Trends and Material Needs of the Tire Industry – ARLANXEO’s Perspective

Luc ter Bogt, ARLANXEO Tire & Specialty Rubbers

VKRT Seminar December 2017
ARLANXEO – strong company with two powerful partners

ARLANXEO – Performance Elastomers

- World's largest integrated energy enterprise
- Backward integration into feedstock for synthetic rubber
- Strategic commitment to further develop value chain downstream

#1 in feedstock

- Leading market and technology positions in synthetic rubber
- Well invested asset base
- Broadest product portfolio in the rubber industry with leading brands and quality

#1 in synthetic rubber

ARLANXEO name: combining one syllable each of Saudi Aramco and LANXESS; ending “EO” refers to elastomers
ARLANXEO – a key global player in the synthetic rubber market

Background:
- ARLANXEO: Joint venture formed by LANXESS and Saudi Aramco; Start-up April 1, 2016
- A world-leading synthetic rubber company: development, manufacturing and marketing of high-performance rubber

Global set-up:
- 20 plants in nine countries
- ~3,800 employees worldwide
- Global sales of ~2.7bn € in 2016
- Corporate Headquarters: Maastricht, Netherlands

Business Units:
1) Tire & Specialty Rubbers
2) High Performance Elastomers
Leading with a combined share of 12% of all its relevant synthetic rubber markets

Top 10 players with combined market share of ~50%

ARLANXEO estimated market figures
More than 100 years of experience in performance elastomers

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1909</td>
<td>Fritz Hofmann invented synthetic rubber</td>
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<tr>
<td>1929</td>
<td>Invention of butadiene styrene copolymerization to produce SBR</td>
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<tr>
<td>1930</td>
<td>BUNA registered as trademark</td>
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<tr>
<td>1936</td>
<td>Start of industrial production of SBR (BUNA)</td>
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<tr>
<td>1939</td>
<td>Isobutylene copolymerized with isoprene making Butyl Rubber &quot;cross-linkable&quot;</td>
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<tr>
<td>1943</td>
<td>Synthetic rubber production exceeded 120kt p.a.</td>
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<tr>
<td>1944</td>
<td>Butyl rubber production in Sarnia (Canada) started</td>
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<tr>
<td>1949</td>
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<tr>
<td>1954</td>
<td>Synthetic rubber production exceeded 120kt p.a.</td>
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<tr>
<td>1958</td>
<td>First production of Brominated Butyl Rubber</td>
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<tr>
<td>1961</td>
<td>First production of Chlorinated Butyl Rubber</td>
</tr>
<tr>
<td>1975</td>
<td>Started use of neodymium-based catalyst for BR</td>
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<tr>
<td>1987</td>
<td>Acquisitions of Petroflex, Polysar</td>
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<tr>
<td>1990</td>
<td>Acquisition of DSM Elastomers</td>
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<tr>
<td>2004</td>
<td>Spin-off of LANXESS from Bayer</td>
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<tr>
<td>2008</td>
<td>Acquisitions of Petroflex, Polysar</td>
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<td>2010</td>
<td>Groundbreaking for new Singapore site</td>
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<tr>
<td>2016</td>
<td>ARLANXEO starts — JV of Saudi Aramco and LANXESS</td>
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<tr>
<td>2011</td>
<td>Acquisition of DSM Elastomers</td>
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<tr>
<td>2015</td>
<td>EPDM CHN opening</td>
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<tr>
<td>2013</td>
<td>Butyl SGP opening</td>
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Tire & Specialty Rubbers (TSR) – world’s leading manufacturer of Performance Polymers

<table>
<thead>
<tr>
<th>Facts</th>
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<tr>
<td>Part of:</td>
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<td>Customers:</td>
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<td>Market position:</td>
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<td>Production capacity:</td>
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<th>Products &amp; Brands</th>
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<tr>
<td>Butyl:</td>
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<tr>
<td>BR:</td>
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<tr>
<td>S-SBR:</td>
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<tr>
<td>E-SBR:</td>
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<table>
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<tr>
<th>Applications</th>
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<tbody>
<tr>
<td>Tires</td>
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<tr>
<td>Consumer &amp; pharma</td>
</tr>
<tr>
<td>Plastics</td>
</tr>
<tr>
<td>Golf &amp; sport balls</td>
</tr>
</tbody>
</table>
Broad and innovative portfolio with a truly global footprint

