NanoXplore

Unleashing the Power of Graphene

NanoXplore GmbH

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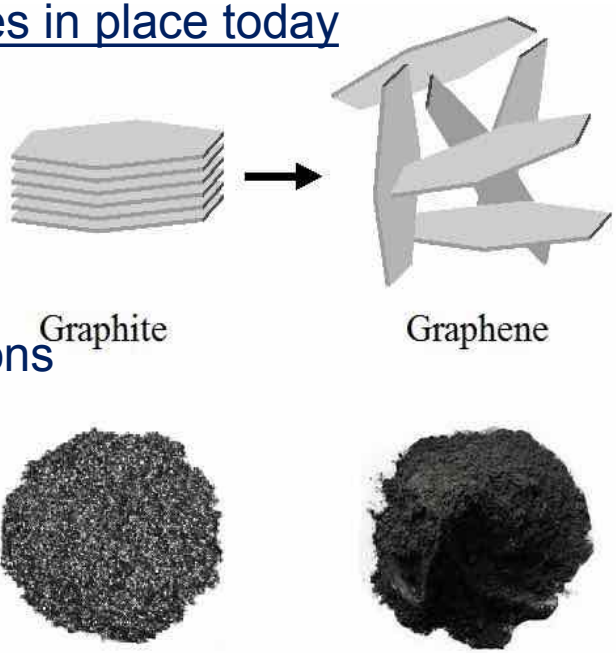
Introduction

- Few Layer Graphene (FLG) from natural flake graphite
  - Proprietary environmentally friendly exfoliation technology (4 patents)
  - 60 tonnes/year production capacity → 18 tonnes in place today
- heXo-G graphene based solutions
  - Powder for compounders
  - Pellets for masterbatch (PE, PP, PC, PET….)
  - Compounds for energy and industrial applications
  - Injection and blow molded plastic parts
- Target Markets:
  - Graphene-enhanced pellets for
    - thermoplastics, thermosets & resins for textiles
  - Specialized compounds for Li-ion electrodes



A Brief History

Four Initial Patents:
Functional graphene, graphite-graphene composite, thin graphite

