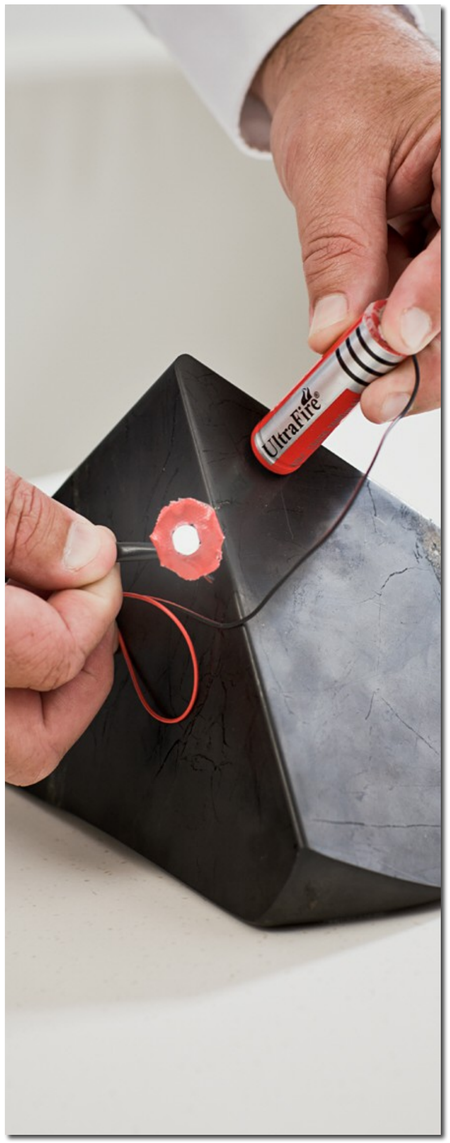
Commercialization of Functionalised Graphene Coating

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.

Operations

Talga Resources Ltd

Australia - Corporate HQ

Part of Talga team at Phase 2 pilot plant commissioning in Rudolstadt, Germany

Talga Mining Pty Ltd Filial

Sweden - graphite source

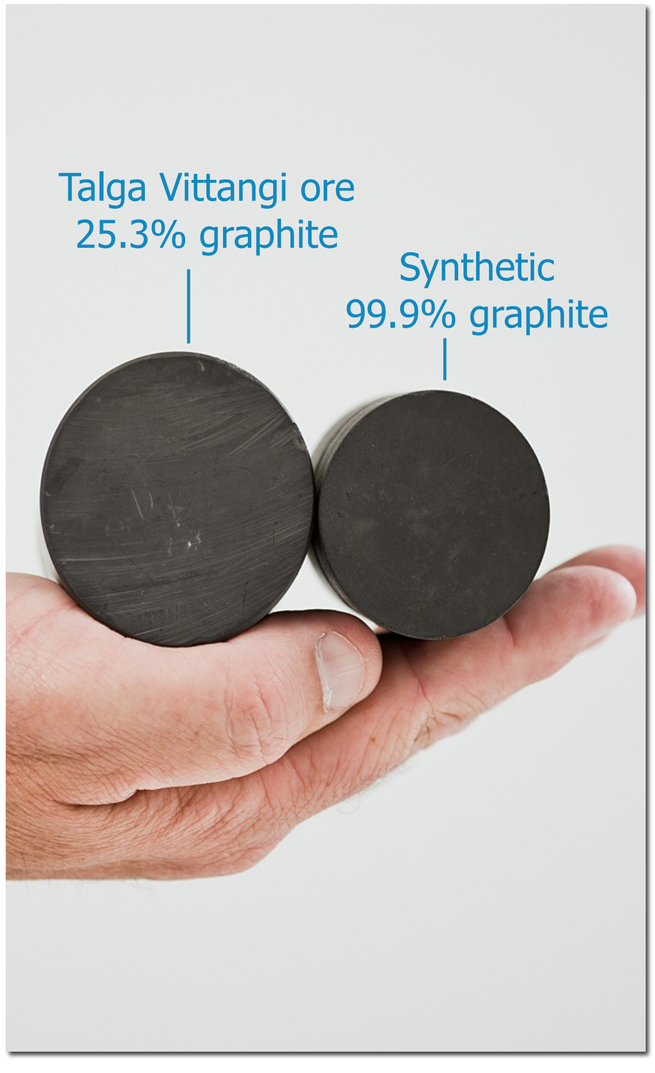
Talga Technologies Ltd

UK - product development

Talga Advanced Materials GmbH

Germany - pilot process facility

Talga is different

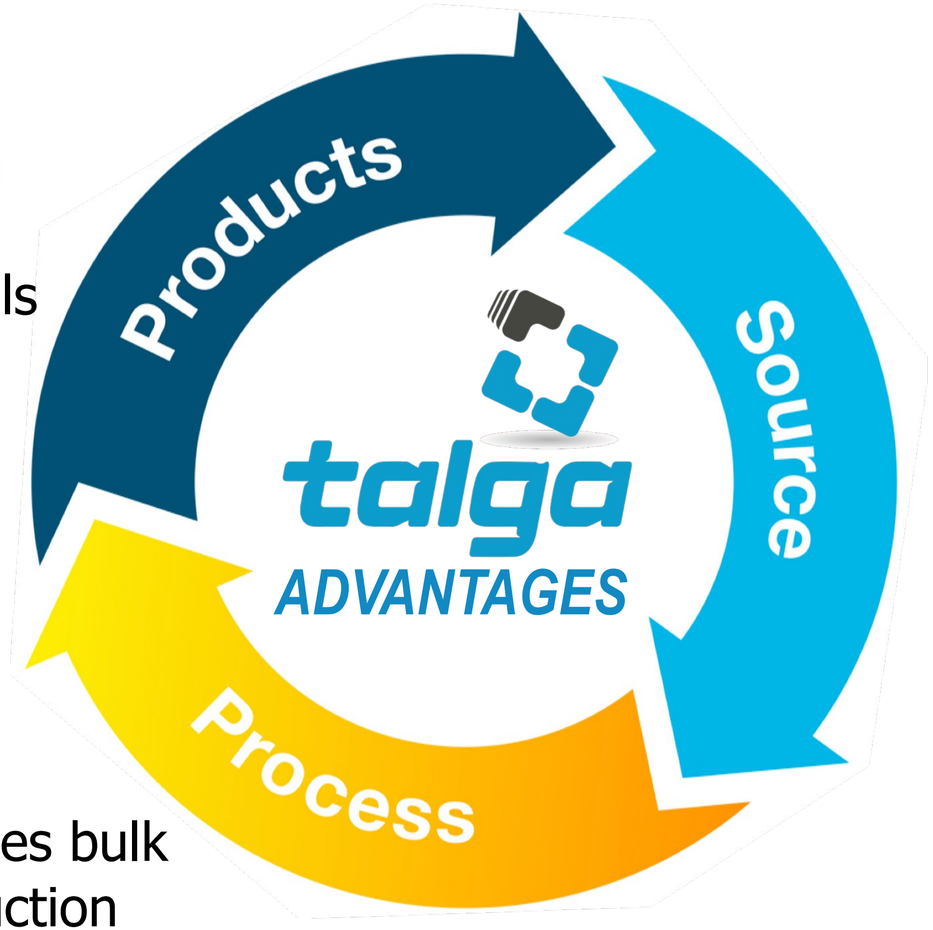


- World's highest grade JORC/NI43-101 graphite resource#
- Process technology requires no crushing, no grinding
- Deposit in **Sweden** - top class jurisdiction
- **Germany** pilot plant scaling up technology and large scale product dev. solution provider to customers
- Vertically integrated raw ore-to-product 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**

see http://www.techmetalsresearch.com/metrics-indices/tmr-advanced-graphite-projects-index/

Commercial Advantages

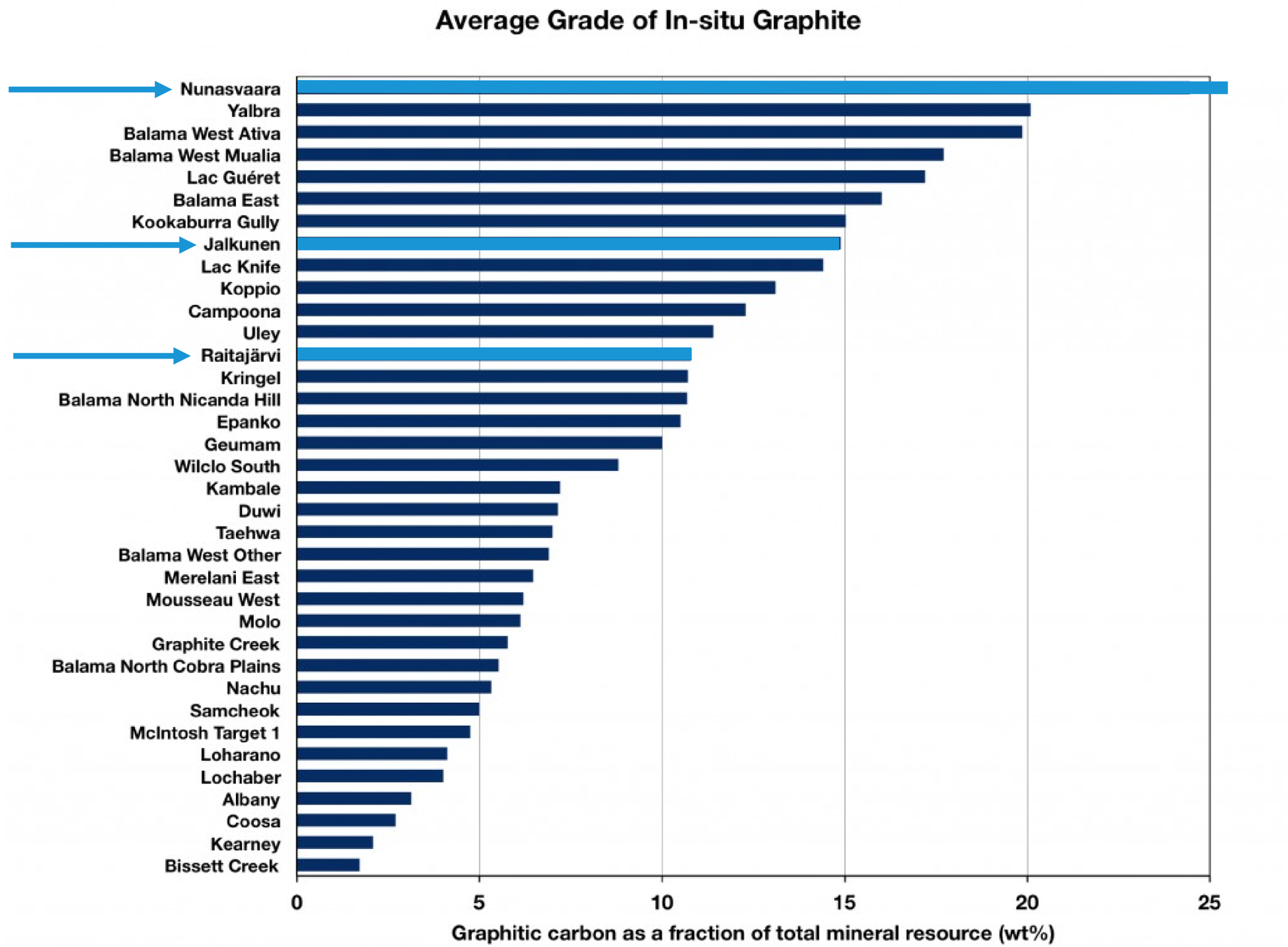
- ✓ **Vertically integrated** with in-house product expertise value-adding to raw materials
- ✓ **Pilot plant** operational & successfully scaling up
- ✓ **Product pipeline** across multiple large technology and bulk sectors
- ✓ **Process technology** enables bulk high quality graphene production
- ✓ **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

