Institute of Materials Research and Engineering
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FIBRE-REINFORCED COMPOSITE SOLID ELECTROLYTES FOR STRUCTURAL BATTERIES

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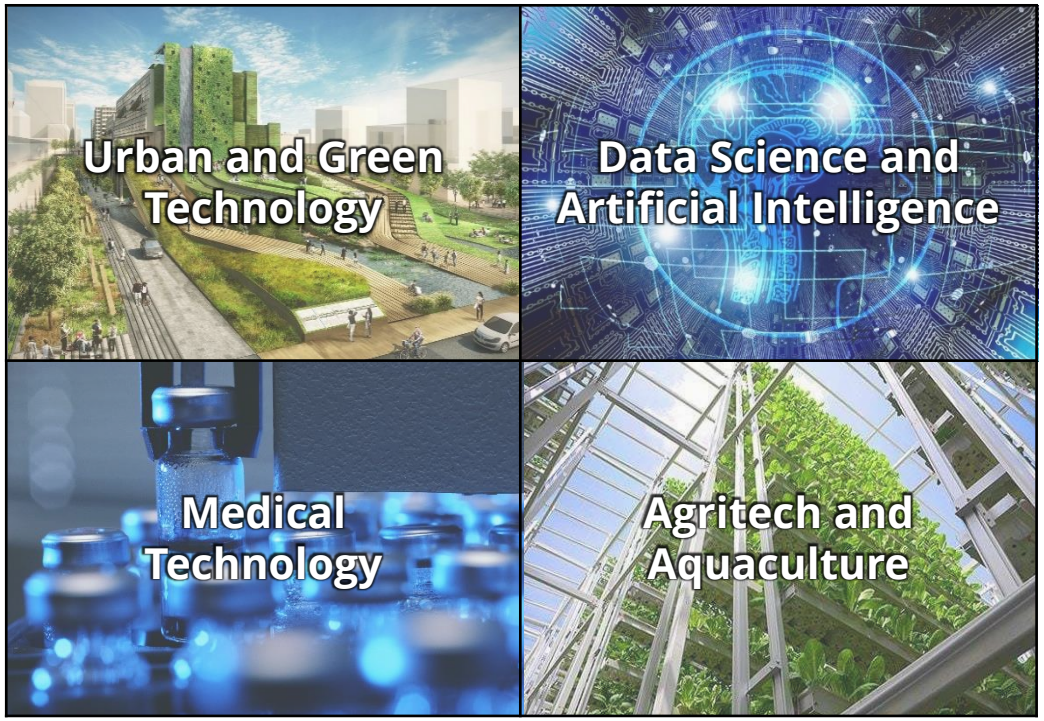
Our Mission

We advance science and develop innovative technology to further economic growth and improve lives