Birth:
R&D services company focused on nanomaterials

Transformation:
- Graphene production
- Graphite applications

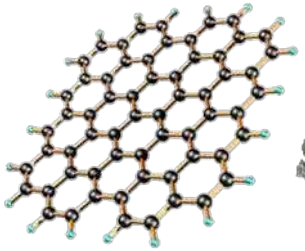
Mason Partnership:
Graphite Investment

Opening of St-Laurent
4 tonnes / year
German office & Two Carbon investment

Acquisition of RADA

Capacity expansion
18T/Year graphene

2011 2012 2013 2014 2015 2016 Today



Natural Graphite → Injection Molded Plastic

Mechanical exfoliation of natural graphite

↓

Twin-screw compounding with resin and proprietary additives

↓

Blow and injection molding

Major Graphite Producer Partners

Colorplastic
Creativity and force of innovation

NanoXplore

Production and R&D Facilities in Switzerland



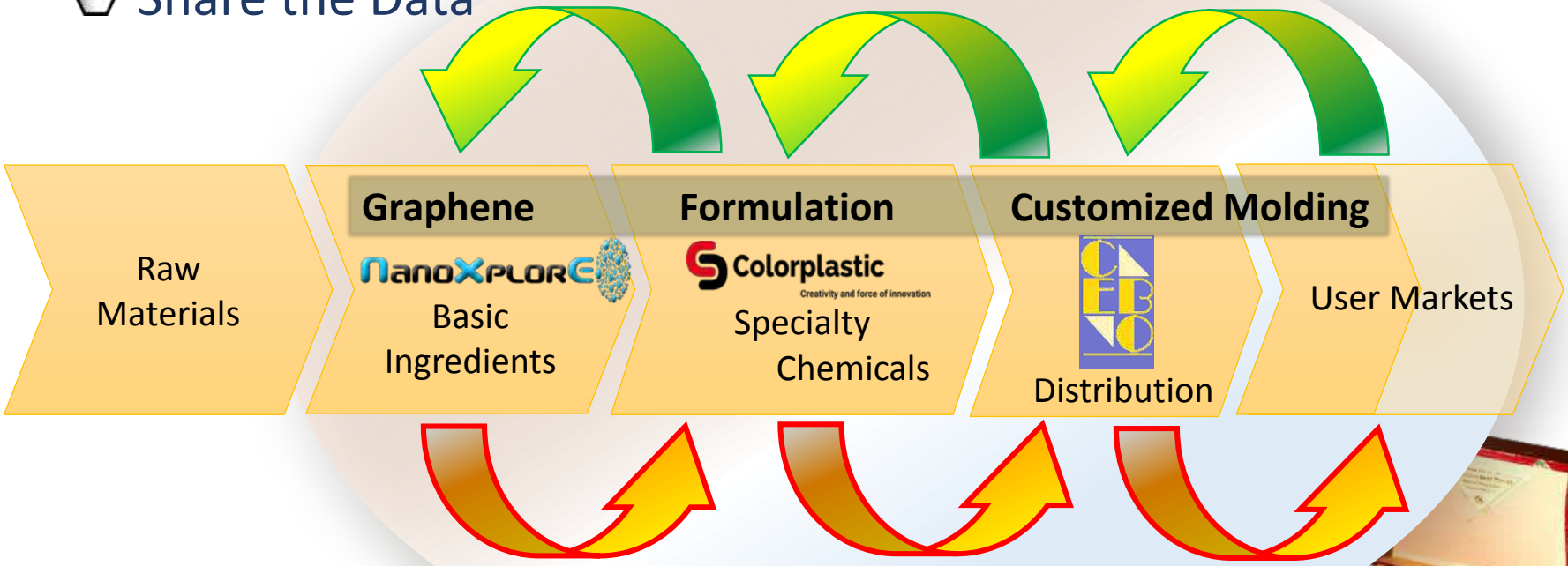

NanoXplore has established a strong partnership with Colorplastic SA here in Switzerland,

With deep and broad knowledge of additives Colorplastic and NanoXplore together produce customized compounds and master batches coverig the thermoplastic and surface technology sectors.



