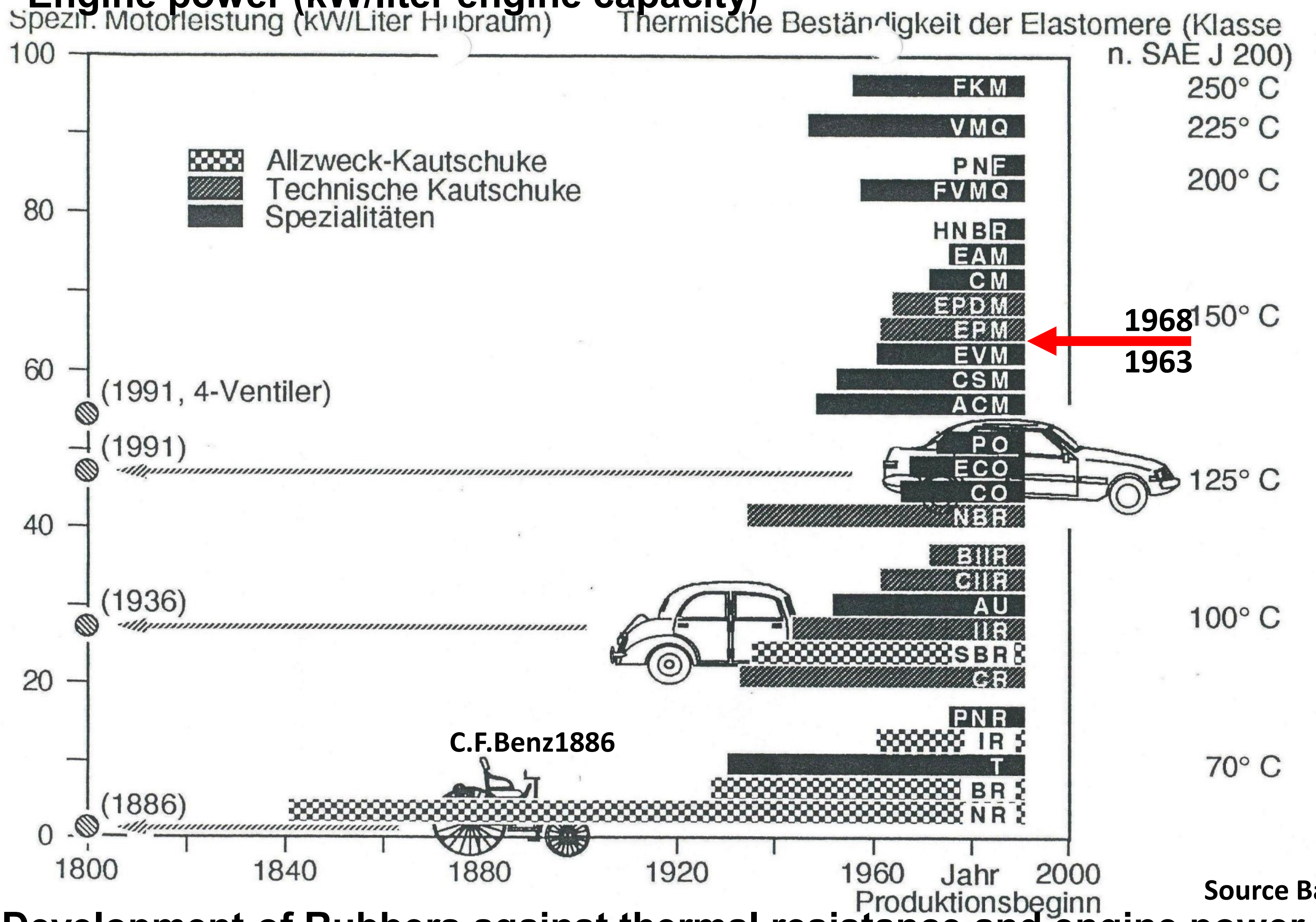
➢ Content

1. History of EPDM Rubber

Engine power (kW/liter engine capacity)



Source Bayer AG

Development of Rubbers against thermal resistance and engine power

History of EPDM-Rubber

1953 **K.Ziegler** invents **titane catalysts** for **ethene polymerisation** to **linear polyethylene**
G. Natta transfers this process later to **propene** resp. **Polypropylene**

1963 **Ziegler and Natta** receive for their work the **Chemistry Nobelprice**

1964 **75 % of all rubbers become synthetically produced**

1964 **Catalyst system** of **Ziegler-Natta(Z-N)** enables the industrial **production of EPM** and **EPDM** primarily **in USA**

1967 **Production of first bales of EPDM** from **DSM in Geleen, NL,** called **Keltan**.
Plant capacity of **12´000 t/a, 2017 180´000 t/a**

