

Graphene Oxide and Reduced Graphene Oxide,

Product Developments for Up-coming Applications

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Outline

1. GO and rGO **products**
2. GO and rGO **production**
3. GO and rGO **applications**
4. GO and rGO **market**

Bussiness Areas and Activities

Commercial Products

1. Graphene Oxide (GO)
2. Reduced Graphene Oxide (rGO)

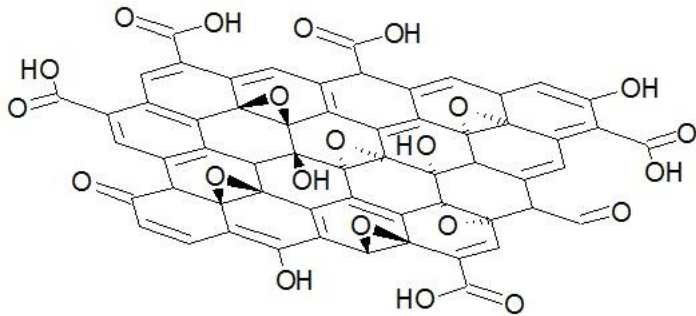


R&D

1. GO-based scavenger system for heavy nuclides
2. GO and rGO composite with Ceramics and Polymers
3. GO and rGO optimized for bio-scaffolds
4. Energy: rGO for batteries and supercaps (Graphene Batteries AS)

Graphene Oxide (GO)

Single sheets of oxidised graphite / graphene

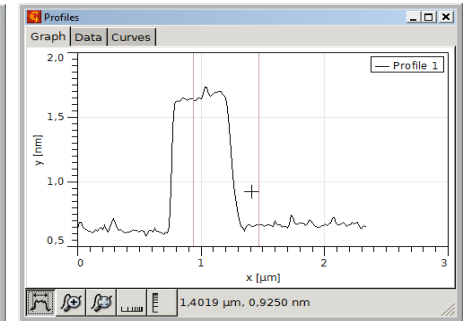
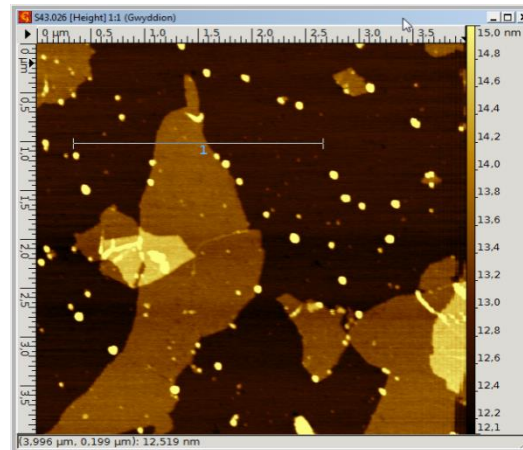


Wt %	C	O	N	C/O
Aba-GO	52.9	39.2	0.13	1.8

Typical chemical composition (wt %), Abalonyx GO

Properties

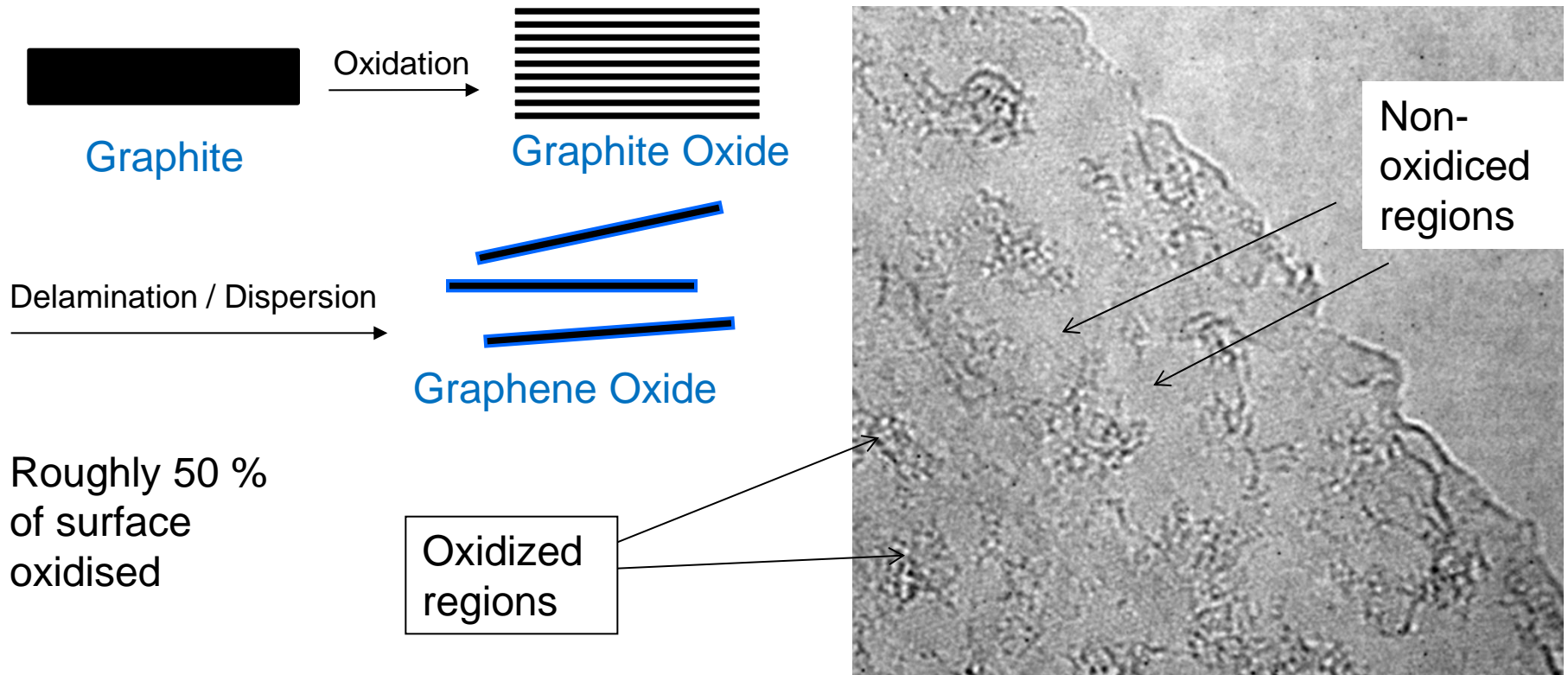
- Non-conductive
- 1 nm thick
- ~1600 m² /g surface area
- Dispersible in polar solvents