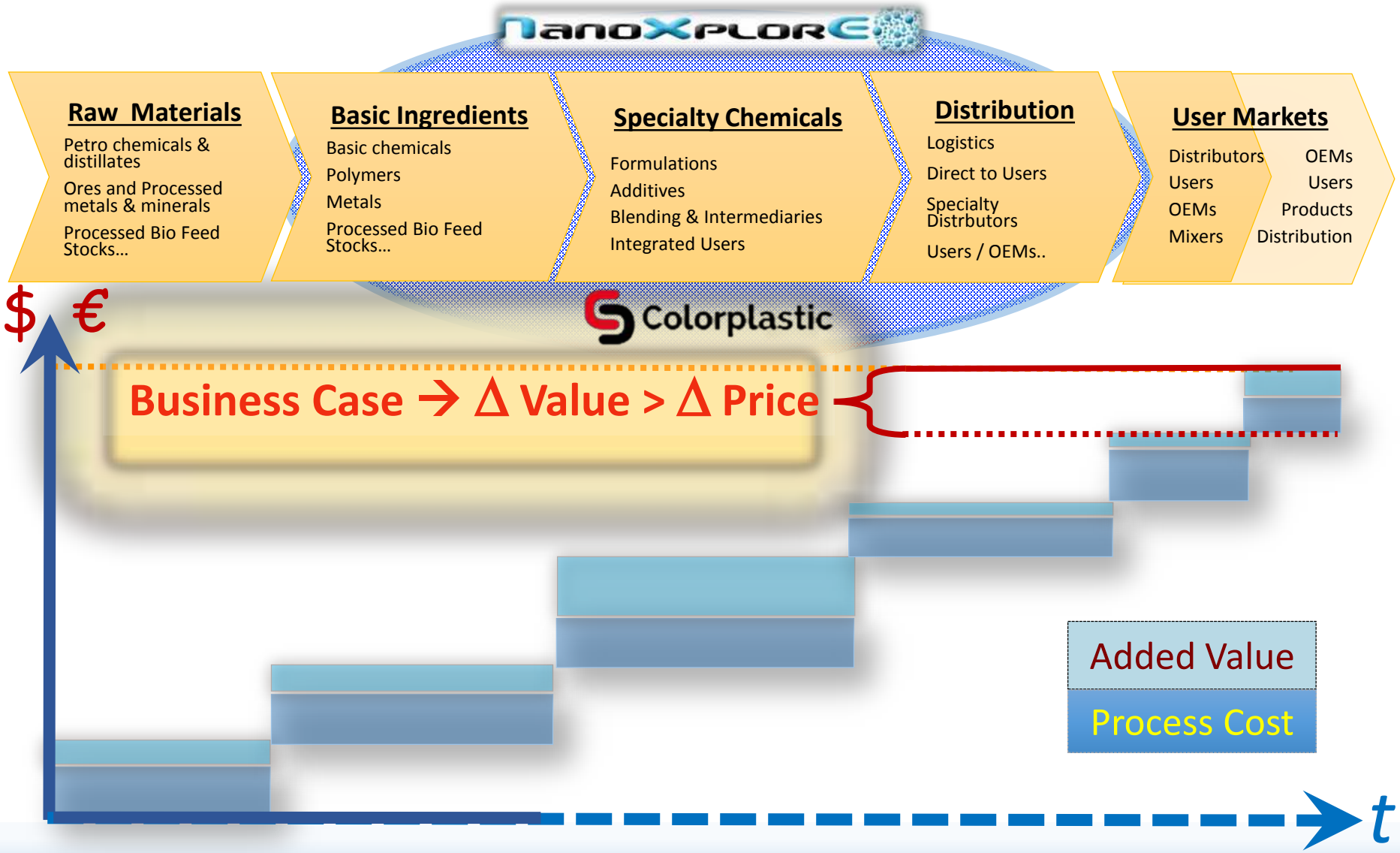
Own Formulation and Process Innovation

- Identify issues
- Propose improvements / innovations
- Share the Data



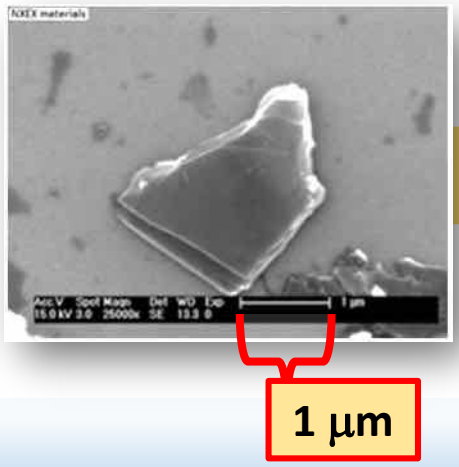
- Engineer solution(s)
- Provide improvements / changes
- Propose improvements / innovations

Capture Broader Polymer Value Chain



he-X-o G graphene → characteristics

- Water-based environmentally friendly exfoliation (4 patents)
- Low surface defects; 2-5 layers; 1 µm – 10 µm lateral
- Ease of dispersion → polymers & resins
- Industrial scalable & high quality
- Graphite flakes → Graphene / Masterbatch / Compound
- Price points → viable business case
- ”Multifunctional” enhancement of polymers



