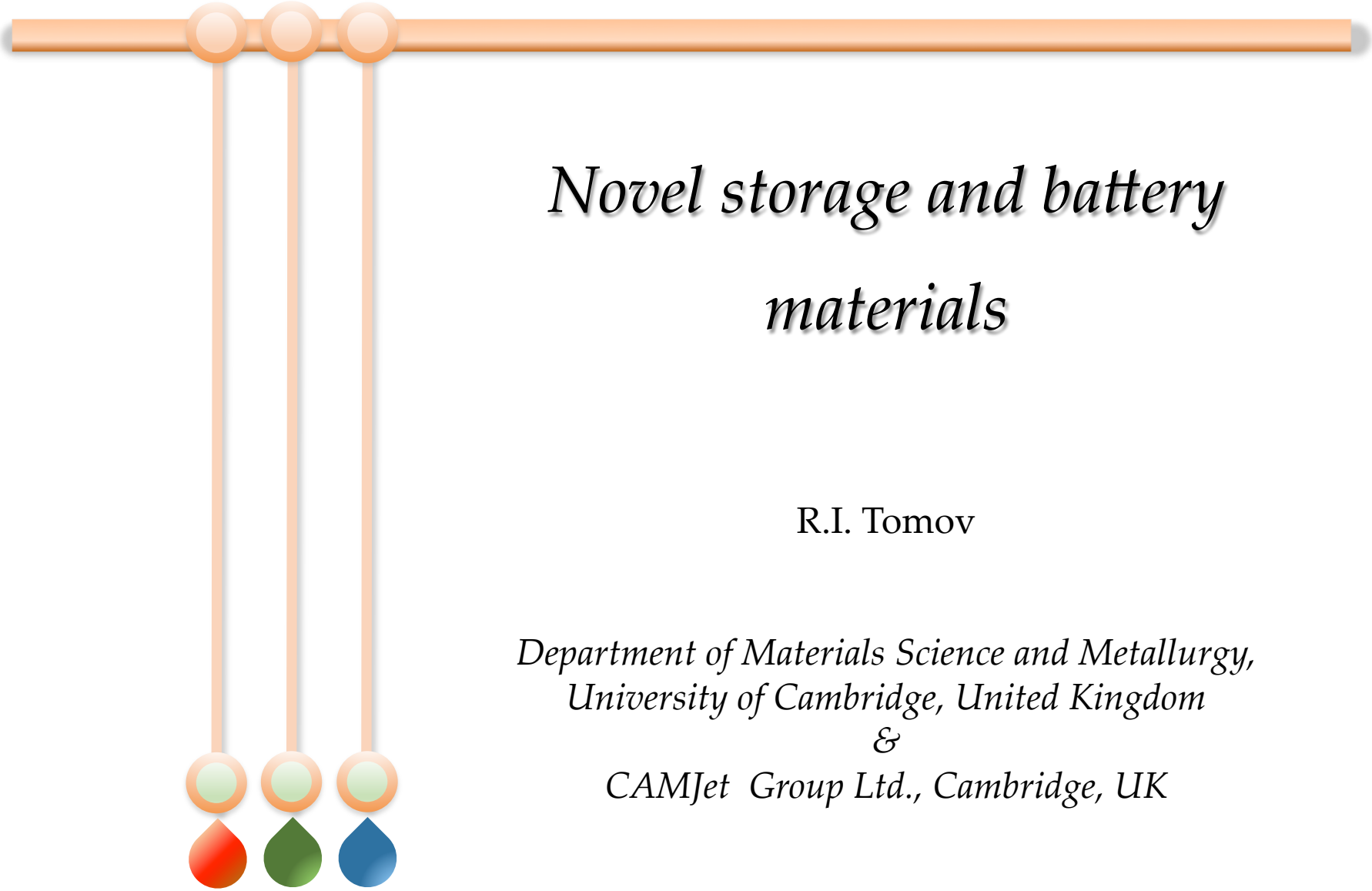

Novel storage and battery materials

R.I. Tomov

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University of Cambridge, United Kingdom
&
CAMJet Group Ltd., Cambridge, UK

Global Drivers

Alternative energy sources for the future economy

Climate change issues

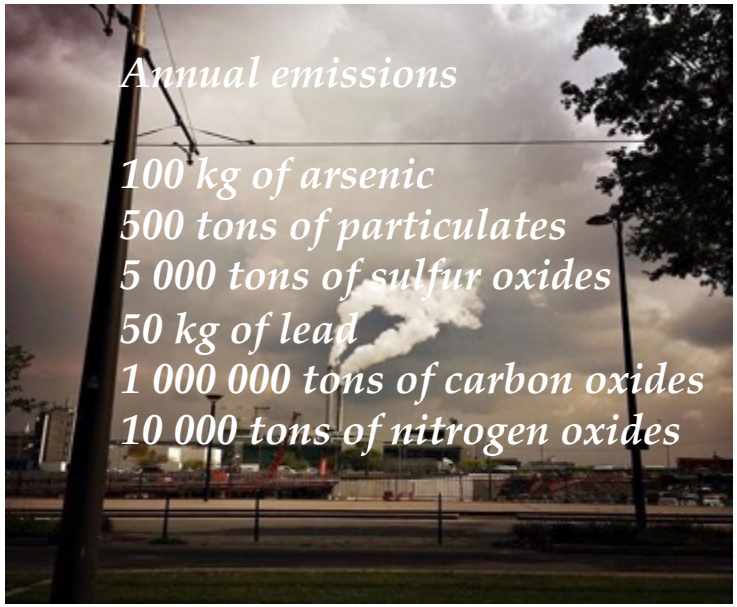
Globalization - new government regulations, work migration

New emerging technologies

Socio-economic factors

Geo-political implication

Global financial instability



Communism is Soviet Power + Electrification of the Whole Country….

….

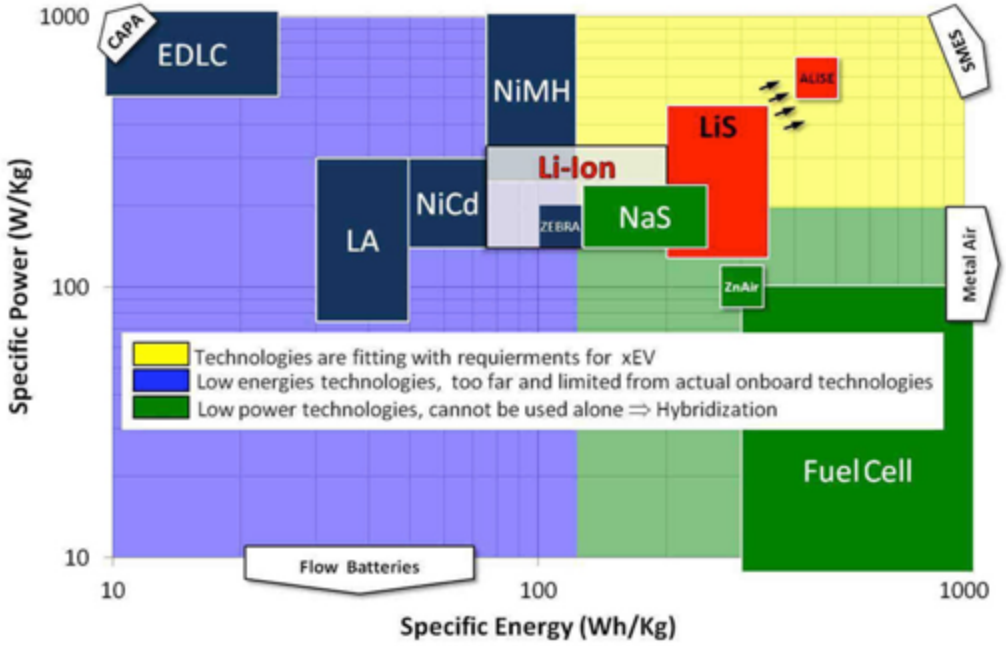
What we must now try is to convert every electric power station we build into a stronghold of enlightenment to be used to make the masses electricity-conscious, so to speak.