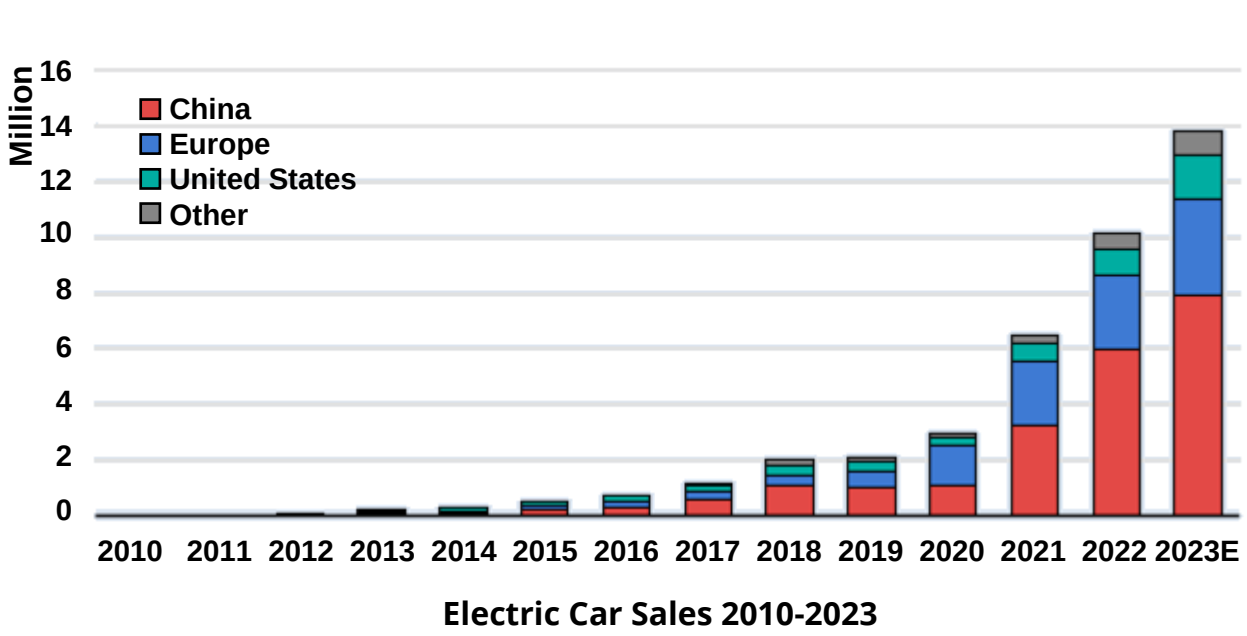
Our Vision

A global leader in science, technology and open innovation

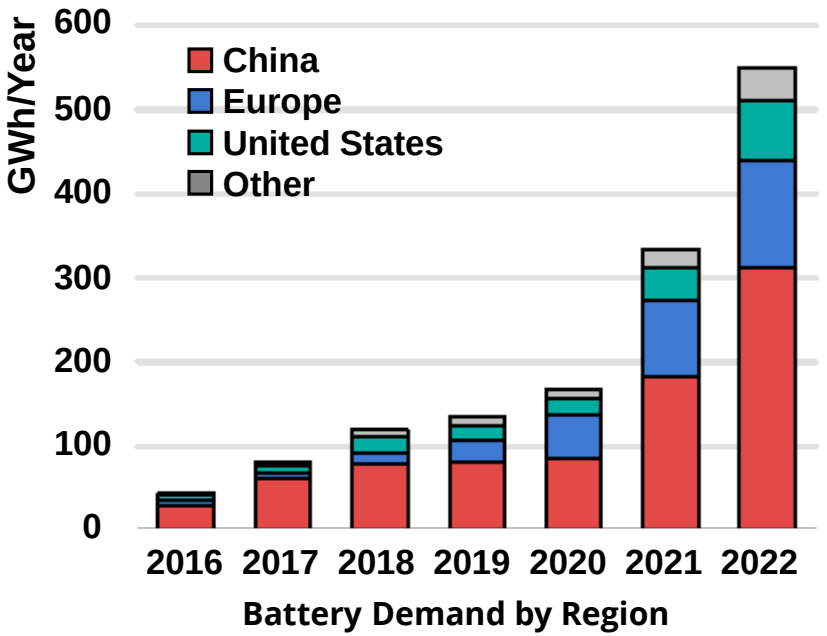


- A*STAR's Horizontal Technology Centres
- Comprising of 18 research institutes
- **Institute of Materials Research and Engineering**

ELECTRIFYING TRANSPORT: emissions reductions to meet net zero targets



Electric Car Sales 2010-2023



Battery Demand by Region

- Demand for passenger EVs more than ***doubled*** from ***2019 to 2021*** *reaching* ***over 10.2 million units in 2022*** (estimated to reach 20.6 million in 2025)*
- Higher demands for EVs means higher demand for batteries
- To meet the net zero targets: zero-emission vehicles need to represent ***61%*** of global new passenger vehicle sales by ***2030***, ***93%*** by ***2035***

Innovation to bridge the gap between demand and supply and stimulate further emissions reductions

***IEA Global EV Outlook 2023**

CONCEPT OF STURUCTURAL BATTERY: Improving kWh/Weight Ratio

Batteries account for **one third of Electric Vehicle's** weight, decreasing available payload volume and energy efficiency

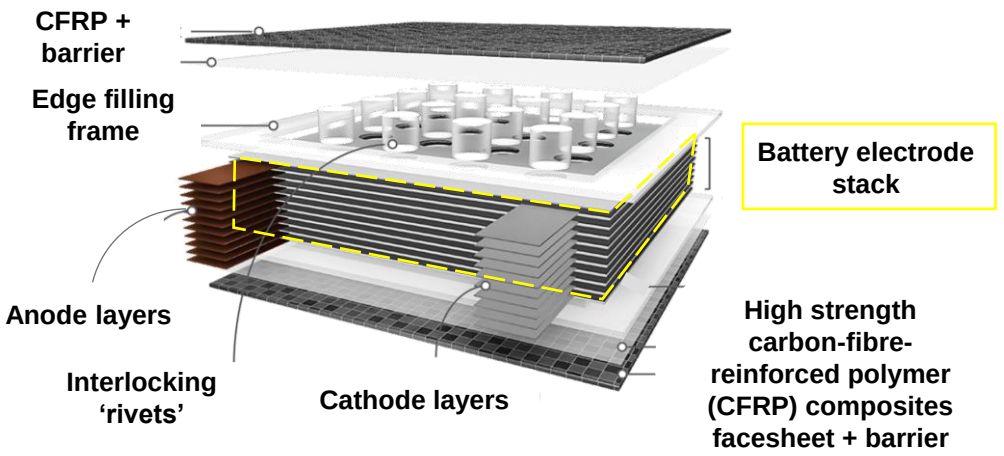
Vaframe/Getty Images

Lowering the weight translates into lower energy consumption and longer driving range

Batteries that can carry load? Multifunctional Energy Storage --- structural components doubling up to store electrochemical energy

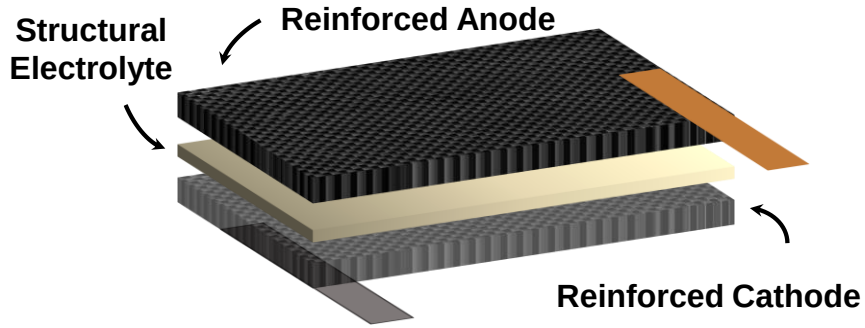
STRUCTURAL BATTERY APPROACHES

Battery Embedded into a Robust Structure

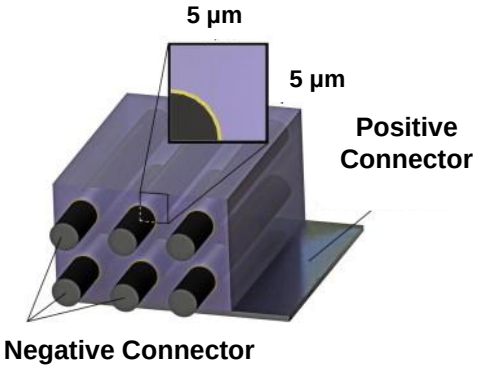


- Li-ion battery materials encapsulated inside high strength carbon-fibre composites
- interlocking polymer rivets to stabilize the electrode layer stack mechanically

