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Aligeramiento de vehículos y aeronaves mediante nanomateriales

Materiales para una mejor defensa
TALLER ORGANIZADO POR LA ACADEMIA DE
LAS CIENCIAS Y ARTES MILITARES (ACAMI)
E IMDEA MATERIALES

Dr Juan J. Vilatela
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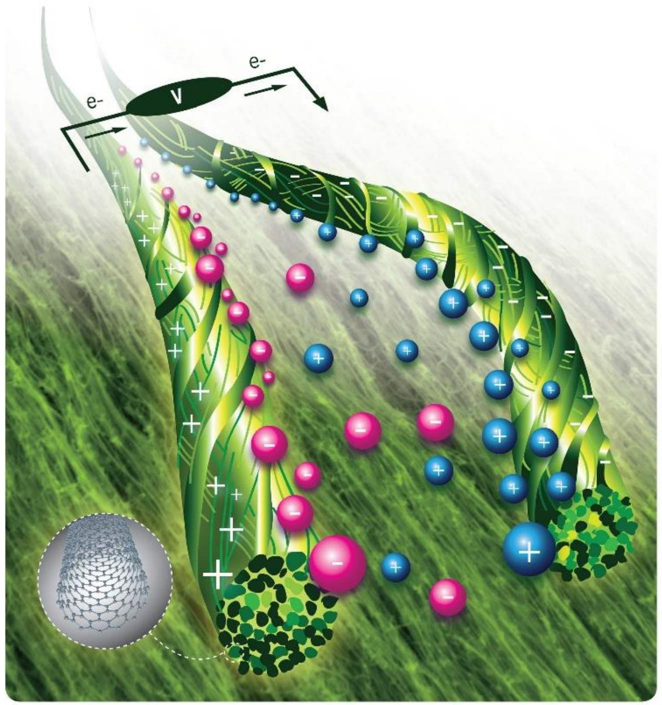
5 diciembre 2024



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Dr Juan José Vilatela
Investigador en IMDEA Materiales
https://www.materials.imdea.org/groups/mng/
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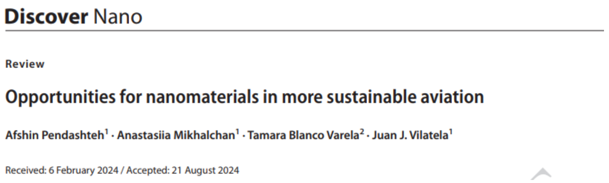
Encargado de proyectos de I+D industriales del sector transporte (aviónica, automoción, aeronáutica) con empresas reconocidas del sector (Toyota, Airbus, RockwellCollins, Shell)


Discover Nano

Review

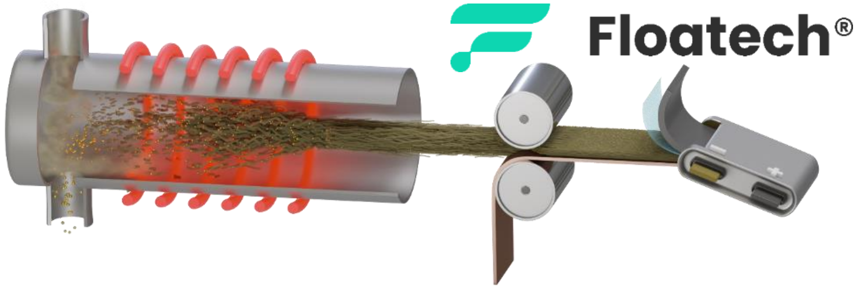
Opportunities for nanomaterials in more sustainable aviation

Afshin Pendashteh[1] · Anastasiia Mikhalchan[1] · Tamara Blanco Varela[2] · Juan J. Vilatela[1]

Received: 6 February 2024 / Accepted: 21 August 2024

Proyectos financiados por el ejército y fuerza aérea de EEUU

CTO de Floatech, empresa fabricante de electrodos nanoestructurados



Profesor asociado:
UC3M, Máster Materiales, Grado Ing. (Ciencia de Materiales, Física)
UPM, Máster Materiales, Máster Compuestos Airbus

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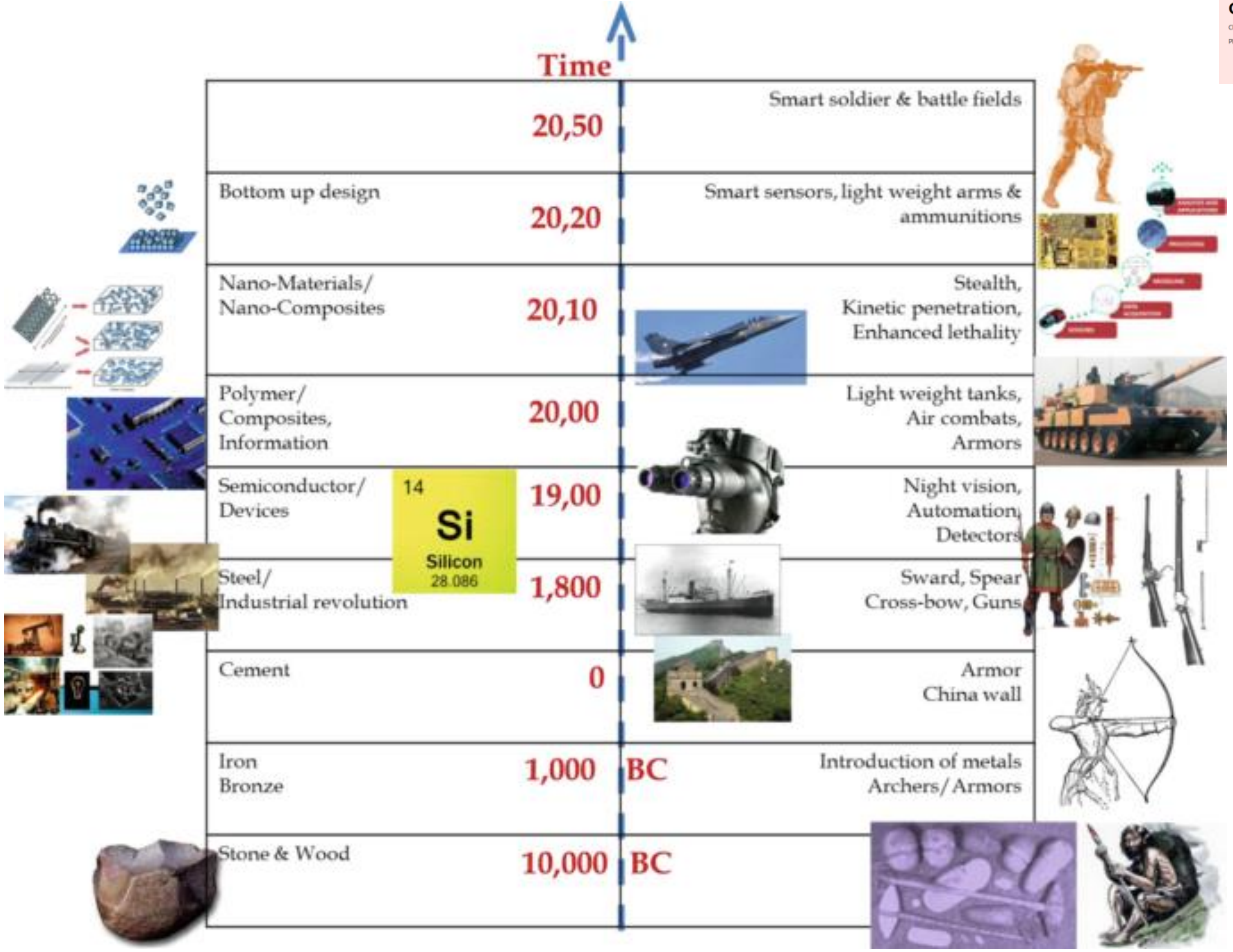

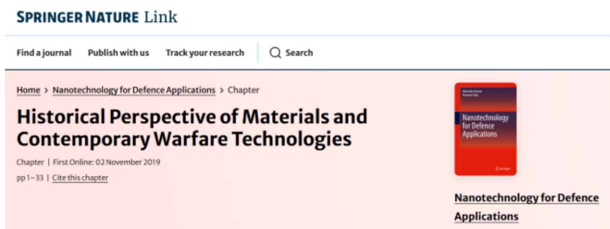
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Home > Nanotechnology for Defence Applications > Chapter

Historical Perspective of Materials and Contemporary Warfare Technologies

Chapter | First Online: 02 November 2019

pp 1–33 | Cite this chapter

Nanotechnology for Defence Applications

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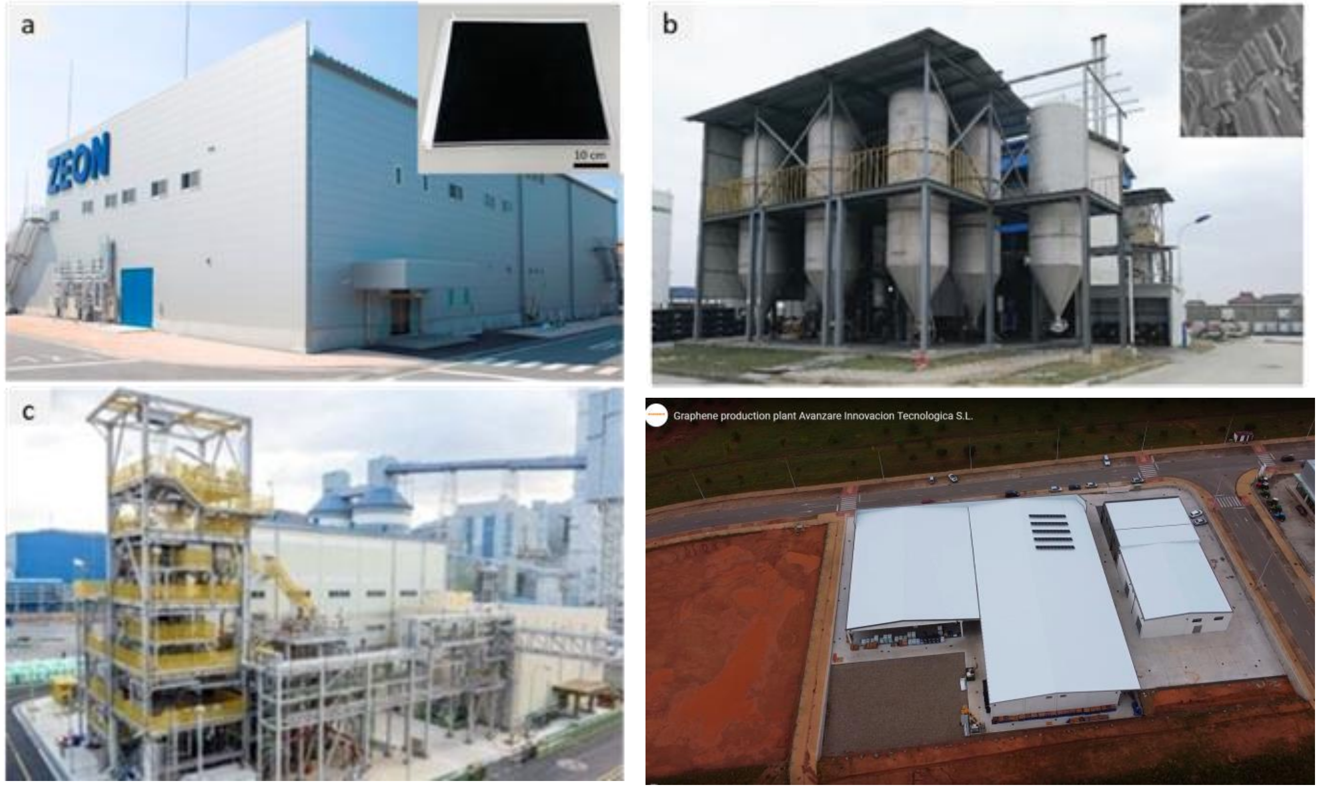
Aligeramiento a través de:

1) Baterías de nueva generación
2) Conductores eléctricos supermetálicos
3) Materiales estructurales para balística
4) Apantallamiento electromagnético y emisores de campo para guerra electrónica
5) Sensores químicos textiles

¿Cuál es el más importante de los nanomateriales usados en la actualidad?

Examples of industrial facilities for nanomaterials production



a) Zeon Corporation plant in Japan; b) 1000 tons per year plant facilities of CNT arrays developed by Tsinghua University (China) [19]; c) LG Chem's Yeosu Plant (South Korea) for 2000 ton per reactor d) Graphene producer Avanzare.

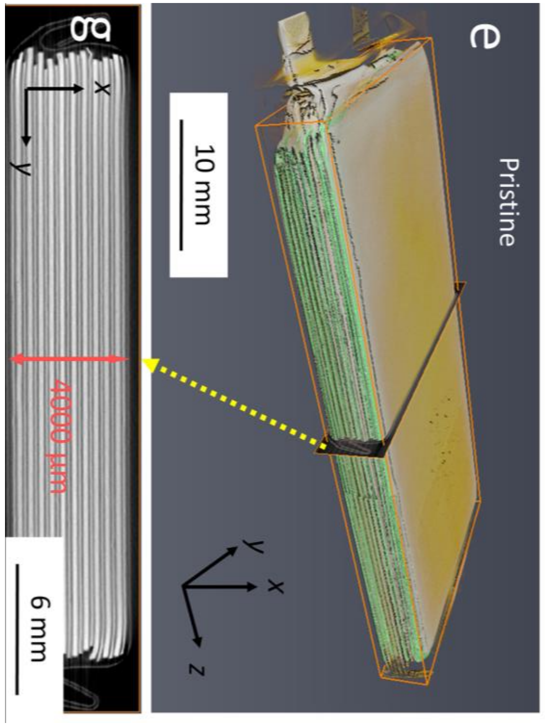
Annual production is 10 000 tons per year, growing at about 20% CAGR

¿Dónde se usan?