Atomic Force Microscopy (AFM) image and profile

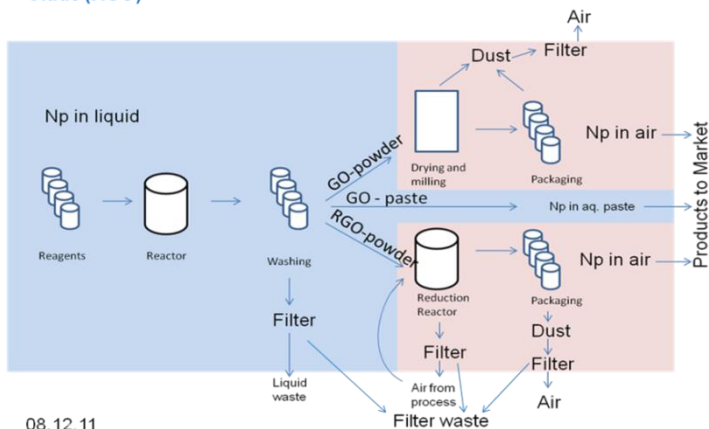
Graphene Oxide Production

Conventional «Hummers method» Hummers and Offeman, 1958



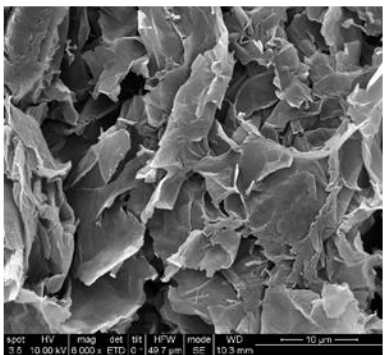
Abalonyx Graphene Oxide Production

Workflow Production of Graphene Oxide (GO) and Reduced Graphene Oxide (RGO)

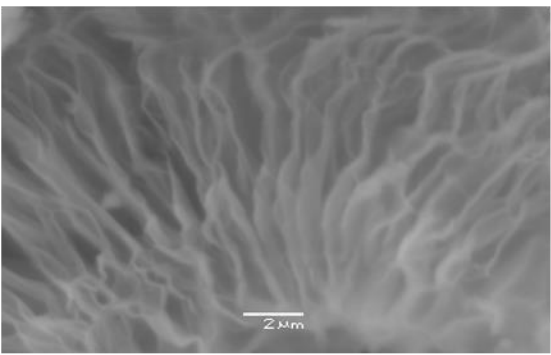


1 Kg batch-size

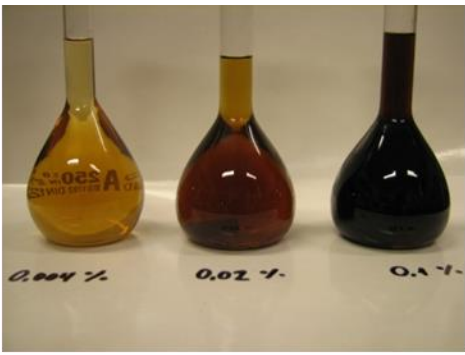
*** SAFE ***
PROCESS



Dry powder

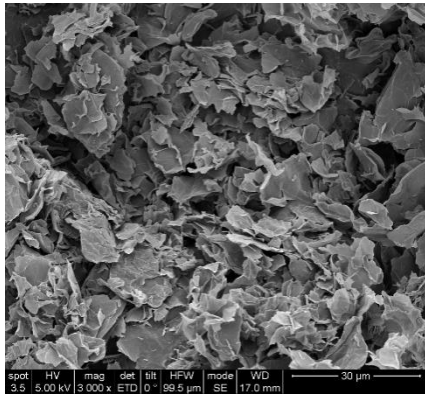


Freeze dried

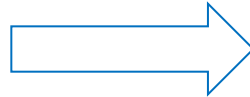


Aqueous suspensions

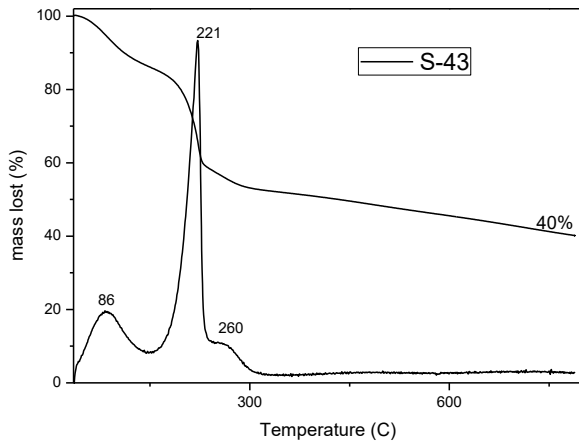
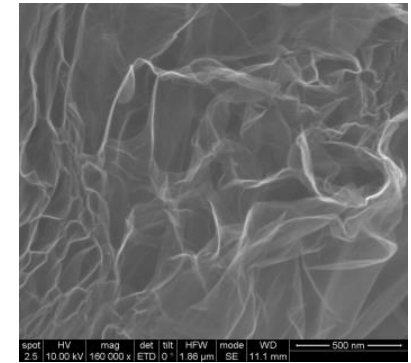
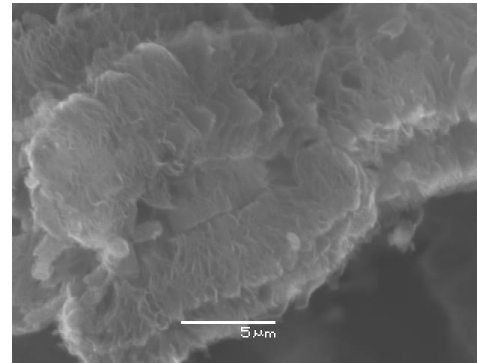
Thermal Reduction of Graphene Oxide



