The Promise & Progress
Single Walled Carbon Nanotubes

Konstantin Tikhonov, VP Energy Applications

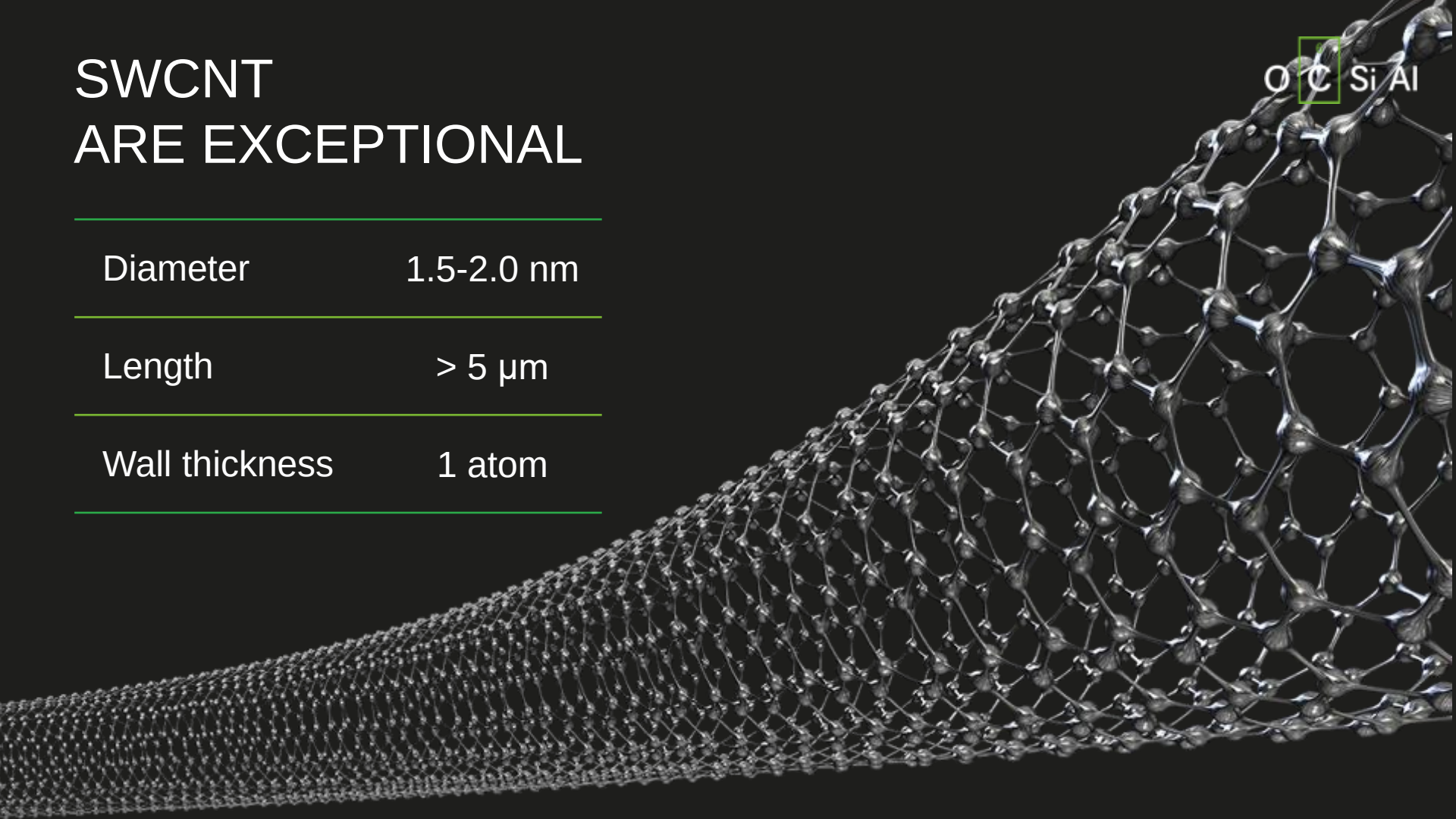
OCSiAl GROUP

Redefining materials
Reinventing technologies

Confidential. Commercial secret of OCSiAl S.À., 33, rue de Puits Romain, L-8070 Bertrange, Luxembourg

