Multifunctional composite materials for energy storage in structural load paths

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ARPA-E safe energy storage systems for electric vehicles, Denver, Nov 12th 2012

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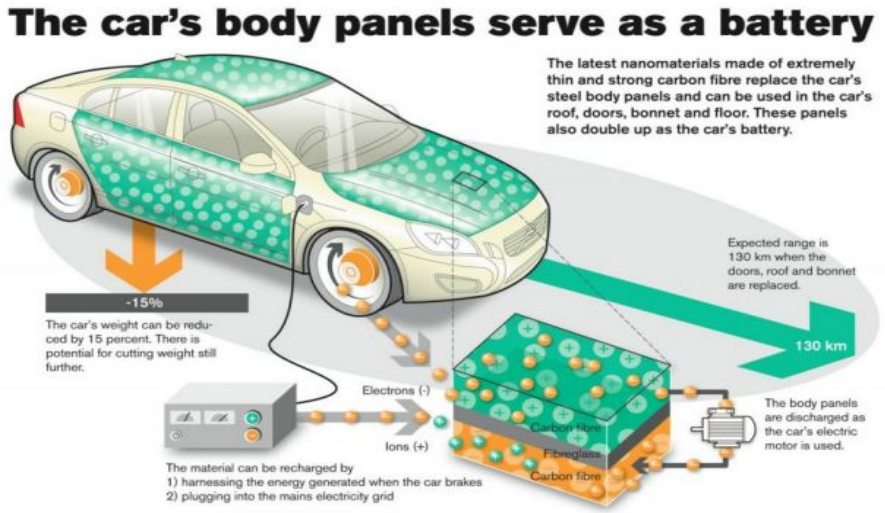
Introduction – Demands for Energy Storage and Lightweight

- Need to reduce demands of system as whole
  - City car; 98% of energy associated with weight
  - *Halving weight doubles range*

- Adopting composites provide weight savings
  - Electric vehicles with reasonable range/endurance

- *Structural power materials*
  - undertake two roles – electrical energy storage & carry mechanical load.

Volvo electric vehicle

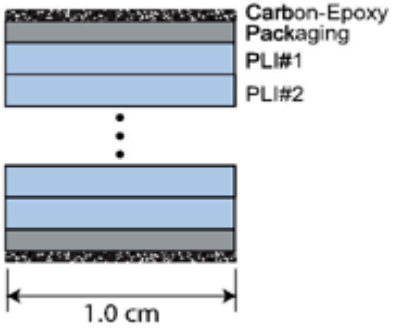


Multifunctional design of materials

- introduce multifunctionality in composites
- **structural** and non-structural (**energy storage** capacity) functions

Multifunctional structure

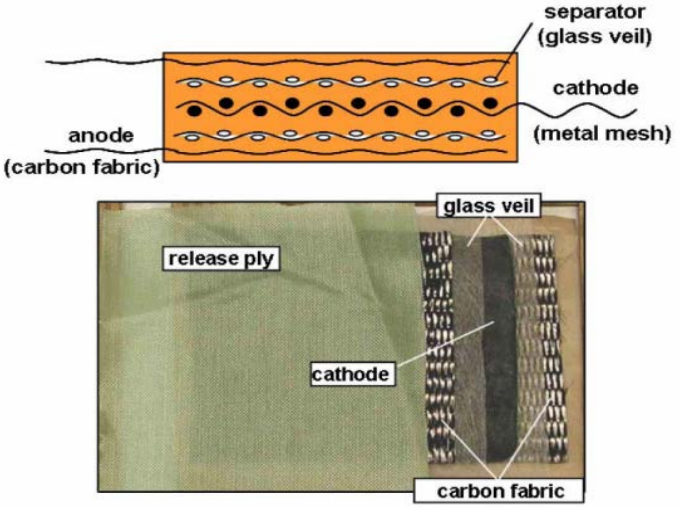
Distinct constituent components packaged together



J. P. Thomas & M. A. Qidwai, JOM. v57 p18-24. 2005.

Multifunctional material

Constituents simultaneously & synergistically undertake two roles



Weztel & Snyder, US Army Research Labs

multifunctional material that simultaneously carries mechanical loads whilst storing electrical energy – 'massless energy'

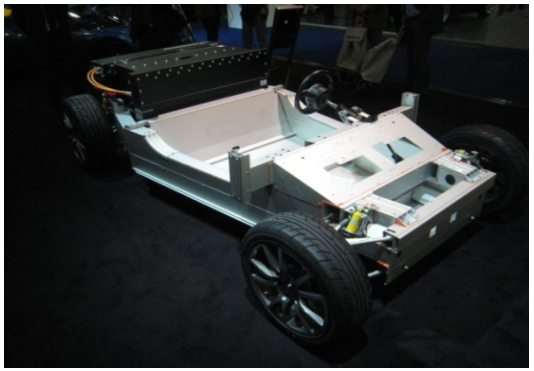
Structural power design example

- Define **Ω_S= structural efficiency**
  Ω_S = 1 implies fully structural (relative to nominal composite)
  Ω_S = 0 implies no structural load bearing capacity
- Define **Ω_E = energy storage efficiency**
  Ω_E = 1 implies full electrical energy storage (relative to nominal energy storage device)
  Ω_E = 0 implies no electrical energy storage