GO → rGO

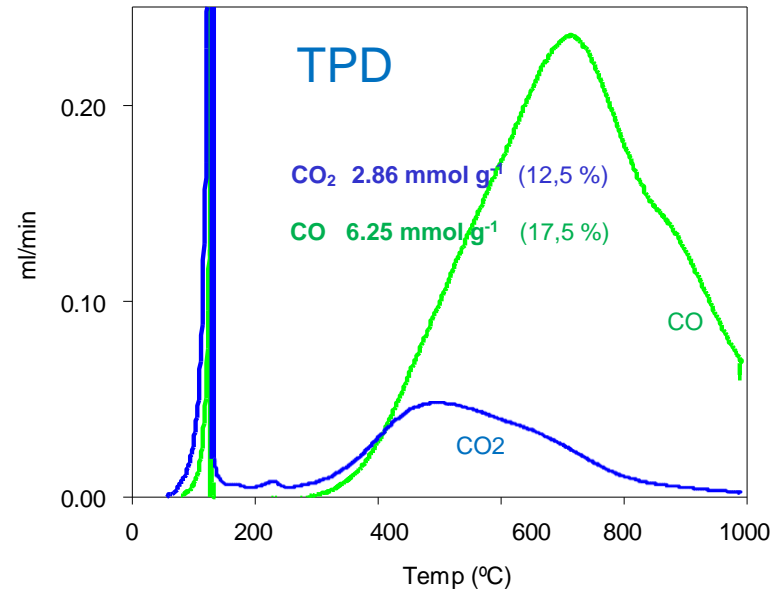


- Thermal
- Chemical
- Light induced



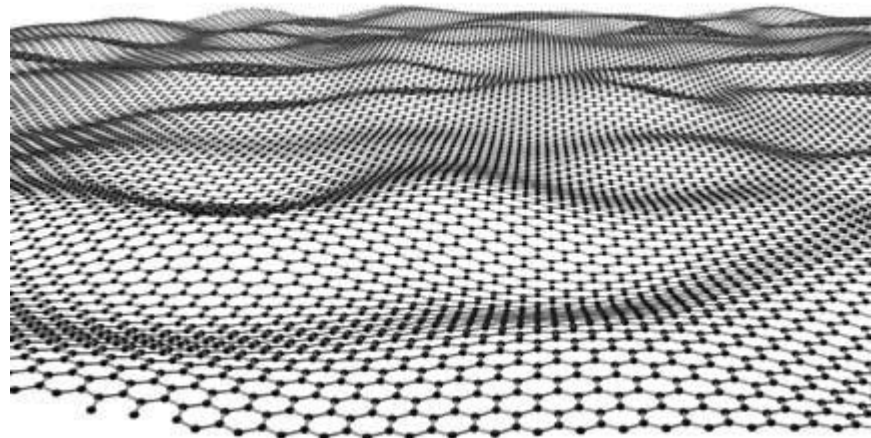
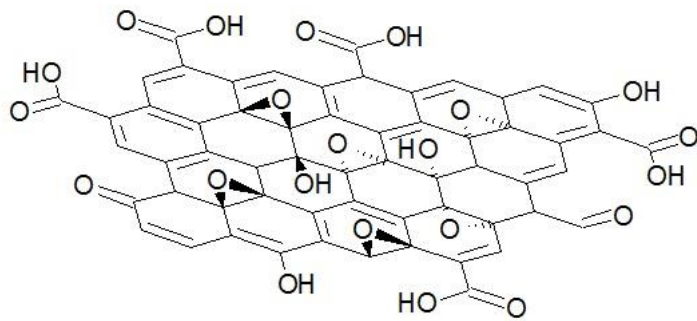
黒い雪

TGA/
DTG



Graphene oxide vs Graphene

Property	GO	rGO	Graphene
Composition	$\sim C_2O$	$C_5O - C_{100}O$	C
Sheet Thickness	1 nm	0.3 – 1 nm	0.3 nm
Sheet width	0.1 - 10 μm	0.1 – 10 μm	∞
Conductivity	Insulator	Conductor	Conductor
Surface charge	Charged (-)	Slightly (-)	non-charged
Wetting	Hydrophilic	Amphiphilic - Hydrophobic	Hydrophobic