Global Graphite Resources by Grade

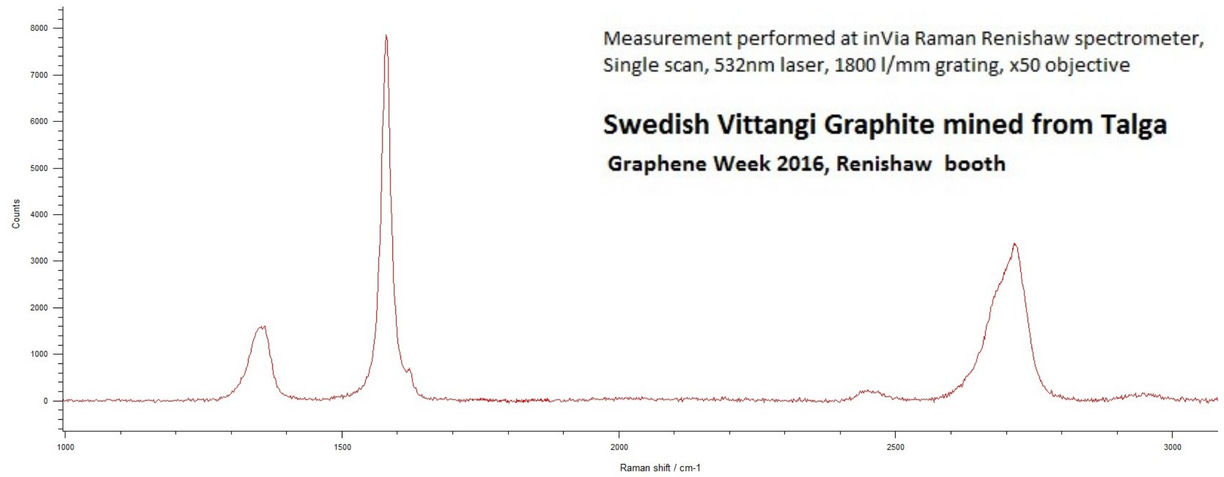
- Talga owns 3 of Top 10 grade graphite resources in world
- Pipeline of development to deliver into market
- Focus on margins and volume of market applications, not resource tonnes for tonnes sake



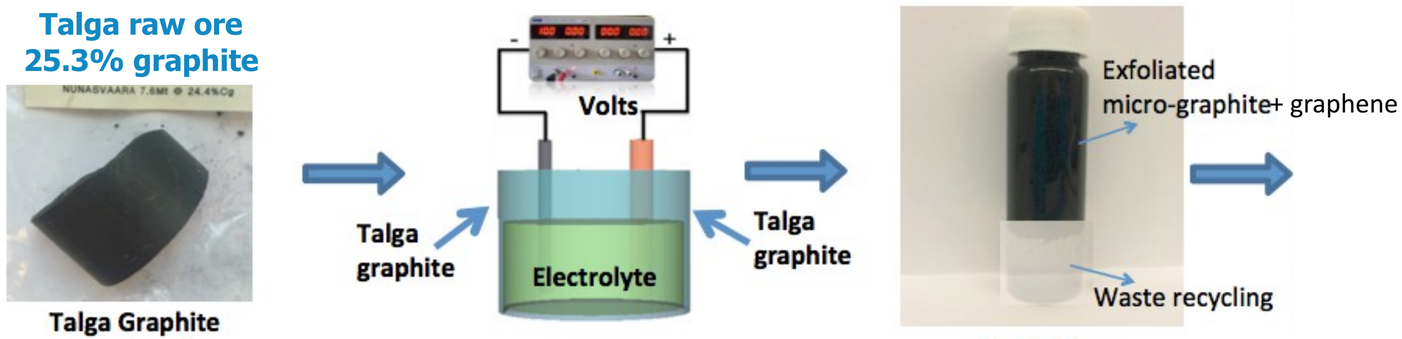
Source: http://www.techmetalsresearch.com/metrics-indices/tmr-advanced-graphite-projects-index/ September 2015

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

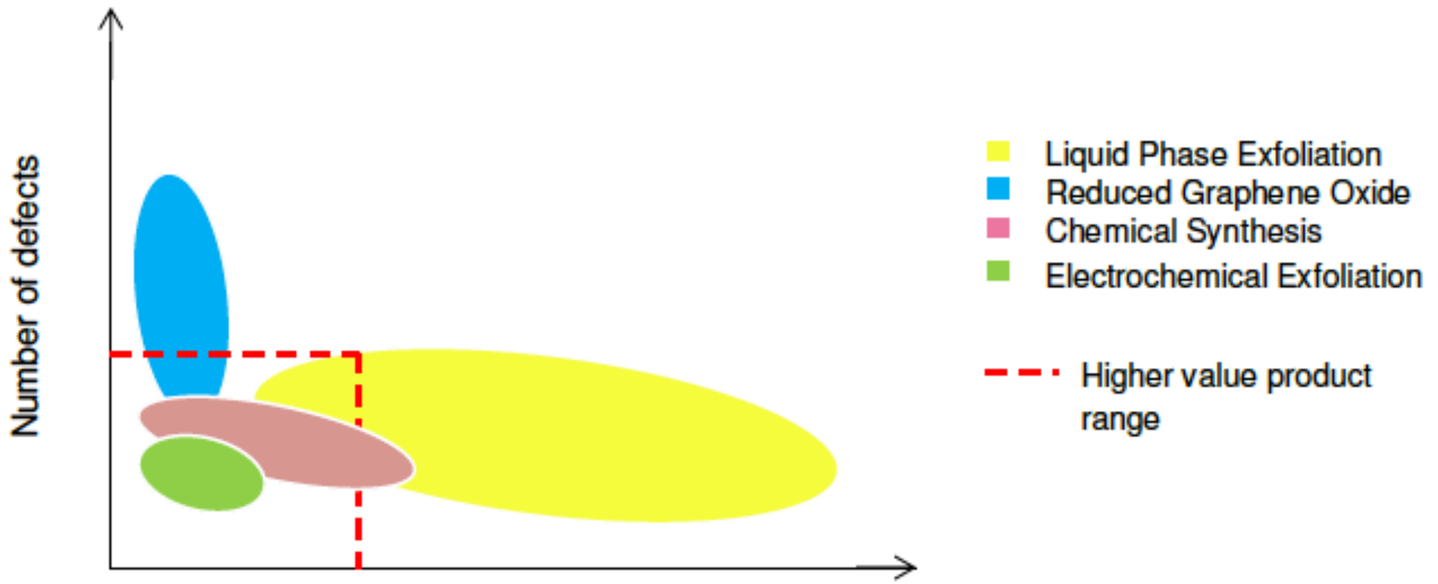


Electrochemical Exfoliation Process - Advantages



- 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 / announcements and reports / videos)

Graphene Production Techniques Electrochemical Advantages



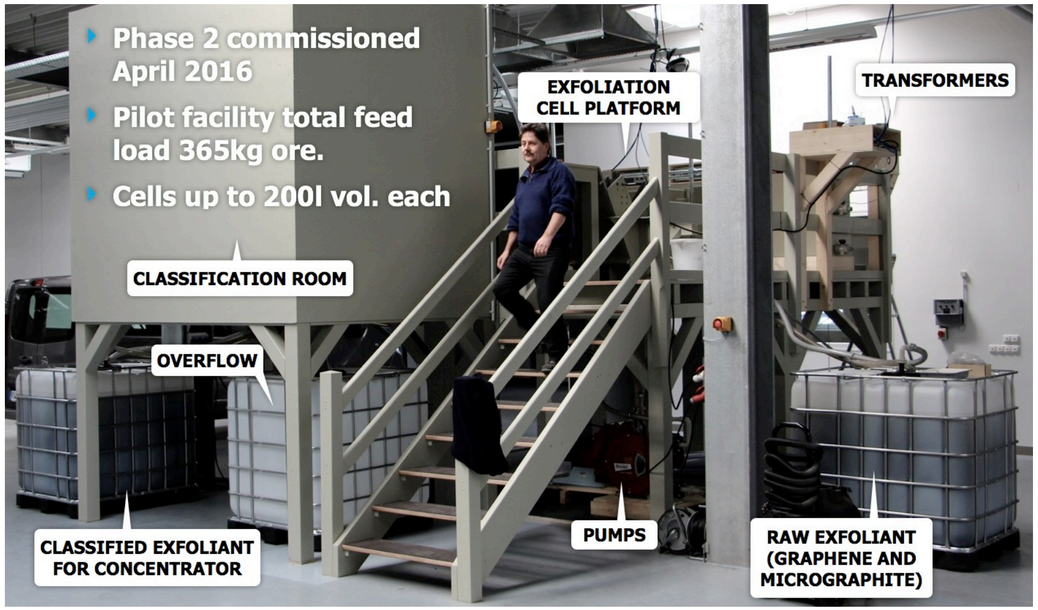
	Method	Approach	Product type	Flake sizes	Chemical purity, structural uniformity
1	Liquid Phase Exfoliation	top-down	**GNP**, MLG	300-50,000nm	average (some low at wt% O2 groups)
2	Graphene Oxide reduction	top-down	**vFLG**	3,000-20,000nm	below average (high at wt% O2 content)
3	Electrochemical Exfoliation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

Source: Fullerex - Webinar

Operations - Pilot Plant

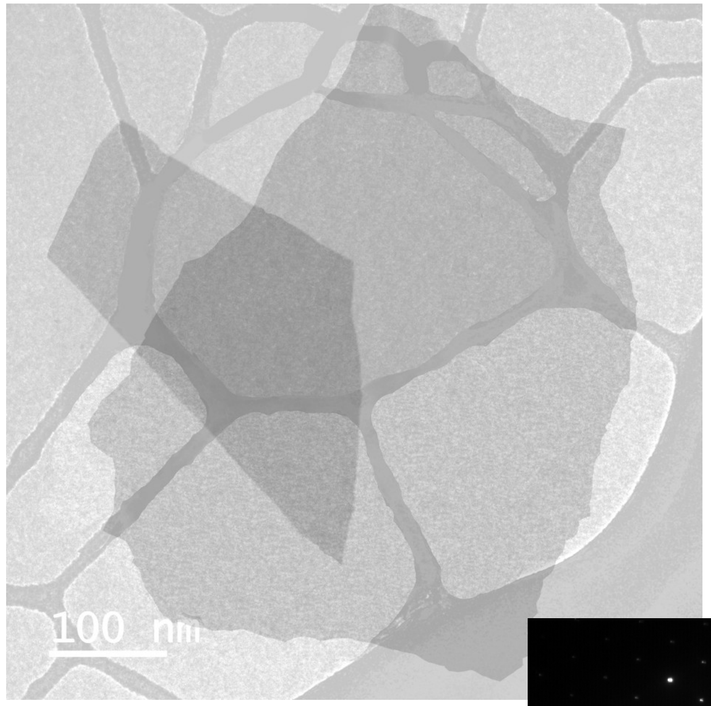
- **Pilot test-work well advanced**
- **3 phases** to upscaling process – Phase 2 just commissioned
- High quality graphene output confirmed, via Key Academic & industrial partners
- ~76% of input carbon converted to graphene
- Capacity scale up continues towards Phase 3
- Product inputs represent the inventory for customer samples
- Plant capacity = 30T of ore from single modular platform, potential to be duplicated

