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Innovative materials

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Upcoming applications of graphene oxide and graphene oxide derivatives

Rune Wendelbo

CEO, Abalonyx AS

www.abalonyx.com

Abalonyx AS

Labs and offices

Oslo, Norway

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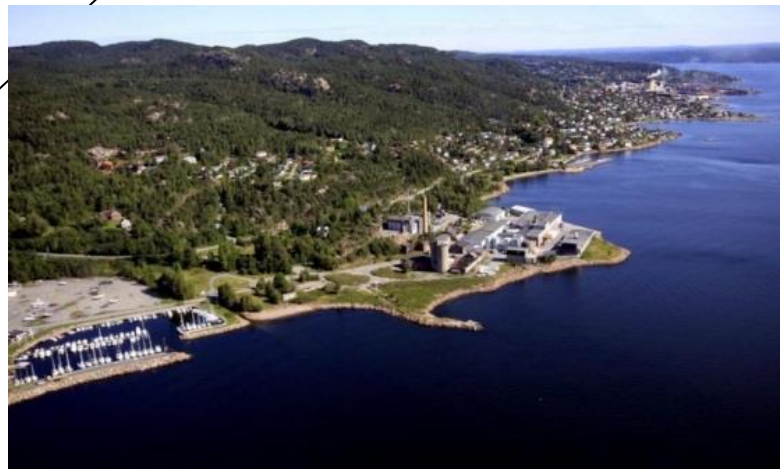
Production