Battery made of Multifunctional Components

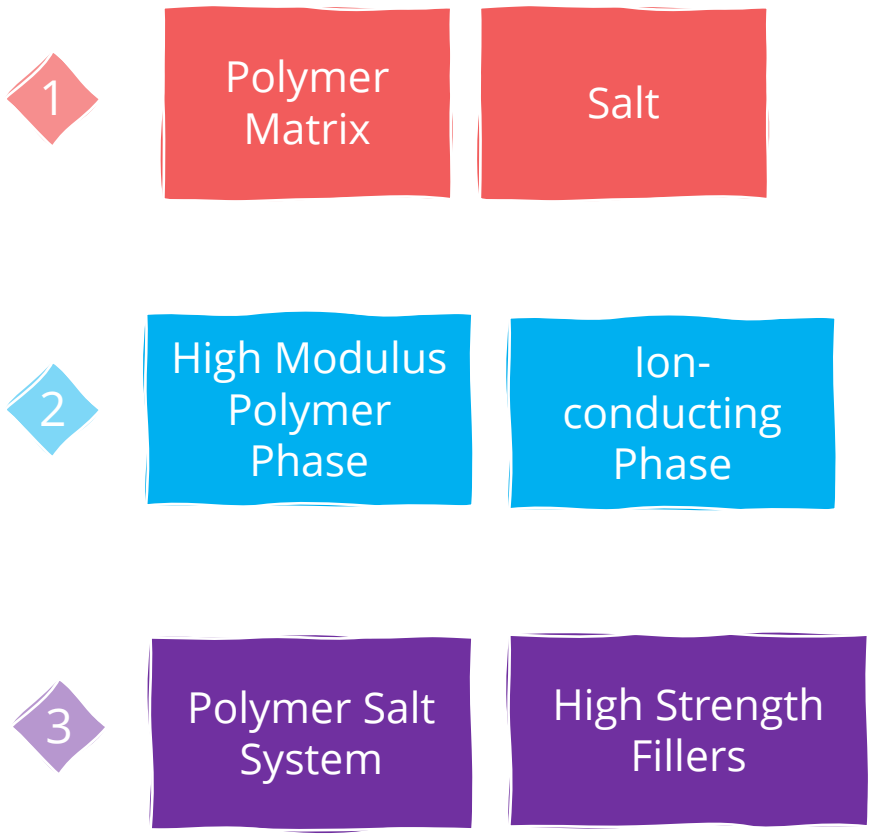


- Carbon fibres coated with a solid polymer electrolyte
- Cathode-doped matrix material



Journal of Power Sources 414 (2019) 517–529
Composite Science and Technology 101 (2014) 41-61

STRUCTURAL ELECTROLYTES



- Commonly known polymer electrolytes (e.g. Polyethylene oxide (PEO)-Li salt systems)
- Negligible load-bearing properties

- Bi-continuous structural electrolyte
- Simultaneous co-polymerization of
  - Robust structural motifs such as epoxy or methacrylates
  - Ion conducting phase such as Ionic liquids

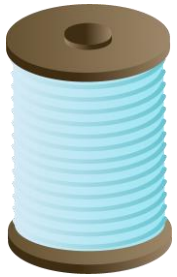
- Nanofibers
- Metal Organic Frameworks
- Inorganic Ceramics (such as high ion conducting ceramics)

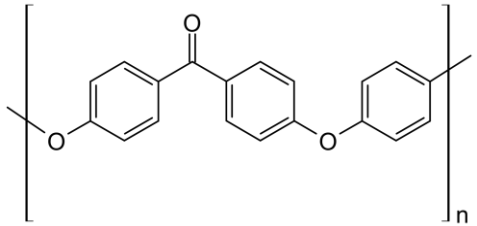
MY. Tan, et al., Chemistry–An Asian Journal 17 (21)

Hot-Pressed Fibre reinforced $P(EO)_{12}LiTFSI$ (Solvent-free)

Objective: To effectively decouple mechanical properties from the ionic conductivity of PEO – LiTFSI solid polymer electrolyte via reinforcement with PEEK microfibres

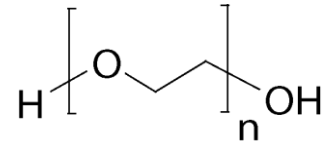
Polyether Ether Ketone PEEK Microfibres

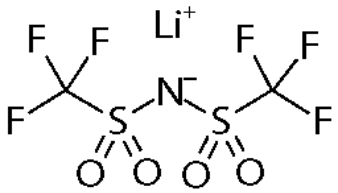




- High Thermal Stability
- Excellent Mechanical Properties

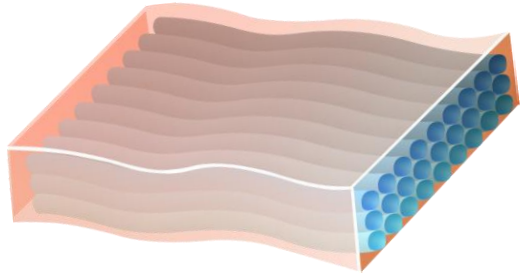
Polymer Matrix of PEO - LiTFSI





- Poly(ethylene) Oxide (PEO)
- Lithium salt of lithium bis(trifluoromethane-sulfonyl)imide salt (LiTFSI)

