



New Eco-Sustainable Polyamide-Based Polymers and Compounds for Multipurpose Applications

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RadiciGroup High Performance Polymers

New Pack Workshop
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Contents

- **RadiciGroup HPP at a glance**
- **Sustainability at RadiciGroup**
- **Bio-Based Polyamides**
- **Properties comparison**
- **Case studies**
 - **Engineering Plastics Compounds**
 - **Film for Flexible Packaging**
 - **Water Management**

*Performance
&
Sustainability*

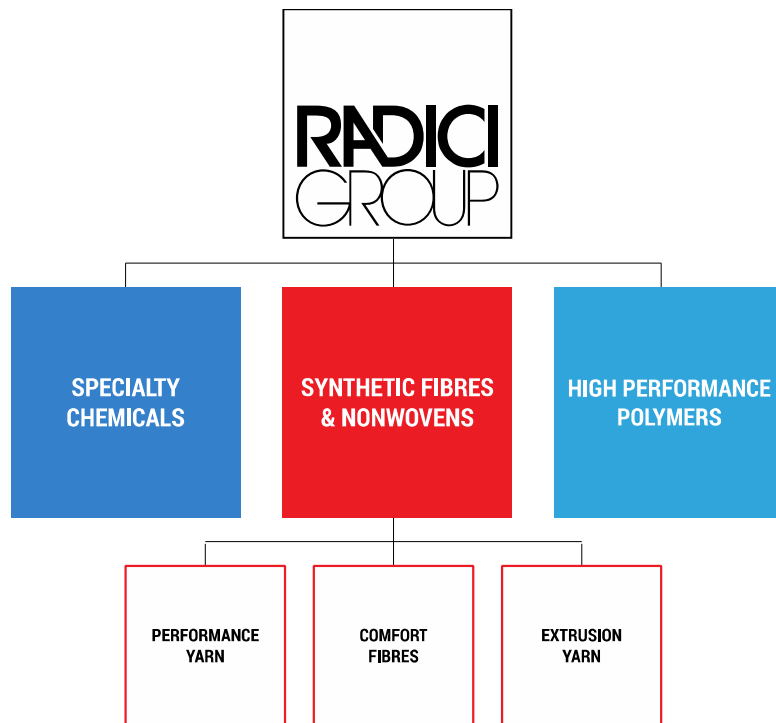


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RadiciGroup is one of the most active chemical companies at an international level. Its diversified businesses operate worldwide and are focused on:

- SPECIALTY CHEMICALS**
- HIGH PERFORMANCE POLYMERS**
- SYNTHETIC FIBRES & NON WOEVNS**



VISION

- To be **one of the leading chemical groups** in the polyamide, synthetic fibres and high performance polymers production chain.

MISSION

- To promote the **development of our businesses** while pursuing our Group **values and culture**.
- To pursue our vision by **valorising and optimizing our resources**, establishing strategic alliances and searching for new markets, including niche markets.
- To embed **sustainability into new product and application development**.

RadiciGroup | Worldwide presence



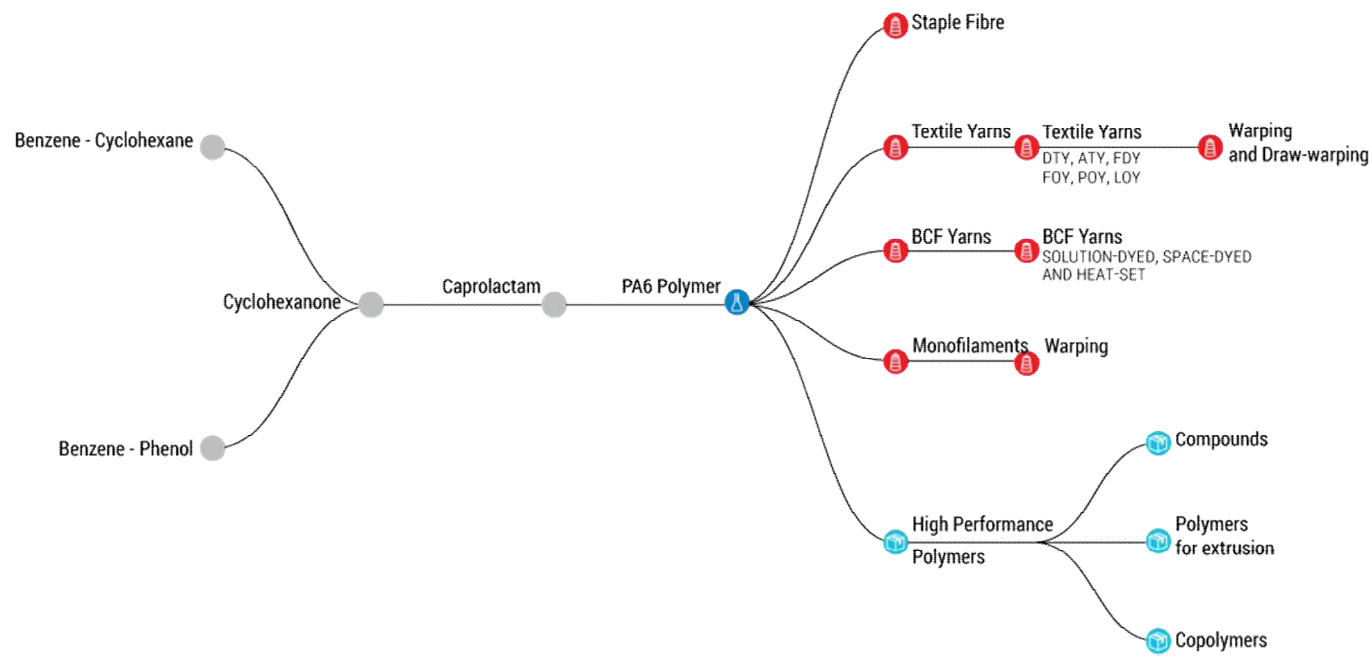
ASIA
China
Shanghai
Suzhou
India
New Delhi

AMERICAS
Argentina
Buenos Aires
Rio Grande
Brazil
Araçariguama
São José dos Campos
Mexico
Ocotlán
USA
Wadsworth

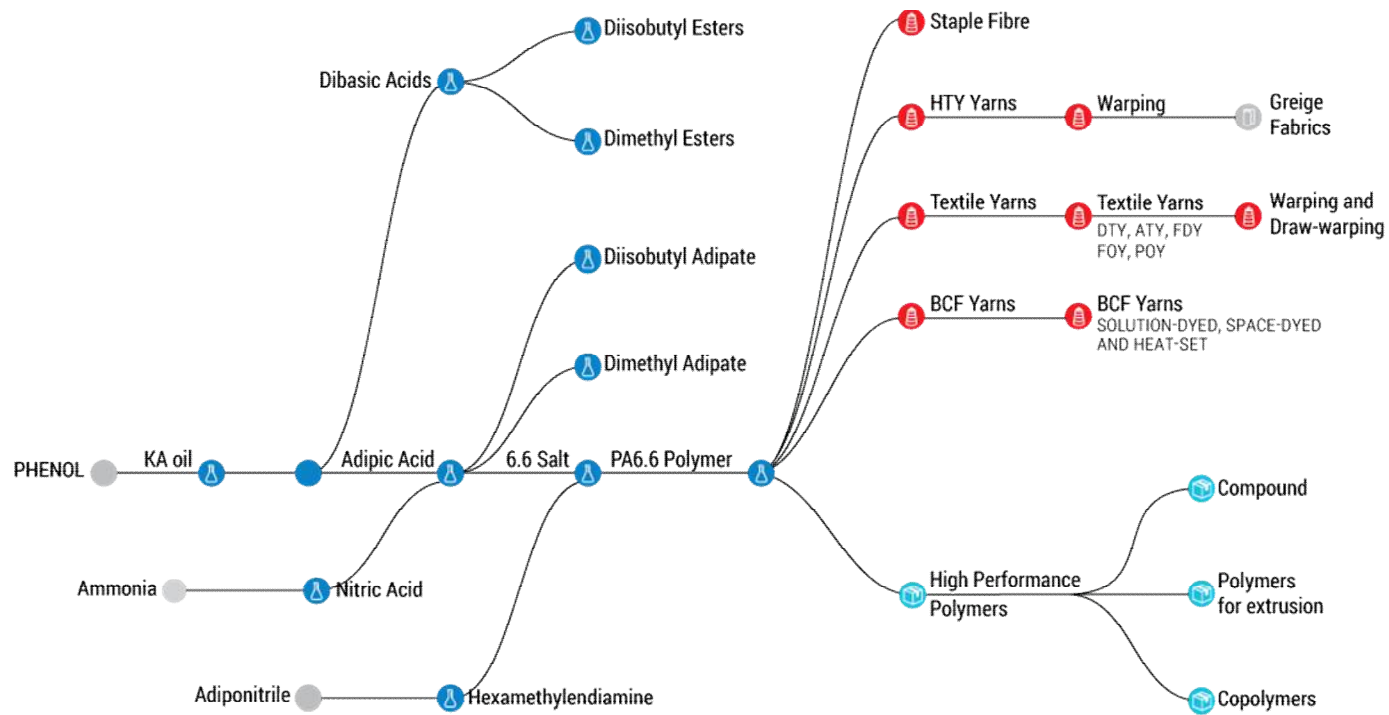
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Podborany
France
Saint Priest
Germany
Hamburg
Lüneburg
Selbitz
Tröglitz
Hungary
Szentgotthard
Switzerland
Stabio
United Kingdom
Wakefield