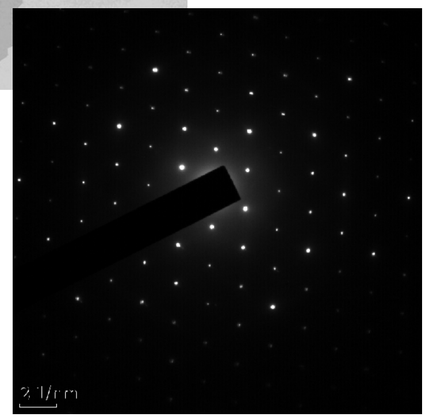
Phase 2 pilot test platform

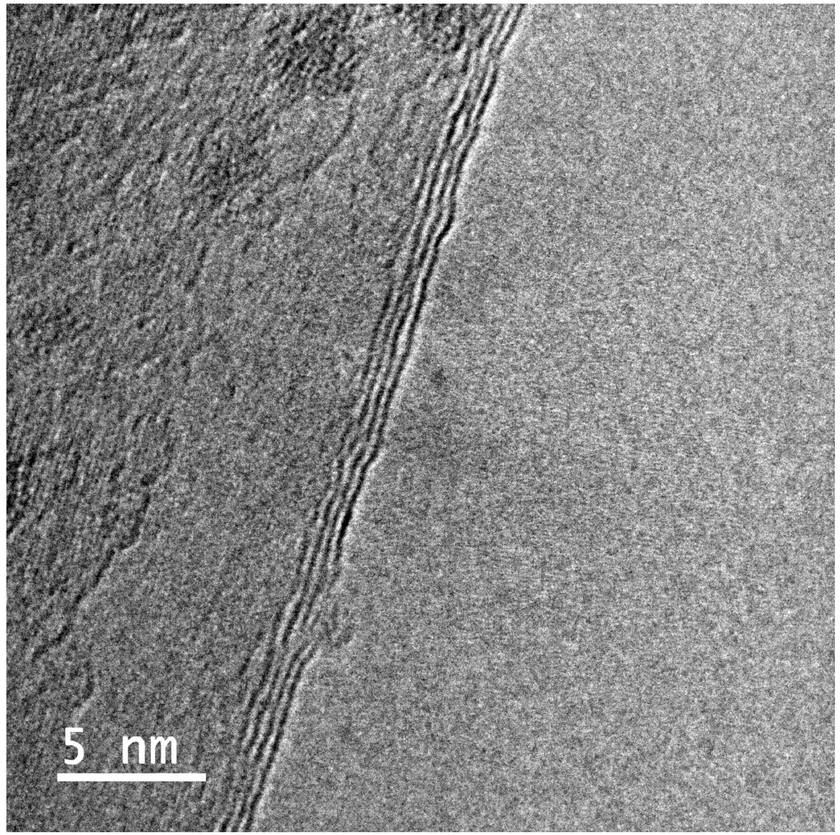


Portion of graphene coating product for customer test program, Talga Advanced Materials GmbH

Graphene (Talphene™) Characterisation

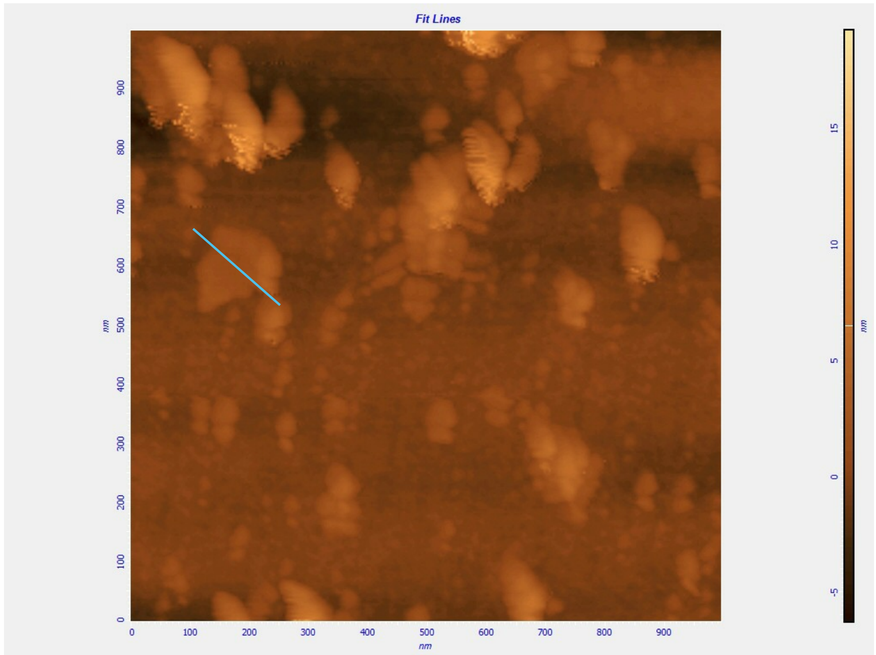


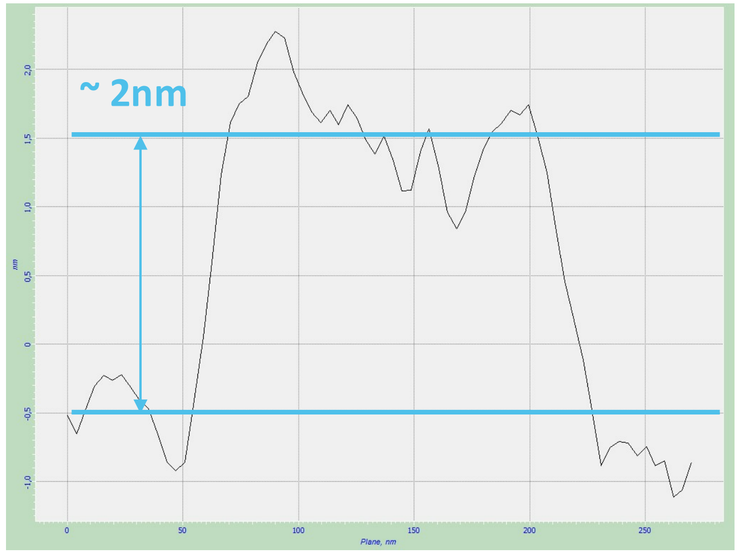


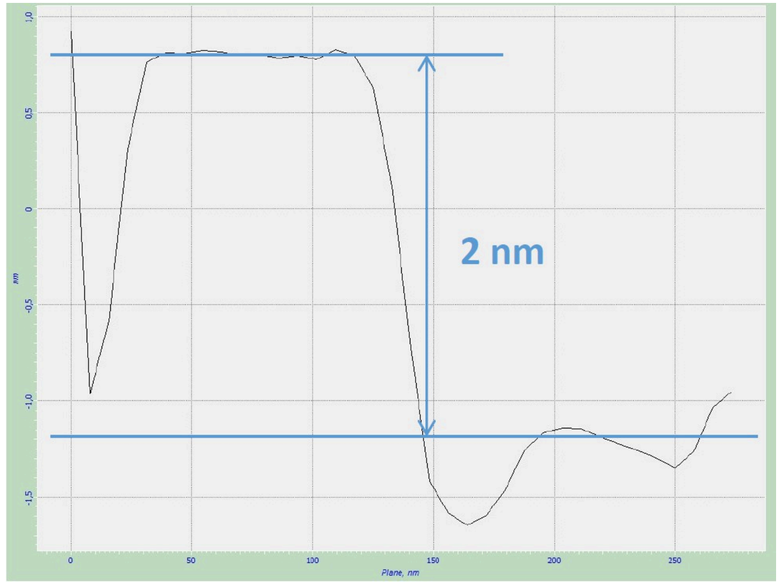


HR-TEM and other tests confirm high quality, 1-4 layer graphene, Lateral Flake size 5-10 microns (Process A- Application A).

Graphene (Talphene™) Characterisation





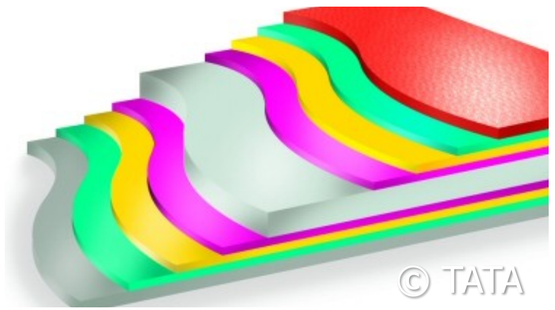


Atomic Force Microscopy (AFM) analysis data confirms:

- **Graphene predominantly thin flakes (up to 2-4 nanometres)**
- **Lateral size of flakes (approx. 100-200 nm - Process B-Application B)**

Target Markets

Coatings



Corrosion Protection Market Size: $11B (2013)

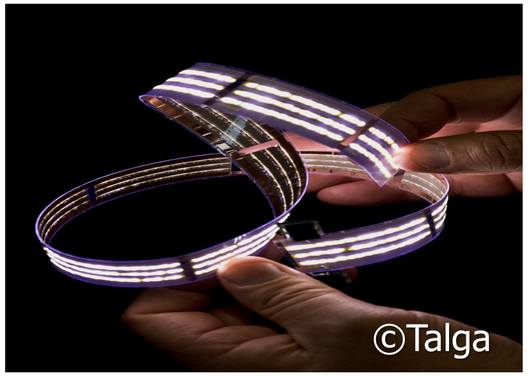
- Anti-corrosion & anti-fouling coatings
- Electric and thermally conductive inks
- Battery and fuel cell coatings
- Current market 40Mt/a

Energy

Batteries & Membranes Market Size: $24B Batteries, $17B Membranes

- Li-ion batteries
- Flow batteries
- Fuel cells
- Solar panels
- Printable batteries and circuits

Conductives



Conductive Ink Market Size: $18B (2015)

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

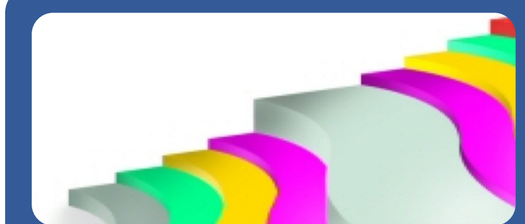
Construction

Cement & Concrete Additives Size: $17B (2016)

- Lighter, stronger cement
- Higher performance insulation materials
- Functional (electrical or thermally conductive) glass & building materials

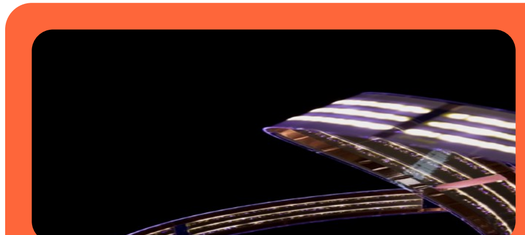
Market size sources: Reports from NACE, IDTechX, Freedonia, www.corrosion.org, Market and Markets, Future Markets Insight, BCC research, www.energy.gov, www.cam.ac.uk, NGI, CGC, IITB, OCCA, PRA, IconiQ, ECCA, BCF, World Steel Organisation, The Graphene Council

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

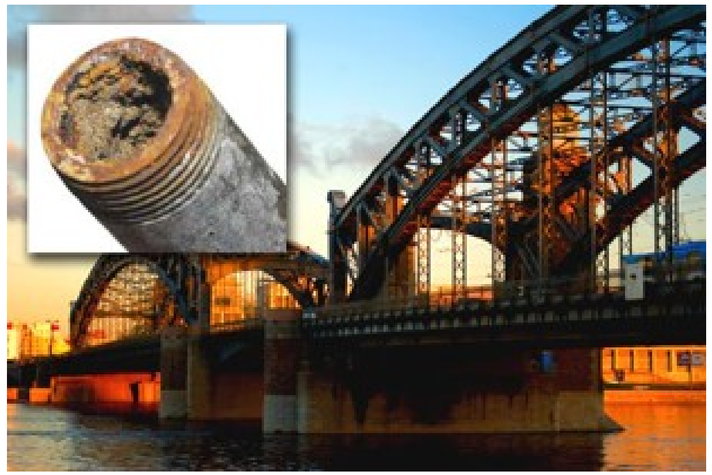
Cost of Corrosion – Global Economic Impact