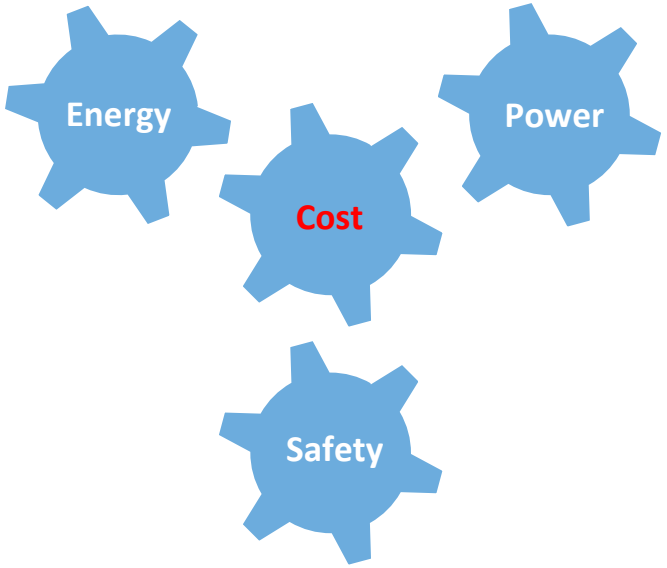
Vladimir Len in,

Report on the Work of the Council of People's Commissars.
December 22, 1920

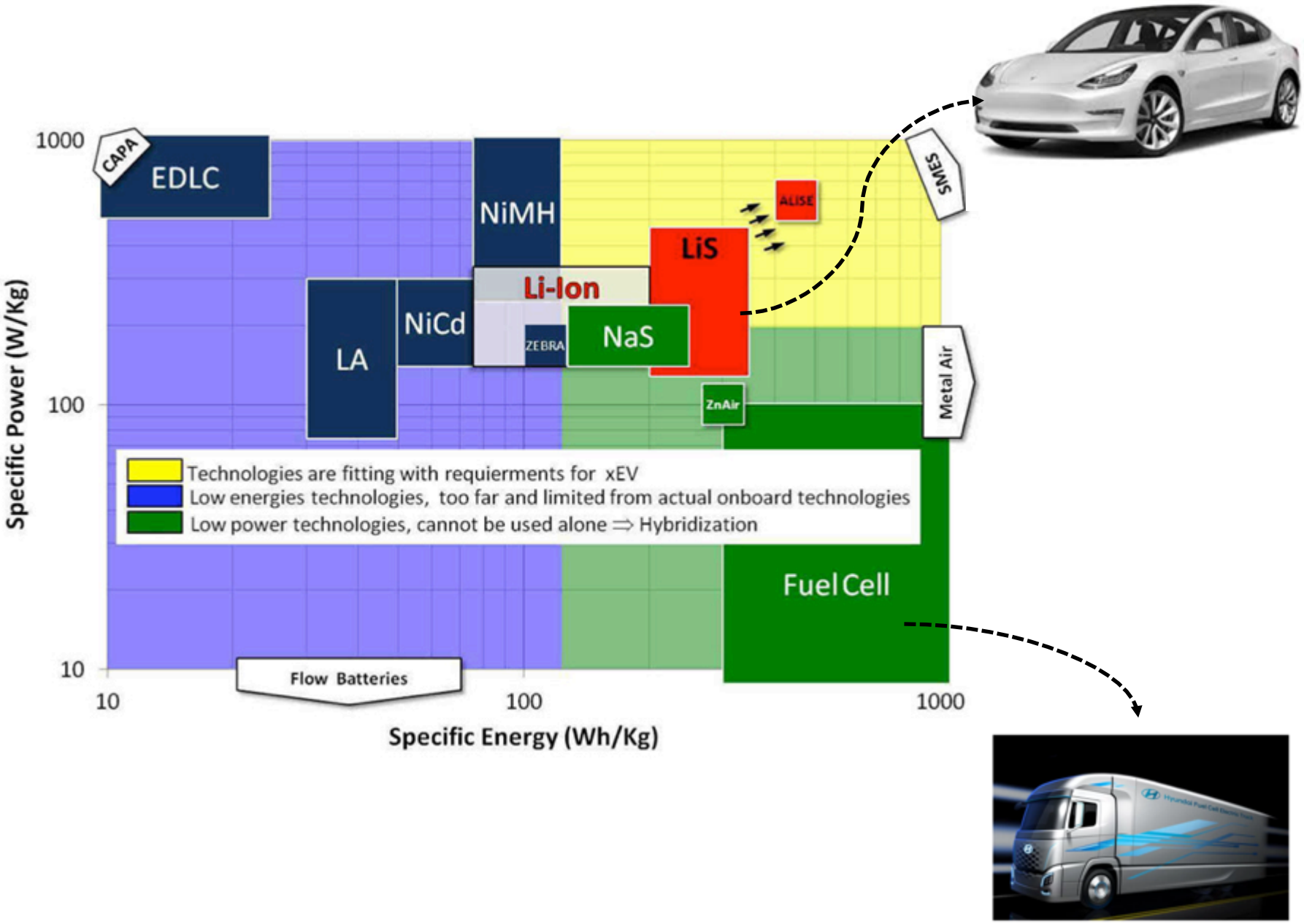
Global Solutions

- **Popular higher rate-of-return alternative energy sources such as: wind and solar cell.**
- **Storing this energy is one of the greatest barriers to the adoption of renewable energy.**
- **Complimentary use of hydrogen (fuel cells) and battery storage is the key to success (**EU "Directive on Deployment of alternative fuels Infrastructure" **).**





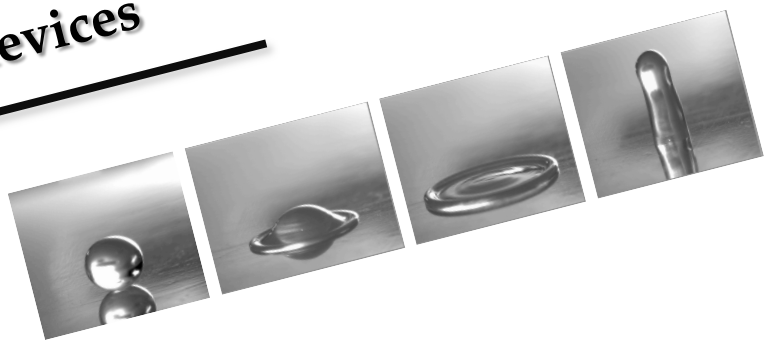
http://www.aliseproject.com/li-s-batteries/



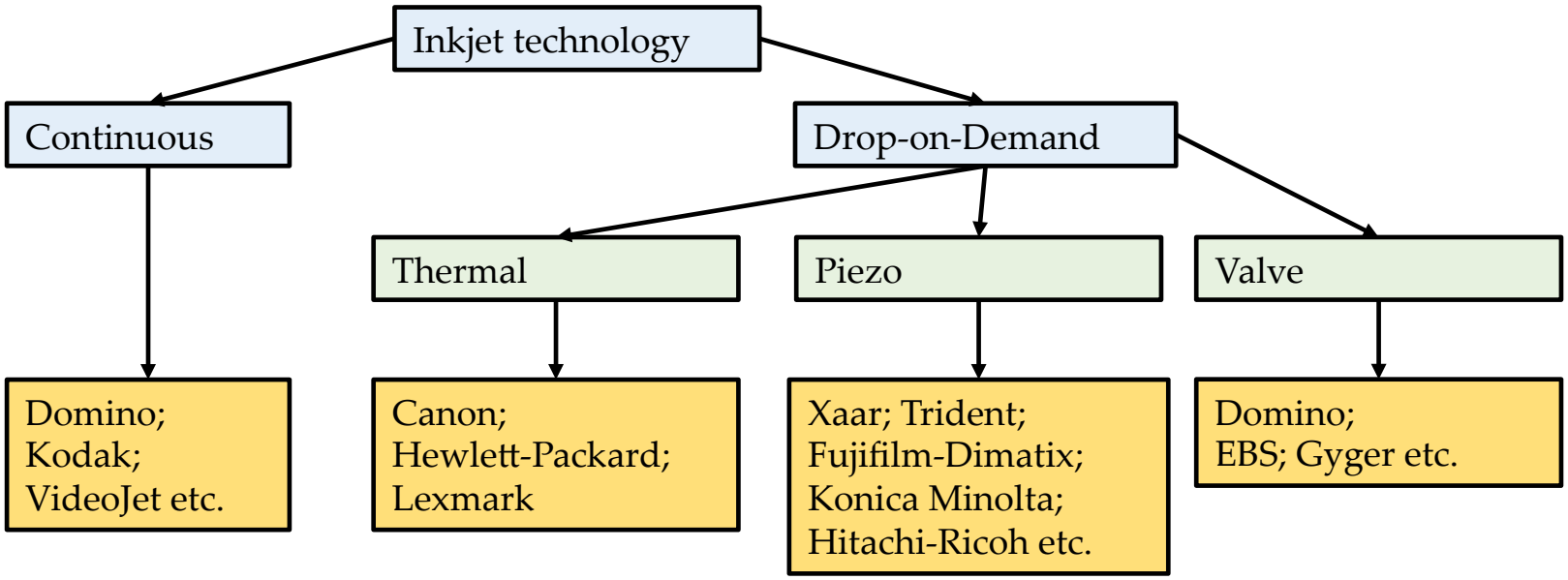
http://www.aliseproject.com/li-s-batteries/