Italy
Andalo Valtellino
Ardesio
Casnigo
Chignolo d'Isola
Gandino
Novara
Villa d'Ogna
The Netherlands
Born
Romania
Savinesti
Spain
Barcelona

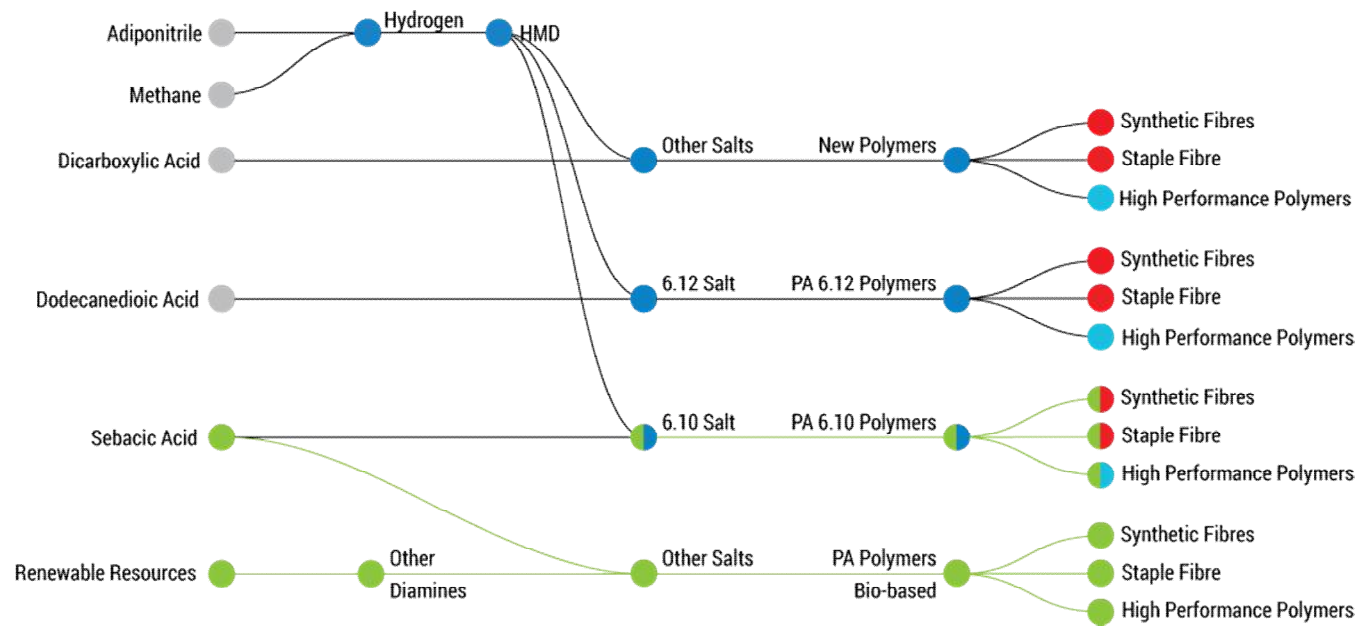
Synergy & Integration | PA6



Synergy & Integration | PA6.6



Synergy & Integration | PA 6.10, PA 6.12 and other polymers



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Sustainability and sustainable developments

Genesis of a concept

- «We do not inherit the Earth from our ancestors, we borrow it from our children» - Proverb attributed to the Natives of North America – 18th Century
- «Our work will influence not only the present generation but also the future ones» - T. Roosevelt (1901):
 - To create and maintain conditions under which human being and nature can exist in productive harmony satisfying the special and economic needs for the present and future generations (USA 1969).
- «Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (Bruntland report, 1987).

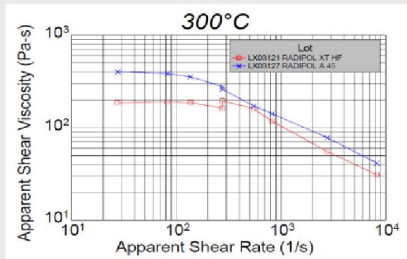
R&D for sustainable products

Bio-sourced polymers



Eco-sustainable approach of product development

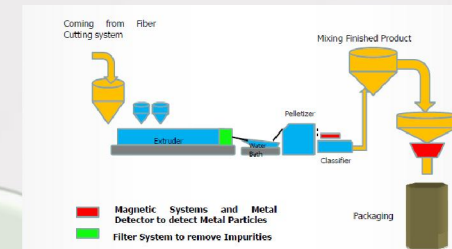
Radilon® A HS144



“Green like” performances

Post industrial recycled polymers

Heramid®



Post consumer recycled polymers to come



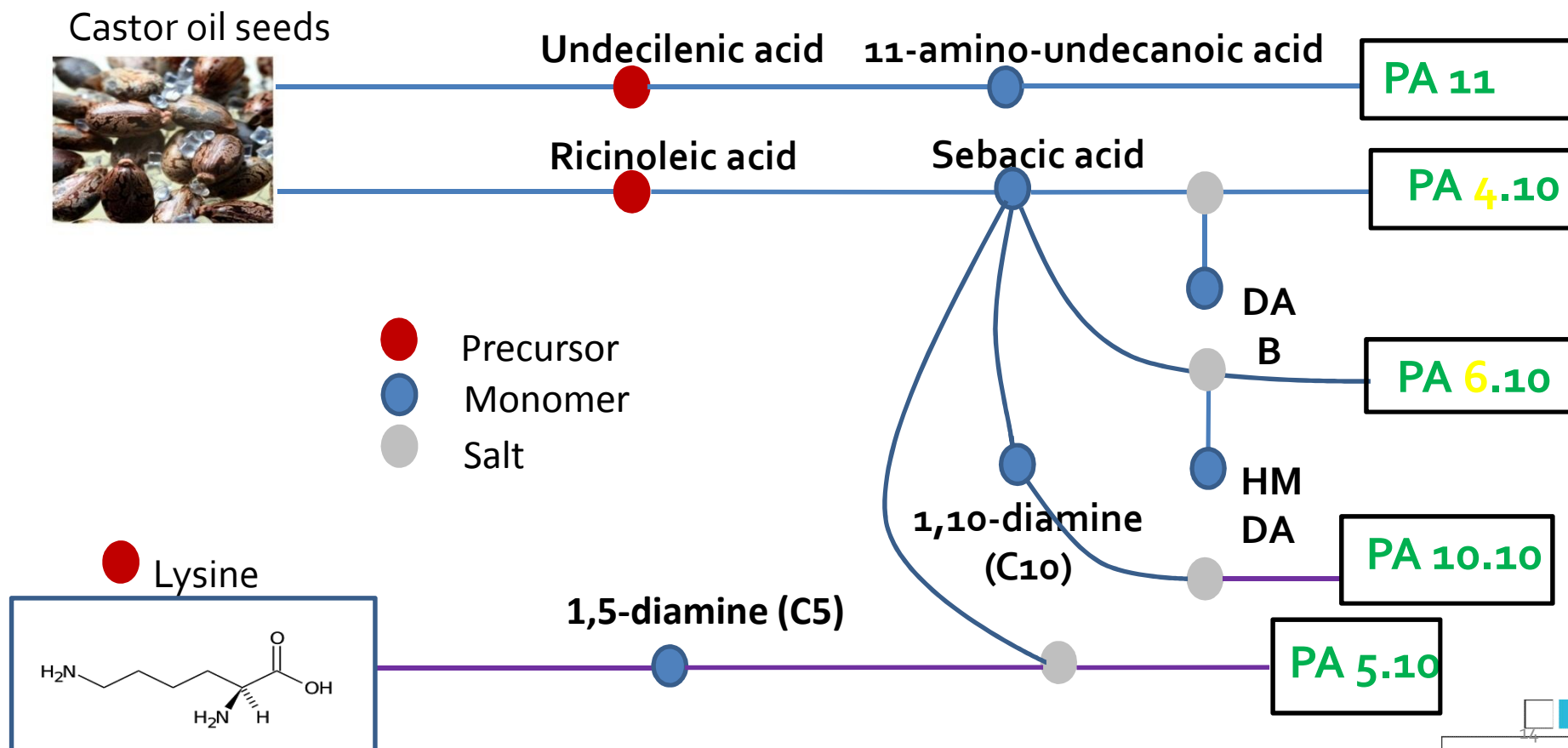
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Bio-polyamides – Main manufacturing routes