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/

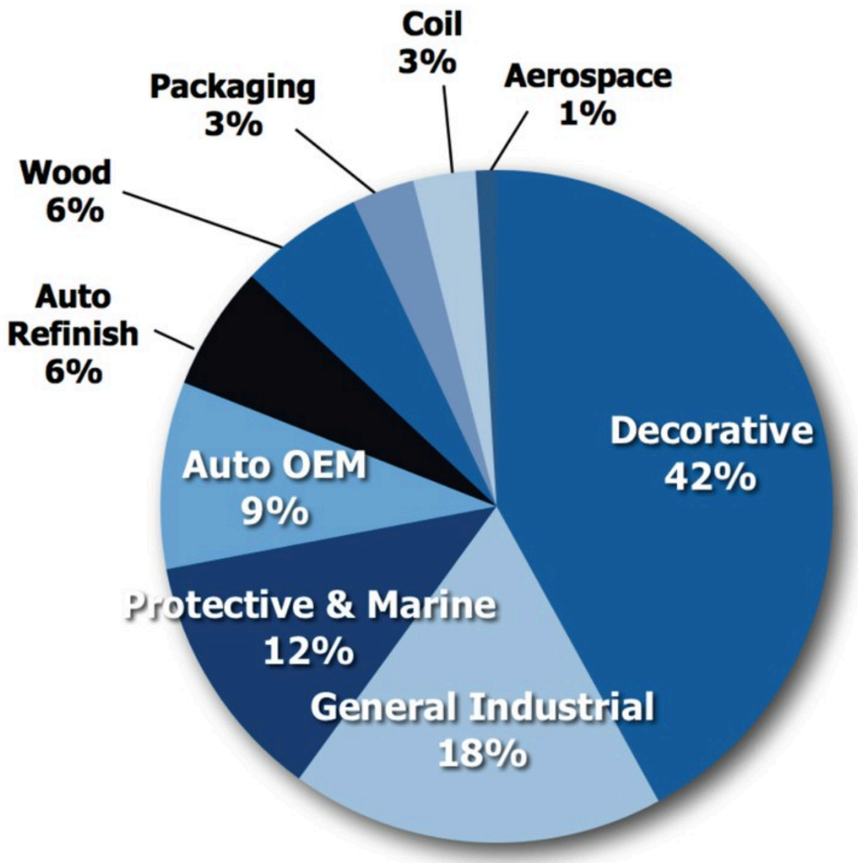


Hohenzollern Bridge in Cologne, Germany (Source: Corrosion - by Gretchen A. Jacobson - Materials Performance)

Alarming corrosion in Eiffel Tower, Paris, France

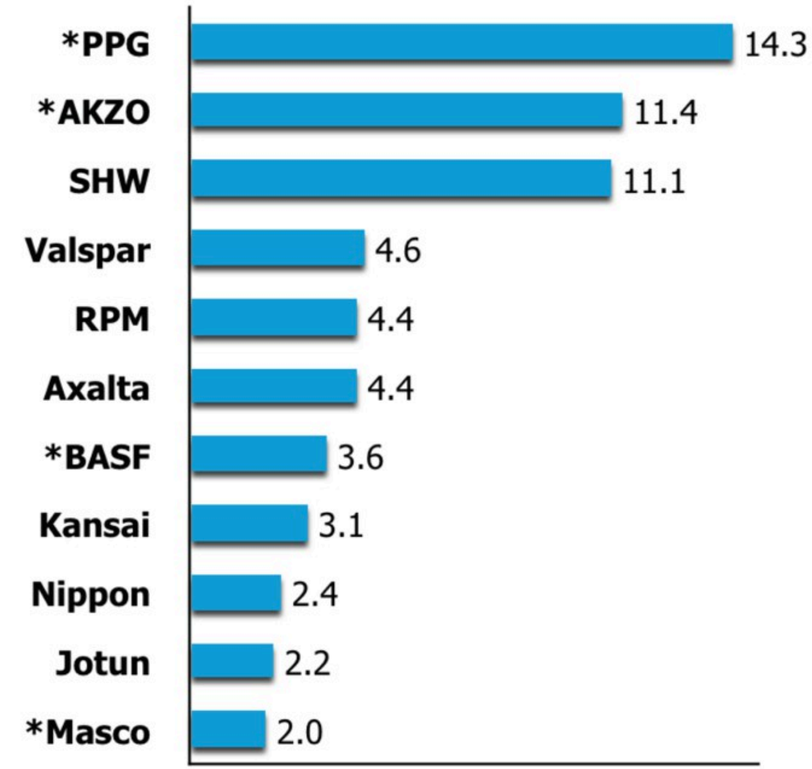
Product – Coatings Market

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



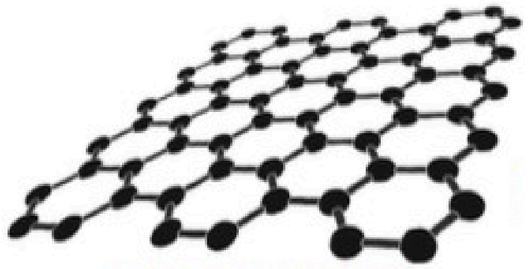
Source: Jan 2016 Valspar Investor Presentation after 2013 Orr & Boss, Kusumgar, Nerlifi & Growney

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



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

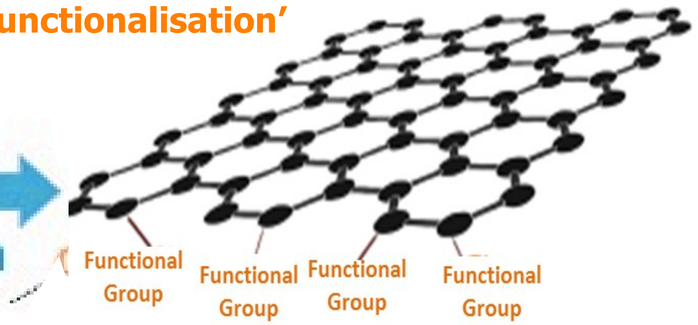
Talga Graphene Coatings



Talga Few layer Graphene

Chemical Modification

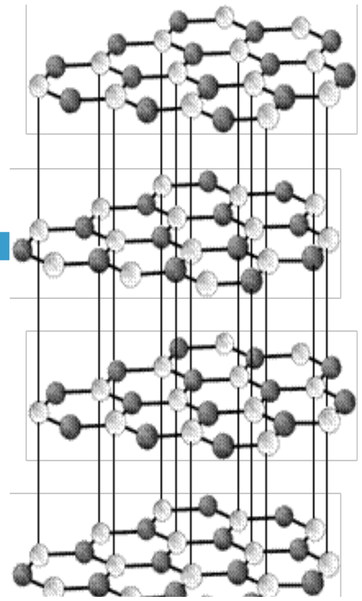
'Functionalisation'