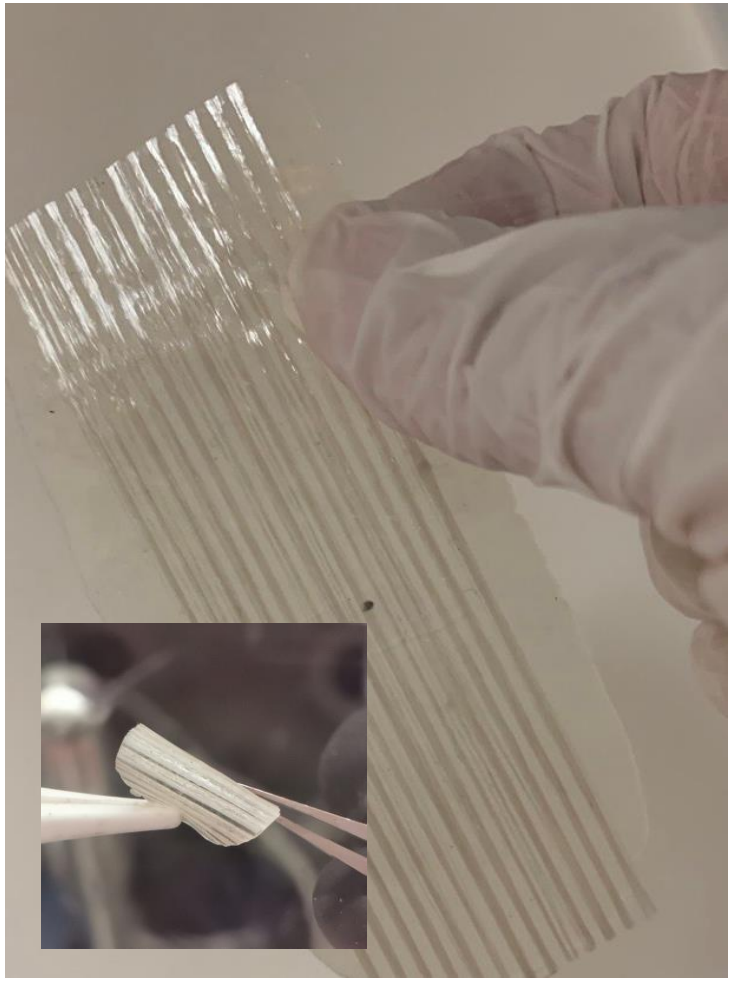
PEEK reinforced PEO - LiTFSI

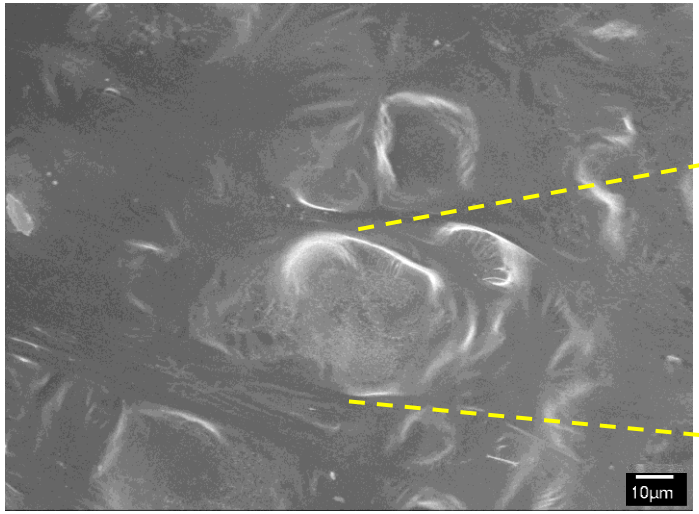


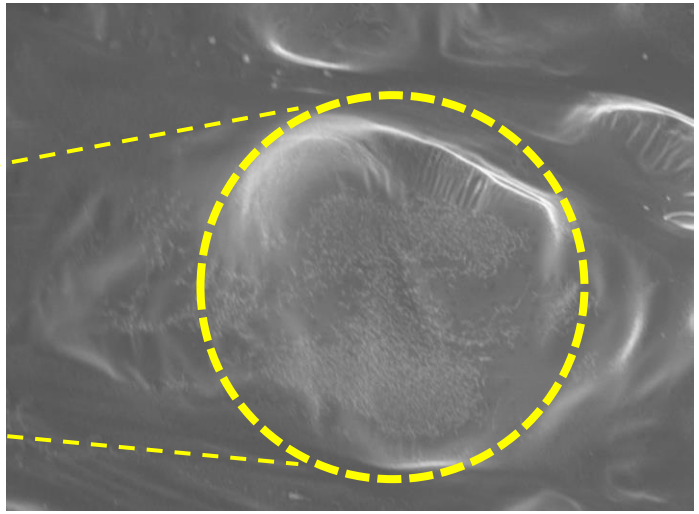
- Solvent-free synthesis
- Hot-pressed at 100 °C (well-above the melting temperature)

Safanama, et al. Composite Science and Technology 241 (2023) 110134

Fibre-Reinforced Composite Solid Polymer Electrolyte (CSPE)