SWCNT ARE EXCEPTIONAL

Diameter	1.5-2.0 nm
Length	> 5 µm
Wall thickness	1 atom



SWCNT EXCEPTIONAL PROPERTIES

O C Si Al

Excellent Conductor

5 Times Lighter than Copper

Stronger than steel

100 times

Thermal stability

up to 1000 °C

The highest length to diameter ratio

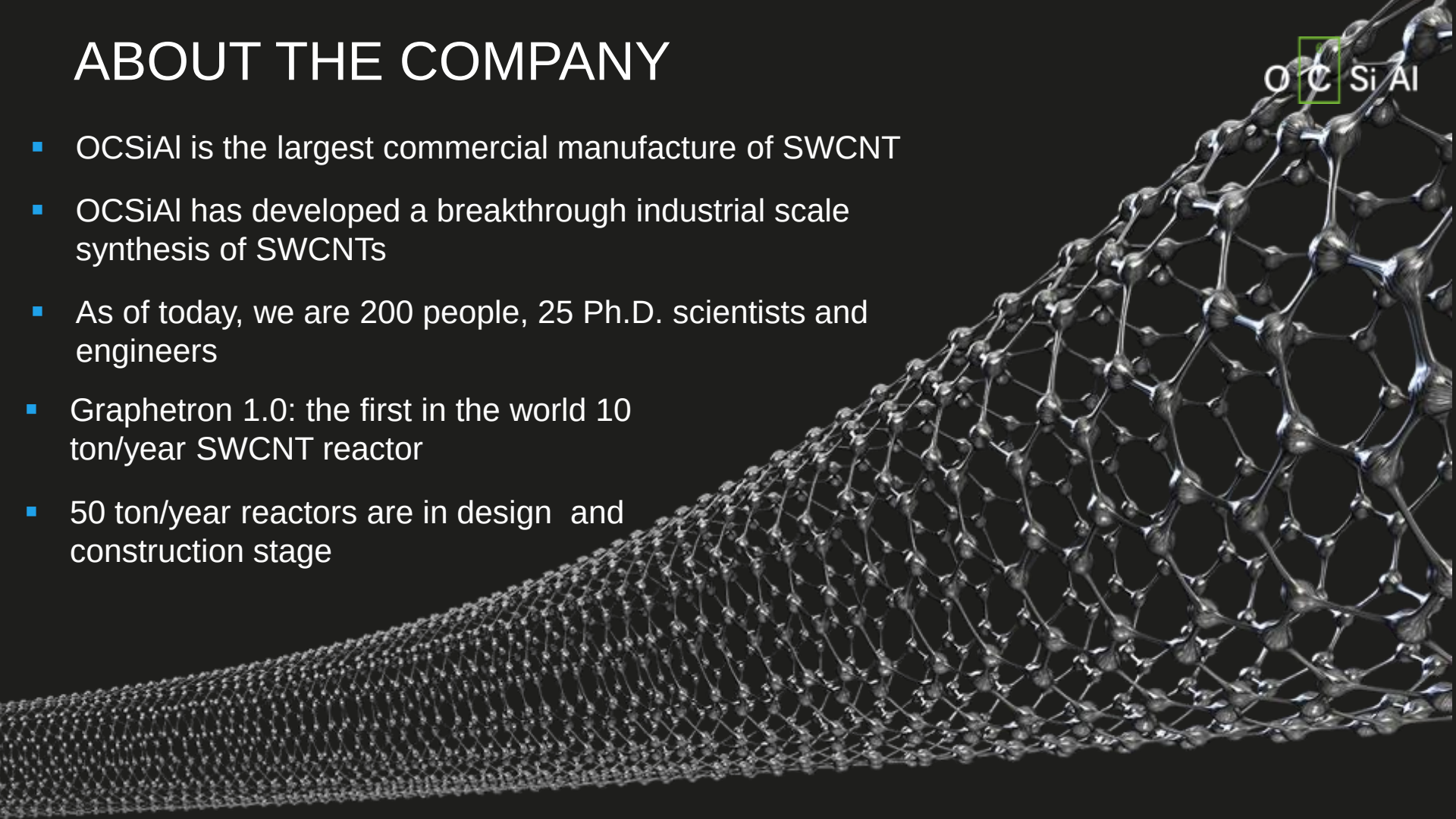
up to 1 million times

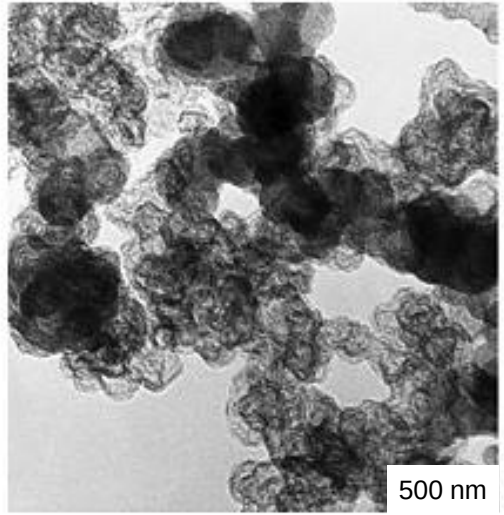
Surface area

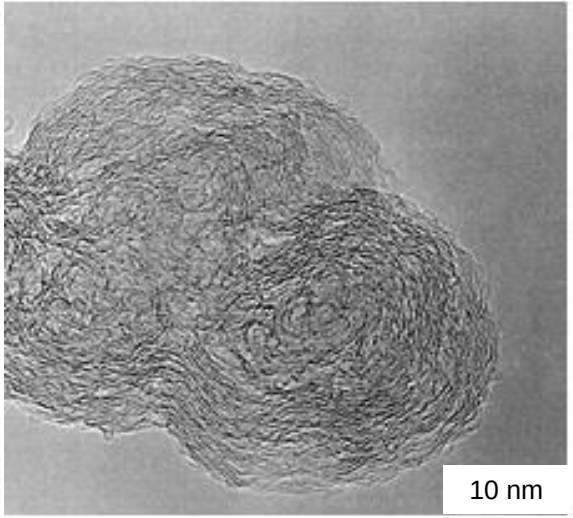
1g = 2 basketball courts

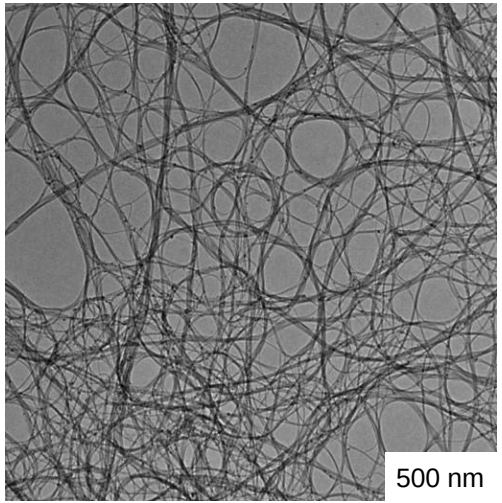
ABOUT THE COMPANY

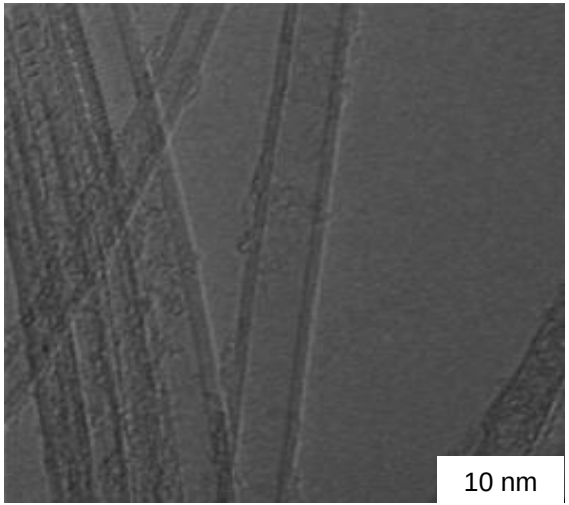
- OCSiAl is the largest commercial manufacture of SWCNT
- OCSiAl has developed a breakthrough industrial scale synthesis of SWCNTs
- As of today, we are 200 people, 25 Ph.D. scientists and engineers
- Graphetron 1.0: the first in the world 10 ton/year SWCNT reactor
- 50 ton/year reactors are in design and construction stage











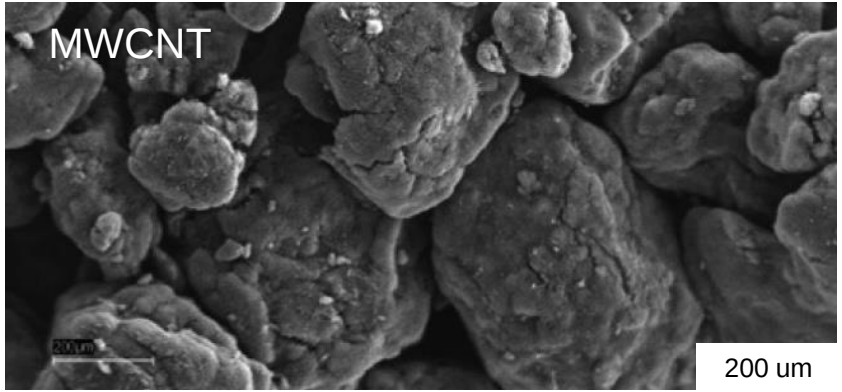
O C Si Al

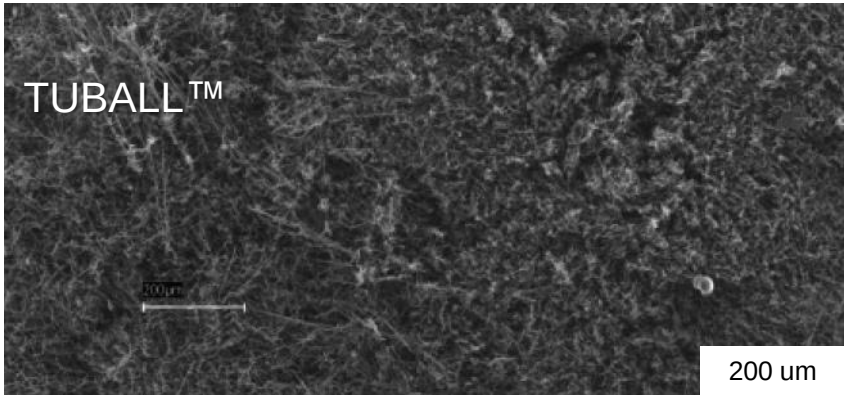
CONDUCTIVE CARBON BLACK

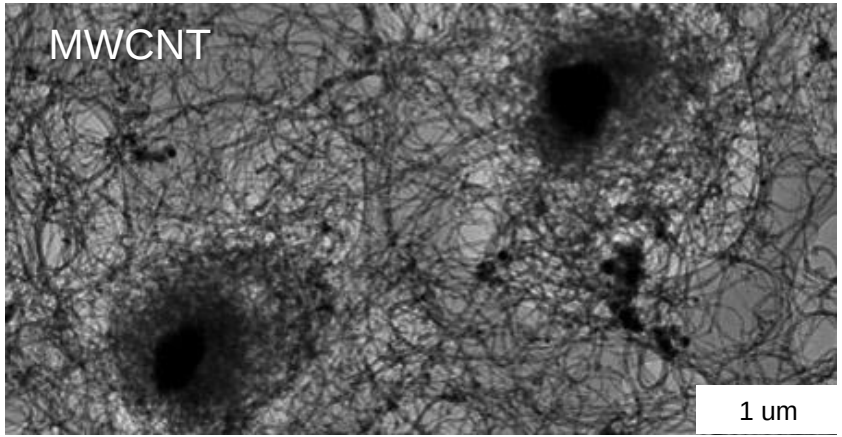
VS

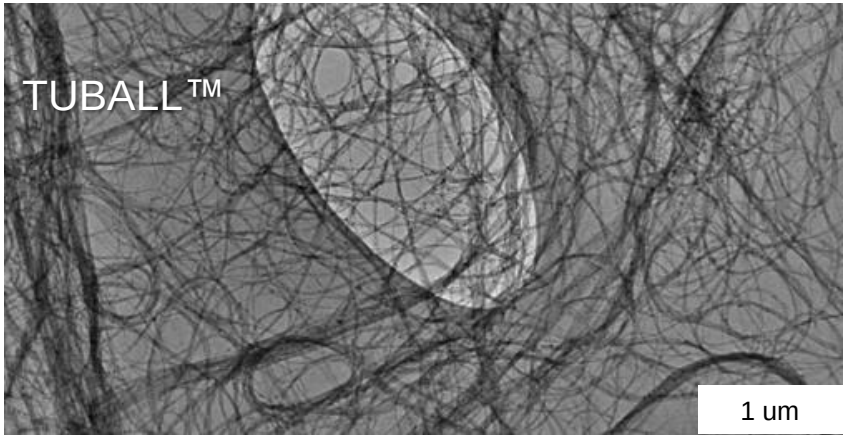
TUBALL™

MULTI WALL NANOTUBES vs TUBALL™





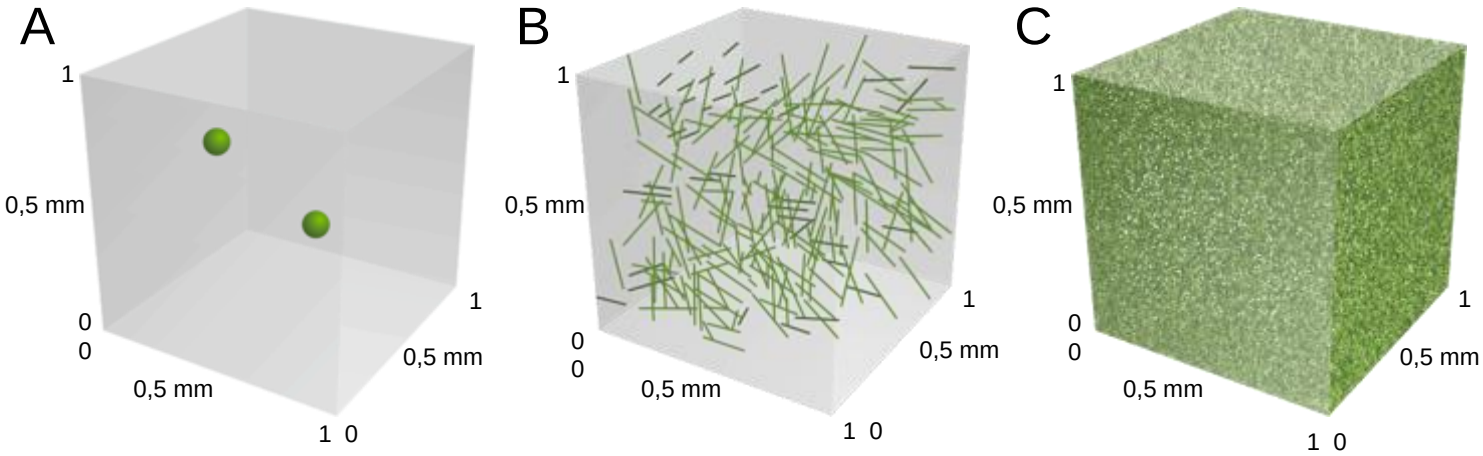




DISPERSION IN MATRIX

1 g = 10^{16} tubes
1 g = 50,000,000 km of tubes

Concentration of particles ~0,1%



MICROPARTICLES **CARBON NANOFIBERS** **SWCNT**

SWCNT FORMS ITS OWN CONDUCTIVE 3D NETWORK

AT ULTRA LOW CONCENTRATIONS

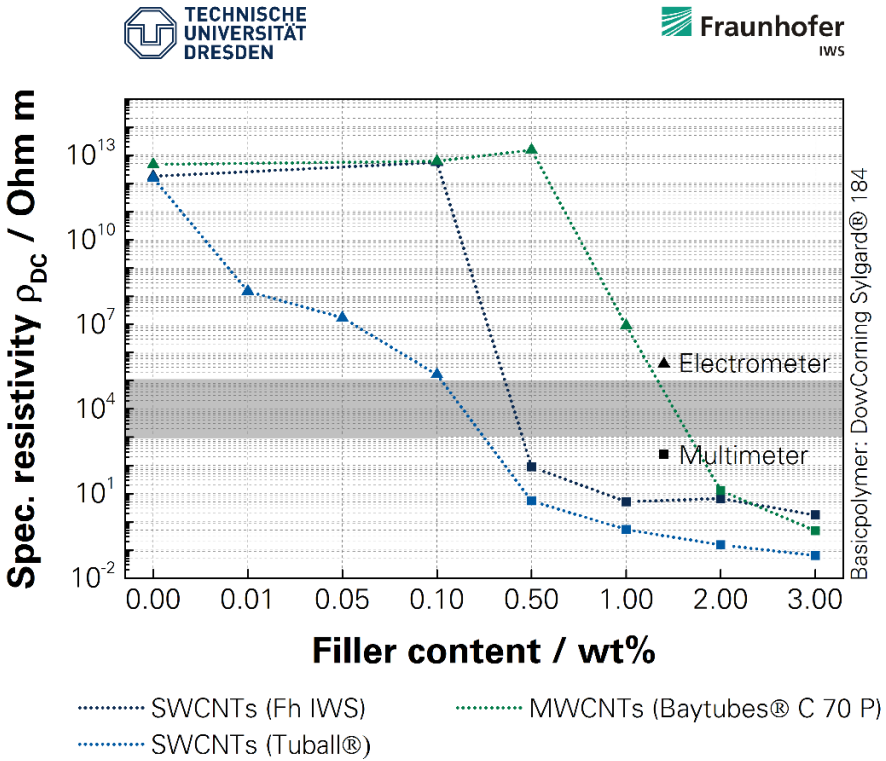
O C Si Al

SINGLE WALL CARBON
NANOTUBES DELIVER IMPROVEMENTS
AT 10 TO 1000 TIMES
LOWER CONCENTRATIONS
THAN OTHER CONDUCTIVE ADDITIVES

KEY FEATURE

- SWCNTs form electrically conductive 3D network in media at extremely low concentrations, typically <0.2%.