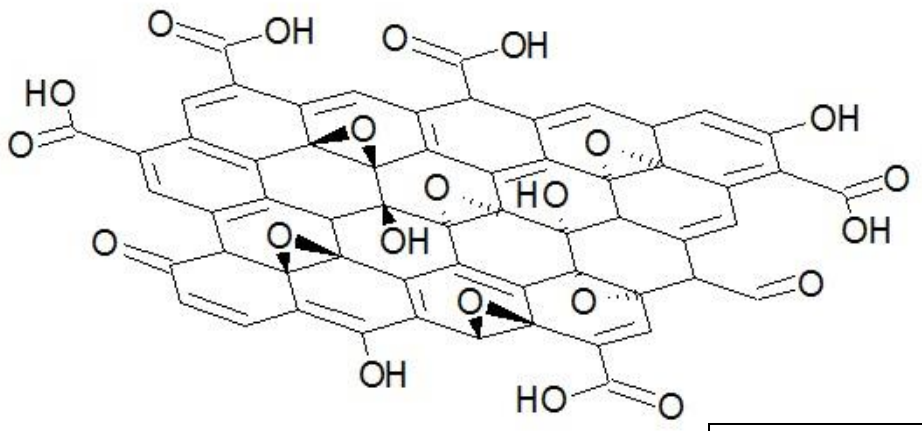
Tofte, Norway

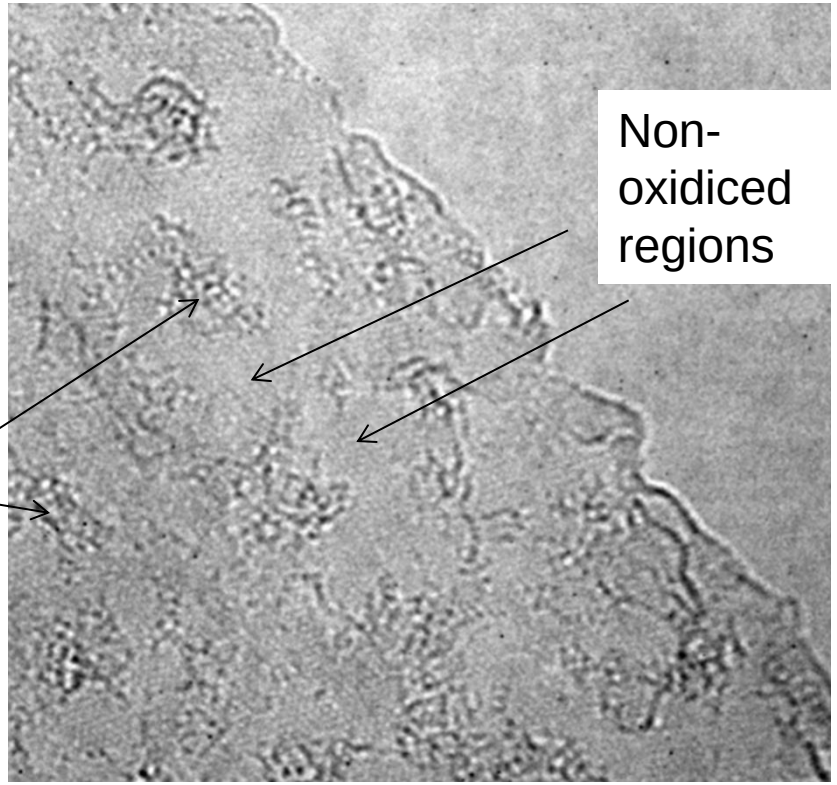


Graphene Oxide (GO)

Single sheets of oxidised graphite / graphene

Wt %	C	O	N	C/O
	52.9	39.2	0.13	1.8





Properties

- Non-conductive
- 1 nm thick
- ~1600 m^2 /g surface area
- Dispersible in polar solvents

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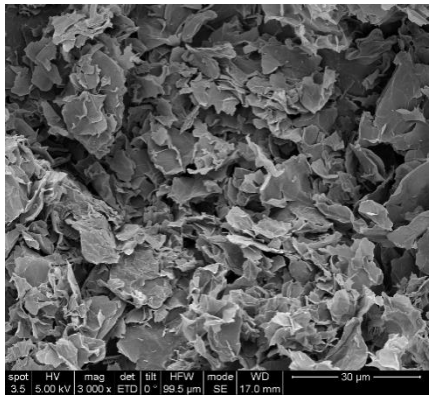
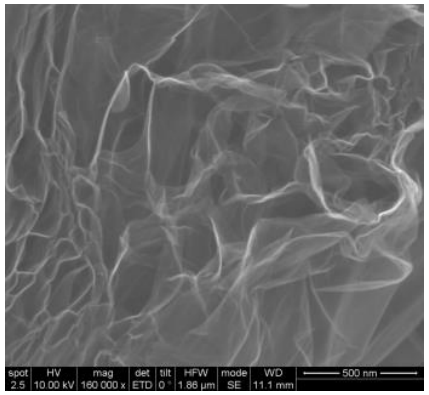
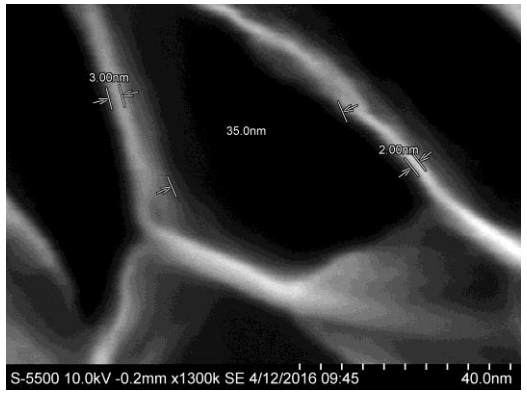
Thermal Reduction of Graphene Oxide