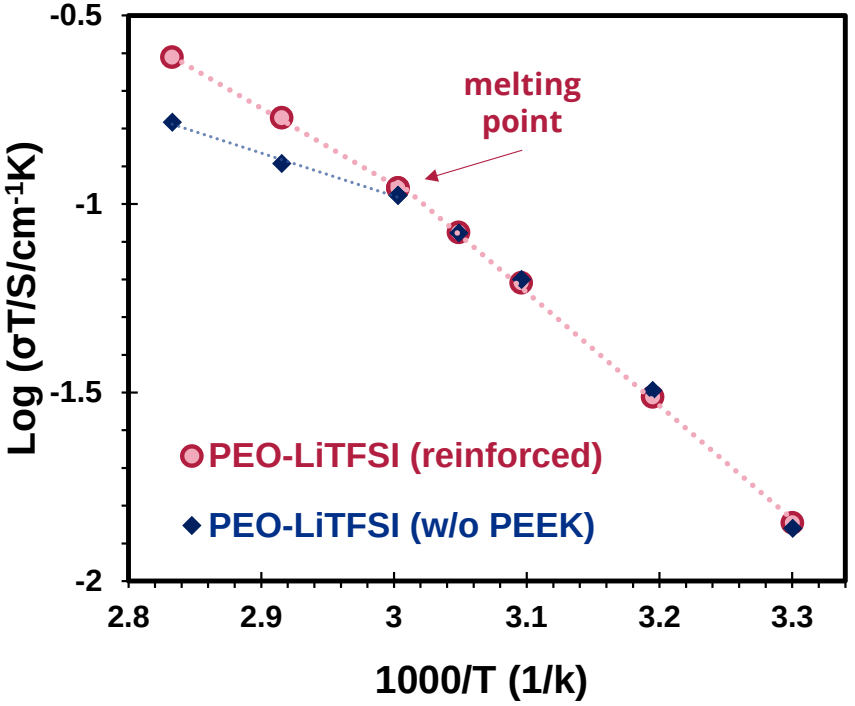


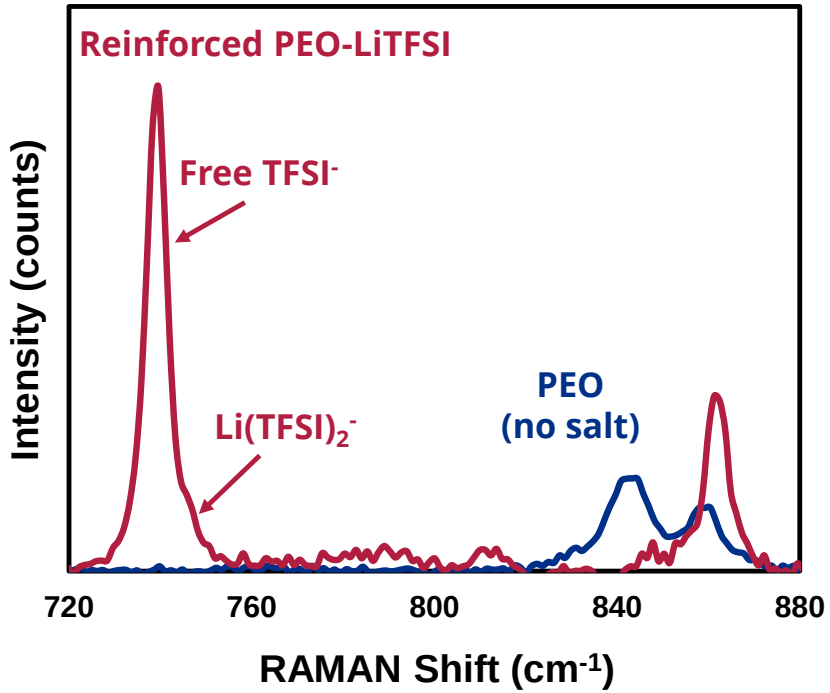




- Uniform alignment of PEEK fibres in the polymer matrix of PEO – LiTFSI
- PEEK fibres well-embedded in the polymer matrix of PEO – LiTFSI
  - ***Effective in enhancing mechanical strength***
- Smooth and void free interface between the fibres and the matrix
  - ***Allowing for optimum and undisrupted ion transport pathways around the fibres***

Full Dissociation of Lithium Salt & Intact Ion Conduction



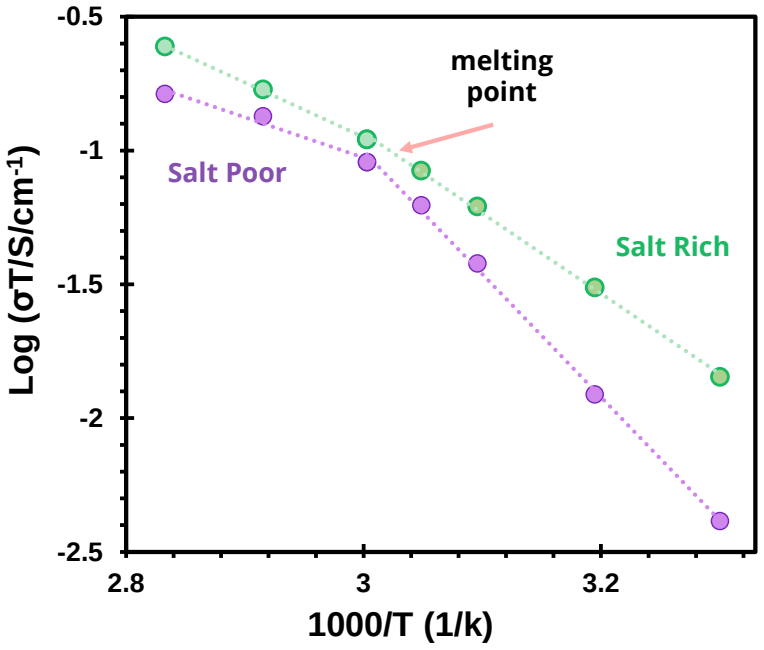


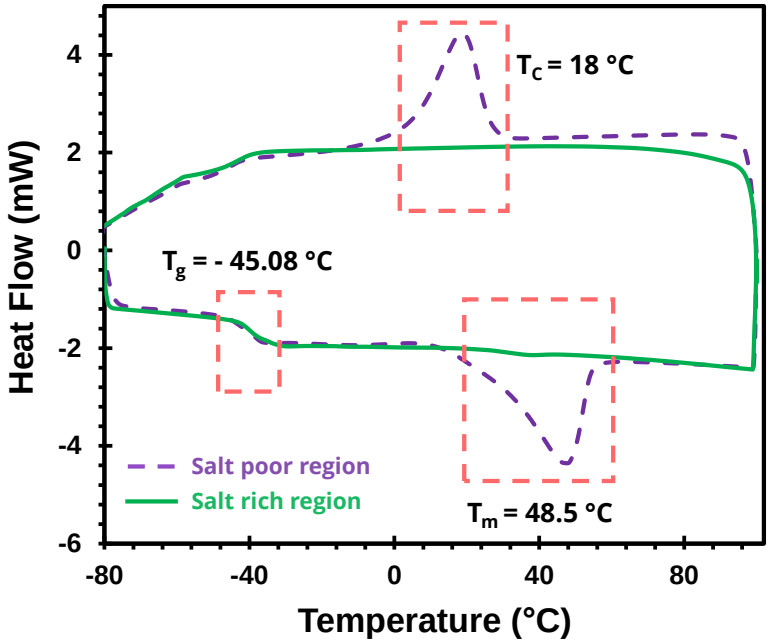
PEO-LiTFSI solid polymer electrolyte (SPE) maintains its high ionic conductivity after PEEK fiber infusion with $\sigma_{T,25°C}$ = *4.7 × 10^{-5} S/cm and* $\sigma_{T,50°C}$ = *2.0 × 10^{-4} S/cm*) with transference number of t_{Li+} ≈ 0.4 and *electronic conductivity ≈ 10^{-07} S/cm*