- TUBALL™ is superior to other SWCNTs and MWCNTs and provides orders of magnitude lower resistivity at very low concentrations (as low as 0.01%)



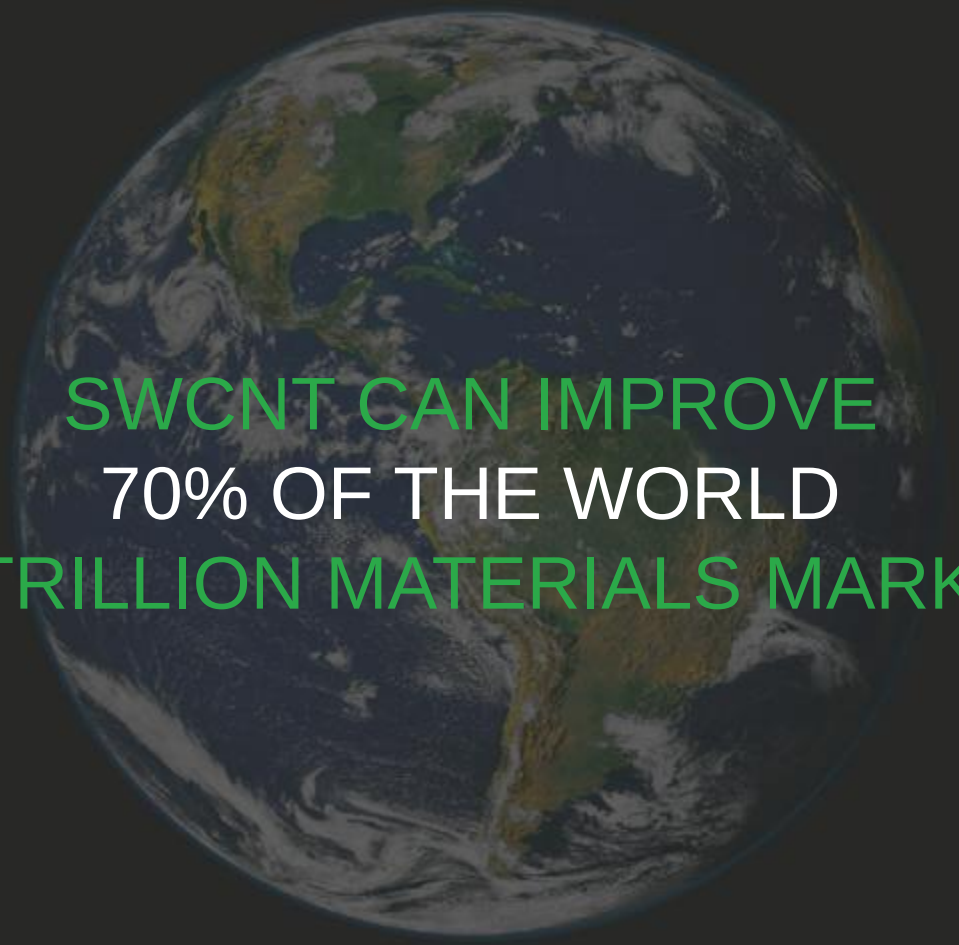
Fraunhofer study: SWCNTs and MWCNTs in silicon rubber (DowCorning Sylgard 184)

Electrical conductivity with CARBON BLACK

Electrical conductivity with **TUBALL**

SWCNT: THE FIRST UNIVERSAL ADDITIVE

- **Add conductivity**
- **Keep the color**
- **Keep or enhance mechanical properties**