- Broad and innovative product portfolio for tire and non-tire applications
- Truly global footprint in all regions featuring state of the art production facilities
- Proximity to major markets, especially Asia including a strong recently built asset base
- Regional technical support and application development with customers
- Global R&D centers
High Performance Elastomers (HPE) – broad portfolio of synthetic rubber for various applications

- Part of: ARLANXEO
- Customers: ~ 800
- Market position: No. 1-2 in High Performance Elastomers

**Products & Brands**
- NBR: Nitrile Butadiene Rubber
  - Perbunan™, Krynac™, Baym® N
- HNBR: Hydrogenated Nitrile Butadiene Rubber
  - Therban™
- EVM: Ethylene Vinyl Acetate Rubber
  - Levapren™, LevaMelt™, Baymod® L
- CR: Chloroprene Rubber
  - Baypren™, Baypren® ALX
- EPDM: Ethylene Propylene Diene Rubber
  - Keltan™, Keltan® Eco

**Applications**
- NBR
- HNBR
- CR
- EVM
- EPDM
Global footprint to serve demand of the rubber processing industry

- Production plants in all key regions
- World’s largest EPDM plants in Geleen, Netherlands and Changzhou, China
- State-of-the-art CR world-scale plant in Dormagen, Germany
- Globally largest NBR plant in La Wantzenau, France
- Only global EVM supplier to offer VA* in the range of 40-90 wt%
- Advanced HNBR technology

* Vinyl Acetate
How does the synthetic rubber market of approximately 10 mn tons p.a. split up?

- Relevant rubber markets can be distinguished into six different rubber types
- Styrene-Butadiene rubber (E-SBR/S-SBR) as the most prevailing rubber type

- Tire as the most dominant application
- Automotive overall with 8%, but high share in EPDM
- Others contains applications with broad range, such as plastics, construction or shoes

- More than 50% of relevant market is already in APAC
- NAFTA and EMEA representing still a significant share of the market

ARLANXEO estimated market figures
How does BR, SBR and butyl markets of approximately 6 mn tons p.a. split up in the tire application?

### by rubber type

- Relevant rubber markets can be further distinguished into 5 different rubber types
- E-SBR as the biggest rubber type in volume for tires

### by application

- Passenger Car Radial (PCR) tires as the most dominant application
- Truck and Bus Radial (TBR) tires second

### by regions

- More than 60% of relevant market is already in APAC
- NAFTA and EMEA representing still a significant share of the market

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ARLANXEO estimated market figures
Global car and tire overview: advanced, yet unbalanced globalization of tire industry

- NAFTA and EMEA as net importing tire markets
- APAC as net exporter for tire, especially China and ASEAN with >40% of exports
- Majority of volumes in all regions going into replacement market
- China with highest share of OEM sales of all regions (40%)

Source: LMC 2017
Tire capacity shifting to NAFTA and South-East Asia

Global capacity 2016: ~ 2,677m tires

- ~ 65% of global capacity in APAC
- Significant capacity increase in the US, with a high share of Asian tire manufacturers
- Chinese capacities shifting to neighboring countries (lower labor cost and avoidance of anti-dumping tariffs)
- EMEA, LATAM and ASEAN with moderate growth
- Middle East growth driven by Turkey

Source: LMC 2017
Tire label initiatives are expected for all major markets and promote UHP tires with Low Rolling Resistance

Increased number of tire label initiatives will push further for high performance materials like Nd-BR and functionalized S-SBR

* Currently voluntary and reviewing mandatory regulation  ** According to UN Global Tire Regulations schedule
The coexistence of several forces and enablers accelerates the industry transformation to autonomous driving

**Legislation/Sustainability**
Up to 40% of gasoline use while looking for parking

**Technology:**
5G & sensors, integrity of systems

**Safety:**
93% of accidents human error
>USD 400b cost for traffic crashes in US

**Urbanization/Efficiency:**
Highway capacity can be increased by 500%, Car is unused for 22 hours a day

**Entrance of new players:**
Tesla, Google and alike disrupt the automobile industry

**Smart Cities:**
Providing the necessary infrastructure

**Consumer Preference:**
Generation Y wants mobility as a service, not a product

Increasing amount of software companies actively shaping developments in the automotive industry
Electrification of cars is an automotive revolution and a shift in tire design and requirements.
Product Developments at TSR aim for improving the tire performance in a holistic way focusing safety & sustainability