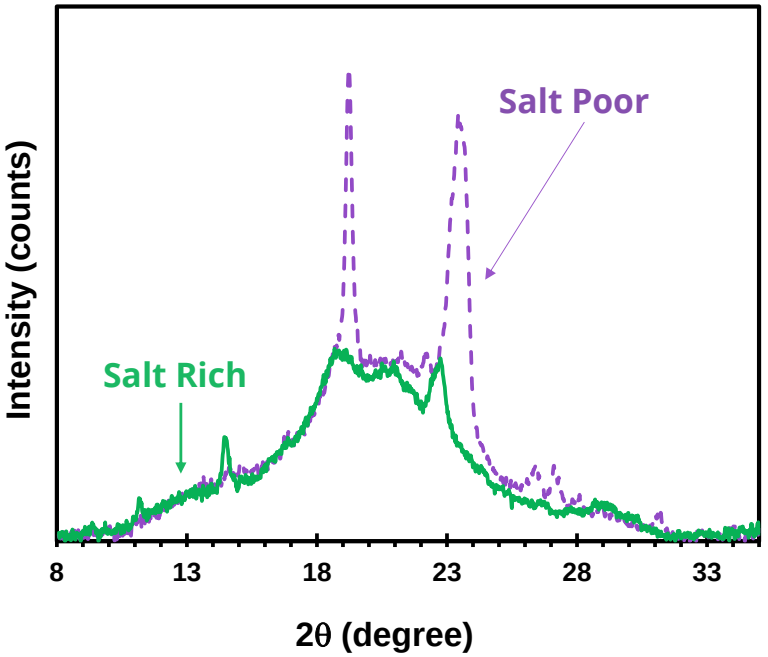
- ***No disruption in ion transport after fibre addition***

- Sharp peak at 740 cm^{-1} corresponding to S-N stretching of free TFSI$^-$ anion
  - ***Proof of dissociation of lithium salt in PEO matrix resulting in higher ionic conductivities***
  - ***Solvent-free approach***

Effective Salt Distribution – Solvent Free Method

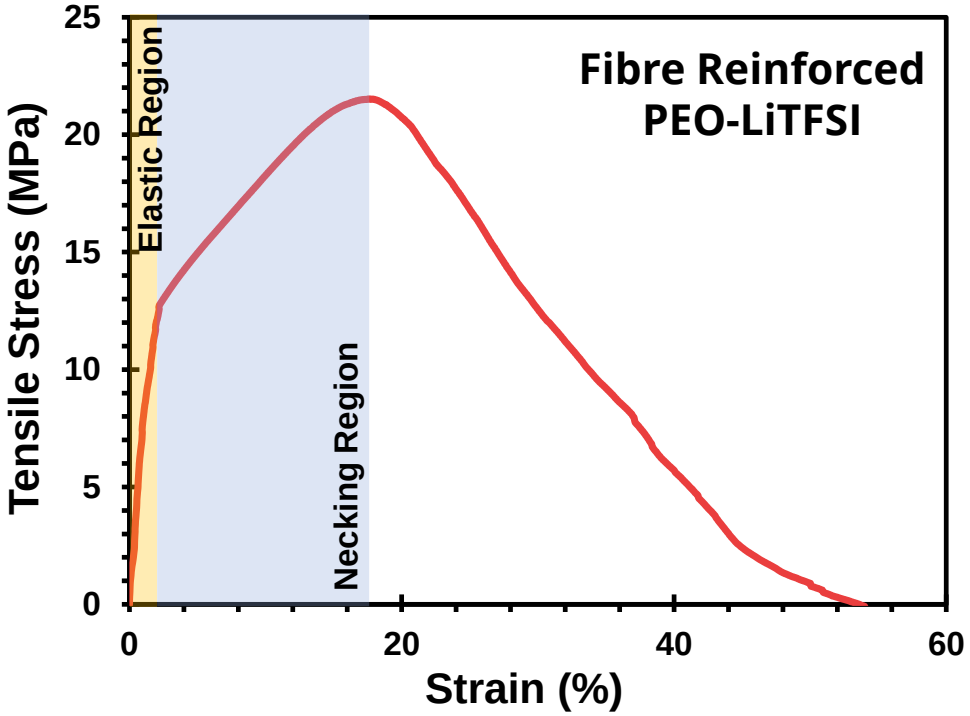






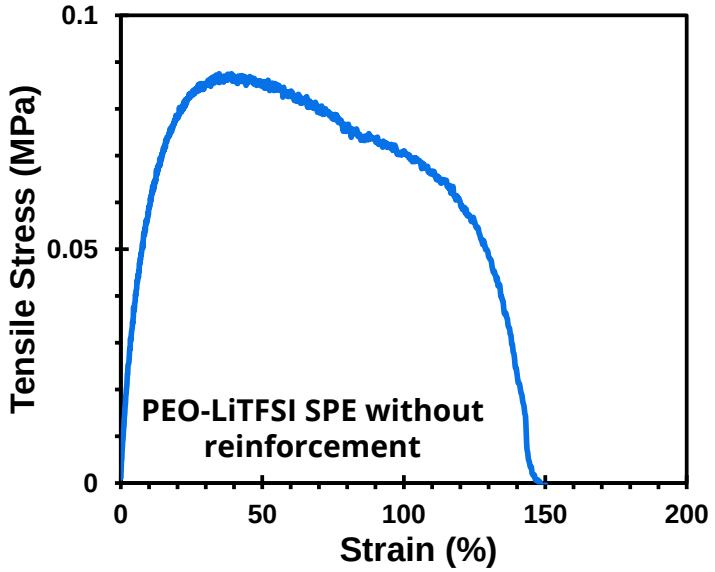
- Non-uniform microstructure upon slow cooling of the reinforced CSPE or insufficient dwell times at temperatures
  - *Arising from **disparity of the salt content** in different regions*
- **Lower degree of crystallinity** for the salt rich CPSEs according to DSC and XRD pattern
  - *Resulting in **higher ionic conductivity values***

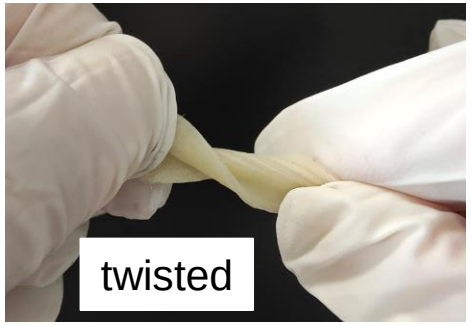
Significant Enhancement in Mechanical Integrity