450kg Battery

$\Omega_S = 0$
$\Omega_E = 1$

+



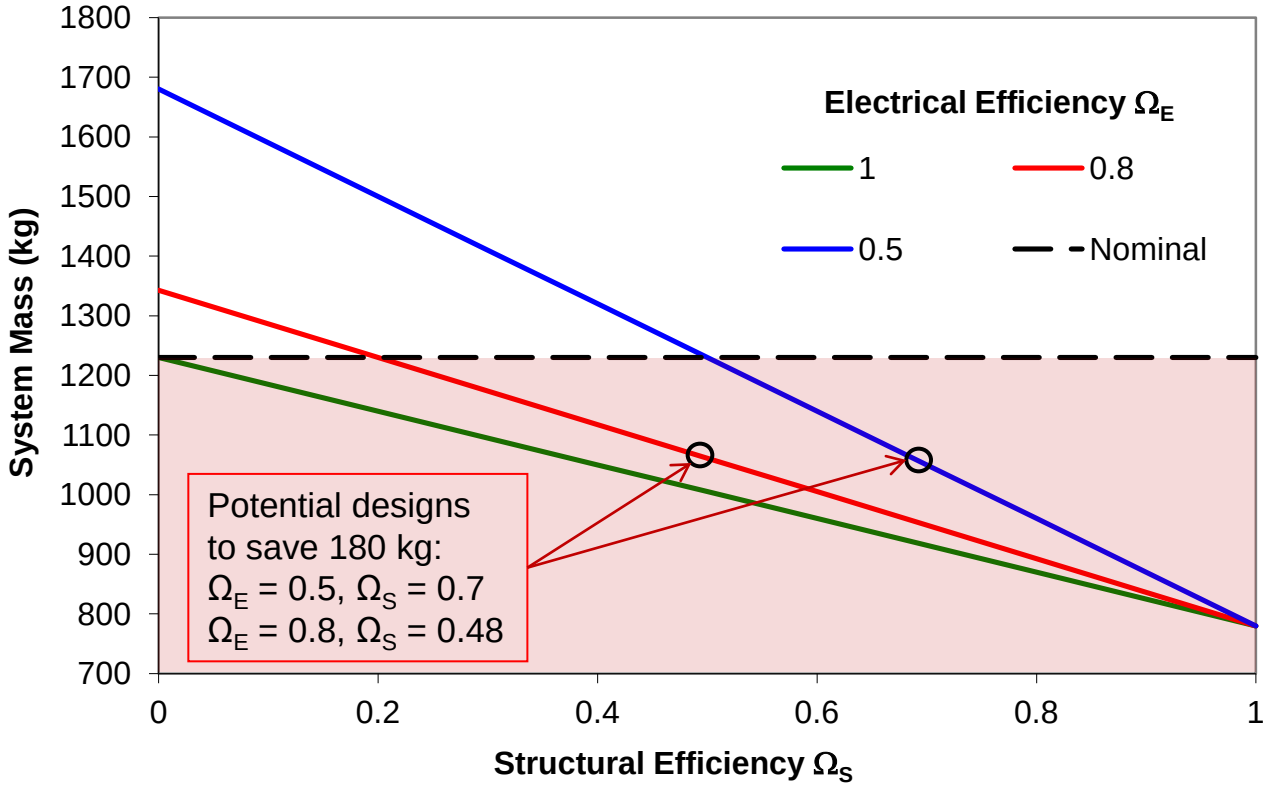
780kg Structure/Systems

$\Omega_S = 1$
$\Omega_E = 0$

=

Tesla Roadster 1230kg

Structural power design example



$\Omega_s = 0$
$\Omega_E = 1$

$\Omega_s = 1$
$\Omega_E = 0$

Structural Power Material

$\Omega_s = ?$
$\Omega_E = ?$

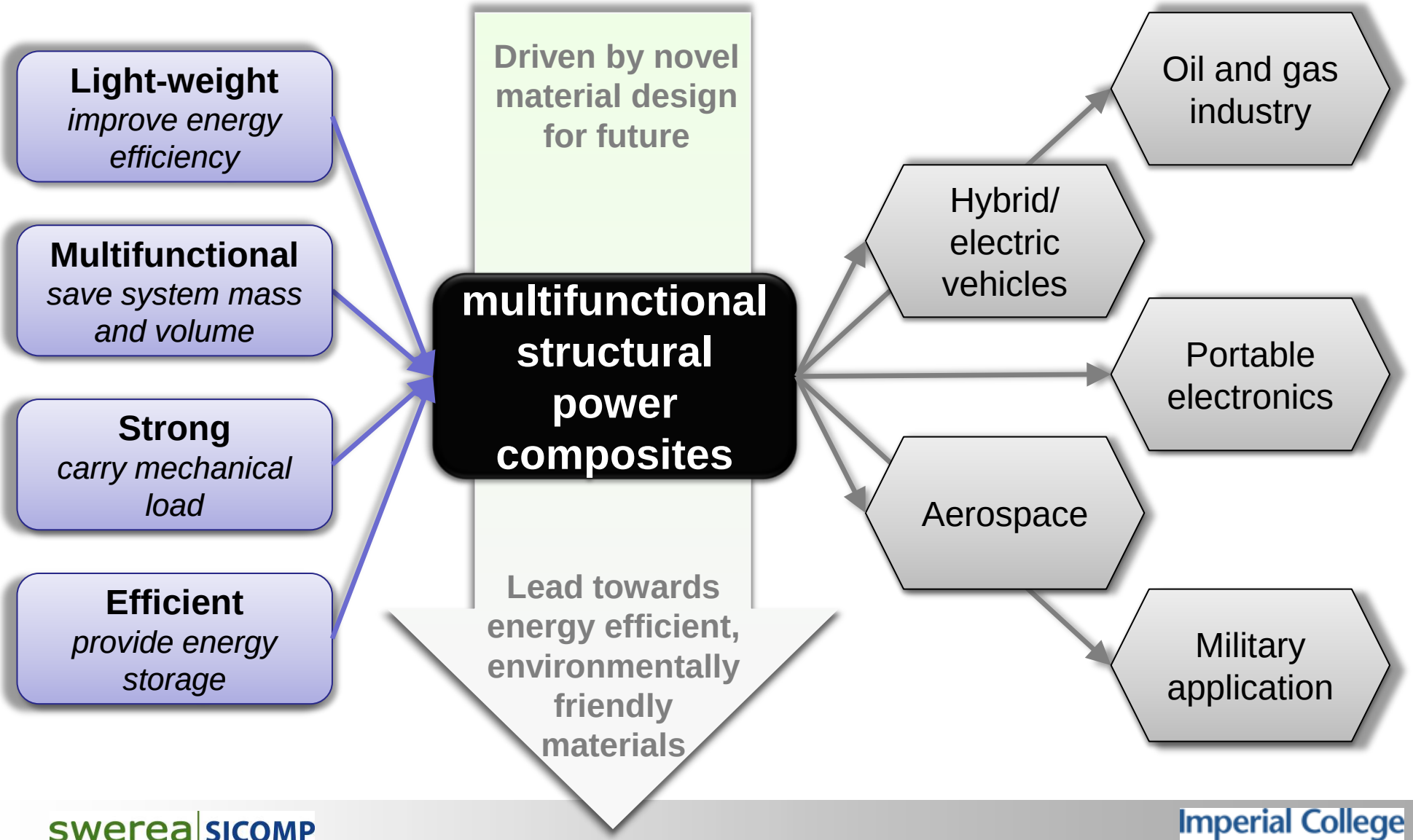
Rule of thumb

$$\Omega_E + \Omega_S > 1$$

$\Omega_s = \Omega_E = 1$; Ideal multifunctional energy source that can be designed into the structure without any compromise in energy output - *Maximum mass saving of 450 kg*

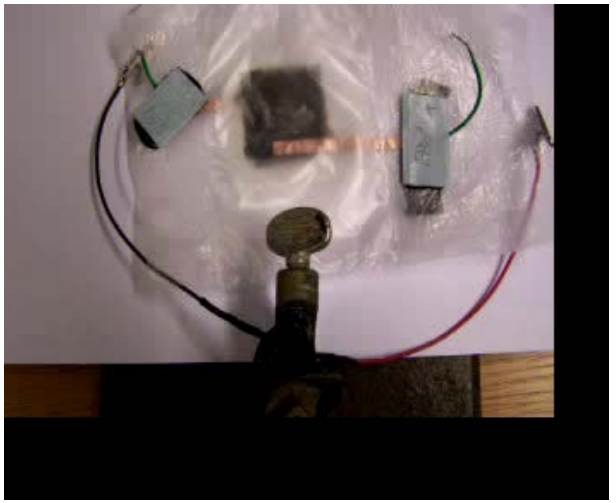
Ω_s , $\Omega_E < 1$ More realistic examples where the structural performance of the energy source leads to a compromise in the energy output

Vision and ambition



Interdisciplinary materials research

- Structural Power Materials
  - New & technically challenging
  - Potentially huge savings in diverse range of applications
- Interdisciplinary skills required
  - *Electrochemistry, polymer chemistry, mechanical engineering, materials science, physics, chemical engineering*
- Spectrum of materials – modify proportion of matrix constituents to change characteristics
  - *Mechanically dominated* – e.g. bike frame powering a GPS, ($\Omega_S > \Omega_E$)
  - *Electrically dominated* – e.g. shell of a radio controlled aircraft, , ($\Omega_E > \Omega_S$)



