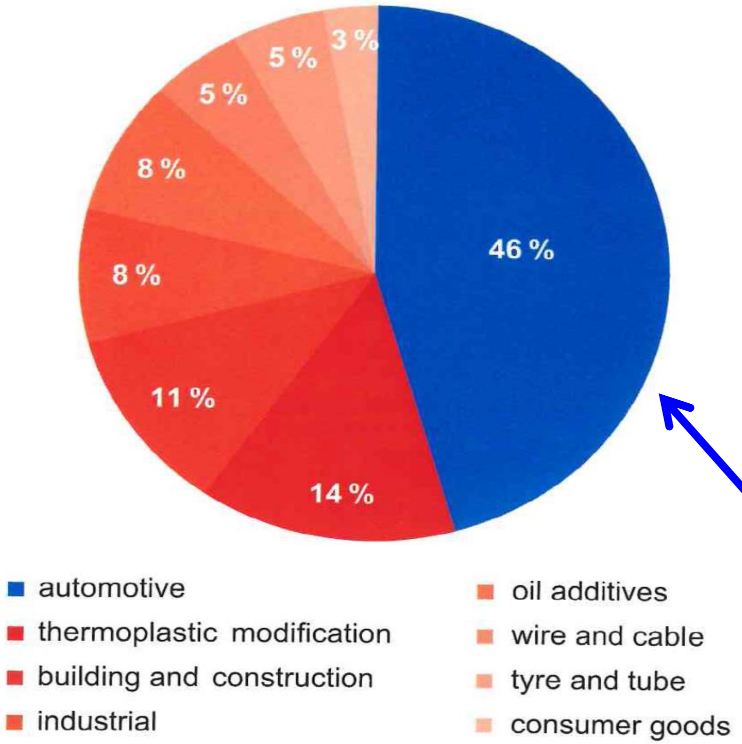
S-SBR + BR + IIR



Arlanxeo. Handbook of synthetic rubber

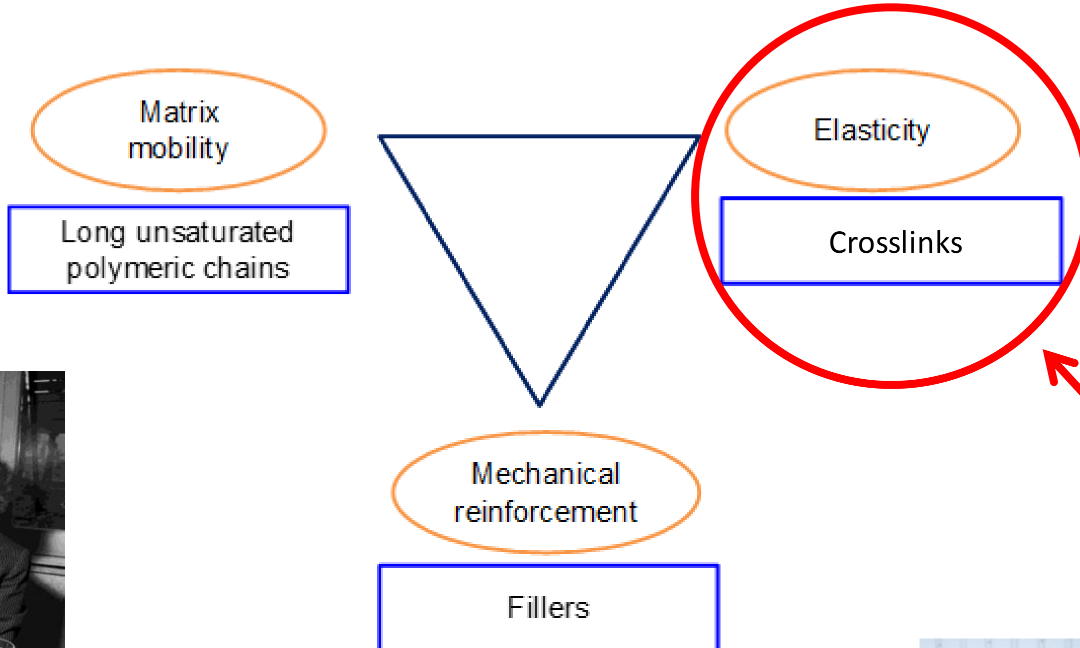
Arlanxeo. Handbook of synthetic rubber

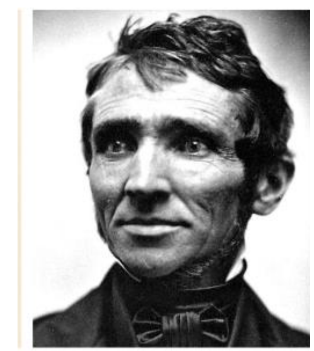
Saturated rubber. EPDM. Main applications



Arlanxeo. Handbook of synthetic rubber

Rubbers need to be crosslinked

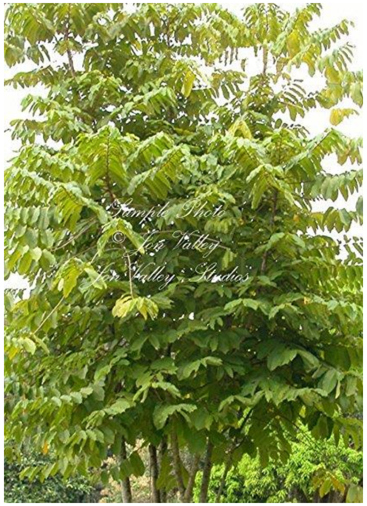


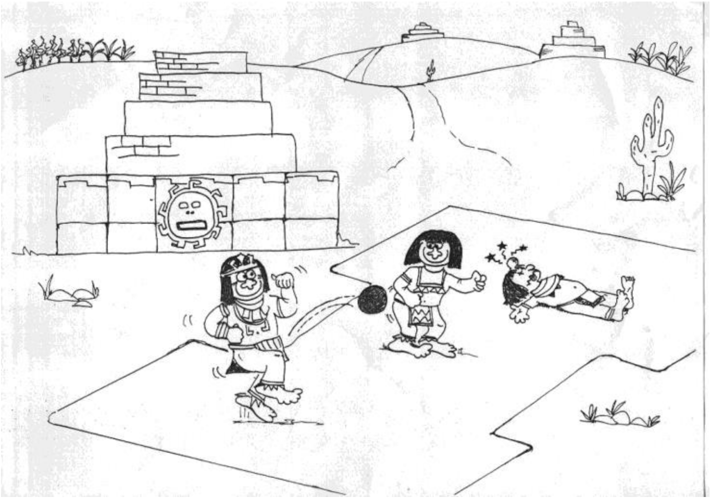


Rubbers need to be crosslinked

Ipomoea alba

Castilla elastica tree



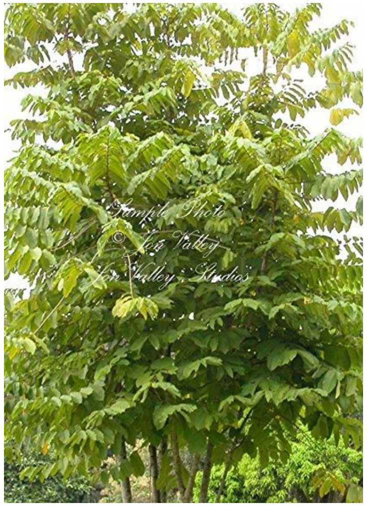


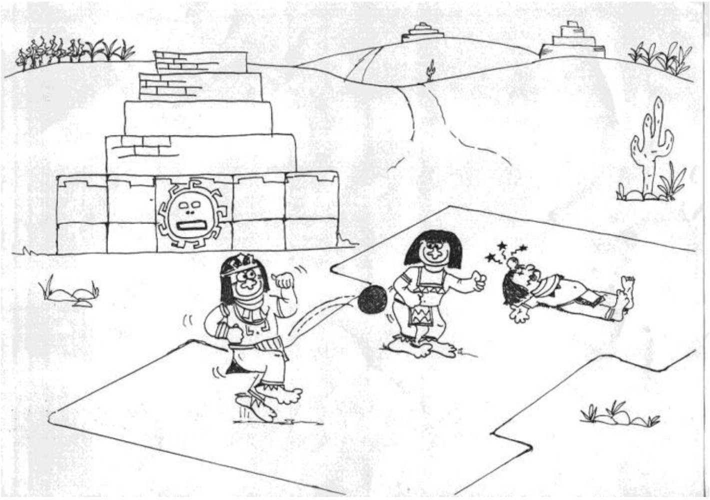
Rubber processed in ancient Mesoamerica, MIT researchers find - MIT News Office

Rubbers need to be crosslinked

Ipomoea alba

Castilla elastica tree





Crosslinked rubbers are thermoset materials

Rubber processed in ancient Mesoamerica, MIT researchers find - MIT News Office

Rubbers in the real world are rubber compounds

Matrix mobility

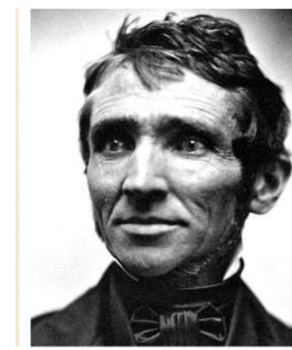
Long unsaturated polymeric chains

Elasticity

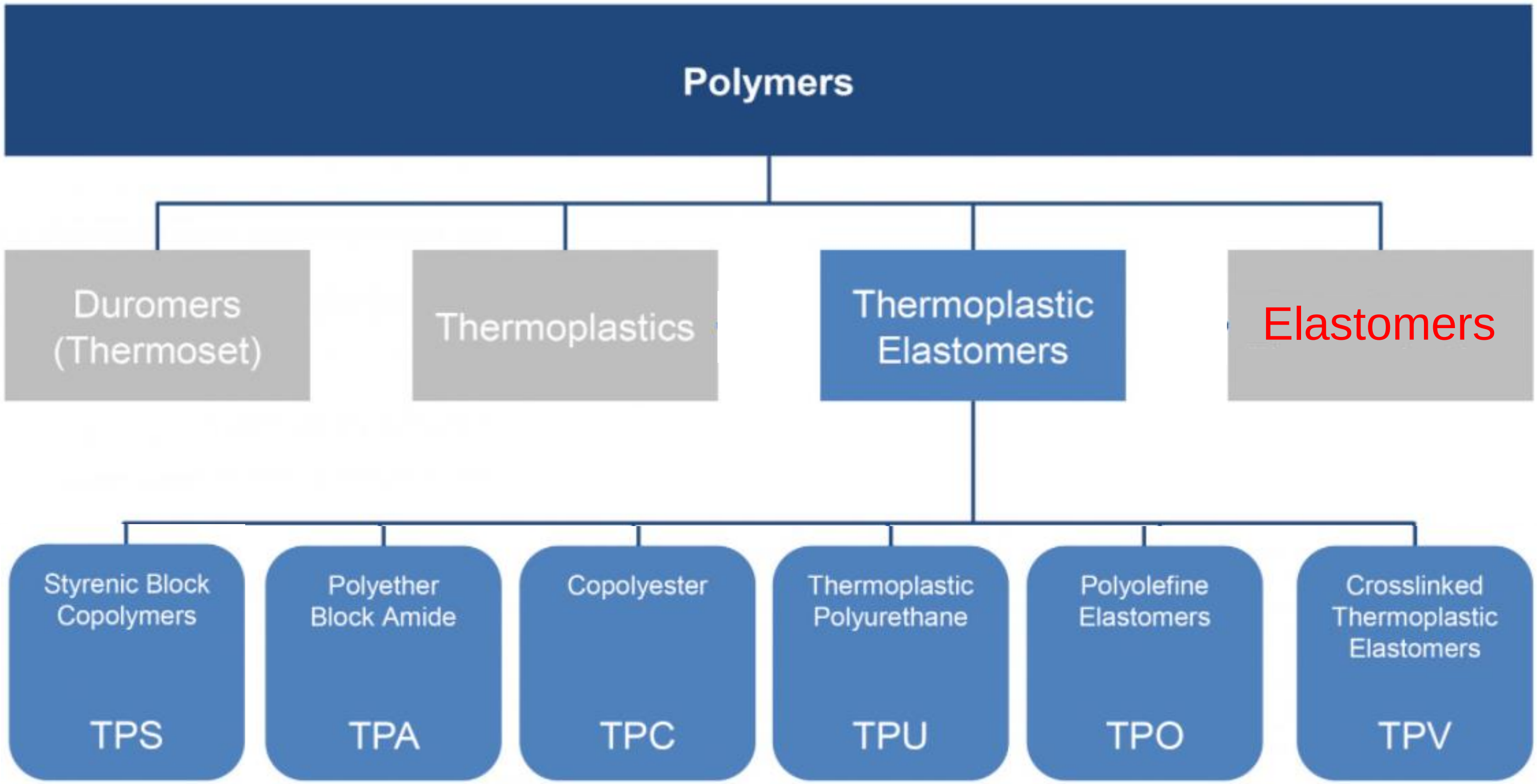
Crosslinks

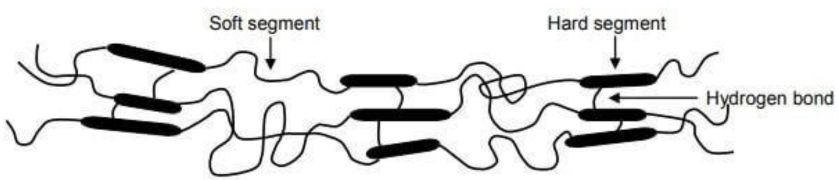
Mechanical reinforcement

Fillers



Thermoplastic Elastomers ! - TPE





Thermoplastic Elastomers - TPE – Definition

ISO 18064

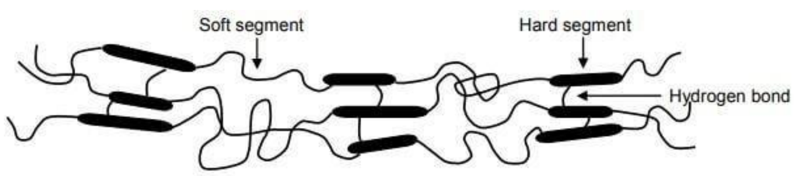
Polymer or blend of polymers

that has properties at its service temperature

similar to those of vulcanized rubber

but can be processed and reprocessed at elevated temperature

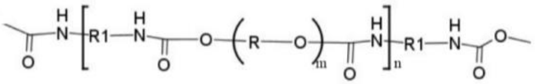
like a thermoplastic

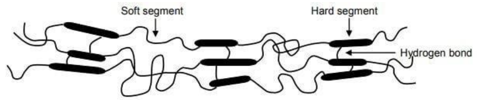


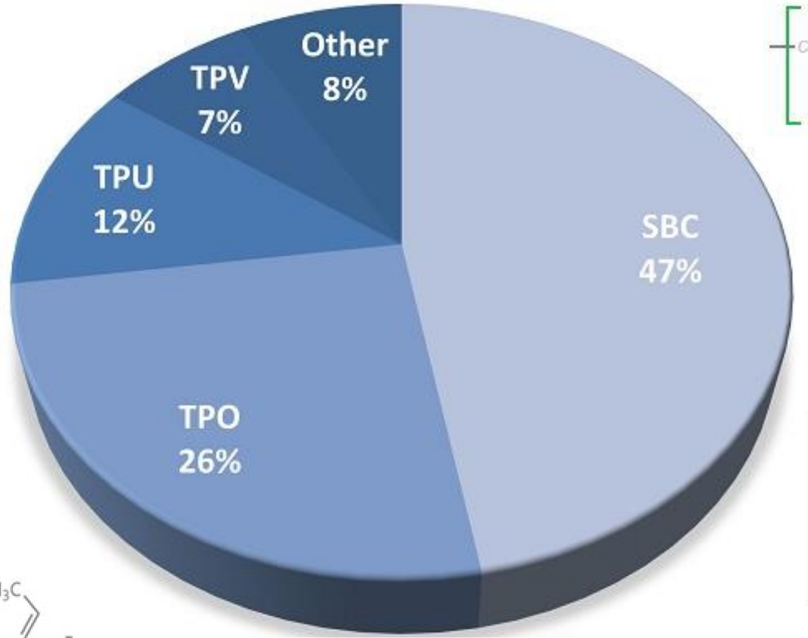
Thermoplastic rubber is a commonly used term

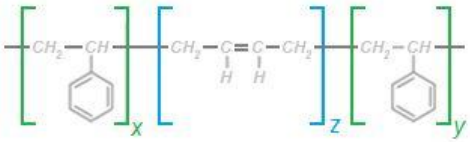
for thermoplastic elastomer.

