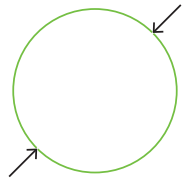# TUBALL™

graphene nanotubes

Wall thinckess

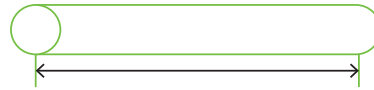# 1 atom

Specific surface area of 1 g

$\geq 300 \text{ m}^2$

Range of outer diameters

1.6±0.4 nm

Length ≥ 5 μm

Thermal conductivity compared with diamond
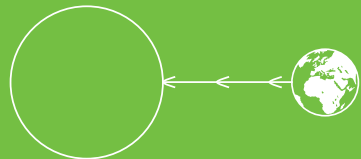
3 times more

G/D ratio

>90

Amount pcs in 1 g

10^{17}

1 gram of TUBALL™ nanotubes contains enough to stretch from the earth to the sun and back

GRAPHENE NANOTUBES

Human existence is shaped by the materials we use. More than 50% of all basic materials can be improved by introducing a universal additive – graphene nanotubes. These tiny tubes provide us with a rare opportunity to create nanoaugmented materials that have extraordinary properties.

Graphene nanotubes (GNTs) can be described as a one-atom-thick graphene sheet rolled in a tube more than 5 μm length. This material is also commonly called single wall carbon nanotubes (SWCNTs).

UNIQUE PROPERTIES OF GNTs

With these unique properties of graphene nanotubes, many characteristics of materials are improved.
The pre-eminence of these nanotubes is related to their exceptional properties, such as superior conductivity, high temperature resistance, ultralow weight, record strength and high flexibility.

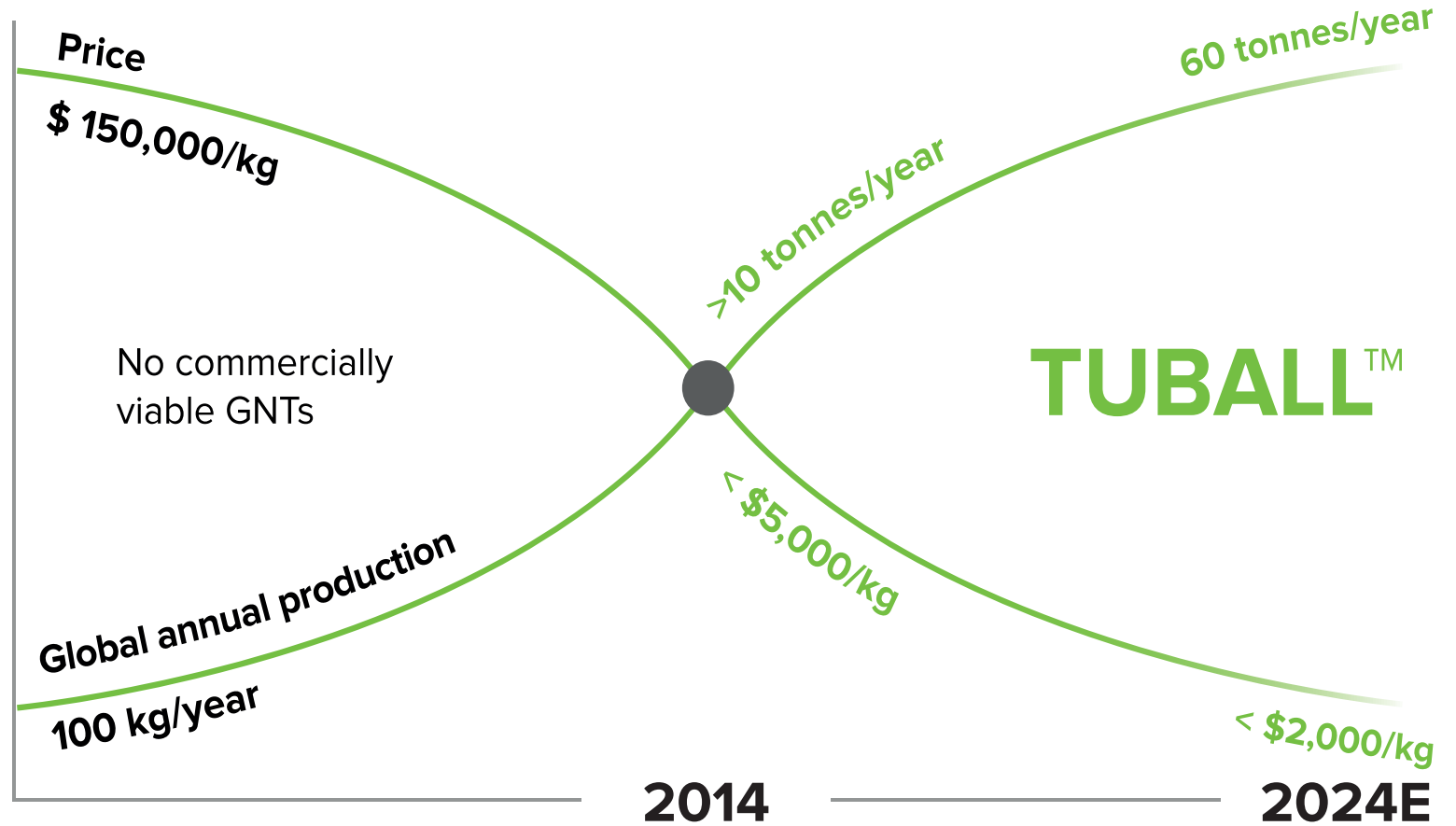| Excellent conductor	Stronger than steel	Thermal stability	Length to diameter ratio
and 5 times lighter than copper	**up to 100 times**	**up to 1,600°C in a vacuum**	**about 3,000 times**

GNTs — THE FIRST UNIVERSAL ADDITIVE FOR MATERIALS

Owing to their extraordinary electrical conductivity and their mechanical properties and thermal stability, GNTs find applications as additives in an extremely wide range of structural materials.

Electrochemical power sources	Rubber materials	Adhesives
Plastics	Copper	Paints
Composites	Concrete	Ceramics
Glass	Aluminium	Sensors

WHY GNTs LEFT UNUSED BY CIVILIZATION BEFORE?