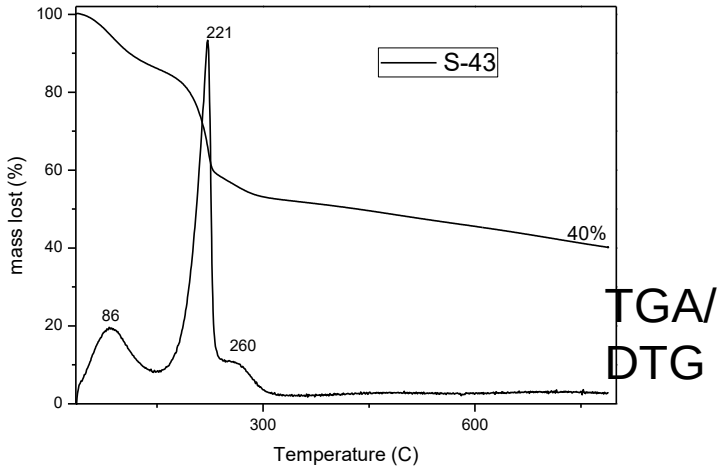


GO rGO

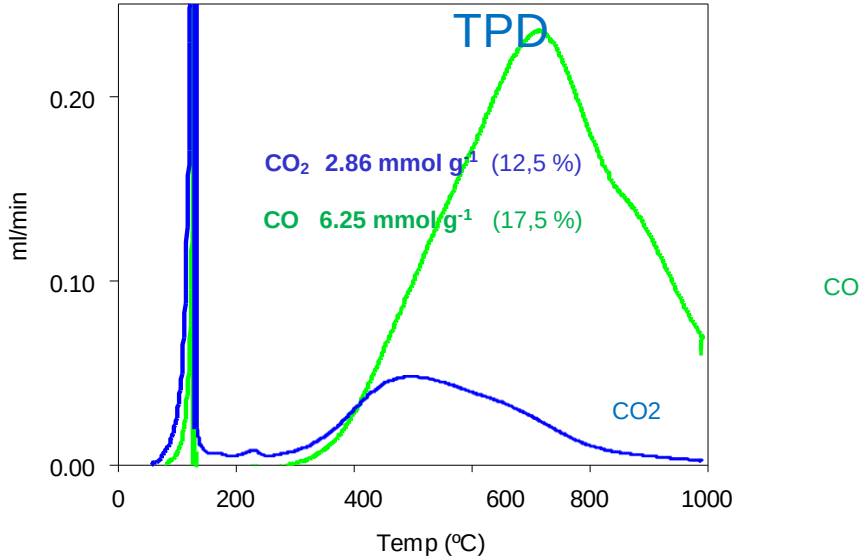
- Thermal
- Chemical
- Light induced







TGA/
DTG



CO

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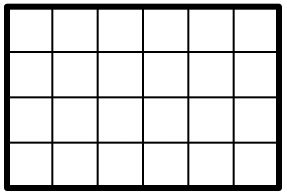
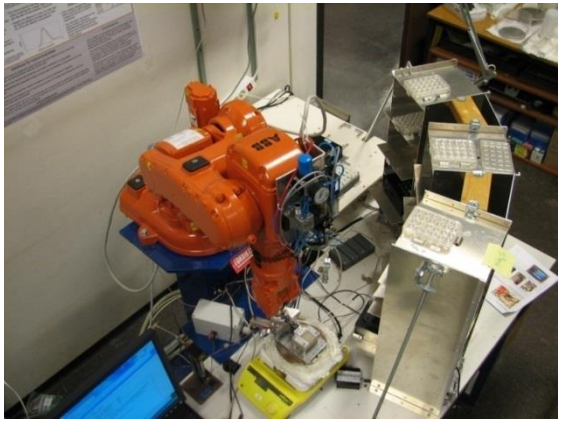
Our first graphene project: High Throughput preparation of Transparent Conductive Films

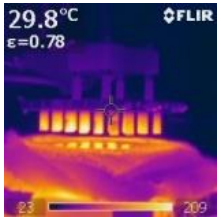
6 x 4 platform

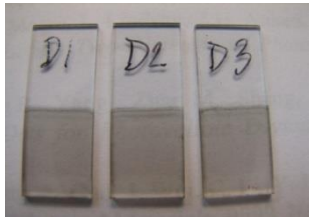


-
- **Parallelization**
- **Miniaturization**
- **Automation**

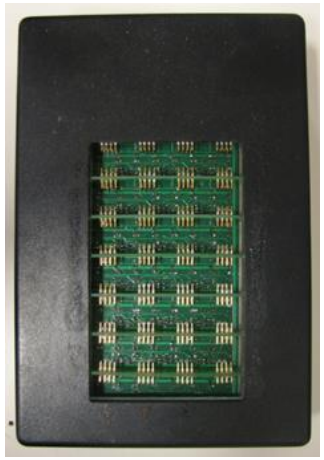
Station for transmittance measurments







Robotic arm set-up. Inserts show vacuum-station and heat-treated samples being withdrawn from oven