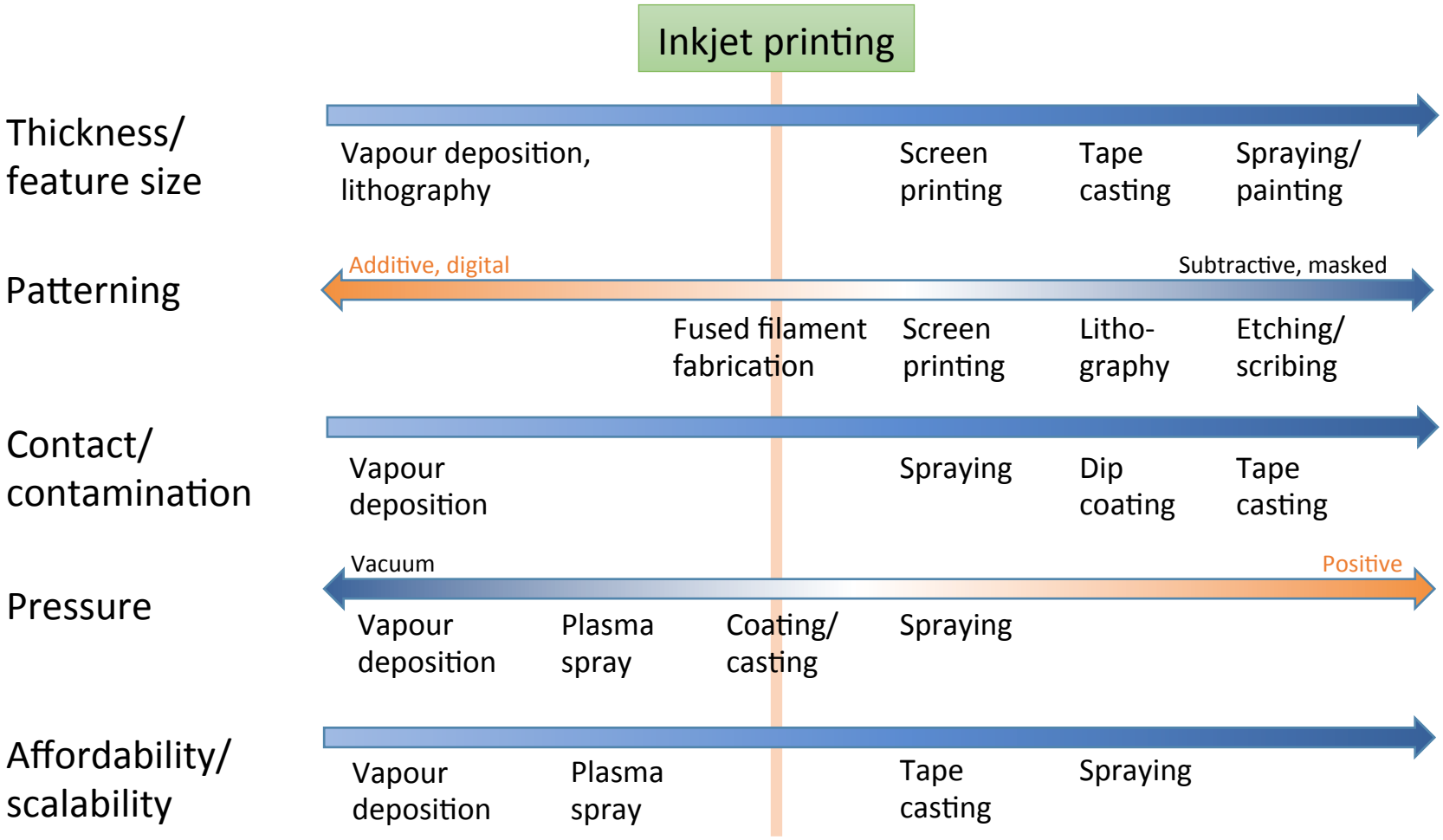
INKJET PRINTING

A tool for nano-functionalization of energy devices



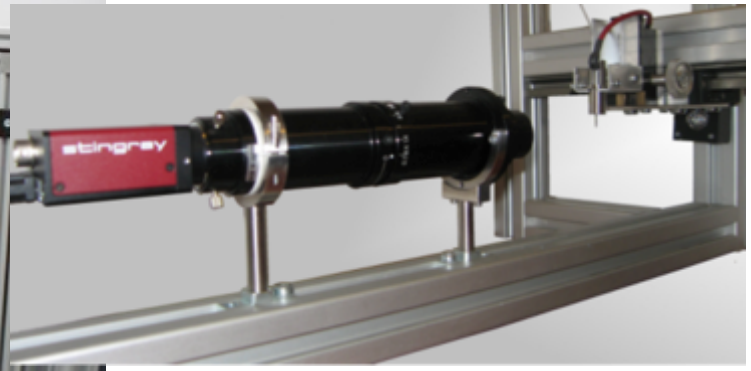
In 1878 Lord Rayleigh studied the breakup of droplets when a pressure wave was applied. However, it was only in 1960 that Richard G. Sweet fabricated printed equipment based on these previous discovered principles.

