Commercialization of Functionalised Graphene Coating

Siva Bohm & Mark Thompson

Talga Technologies Ltd UK, Talga GmbH Germany, Talga Sweden (Subsidiary of Talga Resources Ltd)

Graphene Flagship 2017,
Barcelona-Spain
29th March 2017
What we do

➢ Talga is an advanced materials company with a scalable and cost effective process to liberate graphene and graphite from its large high quality graphite ore deposits without crushing or milling.

➢ Talga is a listed public company on the Australian Stock Exchange (code TLG) with subsidiary operations in Sweden, Germany and United Kingdom.

➢ Potential to be worlds largest volume supplier of graphene products, ultrathin micro/nano graphite, Few Layer Graphene (Talphene™) materials, as well as conductive carbon/silicate filler for industrial applications.

➢ Additionally tuned Graphene applied technology provider, B2B.
Part of Talga team at Phase 2 pilot plant commissioning in Rudolstadt, Germany
World’s highest grade JORC/NI43-101 graphite resource

Process technology requires no crushing, no grinding

Deposit in **Sweden** - top class jurisdiction

**Germany** pilot plant scaling up technology and large scale product dev. solution provider to customers

Vertically integrated raw ore-to-product producer with developing products in energy storage/harvesting, coatings, inks application and advanced conductive material (functional) products

Low capex/opex/funding requirements

Value added Applied Graphene products in Cambridge, Talga **UK**
✓ Vertically integrated with in-house product expertise value-adding to raw materials

✓ Pilot plant operational & successfully scaling up

✓ Product pipeline across multiple large technology and bulk sectors

✓ Process technology enables bulk high quality graphene production

✓ Low cost ‘no crush/grind’ & low enviro-impact process

✓ Highest grade graphite resources in the world

✓ Large and unique ‘electrode’ style ore deposits

✓ Top class jurisdiction Sweden
- Talga owns 3 of Top 10 grade graphite resources in world
- Pipeline of development to deliver into market
- Focus on margins and volume of market applications, not resource tonnes for tonnes sake

Operations - Trial Mining 2016

- **Innovative** graphite ore mining technique
- Extracts ore as direct use “electrodes”
- No ‘drill and blast’ of ore = less dust and noise/minimise environmental impact
- Trial of larger, tailor-made and automated ore block cutting equipment successful
- ~5,000t extracted to date to feed upscaled pilot test processing and graphene product development

Measurement performed at inVia Raman Renishaw spectrometer,
Single scan, 532nm laser, 1800 l/mm grating, x50 objective

**Swedish Vittangi Graphite mined from Talga**

Graphene Week 2016, Renishaw booth
Electrochemical Exfoliation Process - Advantages

- Process liberates **graphene and micrographite** directly from **raw ore**
- Requires **no crushing, no grinding, no jet milling**
- Makes **ultrafine** and **ultrathin** size particles, a type of material not previously available **economically** at this **scale**
- Lowers **energy, costs** and **emissions of graphene production**
- Higher **performance** in some applications – pristine platelets, no reduction damage, larger size particles
- Talga owned technologies large volume FLG, MLG, GNP and 99.9% Graphitic Carbon (see [www.talgaresources.com](http://www.talgaresources.com) / announcements and reports / videos)
Graphene Production Techniques

Electrochemical Advantages

<table>
<thead>
<tr>
<th>Method</th>
<th>Approach</th>
<th>Product type</th>
<th>Flake sizes</th>
<th>Chemical purity, structural uniformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Liquid Phase Exfoliation</td>
<td>top-down</td>
<td>GNP, MLG</td>
<td>300-50,000 nm</td>
<td>average (some low at wt% O2 groups)</td>
</tr>
<tr>
<td>2  Graphene Oxide reduction</td>
<td>top-down</td>
<td>vFLG</td>
<td>3,000-20,000 nm</td>
<td>below average (high at wt% O2 content)</td>
</tr>
<tr>
<td>3  Electrochemical Exfoliation</td>
<td>top-down</td>
<td>vFLG</td>
<td>500-10,000 nm</td>
<td>very good</td>
</tr>
<tr>
<td>4  Chemical Synthesis</td>
<td>bottom-up</td>
<td>FLG, vFLG, MLG, GNP</td>
<td>20-6000 nm</td>
<td>good (some low level metal impurities)</td>
</tr>
</tbody>
</table>

Source: Fullerex - Webinar

Copyright Talga Technologies Ltd, 28.03.2017
Operations - Pilot Plant

- **Pilot test-work well advanced**
- **3 phases** to upscaling process – Phase 2 just commissioned
- High quality graphene output confirmed, via Key Academic & industrial partners
- ~76% of input carbon converted to graphene
- Capacity scale up continues towards Phase 3
- Product inputs represent the inventory for customer samples
- Plant capacity = 30T of ore from single modular platform, potential to be duplicated
HR-TEM and other tests confirm high quality, 1-4 layer graphene, Lateral Flake size 5-10 microns (Process A- Application A).
Graphene (Talphene™) Characterisation