<table>
<thead>
<tr>
<th>Component</th>
<th>Influence</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tread</td>
<td>influences grip, fuel economy, durability &amp; noise</td>
<td>Fct. S-SBR / Nd-BR</td>
</tr>
<tr>
<td>Undertread</td>
<td>provides stiffness, affects fuel economy</td>
<td>Nd-BR</td>
</tr>
<tr>
<td>Upper steel belt</td>
<td>influences driving features and shape</td>
<td>Nd-BR</td>
</tr>
<tr>
<td>Sidewall</td>
<td>offers ride comfort and protects carcass crack resistance &amp; elasticity</td>
<td>Nd-BR / fct. Li-BR</td>
</tr>
<tr>
<td>Lower steel belt</td>
<td>influences the driving features and shape</td>
<td></td>
</tr>
<tr>
<td>Carcass</td>
<td>gives support and carries the load of the vehicle</td>
<td>Butyl rubber</td>
</tr>
<tr>
<td>Innerliner</td>
<td>keeps the air in the tire, ensures safety, fuel efficiency and improved handling</td>
<td>Coupled Li-BR / Nd-BR</td>
</tr>
<tr>
<td>Bead area</td>
<td>keeps the tire safely attached to wheel rim high hardness</td>
<td></td>
</tr>
<tr>
<td>Self-sealing</td>
<td>prevents air loss in case of puncture, provides safety and comfort</td>
<td>Polymer based Sealing Compound</td>
</tr>
</tbody>
</table>
Pneumatic tire will remain the major mobility enabler beyond 2030, ARLANXEO is able to rely on its broad product portfolio

2050 vision* of mobility

- Pneumatic tire will still be the core technology for cars and trucks
- Ultra low rolling resistance required for electric and autonomous driving vehicles
- Semi-autonomous and autonomous driving solutions will require different tire types
- Increased demand for energy efficient tires supported by labelling initiatives

* Source: Mercedes Benz mobility concept 2016
SBR

Solution SBR tool box:

- (vinyl, styrene)
- Molecular weight
- Functionalization (end-group, chain)
- Coupling
- Oil extension
The rolling resistance from tires contributes 15 to 30% to the total fuel consumption of passenger cars.

The main contribution to the rolling resistance derives from the interaction of the filler particles in the tire tread compound.

The use of functionalized S-SBR in the tire tread compound reduces the filler-filler interaction and, thus, leads to reduced rolling resistance.
Advanced S-SBR functionalization technologies for better overall performance of tire treads

- Reduction of filler-filler interaction can be obtained with $\omega$-functionalized S-SBR. ARLANXEO launched FX 3234A-2 (HM) and FX 5000

- ARLANXEO’s technology to produce in-chain functionalized S-SBR for silica tire tread compounds allows further significant reduction of filler-filler interaction

- Combination of chain-end & and in-chain functionalized S-SBR in silica all-season tire tread formulation allows improvement of winter tire properties without losing summer tire handling performance
Changing from E-SBR / carbon black to S-SBR / silica leads to significant improvement of:

- wet grip behaviour
- rolling resistance

**Evolution of wet grip vs rolling resistance for tire tread compounds**

![Graph showing the comparison between E-SBR with carbon black and S-SBR with silica](image-url)
Evolution of wet grip vs rolling resistance for tire tread compounds

Changing from unfunctionalized S-SBR to chain end functionalized S-SBR leads to:

- reduction in rolling resistance
- maintained wet grip
Evolution of wet grip vs rolling resistance for tire tread compounds

Changing from chain end functionalized S-SBR to in-chain functionalized S-SBR leads to:
- improved wet grip
- improved rolling resistance
Evolution of ARLANXEO S-SBR portfolio; tailoring microstructures and introducing functionality to fillers

- Non-functional SSBRs. Segregation to high vinyl, high styrene and low Tg grades
Evolution of ARLANXEO S-SBR portfolio; tailoring microstructures and introducing functionality to fillers