History of EPDM Rubber

1968

First EPDM-applications in Europe single ply **EPDM roofings** in NL

still in service today, just and within the specification

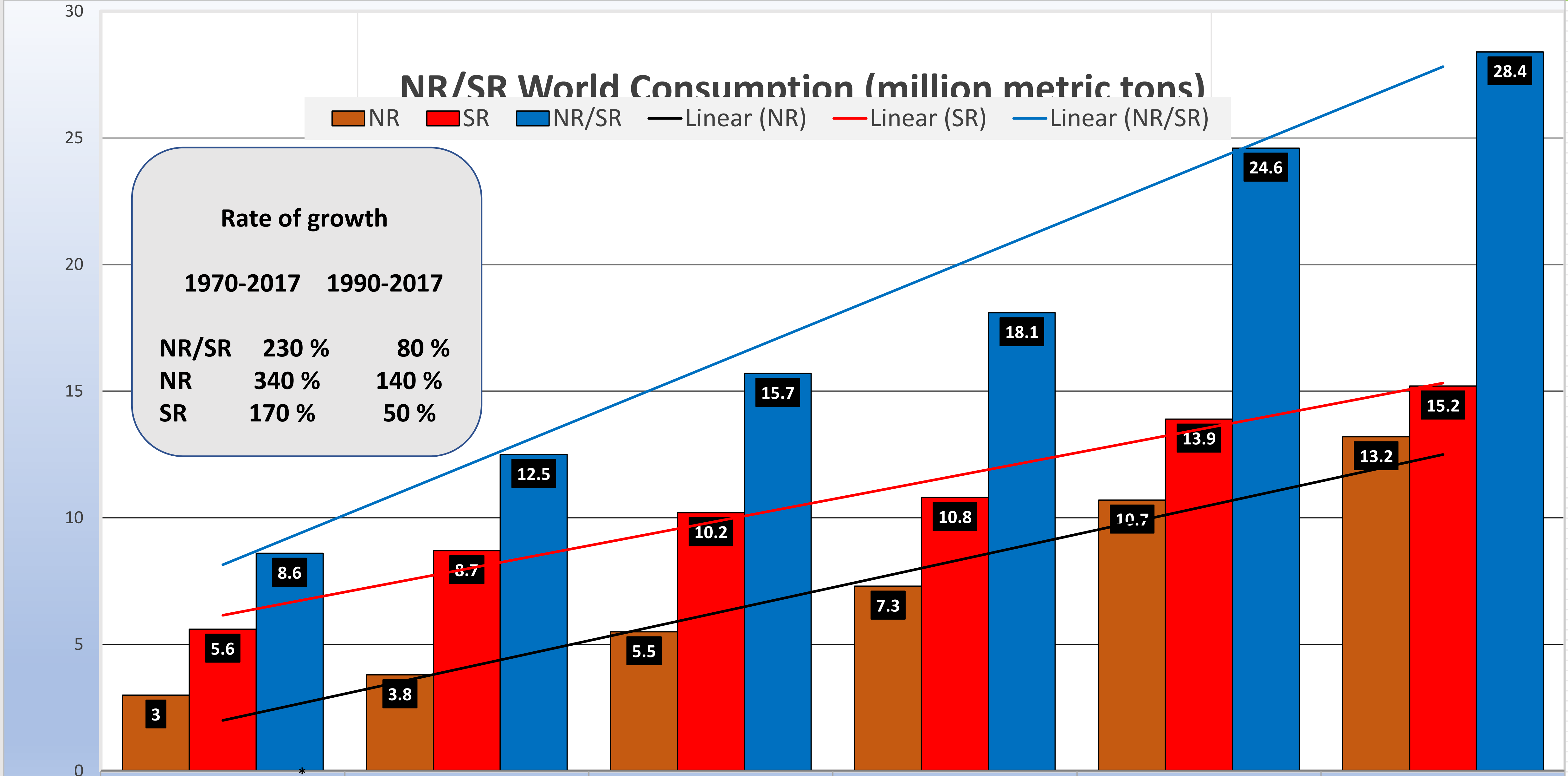
50 years ago start of application of elastic granules (recycled tire, ELT granules)

and later **specially formulated EPDM-granules** for sports surfaces

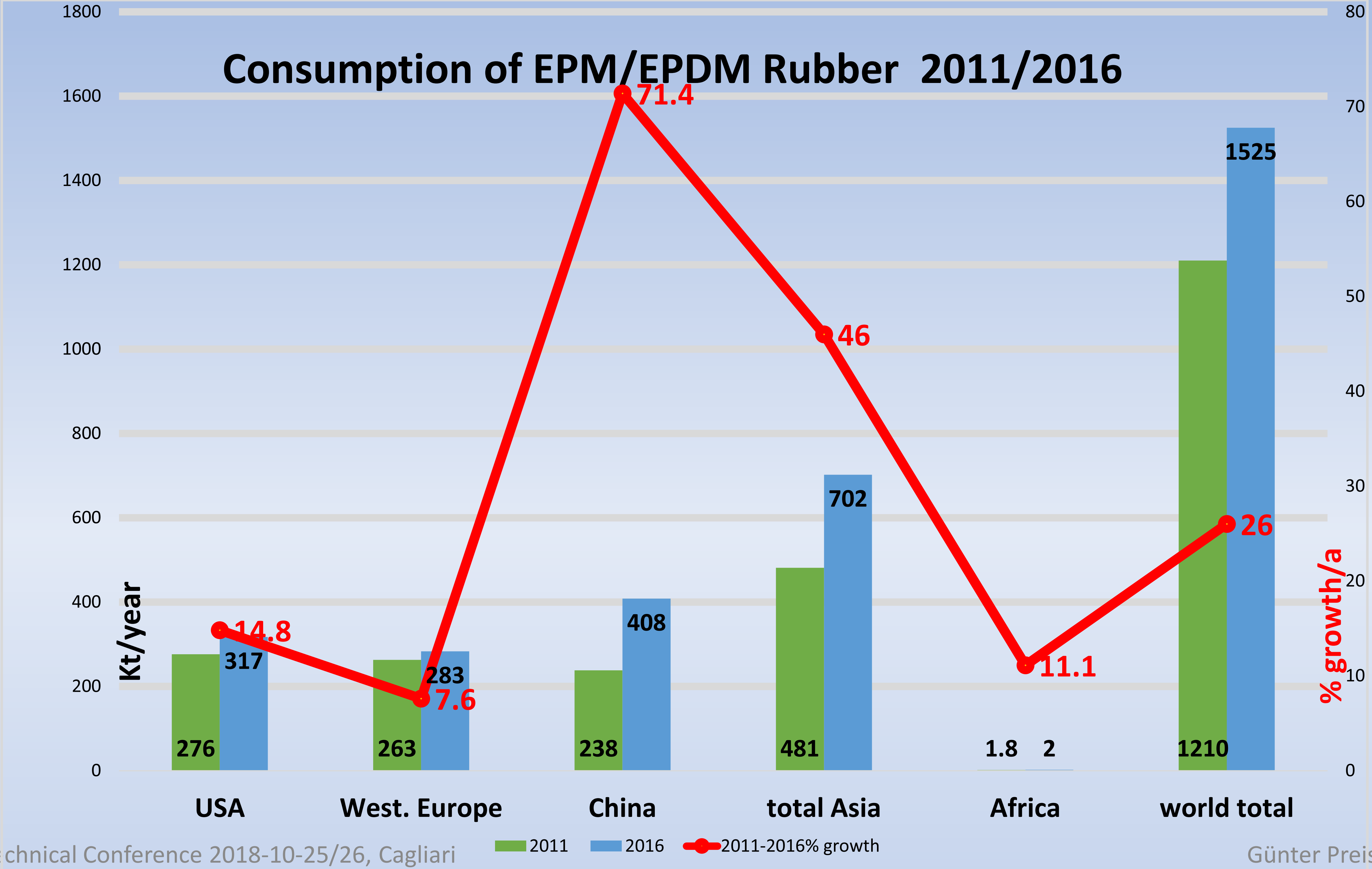
In the **Olympic Games in Mexico** the athletes lined up on synthetic tracks for the first time