Station for 4-point conductivity measurments

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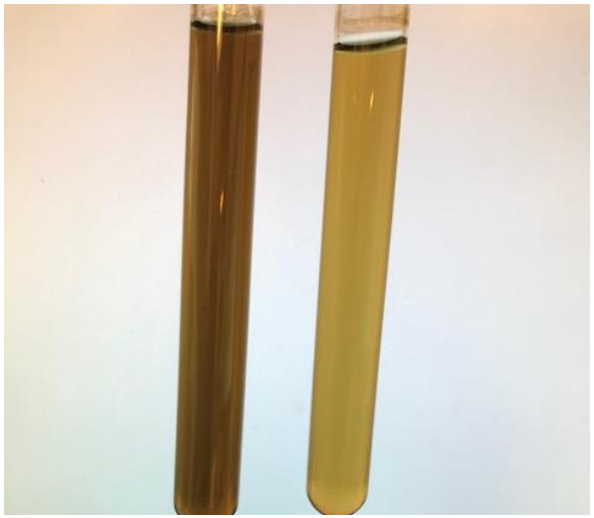
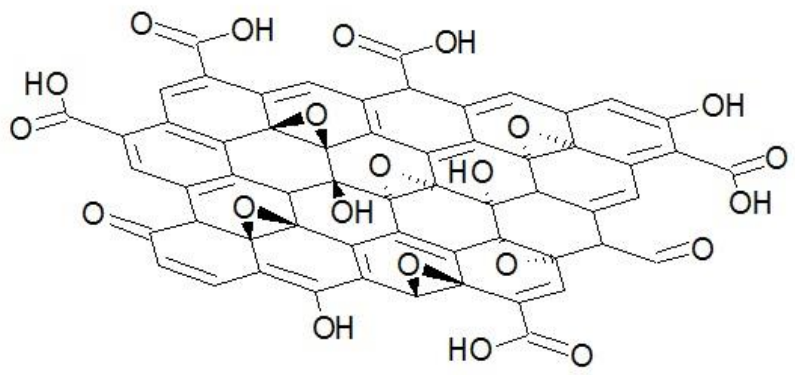
Graphene oxide: Some issues

- EHS-related issues
  - Environmental
  - Health
  - Safety
- Stability
- Cost





Upcoming Applications of GO and rGO

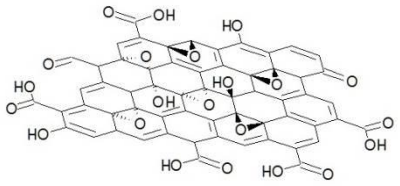
- **Energy**

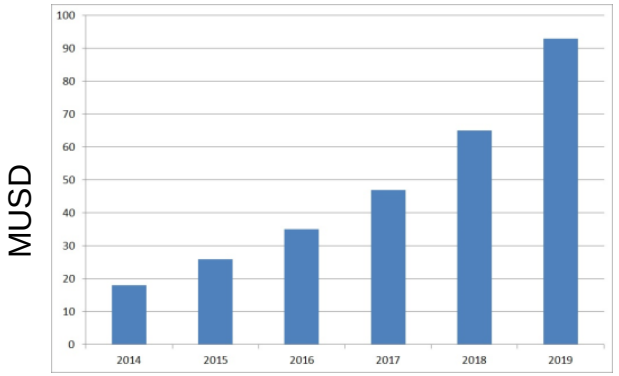
  Batteries, Super-capacitors, Solar
- **Materials**