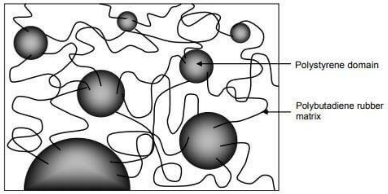
TPE. The market

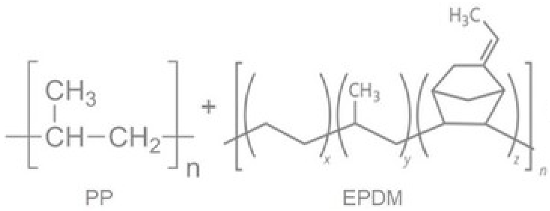






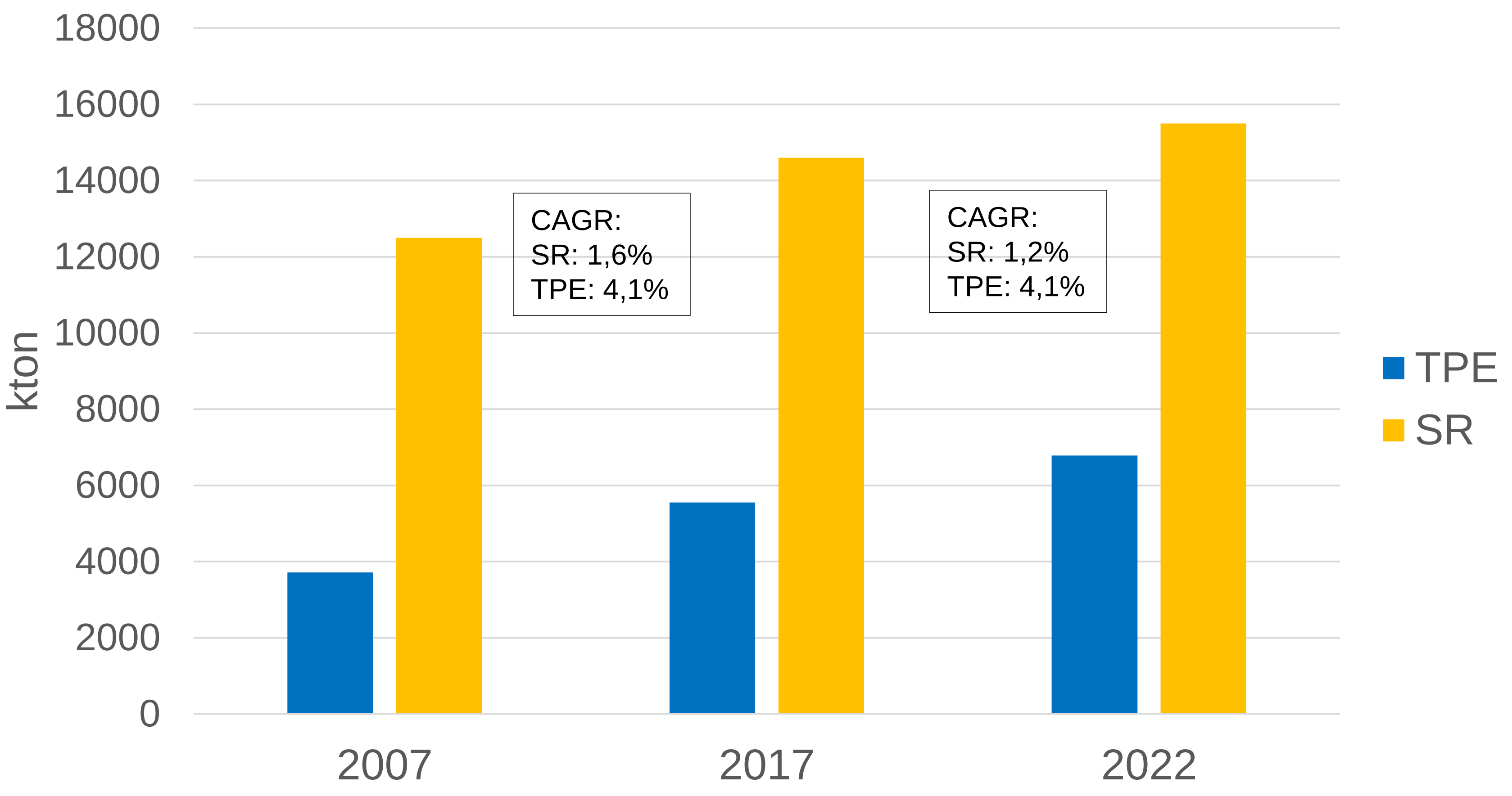






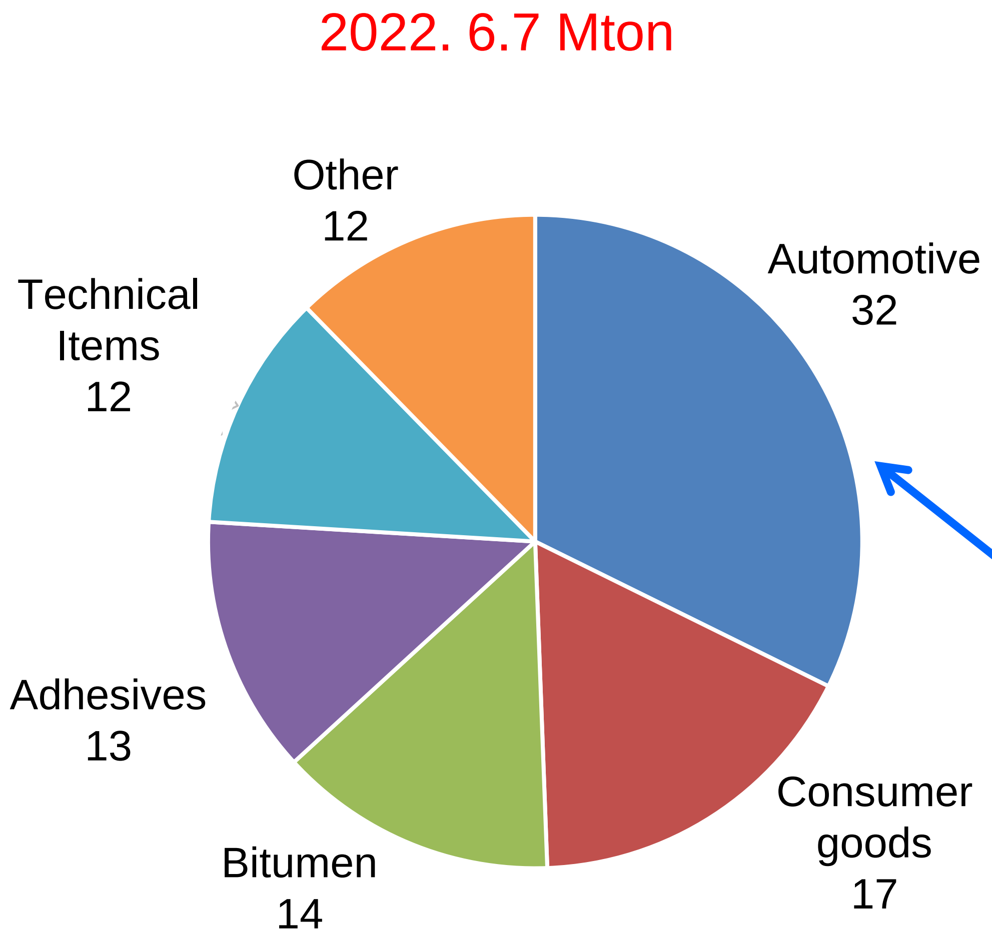
Source: Ceresana

TPE vs Synthetic rubbers



Source: Freedonia, Versalis

TPE. Main applications



Rubbers are key materials to move people and things

Rubber and Sustainability

Rubbers are key materials to move people and things

by 2030

☞ 2.4 billion cars will be on the road

☞ annual passenger traffic and global freight volumes will grow by 50% and 70% with respect to 2015

Global Mobility Report 2017, Tracking Sector Performance. Sustainable mobility for all. **2017**

by 2025

☞ the global market for tires is forecasted to reach 2.7 billion units.

Total weight: 27 billion kg.

https://www.reportlinker.com/p05379599/?utm_source=GNW. Access: July 2022

Rubbers are key materials to move people and things

in 2016

☞ global greenhouse emissions GHG

were 49.4 billion tonnes CO_2 equivalent

☞ Energy is the sector that most contributes

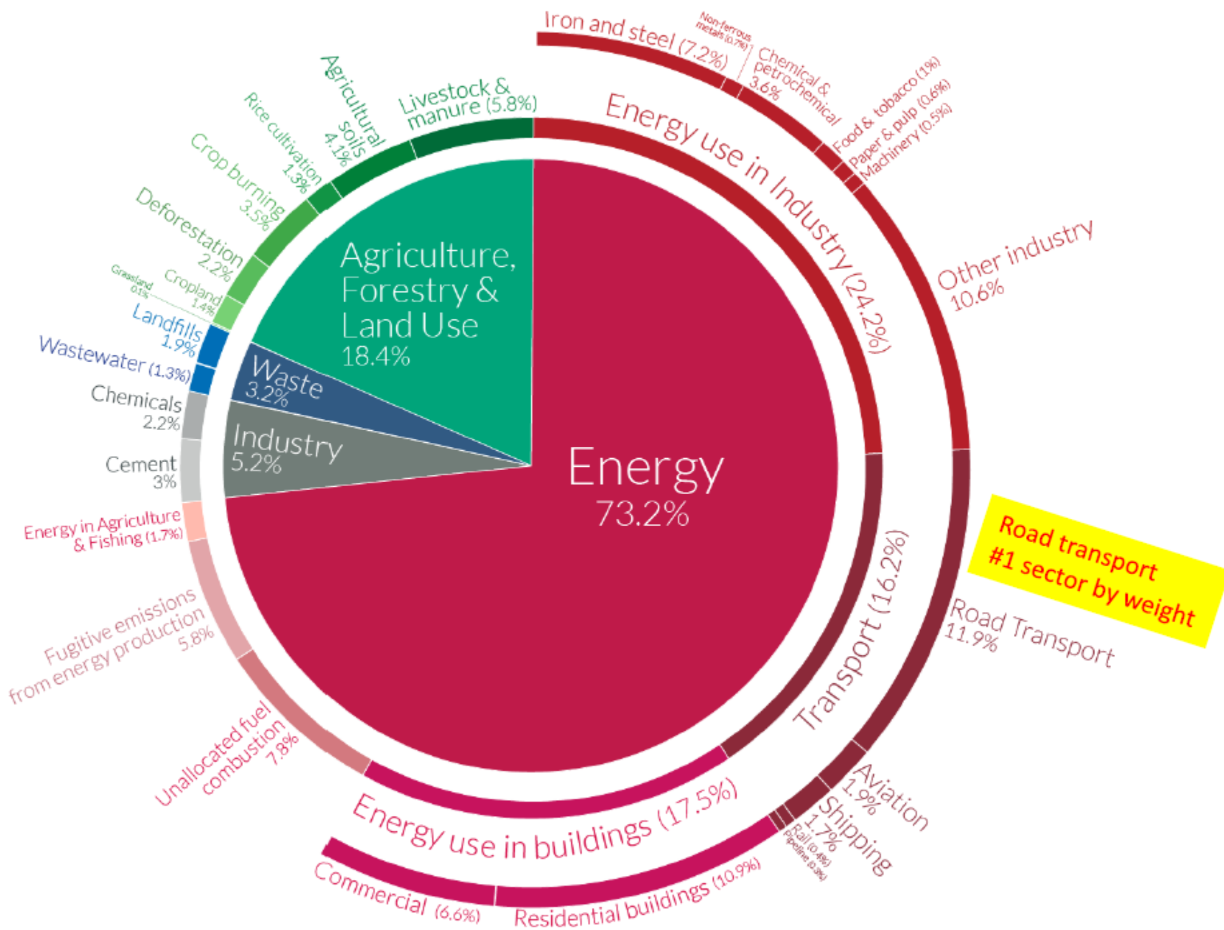
to global greenhouse emissions: more than 70%

↓

What about the road transport in environmental perspective?

Global Mobility Report 2017, Tracking Sector Performance. Sustainable mobility for all. **2017**

Global grrenhouse gas emissions by sector



OurWorldinData.org – Research and data to make progress against the world's largest problems.
Source: Climate Watch, the World Resources Institute (2020).

Rubbers are key materials to move people and things

in 2016

☞ global greenhouse emissions GHG

were 49.4 billion tonnes CO_2 equivalent

☞ Energy is the sector that most contributes

to global greenhouse emissions: more than 70%

↓

The road transport gives the highest contribution: about 12%.

Global Mobility Report 2017, Tracking Sector Performance. Sustainable mobility for all. **2017**

Our world in data. 2020

The UN Sustainable Development Goals - 2015 - 2030

Sustainable Transport

Sustainable transport is integrated

in several Sustainable Development Goals

in the 2030 Agenda for Sustainable Development

United Nations, sustainable development knowledge platform, sustainable development goals. https://sustainabledevelopment.un.org/sdgs. [Accessed August 2022].

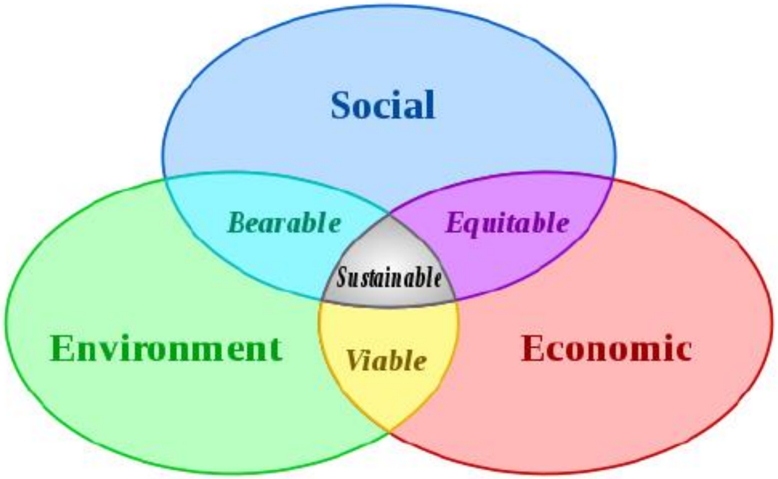
Sustainability. What's in a name?

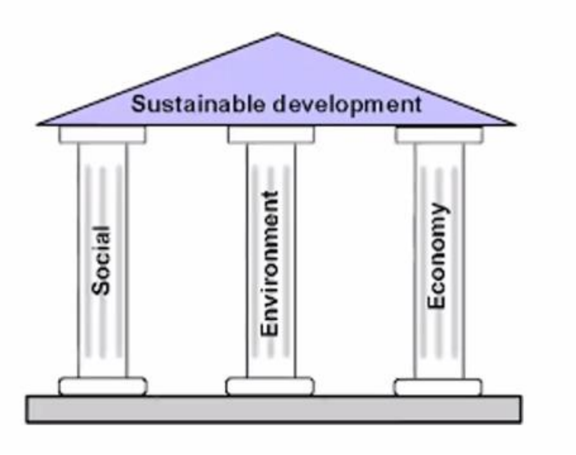
Meeting the needs of the present

without compromising

the ability of future generations

to meet their own needs





Bruntland Report for the World Commission on Environment and Development (1992) - https://www.globalfootprints.org/sustainability/)

Purvis, B., Mao, Y. & Robinson, D. Three pillars of sustainability: in search of conceptual origins. *Sustain Sci* **14,** 681–695 (2019).