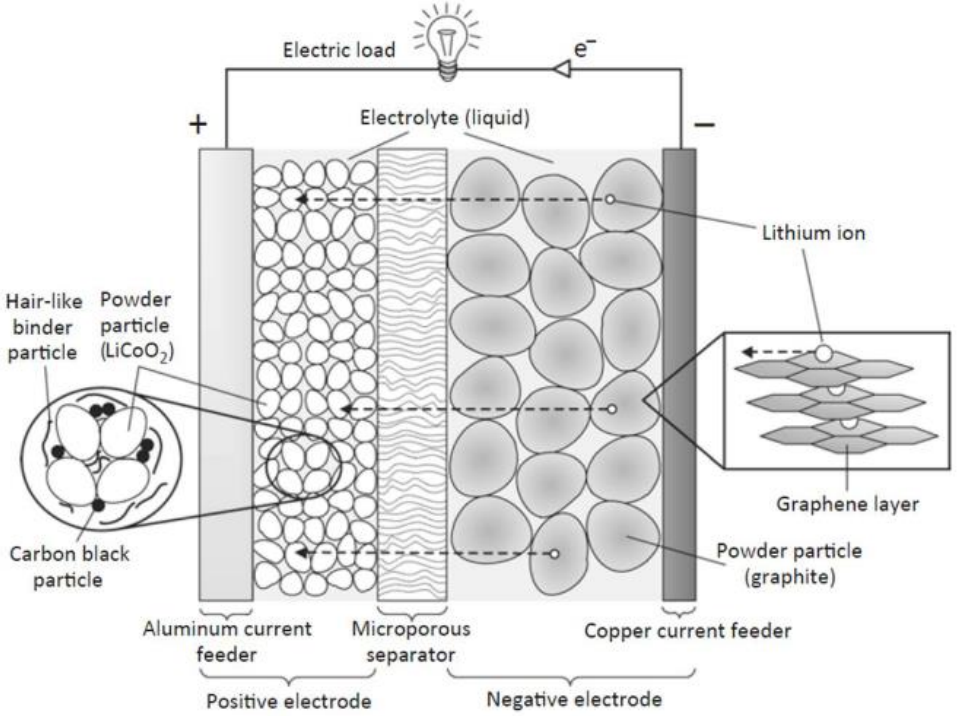
Background: battery electrode and cell assembly

Battery

Multi-electrode construction

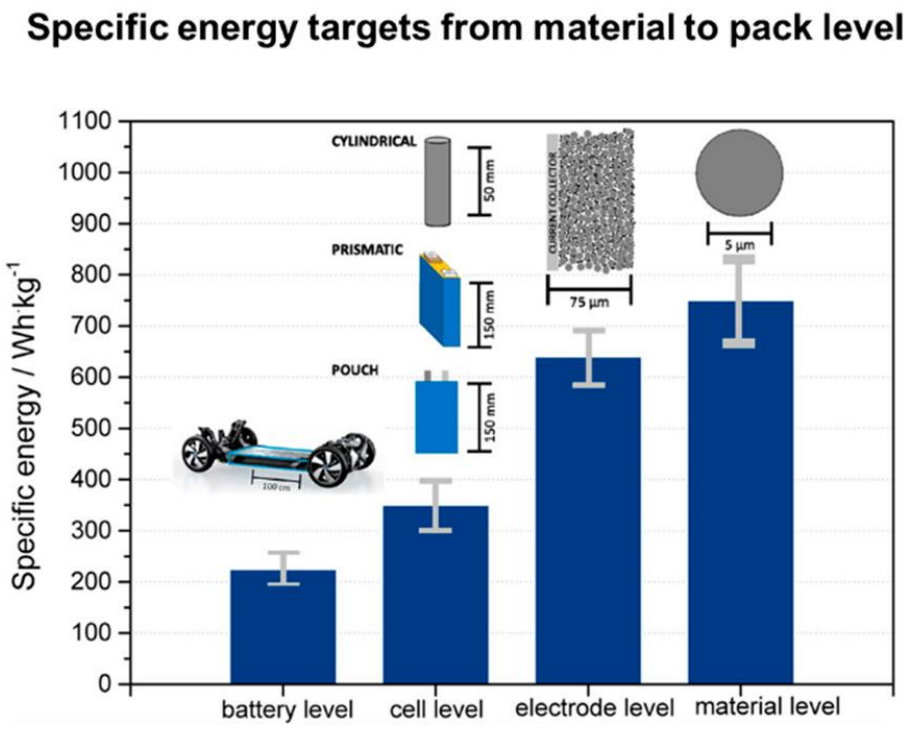


Scheme of a single cell unit



Journal of Power Sources, Volume 520, 2022, 230818

Component breakdown in LIB cell



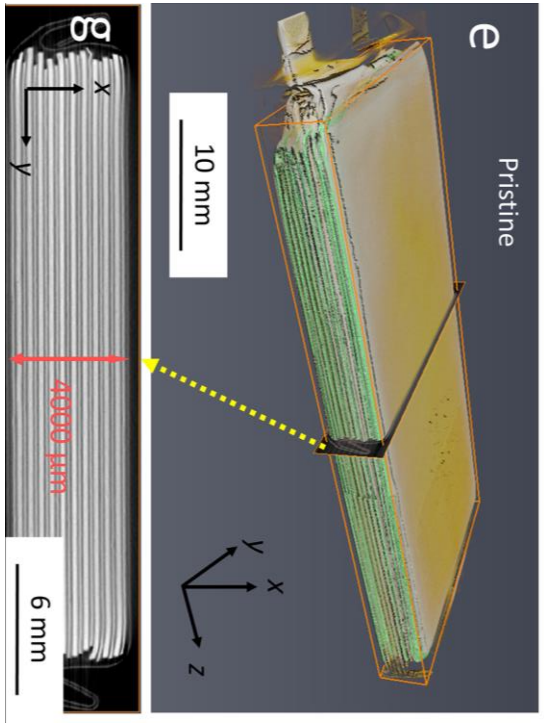
(b) Specific energy targets for automotive applications from material to pack level.

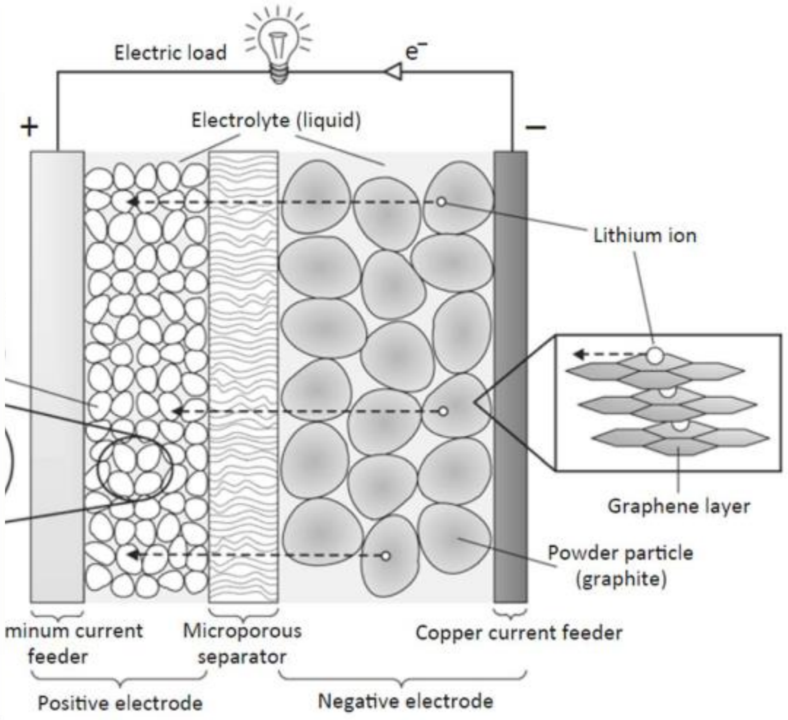
	Specific energy, Wh/kg
Material level	750
Electrode level	650
Cell level	350
Battery level	210

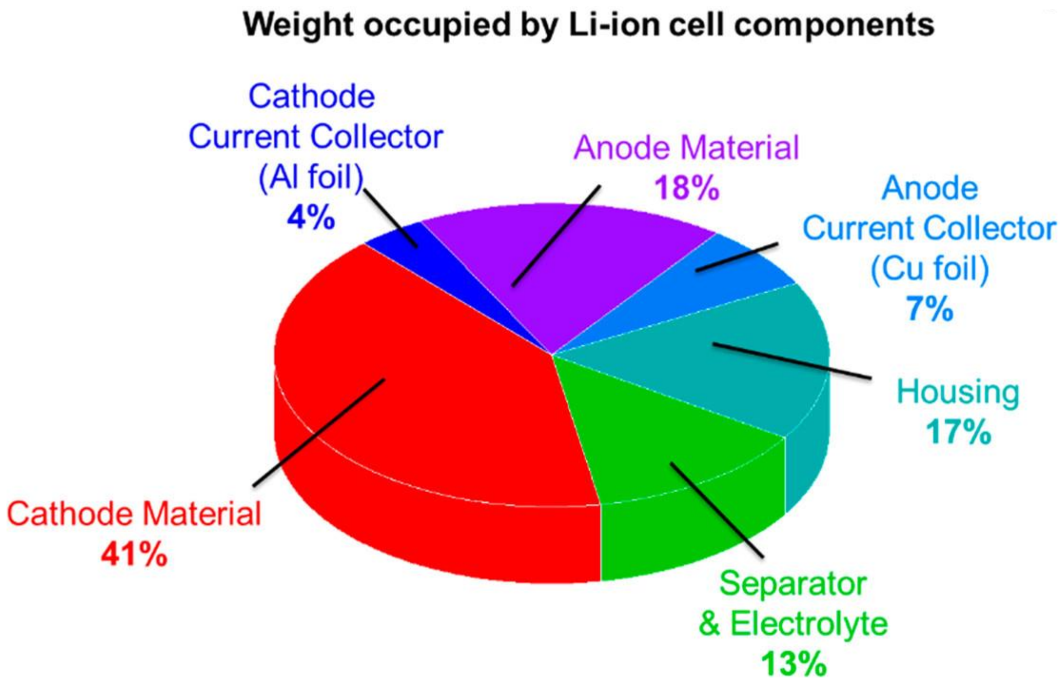
What are the limitations to reduce the weight of auxiliary elements in the cell?

DOI: (10.1021/acsnano.9b04365)

Component breakdown in LIB cell

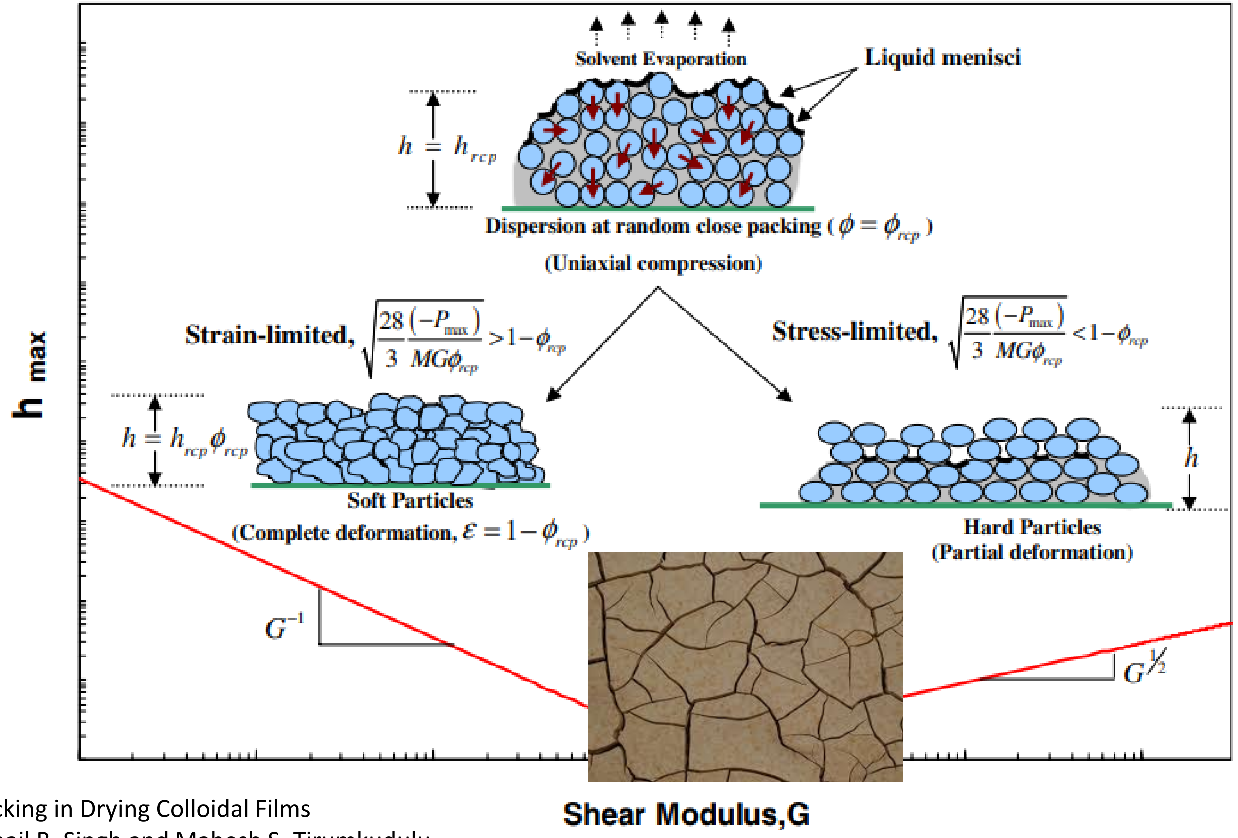






What are the limitations to reduce the weight of auxiliary elements?

Limitations on electrode thickness



Cracking in Drying Colloidal Films
Karnail B. Singh and Mahesh S. Tirumkudulu
Phys. Rev. Lett. 98, 218302 –2007

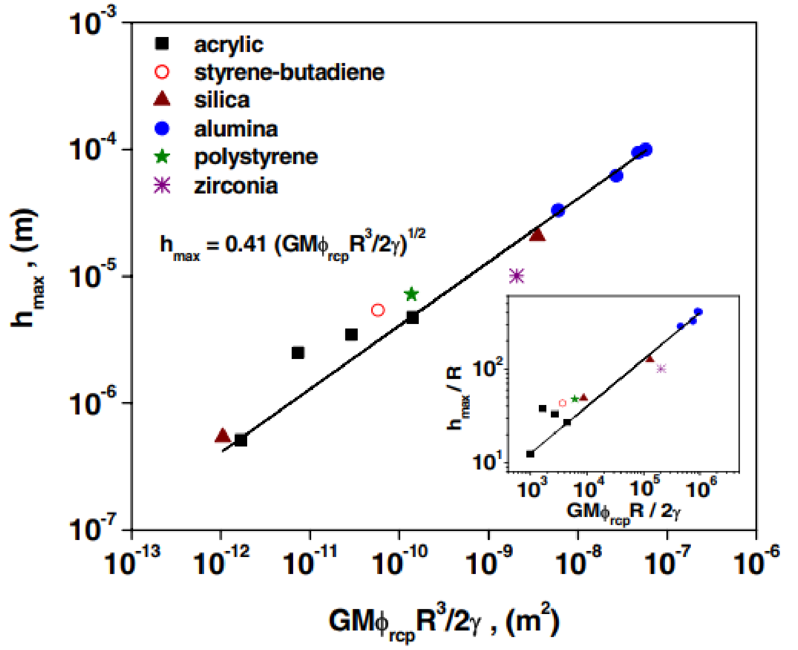
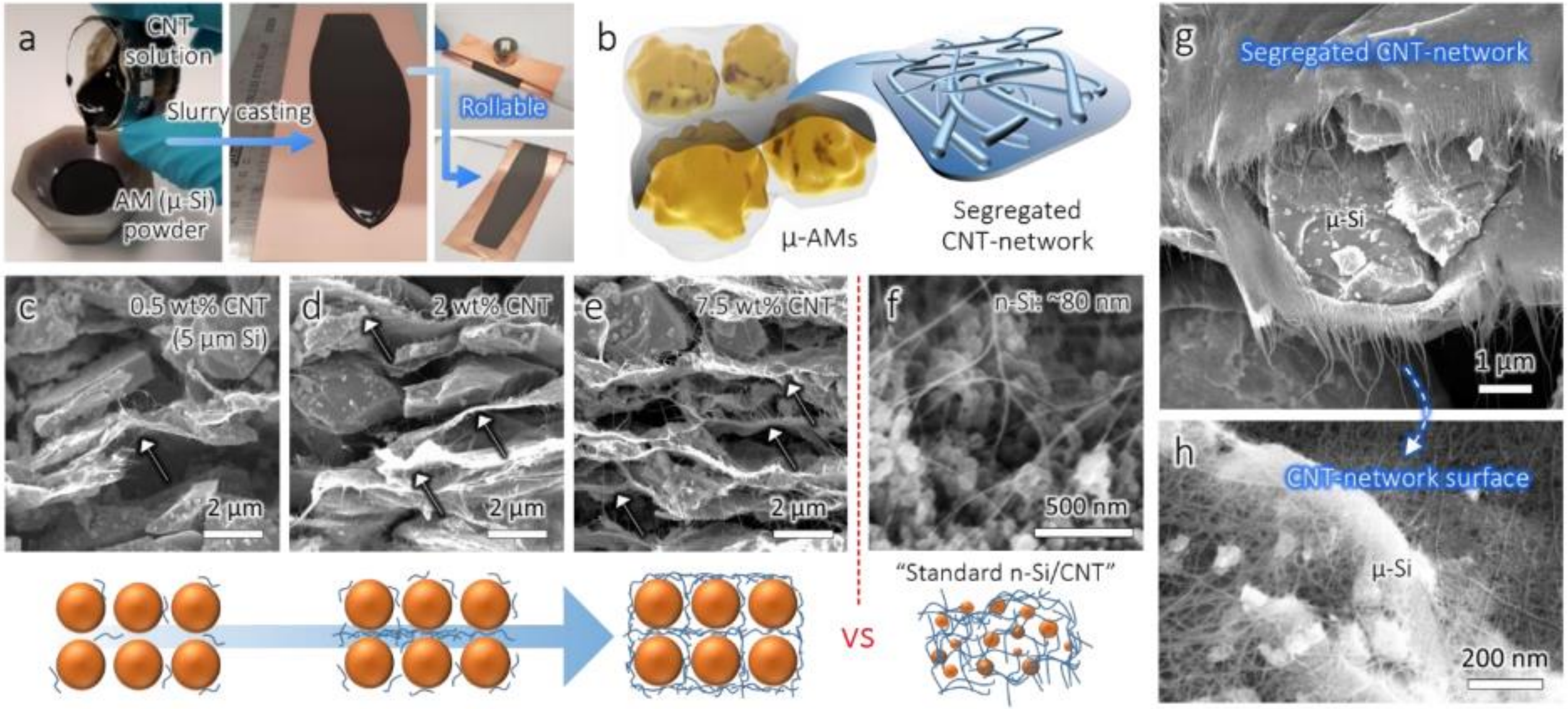