Pyramidal Organization of RadiciGroup Bio-Sourced Polyamides

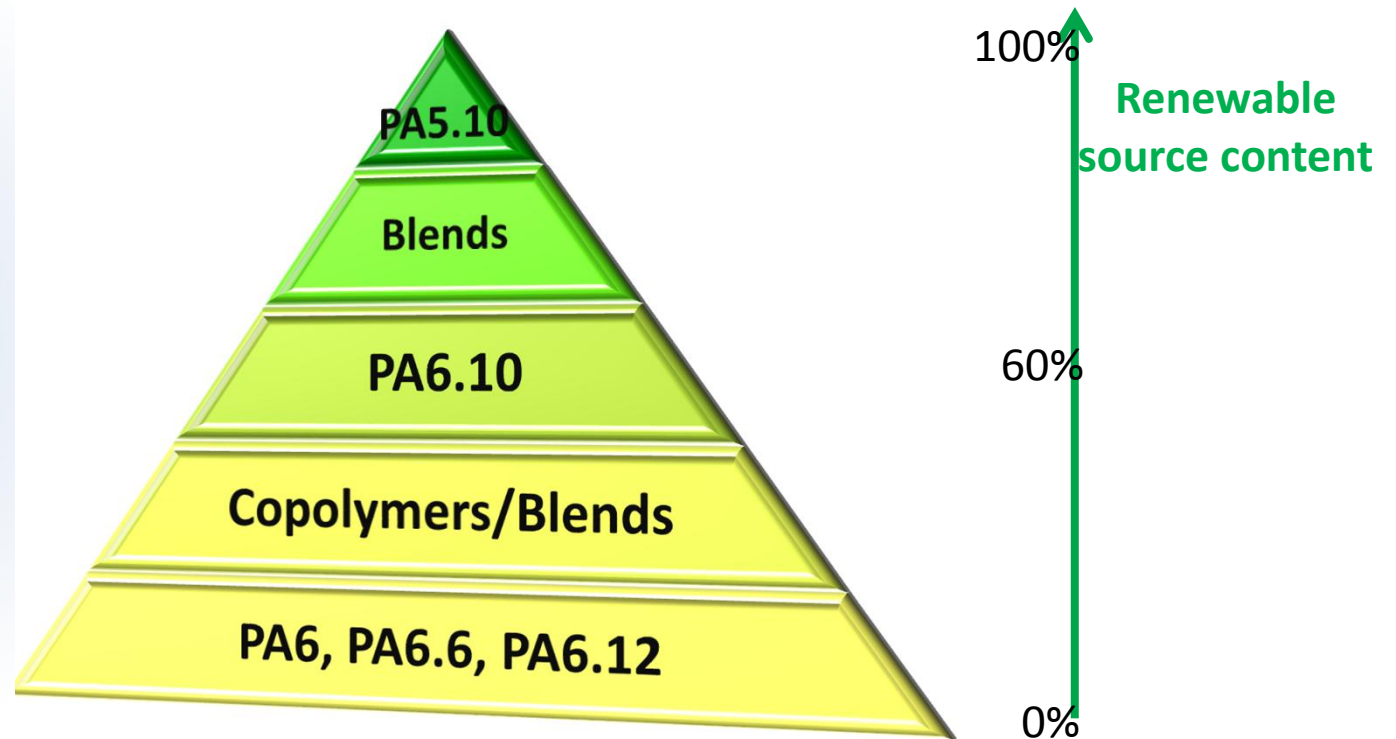
Radici Chimica

polymerization know how and flexibility

+

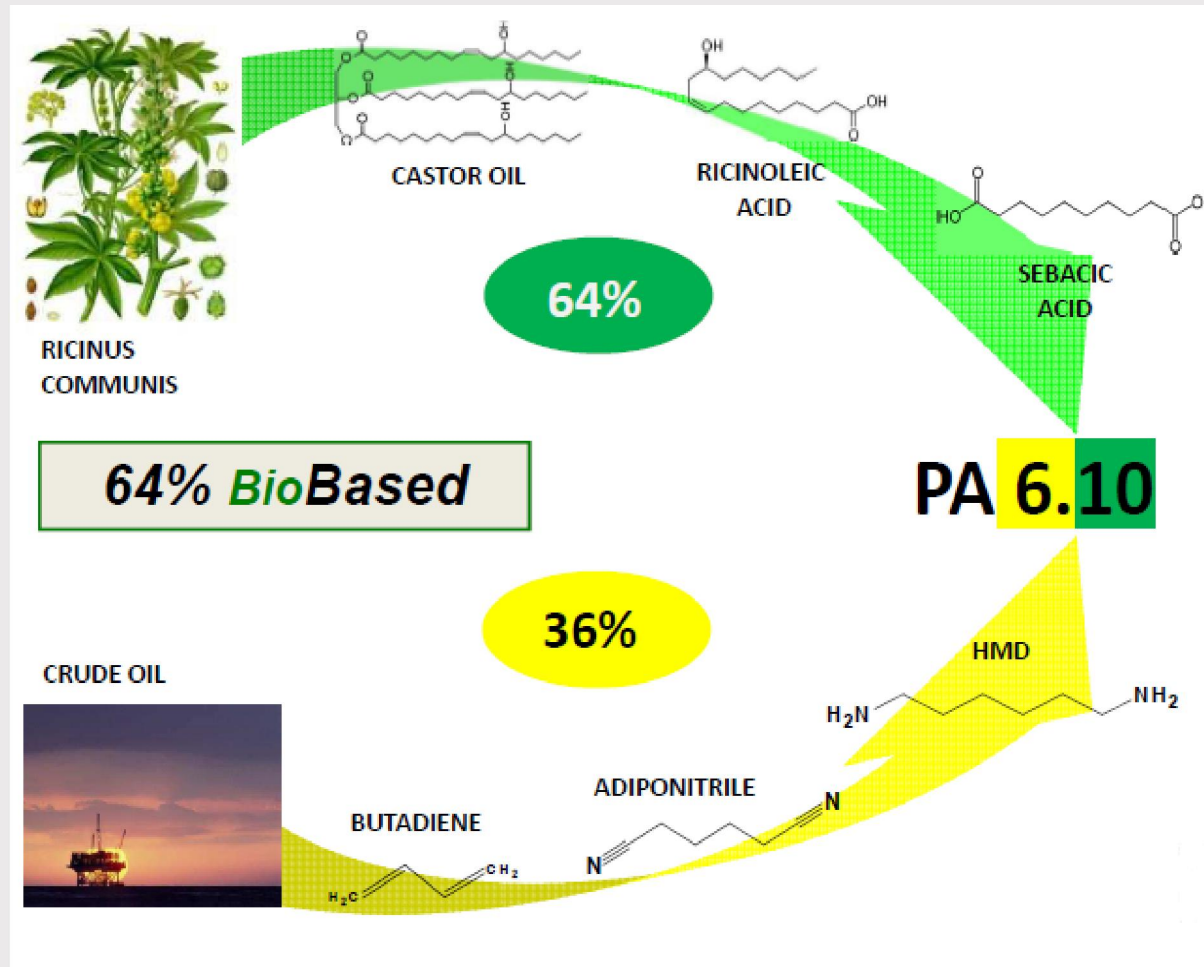
Radici Performance Plastics

compound technology and market knowledge to design high performance polymers and polymer blends



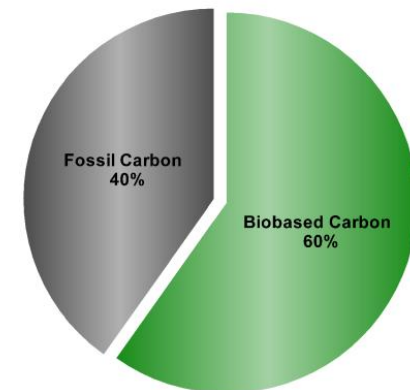
RADIPOL[®] DC : PRODUCTION CHAIN

A new family of semi-crystalline polyamides 6.10 obtained from the polycondensation of 1,6-hexamethylenediamine and 1.10-decanedioic acid (sebacic acid).