Applied Sustainability

FINITE, FOSSIL FUEL

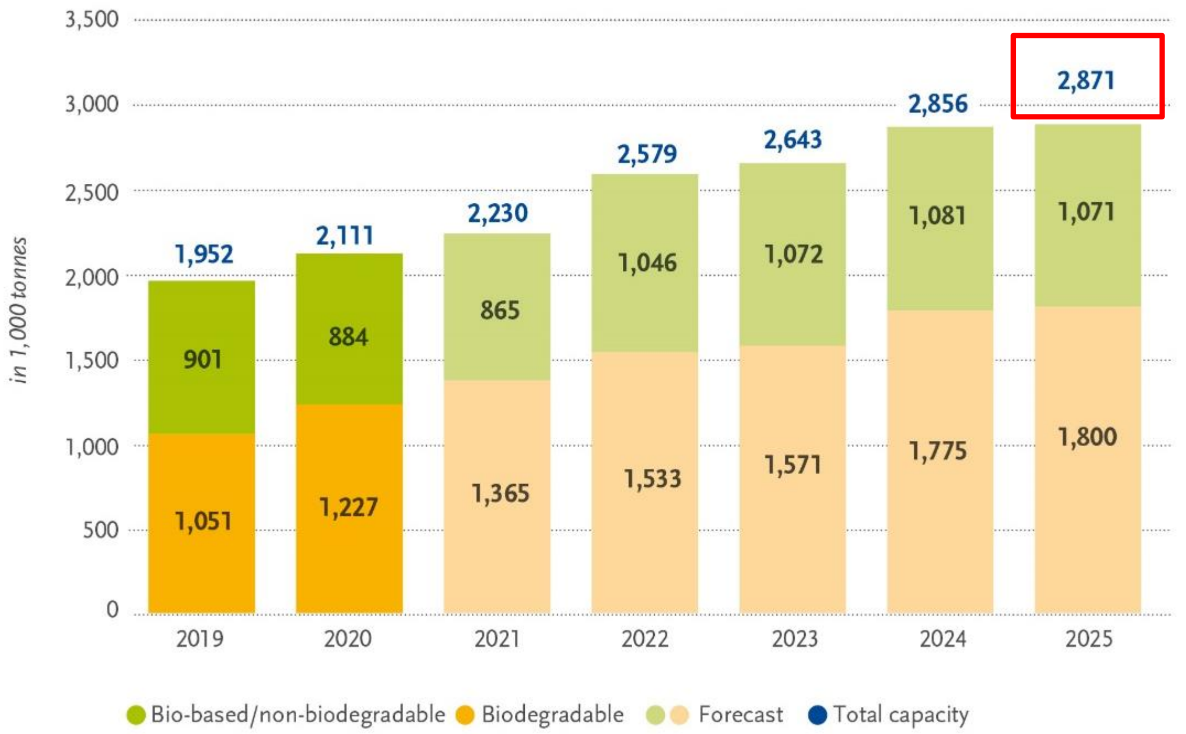
NATURAL SOURCES

LINEAR ECONOMY

CIRCULAR ECONOMY

CARBON CAPTURE
AND UTILIZATION

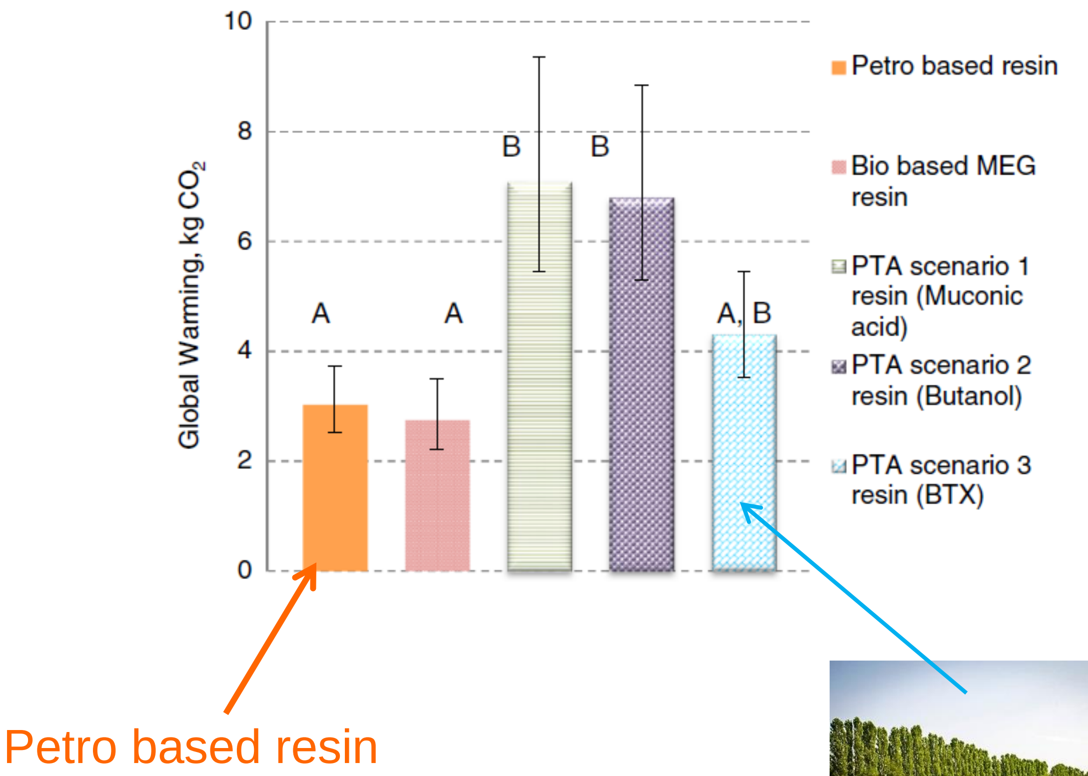
Bioplastics are less than 1% of the plastics' market



Source: European Bioplastics, nova-Institute (2020)
More information: ***www.european-bioplastics.org/market*** *and* ***www.bio-based.eu/markets***

Cradle to gate LCA for terephtalic acid. Oil based vs biobased

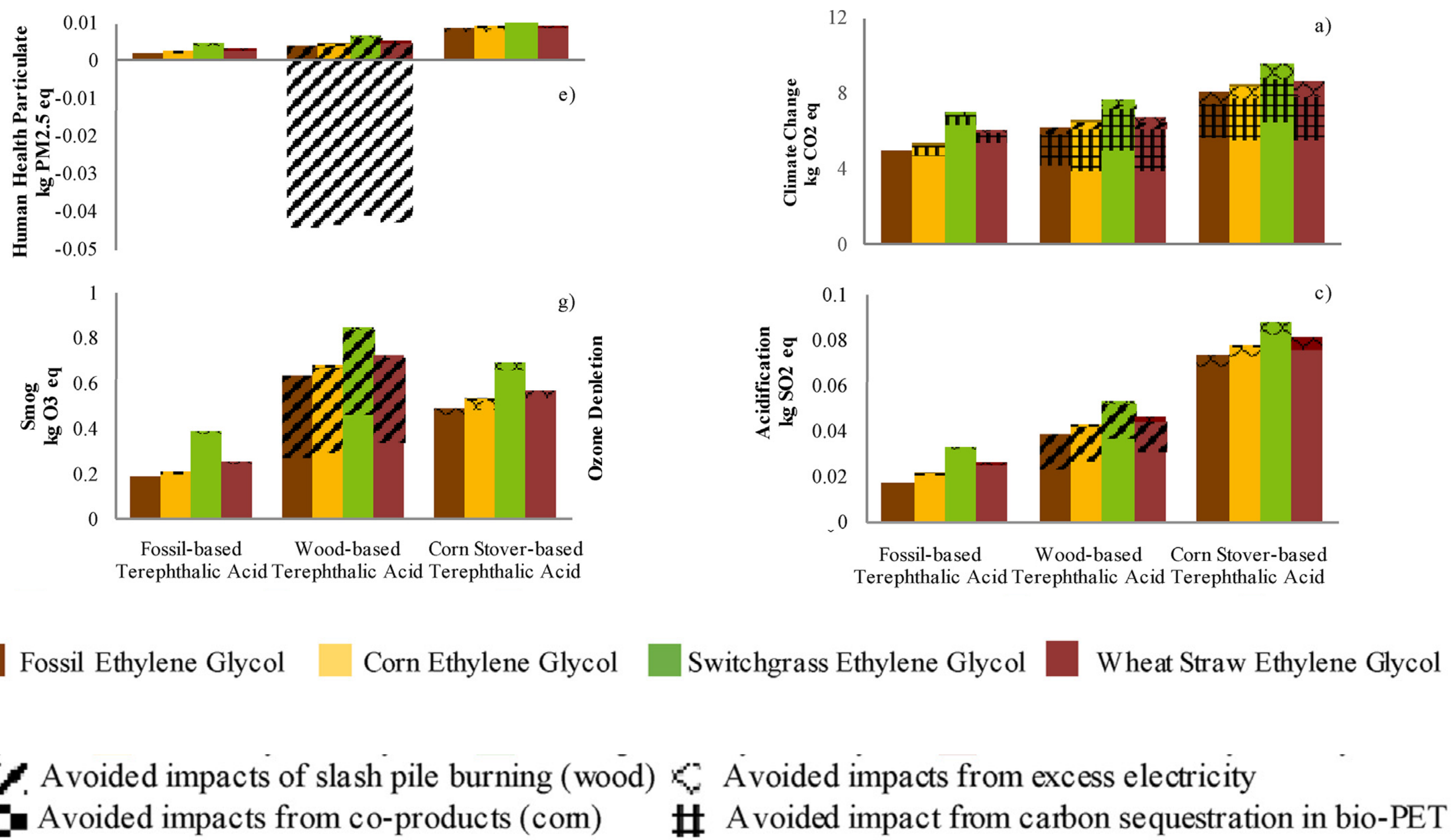
Global warming



Akanuma, Y., Selke, S. E., & Auras, R. (2014). A preliminary LCA case study: comparison of different pathways to produce purified terephthalic acid suitable for synthesis of 100% bio-based PET. *The International Journal of Life Cycle Assessment*, *19*(6), 1238-1246.

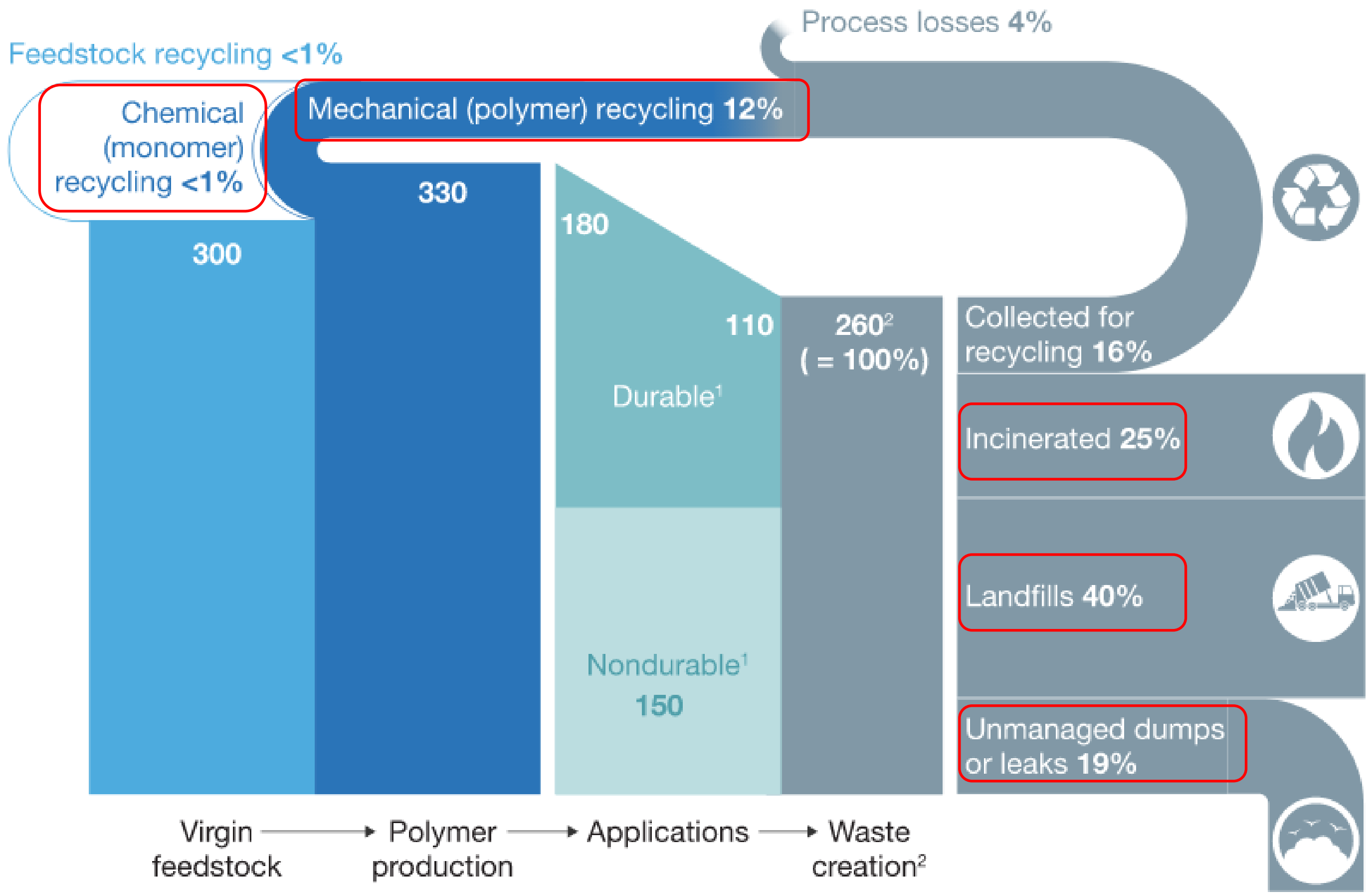
Cradle to gate LCA for PET bottles. Oil based vs biobased

The avoided impacts



L. Chen et al. / Journal of Cleaner Production 137 (2016) 667e676

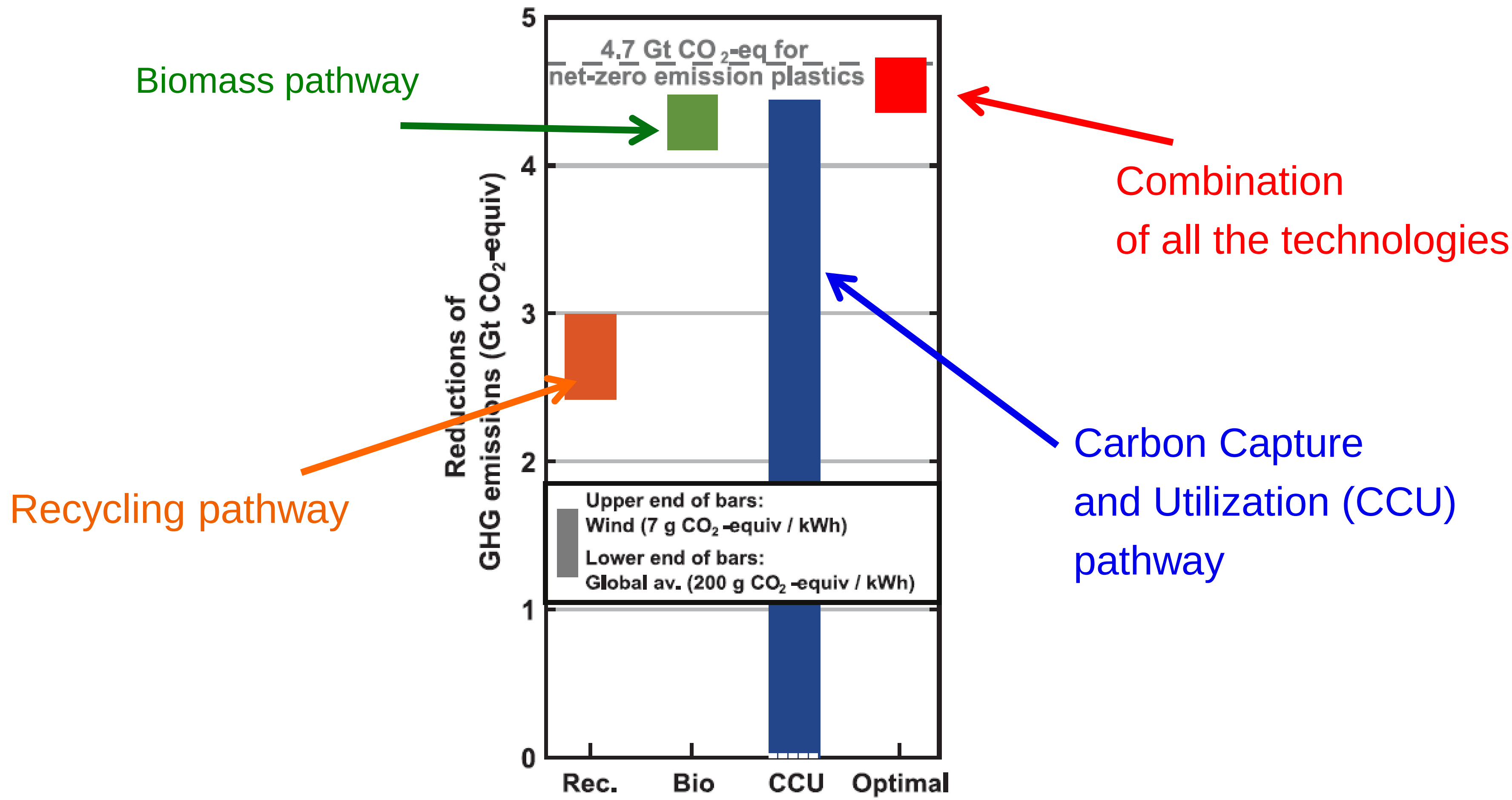
The majority of plastics waste goes to landfill and incineration