  Polymer and ceramic 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

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Examples of recent news

- 3D printed graphene aerogel awarded Guiness World Record: 0.5 mg / cc

- Graphene oxide performs as an effective shape memory material

- Graphene Oxide load-speaker membranes to be commercialized by Canadian company ORA

Source: Graphene-info.com

Abalonyx Products

1. Graphene Oxide (GO)

   Raw GO, De-acidified GO, Freeze-dried GO, GO-films

2. Reduced Graphene Oxide (rGO)

   Raw rGO, Dosable rGO, De-acidified dosable rGO, rGO-films

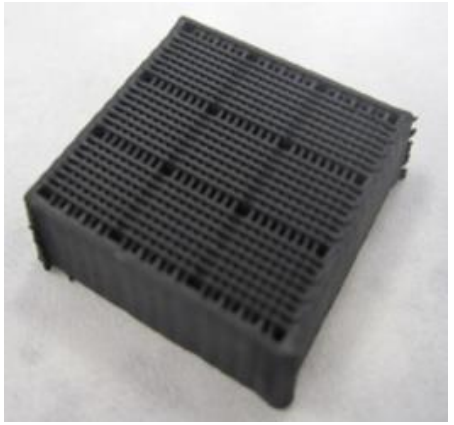
3. GO-ceramic-3D-prints and ink

4. N- doped GO and rGO

   Wet synthesis and plasma

5. Composite powder, GO and rGO

   with CaCo3, TiO2, SiO2, Hydrotalcite etc



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Our R&D activities in EU-funded projects

1. FAST-project: GO/rGO for biomedical

2. NanoElMem-project: GO/rGO for fuel-cell membranes

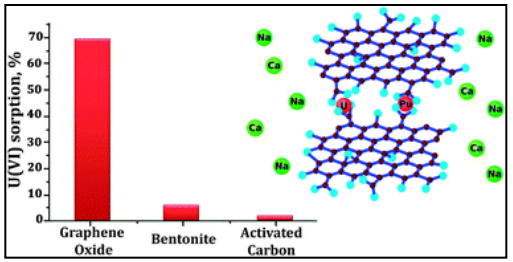
3. CARMOF-project: GO/rGO for CO2-capture composite

4. OLIDIGRAPH-project: GO/rGO for laser-protection

5. SIGNIFICANT-project: rGO for heat dissipation

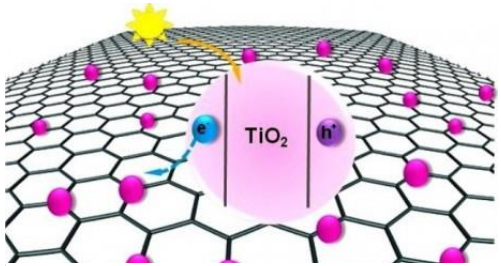
GO for water treatment

1. GO as ion-exchanger / scavenger
   - Radionuclides
   - Heavy metals



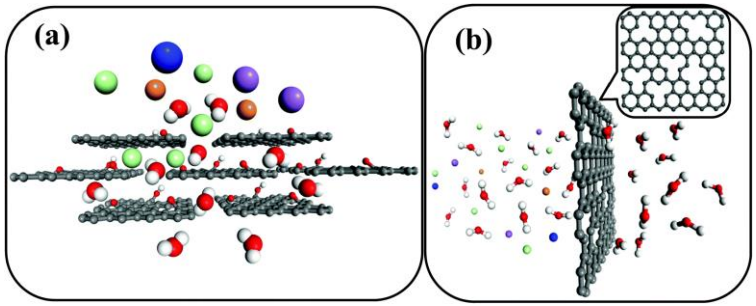
A. Y. Romanchuk et al., ***Phys. Chem. Chem. Phys.***, 2013,**15**, 2321-2327