The **continuous improvement of EPDM-rubbers** connected with an extrem increasing of EPDM consumption happened till this day with a lot applications as a result

EPDM applied >70% in the automotive-industry



	1970	1980	1990	2000	2010	2017
NR	3	3.8	5.5	7.3	10.7	13.2
SR	5.6	8.7	10.2	10.8	13.9	15.2
NR/SR	8.6	12.5	15.7	18.1	24.6	28.4


Consumption of EPM/EPDM Rubber 2011/2016
Kt/year
% growth/a
1800
1600
1400
1200
1000
800
600
400
200
0
80
70
60
50
40
30
20
10
0
71.4
1525
46
702
26
408
14.8
317
283
7.6
11.1
276
263
238
481
1.8
2
1210
USA
West. Europe
China
total Asia
Africa
world total
2011
2016
2011-2016% growth

2. What is EPDM chemically?

EPDM – E**THYLENE **P**ROPYLENE **D**IENE **M

$$-[-CH_2-CH_2-]_m-[-CH_2-\underset{\displaystyle CH_3}{\underset{|}{CH}}-]_n-[-\text{Diene}-]_o-$$

– ***EPDM*** is a **terpolymer** of ***E***thylene, ***P***ropylene and a non conjugated ***D***iene

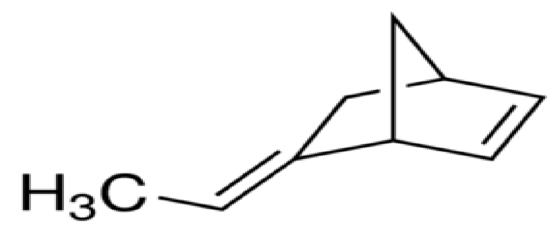
– The diene is usually dicyclopentadiene, ethylidene norbornene, vinyl norbornene

– ***M*** stands for a saturated poly***M***ethylene hydrocarbon main chain (M-class refers to ASTM D-1418, rubbers having a saturated chain of the polymethylene type)

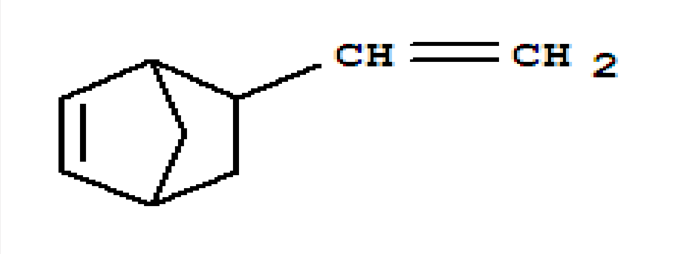
– ***EPDM*** **has a** ratio of ethylene/propylene between **85/15%** and **45/55%** by weight

The mainly used dienes in EPDM:

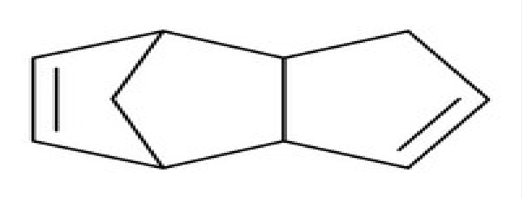
- 5-Ethylidene -2-norbornene (ENB)



- 5-vinyl-2-norbornene (VNB)

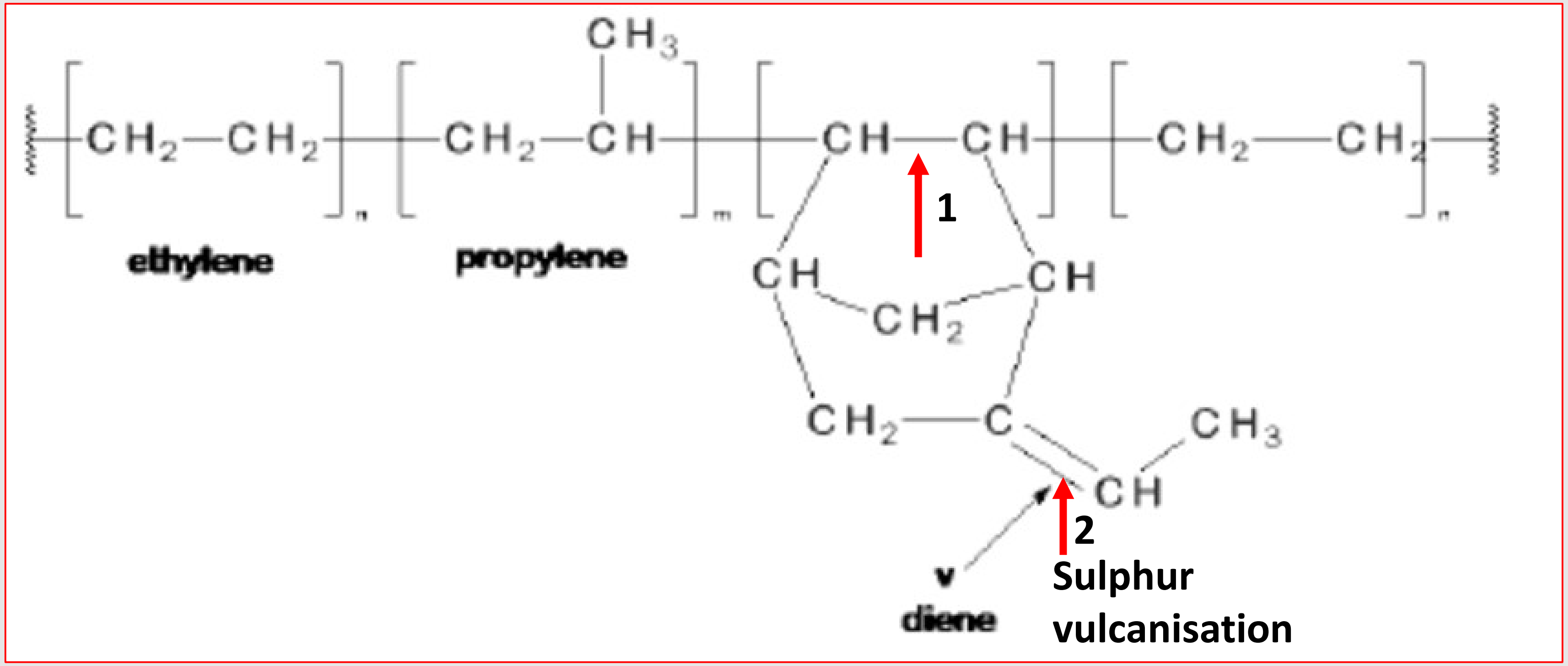


- Dicyclopentadiene (DCPD)