Upcoming Applications of GO and rGO

- **Energy**

Batteries, Super-capacitors, Solar

- **Materials**

Polymer composites, Paints and coatings

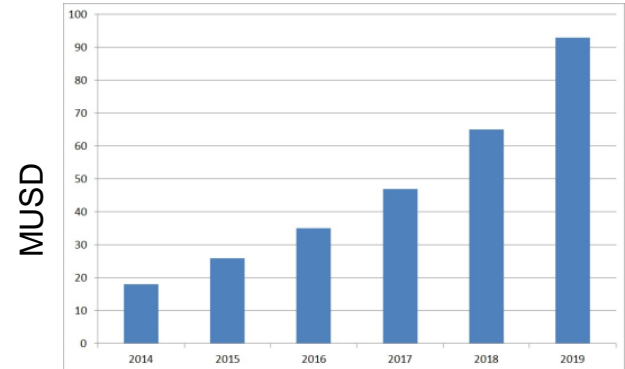
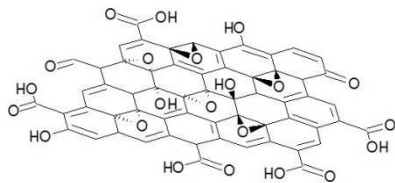
- **Environmental**

Water treatment

- **Medicine**

- **Sensors**

- **Other**



Graphene market prediction. Source: IDTechEx

Unique properties to be utilized

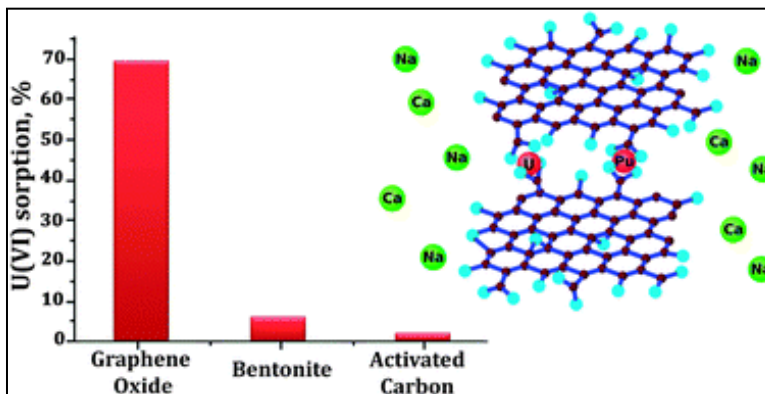
- High surface area - Ultrathin platelets
- GO dispersible – charged surface
- GO easily reduced to rGO
- rGO conductive

GO for treatment of polluted water

1. GO as ion-exchanger / scavenger

- Radionuclides
- Heavy metals

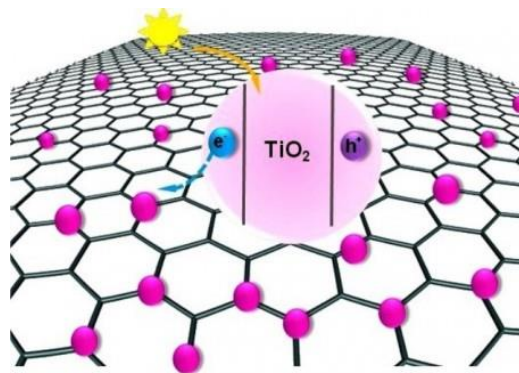
See poster No. 223



A. Y. Romanchuk et al., *Phys. Chem. Chem. Phys.*, 2013, 15, 2321-2327

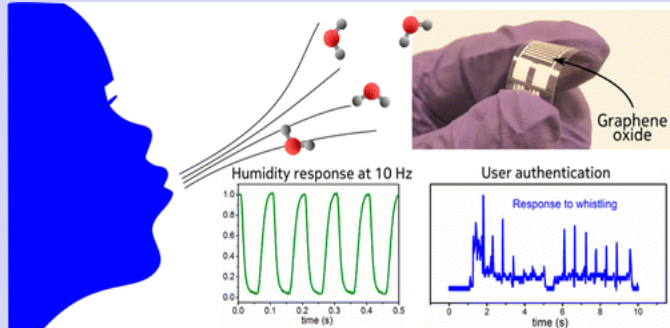
2. rGO as support for photo-catalyst

- Organic pollutants



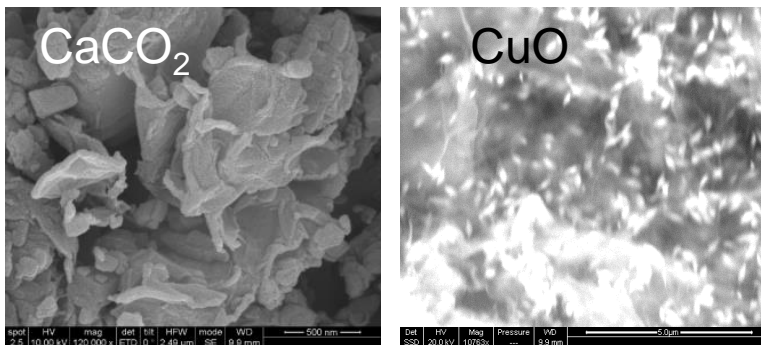
<http://photograph.cubiclemon.net/work-packages/>

Nokia recently developed an ultrafast humidity sensor based on GO



S. Borini et al., *ACS Nano*, **2013**, 7 (12), pp 11166–11173

Examples of GO «decoration»