Biobased content: 60%
(carbon-neutral proportion) (biobased carbon to total carbon)

Biobased vs Fossil Carbon Content
 Determined by radiocarbon analysis



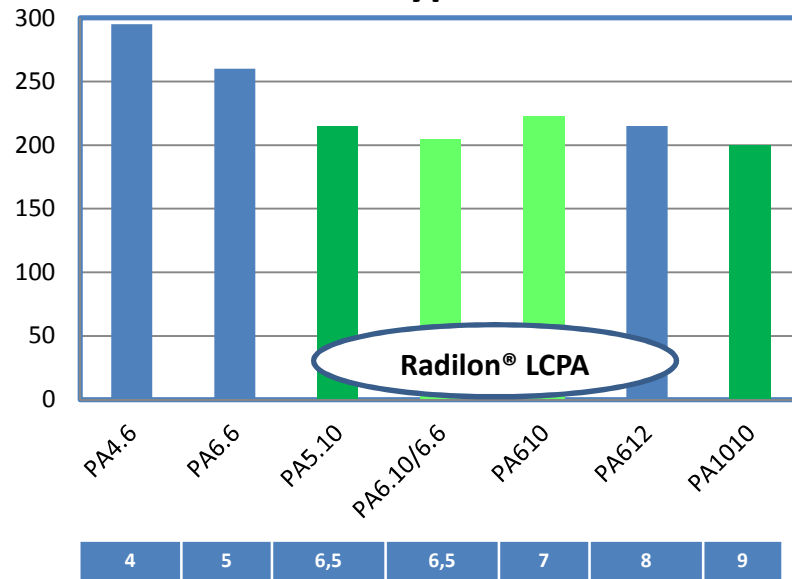
Four Products Families

Brand Name	Chemical Formula	Bio-Content	Distinctive Characteristics	Key Characteristics
Radilon® DT	PA612	0%	<ul style="list-style-type: none"> • Excellent resistance to zinc & calcium chloride solutions and in presence of stress-cracking • Bend recovery (monofilaments) • Easy processing 	<ul style="list-style-type: none"> • Good chemical resistance • Good hydrolysis resistance • Good thermal resistance • Good dimensional stability
Radilon® CD	PA610/PA66	50%	<ul style="list-style-type: none"> • Superior transparency and gloss • Good flexibility and toughness • Good thermoforming and low shrinkage • Easy processing • Cost competitive solutions (vs PA610) 	
Radilon® D	PA610	64%	<ul style="list-style-type: none"> • Bend recovery (monofilaments) • Easy processing by injection molding and extrusion 	
Radilon® PX	PA510	100%	<ul style="list-style-type: none"> • Easy flow • Excellent surface aspect 	

Basic Properties Comparison

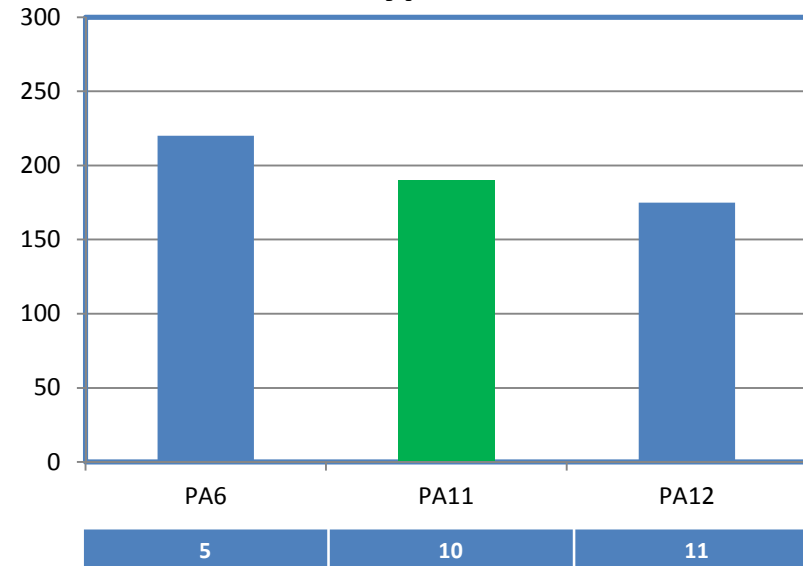
Melt Temperature comparison of some commercial Polyamides as a function of the amide group dilution

AA –BB type of PA

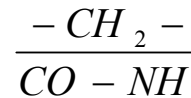


Amide group dilution →

A-B type of PA



Amide group dilution →



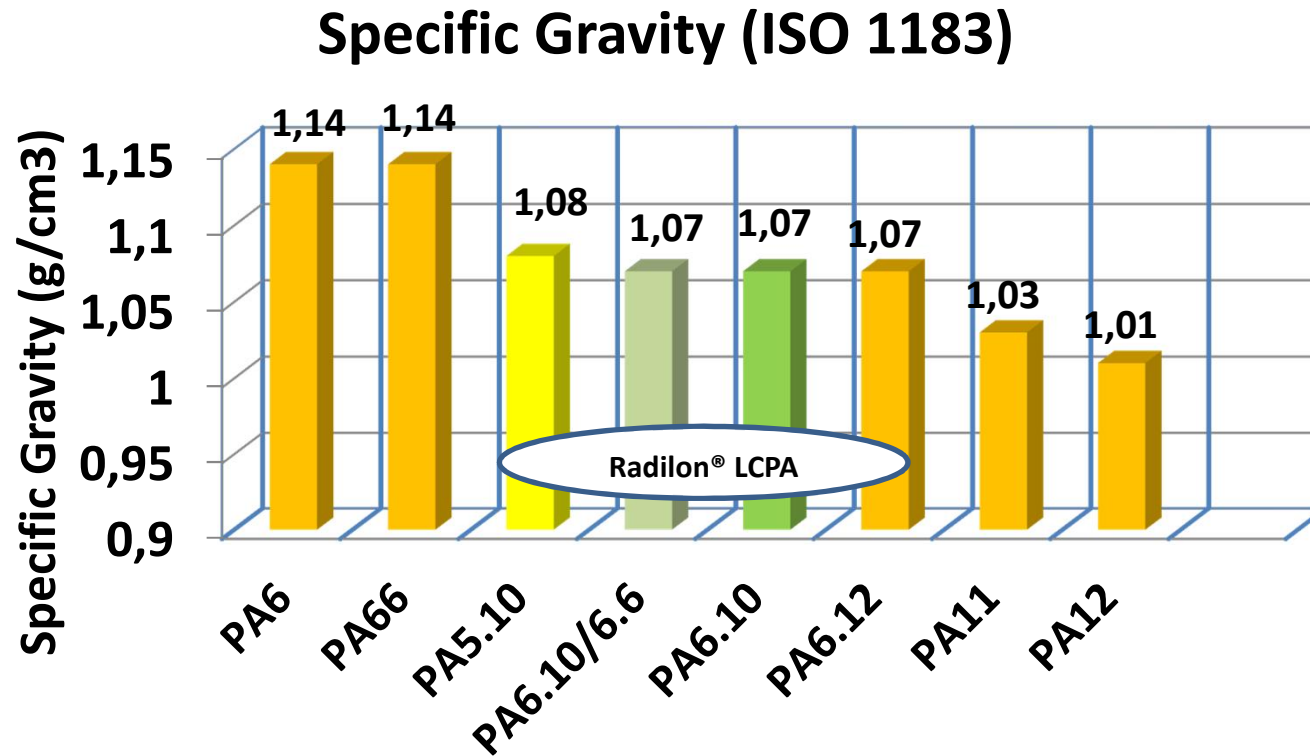
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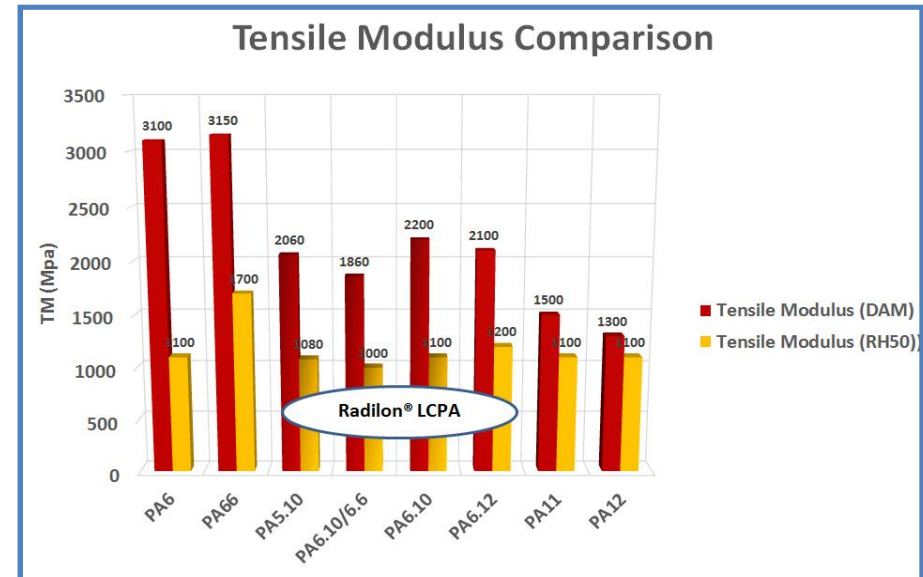
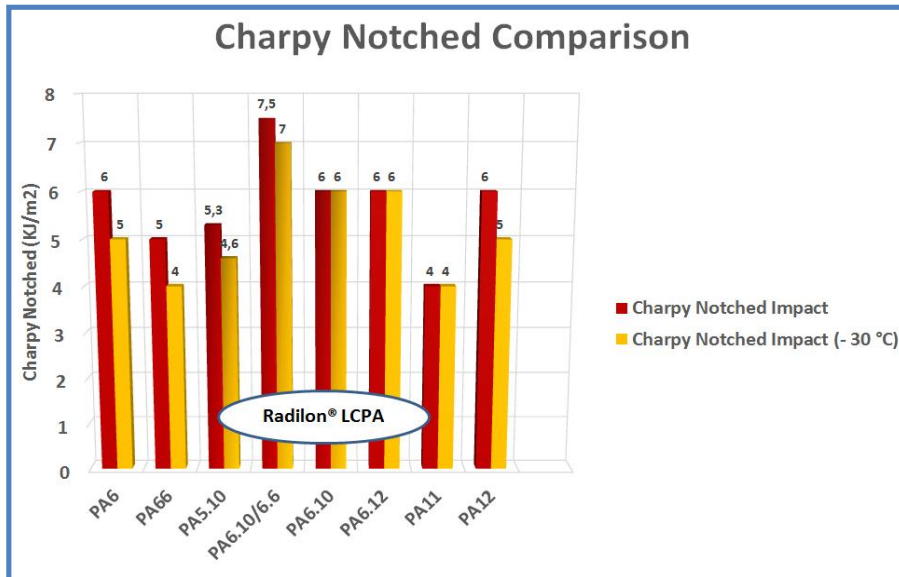