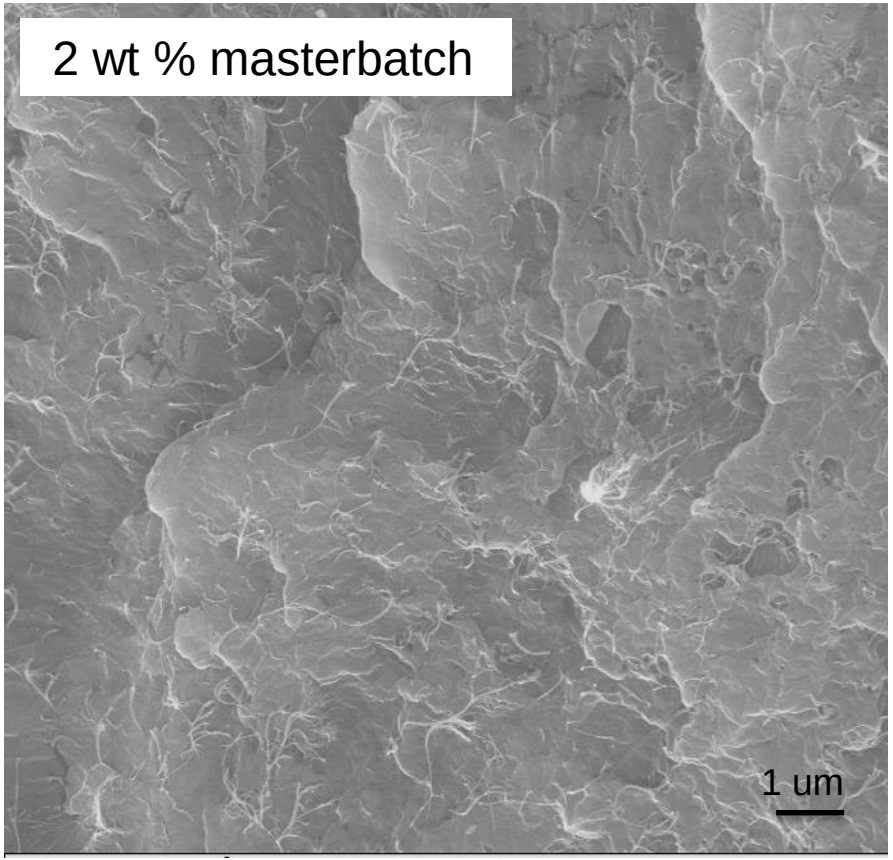


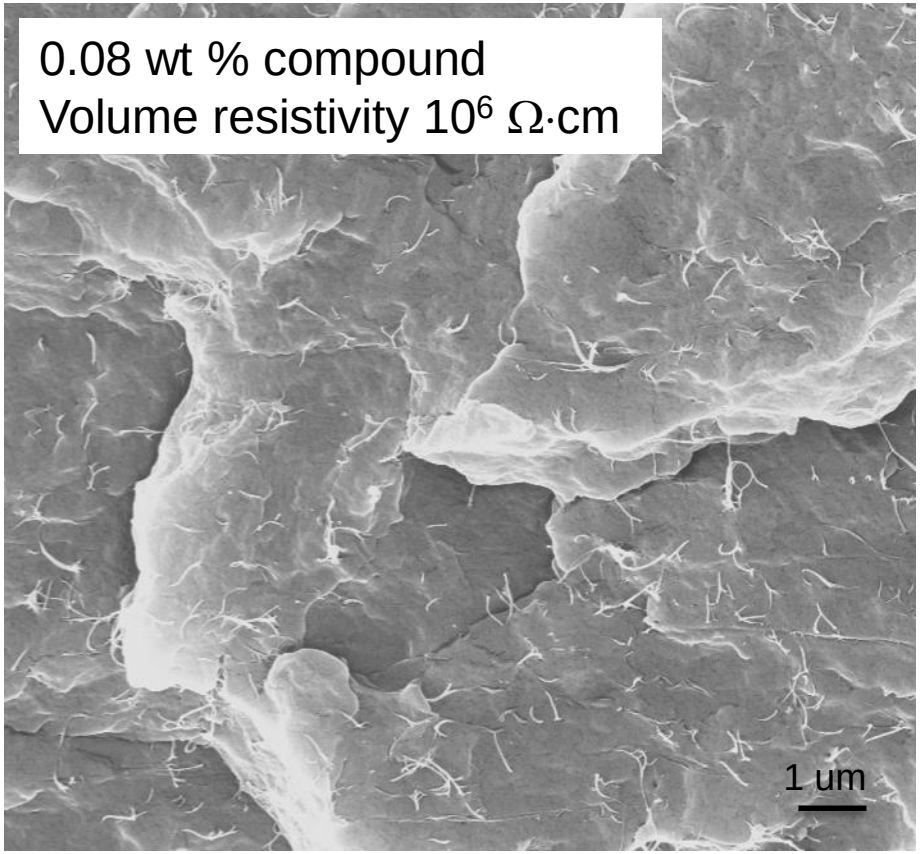
SWCNT CAN IMPROVE

70% OF THE WORLD

$3 TRILLION MATERIALS MARKET

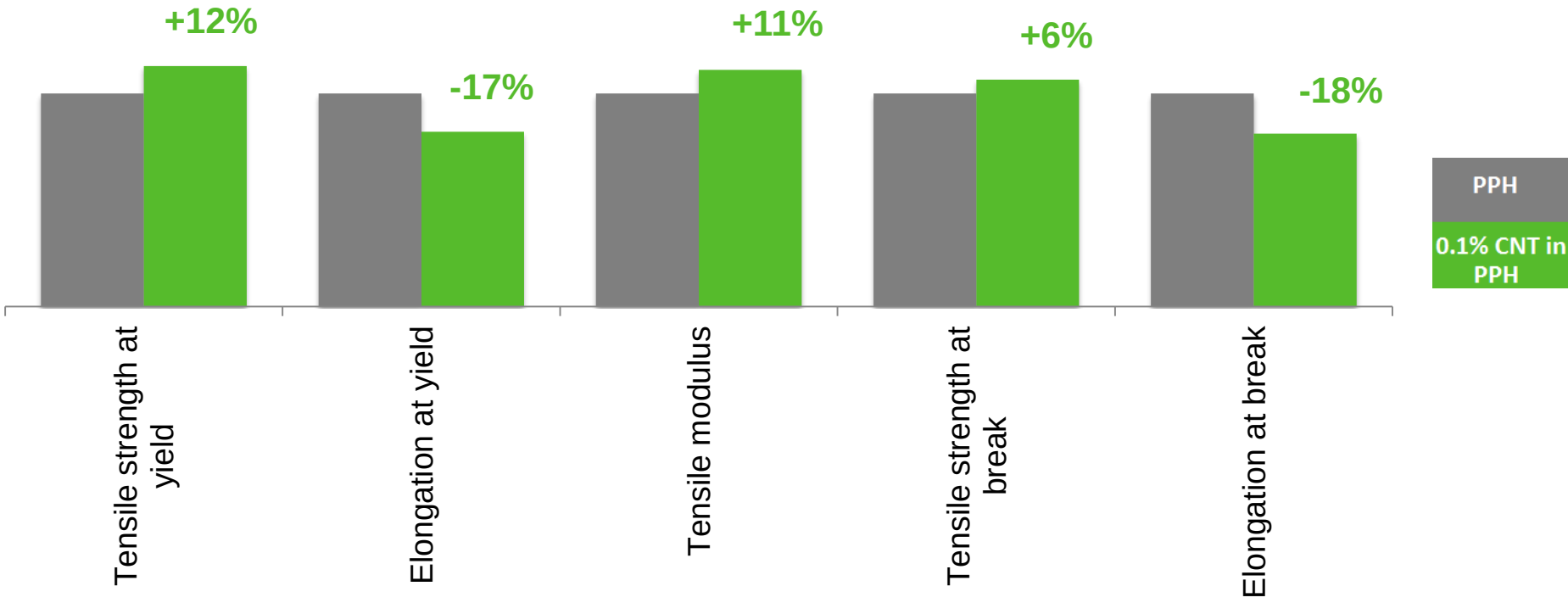
TUBALL IN POLYPROPYLENE



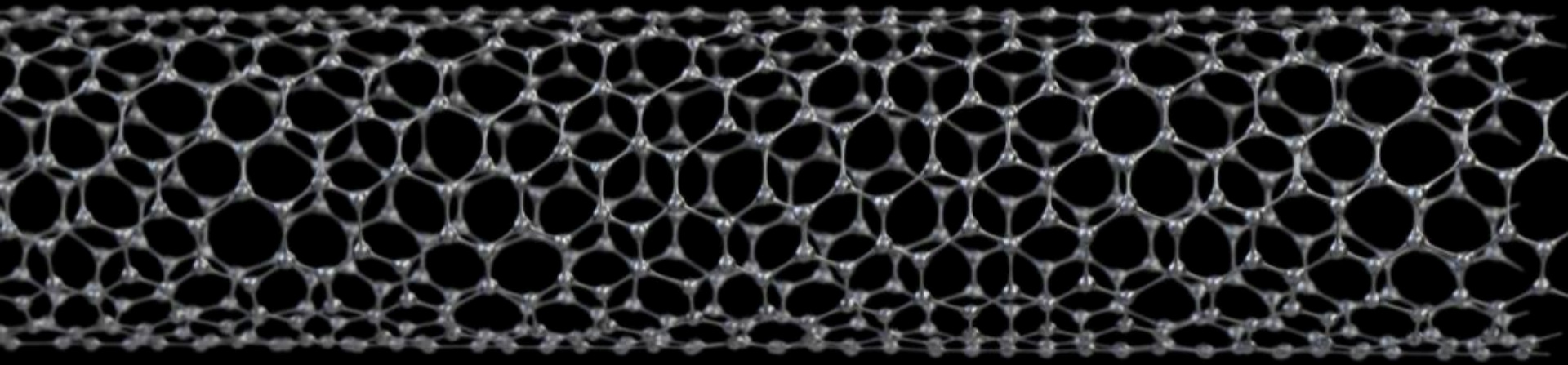


CONDUCTIVITY + STRENGTH

All samples at 10^4 Ohm.cm and based on 0.1% TUBALL in PPH
Results were obtained by compression molding

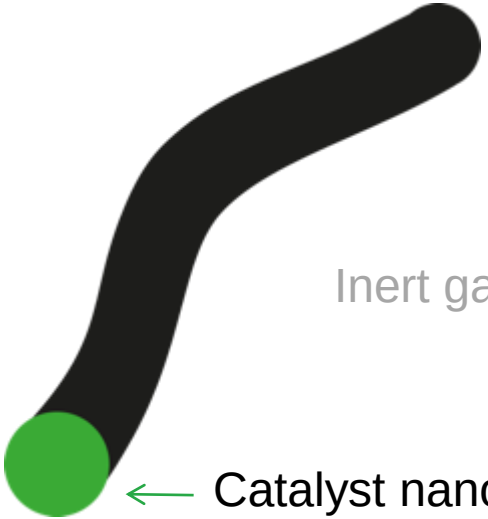


TECHNOLOGY



THE SYNTHESIS OF CNT
FROM A FREE CATALYST PARTICLES

T~600–1000°C
$N(C_xH_y)$



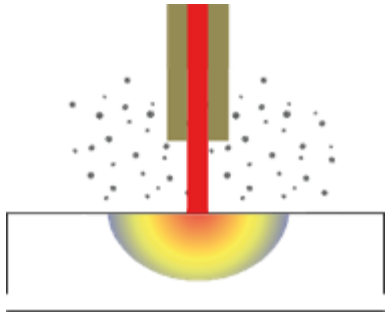
CNT

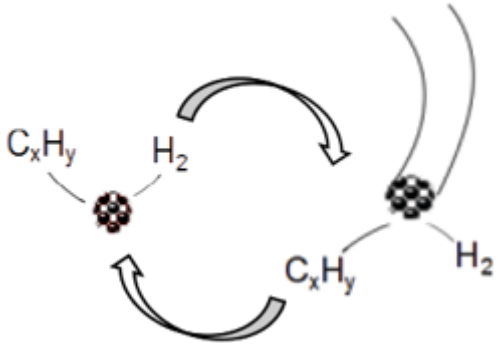
Inert gas

Catalyst nanoparticles

$\mathbf{CH_4 \rightarrow C+2H_2}$

SCHEME OF METAL VAPORIZATION, CLUSTERING SWCNT SYNTHESIS





STEP 1
Metal vaporization

US PATENT 8137653
«SYSTEM AND METHOD FOR PRODUCING CARBON NANOTUBES»

STEP 2
Metal is condensing into nanoparticles

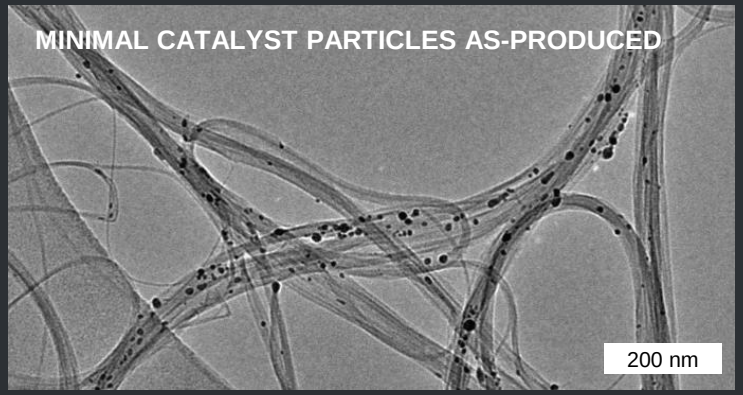
STEP 3
Catalytic decomposition of hydrocarbon on metal nanoparticles and growth of nanostructures

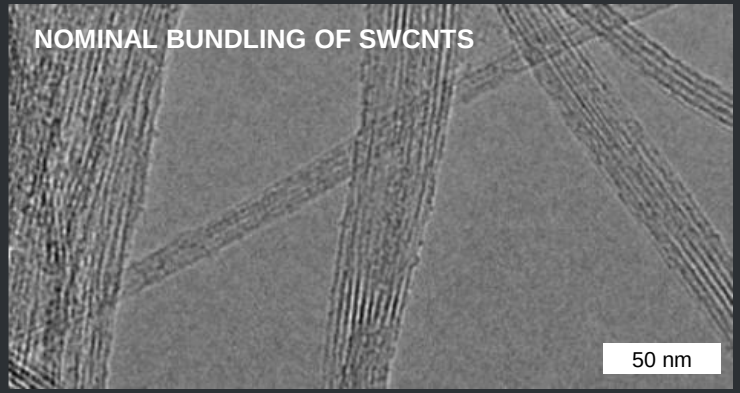
O C Si Al

CORE PRODUCT

TUBALL™ TECHNICAL DATASHEET

SPECIFICATION	UNIT OF MEASURE	VALUE	METHOD OF EVALUATION
CARBON CONTENT	wt. %	>85	TGA, EDX
CNT	wt. %	≥75	TEM, TGA
NUMBER OF LAYERS CNT	unit	1-2	TEM
OUTER MEAN DIAMETER CNT	nm	1.8±0.4	RAMAN, TEM
LENGTH OF CNT	µm	>5	AFM
METAL IMPURITIES	wt. %	<15	EDX, TGA





OCSiAl FIRST FACILITY:
TECHNOPARK IN NOVOSIBIRSK

FOUNDED IN 2010

$100 MLN	4,200	200+
INVESTMENT	**SQM**	**EMPLOYEES**

PROTOTYPING CENTER

150
pieces
of equipment

6
key
technologies

200
t/year
capacity

PROTOTYPING TECHNOLOGIES

RESEARCHING SWCNT PROPERTIES

ENERGY

ELASTOMERS

TRANSPARENT COATINGS

THERMOPLASTICS

THERMOSET COMPOSITES

PRODUCTS AT MANUFACTURING SCALE

TUBALL™

Based on the core technology of SWCNT synthesis, OCSiAl has developed a family of TUBALL™ -based open-source technologies for applications in different industries