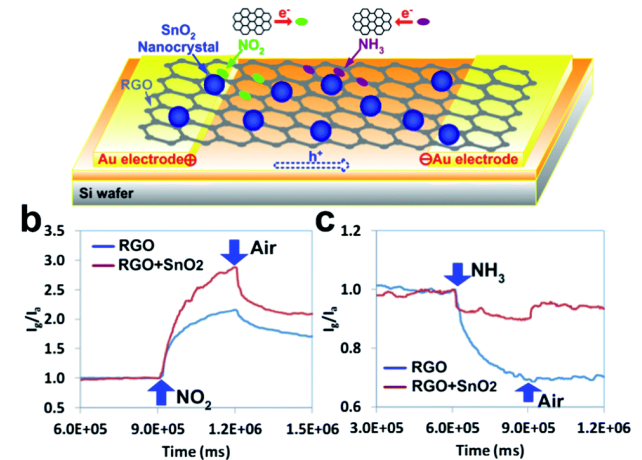


Sensors

Other reported examples

Ammonia
Ethanol
DNA
H₂S
HCN
NO₂
H₂
etc

Sensing principle



S. Mao et al. *J. Mater. Chem.*, 2012, **22**, 11009

Energy applications

Abalonyx works closely with our sister company Graphene Batteries AS

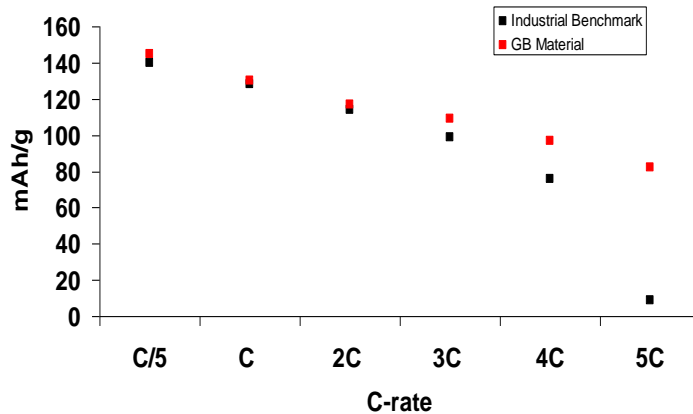


rGO for Batteries

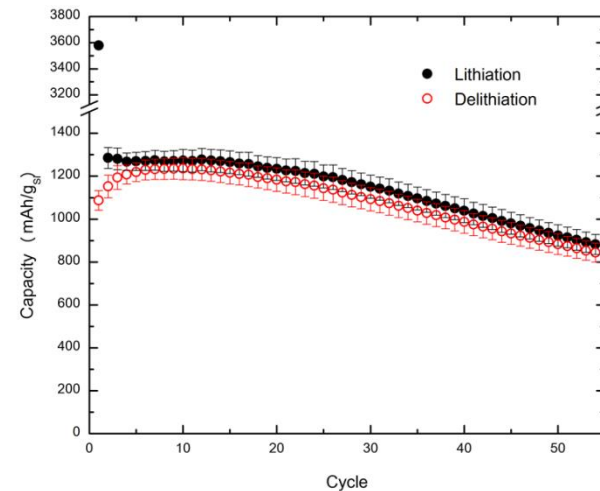
Abalonyx' sister company Graphene Batteries www.graphenebatteries.no develops novel Li-ion battery technology using GO / rGO from Abalonyx



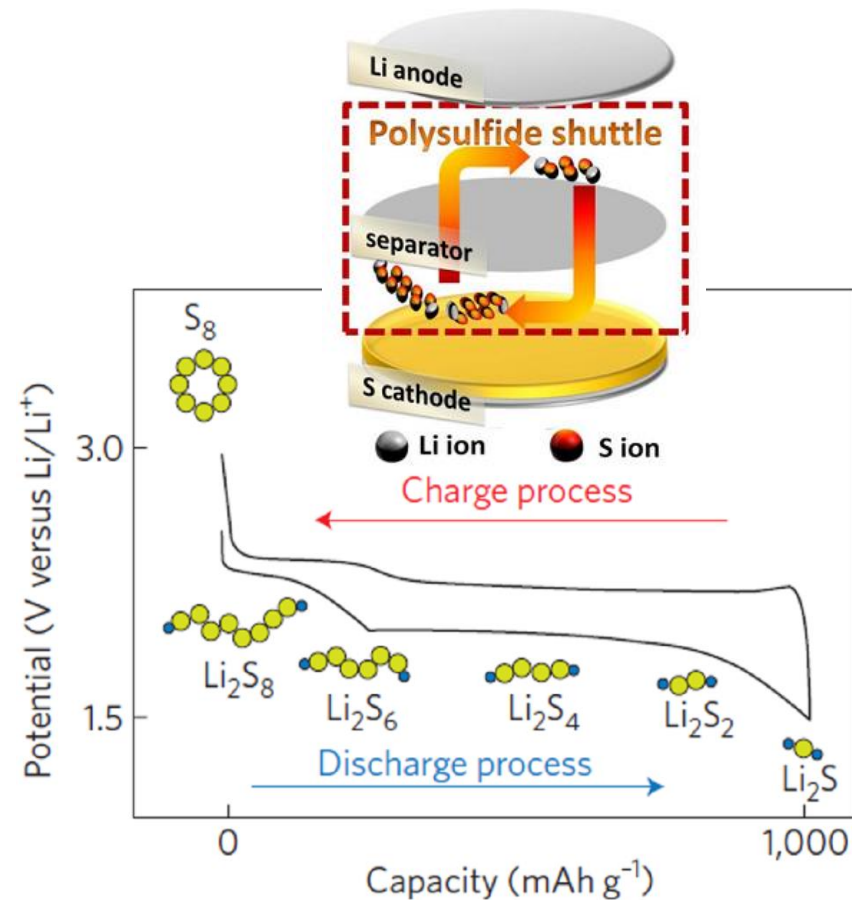
LFP / graphene (rGO)



Graphene/Si anodes



GB`s activities in Li/S batteries

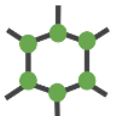
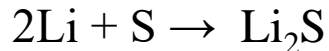
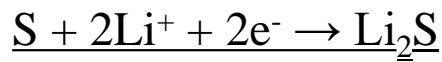
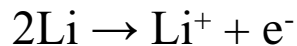