Basic Properties Comparison of neat polymers



The specific gravity of PA5,10, PA6,10 and PA6,12 is intermediate between PA6/PA66 and PA11 and 12

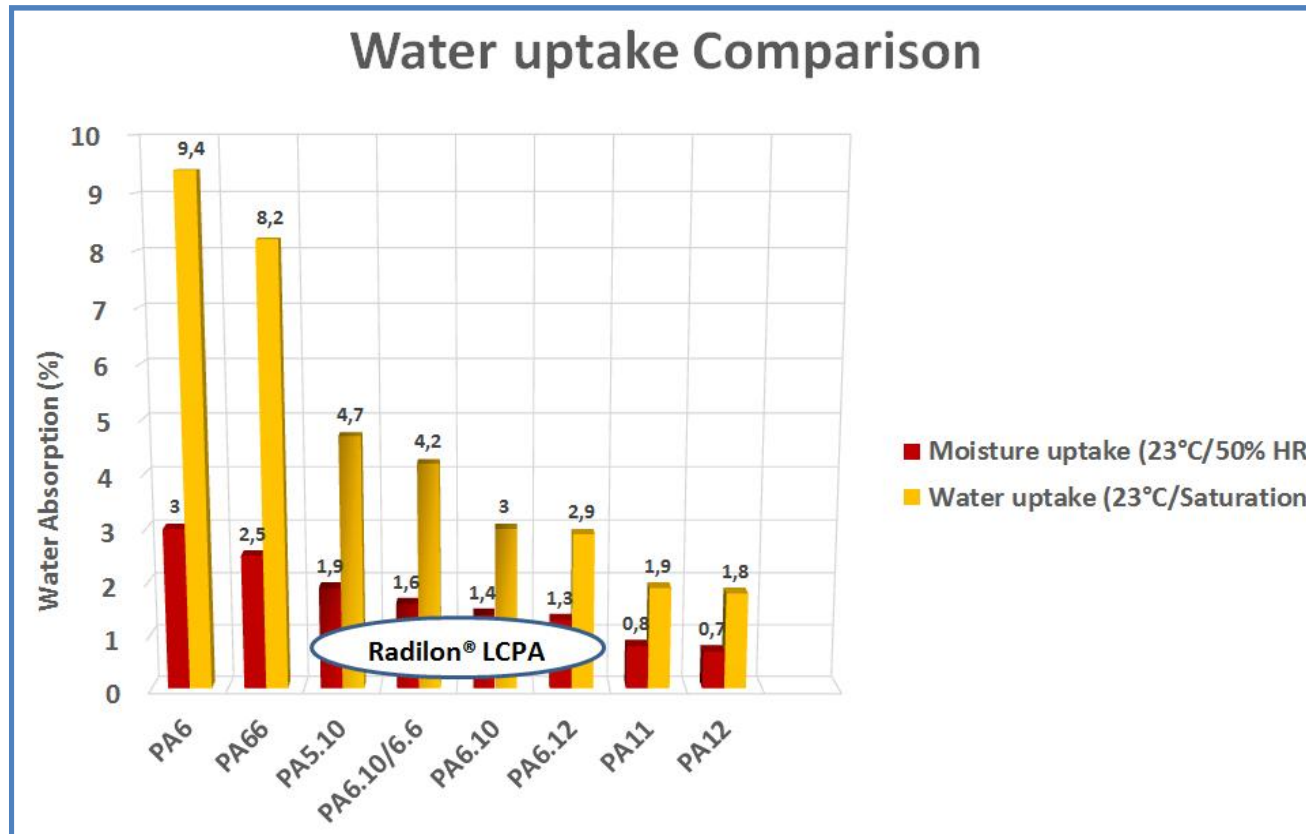
Basic Properties Comparison of neat polymers



PA510, PA610 & PA612 charpy notched impact at same level of PA6 and PA12; better than PA66 and PA11. PA610/66 copolymer exhibits better properties versus all the other grades

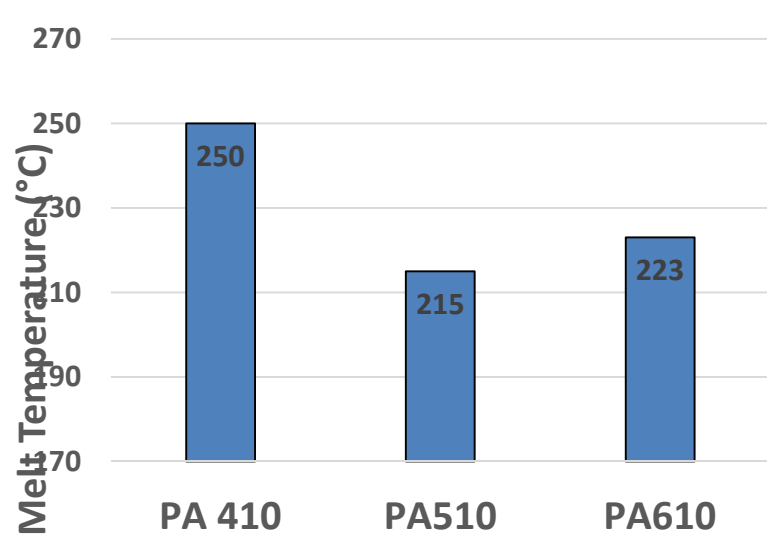
PA510, PA610 & PA612 tensile modulus intermediate between PA12 and PA66/PA6 in DAM conditions. Equivalent to PA11 and PA12 in conditioned state

Basic Properties Comparison of neat polymers

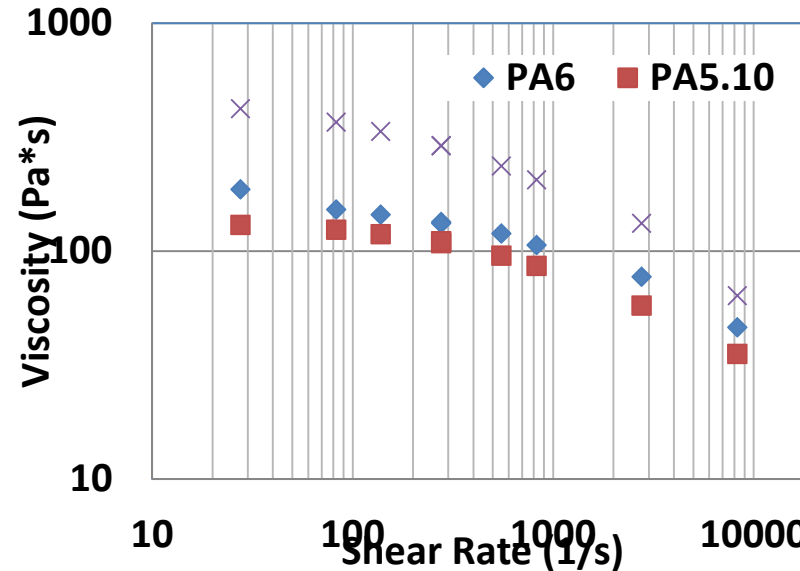


PA5,10, PA6,10 and PA6,12 exhibit much lower hygroscopicity than PA6 and PA66, and its water uptake at saturation is not too far from PA12.