COAT

INK

RUBBER

BATT

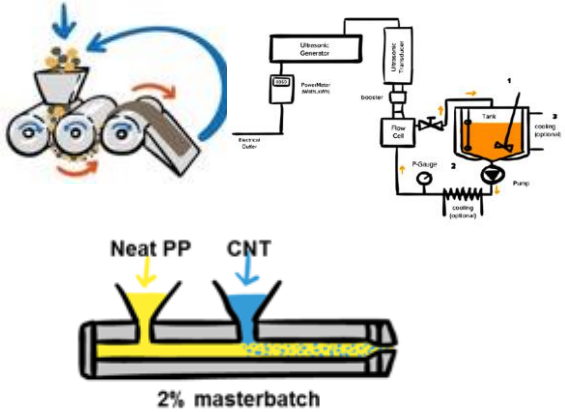
COMP_E

OCSiAl 2016: BUSINESS MODEL

OCSiAl

TUBALL production
TESTING support

PARTNERS



PRODUCTION & SALES

CUSTOMERS

TESTING AND PURCHASE

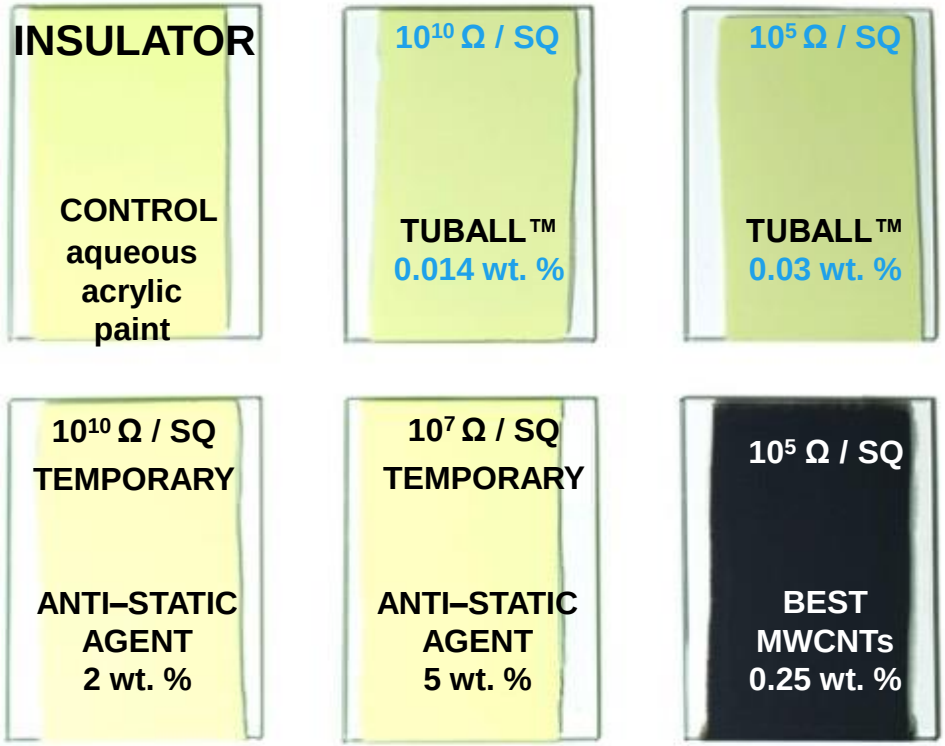
OCSiAl WORLDWIDE

APPLICATION EXAMPLES FROM AROUND THE WORLD

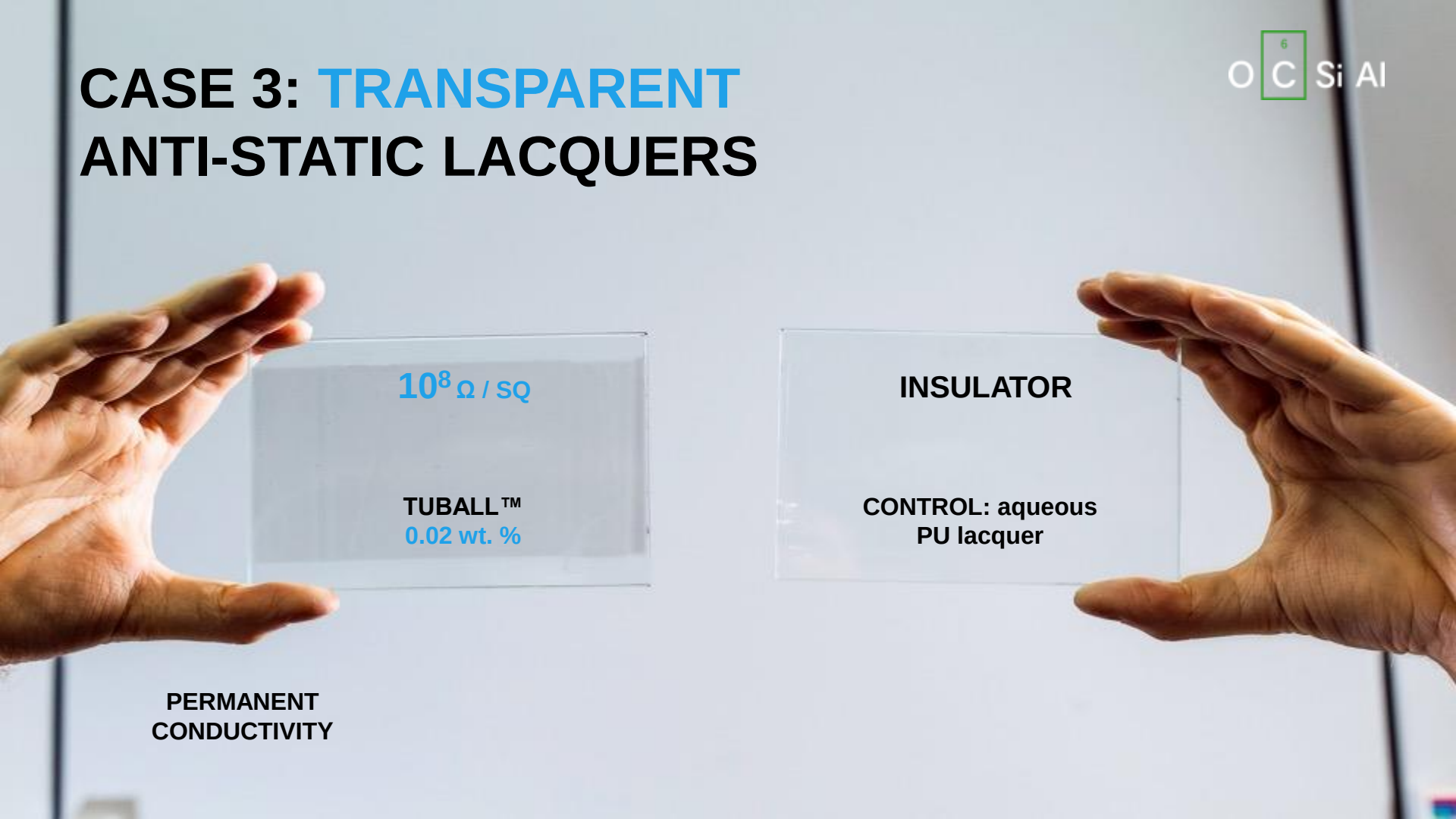
CASE 1: ANTI-STICK COATING

PANS WITH TUBALL

CASE 2: ANTI-STATIC PAINTS
WITH COLOR



CASE 3: TRANSPARENT ANTI-STATIC LACQUERS



PERMANENT
CONDUCTIVITY

CASE 4: TUBALL™ BASED DEVICE INTEGRATED INTO A T-SHIRT

- Semi-transparent flexible conductive PET, direct gravure and laser etching
- Surface resistance = 360 Ohm/sq
  conductivity in a circuit with sensors and power source
- Good wear and water resistance
  can be washed many times while the initial performance maintains well

CASE 5: NATURAL & NITRILE ANTISTATIC LATEX GLOVES

NATURAL LATEX 0.03%TUBALL™ 10^5 Ohm*m

NITRILE LATEX 0.05% TUBALL™ 10^4 Ohm*m

- TUBALL™ introduced to industry in August 2015
- Large industrial gloves manufacturer used TUBALL™ to develop new line of antistatic protective nitrile gloves according to international requirements for protective wear
- Working with largest in the world gloves manufacturer

*Glove made by a customer with 0.05% TUBALL™

ANTISTATIC LATEXES WITH TUBALL™

	CURRENTLY AVAILABLE	RESULTS WITH TUBALL™
Specific resistivity level*	**10^7 – 10^{11} Ω*m**	10^4 – 10^8 Ω*m
Concentration of conductive filler	>5%	0.03 – 0.05%
Negative impact on mechanical properties	Yes	No
Color	Yes	Yes

*Electrical resistivity measurements according to EN 1149 standard

ANTISTATIC GLOVES MARKET

O C Si Al

Dipped industrial

4.3 mn pairs

160 mn $

30-40 $/pair

CAGR **7** %

450 t

0.2 t TUBALL™

Knitted gloves

60 mn pairs

250 mn $

3-6 $/pair

CAGR **7.4** %

1 500 t

0.8 t TUBALL™

Disposable

12 bln pairs

1.2 bln $

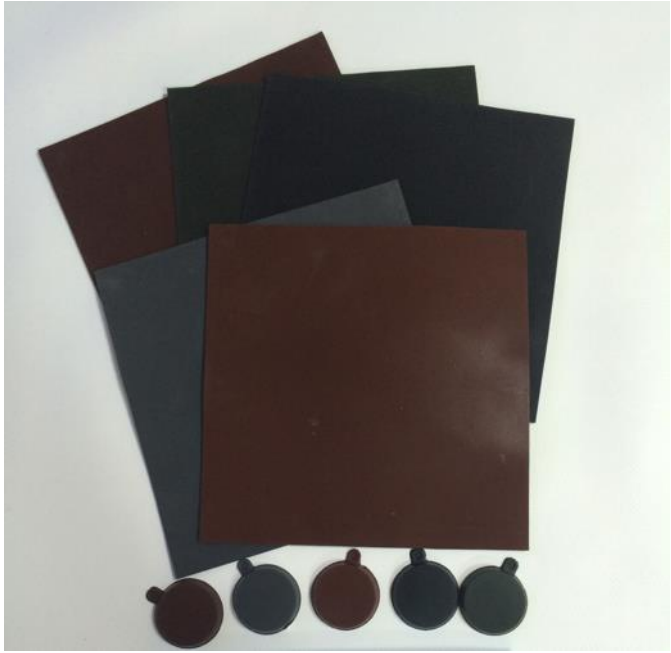
0.15 – 0.30 $/pair

CAGR **13.3**%

120 000 t

60 t TUBALL™

CASE 6: CONDUCTIVE SILICONES WITH TUBALL™

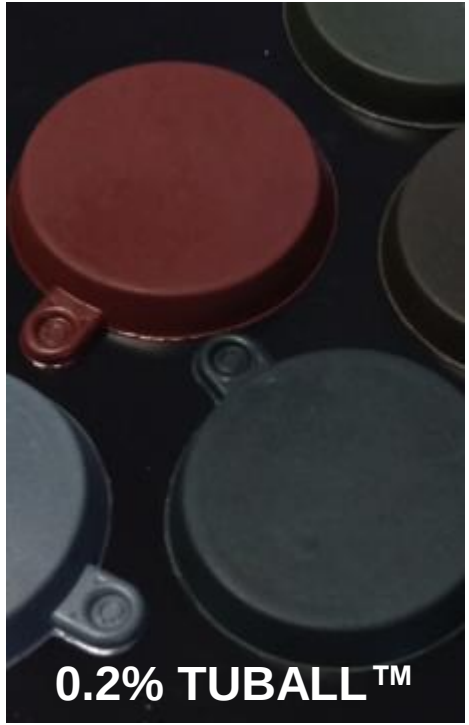


Customer: “This has not been possible before, the result is truly revolutionary”