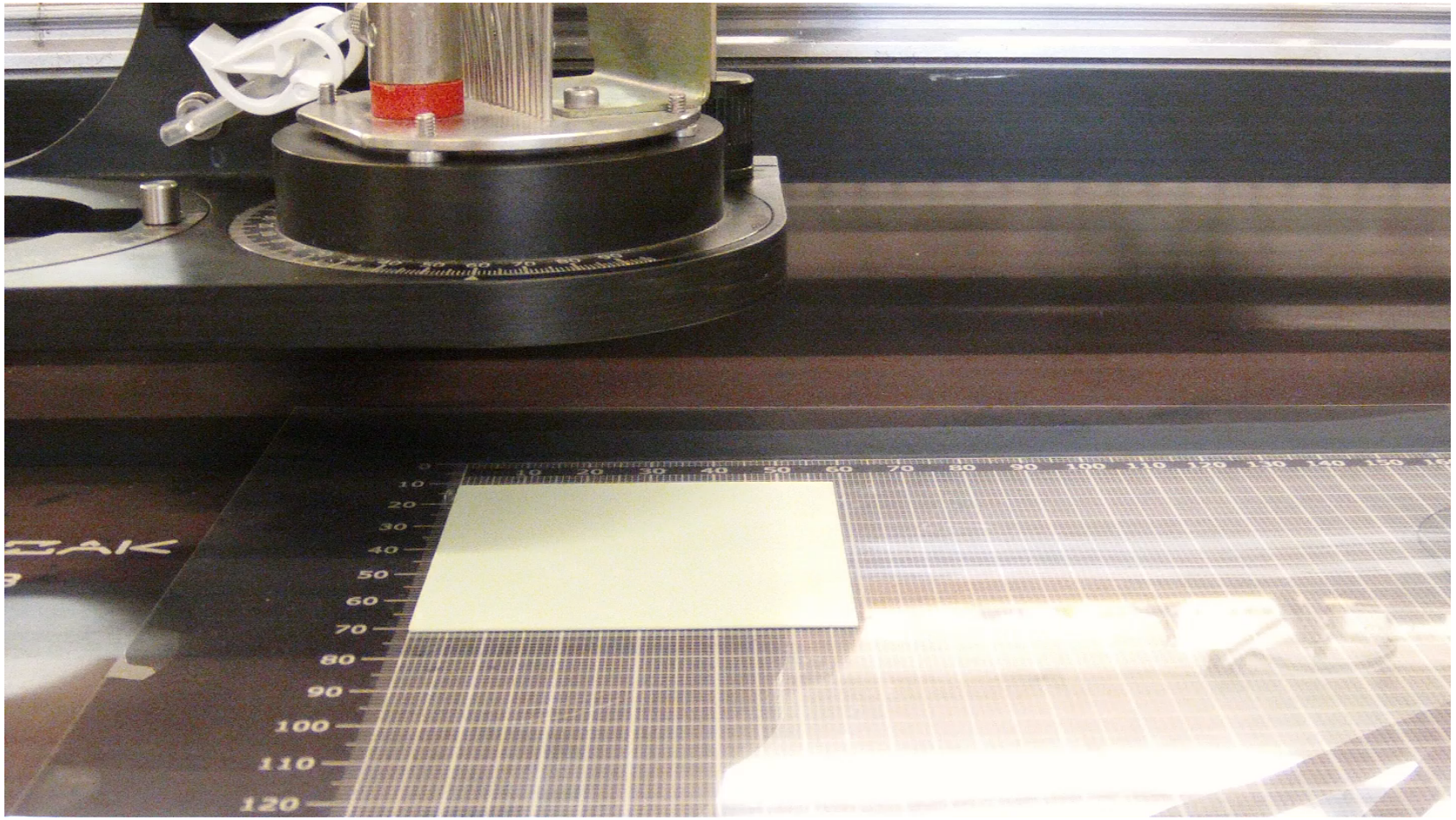



Inkjet printing
Thickness/ feature size
Vapour deposition, lithography
Screen printing
Tape casting
Spraying/ painting
Patterning
Additive, digital
Subtractive, masked
Fused filament fabrication
Screen printing
Litho-graphy
Etching/ scribing
Contact/ contamination
Vapour deposition
Spraying
Dip coating
Tape casting
Pressure
Vacuum
Positive
Vapour deposition
Plasma spray
Coating/ casting
Spraying
Affordability/ scalability
Vapour deposition
Plasma spray
Tape casting
Spraying

C*jet* printer

- Bespoke inkjet printing equipment and software developed, designed for materials applications
  - Interchangeable print-heads and inkjet printing technologies
  - Integrated drop visualisation
  - Robust and affordable

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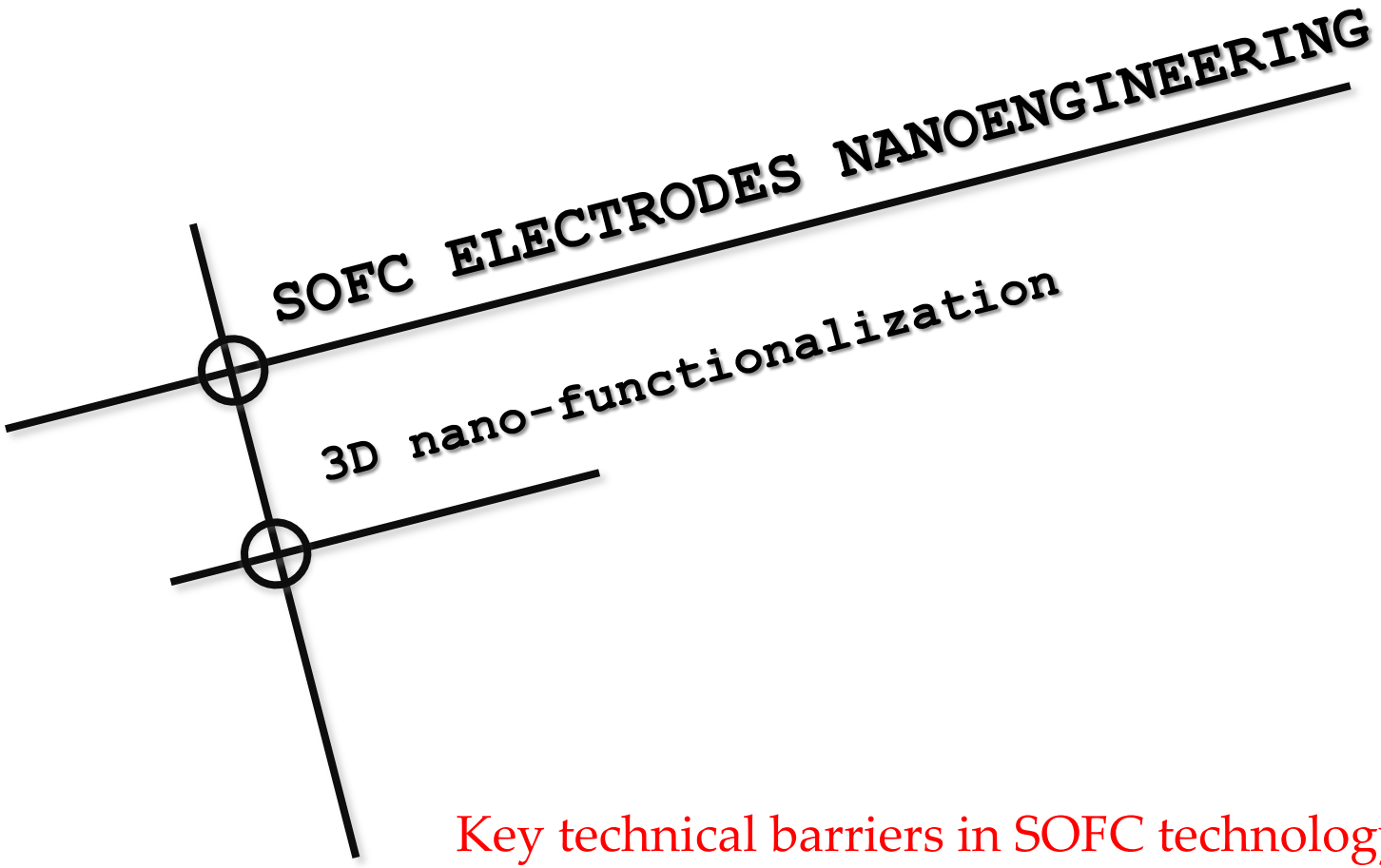
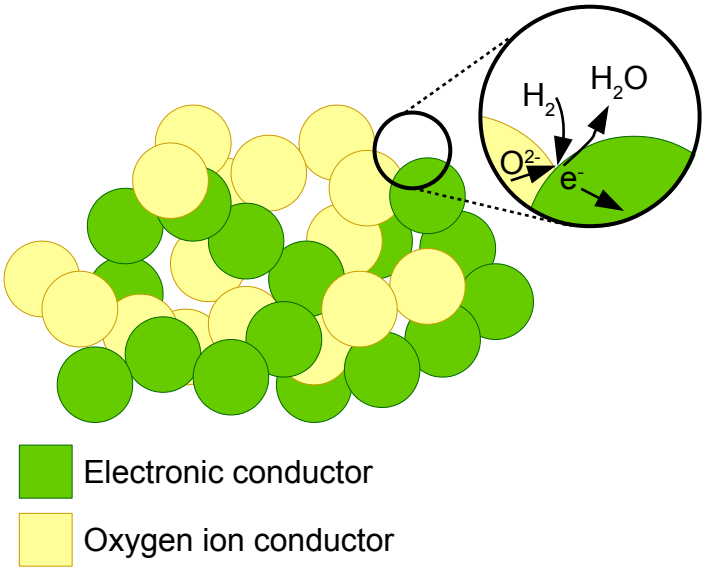


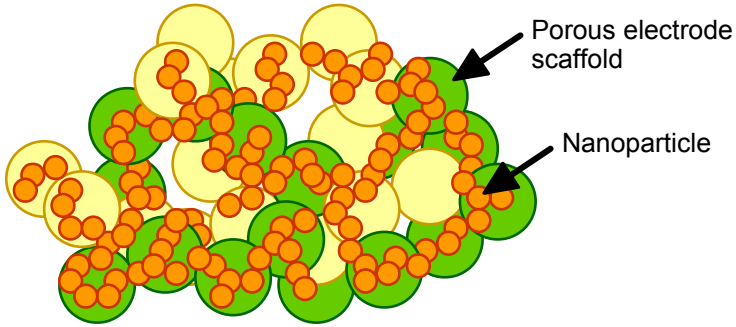
Key technical barriers in SOFC technology
(i) insufficient thermal resistance,
(ii) insufficient overall energy efficiency of SOFC stacks,
(iii) insufficient lifetime utilisation.