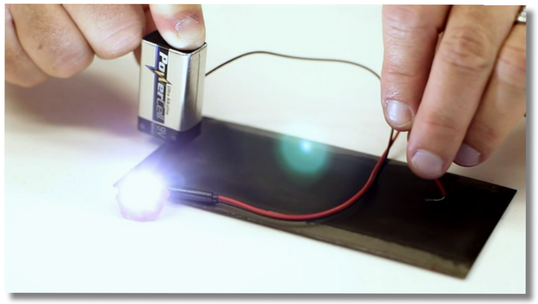


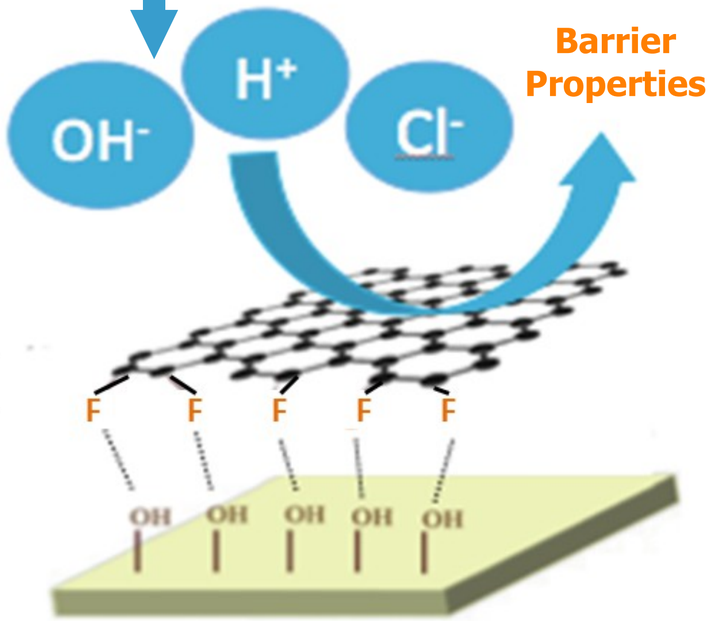
Surface Interaction/Adhesion

Metal substrate

Talga Novel Exfoliation Process



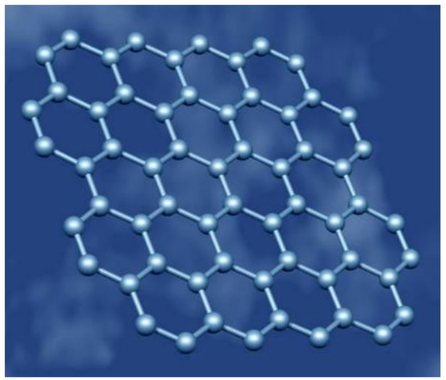


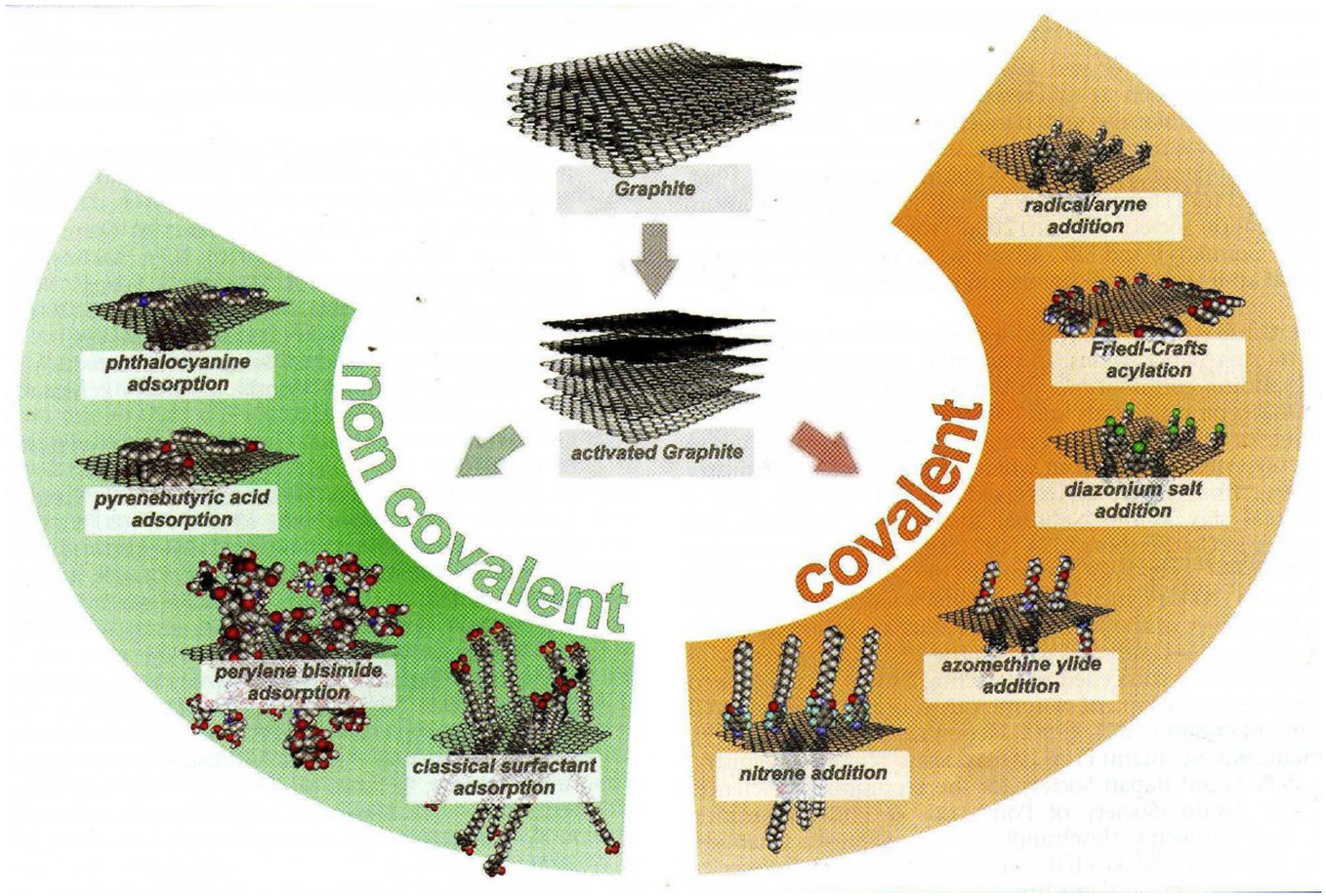


Talga Raw Graphite Ore

Talga Few Layer Graphene Coated Metal

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, sp^2 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

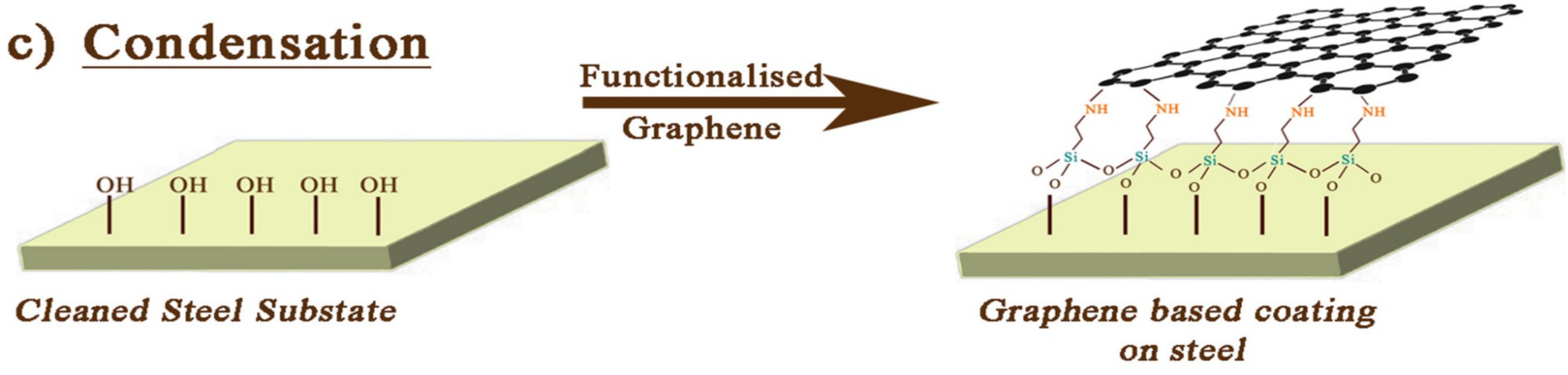
Functionalised graphene *or* Dispersed GO/rGO *or* GNP in resin (thermosets or plastics)

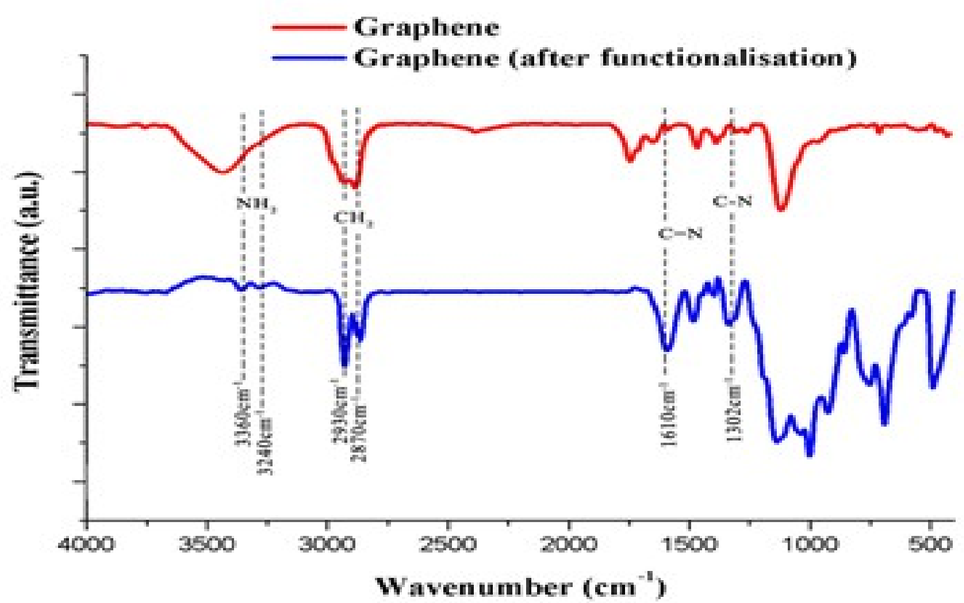
Compounding/ Polymerisation

Protective Coatings- Depends On Customer needs

✓ Improved performance can be seen only with correct dispersion

Functionalisation of Graphene for Coating



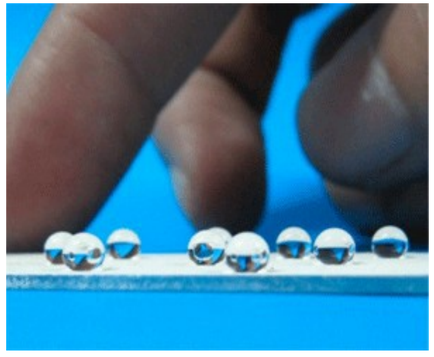


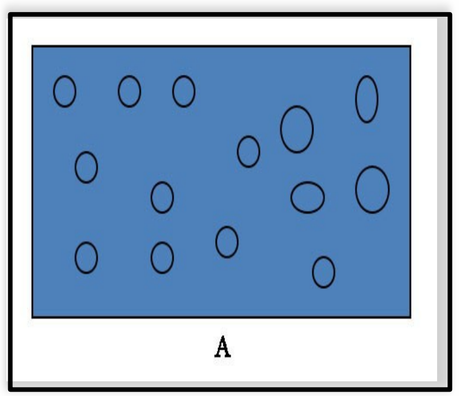
Graphene Anti corrosion coating: Nanoscale, 7(42) 17879 (2015)

Multi Functional Coatings - Customer demand

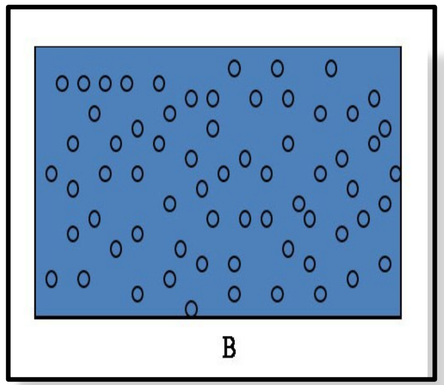
Coatings → **Functional value** (e.g. anticorrosion, hydrophobic intumescent, etc.)