- Electrically conductive silicones applied for electronic and automotive applications
- Decreasing of loading level of conductive filler in silicon compound is one of the goal in industry
- TUBALL™ introduced to industry in August 2015
- February 2016 finish first evaluation with most largest silicon manufacturer (~20% of world capacity)

CONDUCTIVE SILICONES WITH TUBALL™

	CURRENTLY AVAILABLE	RESULTS WITH TUBALL™
Specific resistivity level	**10^4 - 10^6 Ω*m**	**10^1 - 10^6 Ω*m**
Concentration of conductive filler	30-40%	**0.05 – 0.3%**
Negative impact on mechanical properties	Yes	No
Possibility to mix at **"clean"** facilities	No	Yes
Color	No	Yes



CASE 7: NBR (HNBR) RUBBER O-RING COMPOUND

NBR-based O-ring with TUBALL™

- Industrial introduction technology for adding of TUBALL™ based suspension to industrial process of rubber polymer production
- Customer samples of NBR with 0.05% TUBALL™ are currently produced by one of the leading rubber polymer manufacturer

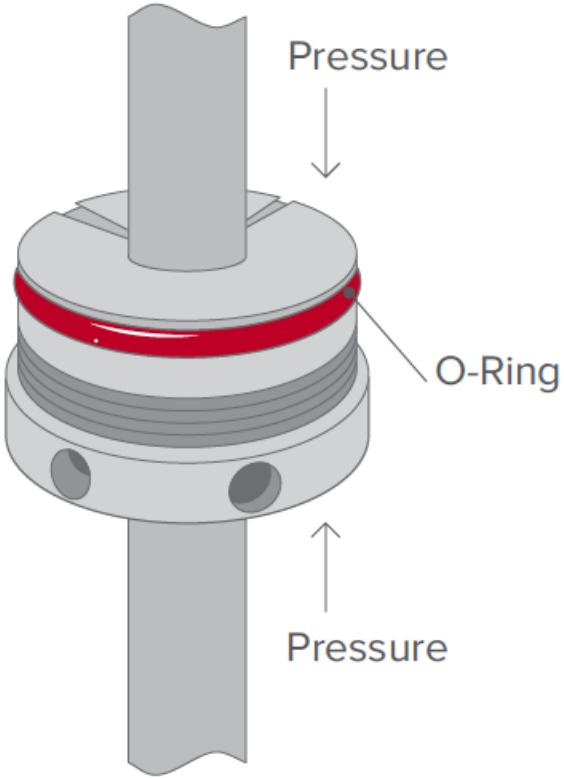
NBR (HNBR) RUBBER O-RING COMPOUND

O 6 C Si Al

heat

oil/
fuel

rapid
gas



+10%

properties after heat aging

+20%

reduced property loss after
rapid gas decompression

+ 33°C

temperature before degradation of
material (thermal resistance)

ADOPTION IN ENERGY FIELD

O C Si Al

- Fast adoption in energy field: Li-ion, primary cells, lead acids, super caps
- Material introduced in April 2014
- >100 battery companies sampled, working with most largest battery manufactures
- CM Partner is the first battery customer to go public with using TUBALL™
- MOU and contract for 100kg of TUBALL™ signed on NanoKorea 2015
- Sunbike uses 0.04% of TUBALL and no carbon black in LFP cathode
- Demonstrated: higher energy density, higher rates and cycle life improvement

http://ocsial.com/en/news/127/

CASE 7: BIKE WITH TUBALL™ BASED BATTERY

Battery Specification	
Battery Type	Li - ion
Nominal Voltage	48V
Nominal Capacity	30Ah
Pack Energy	1.5kWh
Max Discharge Current	2C(60A)
Size	167 x 185 x 350 (Wide x Length x High)
Weight	13 kg
Charging Time	3 Hour
Operating Temperature	-20~50°C

BENEFITS FOUND BY CM PARNTER

O C Si Al

- Replaced 4% or carbon with 0.04% of TUBALL in LFP cathode
- **More active material** (>98% with TUBALL vs 92% with carbon black)
- Thinner cathodes → **thinner cells** by 1mm each → two more cells per pack → **higher pack capacity**
- Significantly **improved cycle life** (>1000 cycles with virtually no degradation)
- **Better performance at high discharge rates** (baseline formulation – 85% at 2C rate; TUBALL – 95% at 2C rate)

LI-ION SUCCESS STORIES

O C Si Al

- Most common driver behind TUBALL adoption: **energy density**
- Everybody wants to increase % active
- Even in most optimized LCO chemistry for consumer electronics applications, companies always worked over many years to increase % active
- TUBALL adoption is **inevitable**

PROGRESS

Year	*1990s*	*2010*	*2012*	*2014*	*2015*
LCO	**85%**	**96%**	**97.30%**	**98%**	**>99%**
Conductive additive	SuperP, KS6 5%	SuperP 2%	ECP Ketjen Black 1.2%	MWCNT 0.8%	TUBALL 0.04%
PVDF	10%	2%	1.50%	1.20%	0.80%

EXAMPLE WITH LFP

10Ah cell trial: 0.2% TUBALL BATT NMP PVDF

✓ Control:

- Cathode: LFP:SP:KS-6:PVDF(5130)

  90.5 : 4 : 2 : 3.5

- Press density: **2.2** g/cc

18% thinner cathodes
10% thinner cells

✓ TUBALL Recipe:

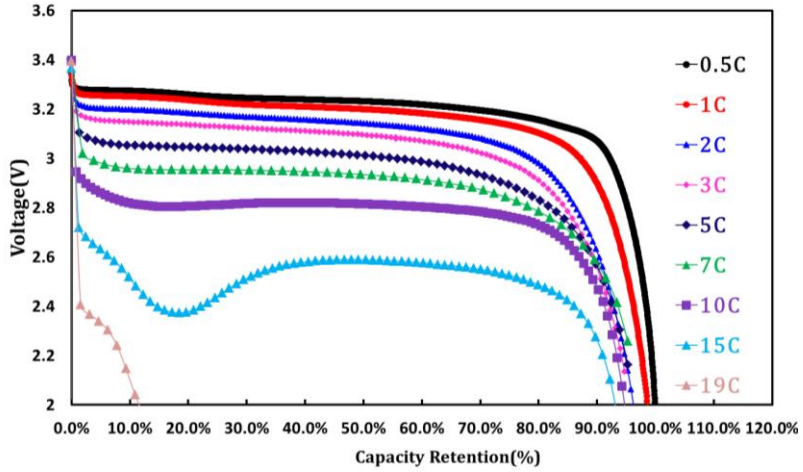
- Cathode Ratio： LFP : CNT : PVDF(5130)

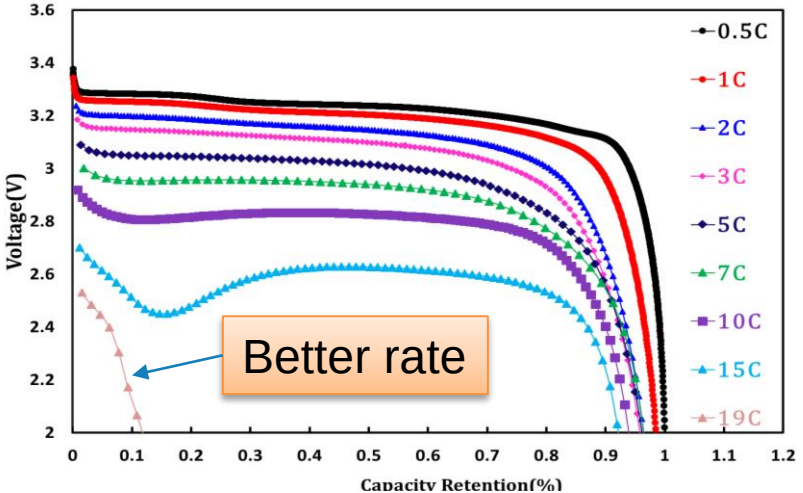
  98.4 : 0.1 : 1.5

- Press density: **2.4** g/cc

Anode：Synthetic graphite (FT-1)

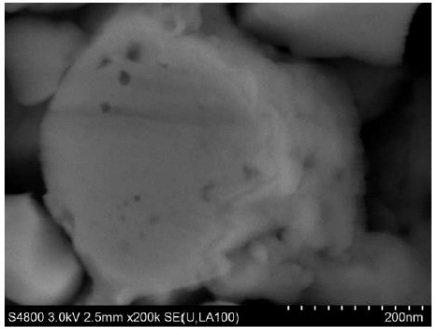
Electrolyte：1.0 M LiPF6 /EC:DEC:DMC =30:20:50 2%VC