Swerea SICOMP first structural battery

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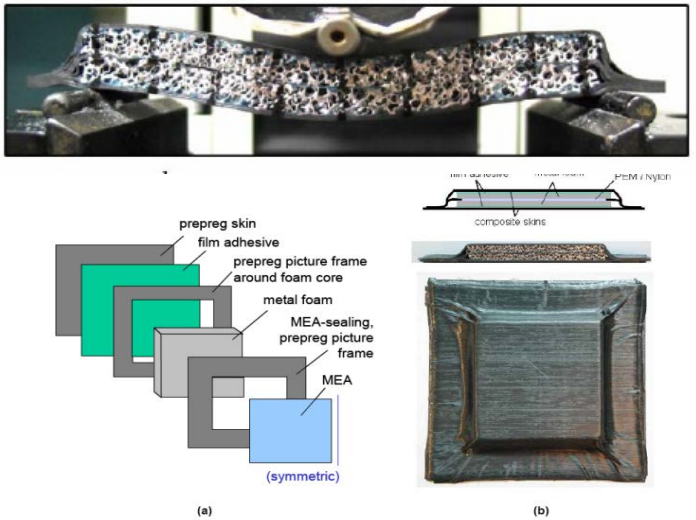
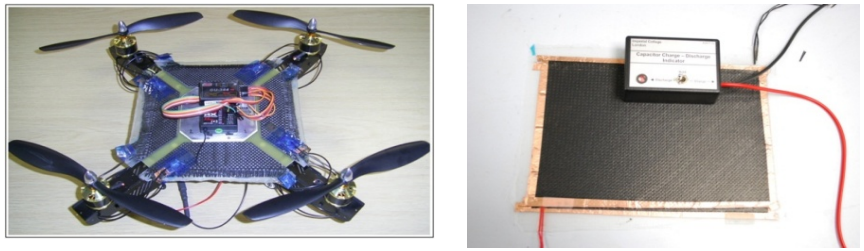
State of the Art

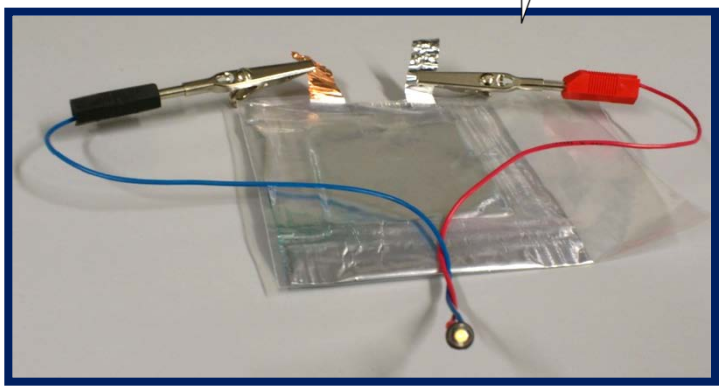


Structural Fuel Cell (ARL)

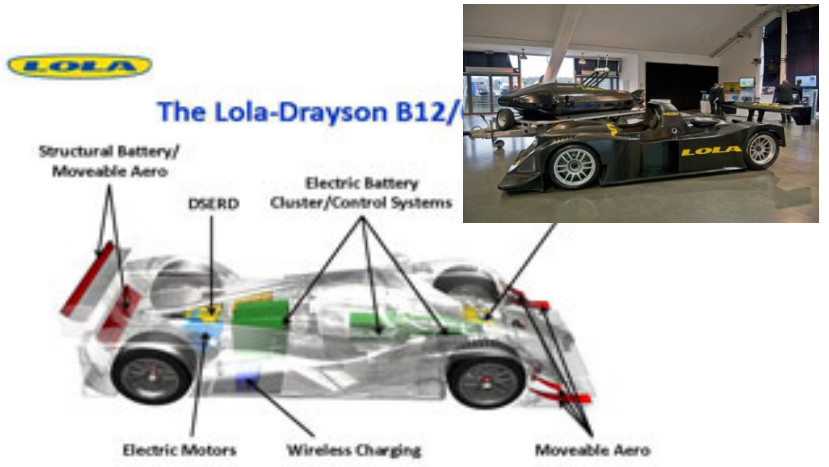


Structural Supercapacitor (Imperial)

STORAGE -KOM BATT+



Li-ion Structural Battery (Swerea SICOMP/KTH)



NiOH/ZnO Structural Batteries (BAE Systems/Lola)

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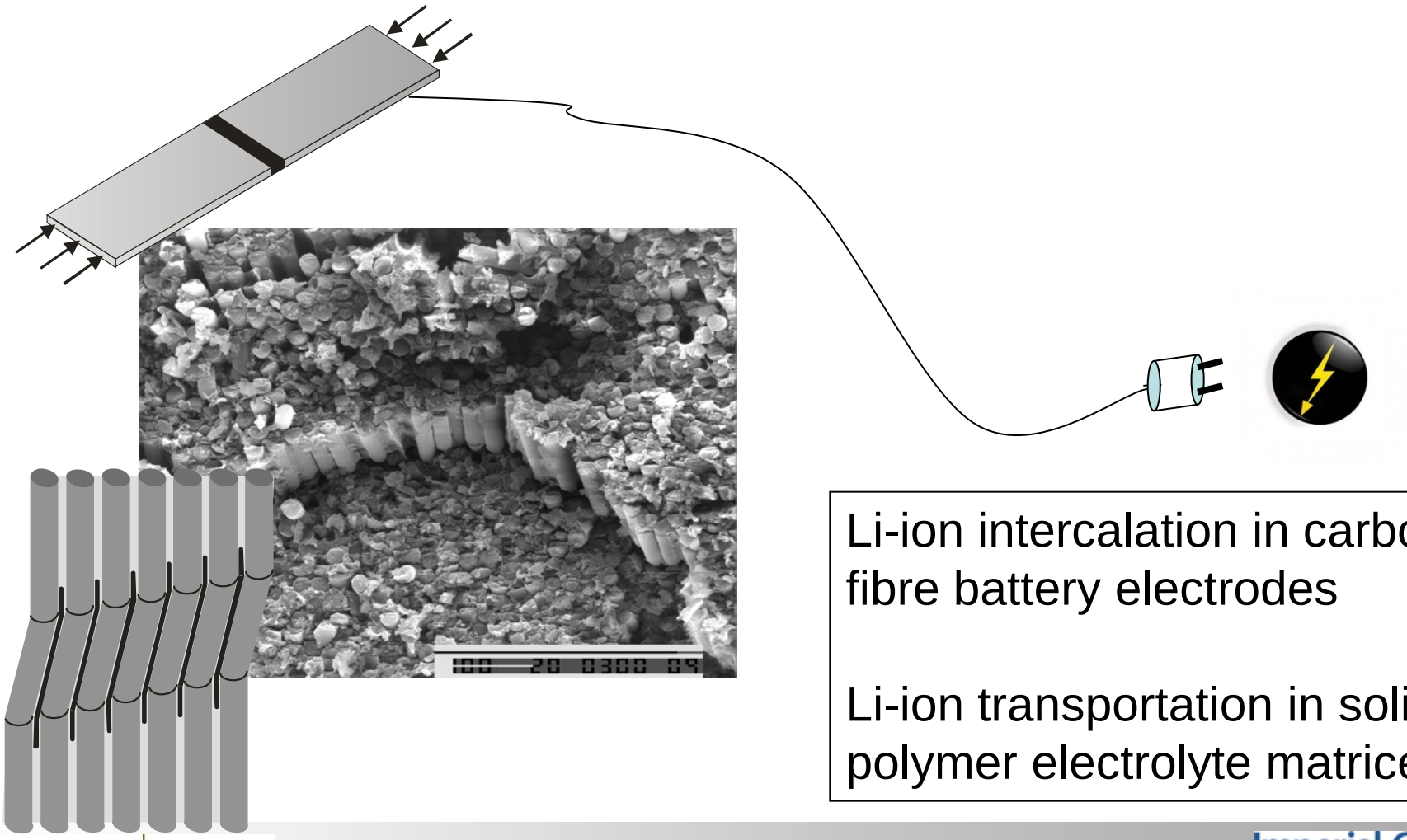
Make carbon fibre composites into batteries