Basic properties PA 510 – Radilon® PX

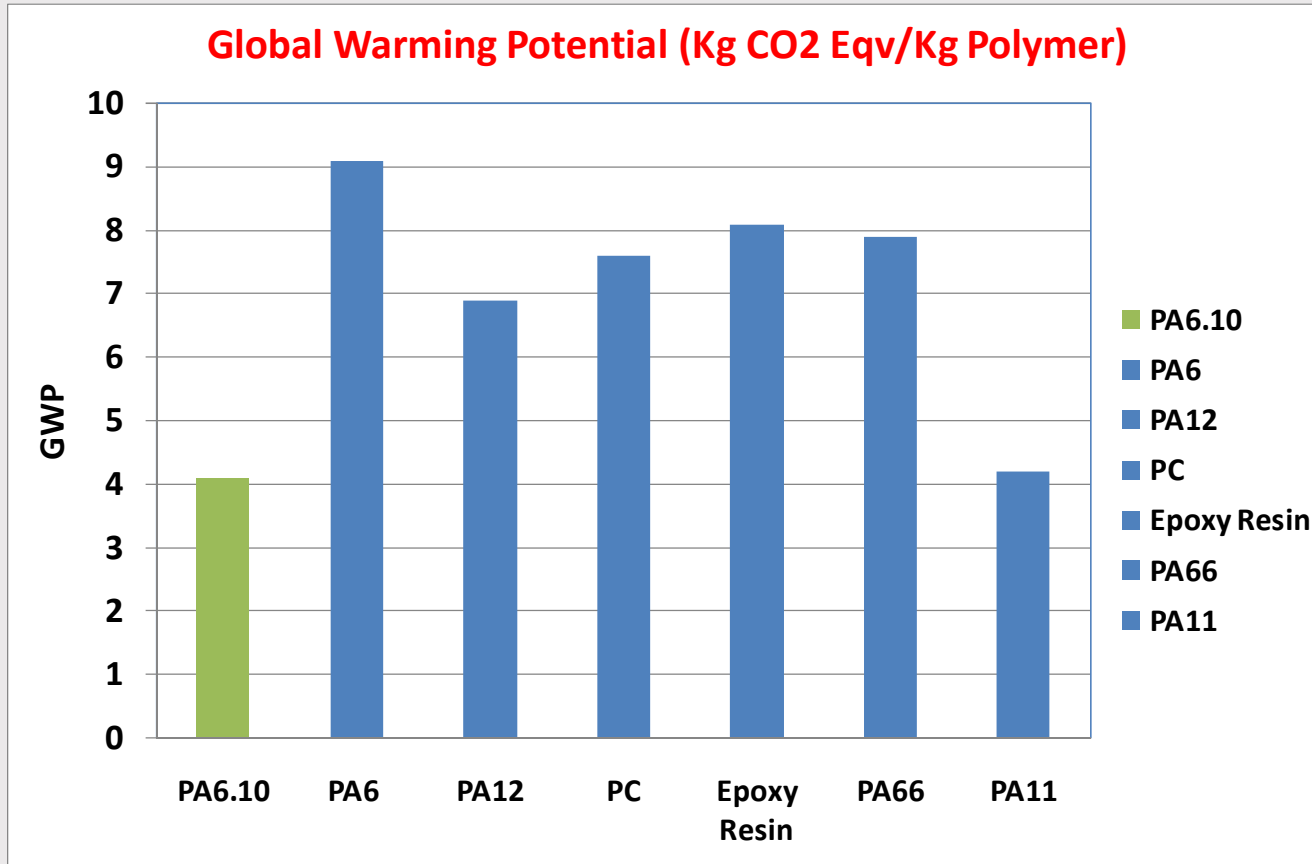


PA5.10 is an odd – even nylon with a melt temperature lower than the correspondents in the series



PA5.10 shows a lower melt viscosity vs LCPA and standard PA at same relative viscosity

RADIPOL® DC PA6.10: environmental benefit, reduced carbon footprint



PA6.10: GWP much lower than technical polymers like PC, PA6, PA66
Comparable to PA11 (Data collected from literature)



RADIPOL® DC PA6.10 KEY FEATURES



- *Best compromise between properties/costs/eco-content*
- *Greater dimensional stability compared to PA6 and PA6.6, due to less water and moisture uptake that lead to a superior hydrolysis resistance*
- *Higher chemical resistance compared to PA6 and PA6.6*
- *Grater resistance at high temperature than PA11&PA12*
- *Superior resistance to peroxides*
- *Excellent elastic memory, superior to traditional polyamides, i.e. better bending*



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Applications in the Automotive Industry



In-tank low extractable fuel pipes



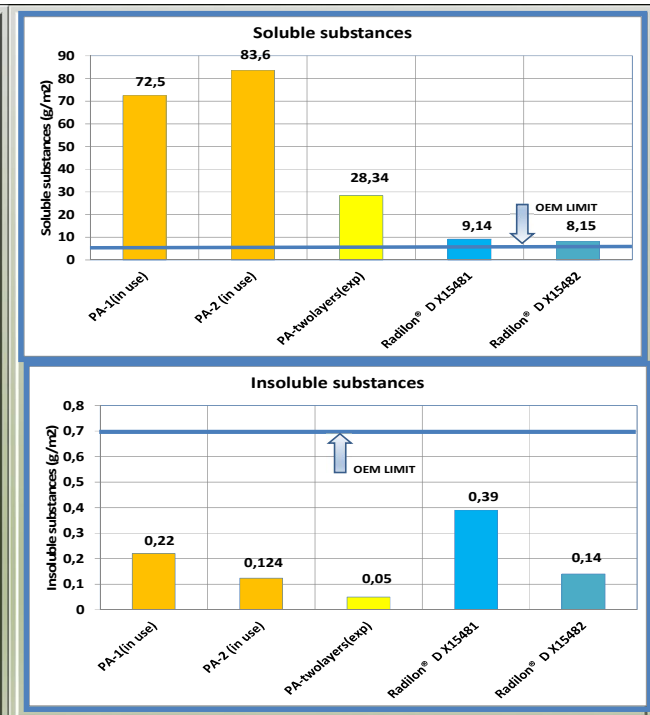
Key requirements

- Resistance to prolonged contact with different fuels (gasoline, diesel)
- Limited substances release
- Excellent processability by extrusion
- Very low release of soluble and non-soluble substances

Materials

PA610 & PA610/66, flexible, low extractable, **extrusion experimental grades**

- Radilon® D X15481 (PA610)
- Radilon® D X15482 (PA610)
- Radilon® CD X15220 (PA610/66)
- Radilon® CD X15221 (PA610/66)



Applications in the Automotive Sector

Fuel connectors

Key requirements

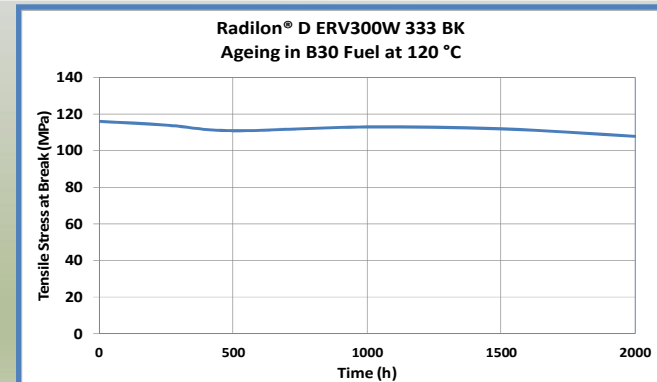
- *Strict dimensional tolerances*
- *Low dimensional change after moisture absorption and contact with fuels*
- *Excellent impact resistance at low temperature*
- *Resistance to fuels after prolonged contact*
- *Resistance to zinc-chloride and calcium chloride*
- *Resistance to heat ageing*