2. rGO as support for photo-catalyst
   - organic pollutants



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

3. Filtration
   - Desalination



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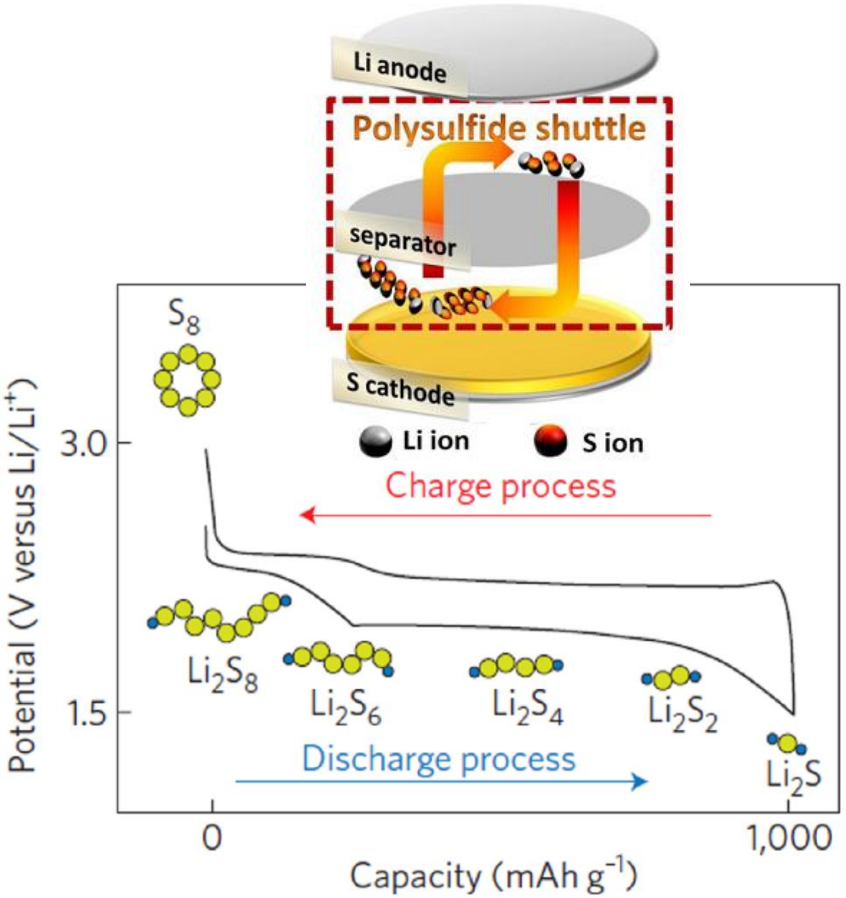
Energy applications

Abalonyx works closely with our sister company Graphene Batteries AS

- Super- and ultra-capacitors
- Graphene coated current collector
- Li-S-batteries

GB`s activities in Li/S batteries



$2Li \rightarrow Li^+ + e^-$

$S + 2Li^+ + 2e^- \rightarrow Li_2S$

$2Li + S \rightarrow Li_2S$

Challenges

- Electronic conductivity
- Polysulfide shuttle
- Energy density

GB addresses these challenges

1- Ultra-thick cathode

2- GO/rGO improved cathode

3- Electrolyte pre-treatment

Graphene Batteries

Formulations

Coatings, Composites, Inks etc

Conductive coatings

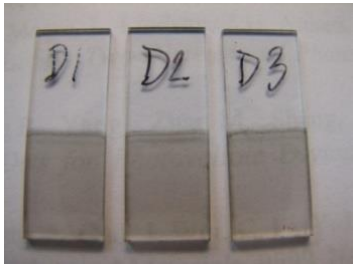
- **Electrically conductive**
- Thermally conductive