Li-ion intercalation in carbon fibre battery electrodes

Li-ion transportation in solid polymer electrolyte matrices

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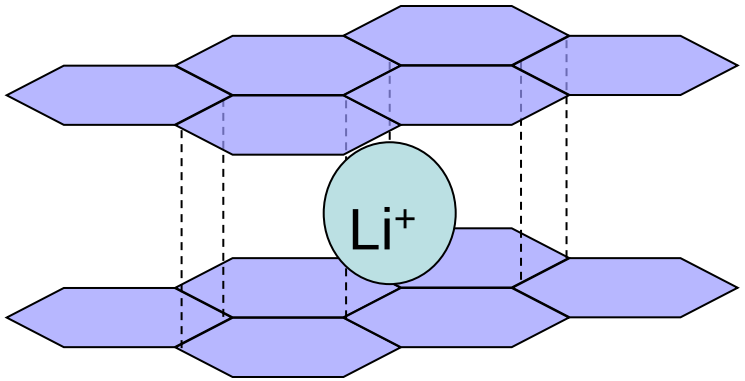
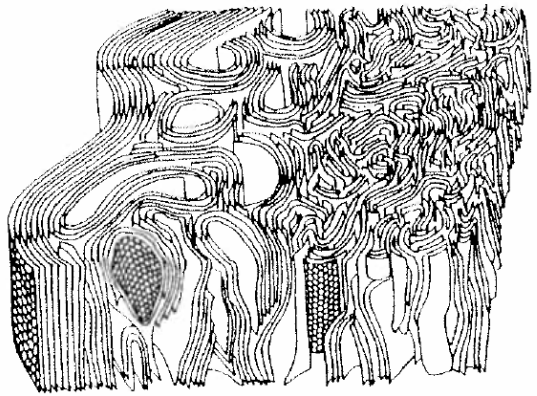
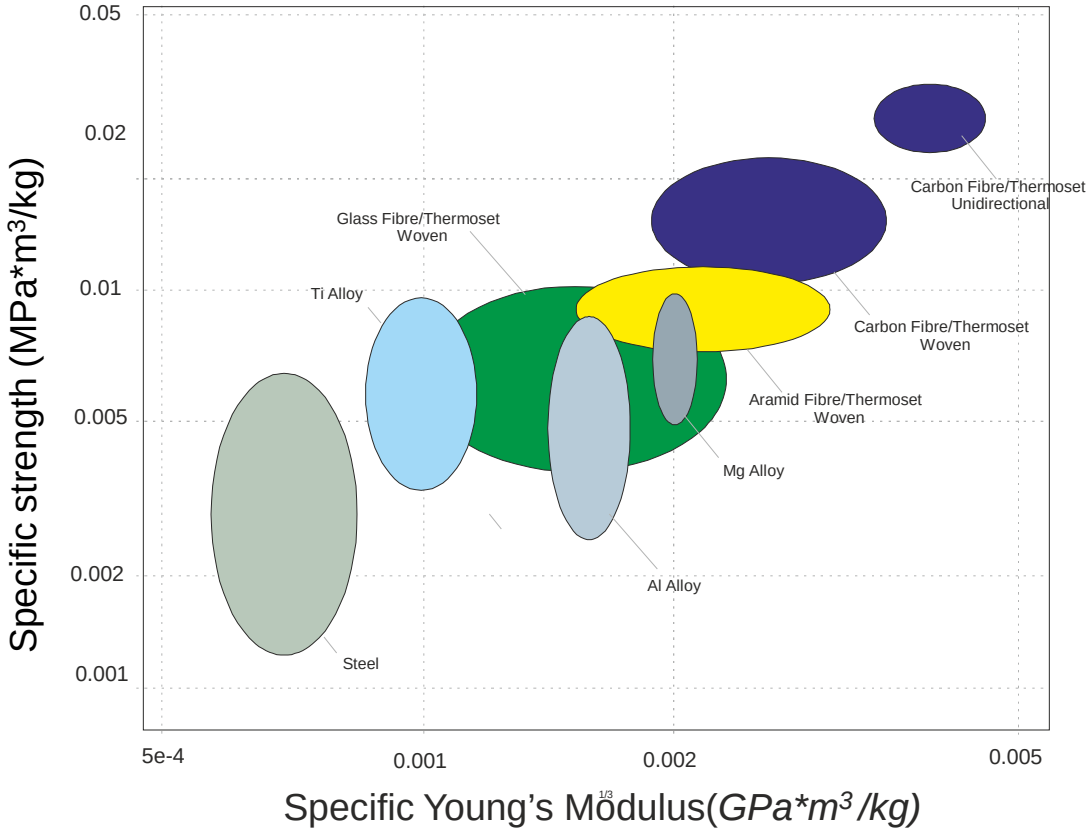
Carbon Fibres – do they have potential for multifunctionality?