[1]Durable applications with an average lifetime >1 year will end up as waste only in later years; nondurable applications go straight to waste.
[2]150 million metric tons of mixed plastic waste from nondurable applications that end up as waste in same year, plus 110 million metric tons of mixed plastic waste from production in previous years.

https://www.mckinsey.com/industries/chemicals/our-insights/no-time-to-waste-what-plastics-recycling-could-offer

Net-zero greenhouse gas emission. For plastics



Reduction of GHG emissions. With respect to linear carbon pathway

Science 374, 71–76 (2021)

Sustainable rubbers - Natural Rubber

hevea brasiliensis

energy input for the production (1)

NR: 15-16 MJ/kg

synthetic rubber: 100 MJ/kg

carbon sequestration by the *Hevea* tree (2)

photosynthetic rate

Hevea leaves: about 11 μmol/m^2·s

other trees: 5–13 μmol/m^2·s

partenium argentatum

taraxacum kok-saghyz

(1) Chapman, A .V. Natural rubber and NR-based polymers: renewable materials with unique properties. In Proceedings of the 24th International H.F. Mark-Symposium, 'Advances in the Field of Elastomers & Thermoplastic Elastomers, Vienna, Austria, 15–16 November 2007.

(2) Jones, K.P. The paradoxical nature of natural rubber. Kautsch. Gummi Kunstst. 2000, 53, 735–742

More sustainable synthetic rubbers

Mass Balance Approach

Bio- and circular Attributed polymers

Tyres and rubber waste Recycling

Devulcanized rubber

SBR/ELT powder masterbatch

New polymers

Next gen SSBR, BR

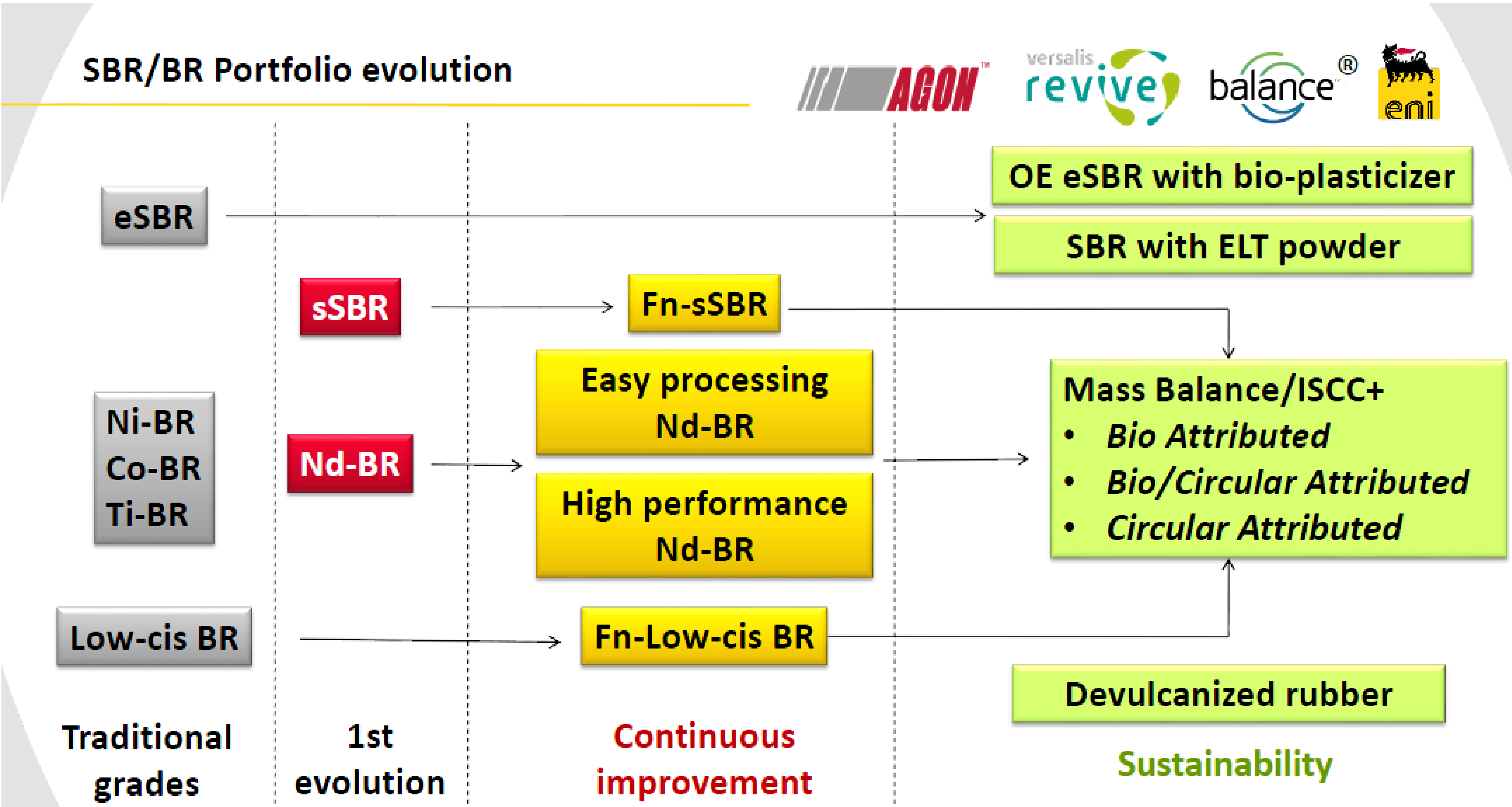
Bio-extended eSBR

versalis

ELT = End of Life Tyres

F. Bacchelli. A multi-perspective model for sustainable synthetic rubber. Presentation at DKT IRC 2021

More sustainable rubbers



Product Performance Sustainability

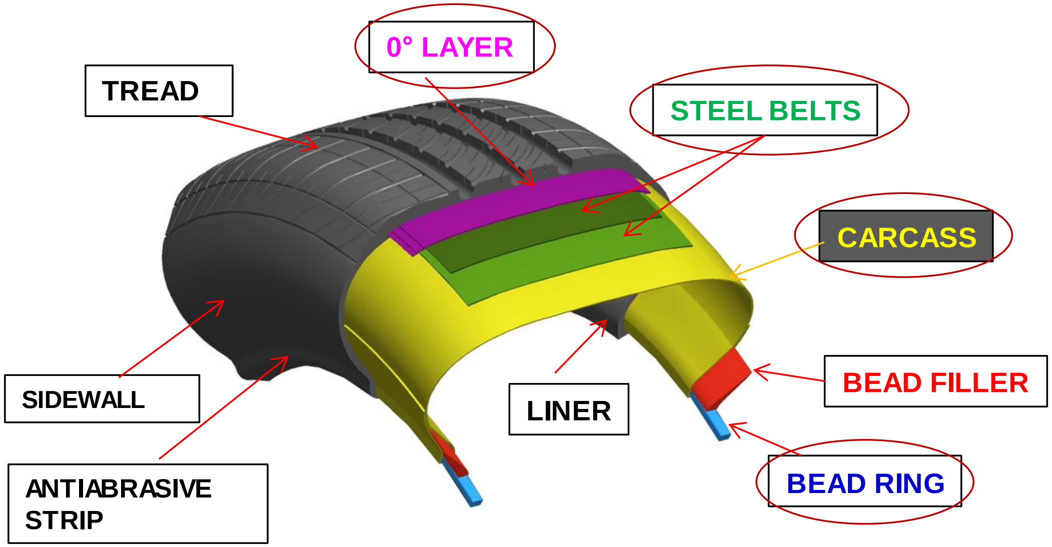
F. Bacchelli. A multi-perspective model for sustainable synthetic rubber. Presentation at DKT IRC 2021

Focus on the main application of rubbers

The main application of rubbers. Tyres. Not just black and round

A complex composite of different **semi-finished materials**

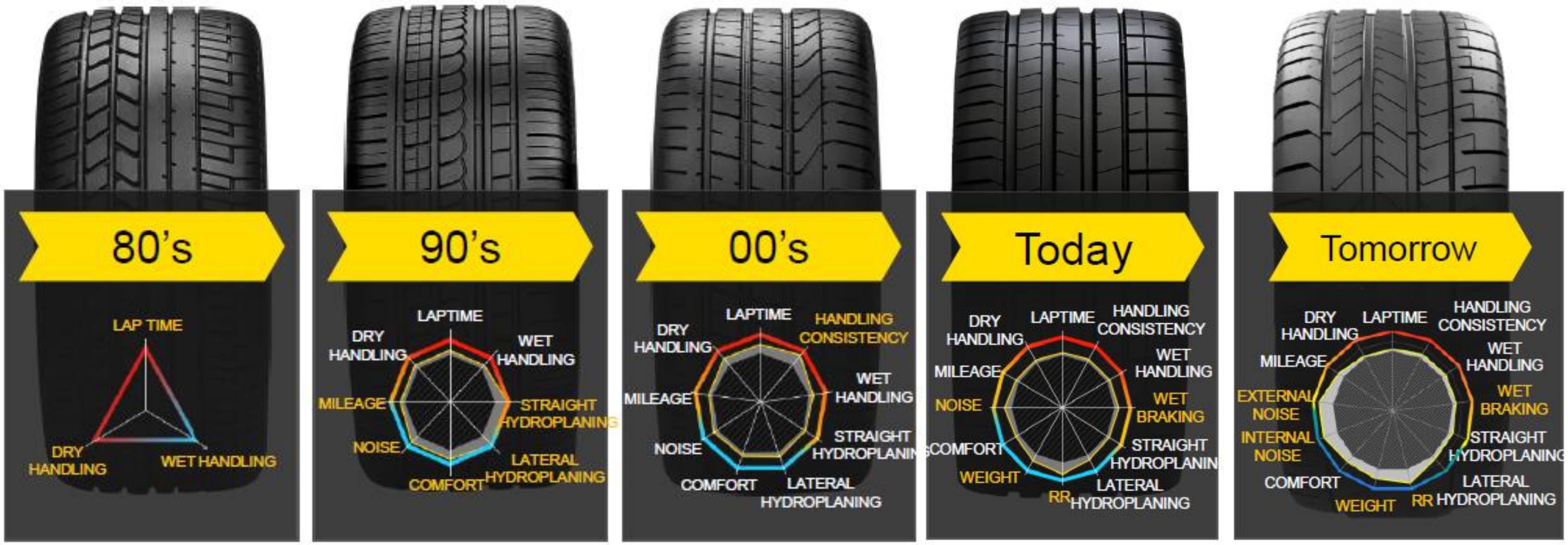
made of rubber, textile and metal reinforcements