Solid oxide fuel cells – infiltration nano-engineering

- Nanostructuring the porous electrode: reduce R_p, increase TPB & power output and improve long term stability

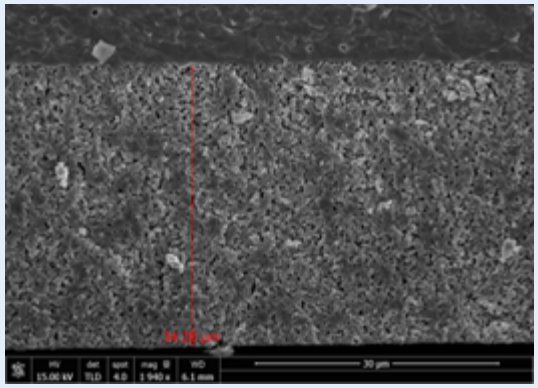
- Solution infiltration via inkjet printing

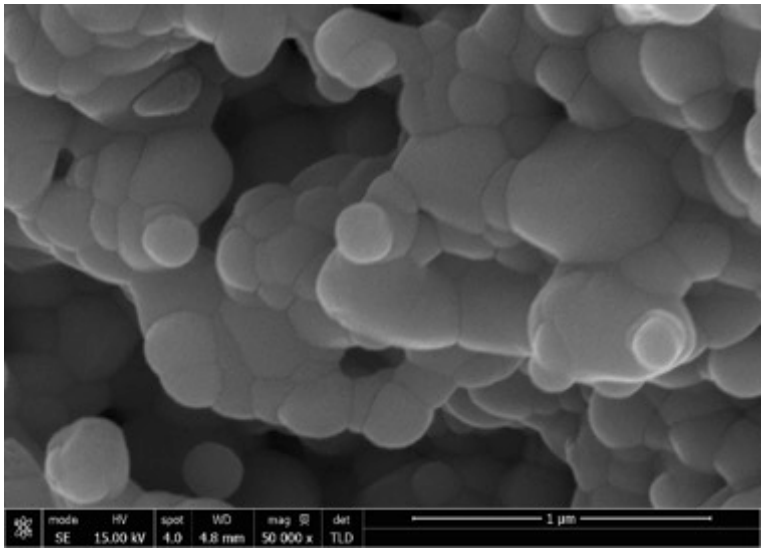


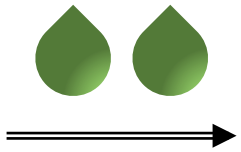


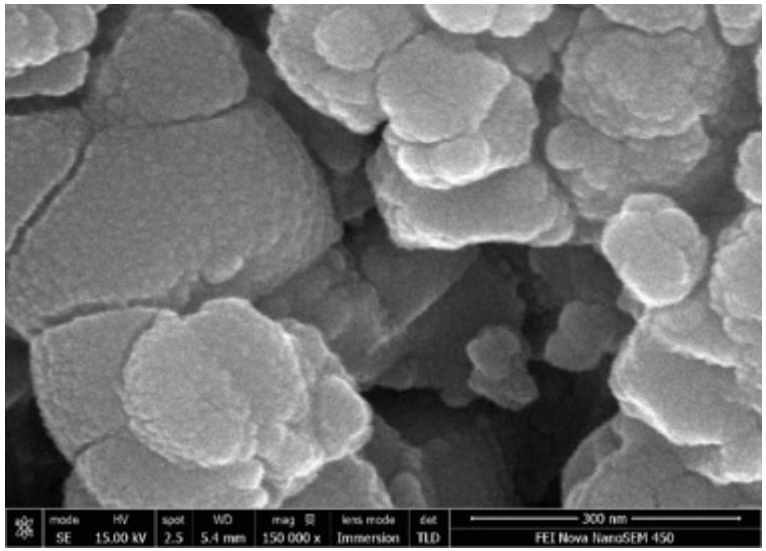
SOFC cathode infiltration

- Cathode: $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_3/Ce_{0.9}Gd_{0.1}O_2$ composite
- Electrolyte: $Ce_{0.9}Gd_{0.1}O_2$
- Infiltrated with Co_3O_4 and Gd:doped CeO_2







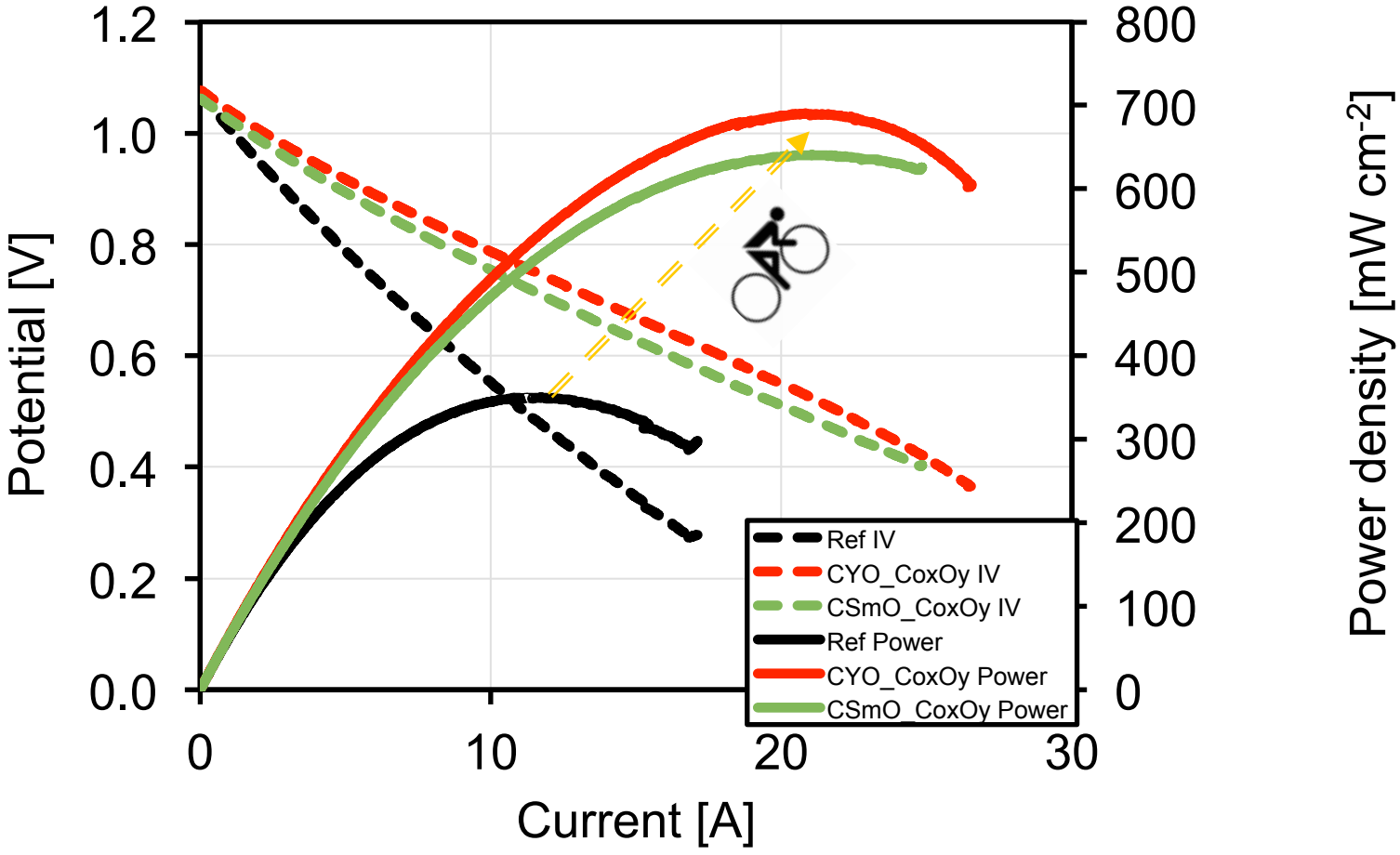


Nano-structuring objectives

- *Enhancement of the electrochemical performance* by extension of TBP / density of active catalytic sites
- *Low temperature calcination* of infiltrated materials
- *Avoidance* of detrimental interactions
- *Minimizing* concentration polarization losses
- *Long term stability* improvement