Atomic Force Microscopy (AFM) analysis data confirms:

- Graphene predominantly thin flakes (up to 2-4 nanometres)
- Lateral size of flakes (approx. 100-200 nm - Process B-Application B)
Corrosion Protection
Market Size: $11B (2013)
- Anti-corrosion & anti-fouling coatings
- Electric and thermally conductive inks
- Battery and fuel cell coatings
- Current market 40Mt/a

Batteries & Membranes
Market Size: $24B
- Li-ion batteries
- Flow batteries
- Fuel cells
- Solar panels
- Printable batteries and circuits

Conductive Ink
- Flexible conductive plastics
- Stronger, lighter plastics and carbon fibre materials
- 3D printing inks

Cement & Concrete Additives Size: $17B (2016)
- Lighter, stronger cement
- Higher performance insulation materials
- Functional (electrical or thermally conductive) glass & building materials

Target Markets


Copyright Talga Technologies Ltd, 28.03.2017
Products (Functionalised Coatings & Composites)

**Protective Coatings & Composite**
- **Problem:** e.g. coatings need to be thinner, higher performing, Cr(VI) being banned, zinc expense
- **Solution:** graphene enhanced anti corrosion coatings – inert, conductive, barrier properties

**Conductive Ink & Sensors**
- e.g. **Problem:** Expensive incumbents (nano-silver), not flexible, weight of copper alloy wires
- **Solution:** graphene conductive inks that are flexible, printable or part of composite matrix

**Concrete**
- e.g. **Problem:** low strength without corrosive rebar or magnetite, heating wires required = expensive
- **Solution:** graphene enhanced concrete with electrical/thermal conductivity, improve performance

**Energy Storage – Batteries & Fuel cells**
- **Problem:** Fuel cell bipolar plates rely on expensive platinum, membrane efficiency low
- **Solution:** conducting and corrosion resistant graphene membranes in fuel cells and batteries

Copyright Talga Technologies Ltd, 28.03.2017
Cost of Corrosion – Global Economic Impact

Corrosion causes significant costs in infrastructure, maintenance and replacement.
Global coatings market = $120 billion per annum.

United Kingdom
GDP (2008) $2,279 billion
Annual cost of corrosion: $70.6 billion

Australia
GDP (2009) $920 billion
Annual cost of corrosion: $70.6 billion

USA
GDP (2007) $13,840 billion
Annual cost of corrosion: $429 billion

Average of 3% GDP

Reference:
NACE figures: http://events.nace.org/publicaffairs/cocorrindex.asp
GDP figures: http://www.economywatch.com/

Alarming corrosion in Eiffel Tower, Paris, France
Hohenzollern Bridge in Cologne, Germany (Source: Corrosion - by Gretchen A. Jacobson - Materials Performance)
Product – Coatings Market

Fig 1. Paints and Coatings Global Market US$/annum.

Total Paints and Coatings Market: $120 Billion

- Decorative: 42%
- Protective & Marine: 12%
- General Industrial: 18%
- Auto OEM: 9%
- Auto Refinish: 6%
- Wood: 6%
- Packaging: 3%
- Aerospace: 1%
- Coil: 3%

Source: Jan 2016 Valspar Investor Presentation after 2013 Orr & Boss, Kusumgar, Nerifi & Grownery

Fig 2. Paints and Coatings Market Leaders US$/annum.

Global Leaders by Sales ($Billion)

- *PPG: 14.3
- *AKZO: 11.4
- SHW: 11.1
- Valspar: 4.6
- RPM: 4.4
- Axalta: 4.4
- *BASF: 3.6
- Kansai: 3.1
- Nippon: 2.4
- Jotun: 2.2
- *Masco: 2.0

Source: Jan 2016 Valspar Investor Presentation & Company reports. *Excludes non-coating sales
Talga Graphene Coatings

Talga Raw Graphite Ore

Talga Novel Exfoliation Process

Chemical Modification

Functionalisation

Surface Interaction/Adhesion

Barrier Properties

Metal substrate

Talga Few Layer Graphene Coated Metal

Talga Few layer Graphene

Copyright Talga Technologies Ltd, 28.03.2017
Functionalisation of Graphene is key for performance

- Sheets of Graphene can be readily functionalized using reactive reagents also different routes e.g. radicals, plasma, fluorine, diazonium salt and nitrene.

- By functionalizing the sheets, sp² hybridised carbon atoms become sp³ hybridised carbon atoms, this allows us to control the electronic properties of Graphene, as well as compatibility current materials.
Processing Graphene into Products

Graphene or GO/rGO or GNP → Functionalisation

Functionalised graphene or Dispersed GO/rGO or GNP in resin (thermosets or plastics) → Compounding/Polymerisation

Protective Coatings - Depends on Customer needs

✓ Improved performance can be seen only with correct dispersion
Functionalisation of Graphene for Coating

c) Condensation

Cleaned Steel Substate

Functionalised Graphene

Graphene based coating on steel

Graphene
Graphene (after functionalisation)

Transmittance (a.u.)