In 2014 GNTs became available to the mass industry

Price

$ 150,000/kg

No commercially viable GNTs

Global annual production

100 kg/year

>10 tonnes/year

60 tonnes/year

< $5,000/kg

< $2,000/kg

TUBALL™

2014

2024E
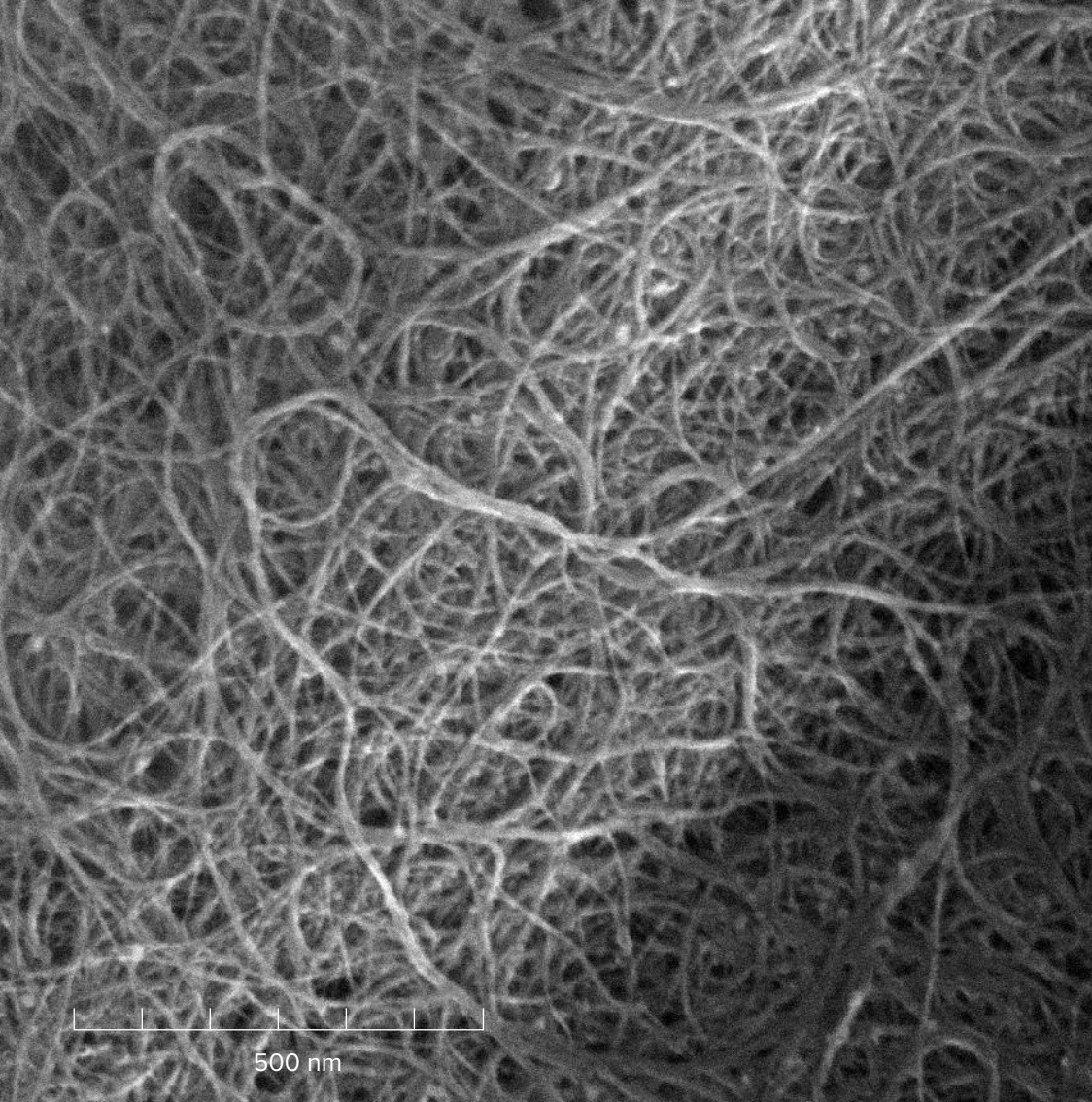
TUBALL™ is the brand name of single wall carbon nanotubes, or graphene nanotubes, produced by OCSiAl

6

7

FIRST MASS-PRODUCED GNTs

500 nm

TUBALL™

While the huge potential of GNTs has been recognised for many years, until recently their wide application in industry was not possible because of the absence of technology for their mass production, their high price and the lack of methods for introducing them into materials.

TUBALL™ nanotubes are the first GNTs to be available for commercial applications in a wide range of industries. OCSiAl's breakthrough is low-cost mass-production technology has made the widespread use of nanotubes economically viable while still preserving their high quality.

FEATURES

• High-quality nanotubes (G/D ratio > 90)
• Gains traction starting from ultralow concentrations
• Adds uniform, permanent and stable electrical conductivity
• Enhances mechanical properties
• Maintains color, elasticity, durability and other key properties of improved materials
• Versatile for an extremely wide range of applications

TECHNICAL INFO

	UNIT OF MEASURE	VALUE	METHOD OF EVALUATION
CNT content	wt.%	≥ 80	OCSiAl internal method: ash residue
Number of layers CNT	unit	1	TEM
Outer mean diameter CNT	nm	1.6 ± 0.4	Optical absorption: ISO/TS 10868:2017 (E)
Length of CNT	µm	> 5	AFM
Metal impurities	wt.%	≤ 15	OCSiAl internal method: ICP-AES
Moisture	wt.%	< 5	OCSiAl internal method: infrared thermogravimetry