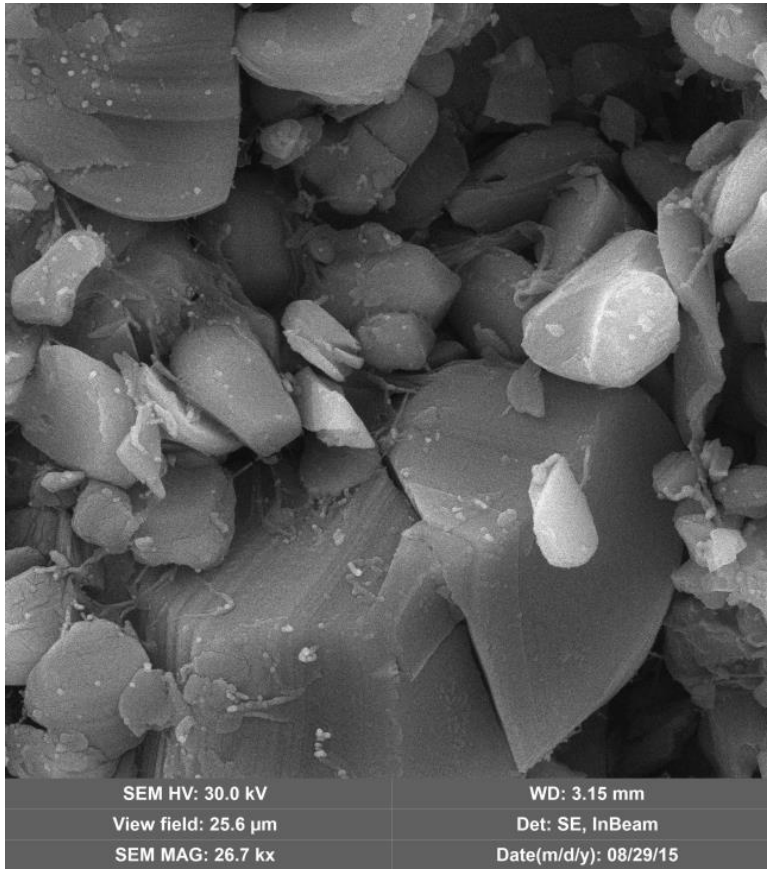




IMPROVING EXISTING CATHODE MATERIALS

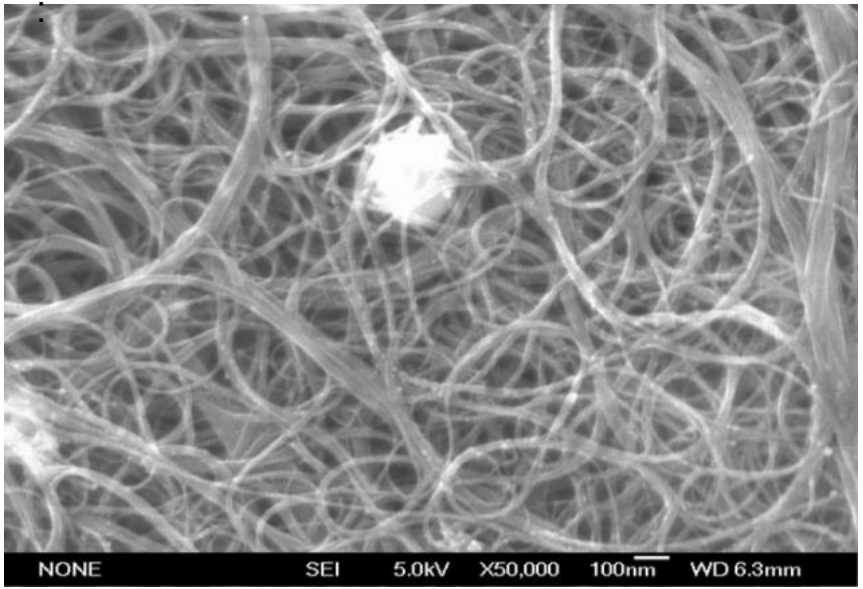
- TUBALL: stable ~450°C in oxidizing environment
- Stable >1000°C in inert atmosphere
- Introduction
  - during synthesis
  - during washing steps
- Materials:
  - LFP
  - MnO_2
  - Future: LTO, NCM, silicates, fluorides
- Benefits:
  - Extreme conductivity, high rate
  - Mechanical reinforcement, cycle life



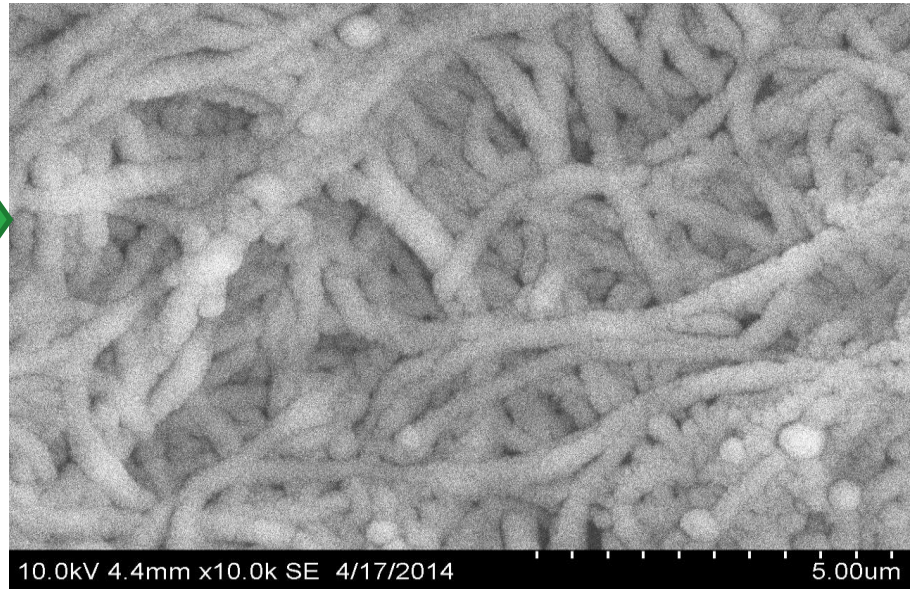


Future structures: Composite Si + SWCNT anode

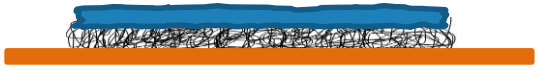
CVD from SiH_4 excited by electron beam, temperature of deposition can be reduced to 200°C and Si deposits on SWCNTs as layers:



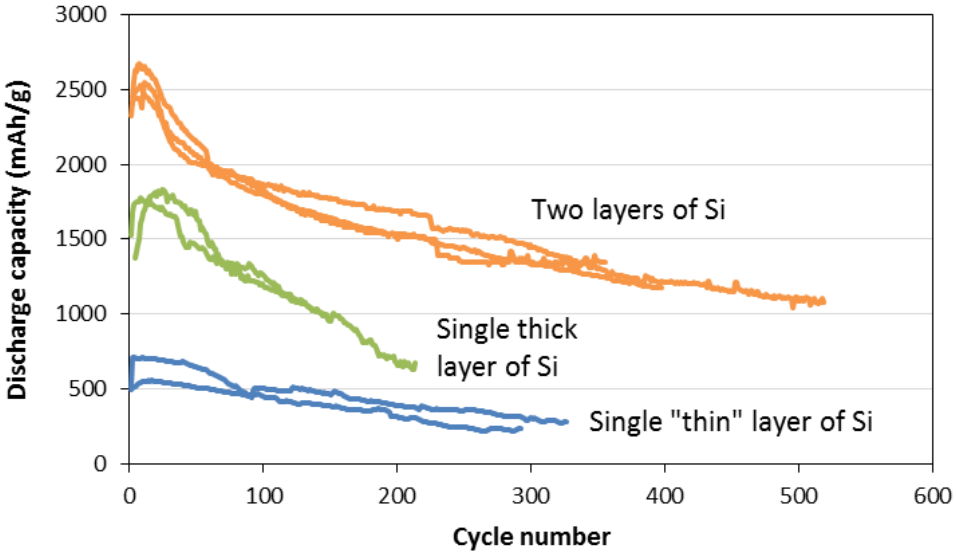
Cu foil + SWCNT 0.5 mg/cm^2



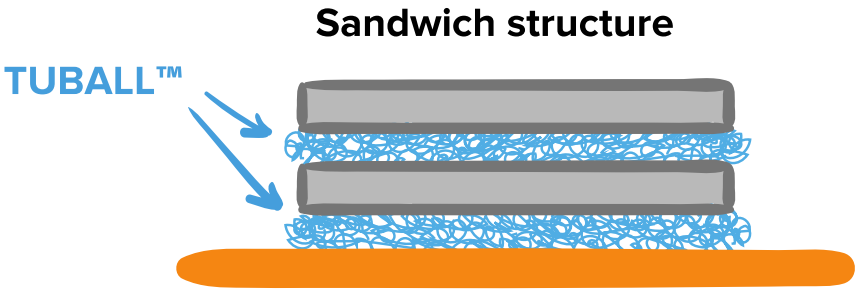
+ Si **0.13** mg/cm^2



Composite Si + SWCNT anode



Pouch cells, Li foil counter electrode, C/2 rates

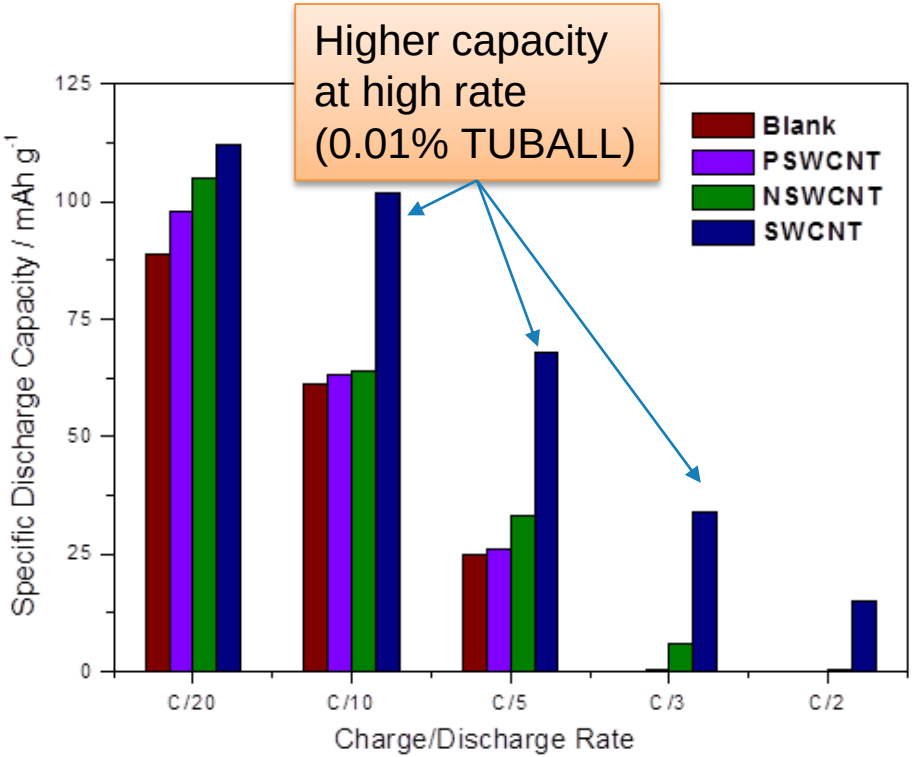


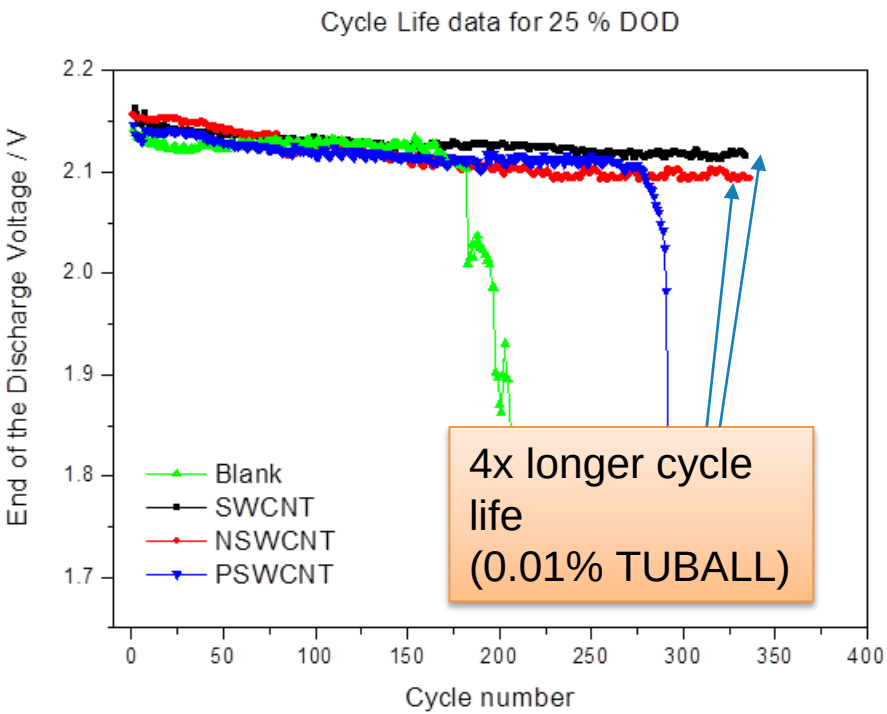
0.16 mg/cm^2 TUBALL™ and 0.5 mg/cm^2 Si

- >2500 mAh/g achieved today
- 1st cycle efficiency >75%
- Next generation structures are under development

CASE 10: LEAD ACID

Bar Ilan: lead acid batteries





CASE 12: CONDUCTIVE EPOXY FLOORS

The required volume resistivity of **10^6 Ohm*m** was reached in the epoxy flooring with the addition of **only 0.009% of TUBALL.**

No negative impact on viscosity and color of epoxy resin was observed.

The company has **already gone commercial** and **currently promoting** the new product line to consumers.

Anti-static epoxy floorings with TUBALL

CASE 13: SMC-COMPOSITE

German company applied TUBALL to the gel-coat for antistatic pipes

A surface resistivity of 10^4 Ω/sq with 0.05% of TUBALL was achieved while **maintaining the original color** of the pigmented gelcoat.

No negative impact on mechanical properties was observed.

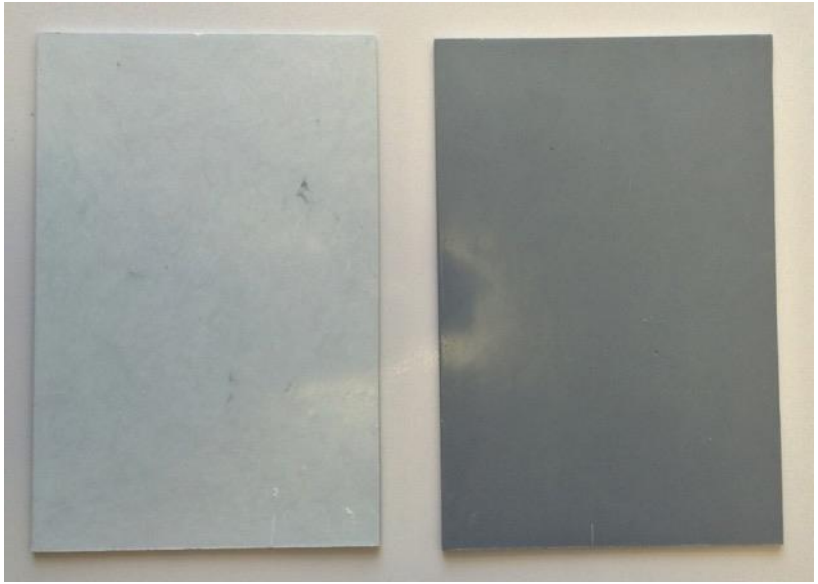
Conductive glass-fiber composite pipes

CASE 14: BMC-COMPOSITE

A company applied TUBALL to **BMC-composite** which are used for an electronics housings.

10^4 Ω•cm of volume resistivity was achieved **with only 0.02% of TUBALL in the whole composite**, corresponding to 0.20% of TUBALL in the resin itself.

No significant increase of viscosity of the resin was observed.



neat BMC-composite | **BMC-composite** + TUBALL

CASE 15:
CONDUCTIVE LIGHTWEIGHT MATERIALS

Copper shielding braid

Aluminum shielding braid

Tape based on **TUBALL™** is a substitute product to metal shielding braid for cables and wires.

SOLUTION ADVANTAGES

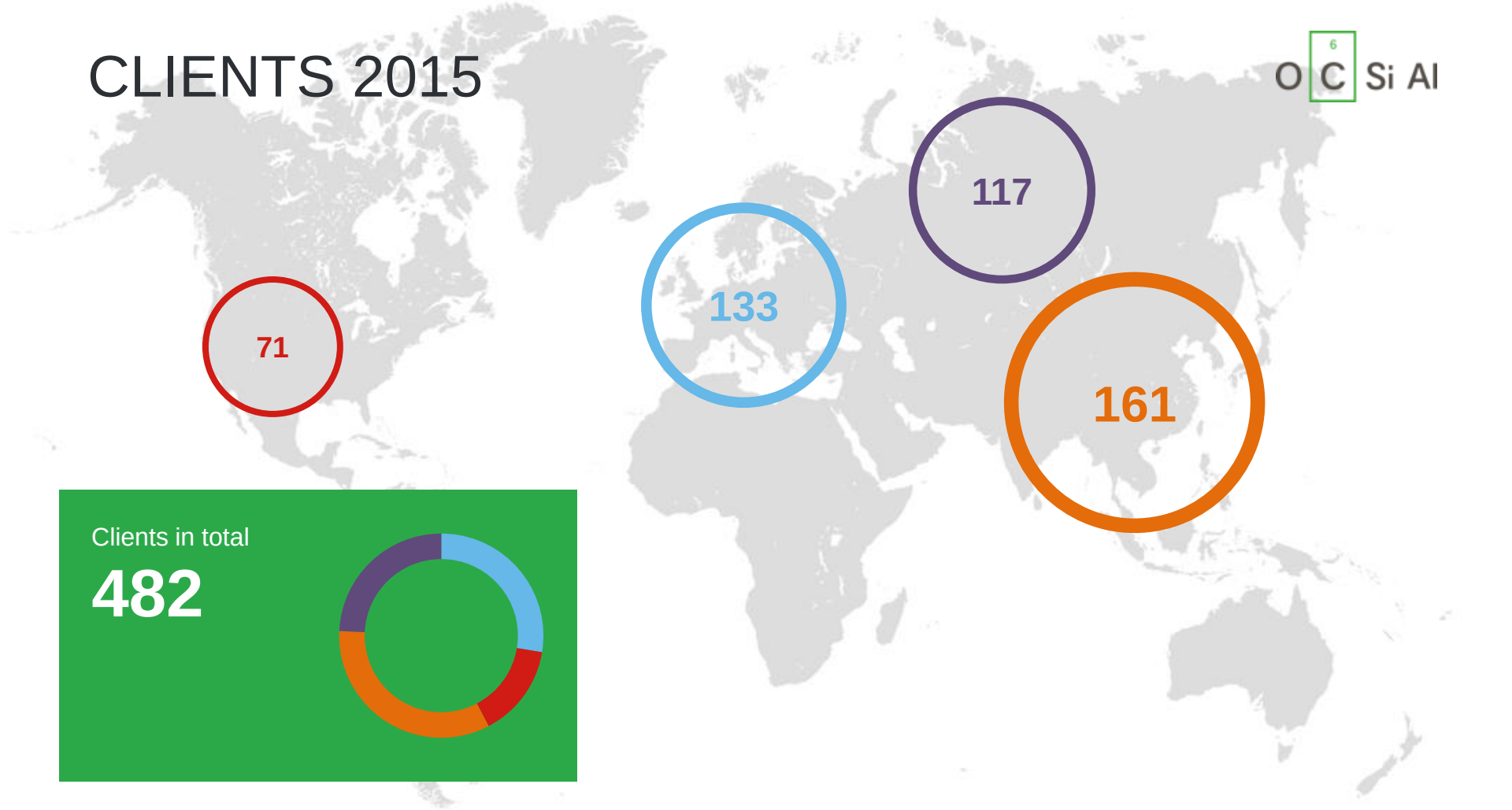
- **WEIGHT REDUCTION** 10-15 times
- **GAUGE REDUCTION** 2 times

Tape (sheet) based on **TUBALL™** allows reaching and exceeding the level of metals' conductivity.

APPLICATION AREA

AEROSPACE INDUSTRY, where lowering the aircraft's weight directly leads to fuel costs reduction and growth of working load.

CLIENTS 2015



Clients in total

482

1ST INDUSTRIAL TECHNOLOGY OF SWCNT PRODUCTION

1 TON OF TUBALL WAS PRODUCED & SOLD IN 2015

NEXT GENERATION OF SWCNT-BASED PRODUCTS
WIN THE GLOBAL MARKET

WHAT IS YOUR APPLICATION?

OCSiAl CONTACTS

OCSiAl ASIA PACIFIC

Korea: 406-840 Republic of Korea, Incheon, Incheon Technopark 12, Gaetbeol-ro, Yeonsu-gu, Pilot Plant Bldg., Office 208.
+82 32 260 0407
asiapacific@ocsial.com

China
Shennan Road, Nanshan District, Shenzhen, Guangdong
Dachong Business Centre, No. 9678, Block B, 20th Floor, #2004.
+86 135 9012 5295

Hong Kong: Suite 1207
100, Queen's Road Central
Hong Kong
+852 3180-9388
china@ocsial.com

OCSiAl LLC

500 S Front St, Suite 860, Columbus, OH 43215
+1 415 9065271

640 W California Ave, Suite 210, Sunnyvale, CA 94086
+1 415 906 5271

usa@ocsial.com

OCSiAl LTD

Luxembourg: L-3364, Leudelange, 1, rue de la Poudrerie, Grand Duchy of Luxembourg
+352 27990373

europe@ocsial.com

OCSiAl.ru LLC

107078, Russia, Moscow
Kalanchevskaya str., 2 bld.
+7 499 653 5152

630090, Russia, Novosibirsk,
Inzhenernaya str., 24
+7 383 201 8387

russia@ocsial.com