Material

PA610, GF30, Impact modified, heat stabilized for injection molding

Radilon® D ERV300W 333 BK



PA 6.10 – Case History

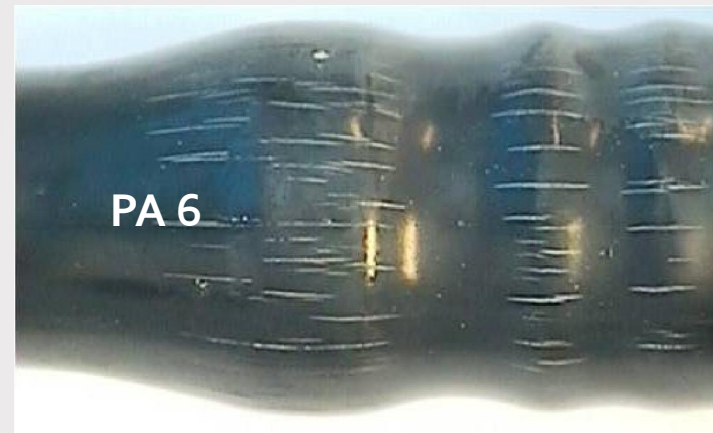
Radilon® D PA6.10 Key Features: Chemical Resistance



- *Two special grades that pass the most severe zinc-chloride test :*

Radilon® D E35ZW (flexible) (dilution of amide groups + stress relief)

Radilon® D E50ZW (semi-flexible)



* PA6.10 Radilon® D E35ZW and Radilon® D E50ZW special grades : no damages after immersion in zinc-chloride/water 50/50 solution for 200 h. Right side picture shows a typical stress cracking damage on high stressed fastening area



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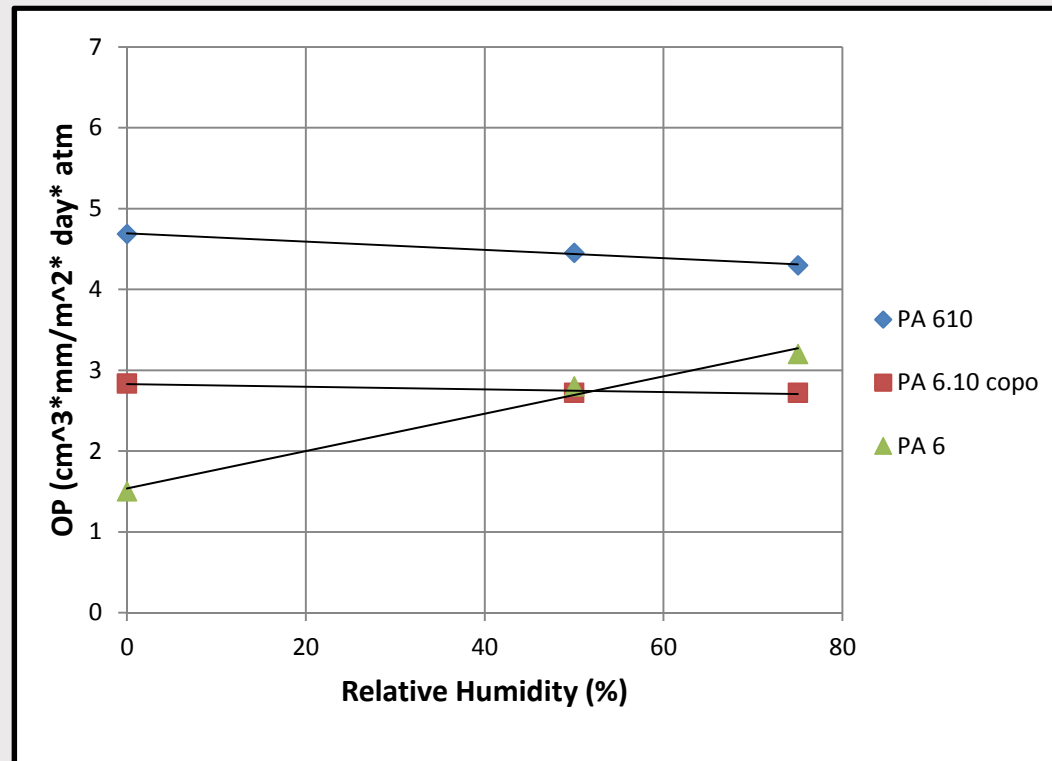
Long chain biopolyamides (homopolymers and copolymers) to produce film for FP

- **Main Potential Benefits**
 - Carbon footprint reduction
 - Easy to process (cast and blow)
 - Good transparency and gloss
 - Good barrier to gas and vapour
 - Good flexibility and toughness
 - High puncture resistance



- ***Effect of relative humidity on the permability coefficient of PA 6.10, PA 6.10 copo and PA 6**

- The coefficient of oxygen permability is robust vs the relative humidty of the long chain PA grades. There is even a slight tendency to decrease as the relative humidity increases
- PA 6 starts from a high barrier to Oxygen, but the permeability increases significantly as the relative humidity increases



*Courtesy of Politecnico di Torino
(A. Frache/A. Sattin)

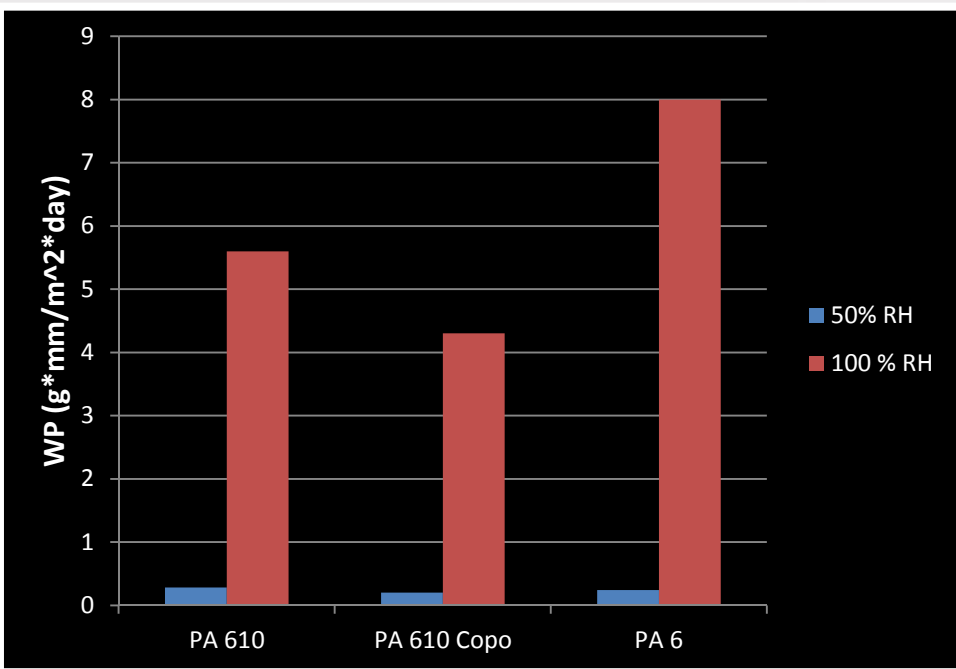


- ***Effect of relative humidity on the permability coefficient to water vapour of PA 6.10, PA 6.10 copo and PA 6**

At 50% relative humidity, PA 6.10 copo shows the highest barrier properties

At 100 % relative humidity the loss of barrier properties of long chain PA is limited compared to PA6

PA 6.10 copo outperforms in all conditions



*Courtesy of Politecnico di Torino
(A. Frache/A. Sattin)