At least 9 Components in a Tyre

Complexity as an opportunity for sustainability

Tyres. Products driven by performance

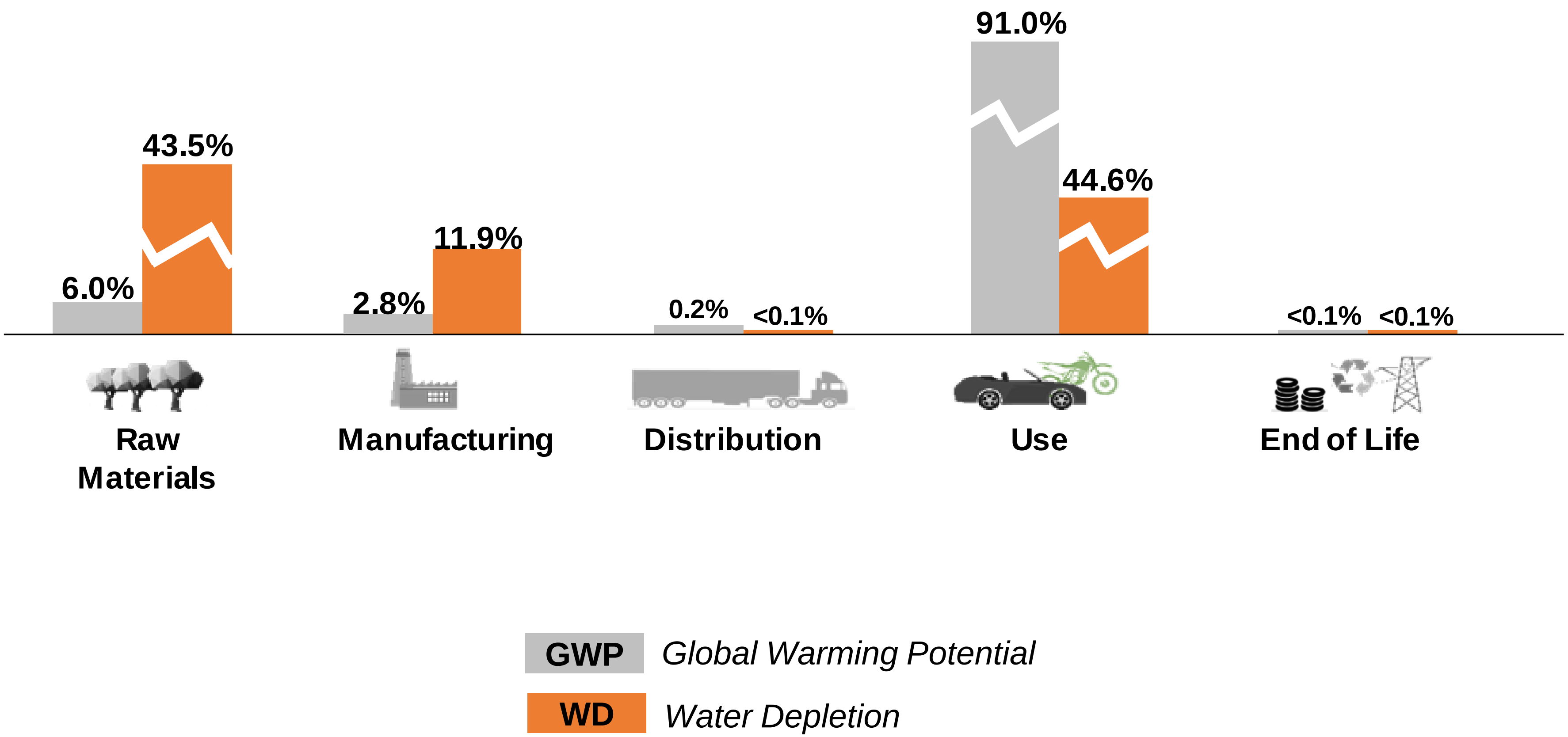


Electric vehicle will impact also: High Load Capacity Tyres, Aerodynamics

(As of today) sustainability must fit with performance

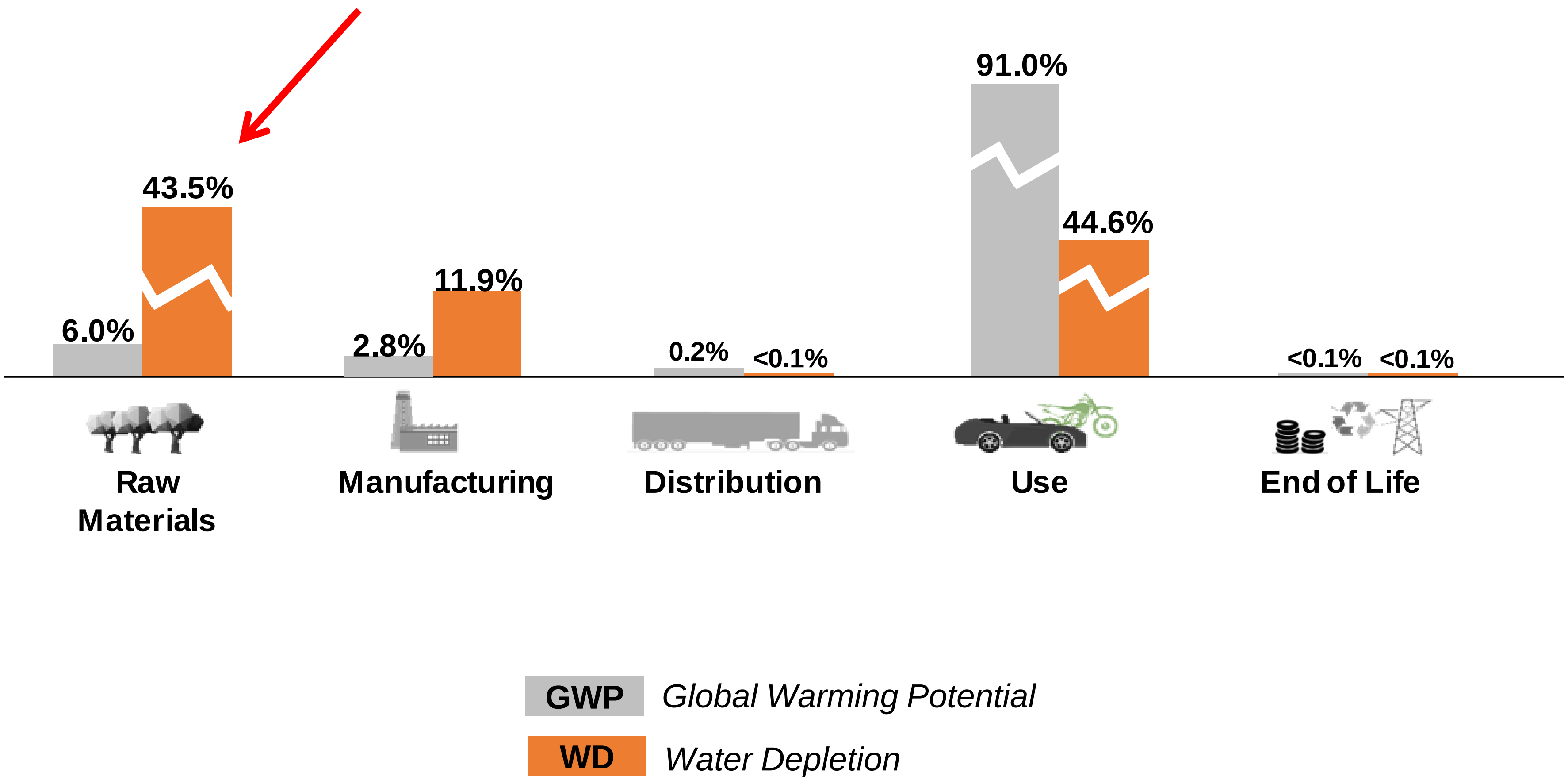
Luca Giannini – Pirelli Tyre - The Challenges of Sustainable Development in Tyre Materials - 2022

Tyres and sustainability. Life Cycle Assessment for a tyre



Luca Giannini – Pirelli Tyre - The Challenges of Sustainable Development in Tyre Materials - 2022

Tyres and sustainability. Life Cycle Assessment for a tyre



Luca Giannini – Pirelli Tyre - The Challenges of Sustainable Development in Tyre Materials - 2022

"Towards 100% sustainable raw materials" - Natural Rubber

The Pirelli roadmap for NR sustainability

Implementation Roadmap 2019-2021 – focus areas

TRAINING to improve farmers' productivity and resiliency

TRACEABILITY towards more & more precise **RISK** assessments

SHARING THE COMMITTMENT along the supply chain

ENGAGE with value-chain stakeholders

Plan 2021

TRAINING
- Training on critical topics as identified through risk assessment, outcomes from training and dialogues
- Tapping competition

TRACEABILITY
- Engage with suppliers to improve upstream traceability and transparency
- on-site audits to detect social and environmental risks

SHARING THE COMMITTMENT
- Suppliers' Roadmap monitoring and implementation support on activities planned for 2021, including 2020 ones delayed due to COVID.

ENGAGE
- Active engagement within GPSNR[1] by participating in four working groups, co-chairing 2 of them

The new forward-looking plan will be released end 2021/early 2022

The Global Platform for Sustainable Natural Rubber

1. Initiated by WBCSD's TIP Tyre makers, the Global Platform for sustainable Natural Rubber (GPSNR) was launched in 2018 and is today an independent multi-stakeholder initiative pursuing sustainable development of the natural rubber value-chain

Luca Giannini – Pirelli Tyre - The Challenges of Sustainable Development in Tyre Materials - 2022

"Towards 100% sustainable raw materials"

SOURCE:	Nokian Tyres	Michelin	Continental	Bridgestone	Goodyear
	PURE CONSUMER (Winter)	CONSUMER + INDUSTR.	CONSUMER + INDUSTR.	CONSUMER + INDUSTR.	CONSUMER + INDUSTR.
APPLICATION SCOPE	NOT SPECIFIED	NOT SPECIFIED	NOT SPECIFIED	NOT SPECIFIED	NOT SPECIFIED
RENEWABLE MATERIALS	• **Guayule** (R&D development, not in NP[1] yet) • **Rice Husk Silica** • **Rapeseed oil**	• **Bio Butadiene** (Bio Butterfly project)	• **Dandelion** (R&D development since 2011, not in NP[1] yet)	• **High Strength Rubber** (HSR) • **Guayule** (R&D development since 2012, not in NP[1] yet)	• **Soybean oil** • **Rice husk ash silica** (NP[1]) • **Dandelion** (not in NP yet) • **Bio-Isoprene**

Public data

"Towards 100% sustainable raw materials"

SOURCE:	NOKIAN TYRES	MICHELIN	Continental	BRIDGESTONE	GOODYEAR
	PURE CONSUMER (Winter)	CONSUMER + INDUSTR.	CONSUMER + INDUSTR.	CONSUMER + INDUSTR.	CONSUMER + INDUSTR.
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Public data

2038 Target:

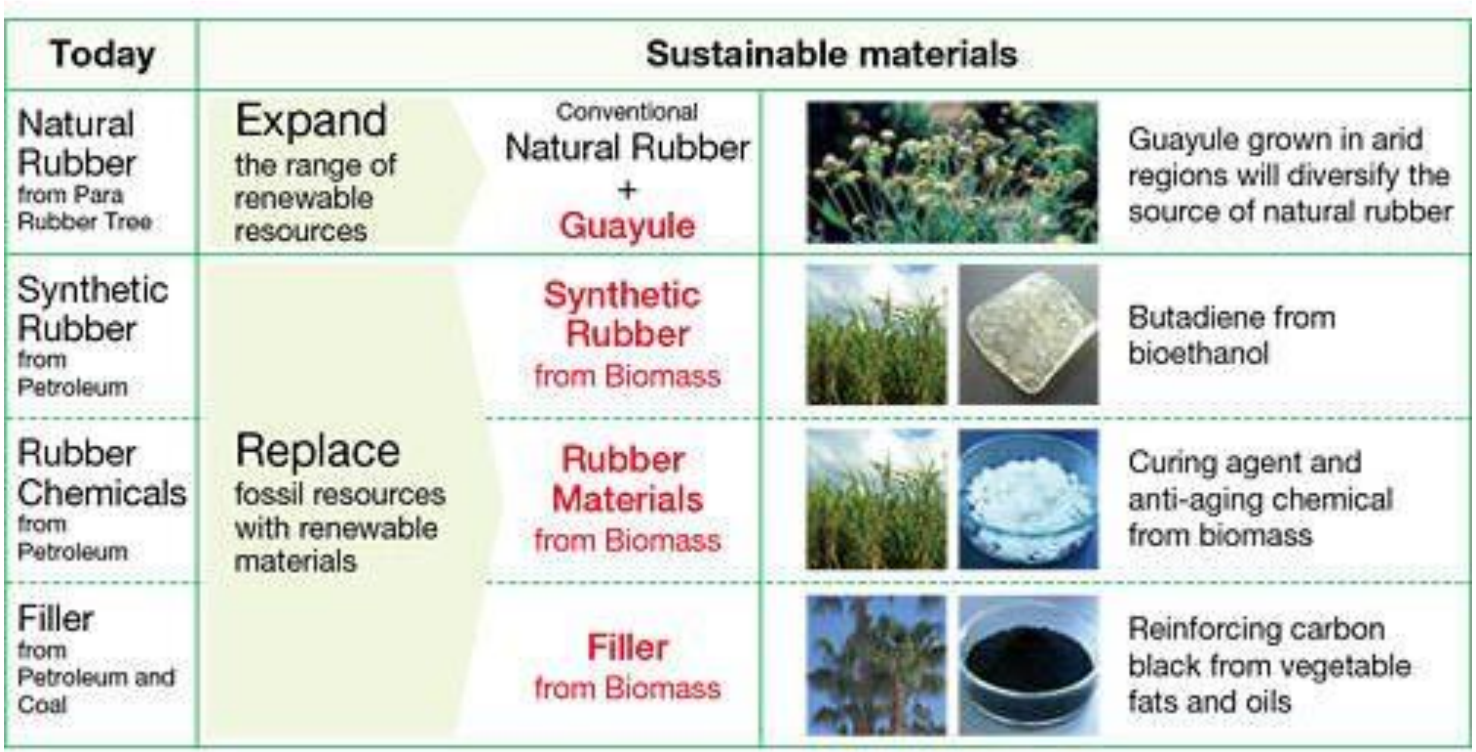
Increase renewable share from 26 to 30%

2048 Ambition:

Biodegradable Tread
that can be renewed with a 3D printer
on non-pneumatic tyre/wheel
made of 100% bio-sourced and recycled products

“Towards 100% sustainable raw materials”

Bridgestone’s view

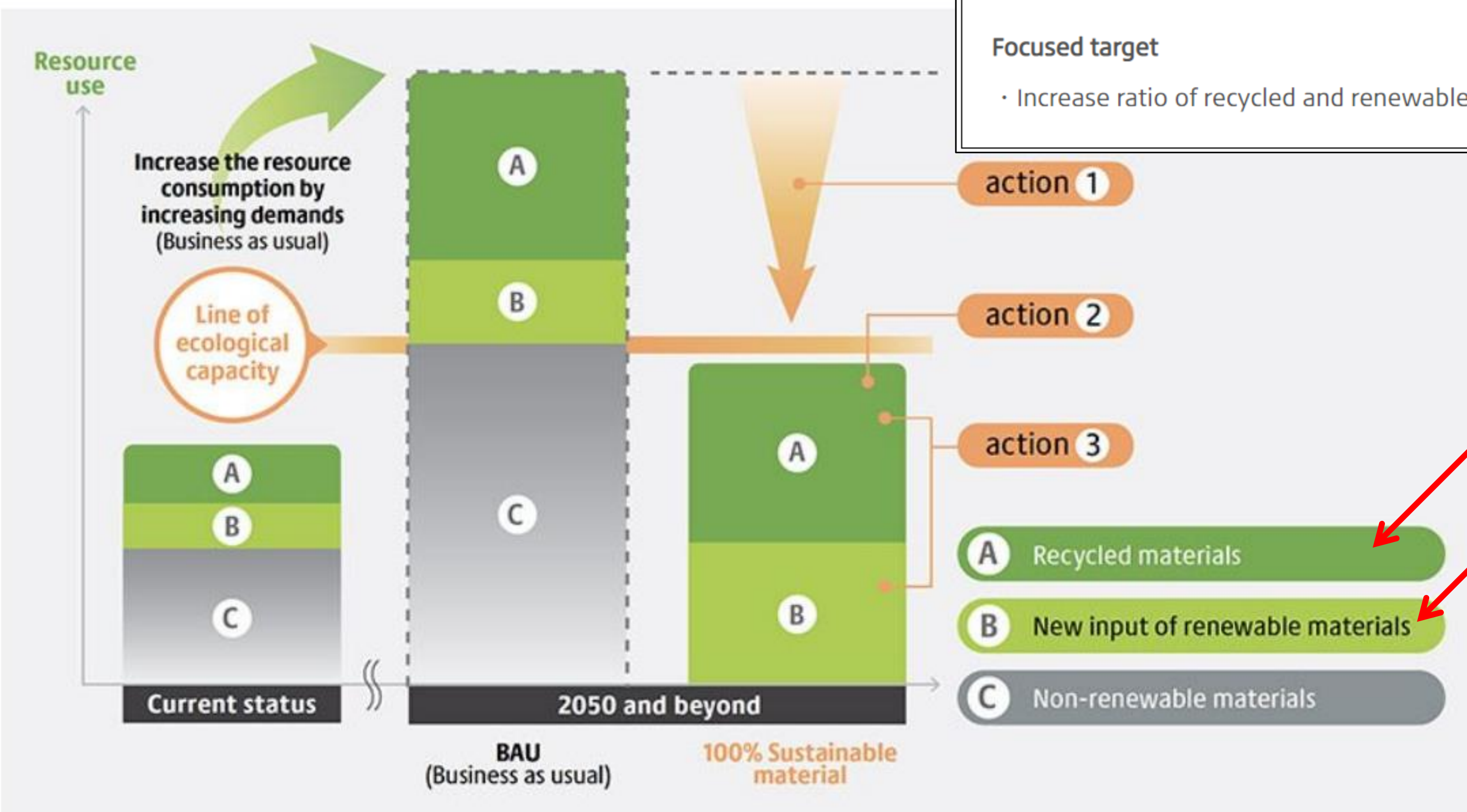


Today	Sustainable materials		
Natural Rubber from Para Rubber Tree	Expand the range of renewable resources	Conventional Natural Rubber + Guayule	Guayule grown in arid regions will diversify the source of natural rubber
Synthetic Rubber from Petroleum	Replace fossil resources with renewable materials	Synthetic Rubber from Biomass	Butadiene from bioethanol
Rubber Chemicals from Petroleum		Rubber Materials from Biomass	Curing agent and anti-aging chemical from biomass
Filler from Petroleum and Coal		Filler from Biomass	Reinforcing carbon black from vegetable fats and oils

Internet site & IRC2020

"Towards 100% sustainable raw materials"