FIG. 3 (color online). The measured critical thickness vs the characteristic scale, $\frac{GM\phi_{rcp}R^3}{2\gamma}$. The data points are for films of acrylic [■, $G = 0.8$ GPa, $2R = 82$, 133, 206, and 353 nm, and $\phi_{rcp}(M) = 0.65(6.7)$, 0.66(6.8), 0.68(7.0), and 0.67(6.9), respectively], styrene-butadiene [○, $G = 1$ GPa, $2R = 250$ nm, and $\phi_{rcp}(M) = 0.64(6.6)$], silica [▲, $G = 31$ GPa, $2R = 330$, and 22 nm, and $\phi_{rcp}(M) = 0.60(6.1)$ for both], alumina [8] [●, $G = 156$ GPa, $2R = 230$, 379, 458, and 489 nm, and $\phi_{rcp}(M) = 0.60(6.1)$ for all], polystyrene [8] [★, $G = 1.6$ GPa, $2R = 300$ nm, and $\phi_{rcp}(M) = 0.60(6.1)$], and zirconia [8] [*, $G = 81$ GPa, $2R = 200$ nm, and $\phi_{rcp}(M) = 0.60(6.1)$]. Here the value of surface tension, γ, is taken as 0.072 N/m for all the cases. The solid line is a power law with an exponent 1/2 and the multiplying coefficient is obtained via regression. The inset plots the same data in the nondimensional form.

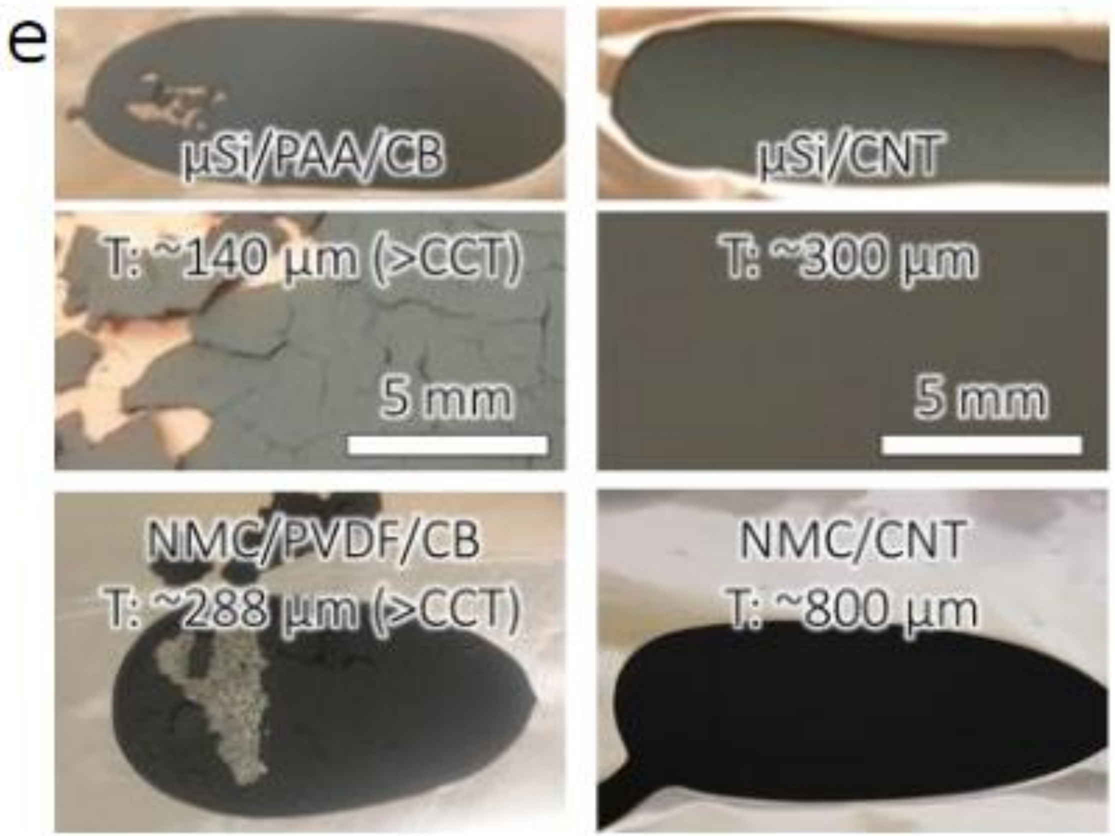
$$Critical\ crack\ thickness\ (CCT), h_{max} = 0.41\sqrt{\frac{GMV_f R^3}{2\gamma}}$$

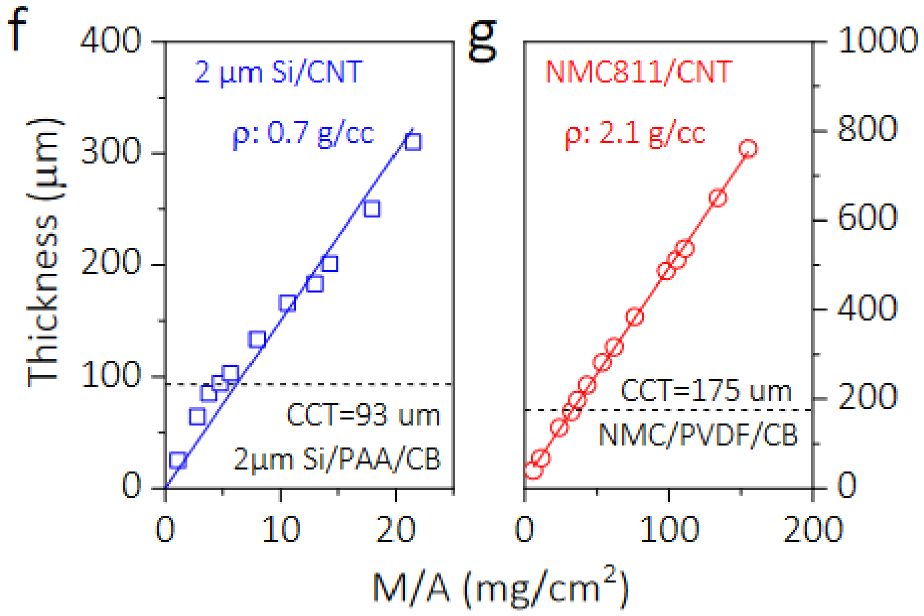
Limitations on electrode thickness

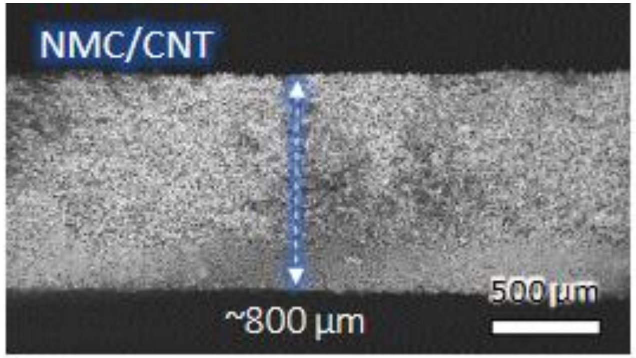


High areal capacity battery electrodes enabled by segregated nanotube networks. Nat Energy 4, 560–567 (2019). https://doi.org/10.1038/s41560-019-0398-y

Limitations on electrode thickness

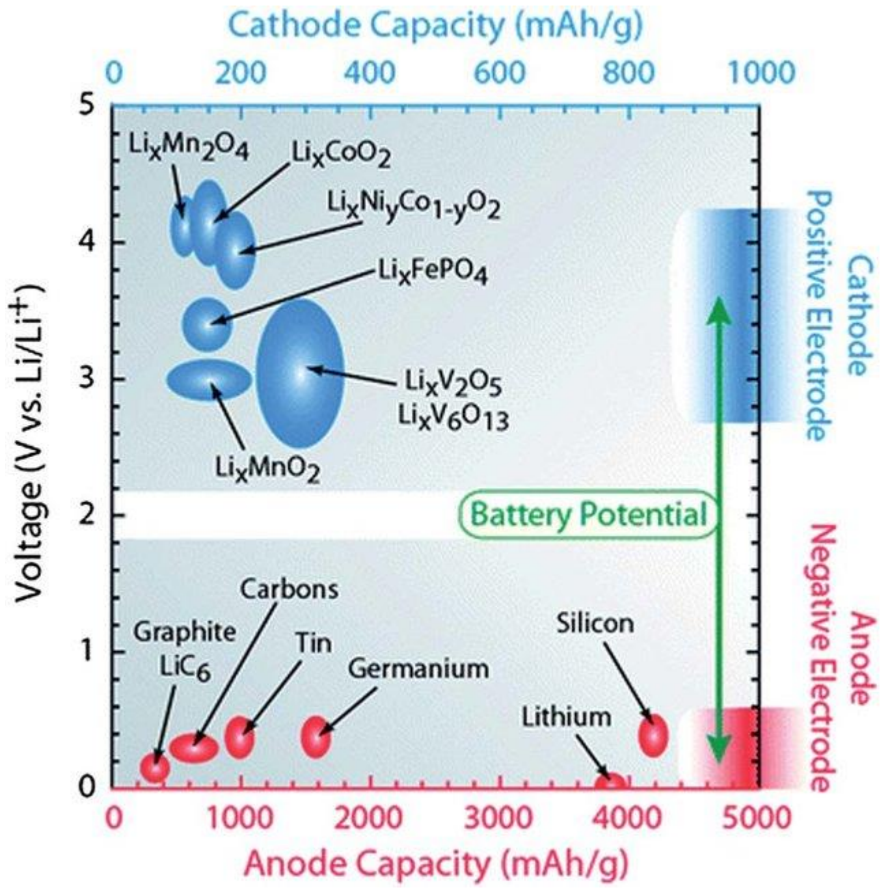




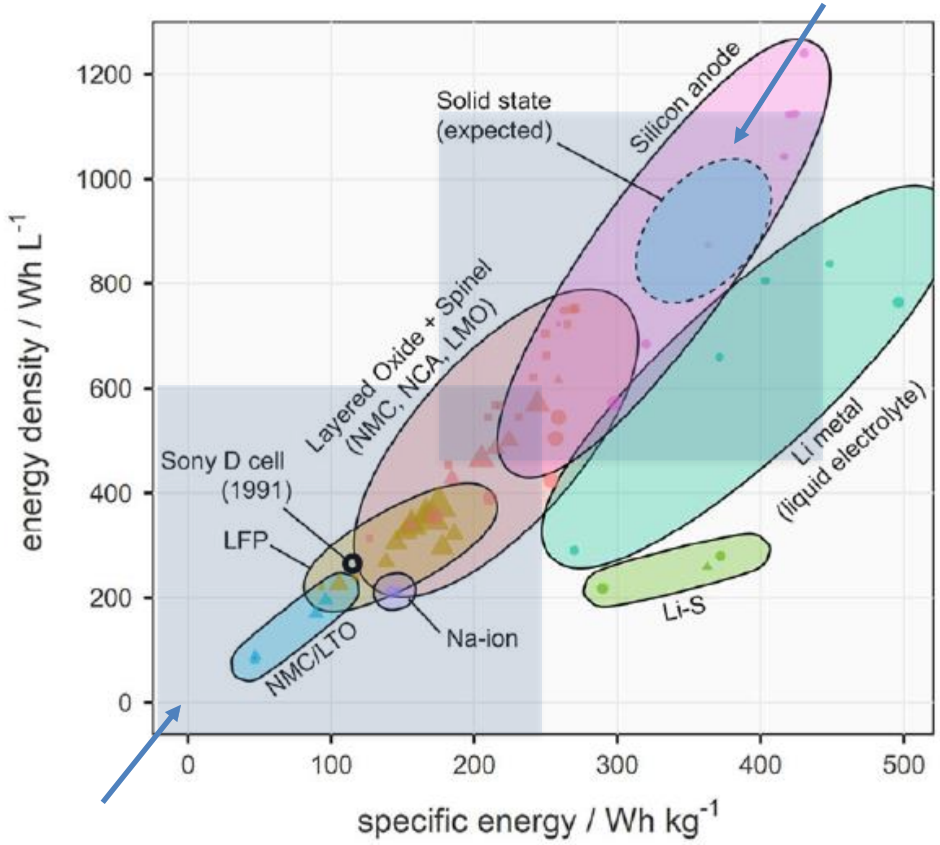


High areal capacity battery electrodes enabled by segregated nanotube networks. Nat Energy 4, 560–567 (2019). https://doi.org/10.1038/s41560-019-0398-y

New generation of batteries



2-5Y (civil applications)

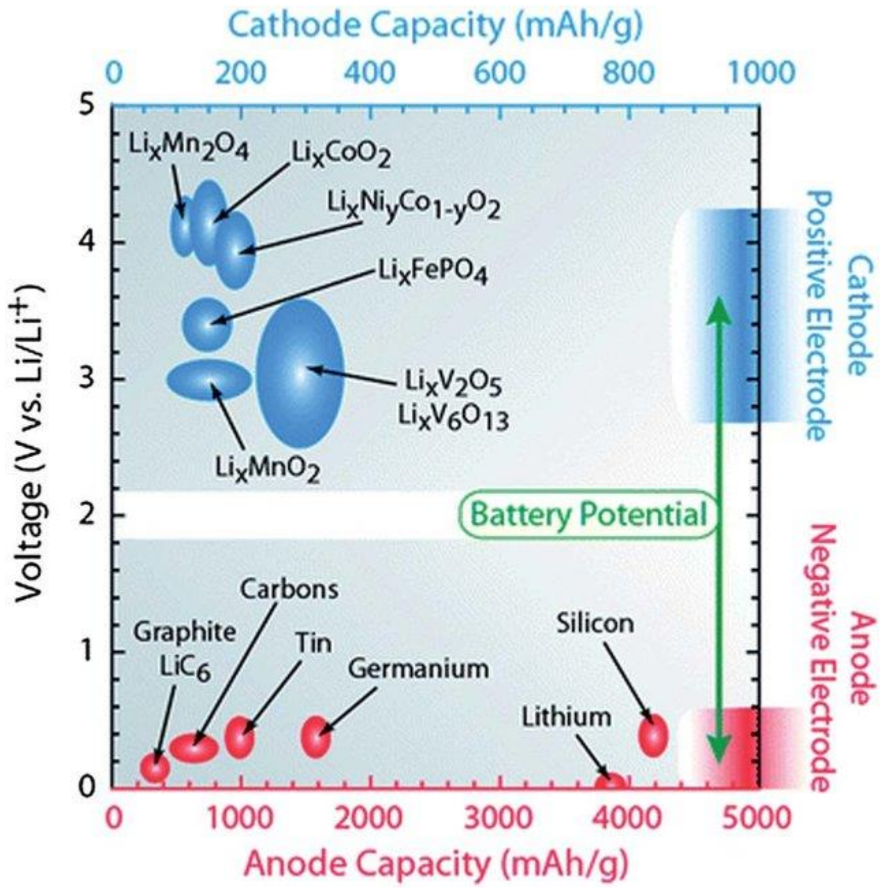


Today

Theoretical capacity (J. Power Sources, Volume 256, 15 June 2014, Pages 72-79)