RAMAN SPECTRUM

TGA CURVES

10 nm

200 nm
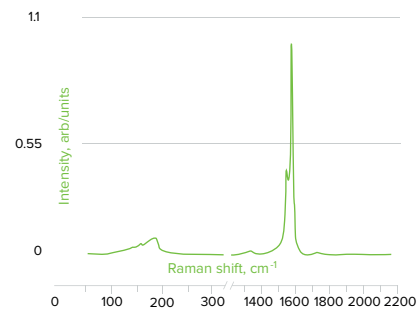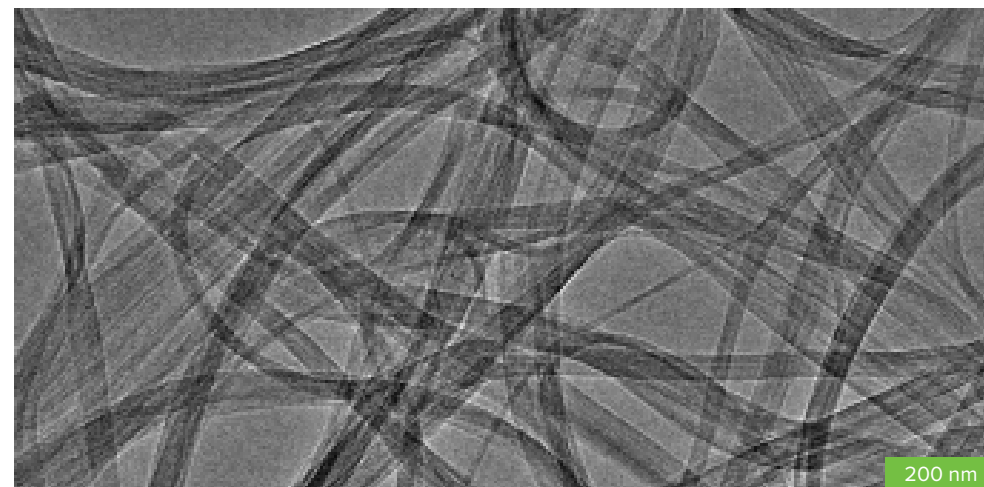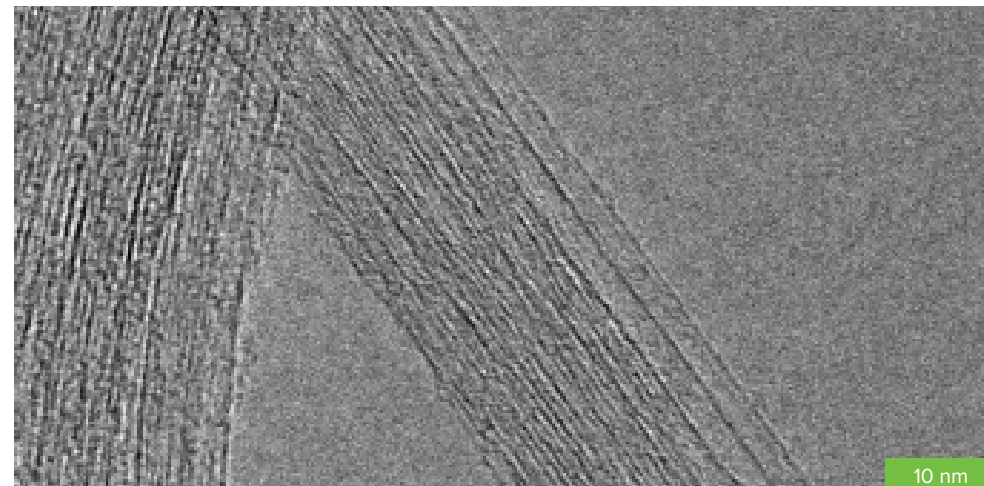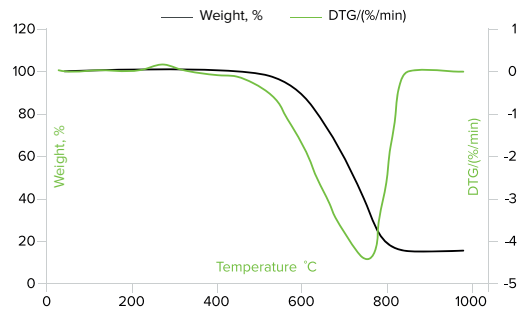
PRODUCTION

INDUSTRIAL PRODUCTION OF GNTs

OCSiAl is the first company to commercialize breakthrough technology for synthesis of high-quality graphene nanotubes at a commercially viable price.

OCSiAl launched large-scale production and delivered the first commercially viable graphene nanotubes to the market under the brand name TUBALL™.

Serbian plant will be the main EU region production hub for TUBALL™ synthesis until the launch of the plant in Luxembourg in 2027. First synthesis unit is in the process of being assembled, launch in 2024E.

The only technology to achieve all three parameters at the same time:

up to
99%
GNT

Industrial scale

High purity

Commercially viable

PLANT IN SERBIA 2024

Capacities, up to t/y

200
TUBALL™ MATRIX
2024

60
TUBALL™
2024

3,500
Suspensions
2024

120
TUBALL™
2026

Stara Pazova

PLANT IN LUXEMBOURG 2027

Up to
700 t/y
TUBALL™ capacity
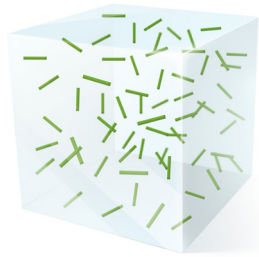
KEY APPROVALS
Received

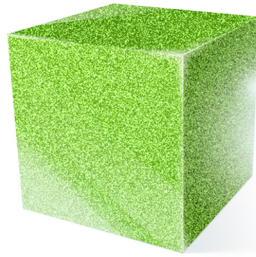Luxembourg

INDUSTRIAL APPLICATIONS

HOW IT WORKS

TUBALL™ provides significant improvements in material properties upon the addition of ultralow loadings, starting from as little as 0.01%.
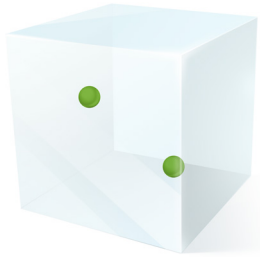
Microparticles   Nanofibers   GNTs

The same concentration of particles (~0.1%) in the same volume

Unlike conventional additives such as multi wall carbon nanotubes, carbon fibers and most types of carbon black, which all disperse unevenly throughout the material's matrix, GNTs create a uniform 3D reinforcing and conductive network.

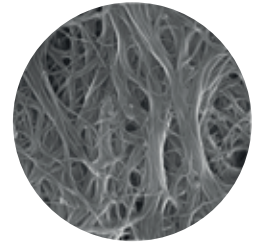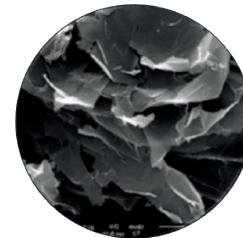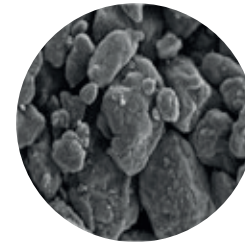## COMPARISON OF ADDITIVES THRESHOLD OF CHANGE

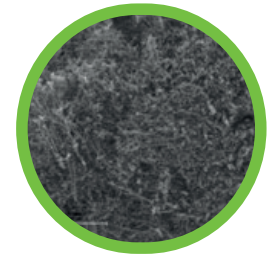CARBON BLACK
20–40%
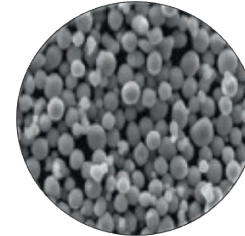
METAL FILLERS
15–35%

CARBON FIBERS
3–12%

ML GRAPHENE*
1–6%

MWCNTs
0.5–5%

**GNTs
0.01–0.1%**

* Graphene nanoplatelets, graphene oxide, reduced graphene oxide, etc.