Coatings → **Decorative value**

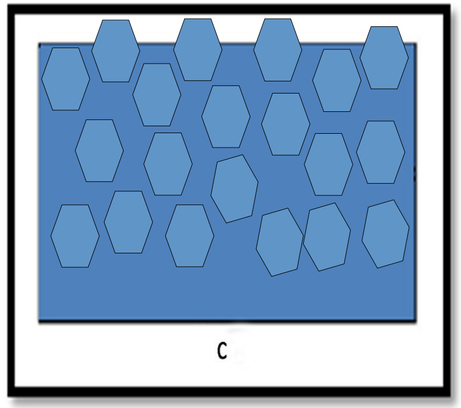




10% additive (micron-sized) in paint matrix

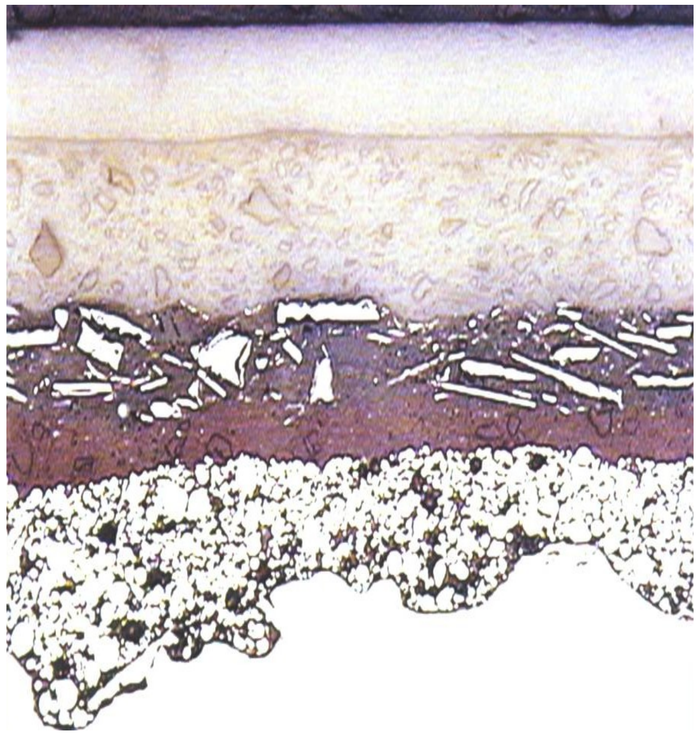


0.1% additive (nano-sized) in paint matrix



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

Protective coatings for Ships, Pipes, Sections…



Acrylic Finish Coat

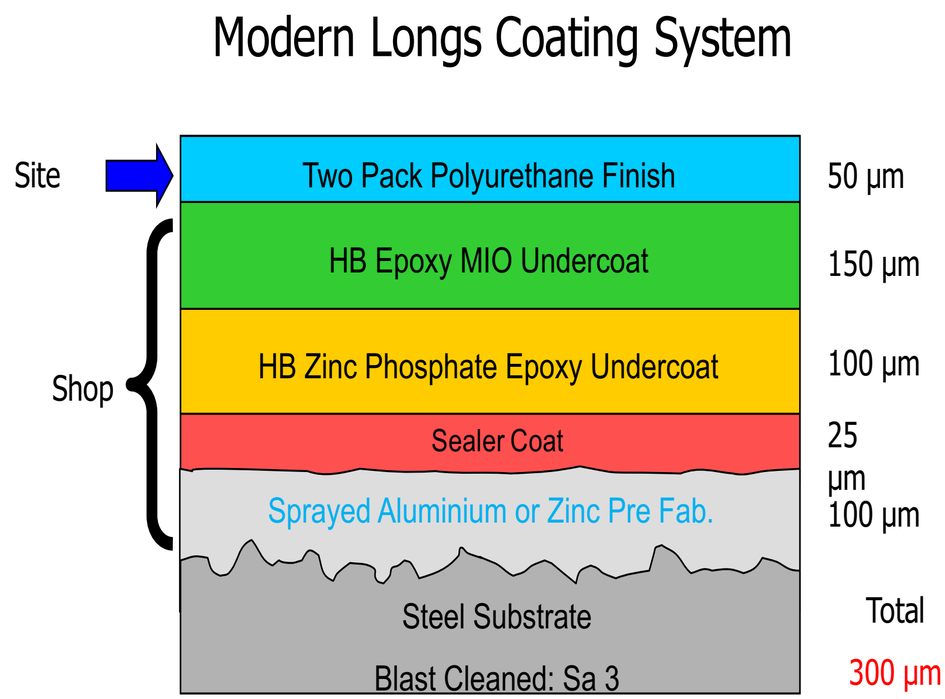
Non Pigmented Epoxy Undercoat

Epoxy MIO

Epoxy Sealer Coat

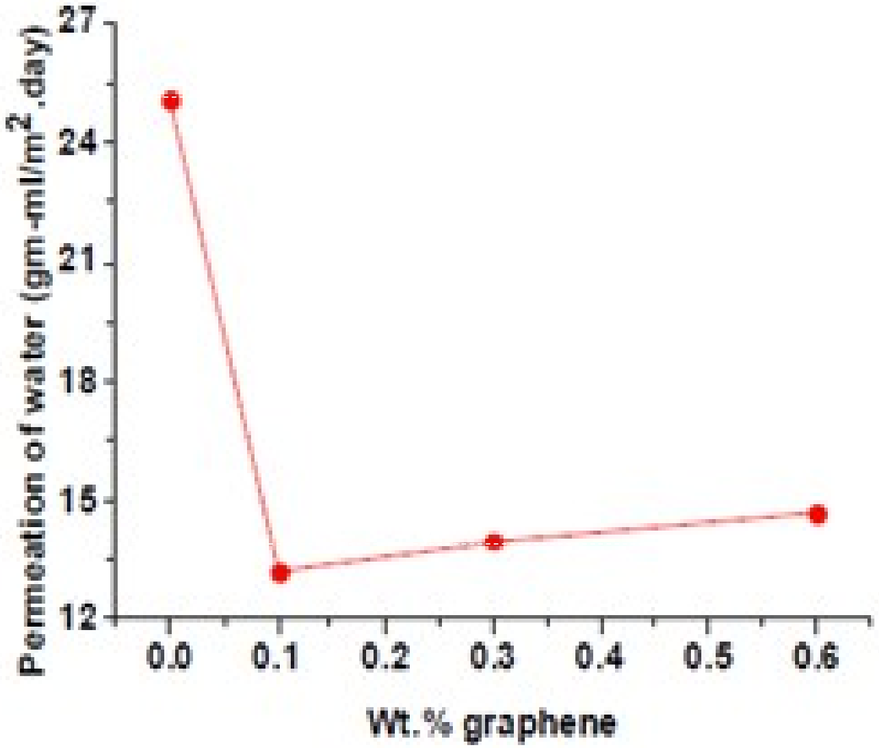
Zinc Rich Epoxy Primer / Zinc Silicate Pre Fab