Diene content may vary from 0,9% up to 12% by weight of the composition
Higher diene percentage enables faster vulcanisation and higher crosslinking degree

i



One double bond -1- of the diene reacts with the main chain, the second -2- remains for a sulphur vulcanisation

EPDM chemical

- **EPDM** is a **nonpolar, fully saturated polymer**, with a **very low level of unsaturation** in the side chain of the polymer

- **EPDM** is a **real synthetic rubber (SR),** one of more than 40, at this time known, different rubber groups

- **EPDM** is **not compatible** with **polar compounds**, it can be **vulcanised with sulphur** curatives as well as **with peroxides**, then with a higher curing efficiency

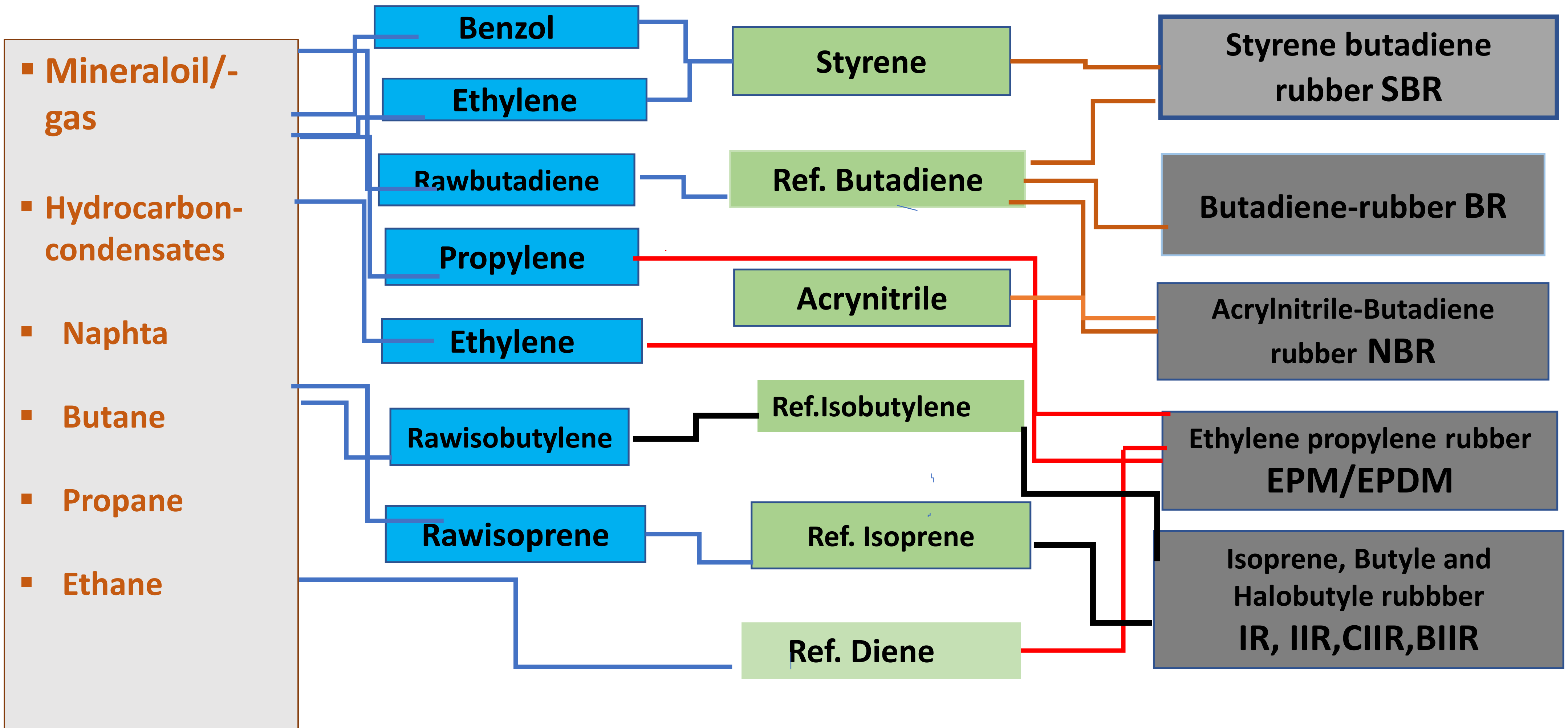
- **EPDM** are the **third-largest volume of SR**, consumed worldwide, after SBR and BR (latter are mainly used for passenger tires)

3. EPDM Production

Synthetic Rubber Production

From Mineraloil and –gas to Synthetic Rubber

Feedstocks **Basic products** ***Key precursor*** Final product Rubber



Production of EPDM Rubber

➢ Three different processes

• **Solution** process	most widely used
• **Suspension** process	enables lower solvent
• **Gas phase** process	no longer used