Bridgestone's view



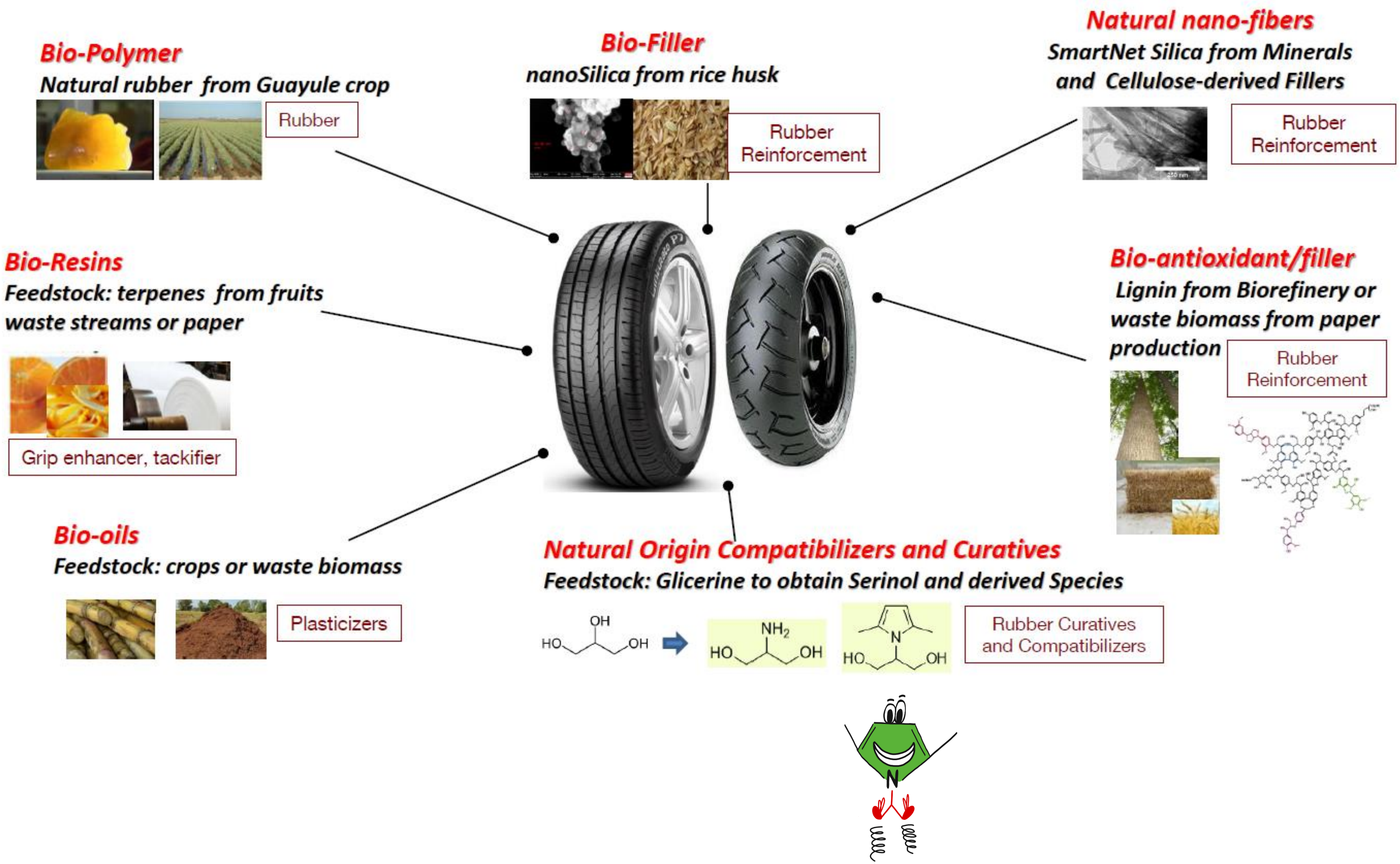
Focused target

· Increase ratio of recycled and renewable material*4 to 40% by 2030

Internet site

“Towards 100% sustainable raw materials”

The Pirelli’s view



Luca Giannini – Pirelli Tyre - The Challenges of Sustainable Development in Tyre Materials - 2022

“Towards 100% sustainable raw materials”

The Michelin’s view. Concept tyre

Airless: a technology that eliminates the risk of flats and rapid pressure loss and reduces environmental impact

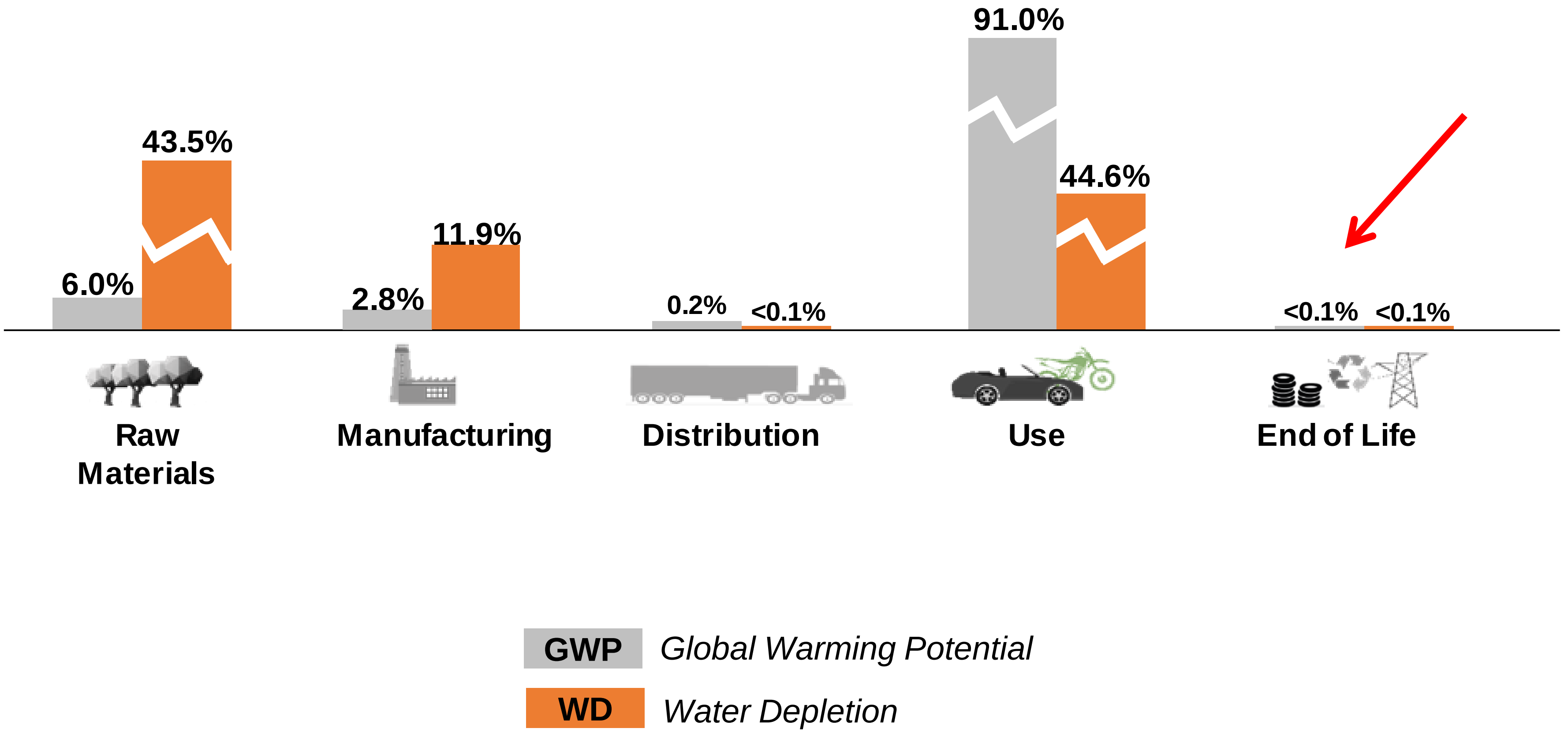
Rechargeable: a tread that can be 3D printed on demand

Connected: for a safe and personalized augmented driving experience

100% Sustainable: disruptive innovation in biosourced and recycled materials

https://www.michelin.com/en/innovation/vision-concept/

Life Cycle Assessment for a tyre



Luca Giannini – Pirelli Tyre - The Challenges of Sustainable Development in Tyre Materials - 2022

What about rubber recycling? What to do with waste tyres?

1.4 billion waste tyres every year

Waste tyre piles. They are visible from the space

west of Sulaibiya, Kuwait – 7 million tyre mountain

from space | on the ground

Image on the left: © DigitalGlobe via Google Earth

Fort Lauderdale (FA). Osborne Reef. A tyre artificial reef

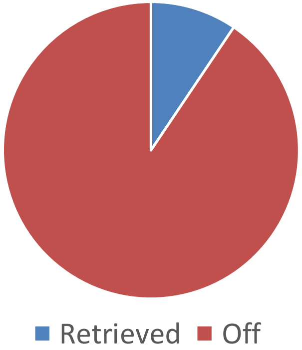
In 1972, a reef was created using 2 million of old tires.

Aim: to generate a new habit for marine life.

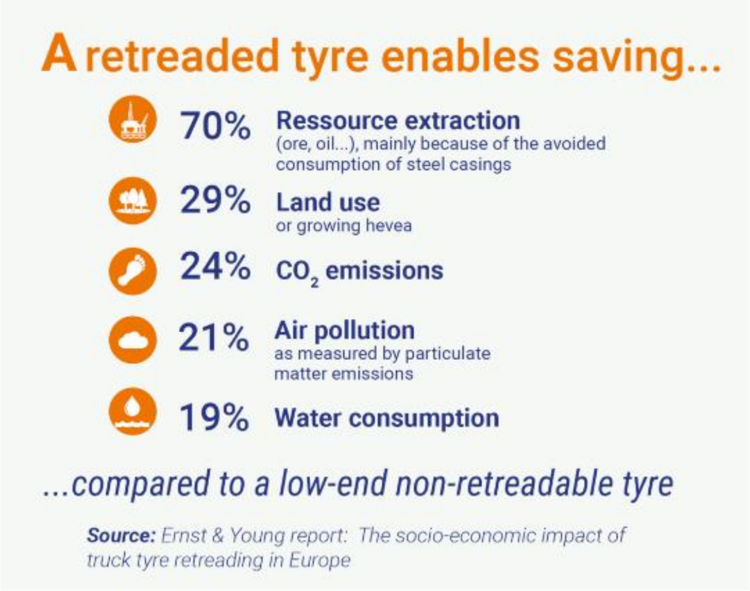
The steel in the tires has deteriorated,

dispersing into the waters destroying sea organisms and preventing the growth of new ones.

Only 73000 tires were retrieved



Retreading tyres



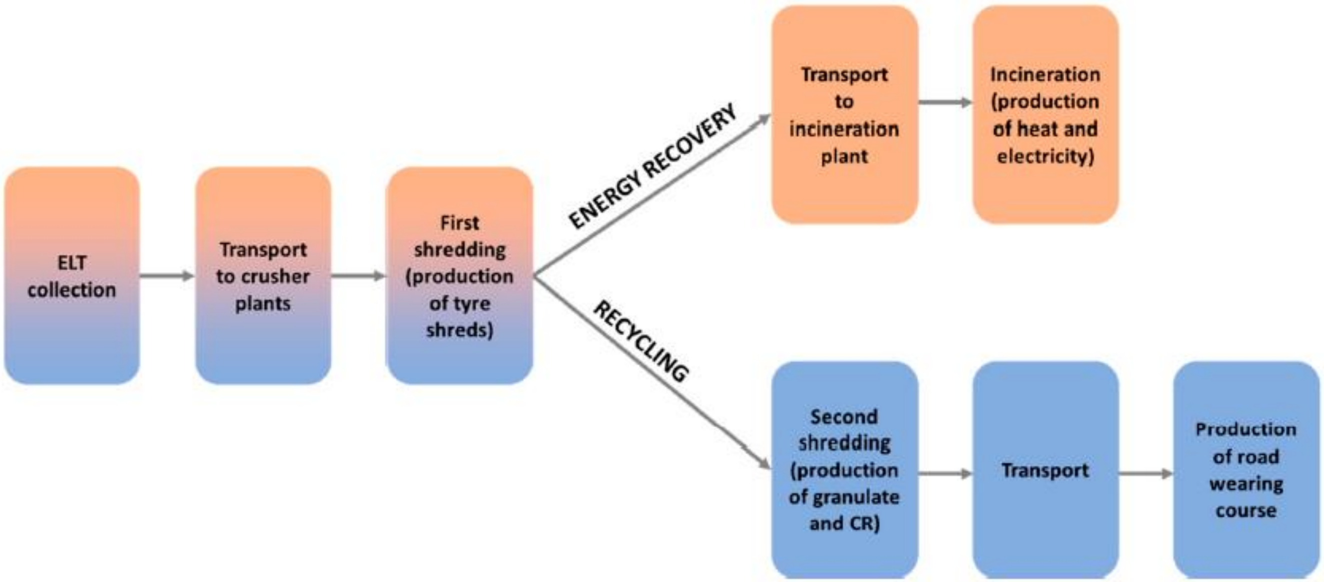
https://www.etrma.org/key-topics/circular-economy/

The R-imperatives

recover, recycle, redesign, reduce, refurbish, refuse, remarket, remanufacture, repair, replace, reprocess, reproduce, repurpose, resale, resell,

What to do with end of life tyres (ELFT)?

Incineration

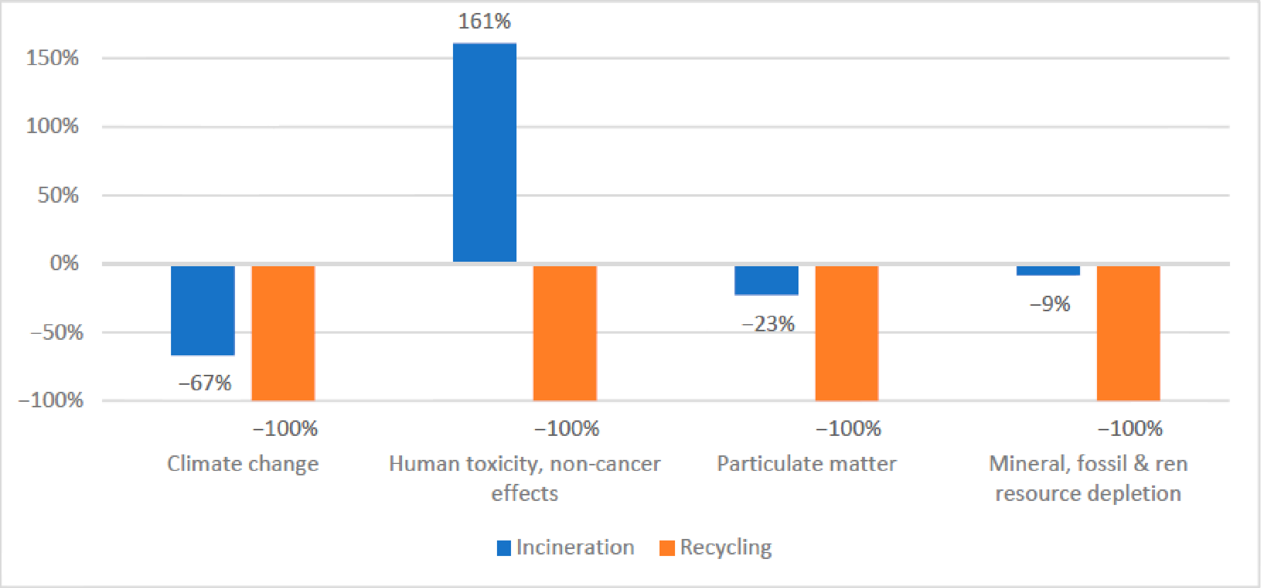


Shredding
and new life

Appl. Sci. 2021, 11, 3599

LCA of end of life tyres

Impact of recycling and incineration



Negative values are OK

Appl. Sci. 2021, 11, 3599

"In Europe every year, more than three million tonns end-of-life tyre are collected and treated through various recycling and recovery processes."

https://www.etrma.org/key-topics/circular-economy/

Recycling of end of life tyres. The use of tyre crumbs

Civil Engineering

Concrete

Bitumen and Asphalt

Railway maintanance

Playground and Sporting Surface

Geotechnical Engineering

Soil stabilization

Unbound pavements

Sub-ballast layers

Seismic isolation systems

Whole-tyre enbankements

Reuse of carbon black from end-of-life tires in new pneumatic formulations. LCA

LCA comprises:

vulcanization of rubber, tire manufacturing,

waste tire transportation to the thermolysis plant, and the thermolysis process.

Avoided impacts!