Material comparison for min weight designs

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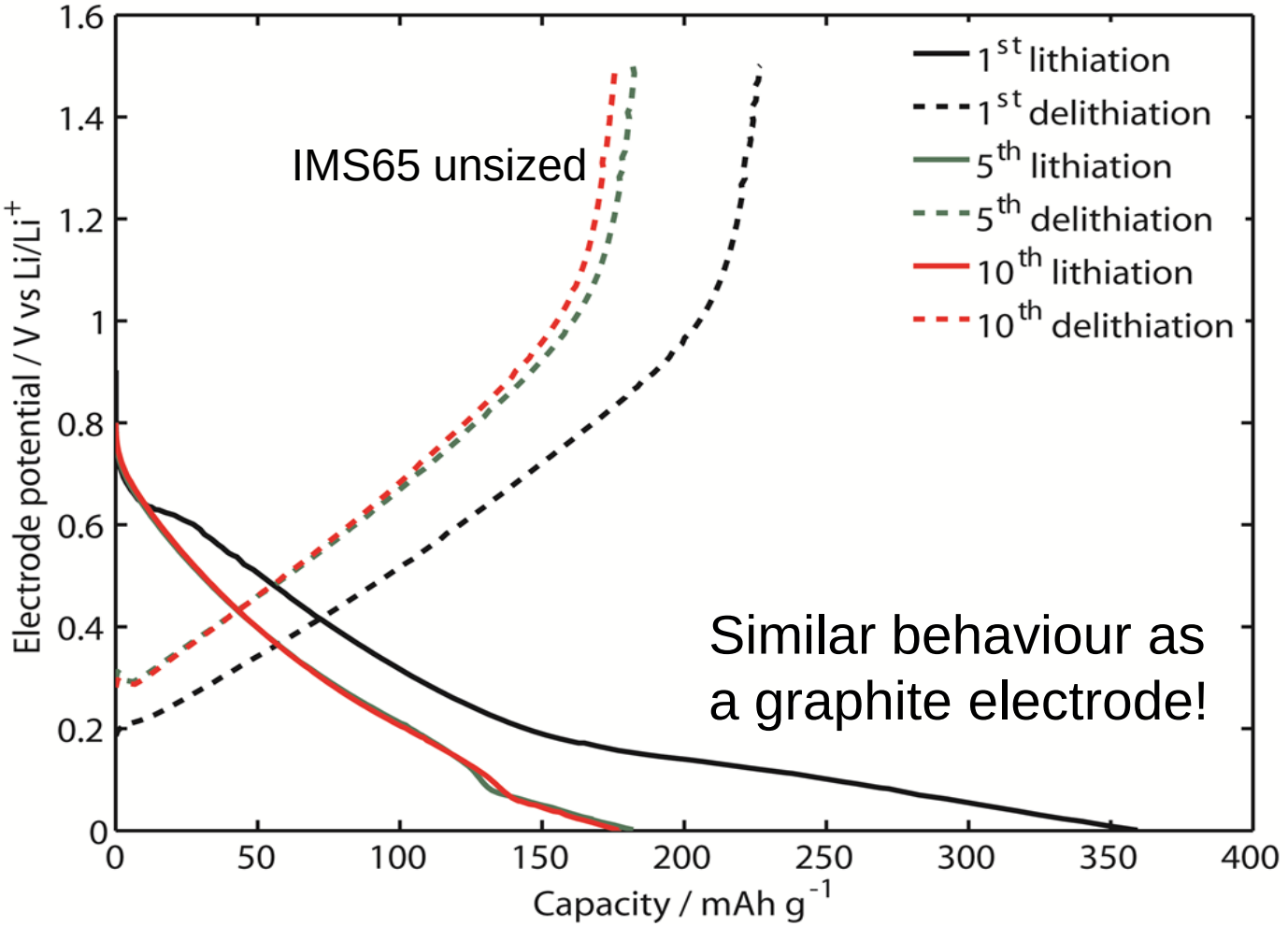
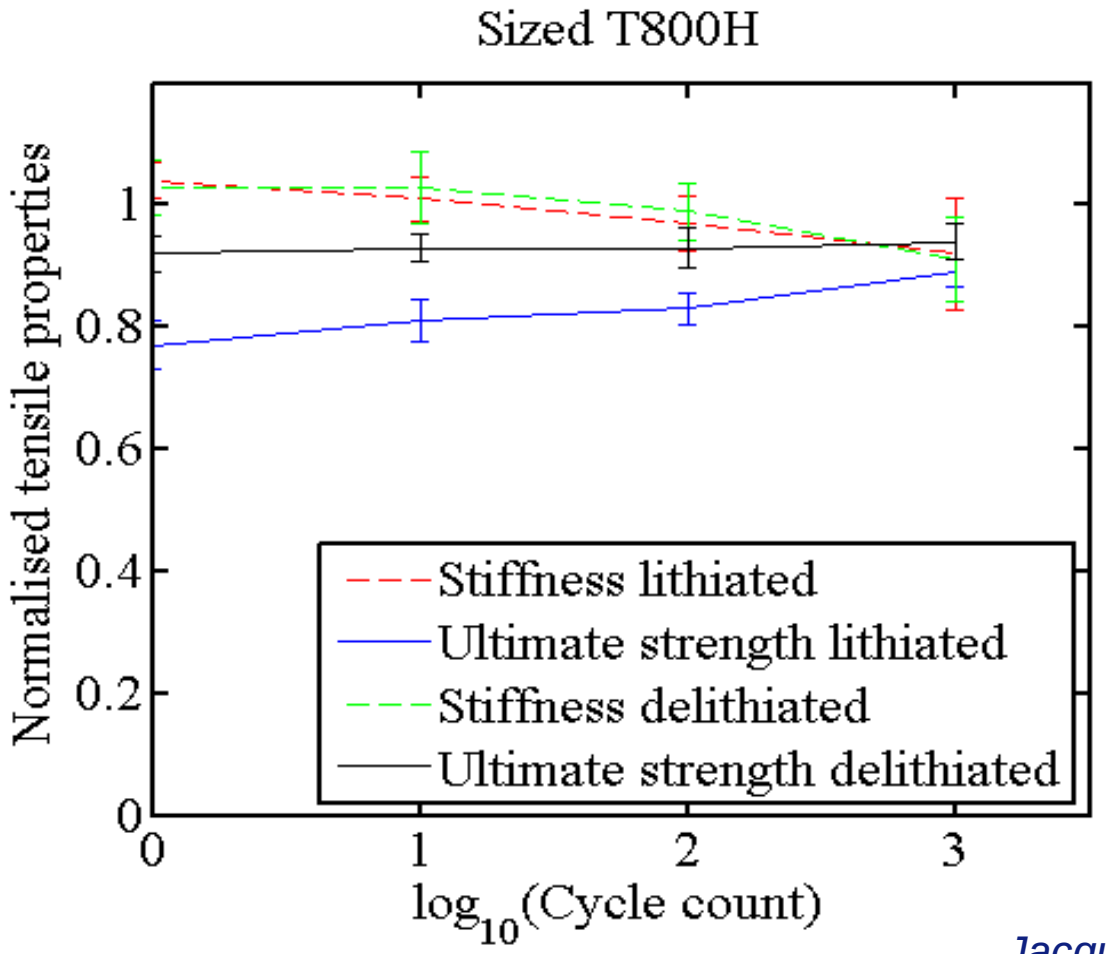
Capacity of PAN-based carbon fibres