Frith, J.T., Lacey, M.J. & Ulissi, U.. Nat Commun 14, 420 (2023)

Background: battery basics



E= V X Q

$V_{cell} = V_{cathode}$- V_{anode}

Consider an LFP cathode-graphite anode battery:

$V_{cell} = 3.55 - (0.05) = 3.5V$

Q/m =300 mAh/g

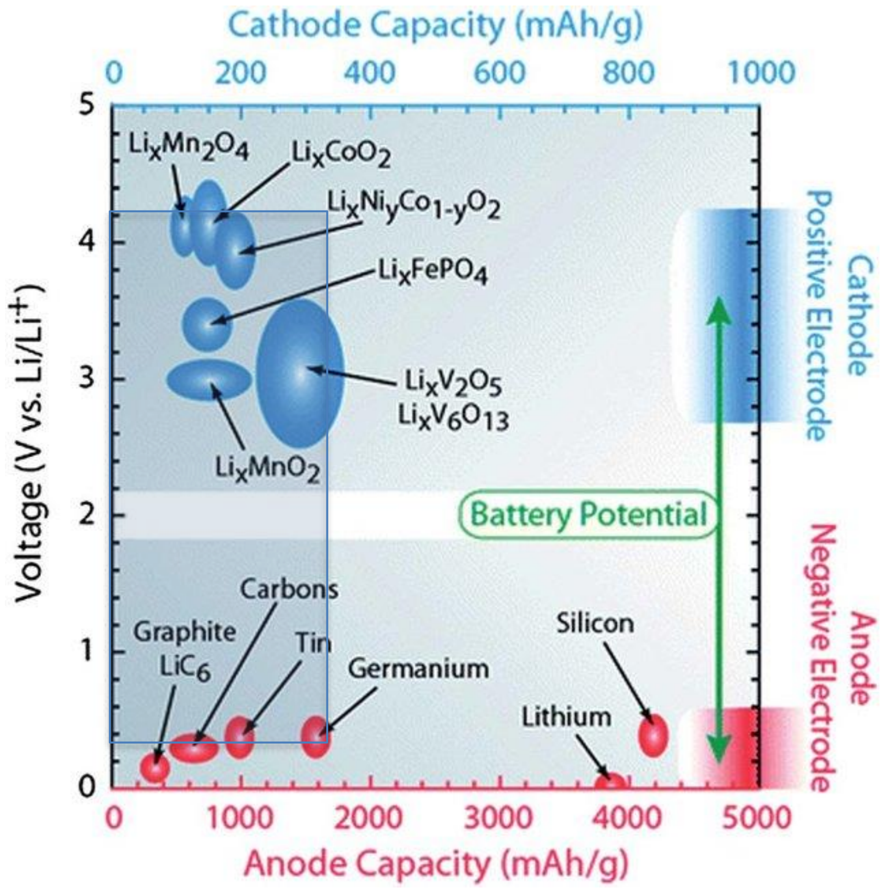
Rough estimate of energy density

$E_s \approx \frac{1}{2} * \frac{Q}{m} * V_{cell}$ =350 Wh/kg

Compare to today's SoA automotive EV Battery (250 Wh/kg)

Theoretical capacity (J. Power Sources, Volume 256, 15 June 2014, Pages 72-79)

Background: battery basics



E= V X Q, but Q is a function of charge rate

$V_{cell} = V_{cathode}$- V_{anode}

Consider an LFP cathode-graphite anode battery:

$V_{cell} = 3.55 - (0.05) = 3.0V$

Q/m =300 mAh/g

Rough estimate of energy density

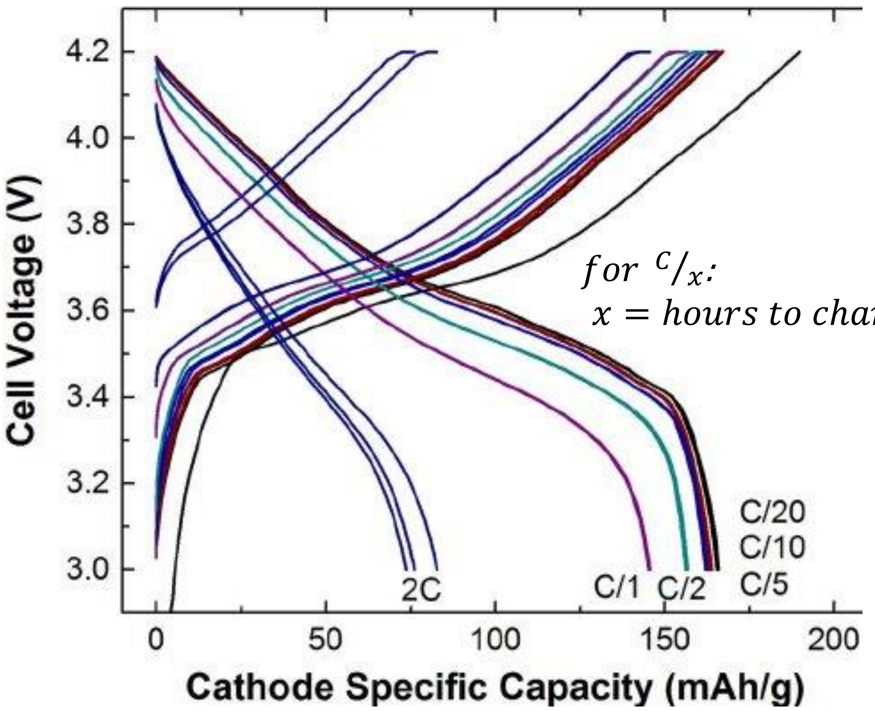
$E_s \approx \frac{1}{2} * \frac{Q}{m} * V_{cell}$ =300 Wh/kg

Compare to today's SoA automotive EV Battery (250 Wh/kg)

Theoretical capacity (J. Power Sources, Volume 256, 15 June 2014, Pages 72-79)

Background: battery basics

Two main sources of limitations in energy density realtive to our theoretical estimate: various resistances and device constraints.



$for\ ^{C}/_{x}$:
$x = hours\ to\ charge$

Figure 9. Initial voltage profiles for a 45 mAh NMC622/Gr pouch cell at C/20, C/10, C/5, C/2, 1C, and 2C discharge rate between 3 and 4.2 V utilizing electrodes with 3.3 mAh/cm^2 available areal capacities. The charge rates were symmetric to discharge until a maximum of C/3 rate. A voltage hold trickle charged the cell at 4.2 V until the measured current was less than that corresponding to C/20.

Capacity is a function of current density

$$Q_{electrode} = Q_{electrode}(J)$$

The real energy density normalised by active materials is

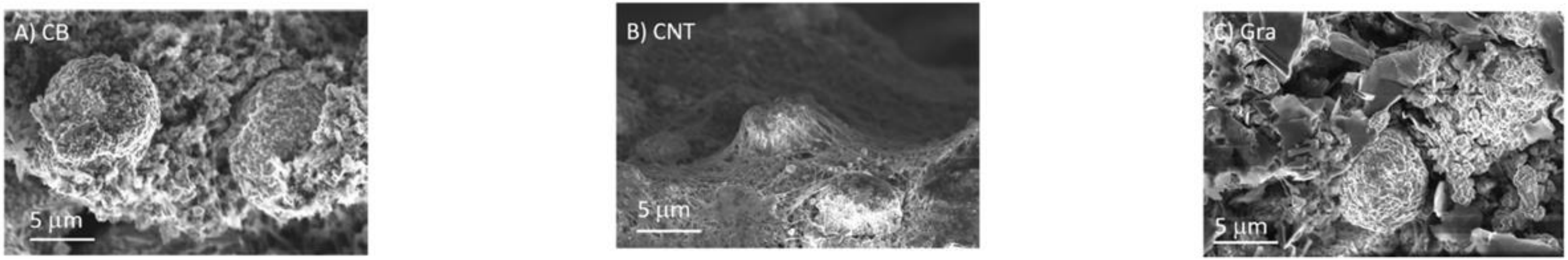
$$E_{s,am} \approx \frac{1}{2} * \frac{1}{m} \int_0^Q V_{cell} * dQ$$

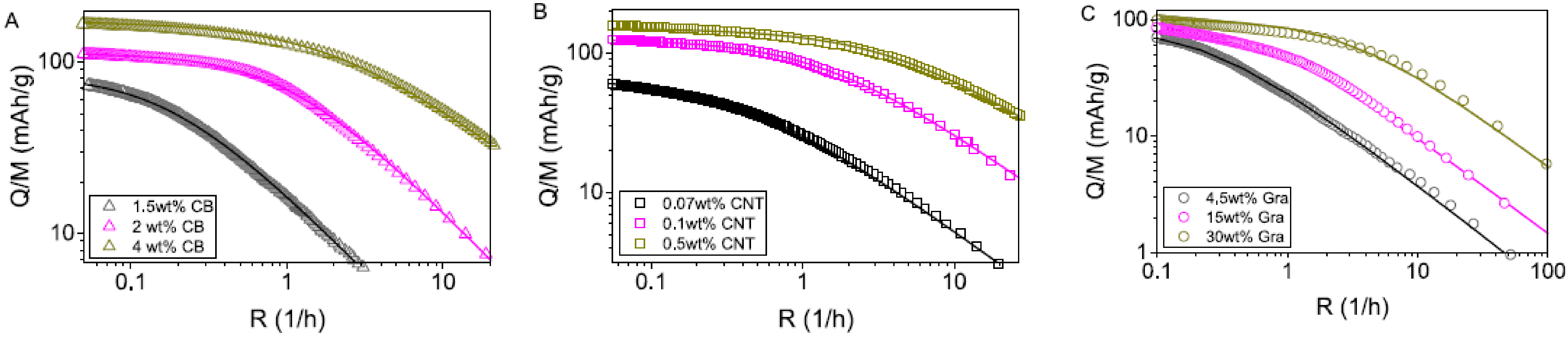
Consider the case of 2C (charging in 30 min):

$$E_{s,am} \approx \frac{1}{2} * \frac{1}{2} * \frac{0.075Ah}{kg} * 4V = 75Wh/kg$$

Optimizing Areal Capacities through Understanding the Limitations of Lithium-Ion Electrodes November 2015Journal of The Electrochemical Society 163(2):A138-A149

Comparison of electrodes with different nanocarbons

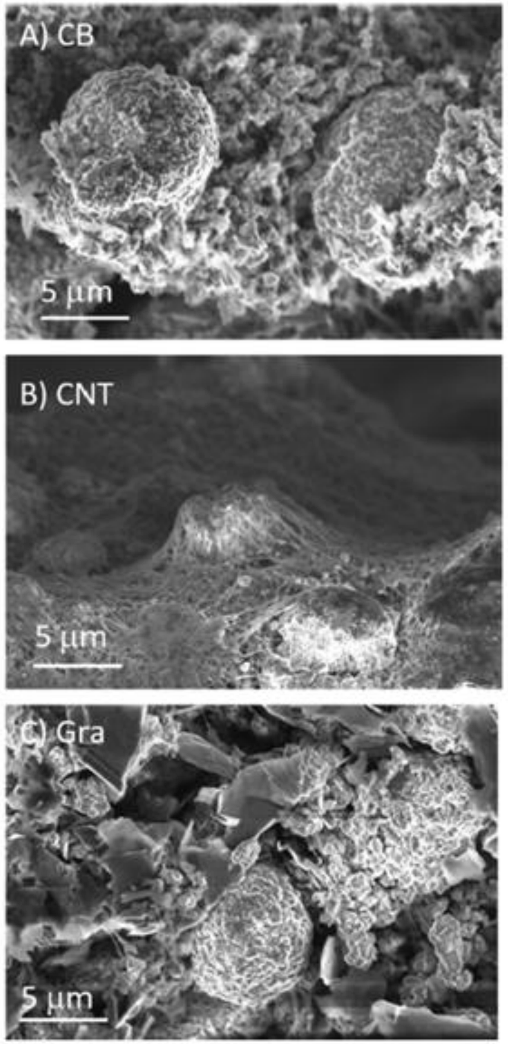


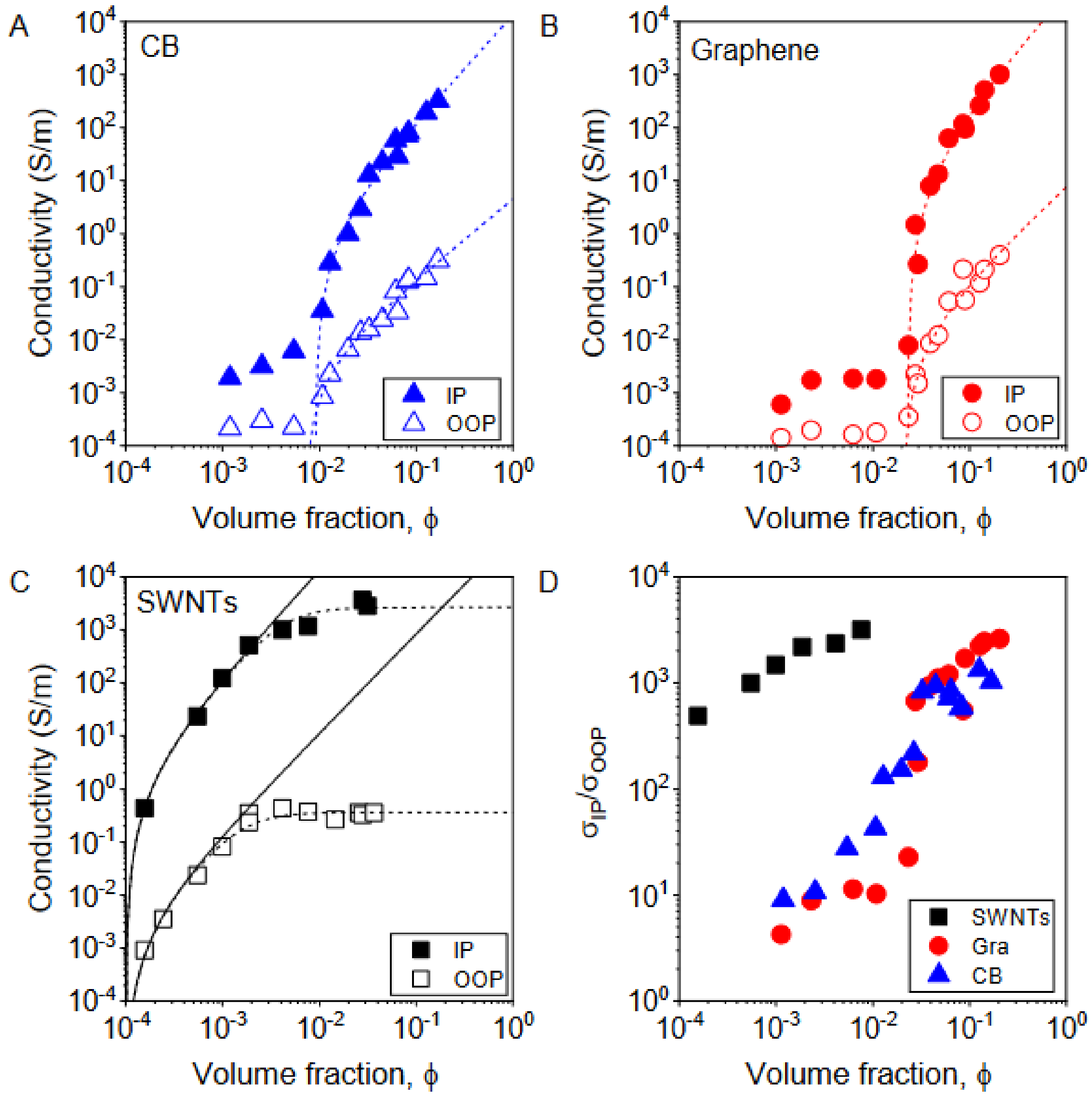


Electrodes of lithium–nickel–manganese–cobalt–oxide (NMC) with different nanocarbons and mass fractions