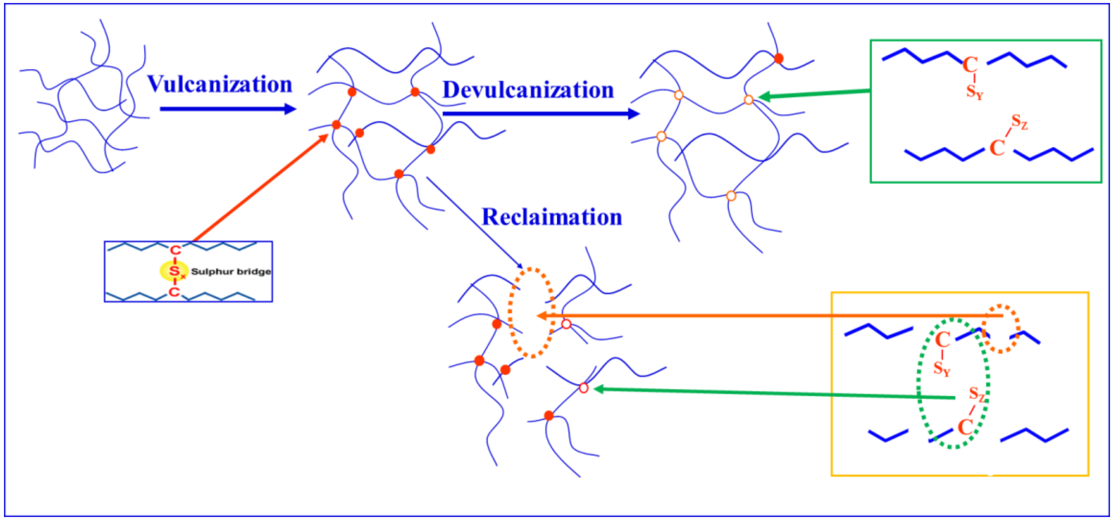
"The overall impacts associated with the production of CB are compensated by the production of other valuable outputs: heavy and light oil, steel, syngas.

Journal of Elastomers & Plastics 2019, Vol. 51(7-8) 740–754

What about rubber recycling? Devulcanization and reclaiming

Devulcanization

is the process of cleaving the monosulfidic, disulfidic, and polysulfidic crosslinks (carbon-sulfur or sulfur-sulfur bonds) of vulcanized rubber.



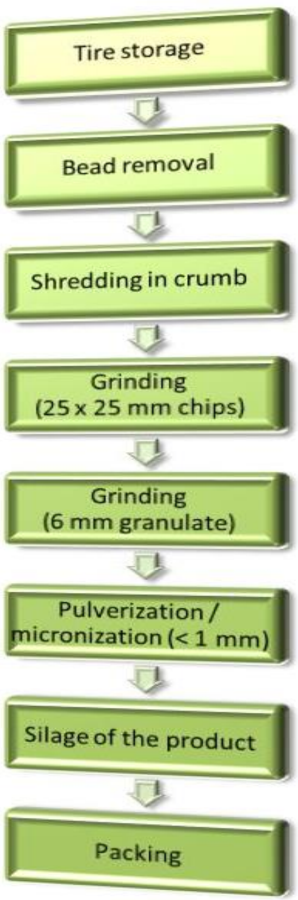
Reclaiming

is a procedure in which scrap (tire) rubber or vulcanized rubber waste is converted - using mechanical and thermal energy and chemicals – into a state in which it can be mixed, processed, and vulcanized again.

DEVULCANIZATION OF WHOLE TIRE RUBBER. *V.K. Rajendran*, L. Reuvekamp, J.W.M. Noordermeer, W. Dierkes, A. Blume*

What about rubber recycling? Grinding, devulcanization and reclaiming

Grinding

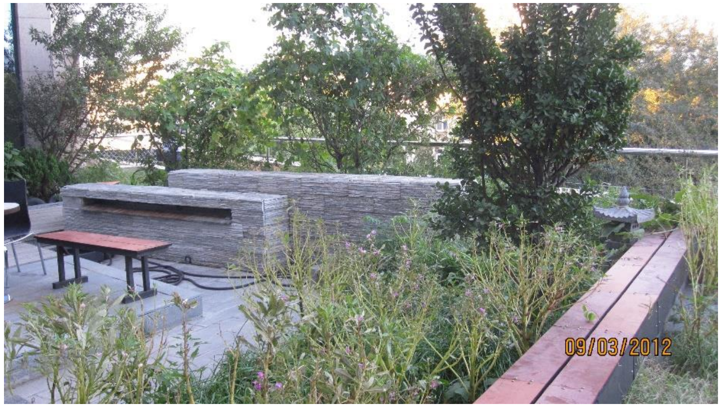


Technologies for devulcanization / reclaiming

Technology	***Basis of Processing***	***Zone of Reaction***
Thermo-mechanical	Mechanical (squeezing) Steam (thermal) TSE	Surface of particles
Physical	Ultrasonic waves	Throughout particles
Physical	Microwaves	Throughout particles
Physical	Supercritical CO_2	Throughout particles
Chemical	Chemicals/chemical reactions	Surface of particles
Biological	Microorganisms	Surface of particles

Results?

Ebonite from scrap NR - BUCT Beijing



TPE vs Thermoset rubbers

shoes

adhesives

Bitumen

Door seal

NR, SBR, EPDM

SBC, TPU, TPO, TPV

Primary microplastics into the environment. Tyre debris

https://www.pin-365.com/

IUCN. Primary Microplastics in the Oceans: A Global Evaluation of Sources. 2017

Primary microplastics into the environment. Tyre debris

	TYRES	SYNTHETIC TEXTILES	MARINE COATINGS	ROAD MARKINGS	PERSONAL CARE PRODUCTS	PLASTIC PELLETS	CITY DUST
%	28	35	3,7	7	2	0,3	24

(46 with NR)

Almost two-thirds of the releases
are from the erosion
of synthetic textiles & tyres

https://www.pin-365.com/

IUCN. Primary Microplastics in the Oceans: A Global Evaluation of Sources. 2017

Primary microplastics into the environment. Tyre debris

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%	28	35	3,7	7	2	0,3	24
	(46 with NR)						

Almost two-thirds of the releases
are from the erosion
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Total release to the environment of microplastics

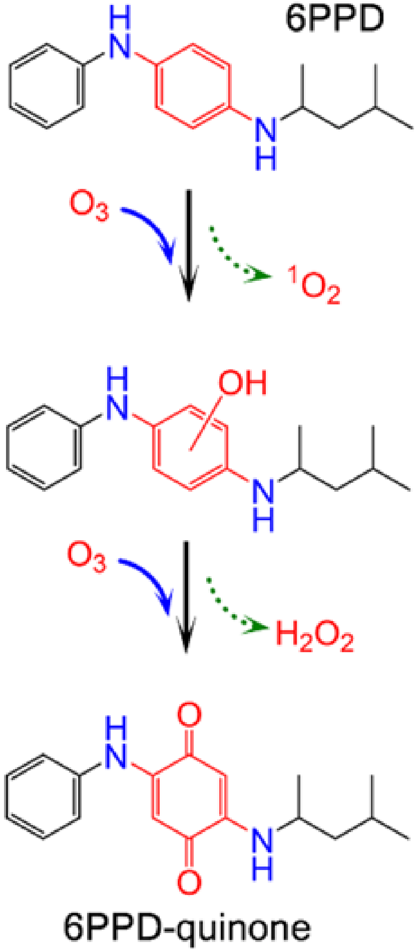
- Optimistic – 1.8 Mtons/year
- Central – 3.2 Mtons/year
- Pessimistic – 5.0 Mtons/year

https://www.pin-365.com/

IUCN. Primary Microplastics in the Oceans: A Global Evaluation of Sources. 2017

6PPD: a powerful protective agent for tyre

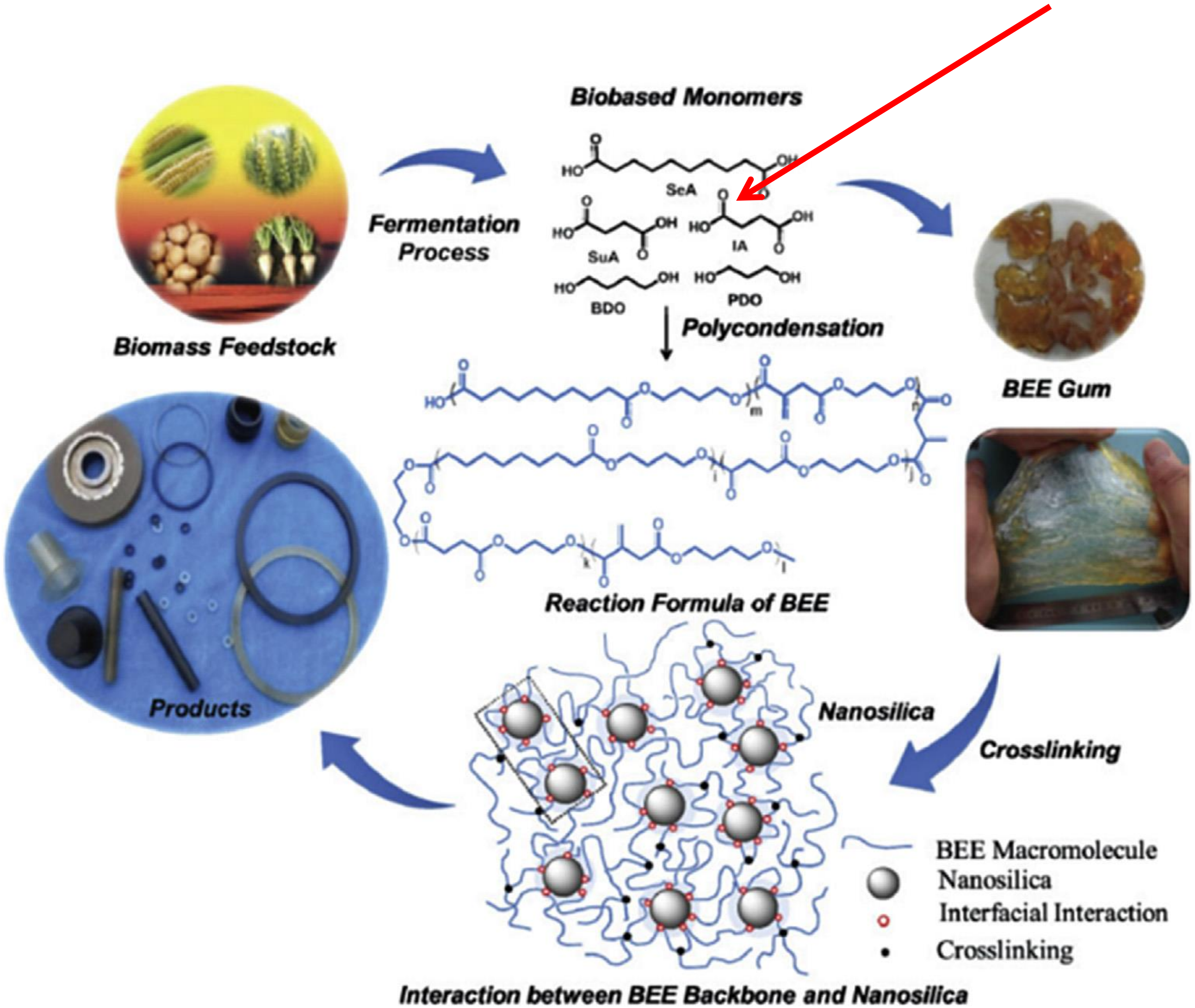
6PPD



Recently, concerns raised for a product of the reaction of 6PPD with ozone: **6PPD quinone**. This product has been reported to be **very toxic and highly lethal** to Coho salmon .

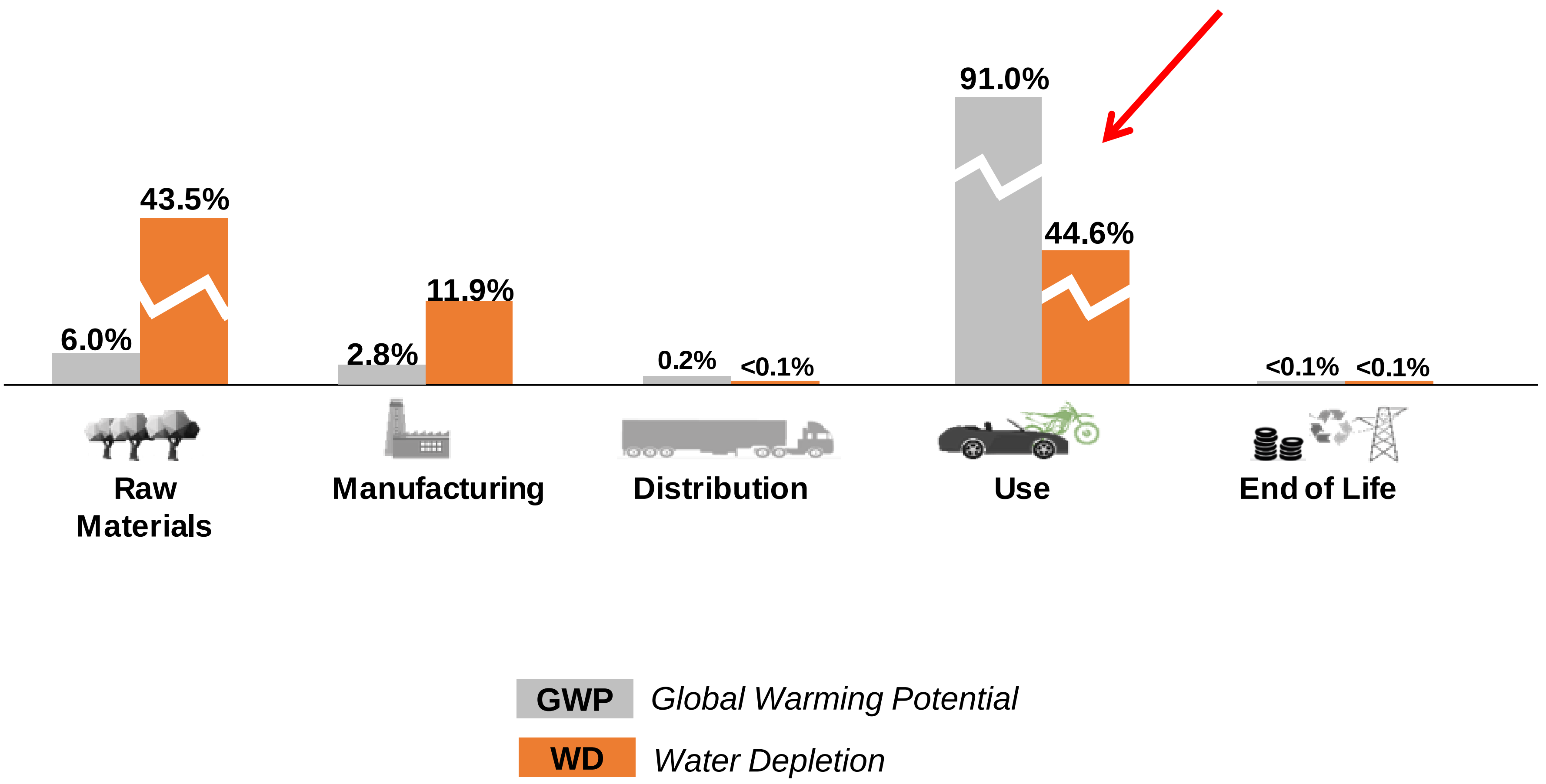
Z Tian et al, Science, 2020, DOI: 10.1126/science.abd6951
C J Walsh et al, J. N. Am. Benthol. Soc., 2005, 24, 706. DOI: 10.1899/04-028.1
A. Agua, R. Stanton, & M. Pirrung, 2021. DOI: 10.26434/chemrxiv.13698985.v1

Towards biodegradable rubbers



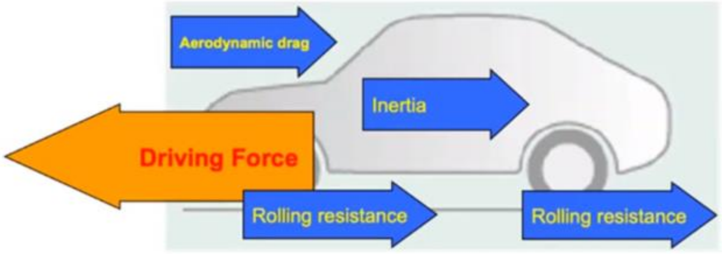
R. Wang et al. / Composites Science and Technology 133 (2016) 136-156