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

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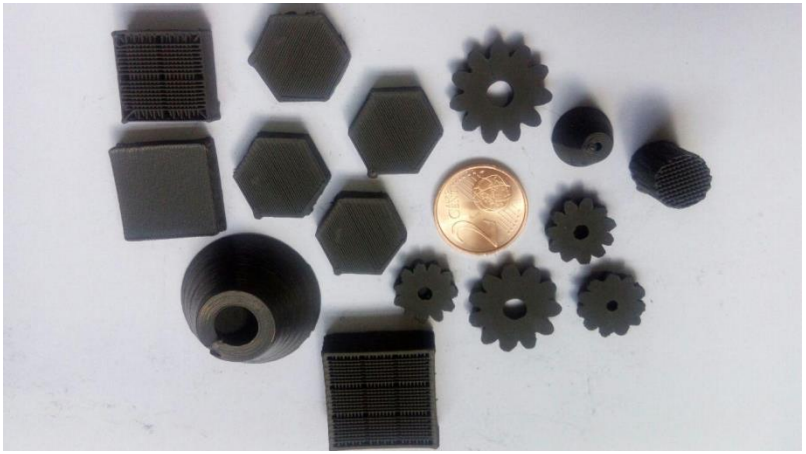
COMPOSITES

Ceramic and Glass - rGO



H2020-funded

FAST

Functionally graded Additive Manufacturing scaffolds by hybrid manufacturing

POLYMER - rGO

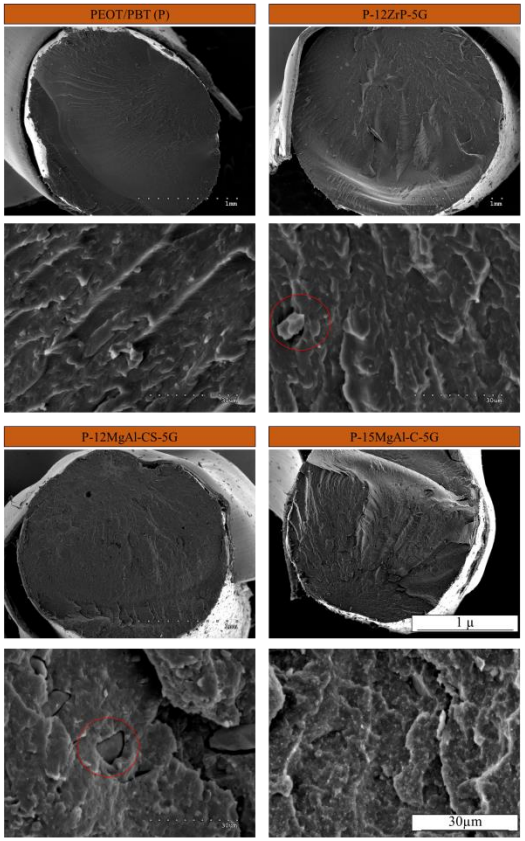


Figure 1- SEM micrographs of fractured surfaces of indicated composites.

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.

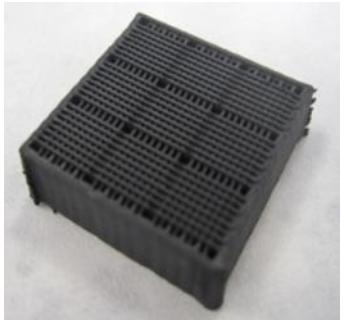
Figure 2 (a) and (b):

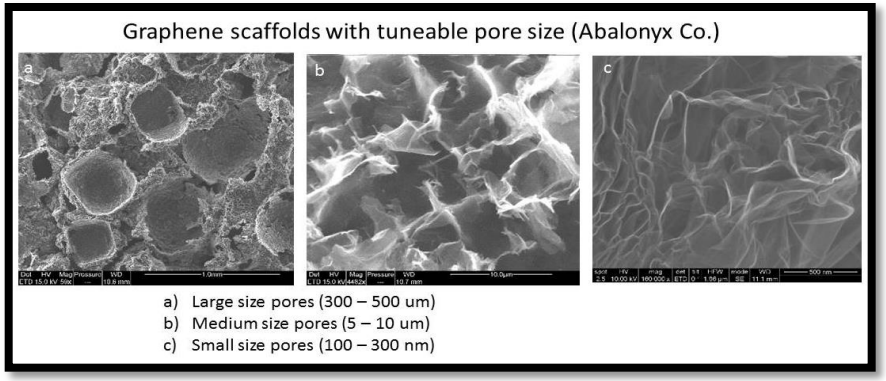
- Representative stress-strain curves and yield strength obtained from compression tests show that:
- By adding nanofillers the elastic modulus of composite is increasing.
- P-15MgAl-C-5G shows the highest elastic modulus and yield strength which could be due to the higher amount of the reinforcing phase 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.