ACS Appl. Energy Mater. 2020, 3, 2966–2974

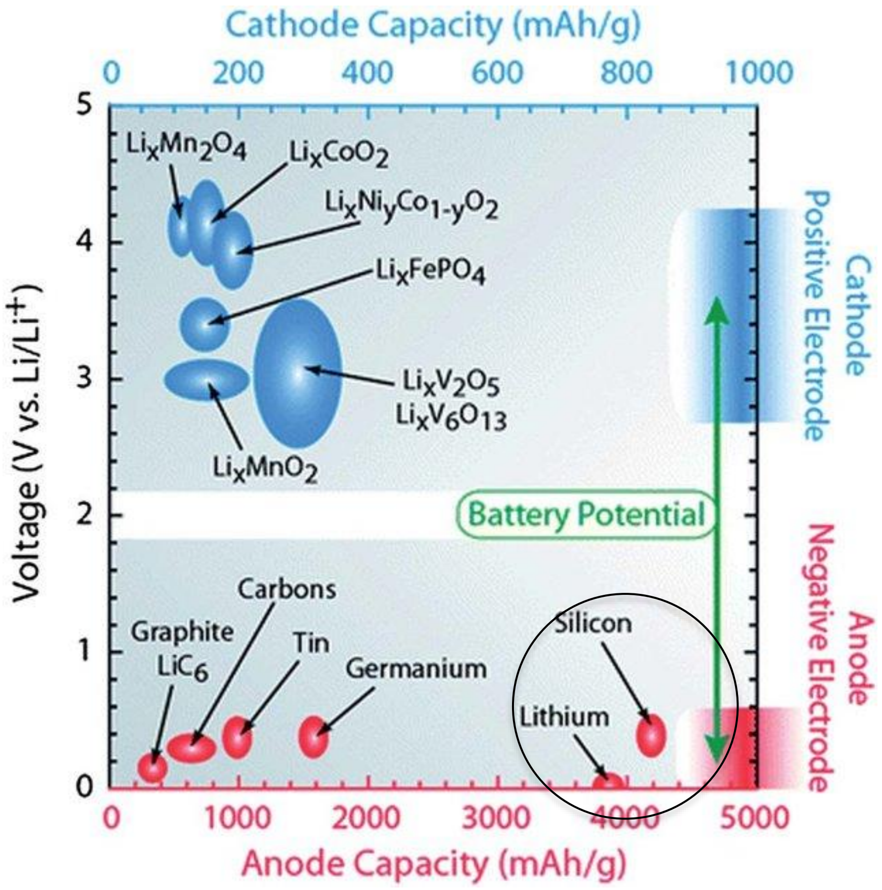
Comparison of electrodes of NMC with different nanocarbons





ACS Appl. Energy Mater. 2020, 3, 2966–2974

New generation of batteries



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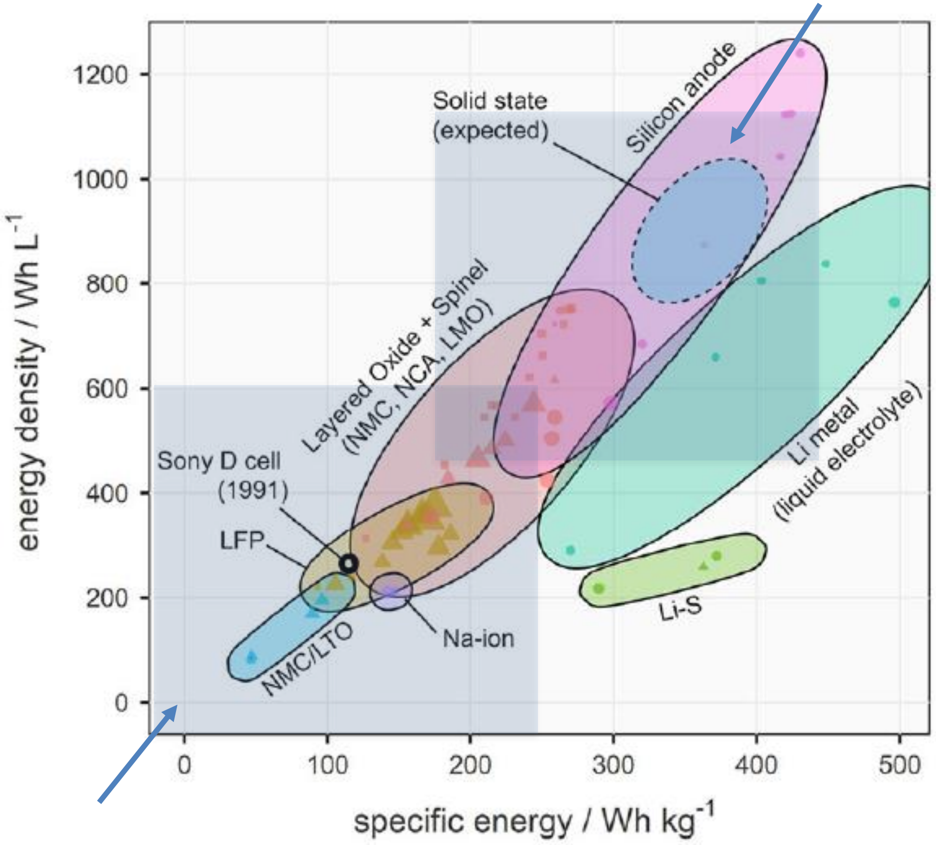

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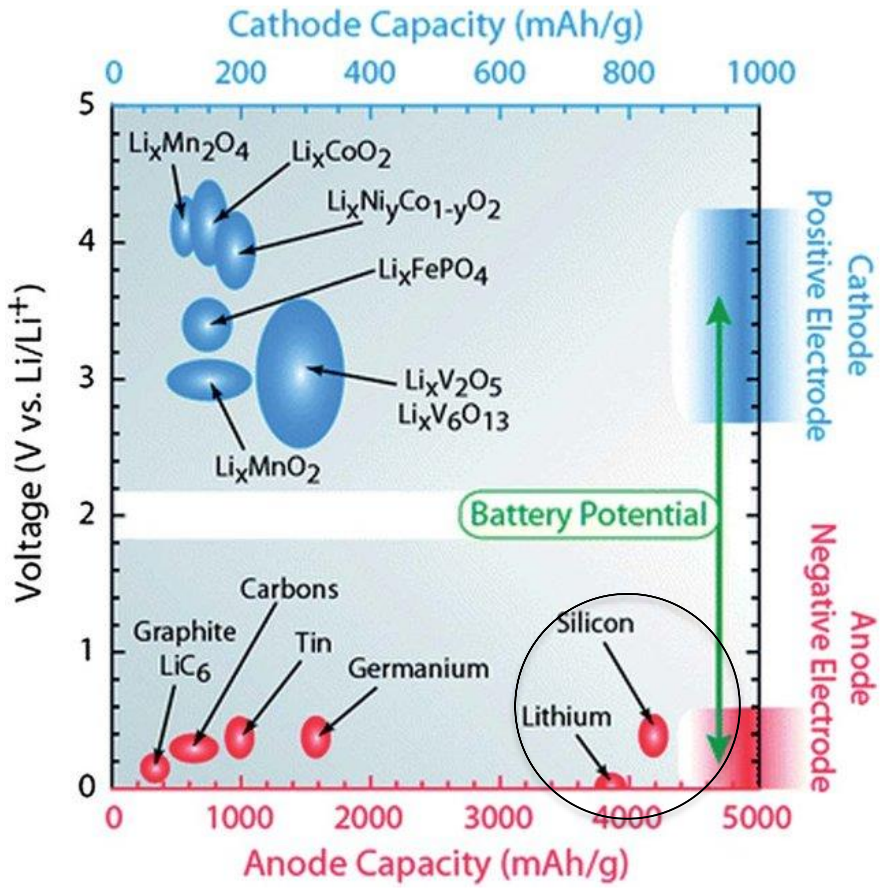


Energy density X 2 compared to legacy batteries (400 – 500 Wh/kg)

EV with 1000km drive range

Charge time below 10s (10 – 80%)

Amprius to Integrate Safe Cells into Next-Generation U.S. Army Wearable Battery Pack

May 9, 2024

Cutting-Edge SiMaxx™ Silicon Anode Safe Cells are Expected to Double the Energy Density of Existing Solutions and Significantly Extend Mission Time for Soldiers

FREMONT, Calif. – May 09, 2024 – Amprius Technologies, Inc. ("Amprius" or the "Company") (NYSE: AMPX), a leader in next-generation lithium-ion batteries with its Silicon Anode Platform, today announced it will supply its state-of-the-art SiMaxx™ safe cells to complete the development and qualification for the U.S. Army's next-generation Wearable Battery pack.

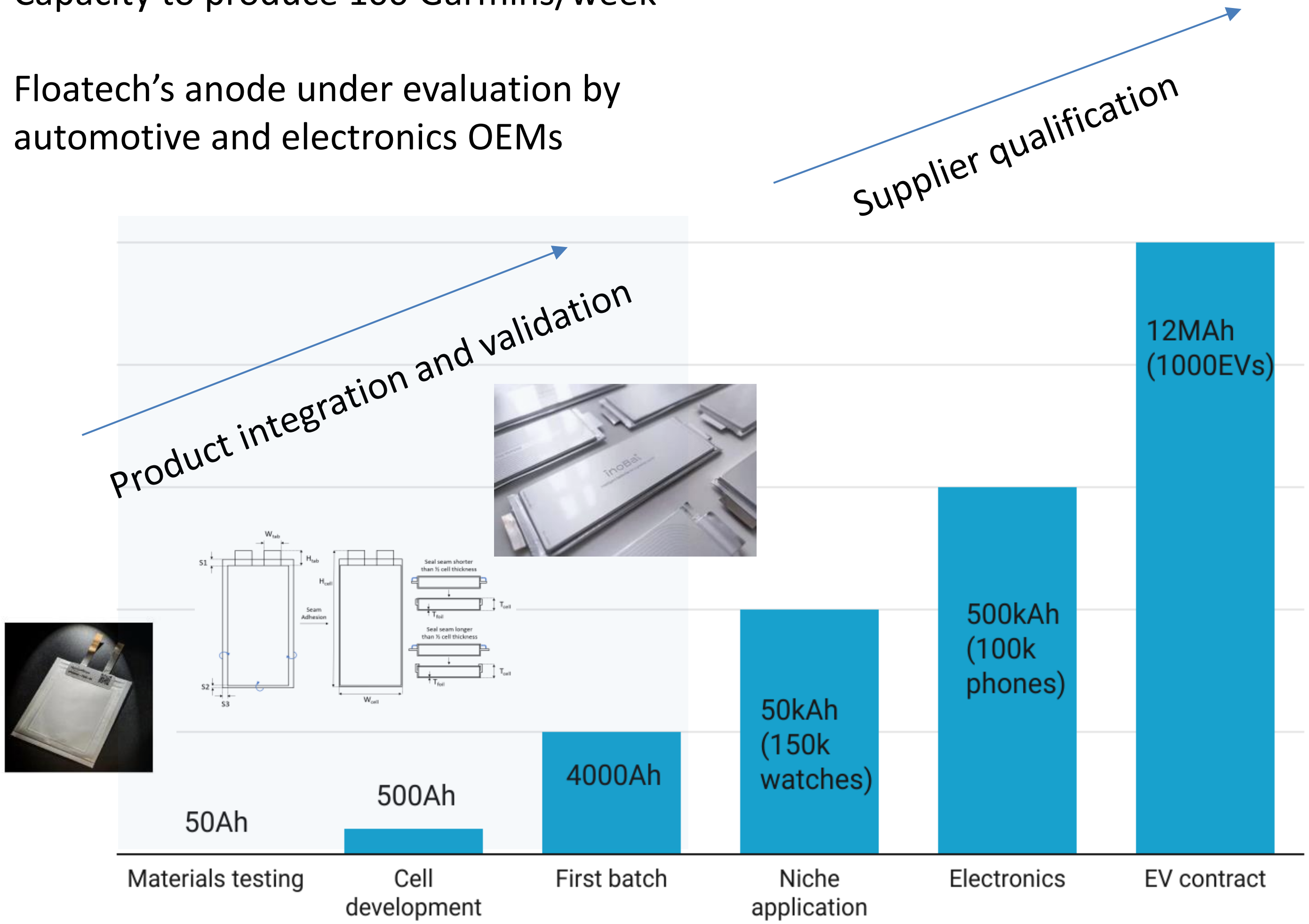
Theoretical capacity (J. Power Sources, Volume 256, 15 June 2014, Pages 72-79)

Floatech®

From plant to pack

Capacity to produce 100 Garmins/week

Floatech's anode under evaluation by automotive and electronics OEMs

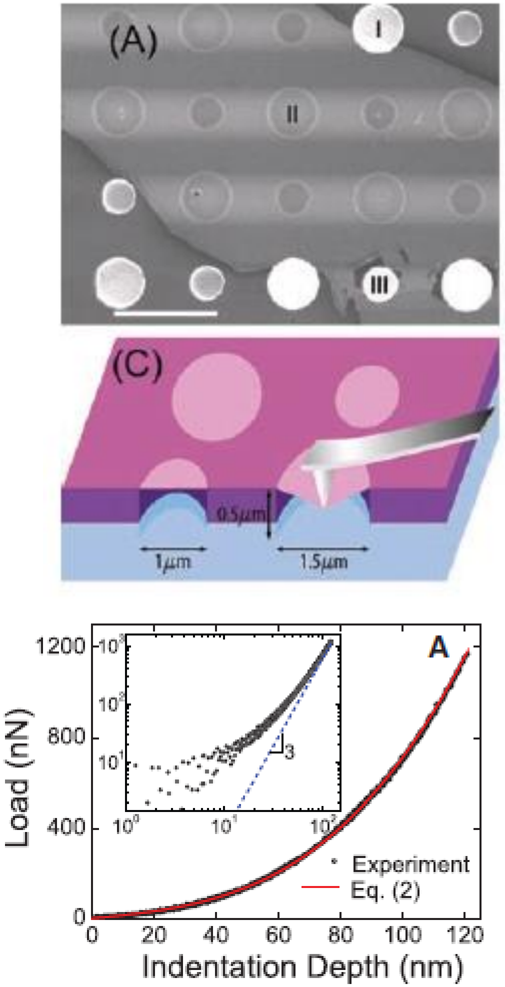


Exponential capacity scale-up (not shown to scale)