Transparency*

PA 6



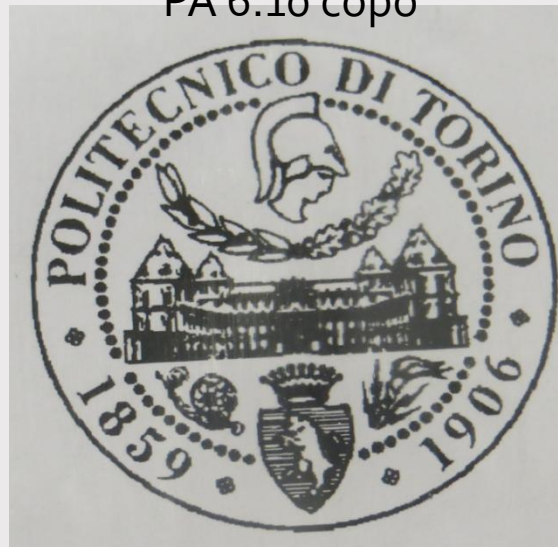
reference



PA 6.10



PA 6.10 copo

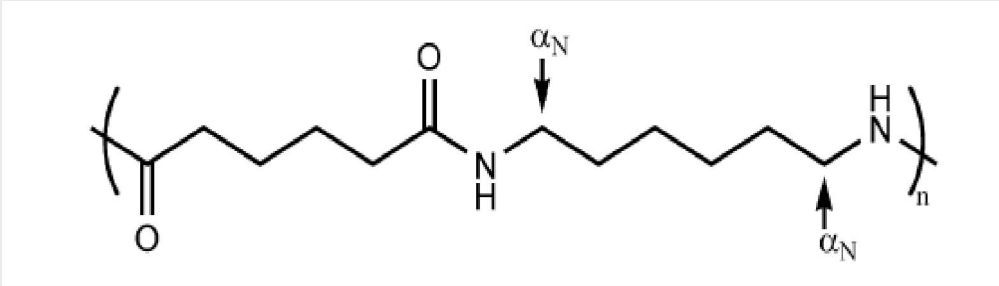


*Courtesy of Politecnico di Torino
(A. Frache/A. Sattin)

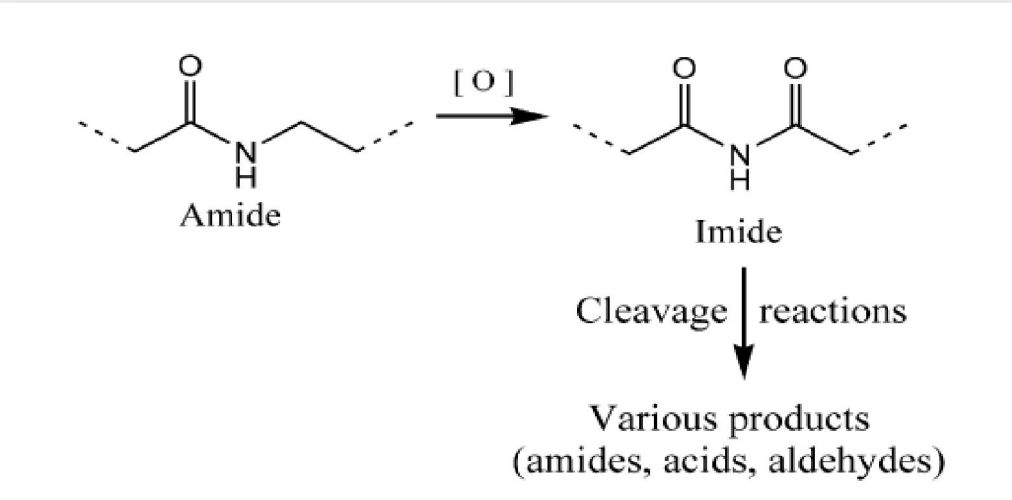
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Polyamides – Degradation mechanism in hot water*



Molecular structure of PA6.6
The methylene carbon adjacent to amide N-H is easy to be oxidated



Mechanisms of degradation of polyamides exposed to hot water that lowers mechanical performances

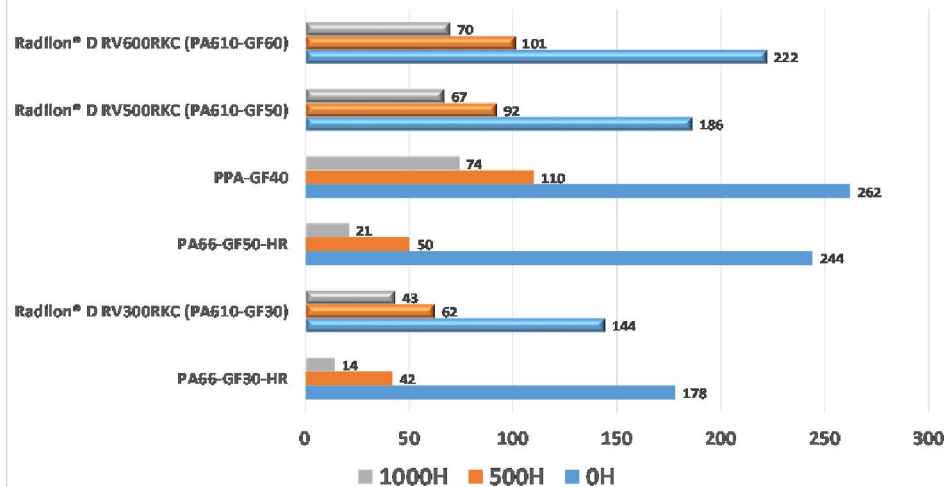
...A dilution of the methylene carbon adjacent to amide N-H results in limiting the loss of mechanical properties

*
E.S. Gonçalves et al. / Polymer Degradation and Stability 92 (2007) 1977–1985

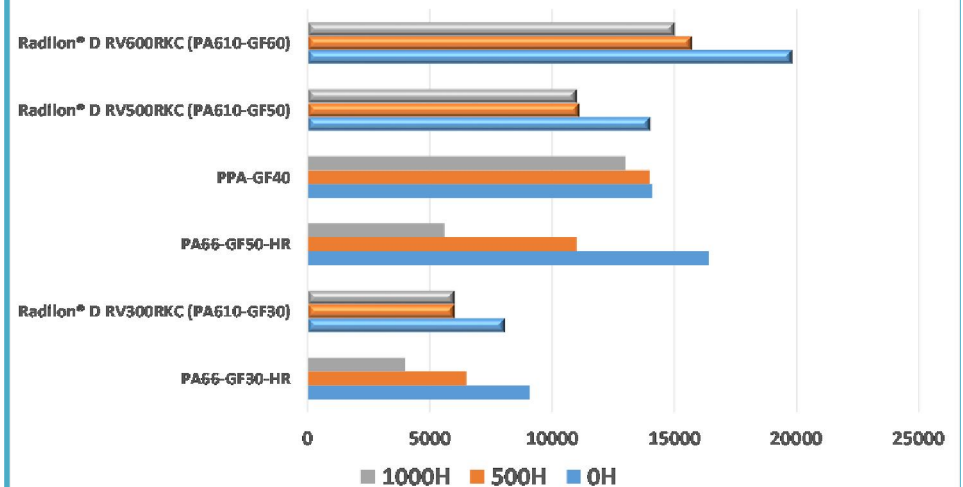


Hydrolysis behavior of materials designed for Water Management Sector

Hydrolysis at 120°C in demineralized water :
Tensile Strength (MPa) after 0, 500, 1000 h



Hydrolysis at 120°C in demineralized water :
Tensile Modulus (MPa) after 0, 500, 1000 h



Tensile Strength

Excellent tensile strength retention of glass filled PA610 after hydrolysis test up to 1000h. The TS final value similar to that of PPA-GF40. Clearly superior in comparison with HR PA66-GF

Tensile Modulus

Very good retention versus HR PA66-GF. Comparable to PPA-GF40

Applications in the Water Management Sector

Key requirements

- Hydrolysis resistance (cold, warm, hot water)
- Creep resistance
- Excellent mechanical properties
- Duration (up to 50 years warranty in some cases)
- Regulatory approvals



Water meter component
(Radilon® D RV600RKC)

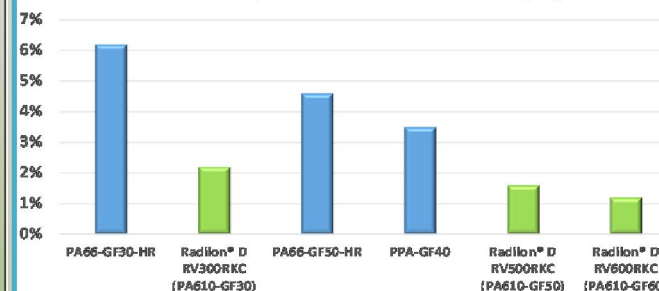
Materials

- Radilon® D RV300RKC – PA610-GF30
- Radilon® D RV500RKC – PA610-GF50
- Radilon® D RV600RKC – PA610-GF60
- Radilon® D HSKC – PA610 unfilled
- New Special PA612-GF30 (very low total organic content extractable for new generation electrovalve)

Typical Applications

- Water meter housing
- Water meter gear wheels
- Showers heads
- Pipes fittings
- New generation electrovalves
- Heating system thermostatic valves

Water Uptake at saturation (%)



Radilon® D polyamide 6-10

Water absorption at saturation much lower than hydrolysis resistant PA66-GF and also lower than PPA. The low level of water absorption lead to an improved dimensional stability



Thank you for your attention