GO and rGO-scaffolds for stem cell differentiation

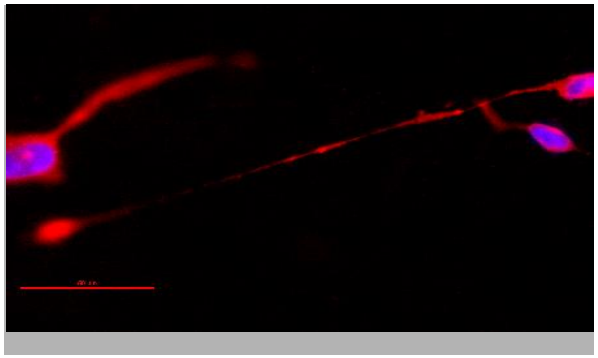
Collaboration w. University of Malaga, Prof. J. Aguirre and Dr. N. Rodriguez-Losada

Abalonyx Graphene scaffolds with tuneable pore size

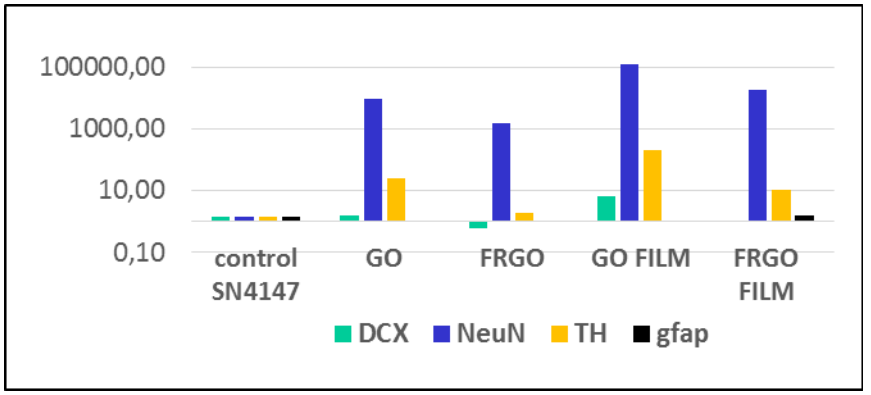




rGO scaffolds facilitates neuronal differentiation by factor 10,000



TH-antibody, dopamine marker/DAPI (nuclei)



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Graphene oxide
Cost vs Market Acceptance

For lab R&D,	100,000 €/Kg OK
For high end applications	1000 – 10,000 €/Kg OK
For commodities	Maximum 50 €/Kg

Our estimates show we can come to 22 € / Kg production cost

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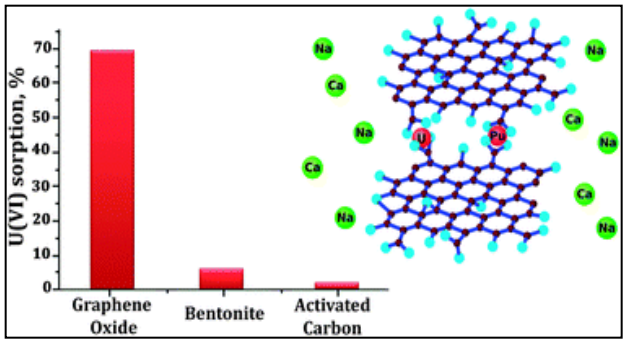
Conclusions

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



Acknowledgements

- Abalonyx Team and Board
- Graphene Batteries Team
- Univ. Extremadura, Spain
- Skaland Graphite AS
- EU
- Innovation Norway
- Research Council of Norway

Thank You!