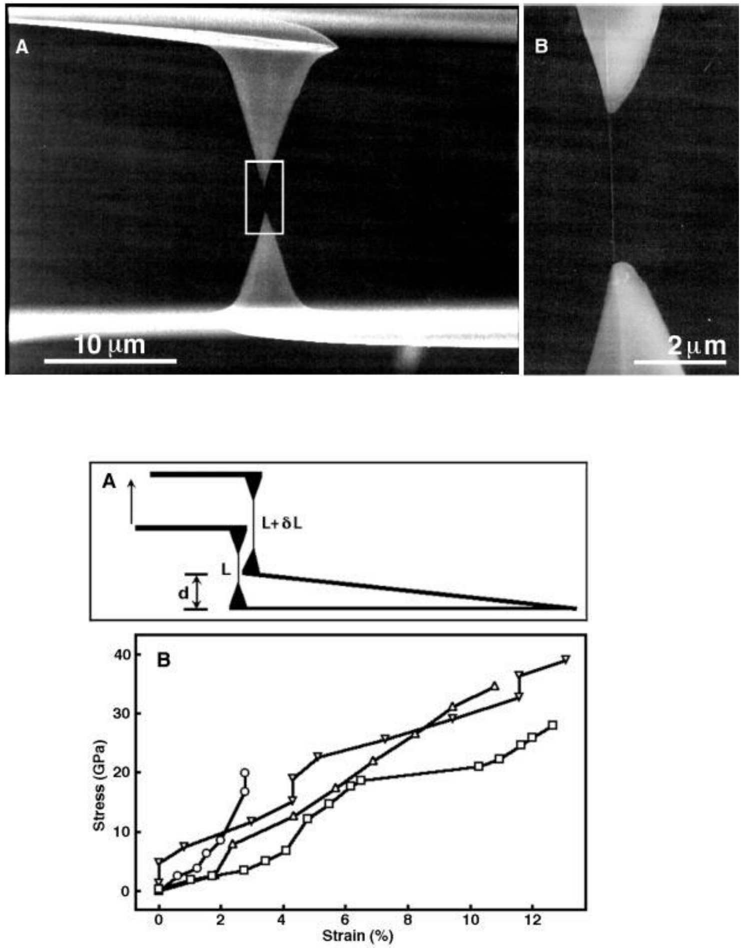
Cables eléctricos y escudos balísiticos nanoestructurados

Motivation: properties of nanomaterials

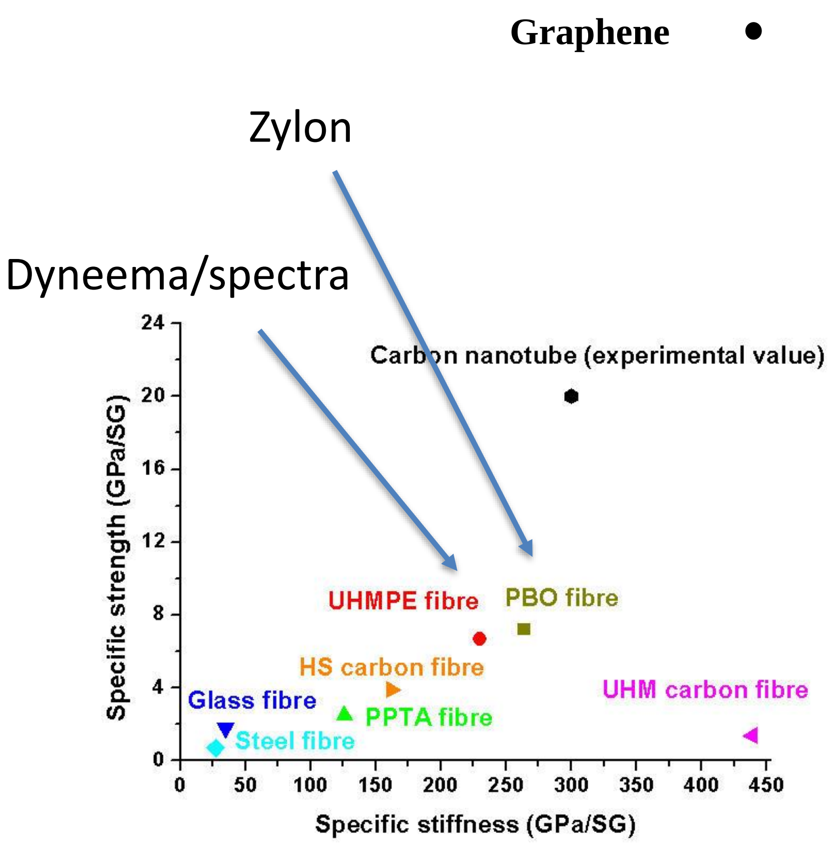
Example: Graphene and CNTs
What is the origin of their outstanding mechanical properties?



Changgu Lee, et al. Science 321, 385 (2008)

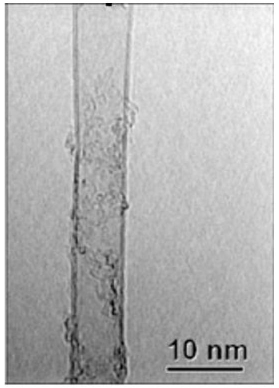


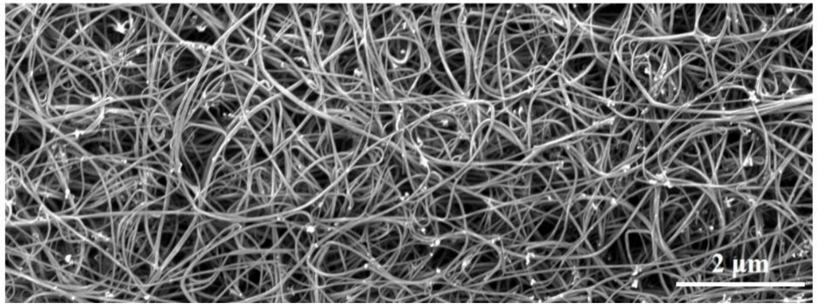
Yu et al. Science 287, 637 (2000)



“Nanomaterials” assembly into macroscopic materials

1D nanoparticle (nanomer) → Engineering material (nanomeric material)

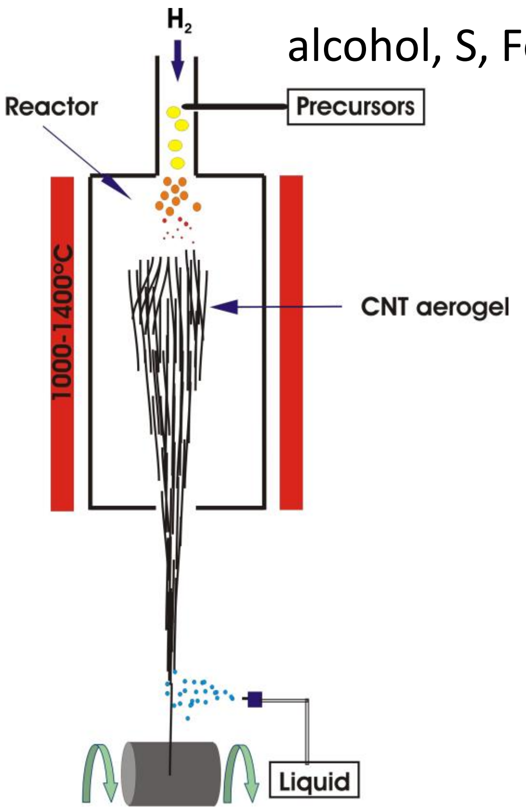


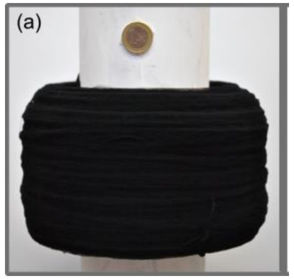


Macroscopic properties depend on assembly and microstructure

Synthesis by floating catalyst CVD

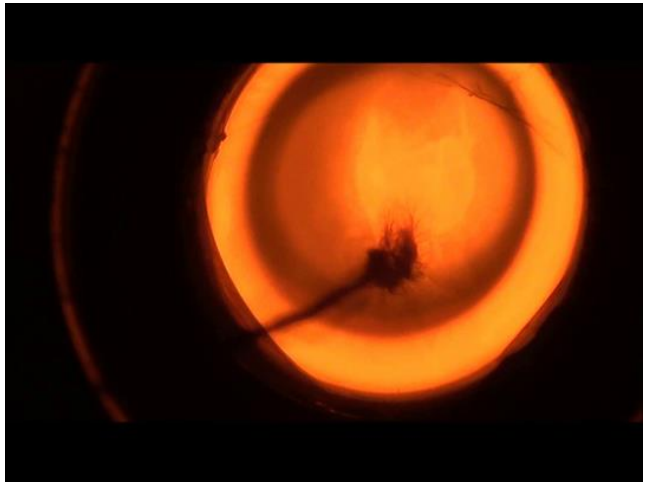
alcohol, S, Fe





Reguero et al, Chem Mater, 26, 3550 2014

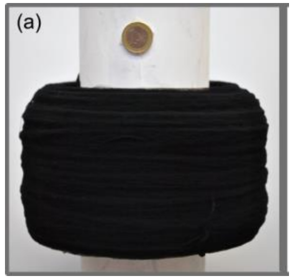
Looking up into the reactor



Continuous spinning of 1km

Synthesis by floating catalyst CVD

alcohol, S, Fe



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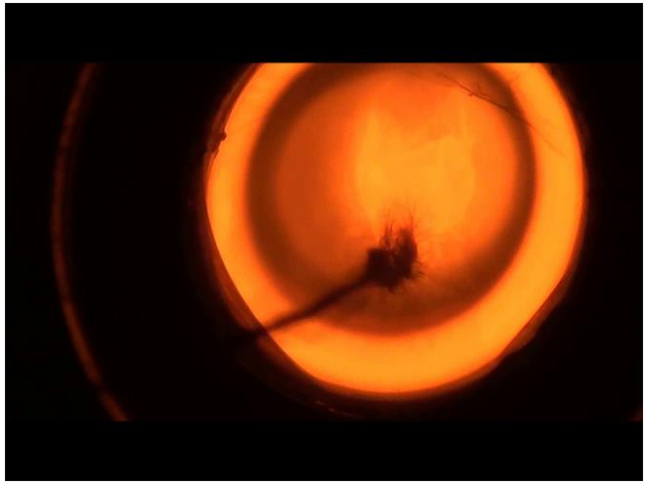

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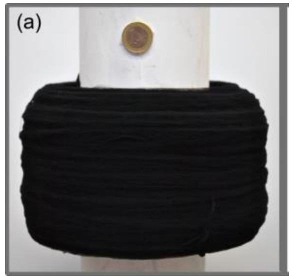

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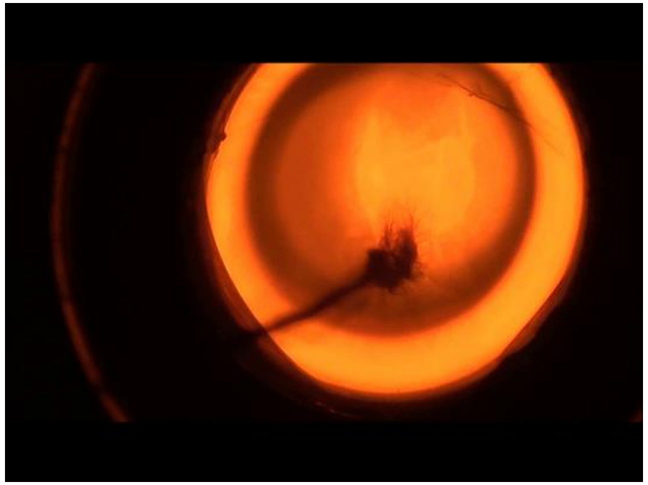
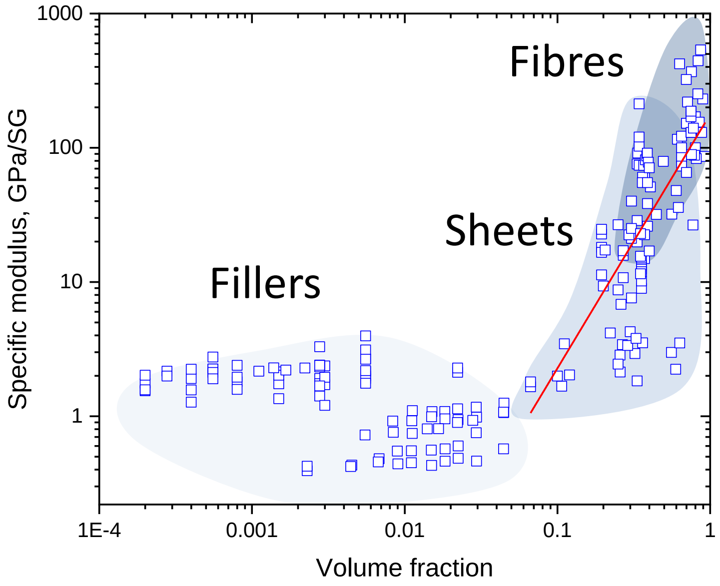
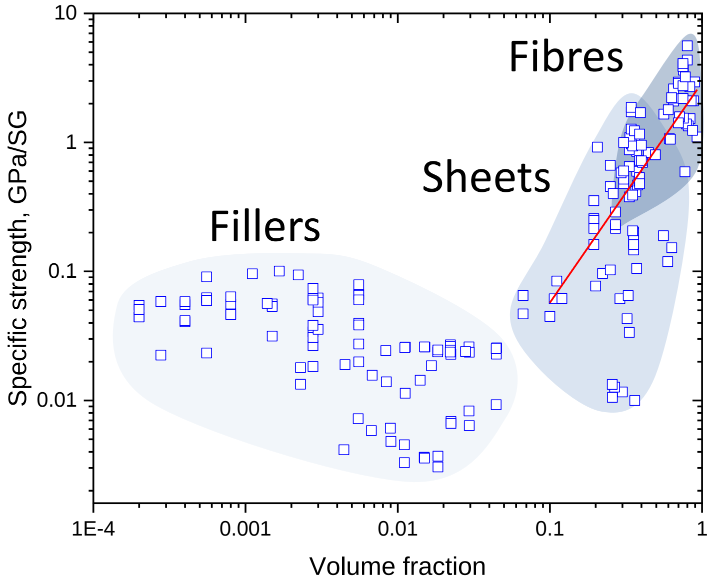
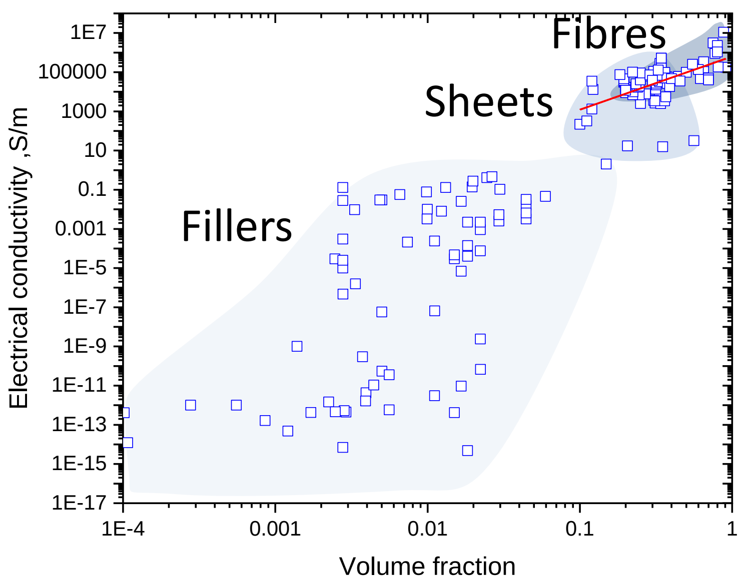