Challenges

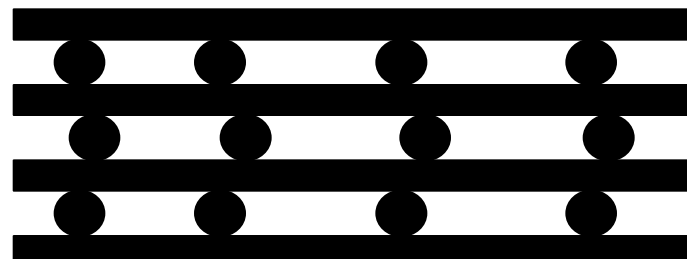
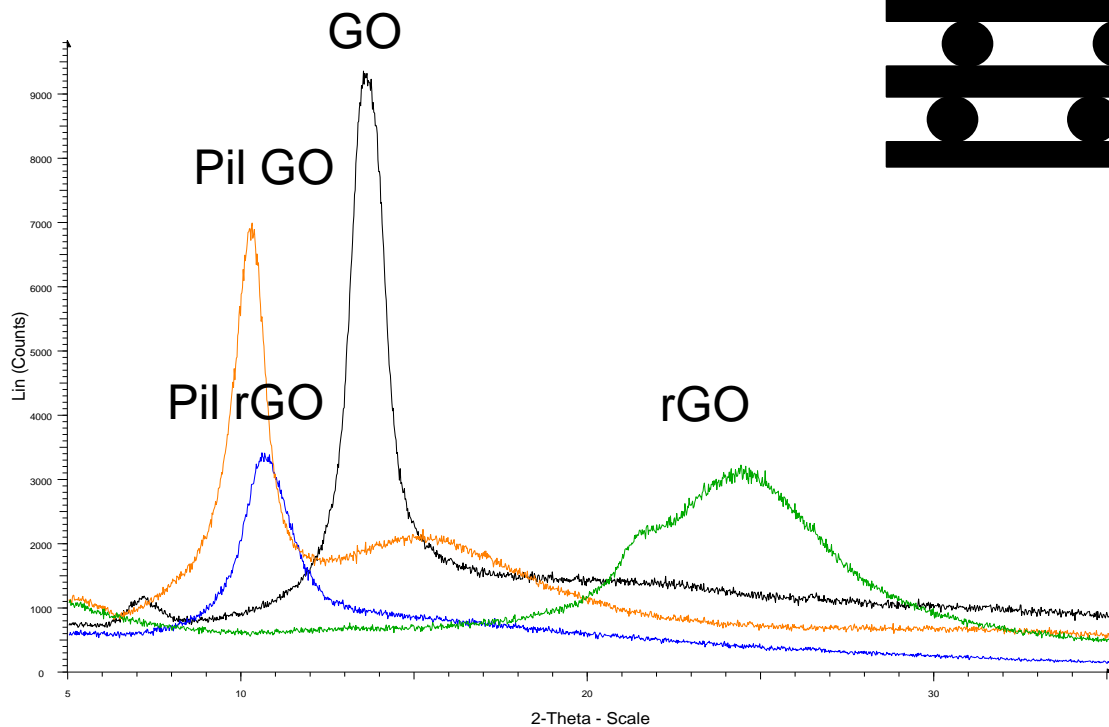
- Electronic conductivity
- Polysulfide shuttle
- Energy density

GB addresses these challenges

- 1- Ultra-thick cathode
- 2- GO/rGO cathode
- 3- Electrolyte pre-treatment



Pillared GO and RGO



Pillared GO and rGO
with conductive spacer
X-ray diffractogram

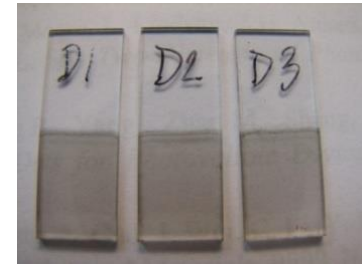
Formulations

Coatings, Composites, Inks etc

Conductive coatings

Electrically conductive

Thermally conductive



Protective coatings

Anti-corrosive

Anti-fouling

EMI and MF-shielding

Anti-ice



Polymer composites

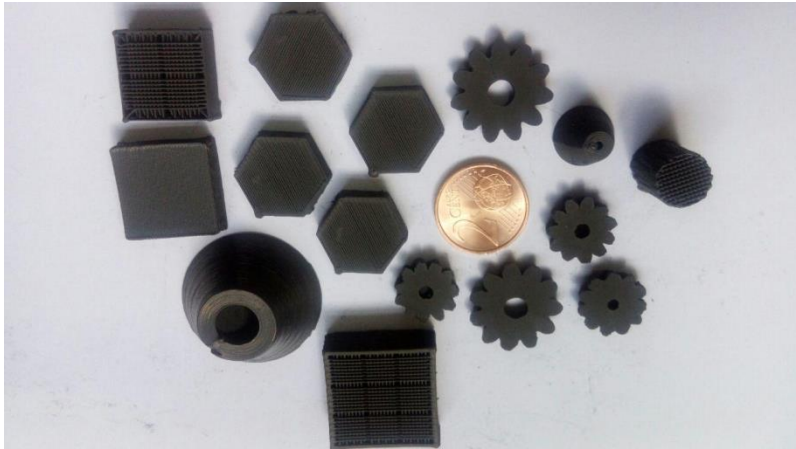
Inks for AM

The end of RUST?