4000 3500 3000 2500 2000 1500 1000 500

Wavenumber (cm⁻¹)

NH₂

C₂H₆

C₂N

Graphene Anti corrosion coating: Nanoscale, 7(42) 17879 (2015)

Copyright Talga Technologies Ltd, 28.03.2017
Multi Functional Coatings - Customer demand

Coatings

Functional value (e.g. anticorrosion, hydrophobic, intumescent, etc.)

Decorative value

10% additive (micron-sized) in paint matrix

0.1% additive (nano-sized) in paint matrix

<0.01% additive (high surface area e.g. Graphene) in paint matrix

Copyright Talga Technologies Ltd, 28.03.2017
Protective coatings for Ships, Pipes, Sections...

- Acrylic Finish Coat
- Non Pigmented Epoxy Undercoat
- Epoxy MIO
- Epoxy Sealer Coat
- Zinc Rich Epoxy Primer / Zinc Silicate Pre Fab
- Shot Blasted Steel Substrate

Modern Longs Coating System

- Steel Substrate: Blast Cleaned: Sa 3
- Sprayed Aluminium or Zinc Pre Fab.
- Sealer Coat
- HB Zinc Phosphate Epoxy Undercoat
- HB Epoxy MIO Undercoat
- Two Pack Polyurethane Finish

Total: 300 µm

Durability of protective coating depends on barrier properties
Graphene oxide-Thermosets resins O2 & H2O

Water Permeation ~ 46% reduced

Oxygen Permeation ~ 31% reduced
Pre finished Steel - Coil Coatings

Protective coatings

Coatings
Surfaces
Interfaces

Adhesion Science
Polymer Chemistry
Degradation
Metallurgy
Coatings Application

Differentiated Products

Copyright Talga Technologies Ltd, 28.03.2017
Hydrolysis

Polymerisation

Precipitation

mechanism of Cr(OH)₃ backbone formation

Condensation of Cr⁶⁺ to Cr³⁺ by nucleophilic attack of hydroxyl ligands in backbone

Hydrolysis-Polymerisation-Precipitation mechanism of Cr(OH)₃ backbone formation

Copyright Talga Technologies Ltd, 28.03.2017
Graphene Coating Evaluation EIS – Cr(VI) vs Graphene

Graphene Anti corrosion coating: Nanoscale, 7(42) 17879 (2015)
Talga Graphene Coatings- Cr(VI) replacement

Graphene based anticorrosive coatings for Cr (VI) replacement, Nanoscale, September 2015.
PREPARATION

- Graphene

Functionalized Graphene

- Graphene Coating

Current commercial Cr(VI)

- After salt spray

Graphene functionalised with inhibitor pre-treatment

- After salt spray

✔ Improved performance over chrome-containing reference
✔ Customer trial of metal surface treatment in progress

Copyright Talga Technologies Ltd, 28.03.2017
Talphene™ anti corrosion coating – EIS Evaluation

**Without TALPHENE™ coating**

- **0 h**
- **288 h**

**With chemically functionalised TALPHENE™ coating**

- **0 h**
- **480 h**

Graphene in pre-treatment “Water Permeation ~ 74% reduced”
Graphene as a barrier against ions

Water uptake vs Graphene concentration

Elsevier Journals, e.g. Flatchem - Special Issue - Industrial applications of Graphene, & 2D Materials Coatings & Inks Q3-2017
Plan to manufacture targeted ‘fit for purpose’ graphene products to complement supply of raw graphene and graphitic materials.

Potential licence income streams with third parties using patented products.

Strategy to realise revenue opportunities during pilot processing stage, prior to full-scale production.

Validation of industrial testing and benchmarking trials to demonstrate tangible outcomes and commercial progress.
Graphene will play an important role in anti-corrosion protective coatings for metals.

Combination of graphene specific anti-corrosion properties and barrier properties enable graphene based coatings to become the future “chrome-free” coatings.

Talga’s graphene production process can be scaled up for industrial demand, is low cost and environmentally friendly.

Talga is working with industrial (e.g. Chemetall – BASF) partners including a major surface treatment supplier, as well as academic partners to speed up different product technologies.
Acknowledgements

Teams at Talga Resources Ltd (ASX:TLG),
Talga Advanced Materials GmbH,
Talga Mining Pty Ltd Filial & Talga Technologies (UK) Ltd

IIT Bombay ME & Materials students

Cambridge University – College of Engineering,
Cambridge Graphene Centre – Prof Andrea Ferrari team

Tata Steel & Tata Group (Europe & India)
Vittangi trial mining For video see https://www.youtube.com/watch?v=q2Xmz7Buj3A

Copyright Talga Technologies Ltd, 28.03.2017