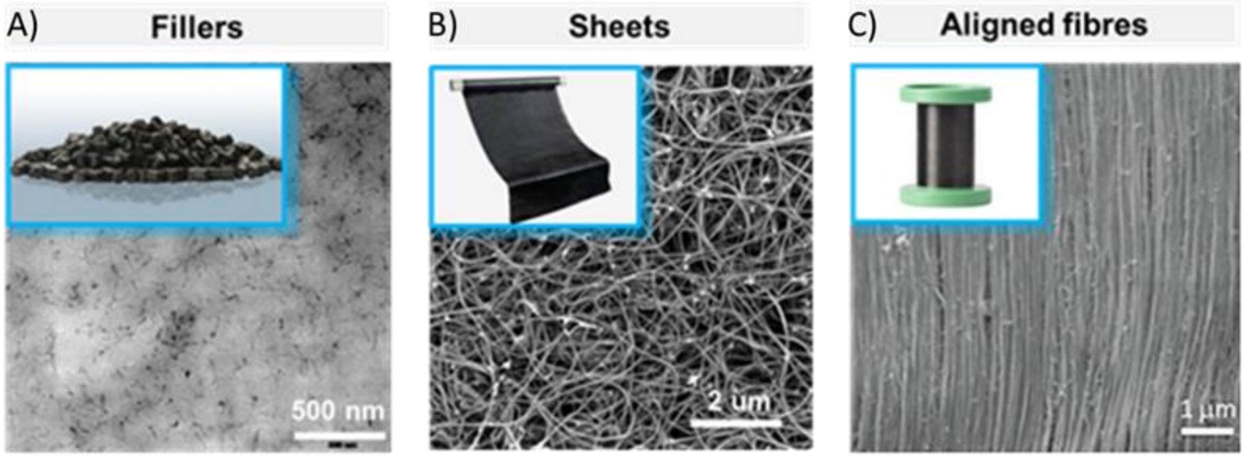
Continuous spinning of 1km

Classification of macromaterials of nanomaterials



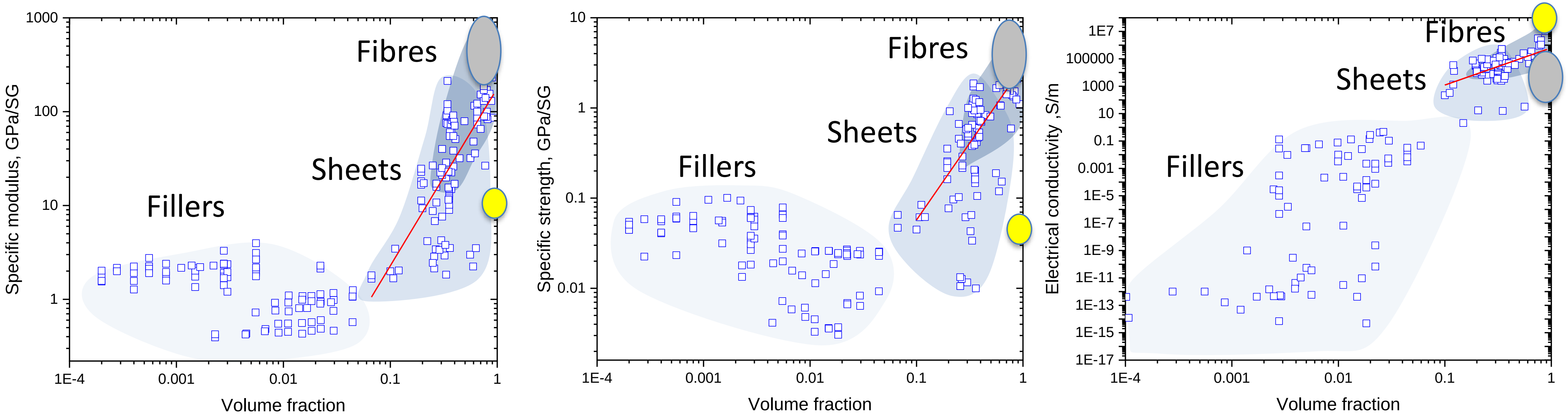






"Product spectra, properties, performances and market applications of carbon materials from hydrocarbons cracking", Chapter in Turquoise hydrogen: an effective pathway to decarbonization and value added carbon materials, 2023

Comparison to conventional materials



$$Property \propto V_f^{\alpha}$$

Carbon fibre

Copper

α = 1.9 modulus; 1.7 strength, 2.7 conductivity

Value at scale, increases from 0.50 to 50 EUR/kg from fillers (CB) to fibres (CF)

“Product spectra, properties, performances and market applications of carbon materials from hydrocarbons cracking”, Chapter in Turquoise hydrogen: an effective pathway to decarbonization and value added carbon materials, 2023

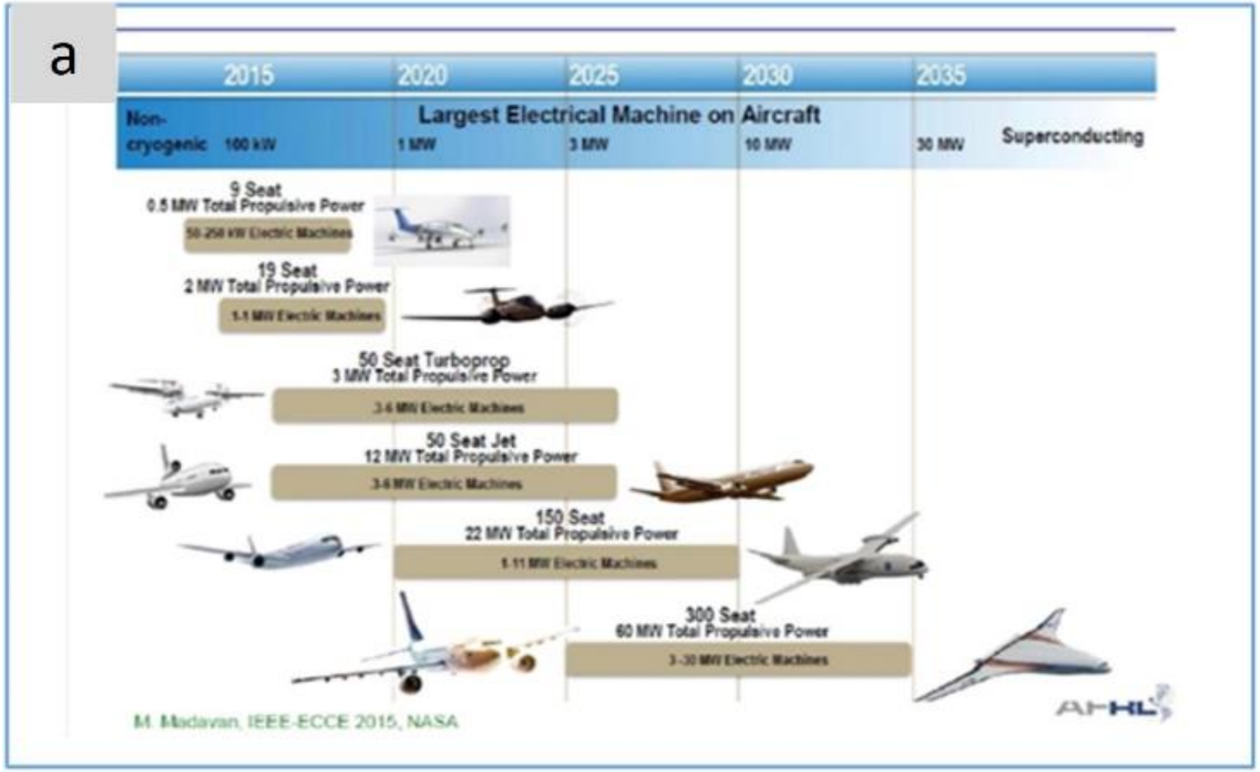
Conductores supermetálicos: con conductividad y peso en el rango de Cu y Al

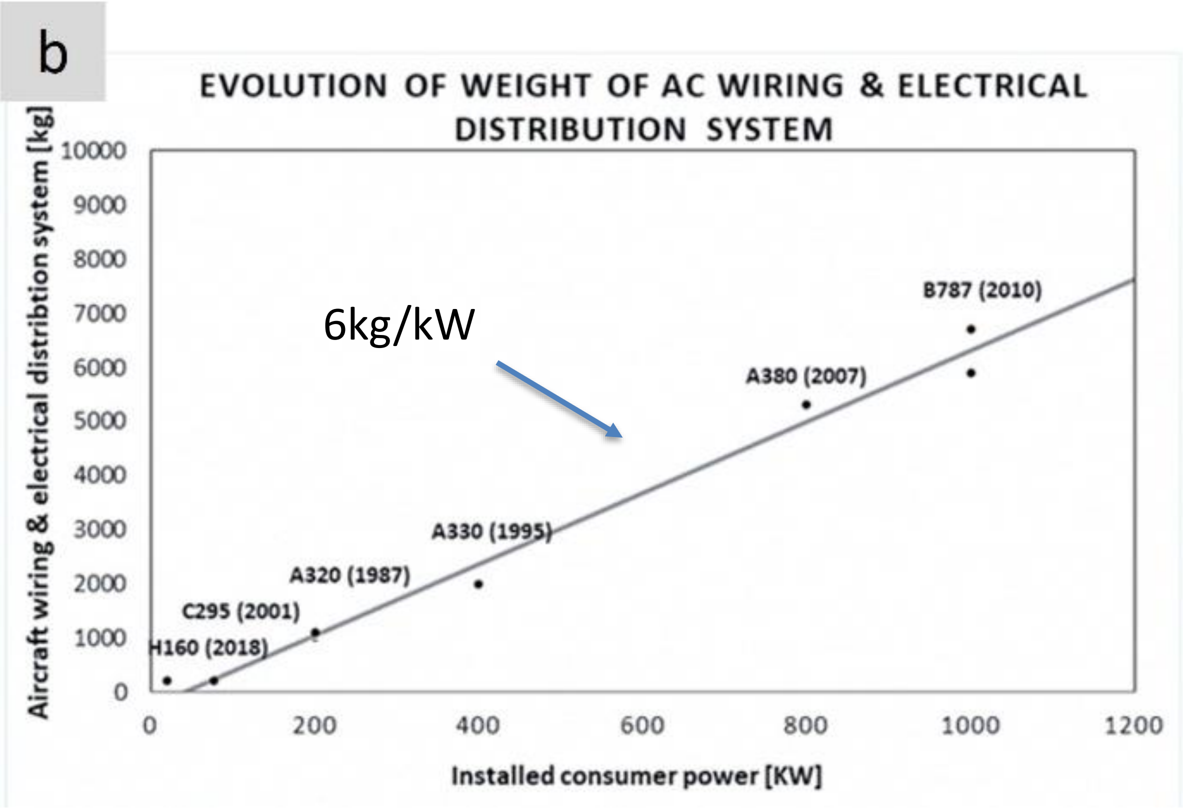
institute imdea materials

Electrical conductors for electromobility

science transfer talent

Motivation for new conductors for electrification of transport

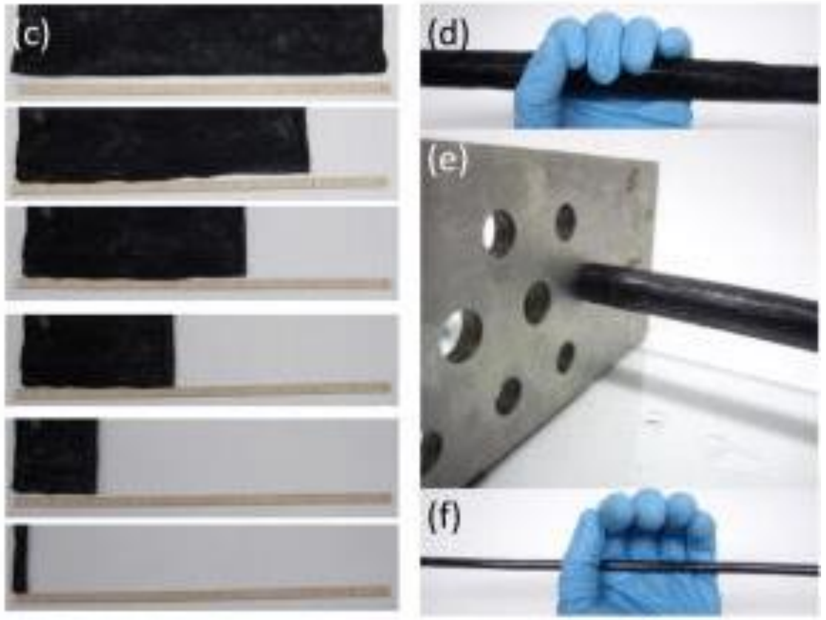




Increasing need for conductors in emerging aircraft. a) Evolution of required electrical power in civil aircraft [118] and b) Historical data showing a linear increase in weight from electrical wiring and distribution / interconnection systems with installed consumer power

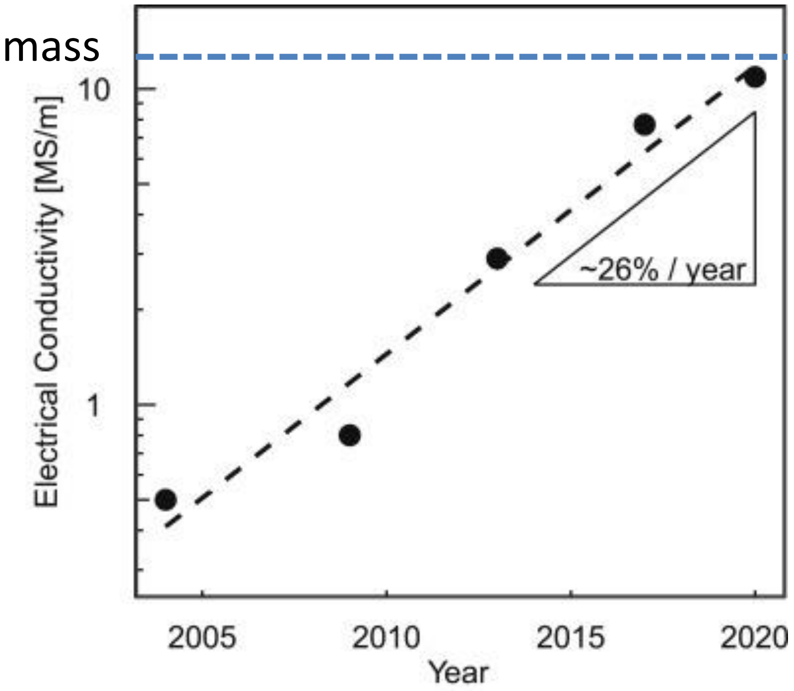
At the current rate of increase in electrical power, by 2035 aircraft would carry wiring weighing as much as an A320!

Can we make cables lighter than copper?