Y. Su et al., Nature Communications 5, Article number: 4843

COMPOSITES

Ceramic and Glass - rGO



POLYMER - rGO

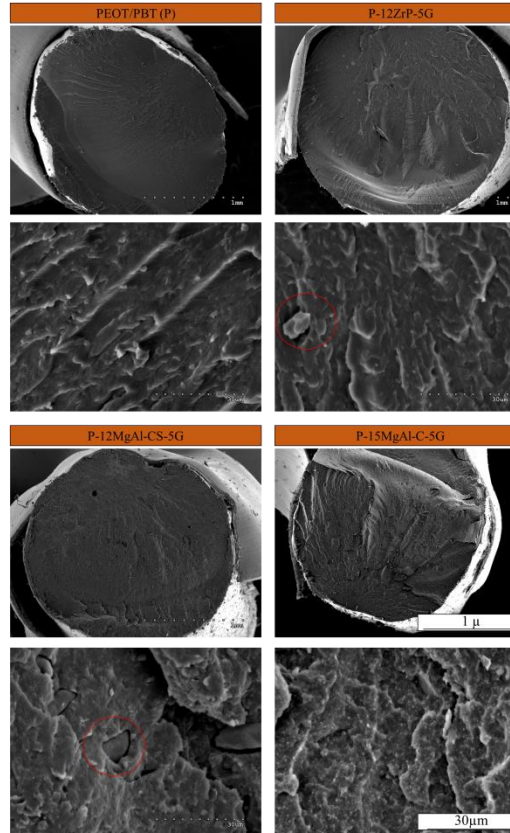


Figure 1:

- ◆ Incorporation of nanofillers in the polymeric matrix was obtained by melt blending showing a good dispersion of nanofillers surrounded by PEOT/PBT in the matrix.

Figure 2 (a) and (b):

- ◆ Representative stress-strain curves and yield strength obtained from compression tests show that:
- ◆ By adding nanofillers the elastic modulus of composite is increasing.
- ◆ P-15MgAl-C-5G shows the highest elastic modulus and yield strength which could be due to the higher amount of the reinforcing phase as well as homogenous distribution of this phase.
- ◆ P-12ZrP-5G and P-12MgAl-CS-5G show lower elastic modulus and yield strength which might be due to insufficient adhesion between nanoparticles and polymeric particles.

Figure 1- SEM micrographs of fractured surfaces of indicated composites.

See Poster No. 367



H2020-funded

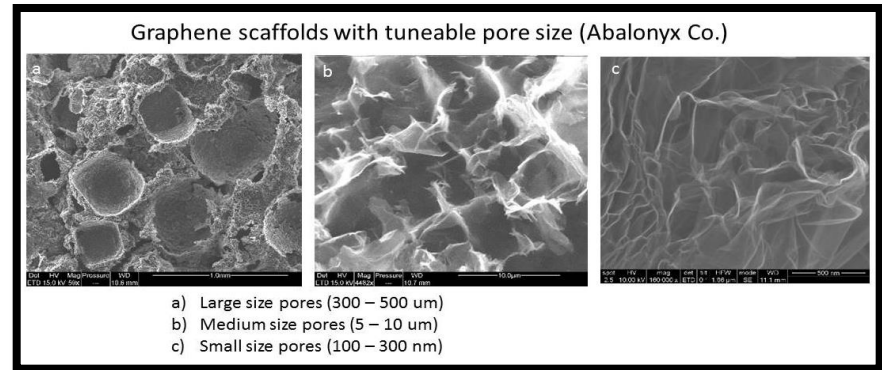
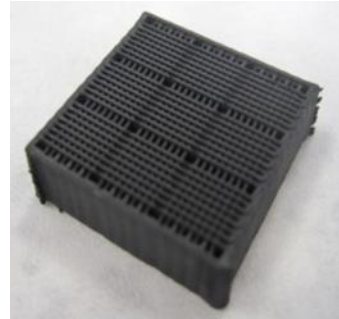
FAST

Functionally graded
Additive Manufacturing scaffolds
by hybrid manufacturing

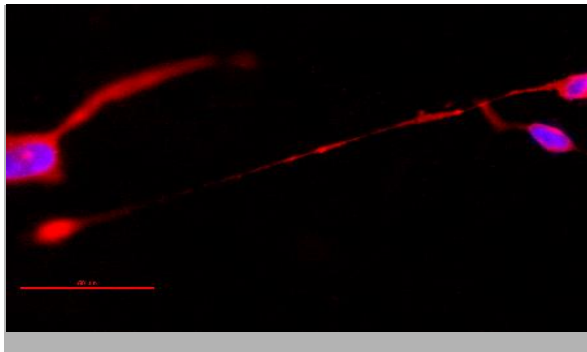
GO and rGO-scaffolds for stem cell differentiation

Collaboration w. University of Malaga, Prof. J. Aguirre and Dr. N. Rodriguez-Losada

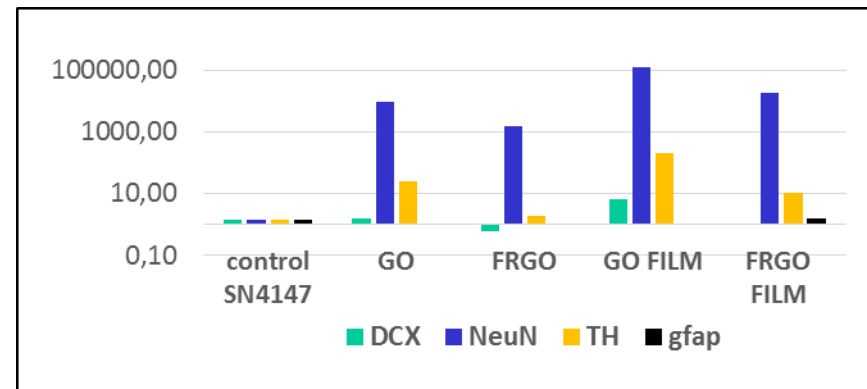
Abalonyx Graphene scaffolds with tuneable pore size