TUBALL™ PROTOTYPING CENTER

electrochemical power sources

coatings

analysis and quality control of graphene nanotubes
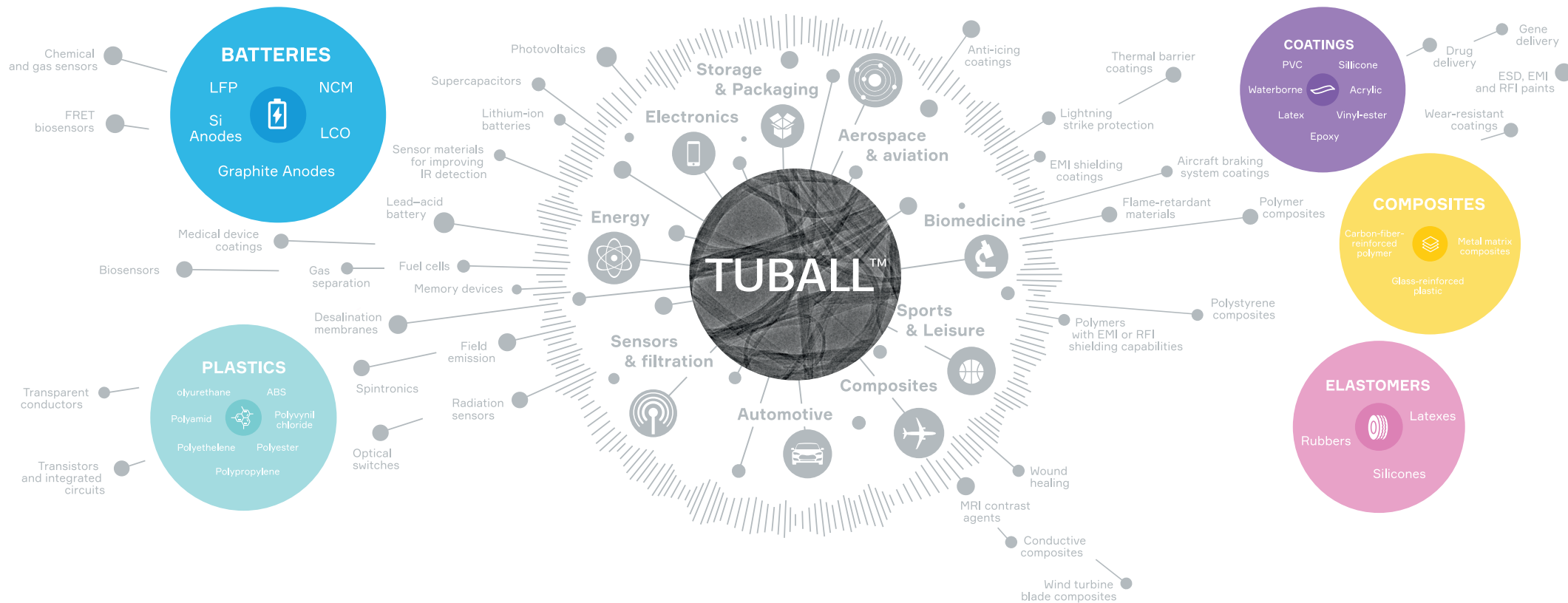
thermoplastics

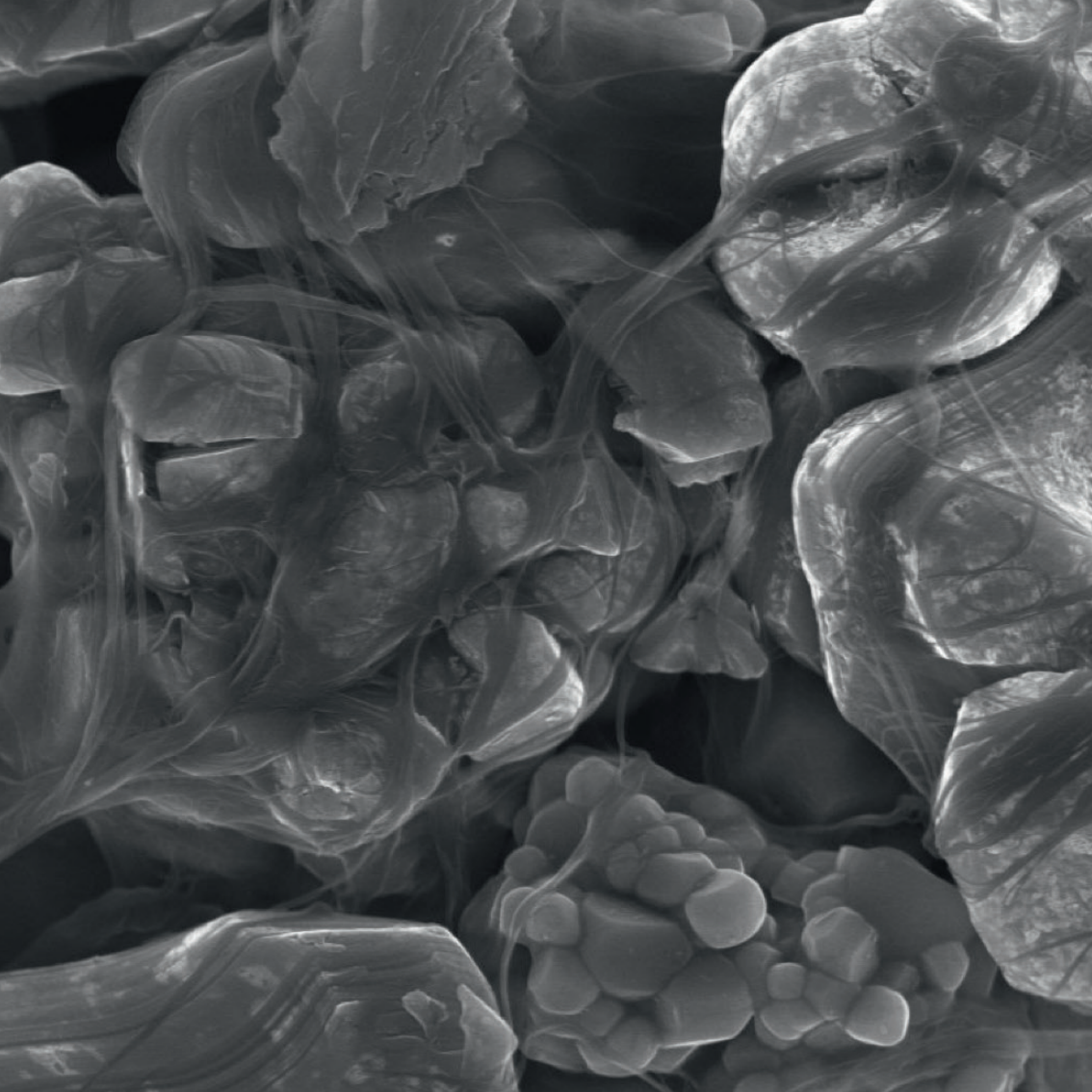elastomers

thermosets

... and others

TUBALL™ APPLICIATIONS: ONE ADDITIVE FOR THOUSANDS OF MATERIALS

TUBALL™ nanotubes can dramatically improve the properties of the majority of materials used in industry. This wonder-material is just at the beginning of its journey. OCSiAl is taking the lead in the developing of numerous dispersion technologies that allow customers to integrate TUBALL™ into their products without changes in manufacturing technology or formulation.