Shot Blasted Steel Substrate

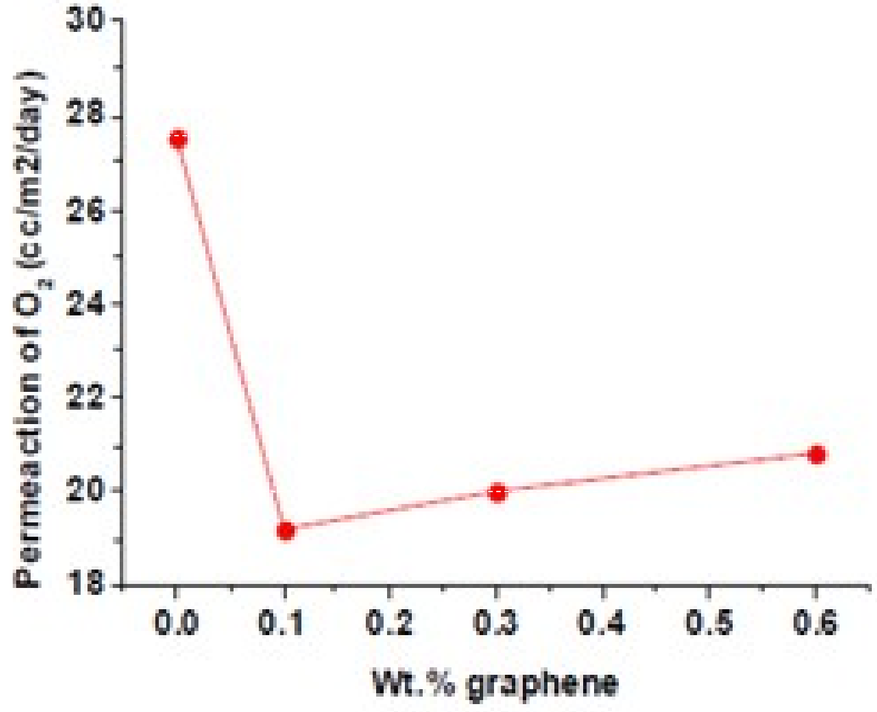


Durability of protective coating depends on barrier properties

Graphene oxide-Thermosets resins O2 & H2O

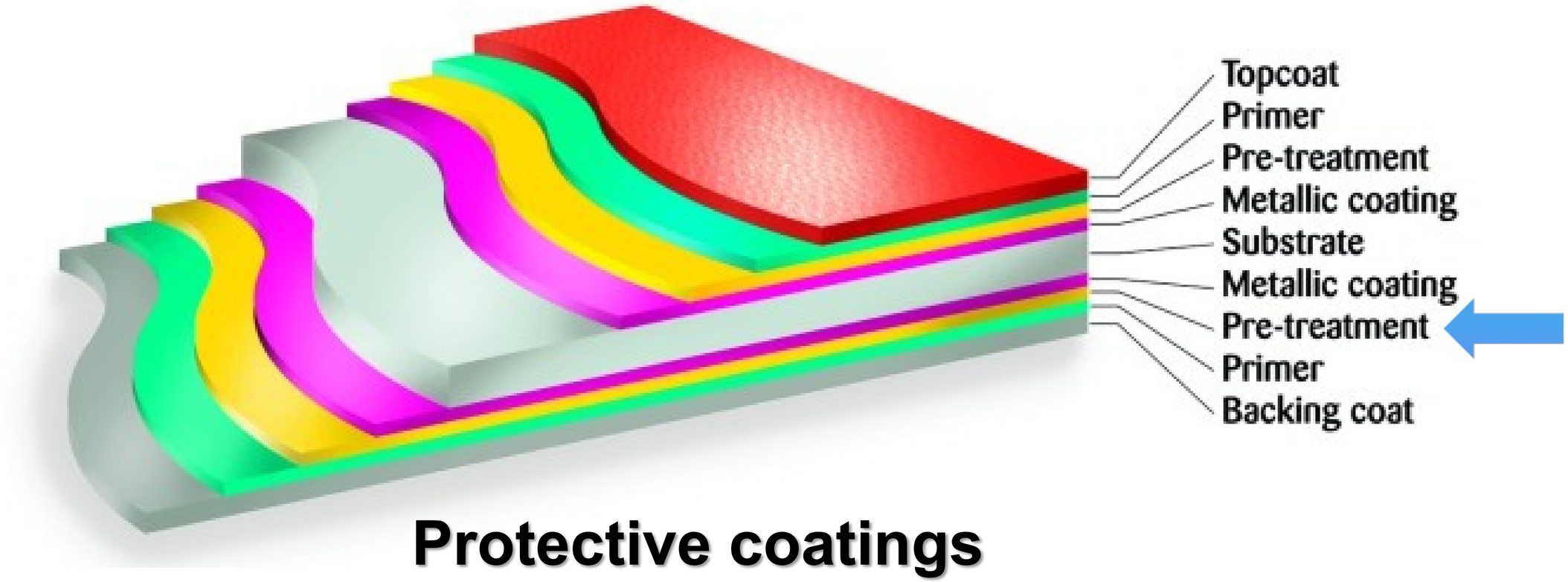


Water Permeation ~ 46% reduced



Oxygen Permeation ~ 31% reduced

Pre finished Steel - Coil Coatings



Protective coatings

Coatings

Surfaces

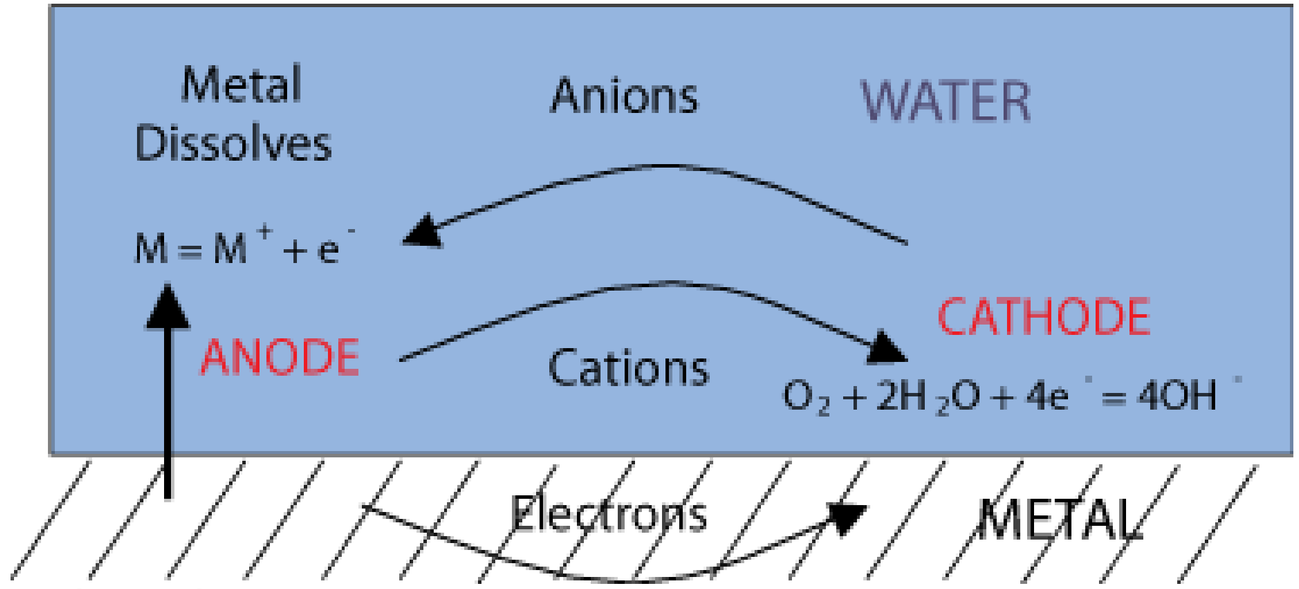
Interfaces

Adhesion Science
Polymer Chemistry
Degradation
Metallurgy
Coatings Application

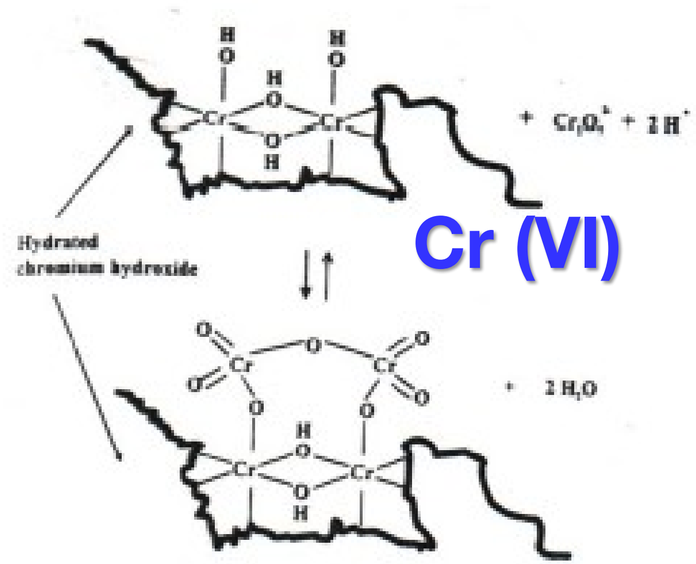
Differentiated

Products

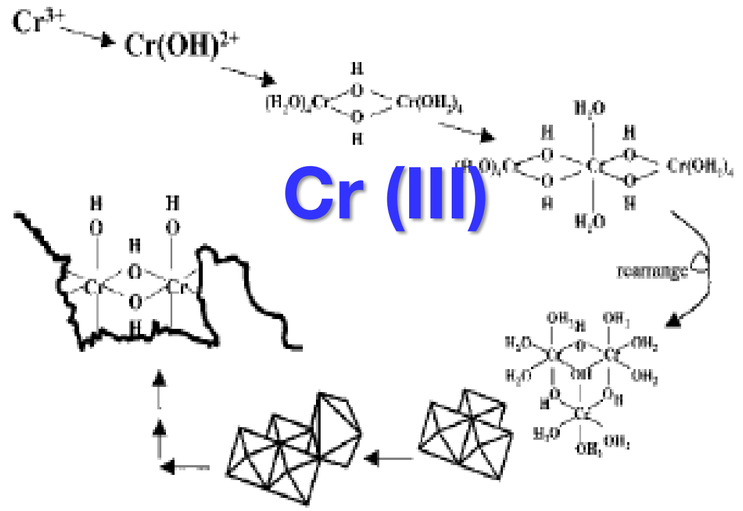
Corrosion & Current Chrome-based Protection



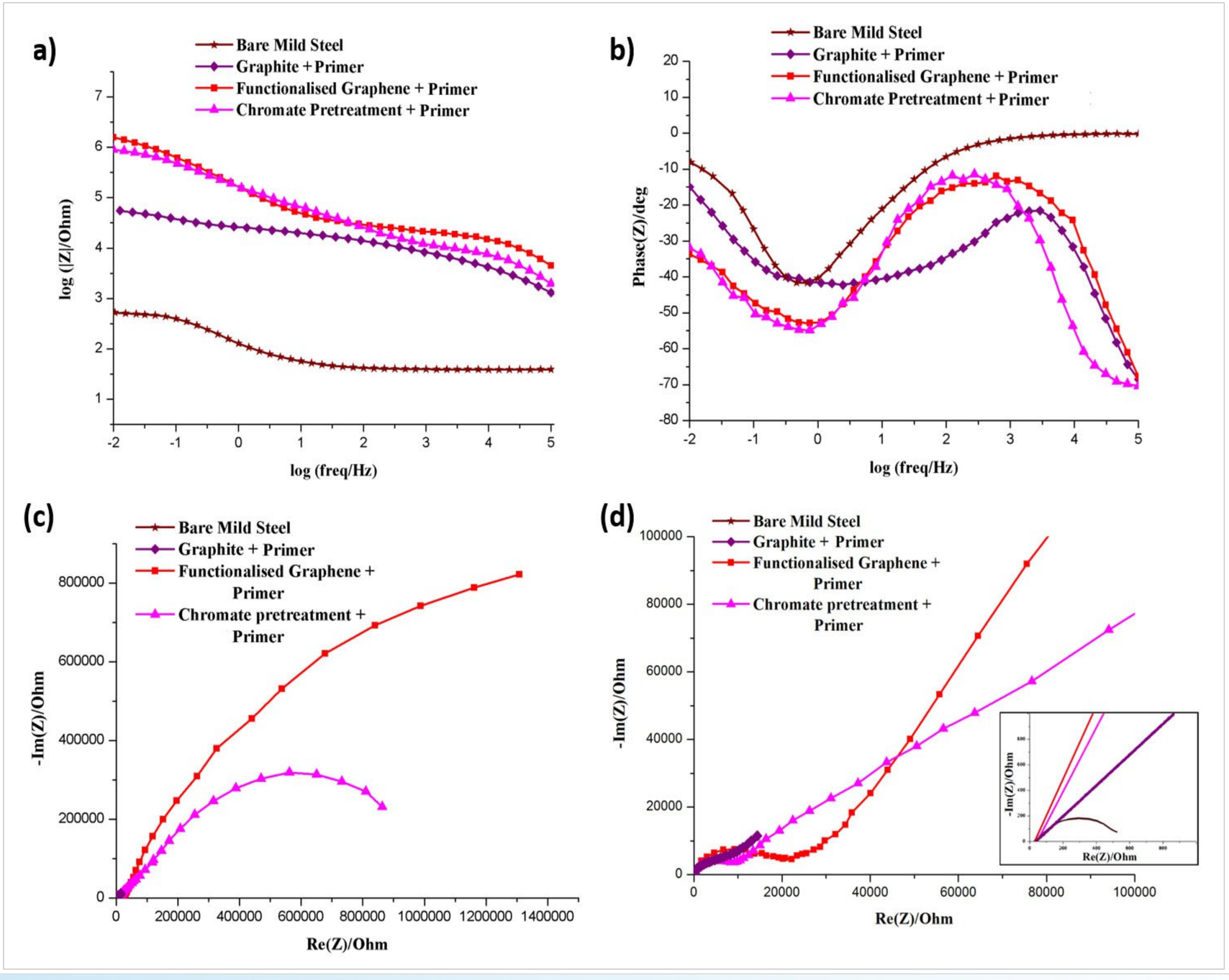
Condensation of Cr^{6+} to Cr^{3+} by nucleophilic attack of hydroxyl ligands in backbone



Hydrolysis-Polymerisation-Precipitation mechanism of $Cr(OH)_3$ backbone formation

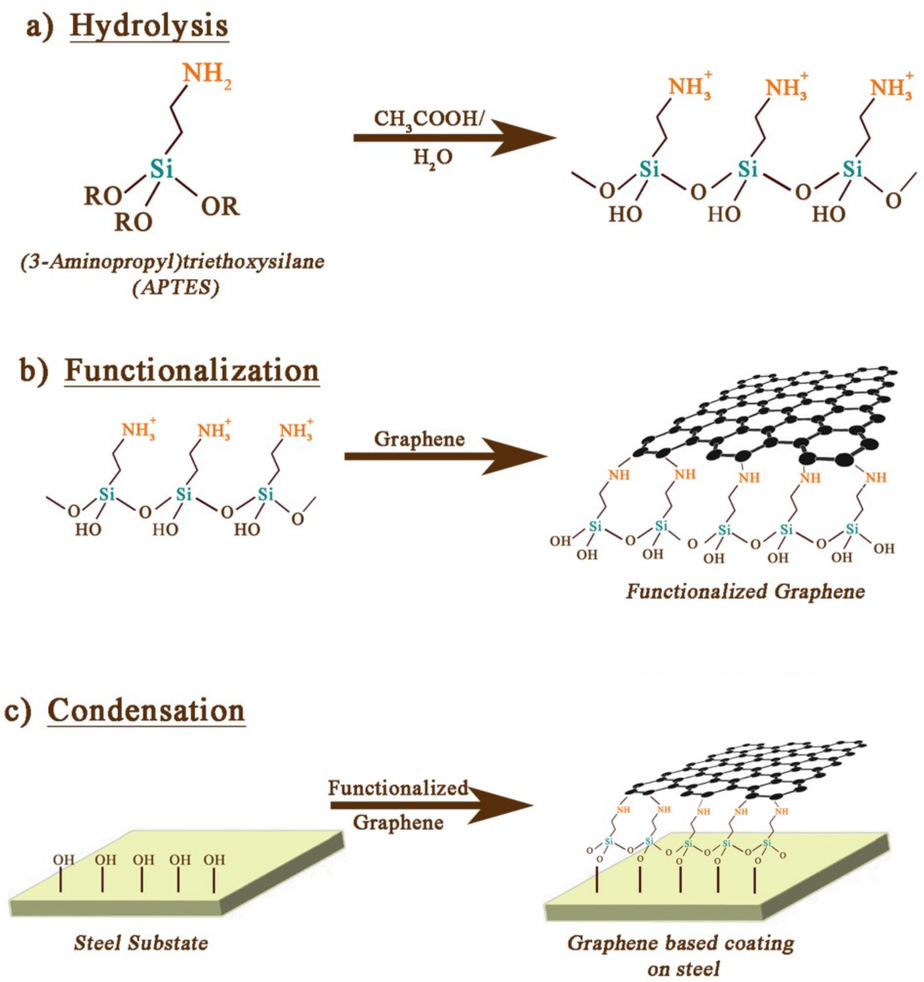


Graphene Coating Evaluation EIS – Cr(VI) vs Graphene

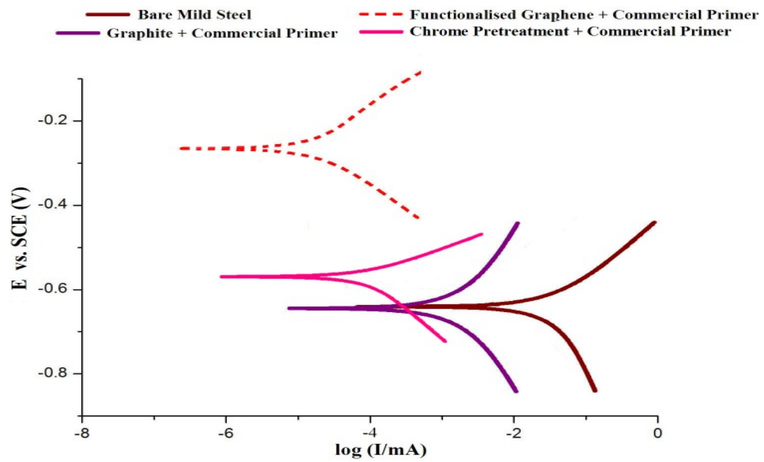


Graphene Anti corrosion coating: Nanoscale, 7(42) 17879 (2015)

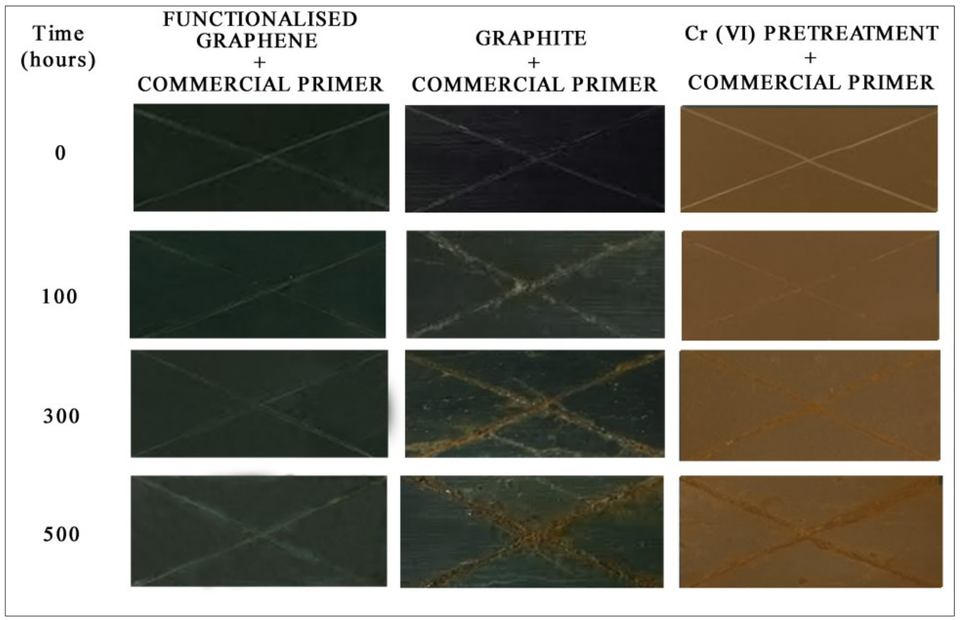
Talga Graphene Coatings- Cr(VI) replacement