rGO scaffolds facilitates neuronal differentiation by factor 10,000

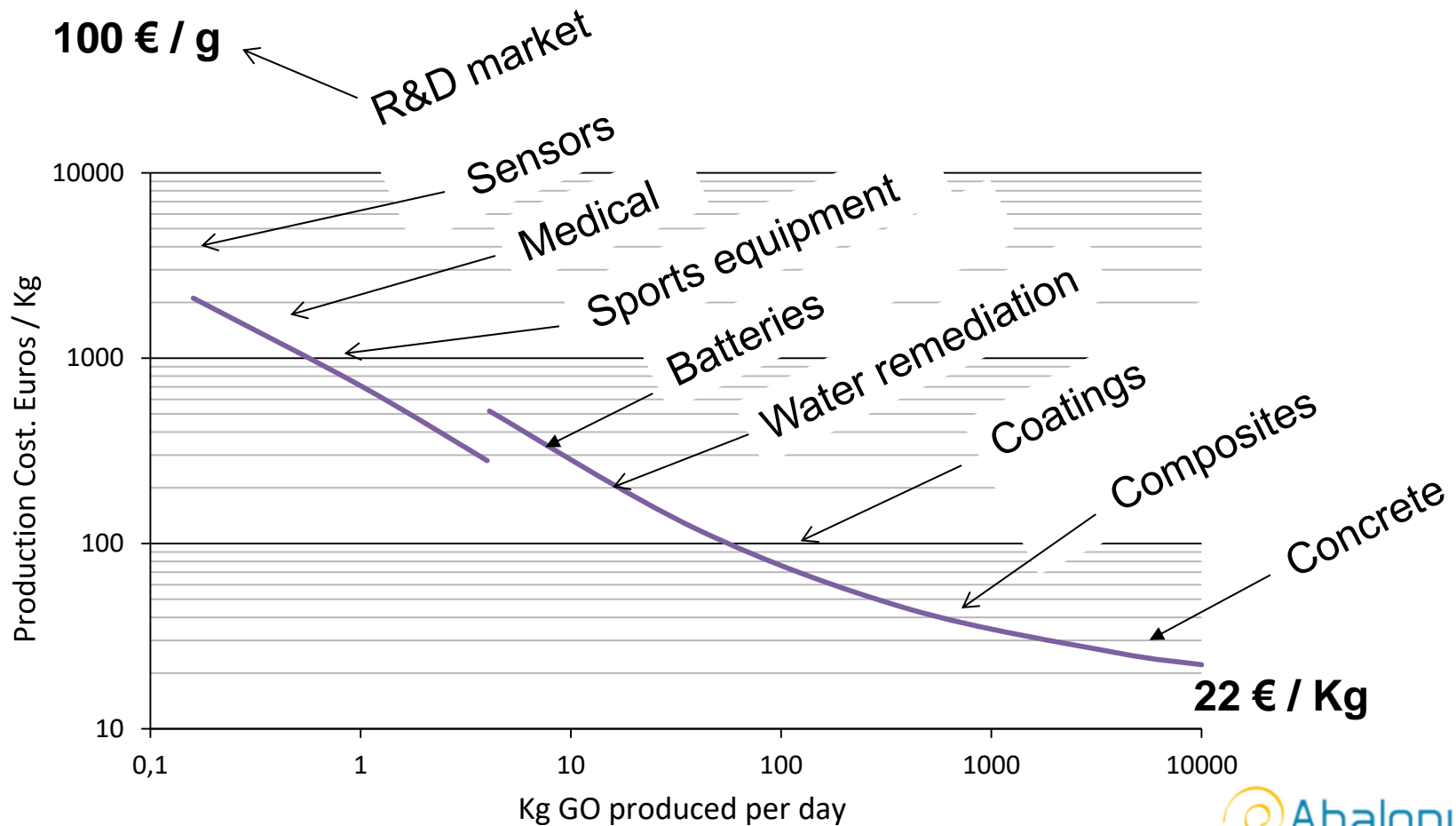


TH-antibody, dopamine marker/DAPI (nuclei)



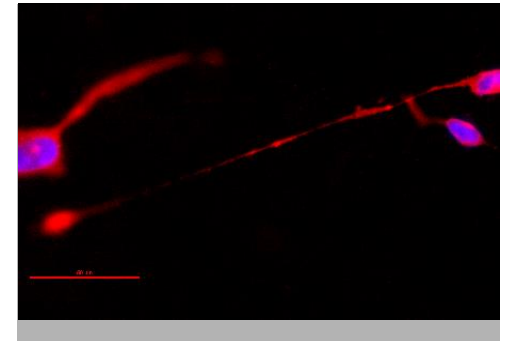
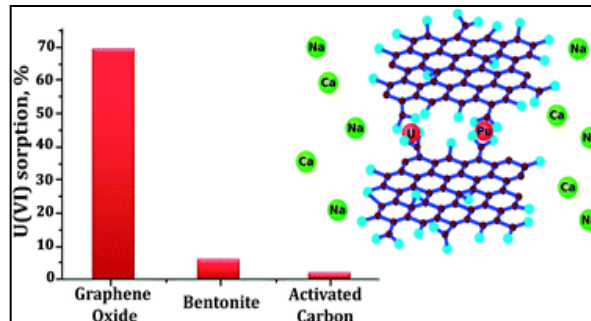
Graphene Oxide Market Forecast

Cost vs Market Acceptance



Conclusions

- Graphene oxide has unique properties
- First industrial applications on the horizon
- Industry acceptance strongly related to cost





The Team

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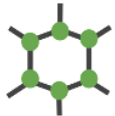
S. Fotedar
BS, Project
Engineer
GB AS

+
Dr. M. Slavik, Sulfur cathode specialist
Mr. W. Haugen, Production manager
Produksjon Abalonyx

Acknowledgements

- Abalonyx Team
- Graphene Batteries Team
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- FAST-project team
- Skaland Graphite AS
- Innovation Norway
- Research Council of Norway

Thank You!



Graphene Batteries