Up the Polymer Pyramid

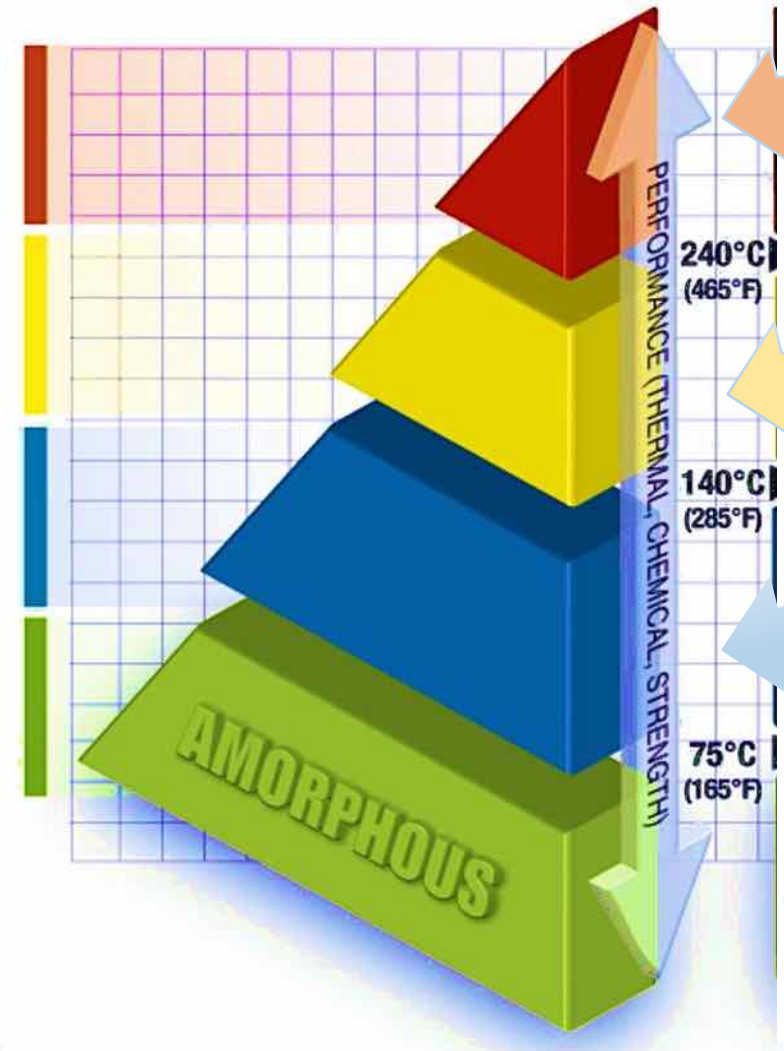
$ €

Esd 520HR
PAI

PEEK, PPSU
PE, PEI

ESd 410C
SBR, EVA, PC
PSU

ABS
PP, PLA, PS
PVG



Performance ↑↑
Cost ≈

Value ↑
Cost ⇔ =

Value ⇔ =
Cost ↓

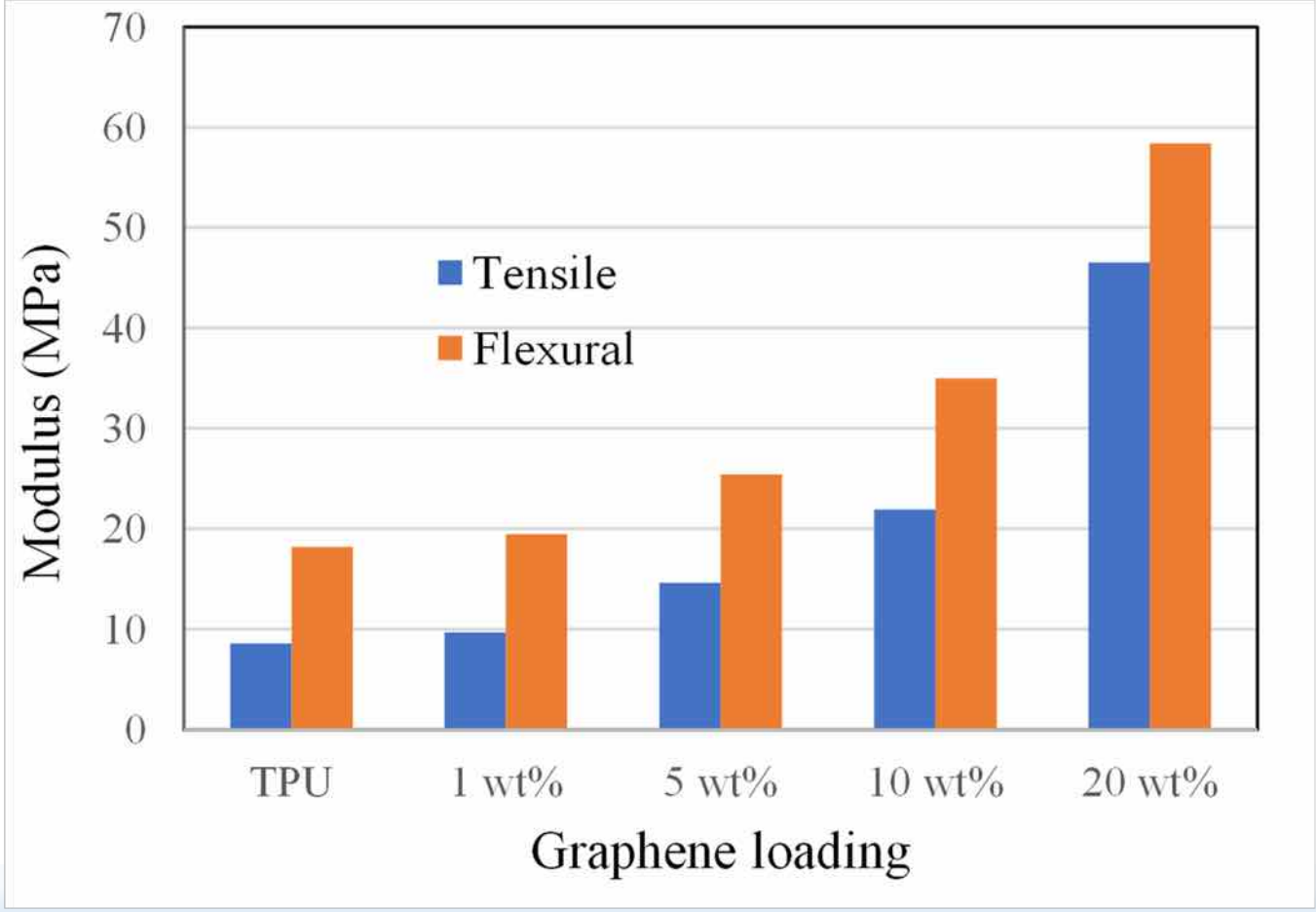
Multiple Enhancements

Polymer performance enhancement examples

Material	Impact	heXo-G wt%
LLDPE	**+10%** in yield strength	2%
HDPE	**+14%** in yield strength	0.5%
PE	Conductivity 10^{-6} S/m	10-12%
PA 6-6 (nylon)	**+10%** in tensile strength	1%
Silicone-rubber	**+10%** in abrasion resistance	0.1%
ABS	**4X** thermal conductivity	0.2%
UHMWPE	**+40%** in fracture toughness	0.5%
HDPE	**+22%** in oxygen barrier	1%