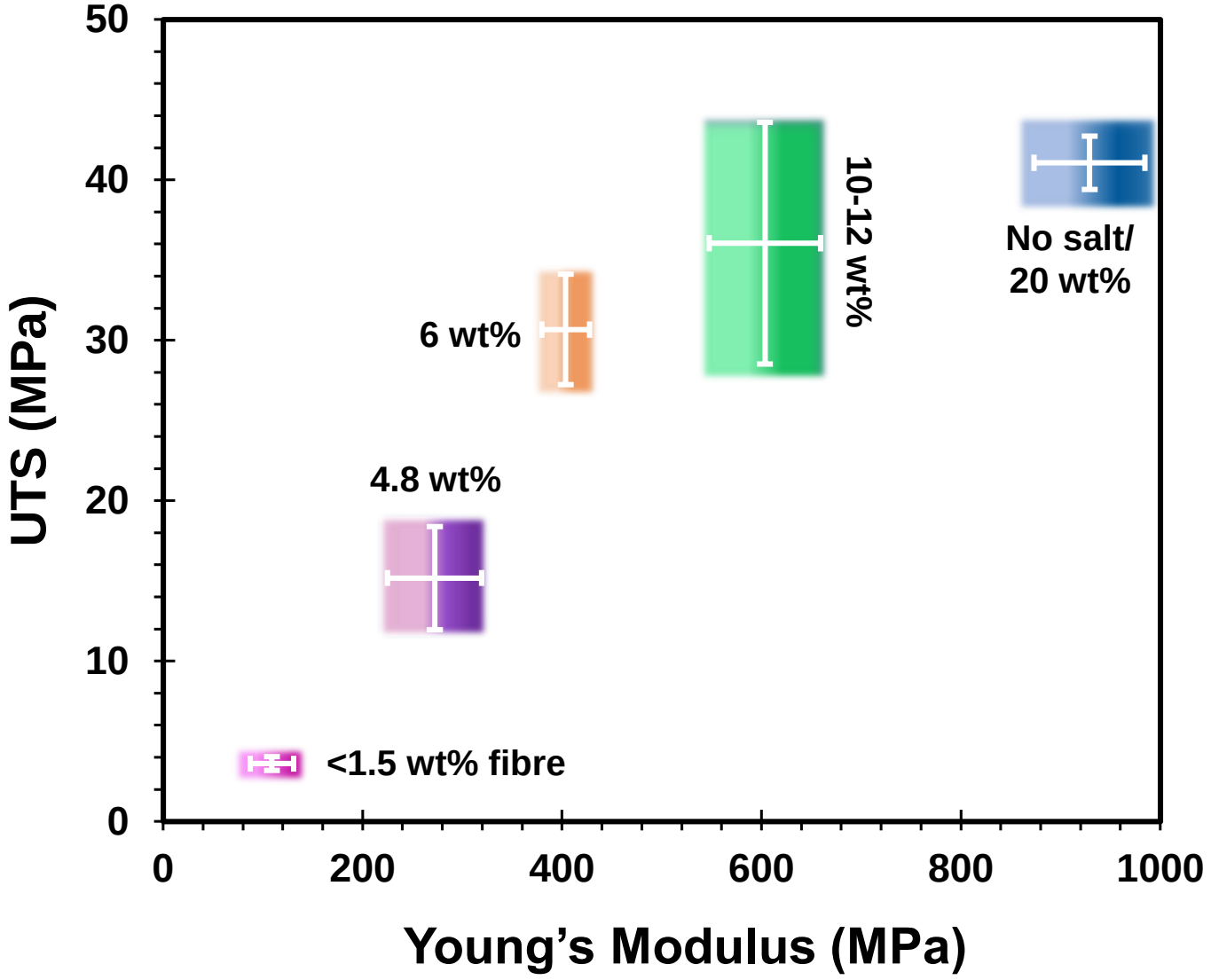
	Young's Modulus (MPa)	Ultimate Tensile Strength (UTS, MPa)
Fibre-reinforced PEO – LiTFSI SPE	upto 900	upto 50
PEO-LiTFSI (without mechanical filler)	0.9	0.1

Translation of robust strength of PEEK fibres into the PEO – LiTFSI matrix with otherwise negligible mechanical integrity