- **Low cost scalable technology**

I-V – commercial cell with $Me_{0.9}Gd_{0.1}O_2$ (Me= Sm, Y)+Co_3O_4



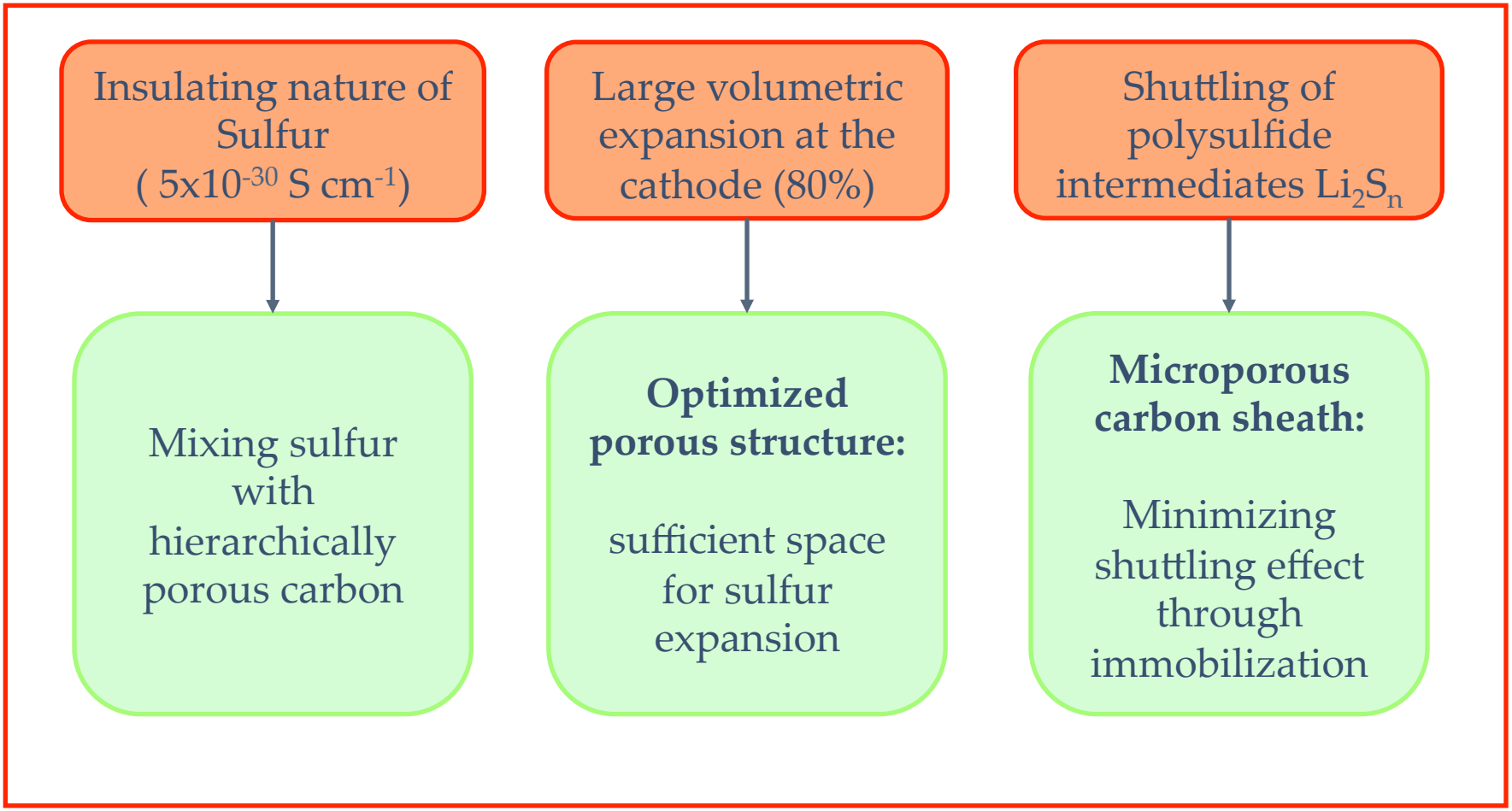
Inkjet-printed LiS battery cathode

3D functionalization

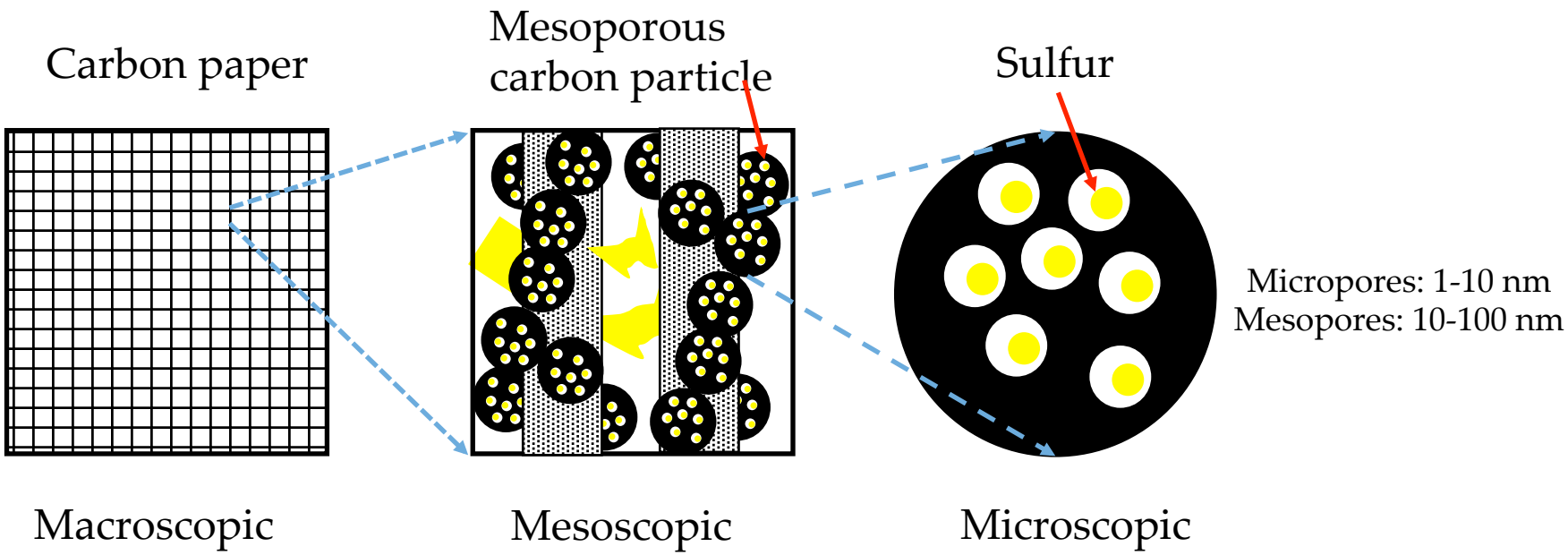
The Zephyr 7 holds the official endurance record for an unrefueled flight, lasting 336 hours, 22 minutes and 8 seconds. It uses sunlight to charge a lithium-sulfur battery during the day.