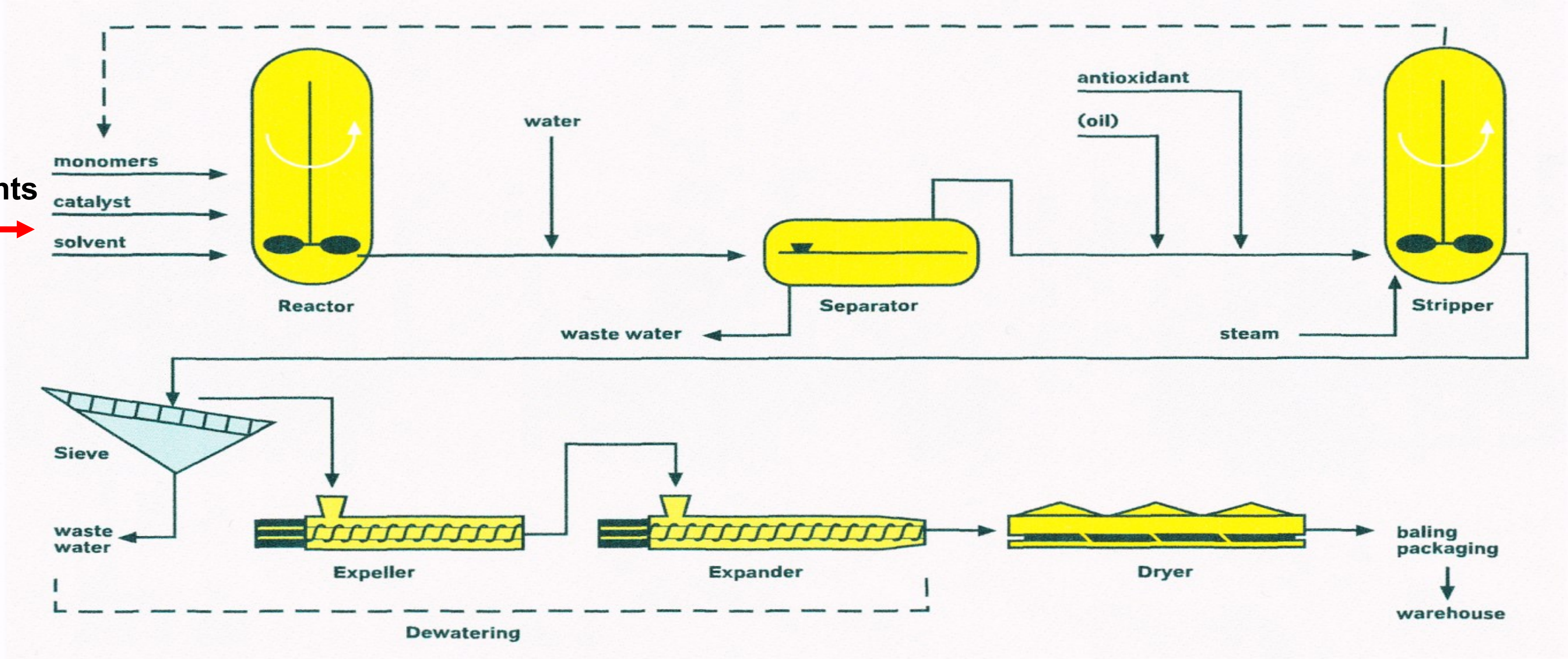
➢ Catalysts

• **Ziegler- Natta (Z-N)**	metall organic compound, vanadium based
• **Metallocene**	group of metallorganic compounds, where one metall-atome is between two organic ligands like a sandwich
• **ACE- A**dvanced **C**atalyst **E**PDM	new catalyst system , special titane complex

Production Scheme for EPM/EPDM Rubber Solution-Process

Ethylene
Propylene
Diene

diluted in solvents



Source: LANXESS „BUNA EP“

Production of EPDM Rubber

- **50 years** of advancements through **continuous improvement** of the…

  - **process**
  - **catalysis**
  - **ecology**
  - **application technology**
  - **economy**
  - **product**

In the past ***gel-formation*** was a big problem in the production-process. Only the ***ACE-technology (Advanced Catalyst EPDM)*** this problem could be solved. However oxidative gels can still be formed during storing and compound mixing in the rubber plants

Major global EPDM-rubber producer:

- Arlanxeo ***> 20% market share, the leader!***
- ExxonMobil
- DOW Elastomers
- SK Chemical
- Sumitomo
- Mitsui Chemicals
- PetroChina
- JSR Corporation
- Kumho Poychem
- ENI
- and others

4. EPDM properties and applications

EPDM Rubber Properties

- A huge number of **EPDM-rubbers** enables a **use oriented compouding**
- The different **EPDM polymers** may vary by…
  - **molecular weight (MW)**
  - **MW-distribution (MWD)**
  - **viscosity**
  - **content of polyethylene and polypropylene**
  - **amount of diene**

Mooney viscosity: 17-115

Ethylene weight %: 45 -78

ENB weight %. : 0,9 -10,0

MWD: narrow up to very broad and bimodal

Typical properties

Grade	Oil phr	Mooney viscosity ML (1+4 at 125°C) ASTM D1646	Ethylene weight % ASTM D3900	ENB weight % ASTM D6047	MWD type	Form
Copolymers						
404	–	28	45	–	Very broad	Dense bale
703	–	21	72	–	Narrow	Bale
706	–	42	65	–	Medium	Dense bale
722	–	17	72	–	Narrow	Pellet
785	–	30	49	–	Narrow	Bale
805	–	33	78	–	Narrow	Crumb
878P	–	52	60	–	Narrow	Pellet
Terpolymers – low to medium diene						
1703P	–	25	77	0.9[1]	Very broad	Pellet
2502	–	26	49	4.2	Medium	Semi-dense bale
2504	–	25	58	4.7	Broad	Dense bale
2504N	–	25	56	3.8	Broad	Dense bale
3666	75	52	64	4.5	Broad	Dense bale
3702	–	60	69	2.8	Narrow	Pellet
5601	–	72	69	5.0	Medium	Pellet
5702	–	90	71	5.5	Medium	Pellet
6602	–	80	55	5.2	Medium	Semi-dense bale
7001	–	60	73	5.0	Narrow	Pellet
7500	–	82[2]	56	5.7	Bimodal	Semi-dense bale
7700	–	115[2]	56	7.0	Bimodal	Dense bale
8731	–	24	76	3.3	Broad	Dense bale
9301	–	67	69	2.8	Narrow	Pellet
Terpolymers – high diene						
7602	–	65	55	7.5	Medium	Semi-dense bale
8600	–	81[2]	58	8.9	Bimodal	Semi-dense bale
8700	–	78	63	8.0	Bimodal	Semi-dense bale
8800D	–	108[2]	54	10.0	Bimodal	Semi-dense bale
8800	15	73	54	10.0	Bimodal	Semi-dense bale

The availability of specific Vistalon™ EPDM rubber grades may vary by region.