Tyres and sustainability. Life Cycle Assessment for a tyre



Luca Giannini – Pirelli Tyre - The Challenges of Sustainable Development in Tyre Materials - 2022

Impact of a tyre on the environment during its use



$$Fuel\ consumption = Power\ train\ \cdot (Weight \cdot \boldsymbol{Tyre\ rolling\ resistance} + Air\ Drag) + Heat\ management$$

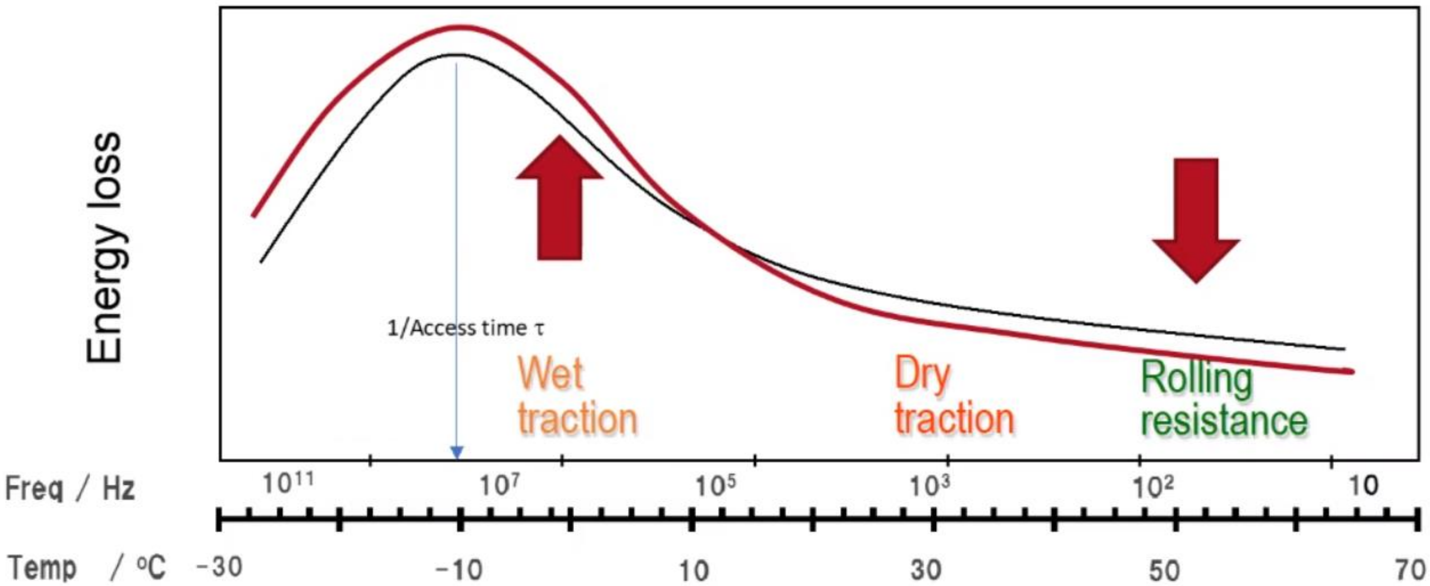
$$\boldsymbol{Tyre\ rolling\ resistance} = Tyre\ rubber\ volume\ \cdot Strain\ energy\ \cdot tan\delta$$

With 20% reduction for each of the terms

one can get 50% reduction of RR

$$\tan\delta = \frac{E''}{E'}$$

Impact of a tyre on the environment during its use. The role of Tan delta



$$\tan\delta = \frac{E''}{E'}$$

Electrical vehicles

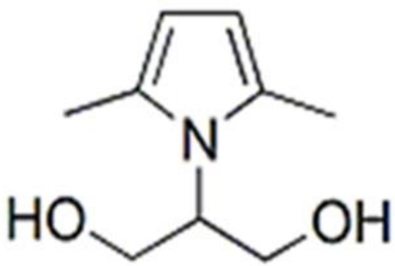
https://www.compositesworld.com/articles/what-is-the-role-of-composites-in-electric-vehicles

- A particularly low rolling resistance: one battery charge
- As quiet as possible
- To suit the higher masses of electric vehicles.
- To handle very high levels of torque without generating excessive wear.

Source: Nokian Tyres

An example from ISCaMaP @Polimi

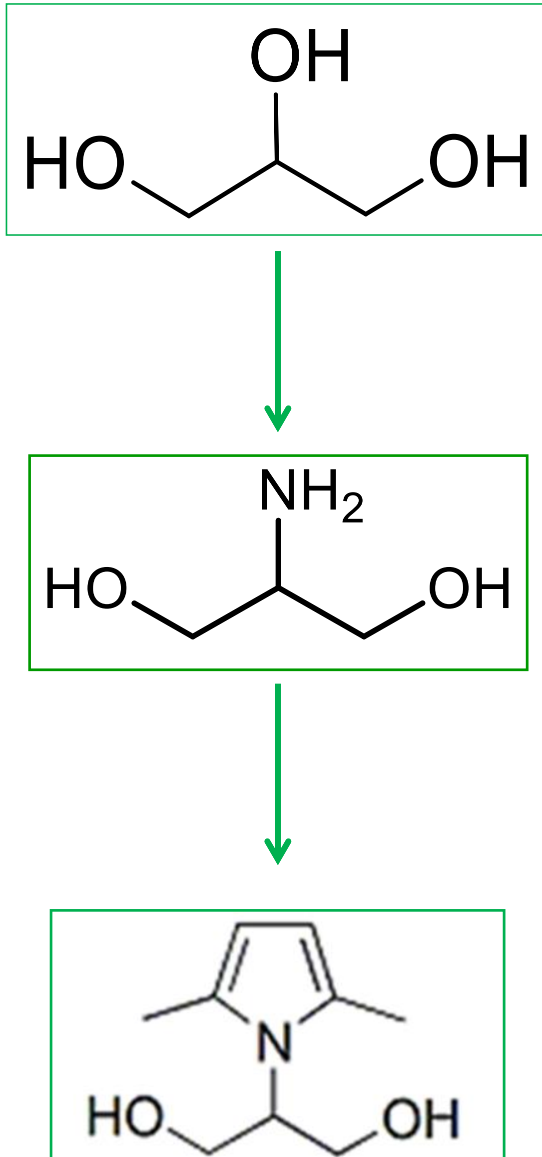
Innovative Sustainable Chemistry and Materials and Proteins



From glycerol

to universal coupling agent for carbon black and silica

Glycerol as the C3 building block. From glycerol to serinol to serinol pyrrole



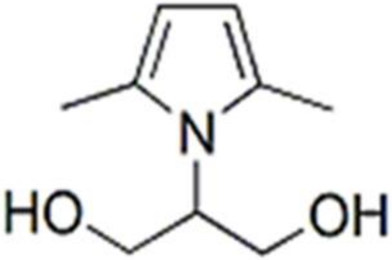
Propane-1,2,3-triol

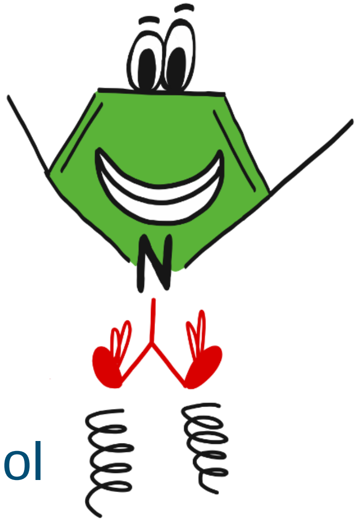
2-Amino-1,3-propanediol

2-(2,5-dimethyl-1*H*-pyrrol-1-yl) -1,3-propanediol

Serinol pyrrole - SP

From glycerol to universal coupling agent for carbon black and silica



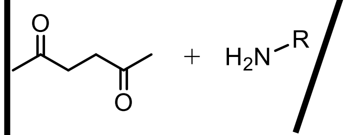


2-(2,5-dimethyl-1*H*-pyrrol-1-yl) -1,3-propanediol

Serinol pyrrole - SP

Mechanism for the formation of CA/PyC adducts

Domino reaction



Carbon allotrope

↓

Paal – Knorr Reaction

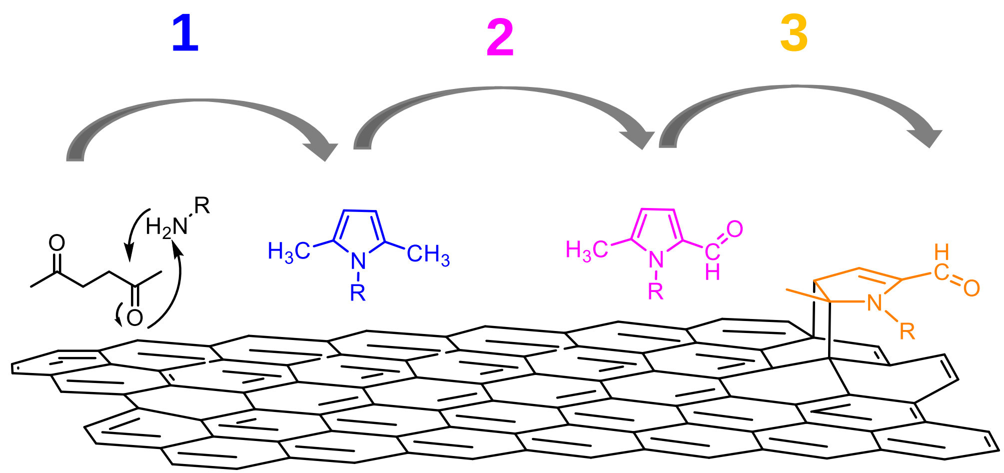
Thermal or mechanical energy

↓

Carbocatalyzed Oxidation

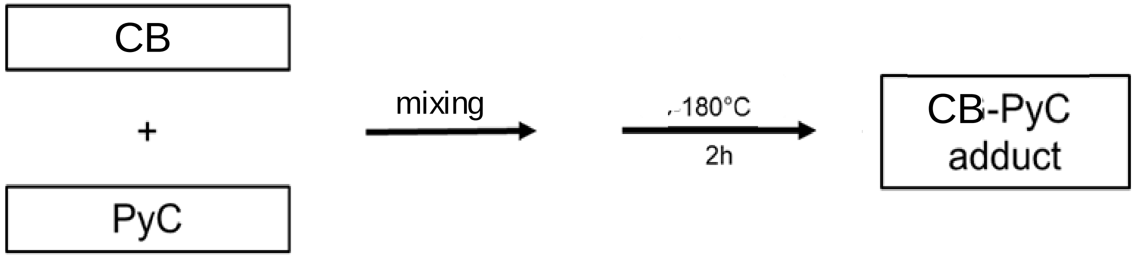
↓

Diels-Alder reaction

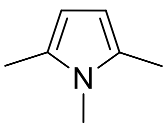


V. Barbera, L. Brambilla, M. Milani, A. Palazzolo, C. Castiglioni, A. Vitale, R. Bongiovanni, M. Galimberti, 2019. Nanomaterials, 9(1), p.44.

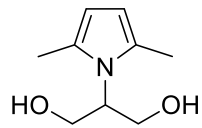
Adducts of PyC with carbon black



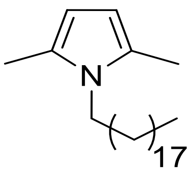
Functionalization Yield %



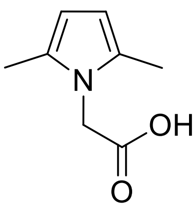
65.6



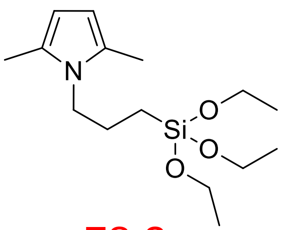
96.0



98.0



81.8



78.2

CB N234 from Cabot

V. Barbera, A.Citterio, M. Galimberti, G. Leonardi, R. Sebastiano, A.M. Valerio *US10160652B2*

M. Galimberti, V. Barbera *WO 2018/087685 A1*

V. Barbera, A. Bernardi, A.Palazzolo, A. Rosengart, L. Brambilla, M. Galimberti Pure and Applied Chemistry 2018, 90(2), 253–270

The CA/PyC adducts

A + B / Carbon allotrope

↓

↓

↓

Functionalized carbon allotropes

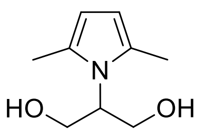
- Functional group:
  from few % to 20%
- Functionalization yield:
  from 85% to quantitative
- Covalent bond
  between functional group
  and carbon allotrope
- Bulk structure of graphitic materials:
  substantially unaltered

V. Barbera, A. Citterio, M. Galimberti, G. Leonardi, R. Sebastiano, S.U. Shisodia, A.M. Valerio. *US10329253B2*
M. Galimberti, V. Barbera, R. Sebastiano, A. Citterio, G. Leonardi, A.M. Valerio. *US10160652B2*
M. Galimberti, V. Barbera, R. Sebastiano, A. Truscello, A.M. Valerio. *EP3180379B1*
M. Galimberti, V. Barbera, *EP3538511A1*
M. Galimberti, V. Barbera, *EP3538481A1*

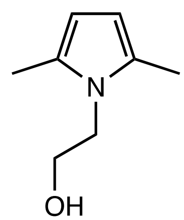
Adducts of Pyrrole compounds with silica

Silica + PyC $\xrightarrow{\text{mixing}}$ $\xrightarrow[\text{2h}]{\text{180°C}}$ Silica-PyC adduct

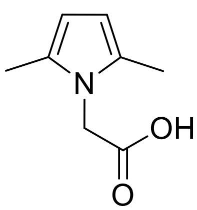
Functionalization Yield %



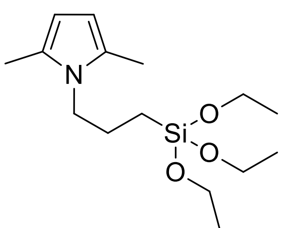
95.1



95.0



93.3

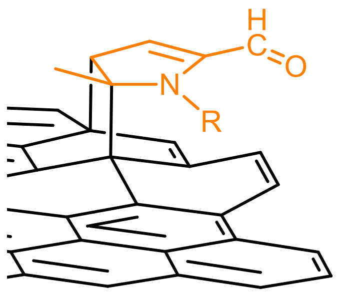


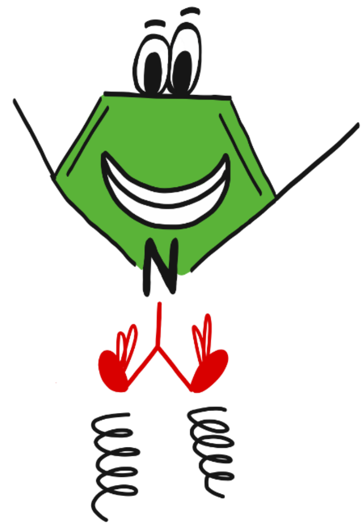
80.0

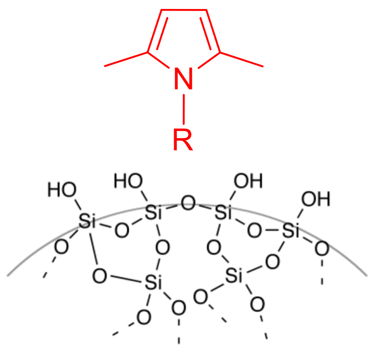
Silica: Zeosil® 1165 from Solvay

M. Galimberti,, A. Bernardi, V. Barbera, D. Locatelli *WO2019162873A1*

Univerasal coupling agents for carbon black and silica







In rubber compounds

Adducts reactive

☞ with the crosslinking system

☞ with the rubbers

Rubber compounds for tyres with CB/PyC and Silica/PyC adducts

- ☞ Better crosslinking efficiency
- ☞ Higher dynamic rigidity
- ☞ Lower hysteresis at high T

Pirelli Tyre; Annual Report: The Human Dimension. 2020, 106.
https://corporate.pirelli.com/var/files2020/EN/PDF/PIRELLI_ANNUAL_REPORT_2020_ENG.pdf

instagram: @ismaterials.polimi

Thanks

for your attention!