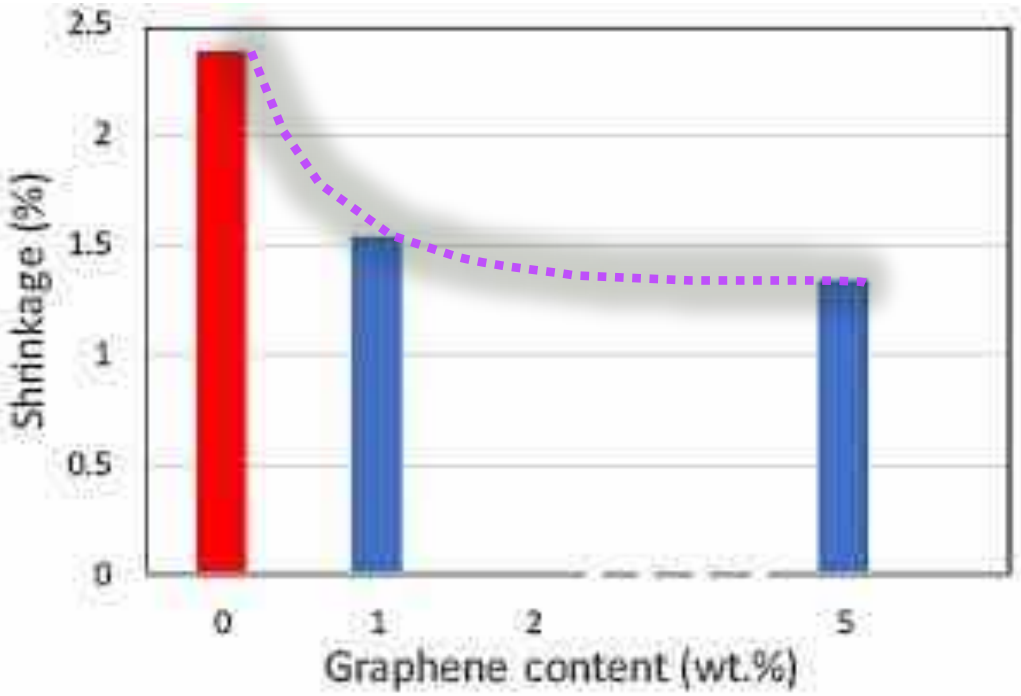
Graphene-enhanced TPU

- Tensile Modulus
- Flexural Modulus



Dimensional Stability

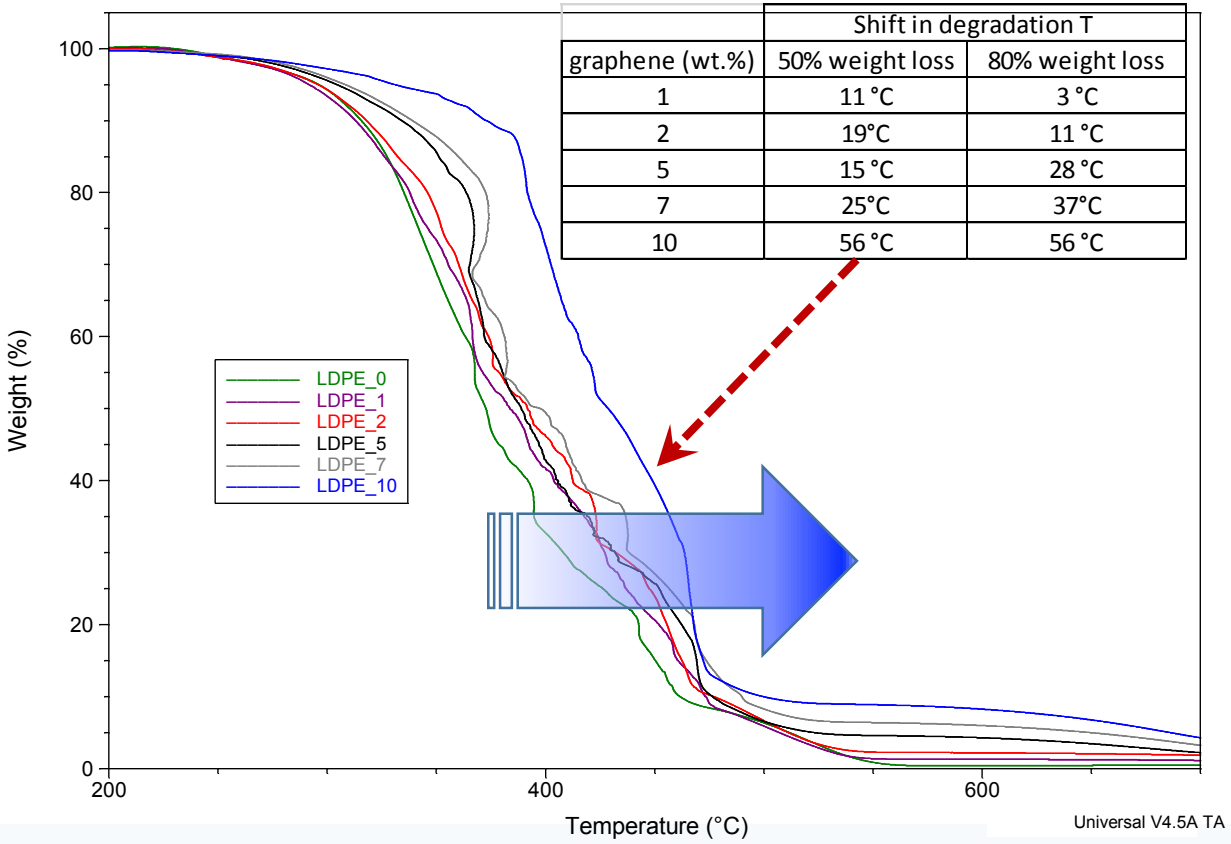
- Graphene reduces shrinkage and increases dimensional stability of LDPE.
- 1 wt.% he-X-o G 4 reduces shrinkage by 35% vs raw LDPE
- 5 wt.% he-X-o G 4 reduces shrinkage by 44% vs raw LDPE