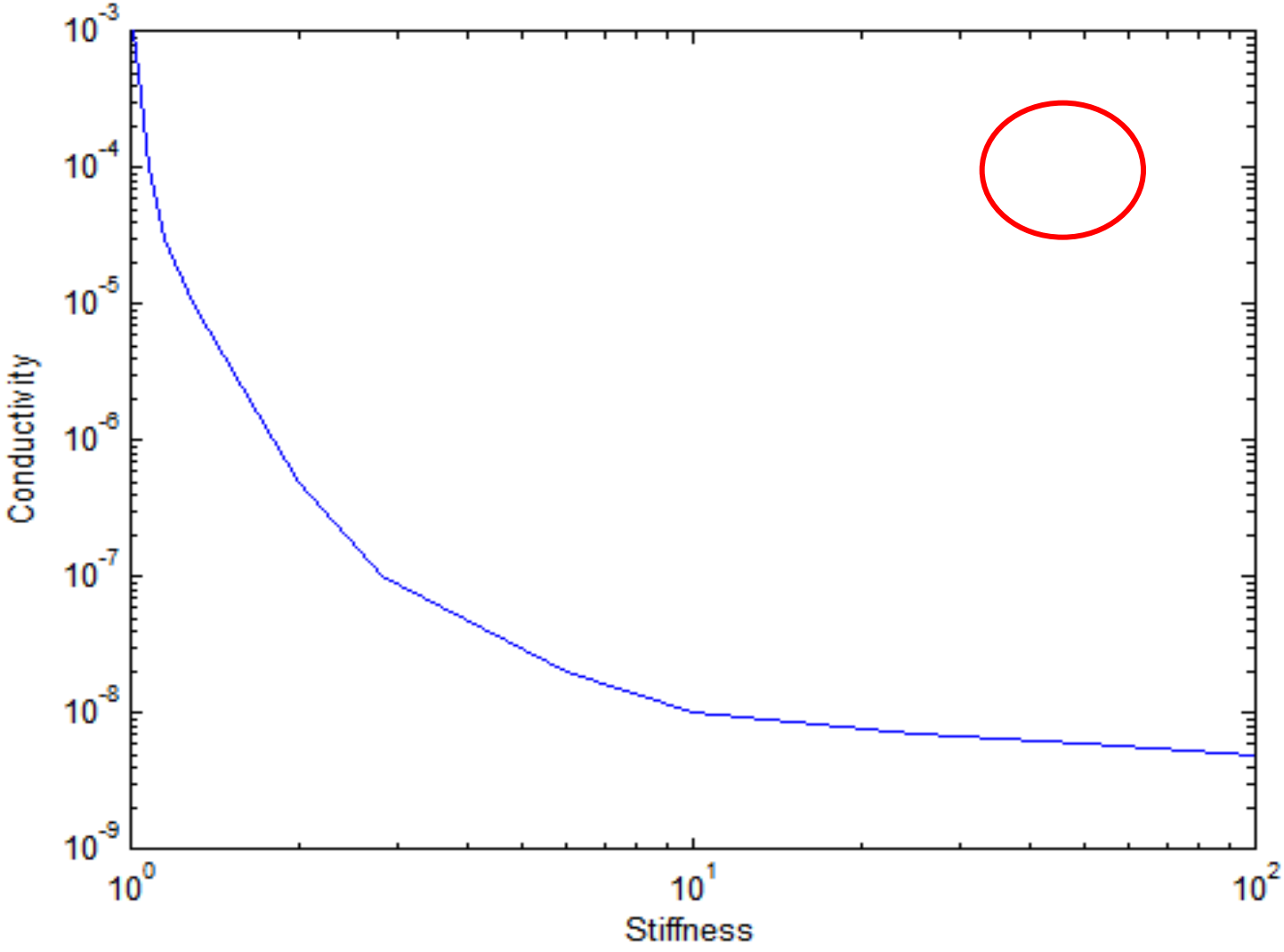
Kjell et al, J Electrochem Soc., 2011

Impact of electrochemical cycling on the tensile properties of carbon fibres



Jacques et al, 2012

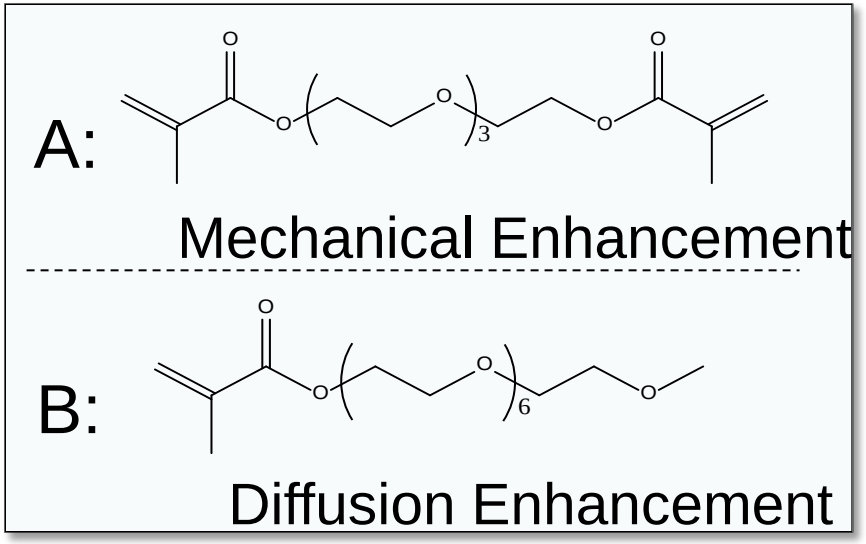
Structural electrolyte polymer matrix materials



SPE – Effect of crosslink density and Li-salt

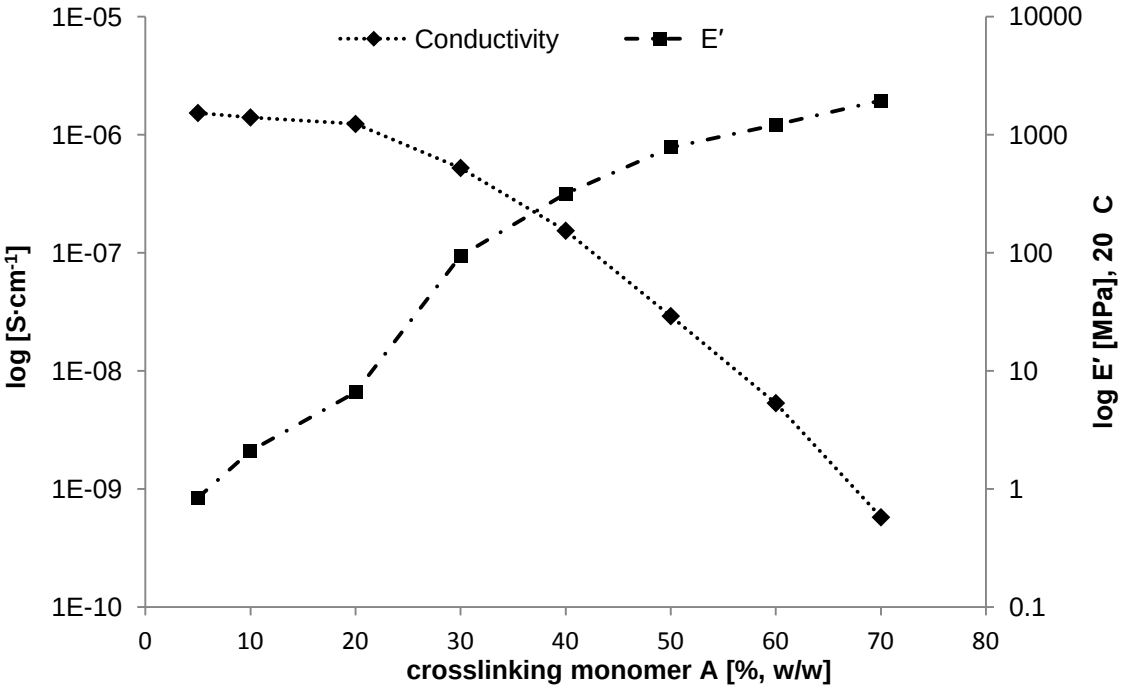
Thermoset electrolyte SPEs

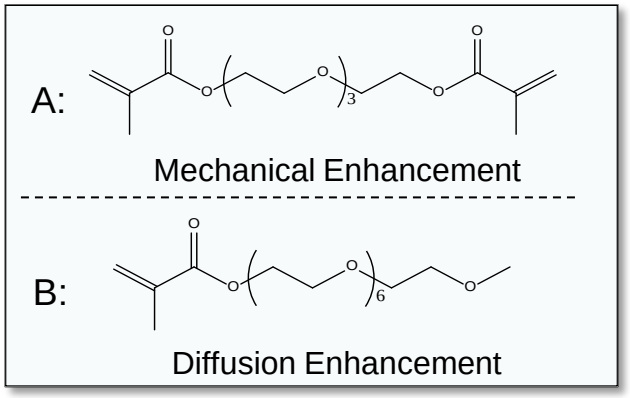
- Crosslinked PEG methacrylates
- Lithium salt dissolved in monomer mixture prior to cure
- Lithium ions can coordinate to oxygen in the ethylene oxide (EO) unit



Willgert et al, 2011

Ionic conductivity vs. Modulus





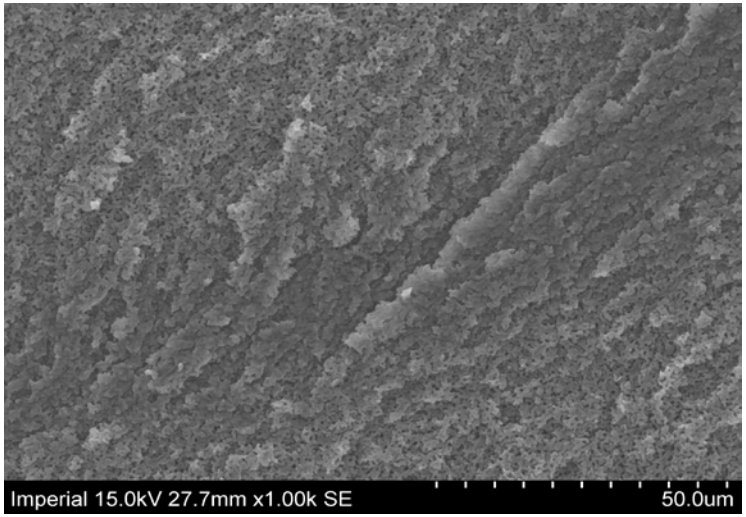
- Higher crosslink density gives higher modulus but lower ion transport number