[1] VNB used as diene
[2] ML (1+8) at 125°C

This table shows **26 different EPDM rubber**, only from one producer the **ExxonMobil**

e.g. **Arlanxeo** offers more than **50 EPDM polymers**

EPDM Rubber Properties

- High filler and plastisizer loading
- Lowest density of all comercially available rubbers (0,86 g/cm^3)
- Fast mixing, no mastication necessary
- Big versatility in processing properties
- Delivery form are bales and crumb

EPDM Elastomer Properties

- **Very good resistance to aging (heat and oxidation)**
- **Excellent weathering -, ozone-, UV light-, and oxigen resistance**
- **Chemical resistance** in polar fluids as alcohols, ketones, glycols, diluted acids and alkalines – unstable in mineraloils and all unpolar fluids
- **Outstanding water and steam resistance**
- **Flame retardent -** if particulary formulated with high loadings of Al- or Mg-hydrates
- **Good low temperature properties –** dependent on the ethene content >65% worse

EPDM Elastomer Properties

– **Hardness**	**30 Shore A up to 50 Shore D**
– **Tensile strength**	**7 - 20 Mpa**
– **Elongation at break**	**150 – 700 %**
– **Heat resistance**	**up to + 150°C**
– **Low temperature**	**up to – 40°C**
– **Ozone and weather**	**excellent**
– **UV resistance**	**black materials excellent, for colored EPDM only with UV-absorber good**
– **Chemical resistance**	**excellent, best from all unpolar elastomers,**
	exception polar fluids unstable

➢ all properties vary with the MW and the ethene content, as well as with the composition of the elastomer compound (filler- and plastisizer amount and the crosslinking degree)

Application of EPDM Elastomers

The big versatility of EPDM elastomers open a great field ofdifferent applications in various industries

- **Automotive**

  The most important sector, **>70% of elastomers** are used **in automotive engineering**

- **Building and Construction**

  A lot of applications, particular **different sealings,** this sector belongs also to:

  granules for rubberized surfaces, like athletic tracks, playgrounds, tennis courts and infill in artificial grass

- **Further Applications**

  such as cables, consumer goods, drive and transmission belts,fire hoses,sealings for washing machines, printing and paper rollers, shoe soles, key pads.... and a lot others

5. Compounding, Mixing, Vulcanisation

Compounding

- **Three main objectives** have to be respected:
  - **Requirements** (of the final product)
  - **Processability** (mixing and vulcanisation)
  - **Profitability** (cost-benefit ratio)
- **Rubber compounds** are composed of **minimum 2 up to maximal 20 different ingredients** with a big dependence of the chemist, perhaps an overkill!

Requirements for EPDM Granules

- Outstanding long term weathering resistance
- UV resistance in practice and lab-tests (colour stability)
- Mechanical properties corresponding with practical function
- Compatible with PU- coatings and binders
- Environmentally compatible
- Consistant colour for different batches
- Colour consistance after longterm outdoor use
- Low odour, Low dust
- Conform with relevant standards
- High cost-benefit ratio

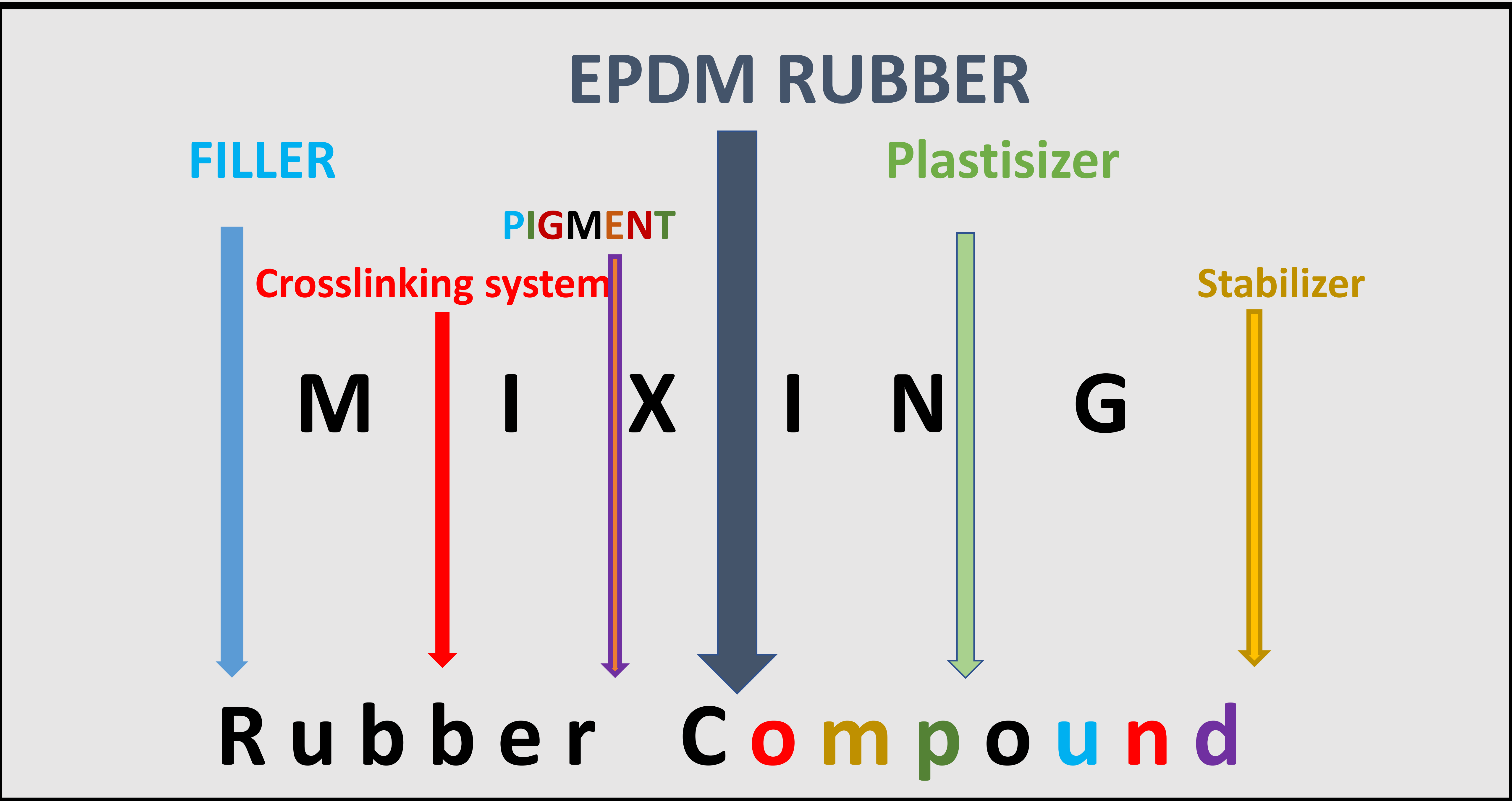
All requirements must be considered for the tailored, coloured elastomer granules:

- Longterm weather resistance
- UV resistance
- Standards e.g. EN 14877,15330-1
- Colour stability and constancy
- Environmental properties
- Mechanical poperties
- Flame retardent
- PU compatible
- Low odour, low dust
- High cost benefit ratio

The tailored elastomer for coloured granules??

only EPDM based elastomers

are predestinated in sport surfaces applications!!!