Cu

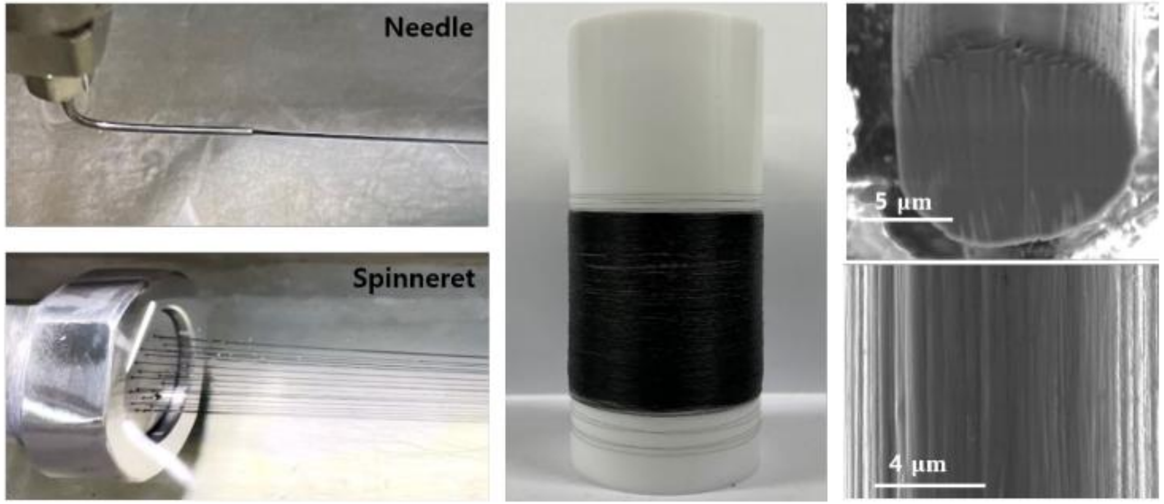
Cu, by mass



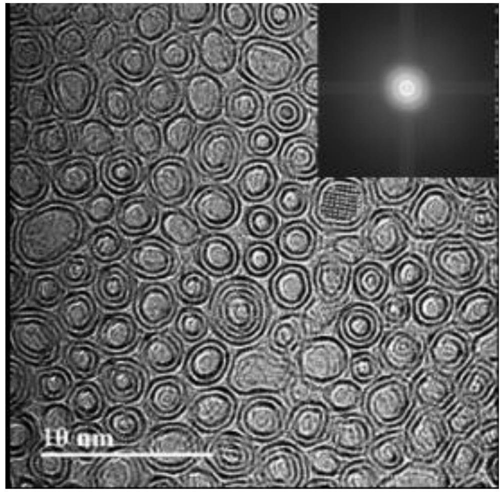
Cu: 7.5 MS/m /density
CNT: 4.8 MS/m /density

J. Appl. Phys.. 2017;122(2). doi:10.1063/1.4990981

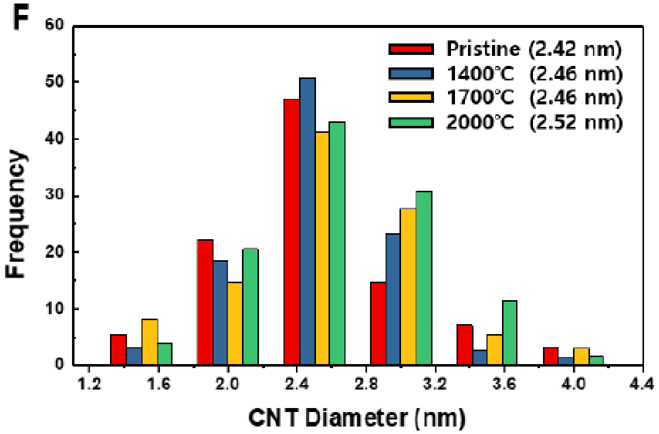
Properties of annealed LC-spun CNT fibres



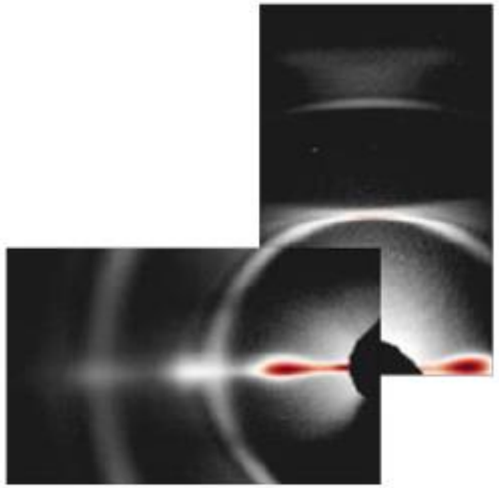
Periodic structure of closed-packed CNTs in regular bundles



Pt-protected FIB milling of lamellae



Long-range order

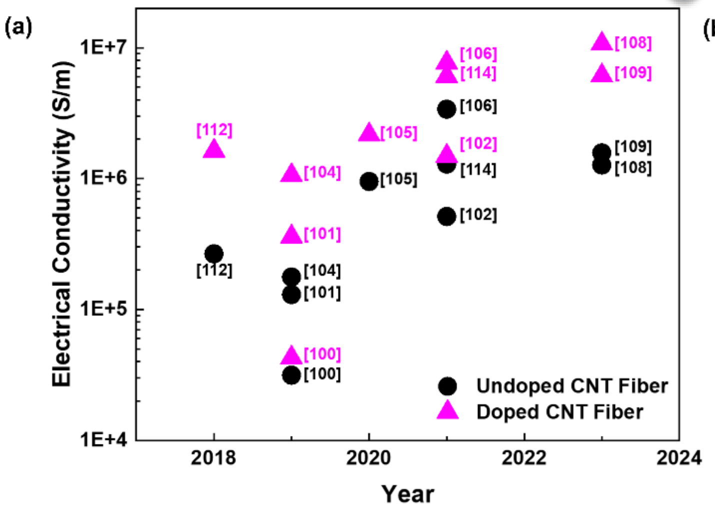


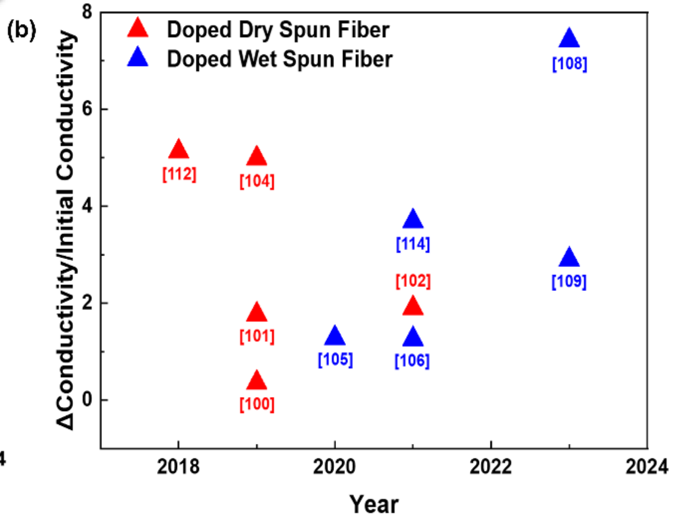
2D WAXS pattern

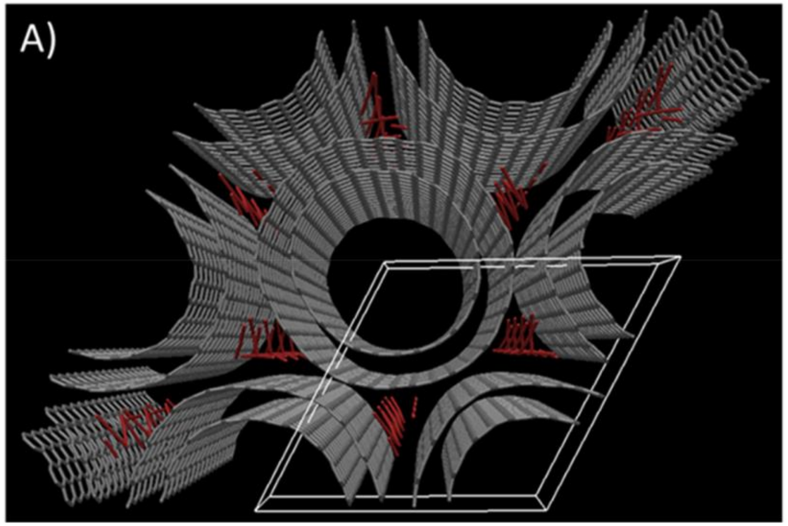
Lee et al., Sci. Adv.8, eabn0939 (2022)

Can we make cables lighter than copper? Yes, we can

Upcoming IMDEA results







Conductivity of all CNT cables produced this decade

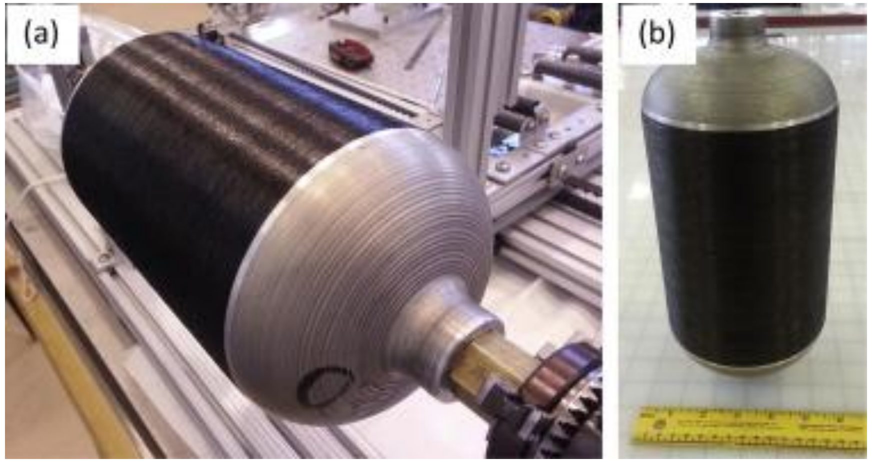
Cu: 7.5 MS/m /density

CNT: 4.8 MS/m /density (2024)
CNT: 8.3 MS/m / density (2025)

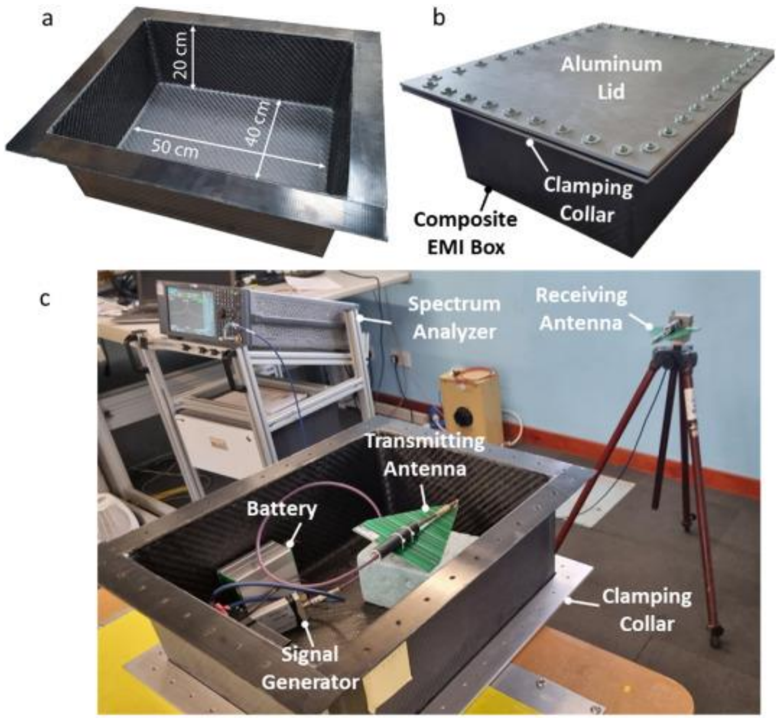
Patent pending

From lab to prototype

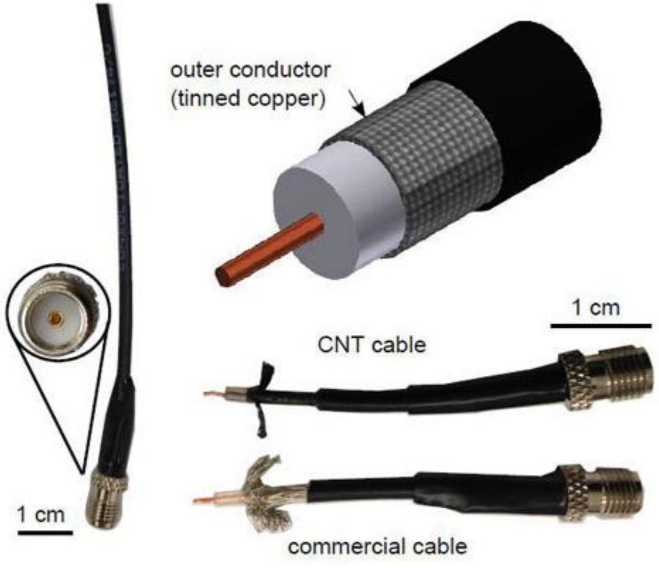
Nasa



Plasan, Israel

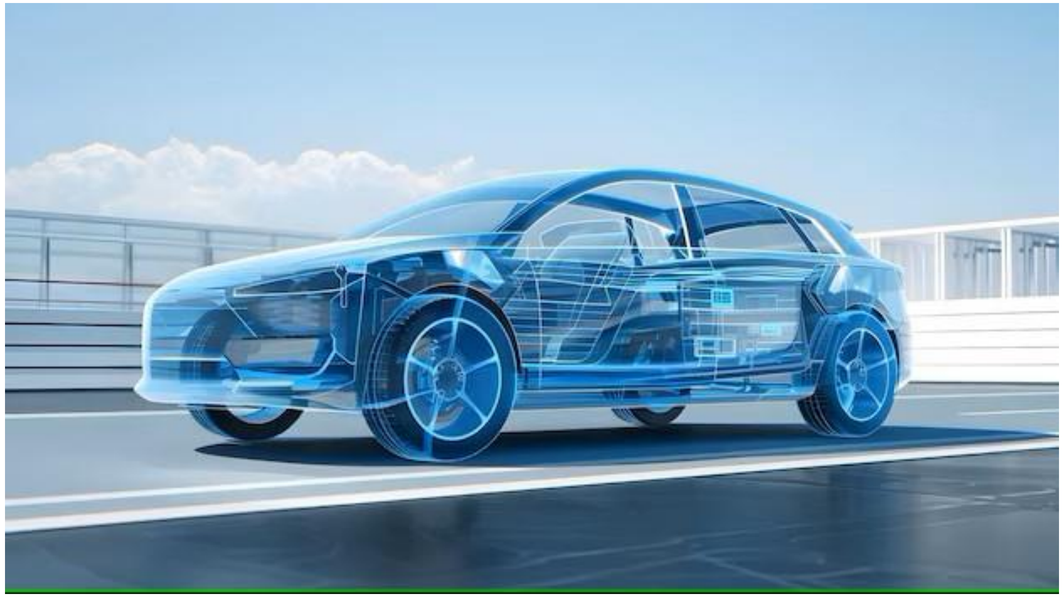


American Boronite Corporation



Carbon Volume 206, 25 March 2023, Pages 166-180

Perspective on weigth reduction in electric vehicles



28% weight reduction in battery

25% weight reduction in wiring of electric motor

20-50% weight reduction in the EMI layer science transfer talent

Thank you

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MNG
Multifunctional Nanocomposites Group

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Carbon Hub

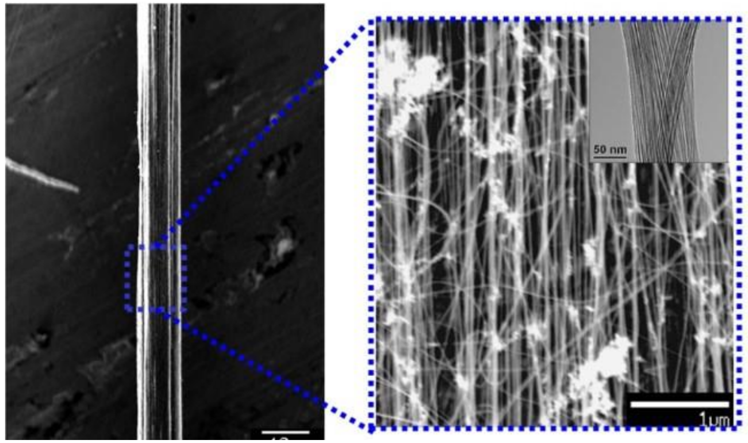
erc European Research Council

La Suma de Todos – Comunidad de Madrid

Gobierno de España – Ministerio de Economía y Competitividad

Tensile properties of aligned fibres and sheets

CNT Fibre



Carbon Fibre