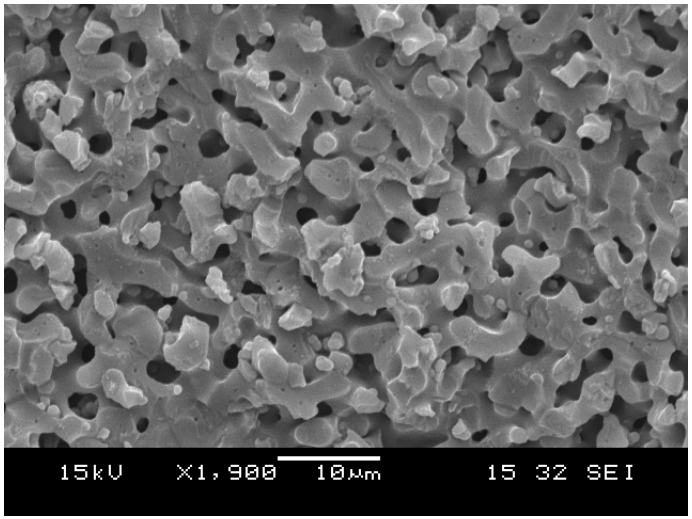
Innovative SPE matrix materials

Conflicting requirements:

high polymer mobility improves ion transport but reduces mechanical performance

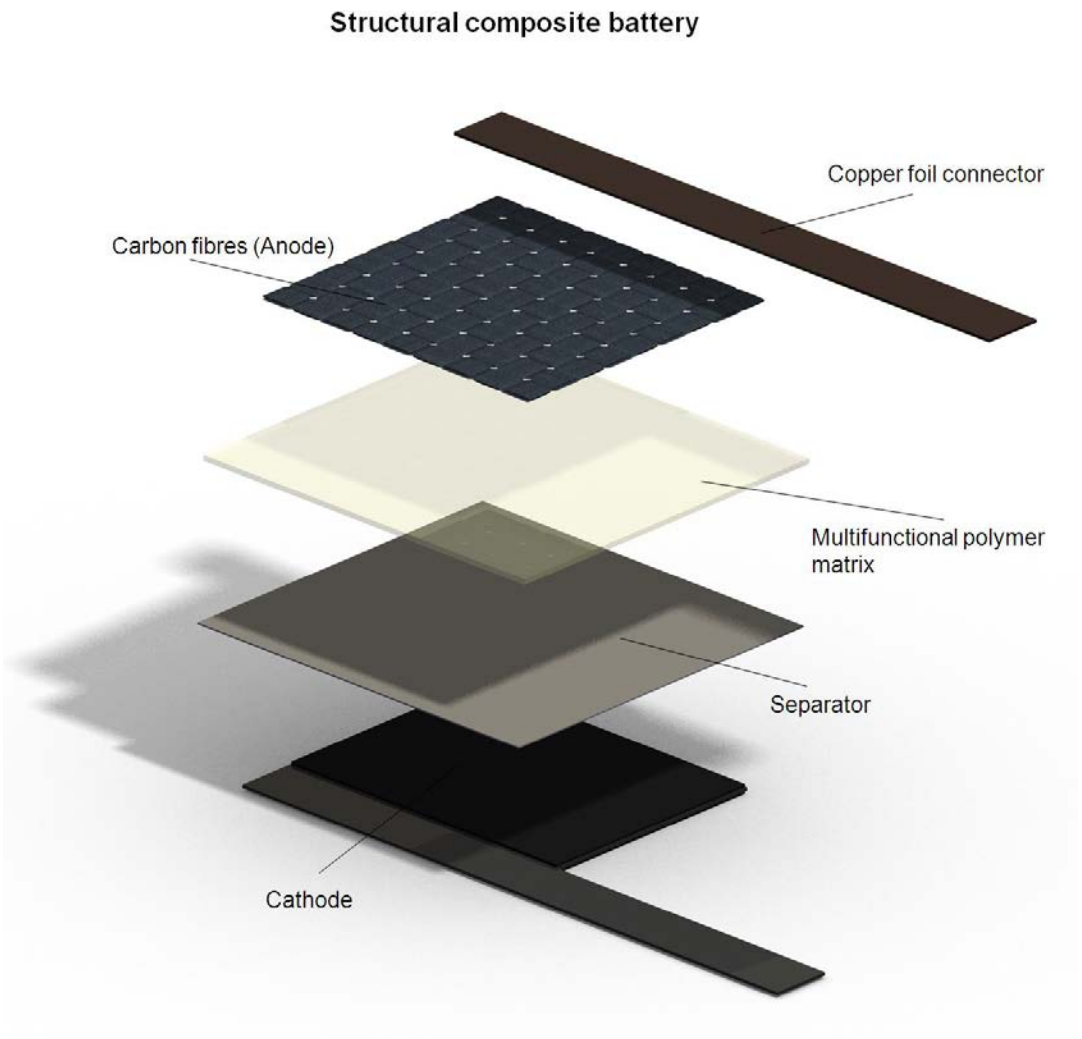
- Nanostructure to ensure structural robustness whilst allowing ion migration

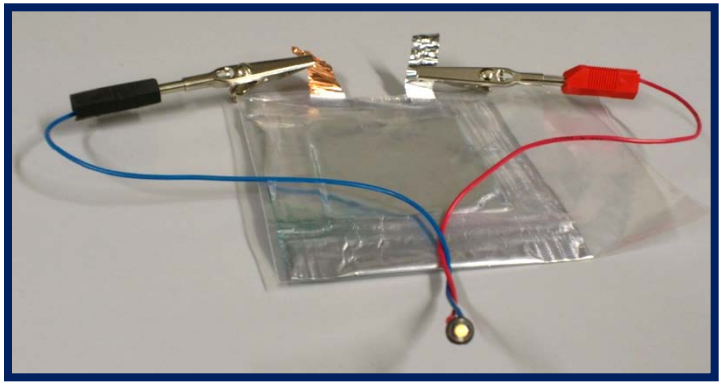




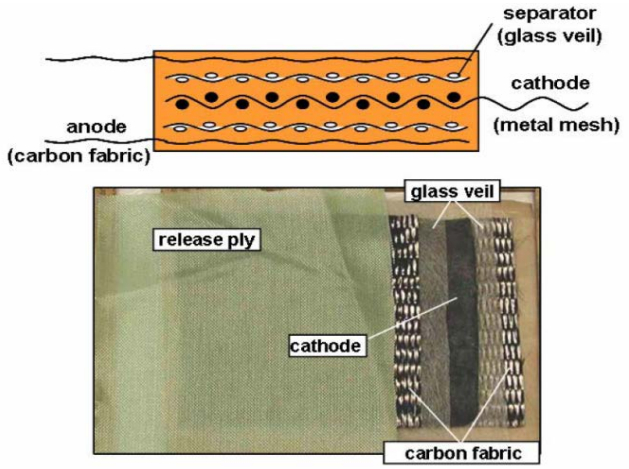
Microstructures for multifunctional matrices, Imperial