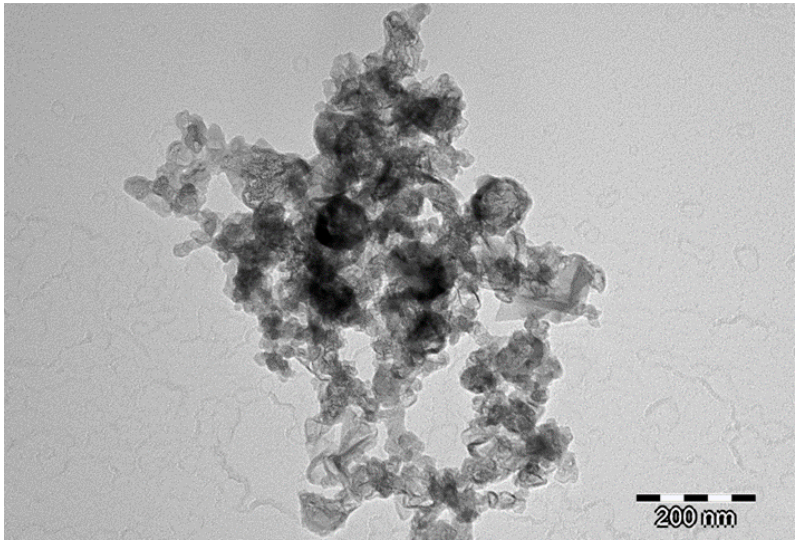
Lithium-Sulfur batteries

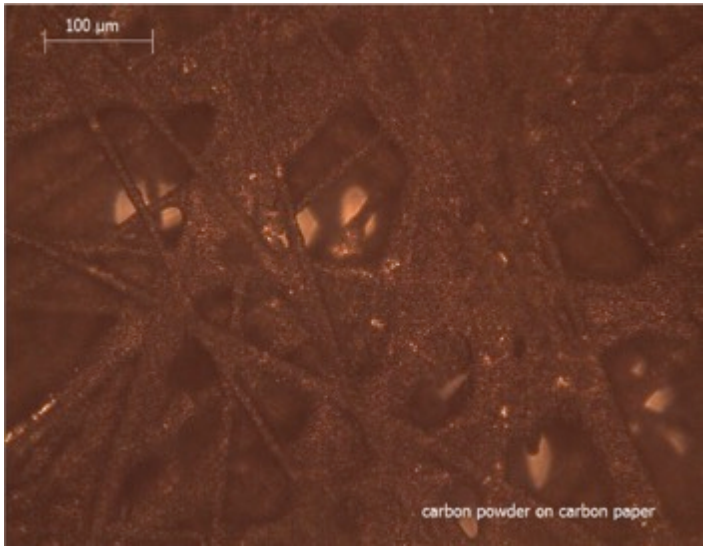
- High theoretical capacity – 1672 mAh/g (practical 400 – 700 mAh.g)!
- Sulfur is inexpensive and abundant (but flammable)!



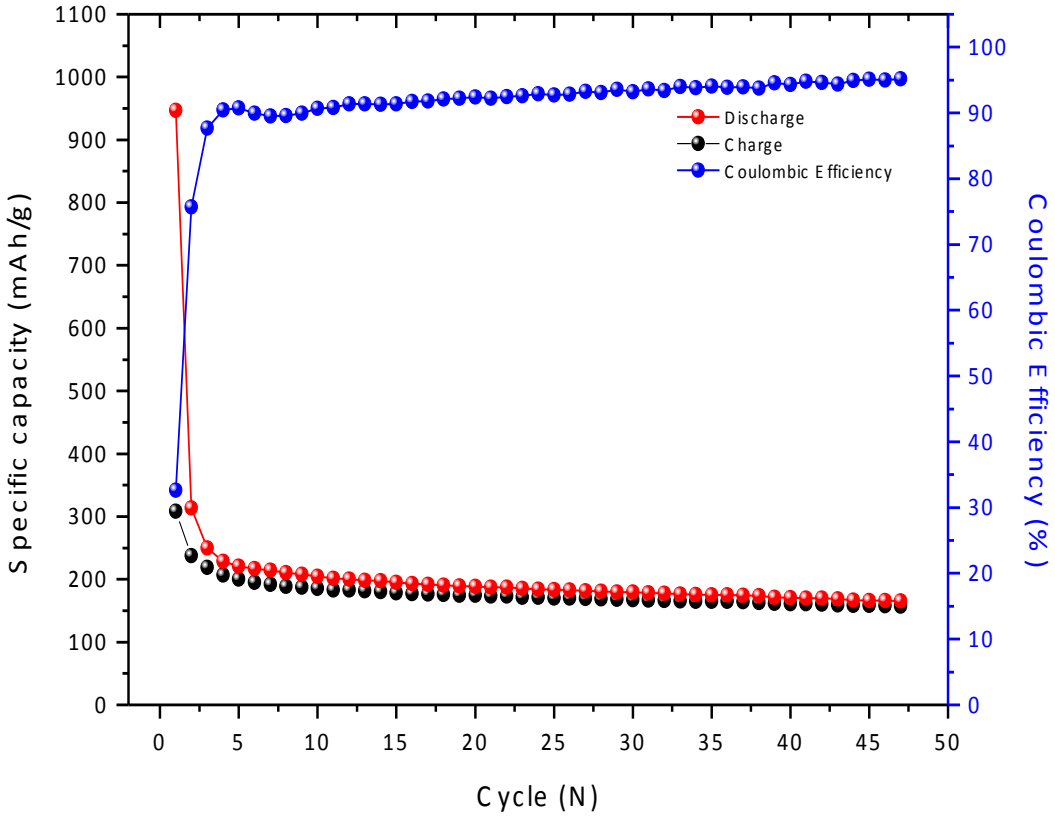
Inkjet-printed LiS battery cathode (I)







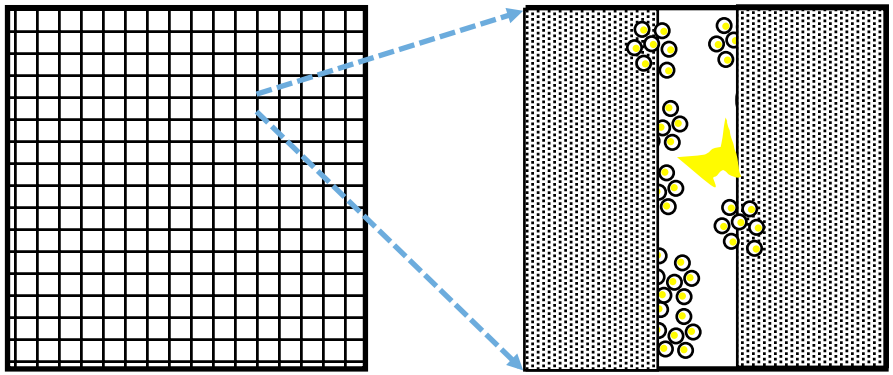
Inkjet-printed LiS battery cathode

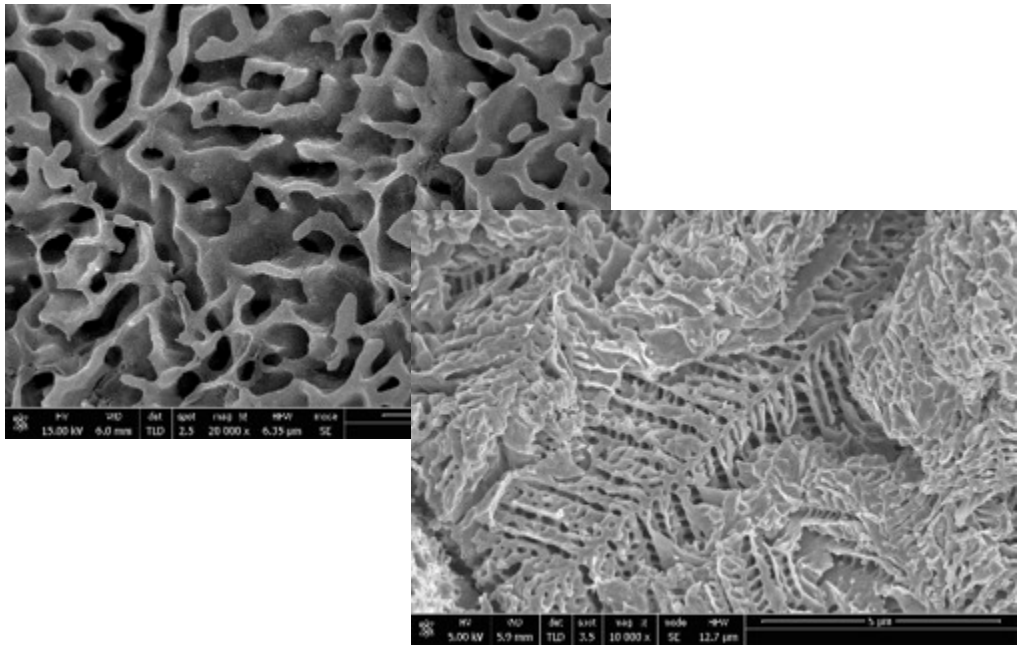


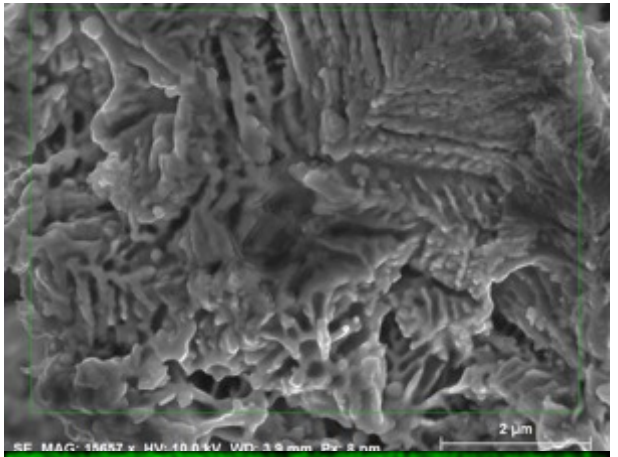
Inkjet-printed LiS battery cathode (II)