Graphene increases operating temperature

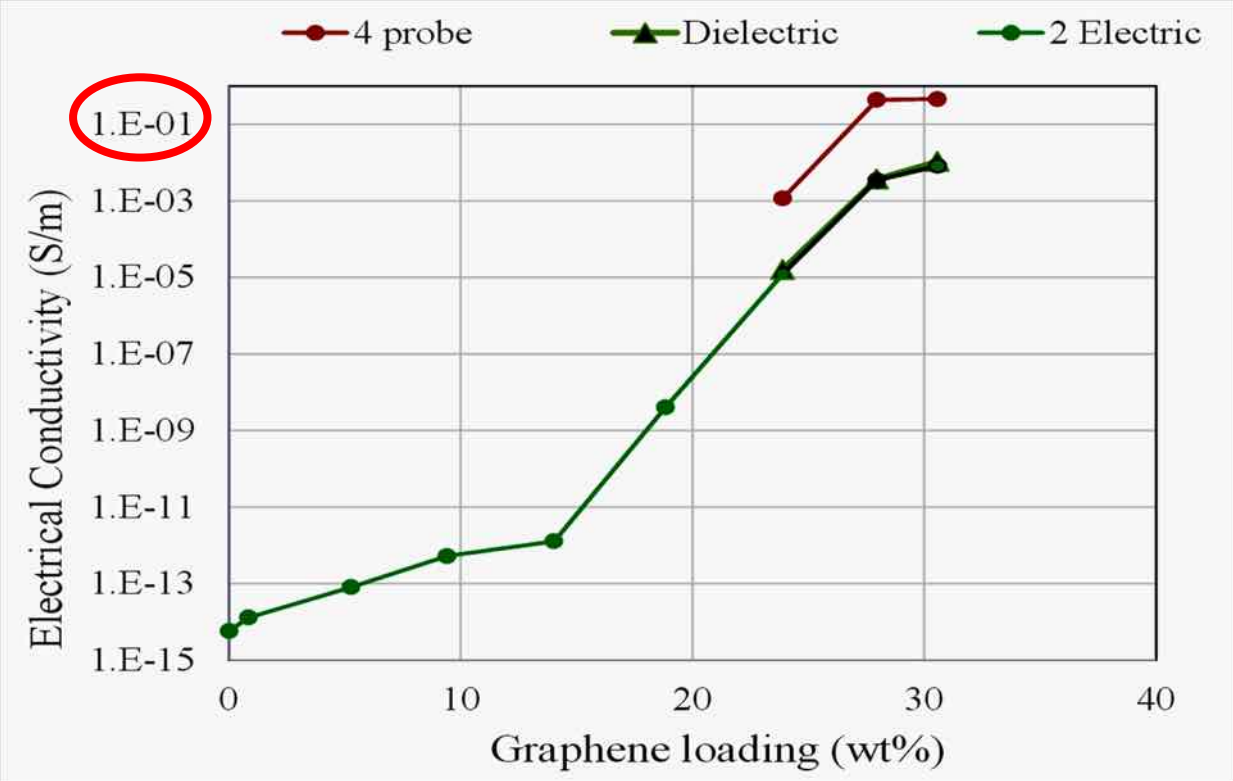
- Increases polymer thermal stability in LDPE (using heXo-G V20)
- Increased degradation temperatures
- Improvement of 56°C at 10 wt.% graphene (TGA curve shift)

	Shift in degradation T	
graphene (wt.%)	50% weight loss	80% weight loss
1	11 °C	3 °C
2	19°C	11 °C
5	15 °C	28 °C
7	25°C	37°C
10	56 °C	56 °C