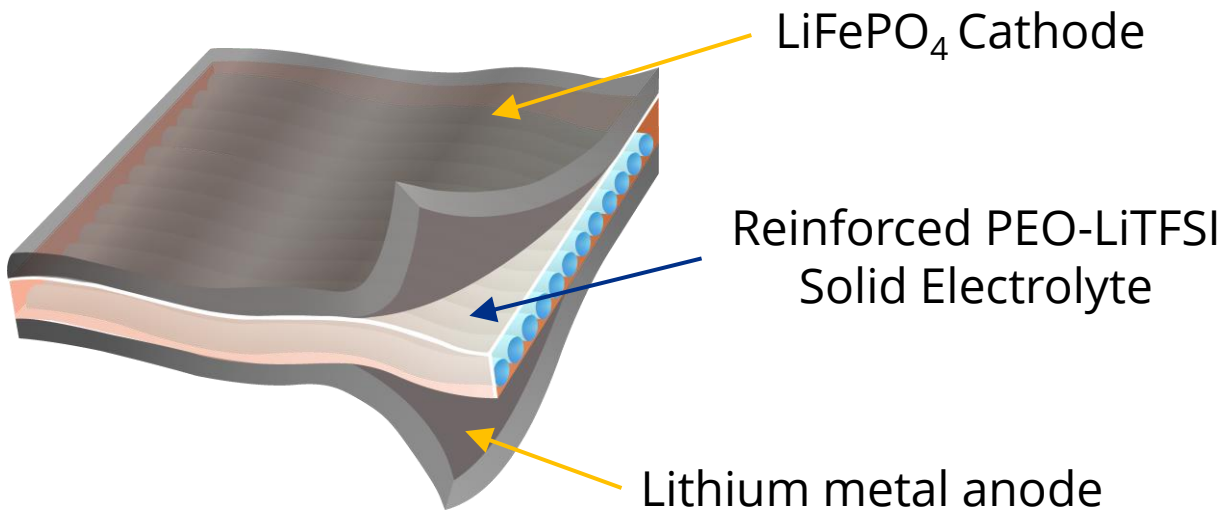


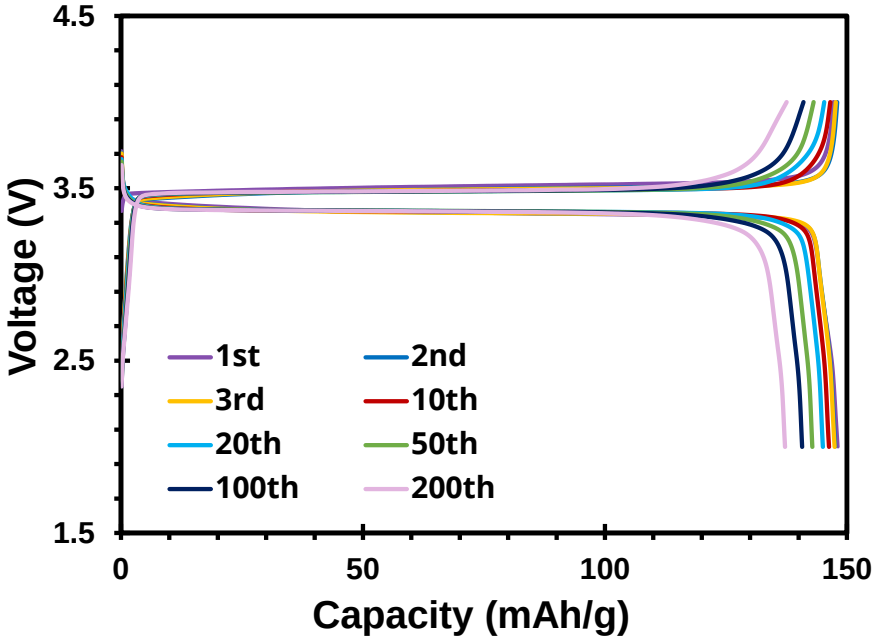
Effect of Fibre Content on the Mechanical Strength of CSPEs

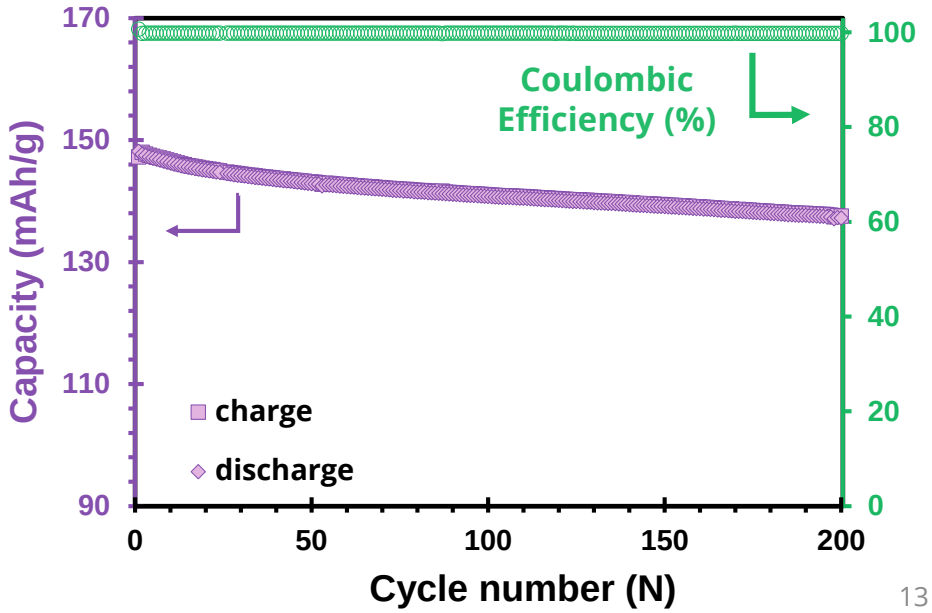


- Higher Young's modulus and UTS for higher loading of fibres in the polymer matrix
- Difficulty in achieving uniform alignment and distribution for higher loading
- Higher values are expected in the absence of moisture (high rate of moisture absorption by the salt)

Cycling Performance of Lithium Metal Battery







- Stable charge/discharge cycling (CE >99%) of reinforced PEO-LiTFSI under current density of 0.1C at 60 °C with lithium as anode and LFP as cathode
- Negligible overpotential of < 0.15 for over 200 cycles
- High capacity retention of > 96% over 200 cycles
- Hindrance of cell short circuit at elevated temperature owing to fibres

Structural Power Programme

WP1
Structural Cathode and Battery Architecture
(Prof. Madhavi Srinivasan, **NTU**)

WP2
Structural Anode and Electrolyte
(Dr Derrick Fam, **IMRE**)

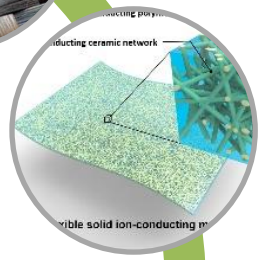
WP3
Modelling of coupled electro-chemo-mechanics
(Dr Sridhar Narayanaswamy, **IHPC)**

WP4
Processing and Device Prototyping
(Professor Tay Tong Earn, **NUS**)

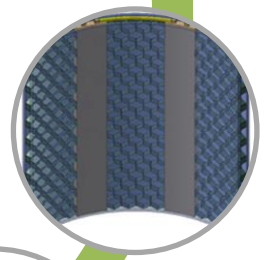
WP5
Digitalisation, Automation & Rapid Experiments
(Dr Jayce Cheng, **IMRE**)

CHALLENGES

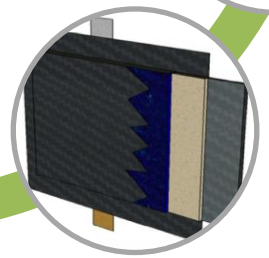
Novel structural electrodes



Novel structural electrolyte



Multifunctional interface materials



New processing techniques

Structural Power Team

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Professor Göran Lindbergh, KTH University
Professor Dame Clair Grey, University of Cambridge
Professor Micheal De Volder, University of Cambridge

RESEARCH INTERESTS

- Multifunctionality in composite materials
- Solid state power
- Sustainable energy solutions
- Anode-free batteries
- 3D printing of batteries
- High throughput experimentation and machine learning guided design of composite battery materials

AME Programmatic project: Structural Power for portable and electrified transportation Grant No. A20H3b0140)

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