Device architecture – Structural Battery





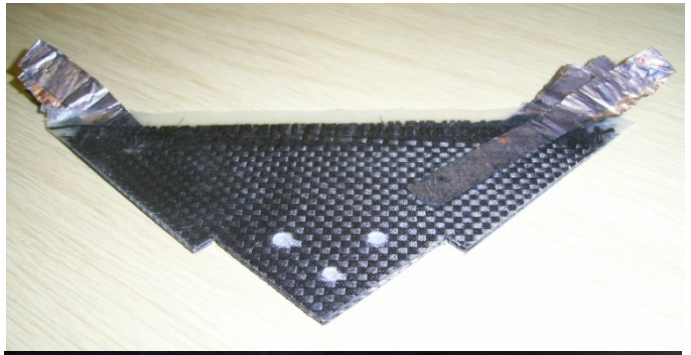
Structural Battery (SICOMP)



Structural Battery (ARL)

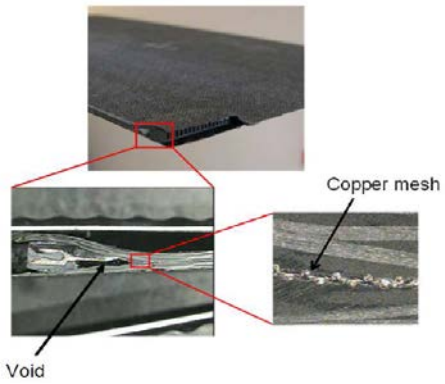
Technical & non-technical needs & bottlenecks

- Power Density; fundamental issue
- ⇨ Moderate electrodes conductivity,
- ⇨ Robust matrix , inhibiting ion migration
- Matrix dominated mechanical properties;
- ⇨ Dictated by delamination & compression ,
- ⇨ Additional electrical functionality,
- ⇨ Conflicting demands on fibre/matrix interface
- Cost and fabrication – principal hurdle for polymer composites;
- ⇨ Structural power materials – make in moisture free environment (<50ppm),
- ⇨ Not amenable to finishing processes (cutting and drilling)
- Ownership Issues;
- ⇨ Durability, repair, lifing, recycling, safety, etc



Opportunities, synergies & common themes

- *Distributed energy storage for safer road vehicles*
- *Highly diverse range of potential applications*
  - As performance improves, it has sparked interest from other sectors
- *Highly multidisciplinary topic* - Electrochemistry & structural materials
  - Fertile ground for development of new technologies
  - Novel material architectures - stimulating development of monofunctional electrical & mechanical materials
  - Solutions for conventional composites - electrical conductivity (lightning strike)



Electrical connections


Lightning strike protection


Energy harvesting

Structural Power Materials - Summary

Paradigm shift for energy materials

Potential to make a considerable difference to how we store and deliver energy in 2050

Acknowledgements

Prof Alexander Bismarck, Prof Anthony Kucernak, Prof Milo Shaffer, Dr Joachim Steinke, Dr Hui Qian, Dr Natasha Shirshova, Dr Kingsley Ho, Prof Göran Lindbergh, Prof Dan Zenkert, Prof Mats K Johansson, Prof J Varna Atif Javaid , Tony Carlson, Maria H Kjell, Markus Willgert, Eric Jacques, Andrejs Pupurs, Per-Ivar Sellergren

Current funding - STORAGE

Composite Structural Power Storage for Hybrid Vehicles

Imperial College London

VOLVO

BAM Federal Institute for Materials Research and Testing

swerea | SICOMP

CHALMERS

ETC Battery and FuelCells Sweden AB

umeco

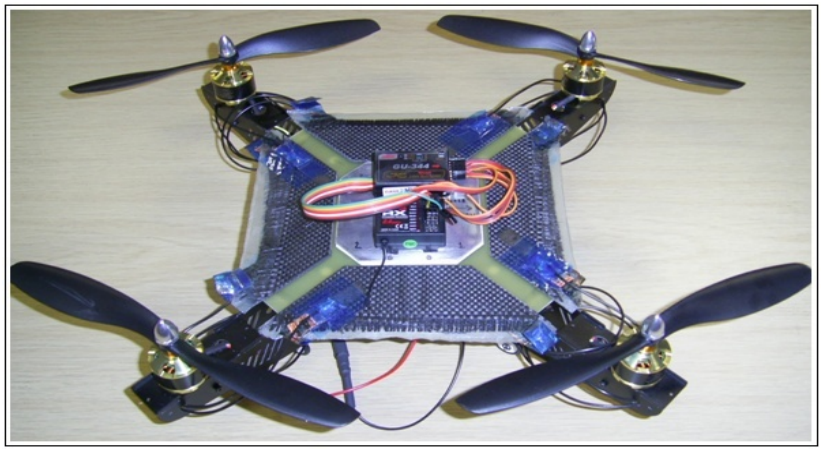
nanocyl

INASCO

STORAGE

- Started January 2010 for 42 months (€3.3M, 9 partners)
- Led by Imperial, who are focusing on supercapacitors . SICOMP leads battery research
- Industrial partners cover the value chain addressing energy demands of future hybrid vehicles
- Demonstrator product will be a booth lid structure (target is 15% weight saving over standard supercapacitor/battery combination)

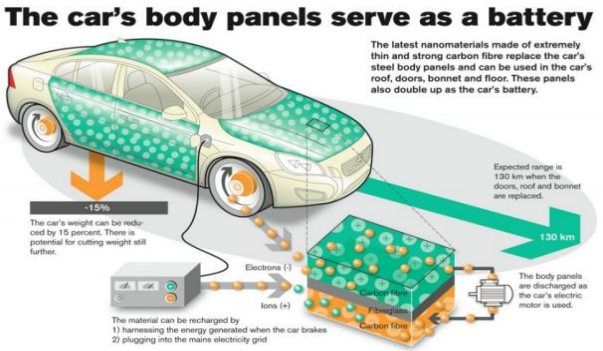
Component Design and Implementation



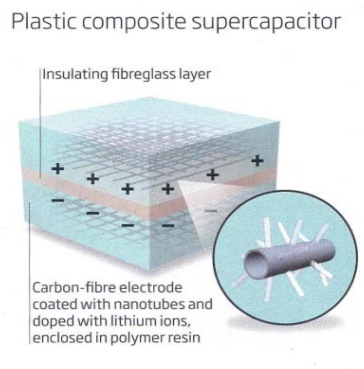
Questions?

Professional Engineer

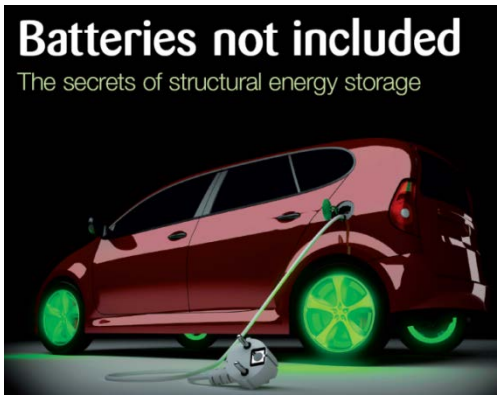
The Economist



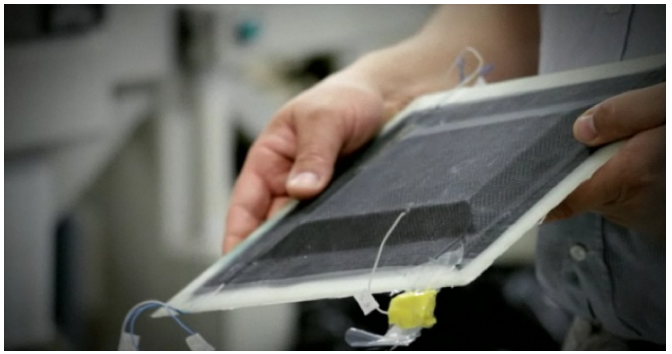
New York Times



New Scientist



Materials world



CNBC

www.energyopportunities.tv/Editorial-Features/An-energy-storage-revolution

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