- Non-functional SSBRs. Segregation to high vinyl, high styrene and low Tg grades
- Extending the non-functional grades
Evolution of ARLANXEO S-SBR portfolio; tailoring microstructures and introducing functionality to fillers

- Non-functional SSBRs. Segregation to high vinyl, high styrene and low Tg grades
- Extending the non-functional grades
- $\omega$ end-group functionalized products introduced in 2016
BR
Different types of BR commercialized. Used catalyst determines the final microstructures and properties

NdBR

- Highest cis-1.4 stereo regularity and lowest vinyl content
- Highest regularity of polymer chains
- Preferred polymer for tire performance (RR, wear)

<table>
<thead>
<tr>
<th>Catalyst</th>
<th>Nd</th>
<th>Co</th>
<th>Ni</th>
<th>Ti</th>
<th>Li</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microstructure</td>
<td>1.4-cis content (%)</td>
<td>98</td>
<td>97</td>
<td>97</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>1.2-vinyl content (%)</td>
<td>0.5</td>
<td>1.7</td>
<td>1.8</td>
<td>5</td>
</tr>
<tr>
<td>Glass Transition Temperature Tg (°C)</td>
<td>-109</td>
<td>-107</td>
<td>-107</td>
<td>-104</td>
<td>-93</td>
</tr>
<tr>
<td>Branching (%)</td>
<td>&lt; 5</td>
<td>20</td>
<td>20</td>
<td>15</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Polydispersity PDI (Mw / Mn)</td>
<td>2.1</td>
<td>3.1</td>
<td>4.2</td>
<td>3.4</td>
<td>2.0</td>
</tr>
</tbody>
</table>
BR with different microstructures: Nd-BR provides superior properties in RRc and wear resistance

Significant improvement in the classification of the EU labeling for fuel economy possible

<table>
<thead>
<tr>
<th>RRc (kg/ton)</th>
<th>ARL Nd-BR</th>
</tr>
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<tbody>
<tr>
<td>7.8</td>
<td>Buna CB 25</td>
</tr>
<tr>
<td>9</td>
<td>Buna CB 24</td>
</tr>
<tr>
<td>9.6</td>
<td>Buna CB 1203 CoBR</td>
</tr>
<tr>
<td>9.9</td>
<td>NdBR Comp</td>
</tr>
<tr>
<td>10.2</td>
<td>NiBR Comp</td>
</tr>
<tr>
<td>10.5</td>
<td>Buna CB 45 LiBR</td>
</tr>
</tbody>
</table>

Rolling Resistance classification (EU Tire Labeling)

Silica filled PCR tire tread compound consisting of 55 phr S-SBR and 45 phr BR

Quelle: Verordnung (EG) Nr. 1222/2009
BR with different microstructures: Nd-BR provides superior properties in RRc and wear resistance

In parallel improvements of wear resistance are clearly observed with ARLANXEO Nd-BRs

Wear tested on Skoda Octavia 1.9 TDI, 14,000 km, average of all 4 wheels
Silica filled PCR tire tread compound consisting of 55 phr S-SBR and 45 phr BR
Processing difficulties with standard high-cis butadiene rubbers can lead to compromises in tire performance.

High Mn Nd-BRs lead to advantageous performance levels, but also partly to processing issues.

Among all high-cis Butadiene rubbers, Nd-BR consists of very narrow polydispersity, comparable high $M_n$ and highest linearity. These result in very fast relaxation behavior, affecting processing.

Note: $M_n$ as numerus average of molecular weight distribution counts the free polymer chain ends.
Buna® Nd EZ: breakthrough technology bridging the gap between processability and tire performance

Buna® Nd EZ compounds have improved processing behavior for customers

New generation of modified Nd-BR combines **long chain branching** for reduced compound Mooney and improved processing on the mill or in the extruder **with chemical modifications** to gain dynamic properties.