BATTERIES
LFP
NCM
Si Anodes
LCO
Graphite Anodes

PLASTICS
olyurethane
ABS
Polyamid
Polyvynil chloride
Polyethelene
Polyester
Polypropylene

COATINGS
PVC
Sillicone
Waterborne
Acrylic
Latex
Vinyl-ester
Epoxy

COMPOSITES
Carbon-fiber-reinforced polymer
Metal matrix composites
Glass-reinforced plastic

ELASTOMERS
Latexes
Rubbers
Silicones

Chemical and gas sensors
FRET biosensors
Medical device coatings
Biosensors
Transparent conductors
Transistors and integrated circuits

Photovoltaics
Supercapacitors
Lithium-ion batteries
Sensor materials for improving IR detection
Lead–acid battery
Gas separation
Fuel cells
Memory devices
Desalination membranes
Field emission
Spintronics
Radiation sensors
Optical switches

Storage & Packaging
Electronics
Energy
Sensors & filtration
Automotive

TUBALL™

Aerospace & aviation
Biomedicine
Sports & Leisure
Composites

Anti-icing coatings
Thermal barrier coatings
Lightning strike protection
EMI shielding coatings
Aircraft braking system coatings
Flame-retardant materials
Polymer composites
Polystyrene composites
Polymers with EMI or RFI shielding capabilities
Wound healing
MRI contrast agents
Conductive composites
Wind turbine blade composites

Gene delivery
Drug delivery
ESD, EMI and RFI paints
Wear-resistant coatings

TUBALL™
DISPERSIONS

TUBALL™ BATT

TUBALL™ BATT is a ready-to-use dispersion designed to easily incorporate TUBALL™ into electrode formulations during the battery manufacturing process.

TUBALL™ BATT provides a complete or partial substitute for carbon black in battery electrodes and can replace several percent of carbon black with 0.02–0.1% of TUBALL™.

TUBALL™ forms conductive 3D networks between active material particles at very low concentrations. The nanotubes reinforce the electrode structure and improve its mechanical stability during cycling. TUBALL™ improves adhesion by establishing strong ties between the particles, reducing the amount of binder required.

H_2O
For high-energy
Si-based anodes

NMP
For high-energy
cathodes

BENEFITS

Si	Solves the Si-anode degradation problem
	Cycle life that meets the targets of the modern EV industry
	Record high energy density achievable
	Fast-charging ability unlocked

BENEFITS

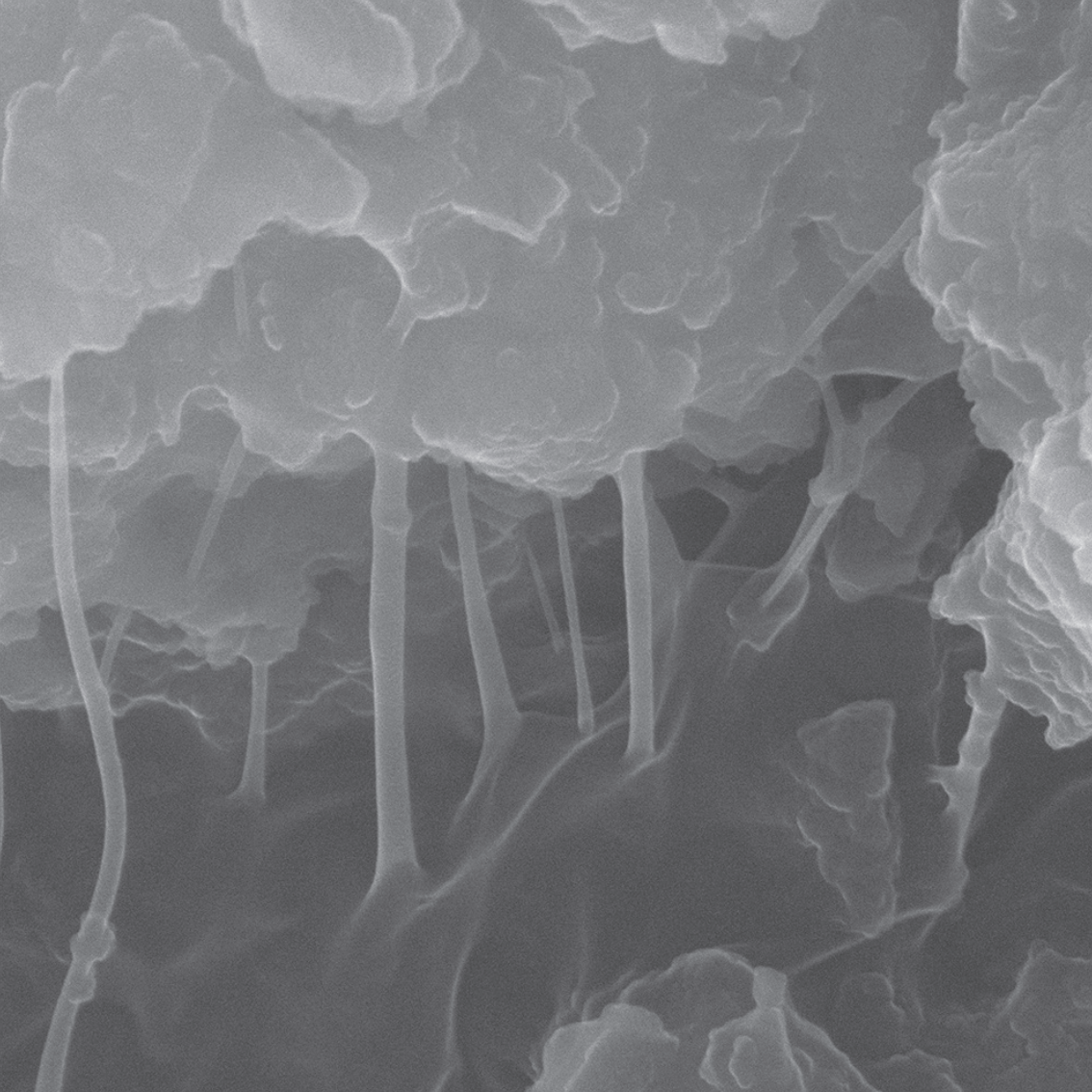|	
	Boosted energy density
	Higher discharge power
	Higher safety
	Improved adhesion

TUBALL™ LATEX

TUBALL™ LATEX is a water-based suspension for manufacturing latex gloves and latex products with anti-static properties, while retaining mechanical properties and minimally impacting the host matrix.