EPDM RUBBER
FILLER
Plastisizer
PIGMENT
Crosslinking system
Stabilizer
M I X I N G
Rubber Compound

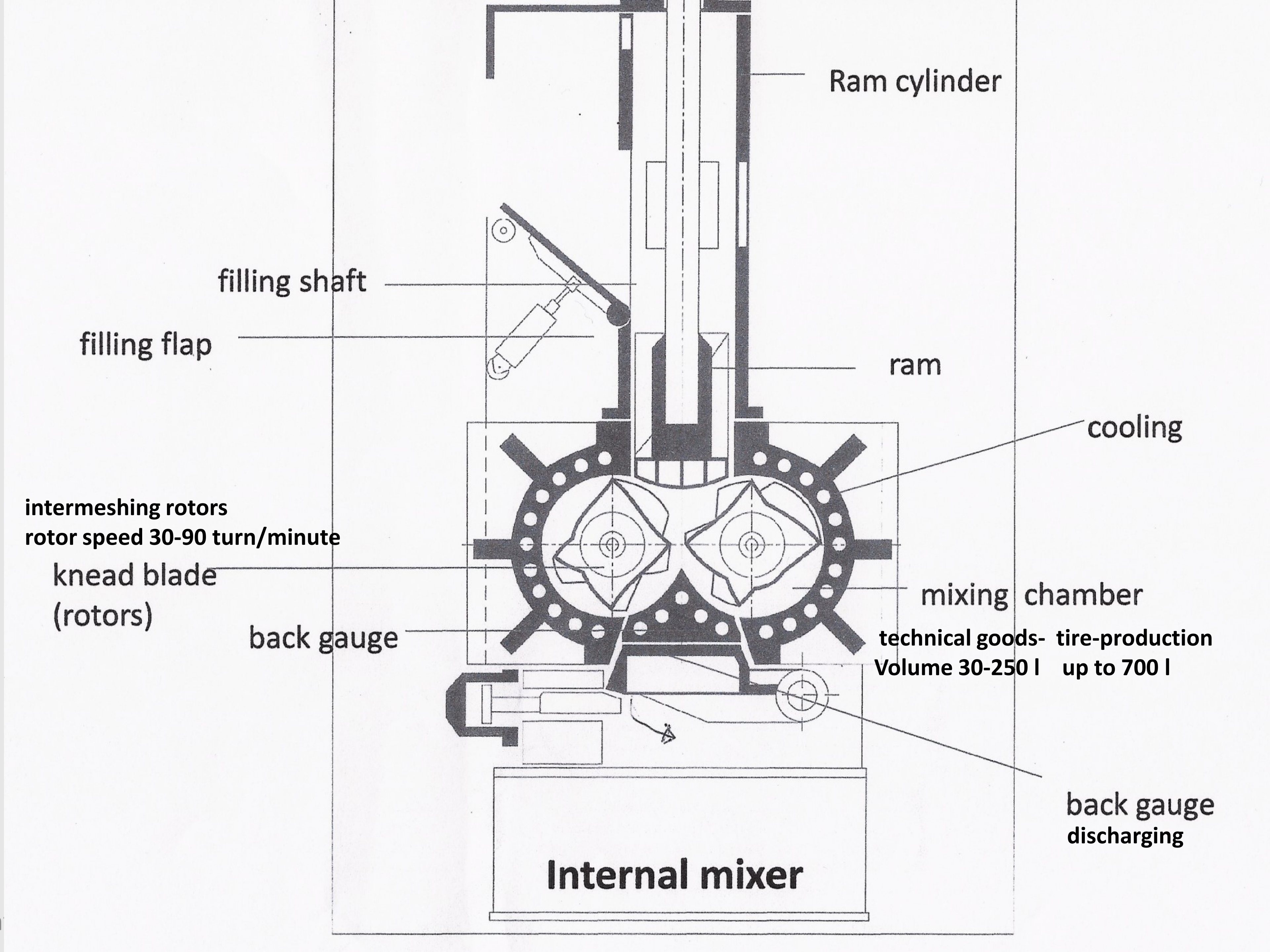
Mixing

- **Discontinuous mixing**

  - **Weighing**
    - automatically
    - manually

  - **Mixing cycles**

    1. **Crushing** and masticating of raw rubber (bales of 20 - 25 kg)
    2. **Increasing** of the polymer surface
    3. **Incorporation** of ingredients (filler, plastisizers, chemicals)
    4. **Degradation** and **dispersion** of filler agglomerates
    5. **Distribution** (filler reduction in the polymer matrix)
    6. **Discharging** on a mill or extruder


Ram cylinder
filling shaft
filling flap
ram
cooling
intermeshing rotors
rotor speed 30-90 turn/minute
knead blade
(rotors)
mixing chamber
back gauge
technical goods- tire-production
Volume 30-250 l up to 700 l
back gauge
discharging
Internal mixer

Mixing

➢ Continuous mixing

- ***Twin screw mixing*** in modular co-rotating twin screw extruders

  - The **ingredients** must be primarily **separately balanced**, **premixed** and then charged into the mixer, plastisizer and crosslinking system mainly separated

  - ***Vulcanisation*** also **continuous** in hot air or steam, temperature **> 160°C**

  - The ***granulation*** occurs after the vulcanisation in the **same processline**