**Buna® Nd EZ**

- Easy processing with reduced mixing time and smoother profiles
- Optimized rolling resistance → increased fuel efficiency and reduction of CO₂ emissions
- Excellent resistance to abrasion, flex cracking and fatigue → improved safety and durability

Note: Extrusion @ 100 °C (30 BR / 70 SSBR / 90 Silica)
Li-BR allowing certain modifications, due to different polymerization mechanism than high-cis BRs

<table>
<thead>
<tr>
<th>Low-cis butadiene rubbers</th>
<th>High-cis butadiene rubbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li-BR</td>
<td>Ni-BR Co-BR Nd-BR</td>
</tr>
</tbody>
</table>

### Anionic polymerization
Carbanion as initiator, e.g. butyl lithium

\[ x \, M + R-Li \rightarrow R-(M)_x \cdot Li^+ \xrightarrow{fx} R-(M)_x-fx \]

### Coordination-insertion polymerization
Multi-component catalyst systems consisting of corresponding metal precursor, co-catalyst and activators

\[ x \, M + [Nd-R] \xrightarrow{fx} R-(M)_x-Nd \xrightarrow{fx} R-(M)_x-fx \]
\[ \text{chain-transfer} \rightarrow R-(M)_x-R \]

Co-catalyst(s) \[ fx \rightarrow \text{Co-catalyst-fx} \]

<table>
<thead>
<tr>
<th>Most promising for end-functionalization</th>
<th>Most difficult for end-functionalization</th>
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<tbody>
<tr>
<td>Low-cis microstructure</td>
<td>High cis microstructure</td>
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</tbody>
</table>

Arlanxeo
Developments of functionalized Li-BRs demonstrate superior properties in carbon black compounds

- **Energy dissipation**: End-functionalized Lithium butadiene rubbers show similar or better energy dissipation than high-cis butadiene rubbers in carbon black applications.

- **Process-ability**: Balanced choice in polarity of the functional group allows to yield a reasonably low compound Mooney.
  - Die swelling is reduced compared to high-cis polybutadienes.

- **Reversion resistance**: Low-cis butadiene rubbers exhibit less reversion at high temperatures.
  - Beneficial for vulcanization of “thick” compounds, e.g. in truck tires.
  - Promising for run-flat inserts, allowing for longer distances under flatted conditions.

\[ RRI = \text{Rebound}_{60^\circ C} + \tan \delta_{\text{max}(MTS)} + \tan \delta_{60^\circ C}(\text{Eplesor}) \]
Functionalization of high-cis butadiene rubbers difficult…
... but not impossible to improve properties further

<table>
<thead>
<tr>
<th>High-cis butadiene rubbers</th>
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<tr>
<td>Ni-BR</td>
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**Coordination-insertion polymerization**

- Multi-component catalyst systems consisting of corresponding metal precursor, co-catalyst and activators

```
[Nd-R] x M → R-(M)ₓ-Nd → R-(M)ₓ-fx
```

Chain-transfer

```
(M)ₓ-R
```

Co-catalyst(s) → Co-catalyst-fx

**High cis microstructure**

Most difficult for end-functionalization …
... but not impossible

![Graph showing Rolling Resistance Indicator vs Compound Mooney Viscosity](Image)

- fx-Nd-BR
- fx-Li-BR
- Li-BR
- Nd-BR
Extended mobility increasing attention – ARLANXEO developing a ready-to-use sealant

- Extended mobility is a topic of increasing attention in the car and tire market
- Full size spare wheels and jacks gradually disappear to save space and weight
- Besides a temporary spare, alternative extended mobility solutions available are: repair kit, self-sealing tires and run-flat tires
- VW is currently the main driver behind self-sealing tires and approved Continental, Pirelli, Goodyear and Hankook tires for fitting to their new cars
- Replacement market to be developed

* Puncture occurs once every 75,000 km in Europe and every 3,000 km in some Southeast Asian countries (source: Michelin). In 2015 globally 45% of new cars had a full spare wheel (source: Notch Consulting)
What do we do from here?

- Independently of the kind and the status of mobility, **tires will remain as the main carrier** for various vehicles.

- **Tire developments need to be continued** to improve fuel economy (driving range), wear resistance, comfort and sustainability of respective tires.

- As such, **developments of tire materials** are essential to be conducted further to support these evolutions.

- Several factors in contradiction, development of materials for specific purposes, there is no ‘one suits all’ solution.

- **ARLANXEO with its broad rubber portfolio** provides already today solutions for those complex trends, but is **carrying out further rubber & material developments** to comply with the requirements of the tire industry.

- **Input from customers** is instrumental in understanding the needs!