TUBALL™ LATEX makes it possible to attain permanent and humidity-independent conductivity that is fully compliant with the most demanding applications, including the new European standard EN 16350:2014 (EN 1149) for anti-static properties in safety wear.

BENEFITS

Standard dipping process

Retain color

Maintain or improve mechanical properties

Electrical resistivity of $< 10^8$ Ω

Material is ready to use "as produced"
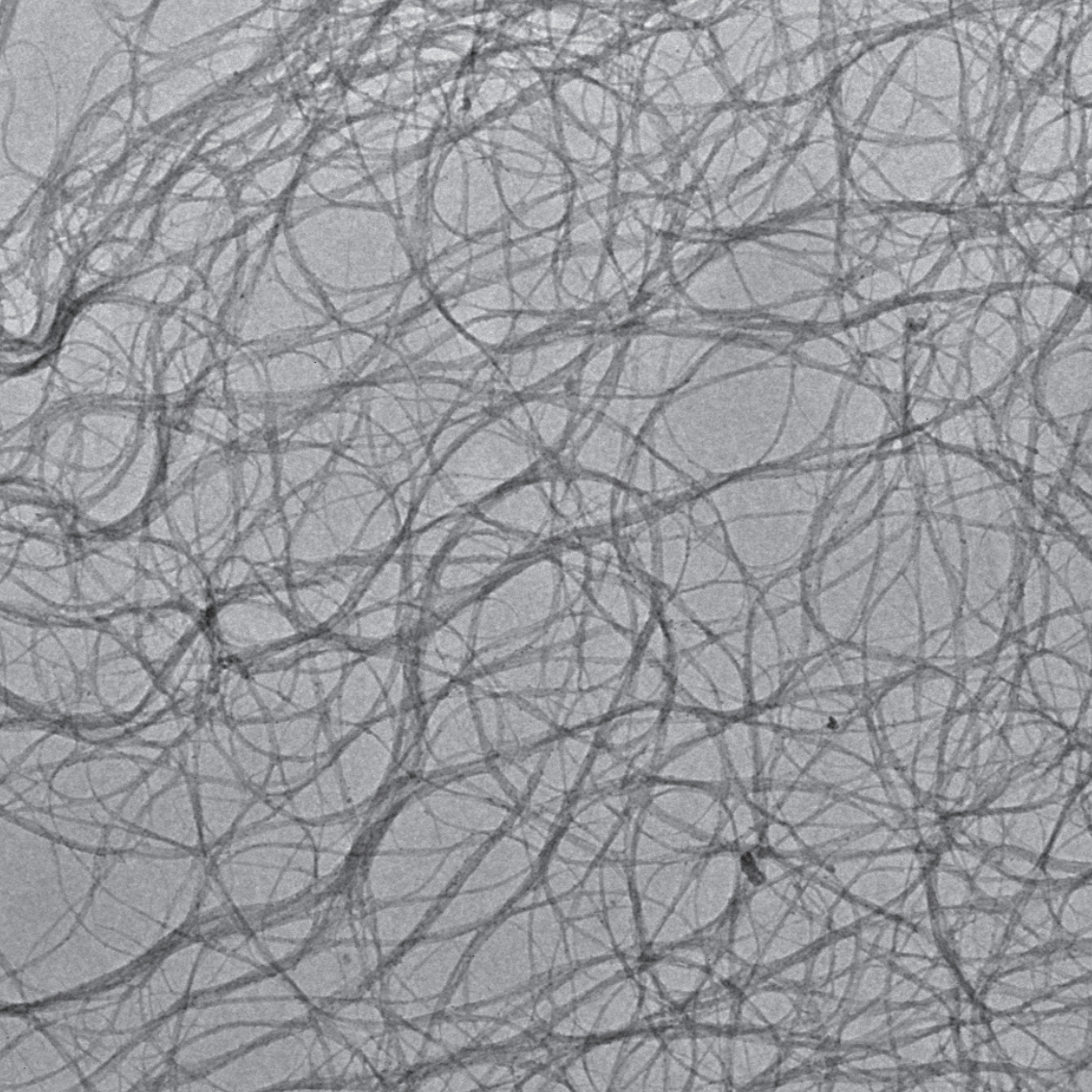
TUBALL™ COAT_E

TUBALL™ COAT_E is an easy-to-use single wall carbon nanotube suspension in water that provides permanent anti-static properties to waterborne paints and coatings with minimal impact on their color and mechanical properties.

TUBALL™ COAT_E is suitable for production of anti-static waterborne paints and coatings intended for the following applications:

• UV coating
• Packaging for electronics

BENEFITS

 Complying with strict ESD standards

 Choice of colors

 Choice of various thickness

 Permanent conductivity

 Easy-to-use

TUBALL™ MATRIX CONCENTRATES

TUBALL™ MATRIX in a polymer
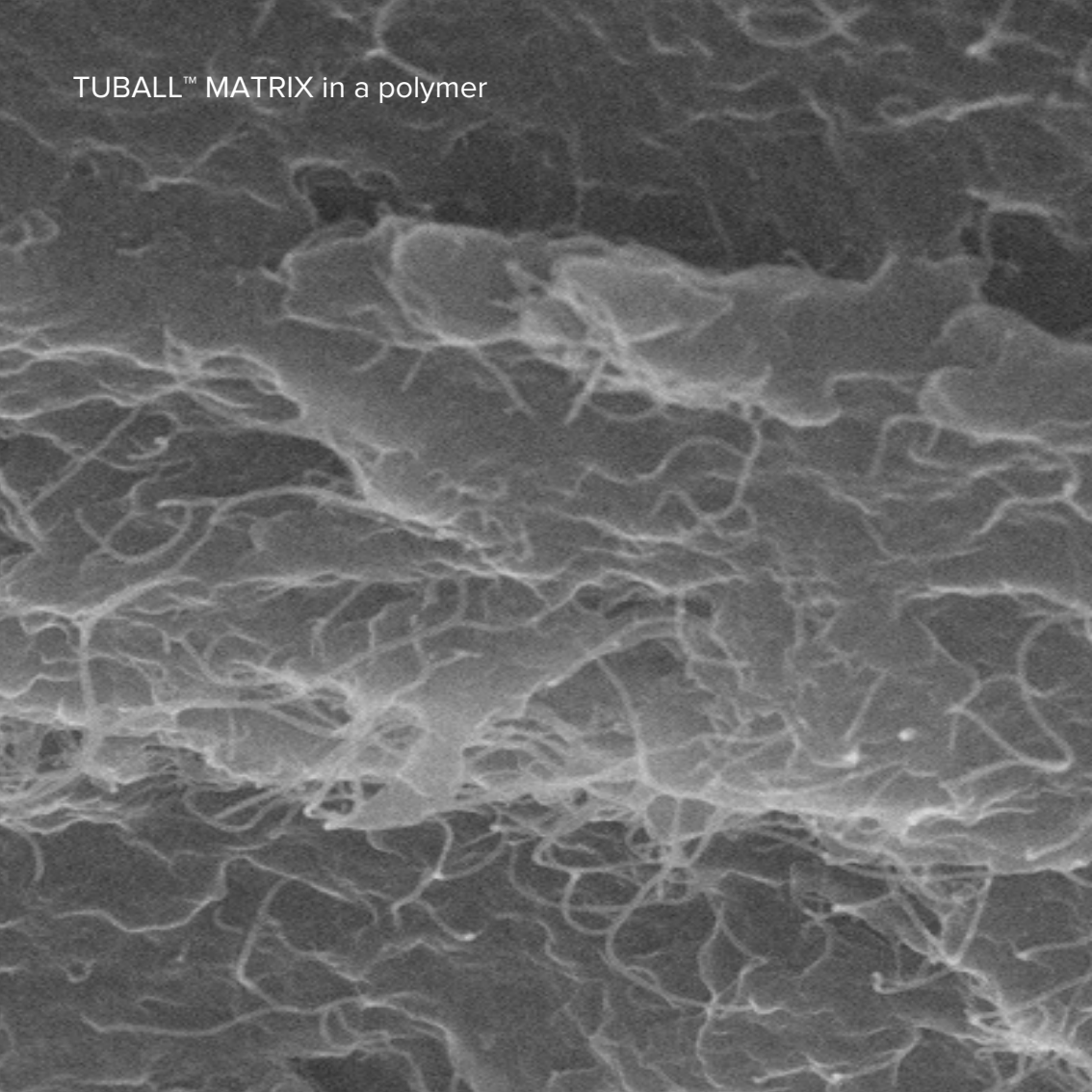
TUBALL™ MATRIX

OCSiAl has taken the lead in the creation of technologies for introducing nanotubes into material matrixes.

In 2016 OCSiAl presented TUBALL™ MATRIX – a line of graphene nanotube-based concentrates that provide materials with uniform and permanent electrical conductivity without compromising the original color or mechanical properties of the product. OCSiAl has now developed concentrates for most of the widely used industry-standard formulations.

BENEFITS

| Ultralow concentration from 0.1% | Retention of wide range of colors | Maintained or even increased mechanical strength | Permanent and uniform conductivity without "hot spots" | Minimum impact on viscosity and density |

FOR NUMEROUS INDUSTRIAL APPLICATIONS

MATRIX 201	**MATRIX 202**	**MATRIX 203**	**MATRIX 207**	
	MATRIX 208	**MATRIX 209**	**MATRIX 301**	Epoxy, polyurethane
			MATRIX 202	Phenolic
			MATRIX 204	Polyester, vinylester, acrylic, melamine
			MATRIX 302	Acrylic
MATRIX 601	**MATRIX 602**		**MATRIX 605**	LSR, RTV and HCR silicones
			MATRIX 610	Rubbers
	MATRIX 808		**MATRIX 814**	Thermoplastics

...and many more to come

CERTIFICATION AND EHS

ENVIRONMENT, HEALTH & SAFETY

OCSiAl is the first company to be authorised to start large volume commercial shipments of SWCNTs to customers in Europe, North America and other key global markets.

REACH

Registration, Evaluation, Authorisation and Restriction of Chemicals
- With the tonnage band upgrade, which is compliant with REACH Annex VIII, as of April 2020, its allowe commercialization volumes in Europe up to 100 tonnes of nanotubes annually
- TUBALL™ is registered under the number 01-2120130006-75-0000
- First and only SWCNT completed (September 2016)

EPA

Environmental Protection Agency
- Since December 2019 TUBALL™ nanotubes can be supplied and sold in the US without any limitations.
- PMN4 number P-17-0257

INDEPENDENT NANOSAFETY TESTINGS

OCSiAl invests in EHS-related research projects that are conducted by independent laboratories

For instance, VITO and INERIS, two of the leading European independent research centers, supported OCSiAl in several studies and testing programs, including incineration and combustion tests, nano ecotoxicity, and various mechanical degrading studies to investigate and measure possible aerosol release to find out whether nano- and micro-sized particles were released from the different TUBALL™-containing composite materials.

ECOTOXICITY TESTS RESULT

TUBALL™ itself has no eco-toxicity effect verified by:

- Daphina magna, Acure Immobilization eco-toxicity test according OECD 202
- Freshwater Alga Growth inhibition eco-toxicity test according OECD 201

PARTICLES RELEASE

When TUBALL™ is used as a reinforcing material in polymer composites, it no longer displays nano-particle characteristics. And even in cases where such composite material is grinded, cut, or otherwise mechanically degraded, pure TUBALL™ typically does not release, but is only release as part of highly aggregated, polymer-bound particles.
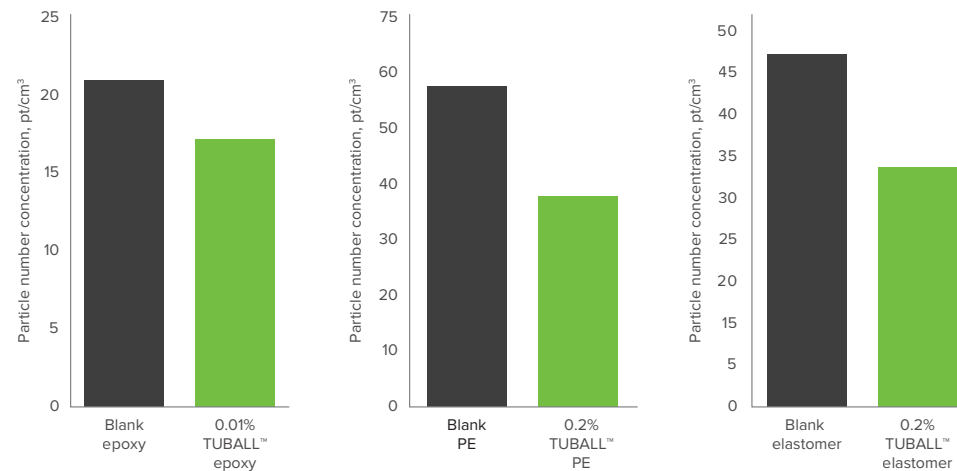
Graphics from original report from VITO

- No protruding nor free-standing TUBALL™ nanotubes were found
- As a result of the strength and cohesion improvement, nanotube-formulated materials release fewer nano-sized particles compared with the neat material

Exposure of TUBALL™ is extremely limited and not considered of posing any hazards to consumers, neither by inhalation, dermal or oral exposure.