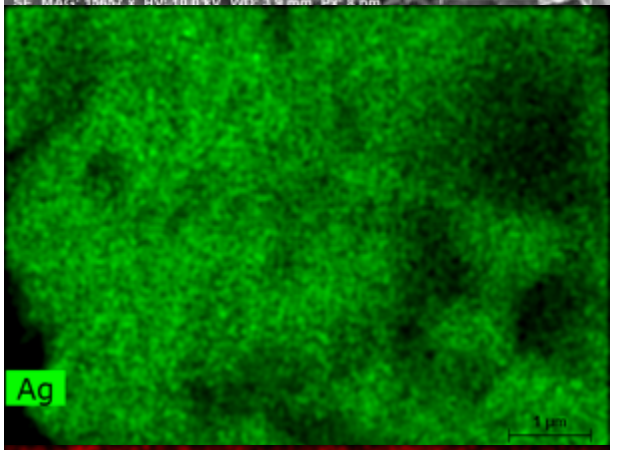
Ag nano-porous tape

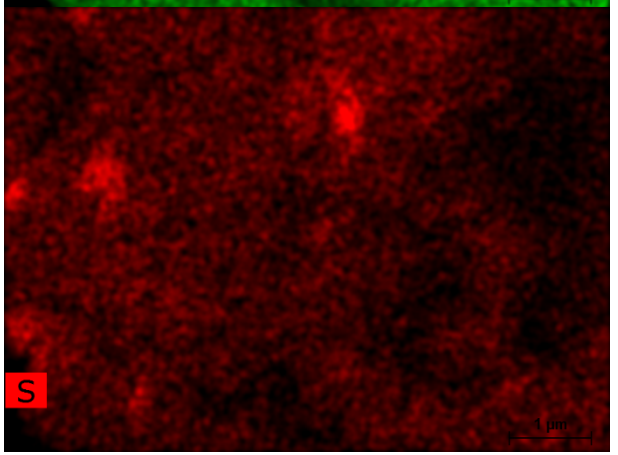
Mesoporous carbon particle

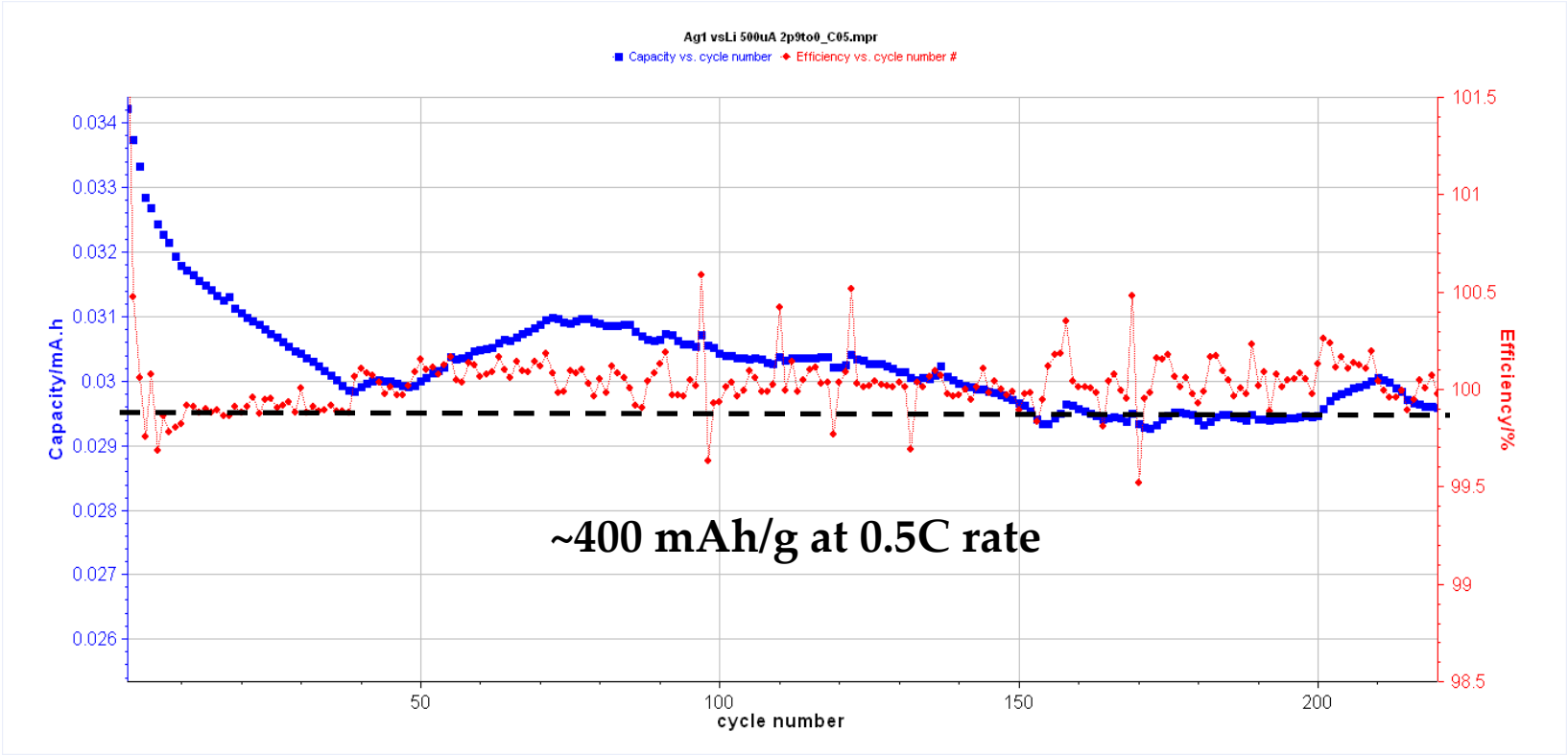


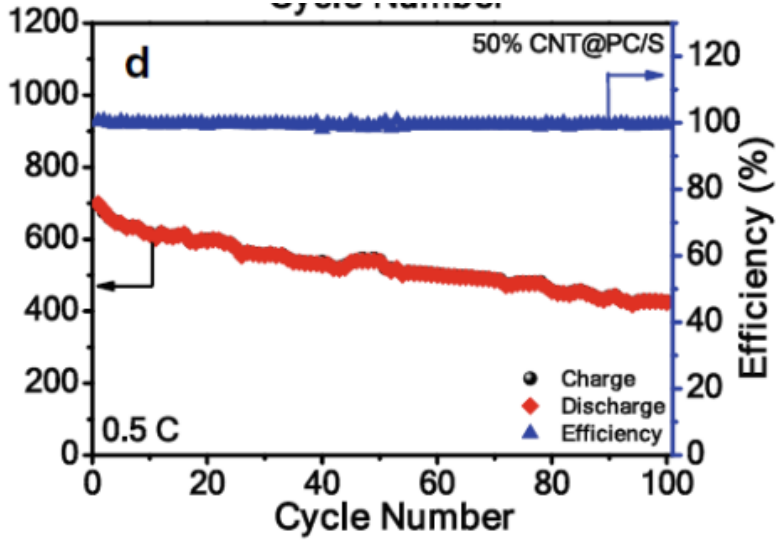












Specific capacity and coulombic efficiency retentions of 50% CNT@PC/S composite for 100 cycles at scan rate 0.5 C,

"A novel carbon nanotubes@porous carbon/sulfur composite as efficient electrode material for high-performance lithium-sulfur battery",
Lei Zhang et al, October 2019, Volume 25, Issue 10, pp 4761–4773.

Conclusions and Suggestions

Inkjet printing nano-functionalization method can be successfully applied in variety of functional energy materials applications

Electrochemistry Li-S composite electrode specific capacity and irreversible capacity show stable performance superior to incumbent commercial electrodes

***CAMJet* Group Ltd. was created with an ambition to commercialize the technology**

"Progress just means bad things happen faster."
Terry Pratchett

Thank you for your attention !