Rubber Compound

Forming, shaping + Temperature 150 - 200°C

Vulcanisation Crosslinking

ELASTOMER

6. Standards for sportsurface granules

EPDM Granules Standards

➢ Unfortunately **beside international standards** (e.g. EN and ISO standards) are still **national standards existing.** The most **common standards** in Western **Europe**:

• **EN 14877**	Synthetic surfaces for outdoor sport areas
• **EN 15330-1**	Synthetic turf and needle-punched surfaces primarily for outdoor use
Part 1	Specification for synthetic turf surfaces for football, hockey, rugby union training, tennis and multi-sports use
• **DIN 18035-6**	Sport grounds – Part 6: synthetic surfaces
• **DIN 18035-7**	Sport grounds - Part 7: synthetic turf areas

EPDM Granules Standards

- **Requirements** of relevant **standards** are partially **difficult to fulfill**
- **Particular** the very low **zinc-content** in **DIN 18035-6** of ***< 1,0 mg/l***
  in **DIN 18035-7 < 0,5 mg/l**
- The **compliance with regulation could activate an undervulcanisation**
- **Standards** for **EPDM elastomers** for **food- or potable water-applications allow higher zinc content**
- **Tests** have to be checked **on testslabs** and **on granules**
  to make sure that testplates and granules respect an **equal material**

EPDM Granules Standards

- All effort has to be made to get **harmonized with international standards**, like ISO or EN, and consequently all national standards should be eliminated
- What are the experts, your knowledge with the current standards, are improvements or **revising necessary?**
- Please take the chemists from the EPDM-elastomer producers with you into the standardization boat!!

Standard should always respect satisfiable properties only as good as necessary!

7. Properties EPDM Granules state-of-the-art Comparison with other granule materials

EPDM Granules state-of-the-art

- **Granule Size** narrow particle distribution, beside turf and crumb
- **Environmental** low havy metal content, less or no VOC, NOA, PAH
- **Colour stability** UV resistant pigments
- **Low dust content** improved technology in granulation process
- **Noise absorption** use of special fillers, high filler loading
- **UV resistance** UV absorber, more practice adapted UV-tests
  up to 8000 hours, in UV-A and -B
- **Flame retardant** EN 13501-1 - without halogen- and phosphor compounds
- **Mech. Properties** abrasion and elasticity at the application range

Material	Weather/ temperatu e resistance	UV/ ozone resistance	Mechanical properties	PU-compati-bility	Environmen-tal compatibility	Odour	Costs
EPDM coloured granules	++	**UV +** **O_3 ++**	+/-	+	++	+	+/-
recycled black granules **(ELT-end of life tyres)**	+/-	**UV +** **O_3 -**	+	+/-	+/-	-	++
TPE-V coloured granules	+/-	++	+/-	++	++	++	-
Cork-coconut-fibres Infill	+/-	+	--		+	+?	???

Comparison of properties

8. EPDM Granules Cause of Failures in the Past

Cause of Granules Failures

- **Main failures**

  - **chemical degradation** (sticky surface, no longer usable soft granules)
  - **mechanical degradation** (destroyed granules)
  - **colour change**
  - **chalking**
  - **blooming**

Cause of Granule Failures

- **Main causes**

  - **Insufficient degree of crosslinking** — not fully vulcanised, or reversion due too high vulc.-temperature
  - **UV absorber** — inhibited from crosslinking system and not reactive, general false UV-absorber
  - **Gel content**
  - **Diene content too low** — reduced crosslinking degree
  - **Peroxide crosslinking** — residual of decomposition products and inhibition of UV- absorber

A lot of possibilities could be responsible for a degradation,
only with phsyico-chemical analytics the root cause can be evaluated!

Cause of Granule Failures

- **Further possible causes**:

  - **Heavy metals influence** especial Cobalt avoiding
  - **Chlorined mains water**
  - **Cure temperature** not correct (too low or too high)
  - **Residual** from the catalysis system
  - **Pigment formulation** anorganic pigments e.g. Ironoxide, titandioxid

A lot of possibilities could be responsible for a degradation,
only with phsyico-chemical analytic the root cause can be evaluated!

Influence Factors on EPDM Degradation

➢ **How can a degradation be avoided?**

• **UV light**	use of particular UV-absorber
• **High outdoor temperature**	quenching with cold water, high amount of white fillers
• **Residual of catalysts**	dependence on the polymer processing use of purer polymers
• **Crosslinking system**	avoiding of peroxide curing and general not any undervulcanisation

Realise: chemical reactions are faster with UV-light and temperature equal for degradations

9. Future of Granules in Sports Fields

Future of Granules in Sports Fields

- **Which changes can be expected?**

  - **EPDM- sizes** granules replaced by turf, stripes or other shape
  - **EPDM-granules** with a self gliding surface
  - **EPDM-granules** spongy, foamed, waterabsorbing
  - **EPDM granules** bio-based EPDM combined with bio based ingredients
  - **EPDM/TPE and –TPV** blends with improved properties
  - **TPE/ TPV** with better thermostability
  - **TPE/ TPV** more price competitive with EPDM

Nowadays EPDM is the optimal choice for coloured granules

Future of EPDM Granules in Sports Fields

- Further **innovations** in the **catalyst-systems** and the **polymerisation process** could lead to further very interesting new polymers with use oriented properties

- A rethinking of the rubber producers, away from the absolute dependency on fossil fuels to more **renewable resources**

- Using of the world´s first **bio-based EPDM rubber**, production start was 2017 in Triunfo (Brazil), commercialized by ARLANXEO under the trade name **Keltan Eco**

Keltan Eco is produced by an solution process with an improved Z-N catalyst technology
The **bio based ethylene originates from sugar cane**, converted to ethanol and dehydrated to ethylene

Future of EPDM Granules in Sports fields

Isn´t a biobased EPDM a big challenge for EPDM-granules producer?

Using **a green polymer**, based on renewable resources, in a **green outdoor area**, like sports fields?

What a benefit **announcing granules based on green polymers** with

- **A green** non mineraloil **plastisizer,** a vegetable oil
- **Fillers** and **pigments** only **from natural sources**
- **An environmental compatible crosslinking system**

Biobased EPDM, with ingredients from natural sources, could change the bad reputations, when media discredit EPDM granules as harmful. What a future prospect and a guaranty for the survival of EPDM granules in sports fields for the next, how many ??? decades

Thank you for your attention

ISSS Technical Conference 2018-10-25/26, Cagliari

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