OCSiAl ENABLES PEOPLE TO BENEFIT FROM ADVANCED TECHNOLOGIES WITHOUT DAMAGING THE PLANET

Materials – at all stages of their life cycle from extraction to recovery – contribute to one of the largest inputs of greenhouse gas emissions. And the production of materials to meet the needs of the increasing population will double in the next 40 years.

Additionally, materials and products are often used only partially to their full potential. Useful load of:

<40%

office building

15-30%

aircraft

20%

passenger car

To reduce global materials consumption, we need to make materials efficient, stronger and more durable.

Graphene nanotubes can improve the properties of most materials exi As a result, less materials can be used to achieve the same result. Enha demonstrate higher energy efficiency and longer cycle life, decreasin new products and thus the CO_2 emissions from their manufacturing.

GHG EMISSIONS REDUCTION

Graphene nanotubes have a significant impact on reducing the carbon footprint thanks to two effects:

strengthening and increasing the durability of material and, as a result, reducing the need for the production of new materials.

increasing the energy efficiency of many physical systems.

* https://www.ev-volumes.com/news/global-ev-sales-for-2022/

For example: a car as a system can become more energy efficient by increasing energy capacity of the battery and reducing rolling resistance.

About 81 million cars* were delivered globally in 2022. 10.5 mln of them were BEVs and PHEVs, while 70.5 mln were ICEs and HEVs.

If all of them had used graphene nanotubes in batteries and tires, the world would additionally have saved up to an additional

62 mln tonnes
of CO_2 equivalent

OCSiAl

OCSiAl

OCSiAl is the world's largest manufacturer of graphene nanotubes, owning the only scalable technology capable of synthesizing them in industrial volumes.

A graphene nanotube, also known as a single wall carbon nanotube, is a rolled-up sheet of graphene possessing exceptional properties, such as high electrical and thermal conductivity, strength, and flexibility. These unique characteristics make graphene nanotubes a versatile additive with potential applications across up to 50% of global materials markets. When integrated into materials, they form a 3D reinforcing conductive network, providing a new set of properties to the final product. Advanced high-performance batteries, composites, plastics, coatings, and other materials additionally enable companies to contribute to reductions in CO_2 emissions at all stages of manufacturing and during usage of new products, stimulating global efforts to achieve carbon neutrality.

OCSiAl produces high-purity graphene nanotubes under the brand name TUBALL™ and accelerates the transformation process of nanotubes from the laboratory to being an industrial-scale material by simplifying their handling. The company has developed TUBALL™-formulated technologies for various applications.

TUBALL™ BATT, an ultrafine dispersion of graphene nanotubes in liquid carriers, is a ready-to-use solution designed for high-energy anodes and cathodes. OCSiAl nanotubes create long, robust electrical networks between active material particles, improving key battery characteristics, including cycle life, DCR (reduced resistance), C-rate performance, and cohesion between active battery material particles, making the battery electrodes more durable. Graphene nanotubes unlock new battery technologies, including high-silicon-content anodes, thick LFP cathodes, fast-charging graphite anodes, and more. They can be applied in both conventional and emerging battery tech, such as a dry battery electrode coating process, and in solid-state batteries.

The TUBALL™ MATRIX nanotube concentrate product line is specifically designed for various elastomers, thermosets, and thermoplastics. It is widely used as a conductive filler to impart anti-static and ESD properties. Depending on the specific requirements, the working dosage is in the range of 0.1–1 wt.% in the final compound. TUBALL™ MATRIX is also increasingly being used as a reinforcing additive in various types of materials, enabling the production of lightweight, strong, smart, conductive, and colored products.

The company's technical support centers are located in Luxembourg, China, and Serbia. They are designed to be capable of completing the full development chain: from initial research to the fine-tuning of the application of TUBALL™ in pilot industrial lines.

TUBALL™ graphene nanotubes are authorized for use across a wide range of industries. They comply with EU-REACH and US Environmental Protection Agency regulations, allowing the commercialization of up to 100 tonnes of single wall carbon nanotubes annually in Europe and an unlimited tonnage band in the US.

Headquartered in Luxembourg, OCSiAl is represented throughout Europe, the US, South Korea, China, Hong Kong, Canada, Mexico, Malaysia, Taiwan, Japan, India, and Serbia. OCSiAl collaborates with more than 1,500 companies in over 50 countries worldwide and enjoys a network of 25 distributors.

200+ PEOPLE
30+ SCIENTISTS
1 DREAM
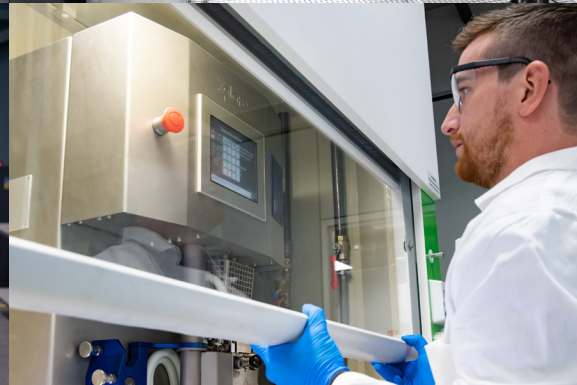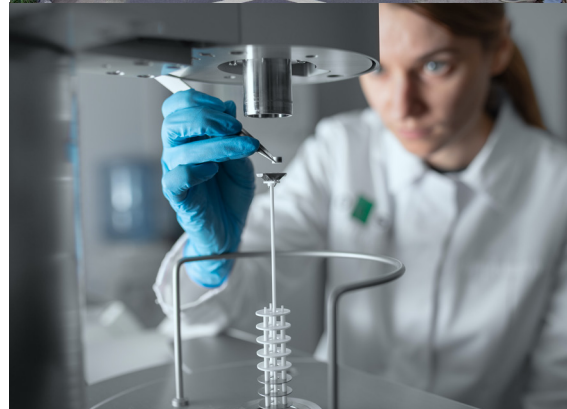
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tuball.com