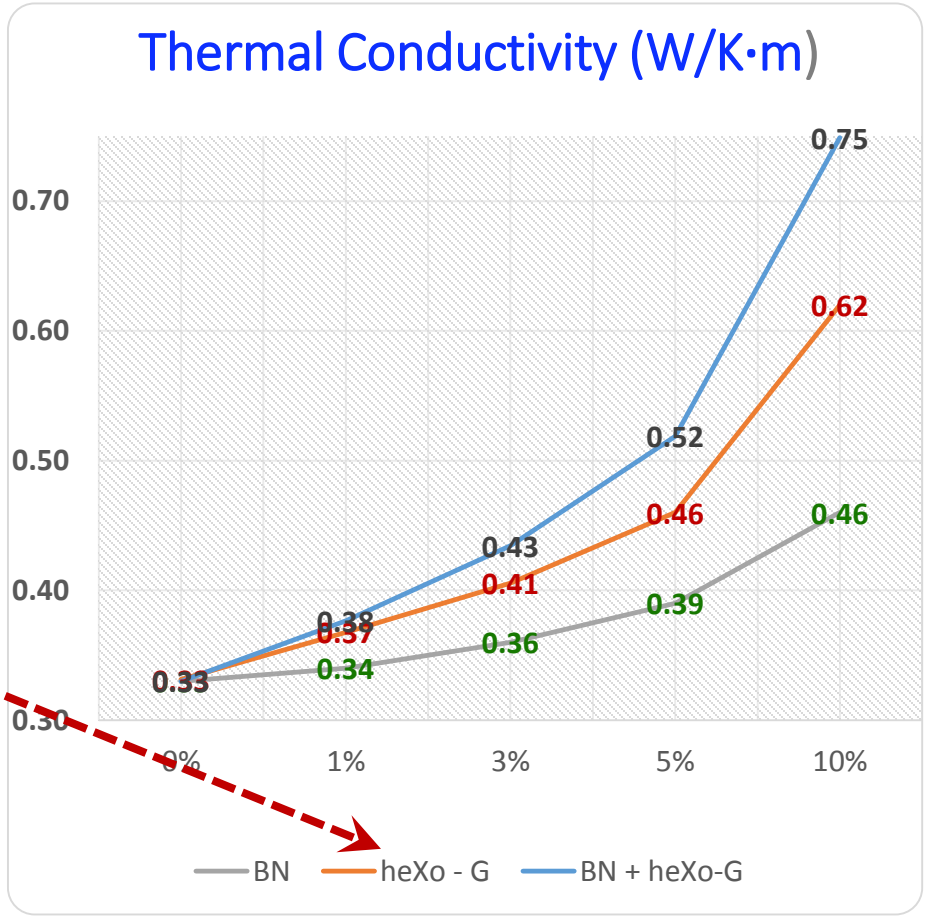
Electrical Properties of graphene - HDPE

- Graphene he-X-o G disperses anisotropic in HDPE
- HDPE 1 wt.% graphene composite conductivity = vacuum dielectric
- HDPE 15 wt.% percolation threshold conductivity increases with graphene loading
- HDPE at 30 wt.% loading increases electrical conductivity $x10^{14}$



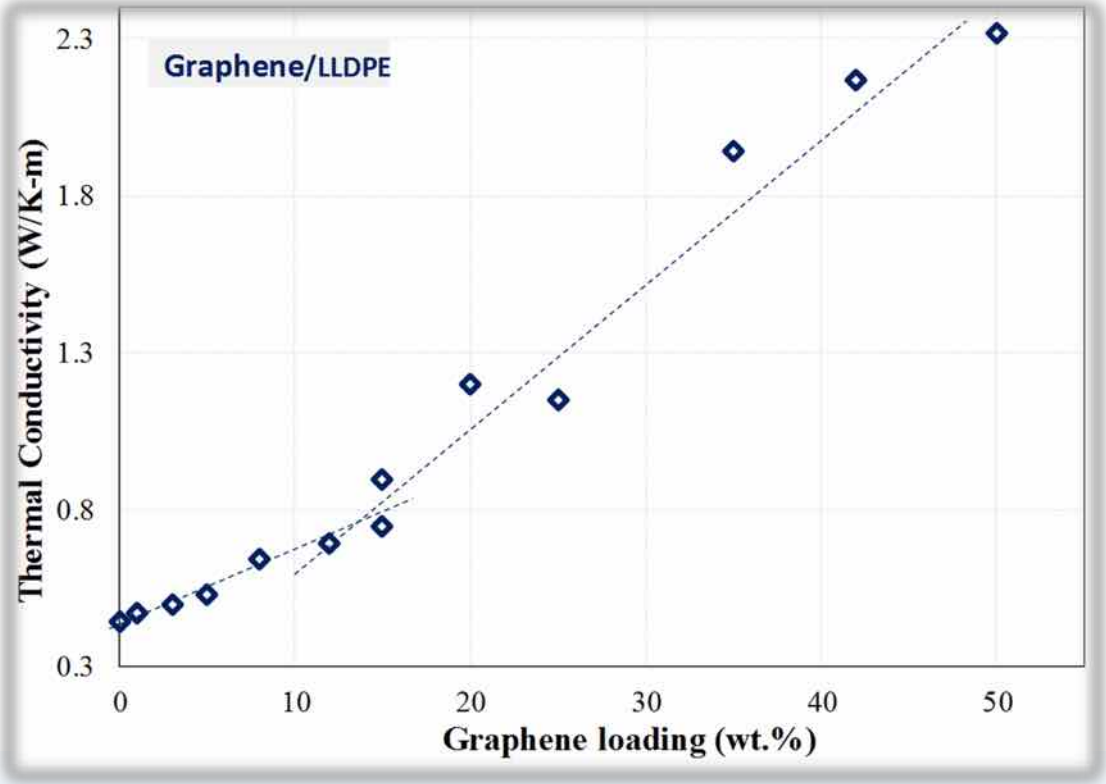
Thermal conductivity vs additive loading in epoxy resin