Functionalisation/Condensation reaction



Potentiodynamic Polarisation curves



Salt Spray Test (ASTM B117)

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

Metal treatment-Commercialisation: Chemetall & Talga

Commercial System vs Graphene Pretreatment

PREPARATION
Graphene

⇩

Functionalized Graphene

⇩

Graphene Coating

Current commercial Cr(VI)

After salt spray

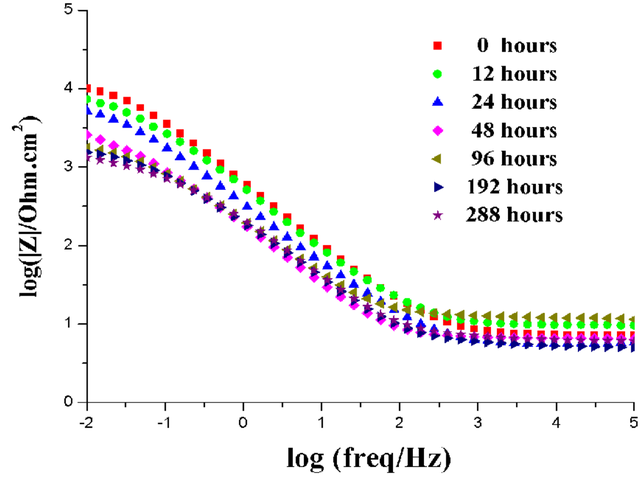
Graphene functionalised with inhibitor pre-treatment

After salt spray

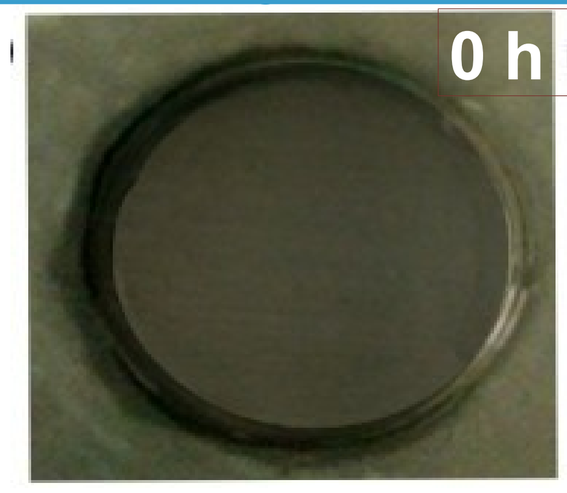
✓ **Improved performance over chrome-containing reference**
✓ **Customer trial of metal surface treatment in progress**

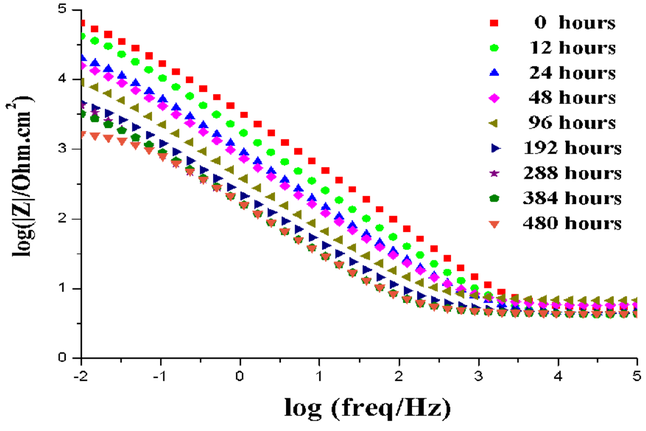
Talphene^{TR} anti corrosion coating – EIS Evaluation

Without TALPHENE^{TM} coating



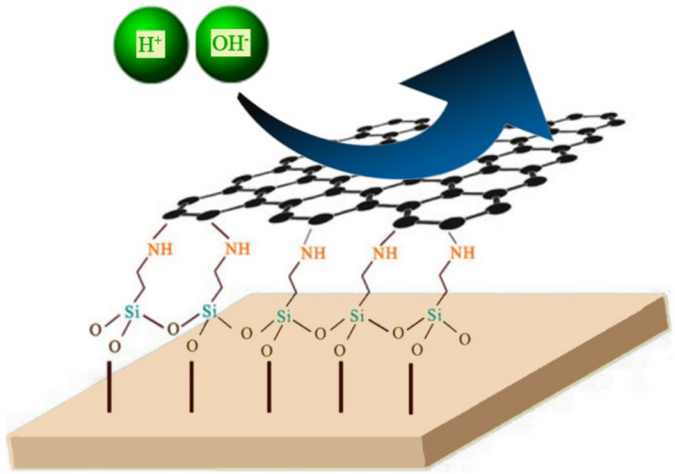
With chemically functionalised TALPHENE^{TM} coating



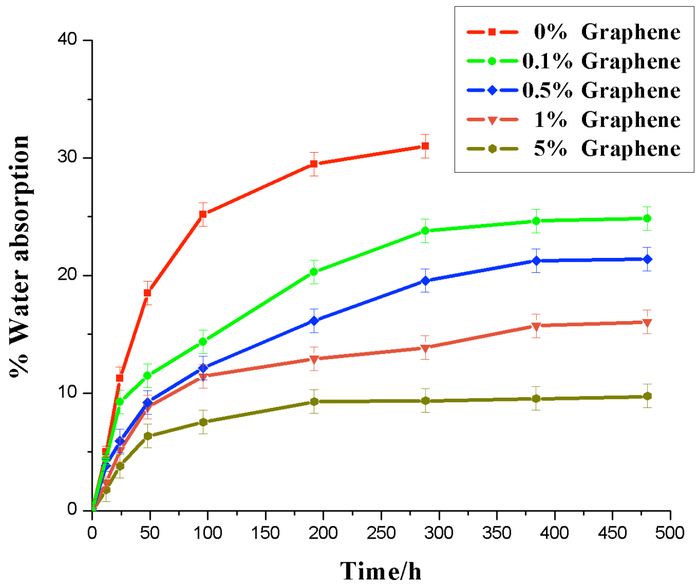


Graphene in pre-treatment "Water Permeation ~ 74% reduced"

Graphene Anti-corrosion coating: Flatchem, 1 (48) (09/2016)



Graphene as a barrier against ions



Water uptake vs Graphene concentration

ELSEVIER

FlatChem

CHEMISTRY OF FLAT MATERIALS

Elsevier Journals, e.g. **Flatchem - Special Issue-** Industrial applications of Graphene, & 2D Materials **Coatings & Inks Q3-2017**

Functionalised Graphene as a barrier against corrosion, Flatchem, September 2016

Talga Graphene Products Business Strategy

- 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

Conclusions

- ✓ 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.

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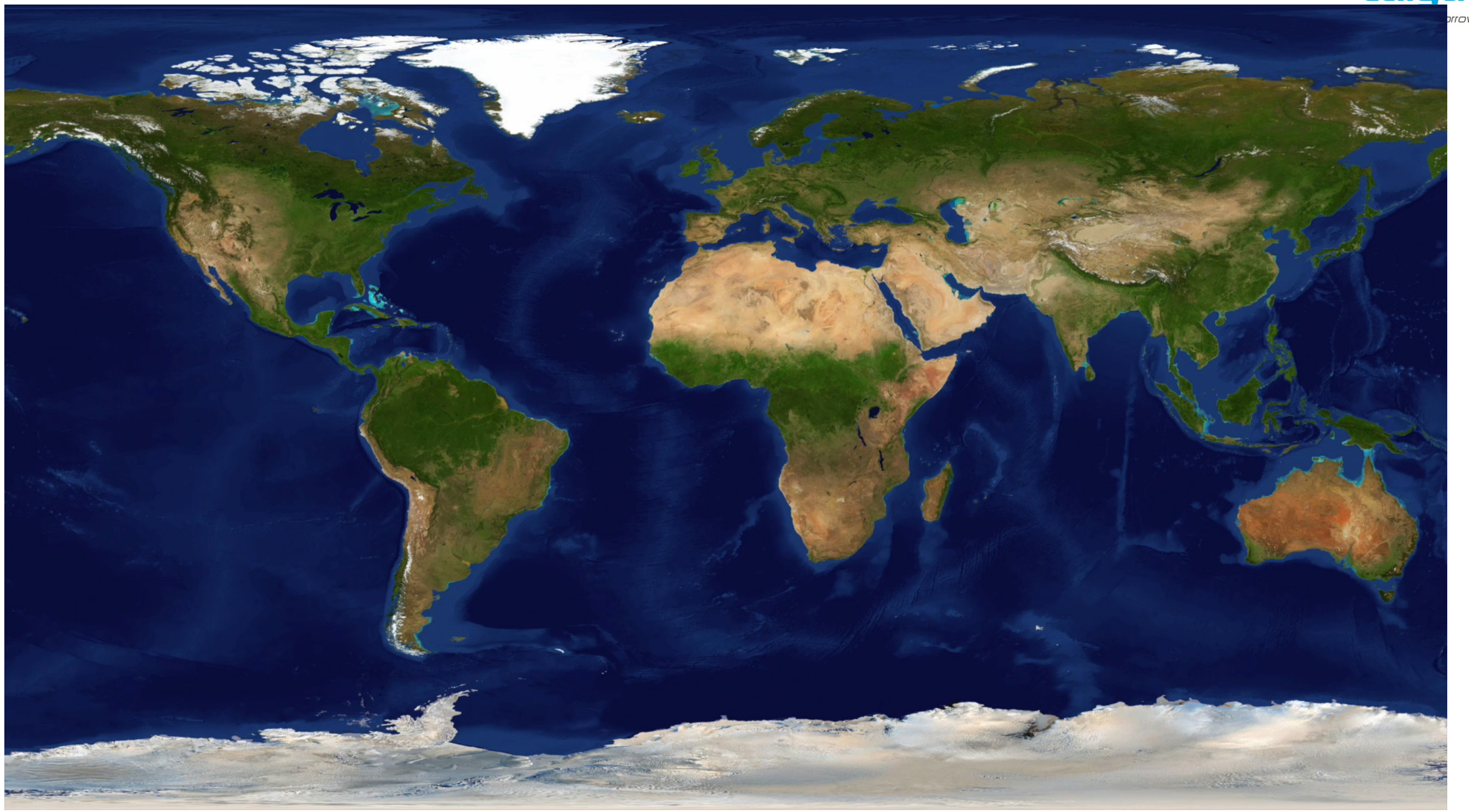
Talga Mining Pty Ltd Filial & Talga Technologies (UK) Ltd

IIT Bombay ME & Materials students

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

Tata Steel & Tata Group (Europe & India)

Trial Mining - Sweden



Vittangi trial mining For video see https://www.youtube.com/watch?v=q2Xmz7Buj3A