- Weight and cost reduction in transportation & aerospace
- Thermally conductivity polymers enabling electronics deployment
- No degradation → boron nitride (BN), aluminum nitride (ALN)… need high wt% concentrations but degrade mechanical properties
- heXo-G graphene provides higher thermal conductivity
  - Can complement and/or reduce the amount of additives used



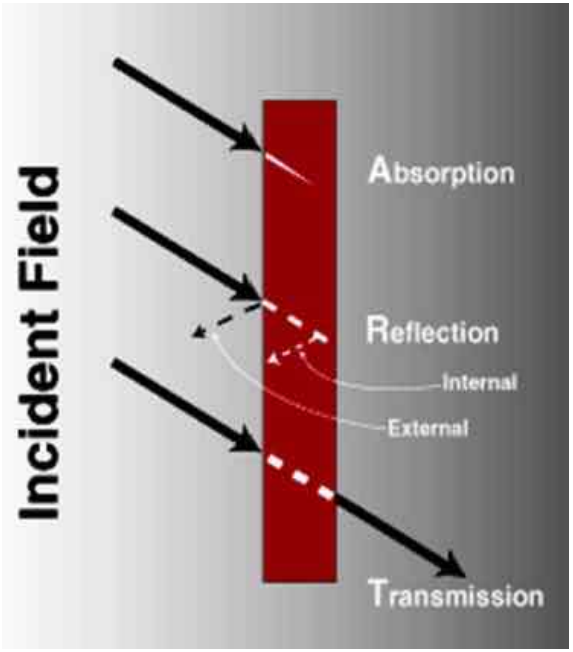
Thermal properties of graphene of LLDPE

- Measured out-of-plane thermal conductivity
- Initial slope is 0.02 W/K·m·% graphene he-X-o G V20
- Steeper slope of 0.04 W/K·m·% beyond 12% percolation threshold
- Thermal conductivity of 2.32 W/K·m reached for 50 wt.% graphene (**factor of 10x**)



EMI shielding example

- Metal-base coatings provide high conductivity, but are heavy, impacted by corrosion and compley to manufacture
- Polymer composites with heXo-G V20 demonstrate >40dB X-Band
- High shielding effectiveness (>99% reduction for 8-12 GHz)
  - Lightweight and corrosion resistant
  - Static and UV protection
  - Increases strength + minimizes elongation



$SE\ (dB) = SE_A\ (dB) + SE_R\ (dB)$

TPU/CB (10 wt%)	TPU/CNT (10 wt%)	HDPE/CB (20 wt%)	TPU/heXo-G (10 wt%)	TPU/heXo-G (20 wt%)
12.2 dB*[1]	21.8 dB*[1]	16 dB*[2]	**29.6 dB**	**40.0 dB**

References
*[1]: Ramoa & al. Polymlnt 2013;62:1477-1484
*[2]: Dinesh & al. ICEBEA'2012, Jan.7-8 2012, Dubai

He-X-o G in geothermal piping

- PE-100 base polymer
- Disperse graphene he-X-o G V4 @ 1 wt% loading
- Use grade he-X-o G V20 @ 8 wt% loading
- Doubles thermal conductivity (0.8 W/m·K)
- Increases tensile strength by 30% with minimal elongation compromise
- Retains high impact resistance and improve the flexural modulus

Other Applications

- Stronger + thermally conductive 3D printing materials
- Plastics with EMI shielding properties
- Antistatic and impermeable packaging
- Thermally conductive polymers / epoxies
- Tougher, abrasion resistant and hydrophobic yarns/textiles/rubbers
- Corrosion resistant paints / coatings
- Higher capacity battery electrodes / fuel cells



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BCR Plastics SA

Two grades of graphene powder

Properties	heXo-G V4	heXo-G V20	
Average thickness	4-6	20	nm
Average flake size	3	50	µm
Bulk density	0.13	0.24	g/cm^3

Content

Carbon Content	> 93	> 92	wt.%
Oxygen contact	< 4	< 5	wt.%

Application & Benefits

Electrical Conductivity	**	***
Thermal Conductivity	***	***
Liquid dispersion	***	*
Mechanical strengthening	**	**
Moisture and oxygen barrier	***	**
Typical Applications	Coatings, antistatic and EMI shielding, sensors, thermal interface materials, UV resistance	Conductive/ESD composites, thermal conductvity, material strengthening, battery electrodes