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Electrochemical Engine Center

Smaller, Faster-Charging Batteries for Affordable and Sustainable Electric Vehicles

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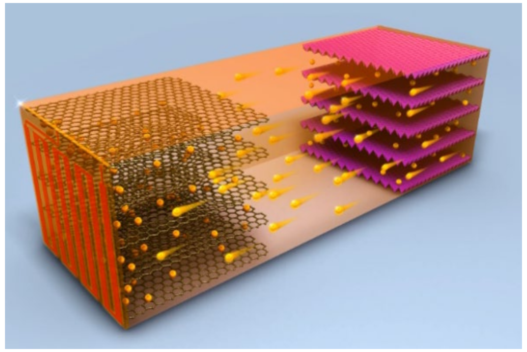
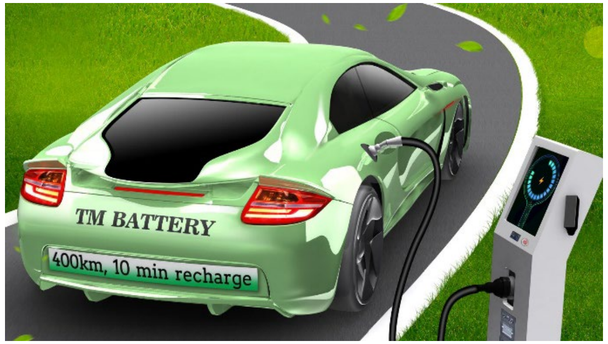
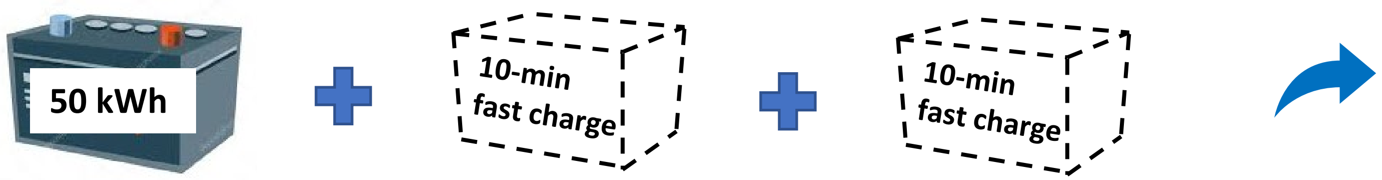




Economics of Battery Fast Charging

- Storing electricity in batteries costs $150/kWh, while refill of the energy costs $0.1 – a 1000x gap.
- Storage is awfully expensive. You don't want to store more energy than absolutely necessary
- An affordable EV simply means a small battery pack capable of 10-minute refill of energy – 10-minute fast-charge.
- Replace 150 kWh with 50kWh, 10-min rechargeable battery



Lean Energy Storage System (LESS) Coupled with Ubiquitous Fast Charging

<u>Fast Charge enables battery/EV affordability</u>

LESS is the Path to Sustainability

- We hear “reuse and recycle”, but the first and most effective path to sustainability is REDUCE.
- Fast-charge enables battery downsizing, dramatically reducing waste of raw materials and carbon emissions from manufacturing batteries.
- Going from 150 to 50 kWh saves 100kWh on each car. If scaled to 50m cars by 2030, this is removing 5 TWh pressure out of the battery supply chain.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Advancements in extreme fast charging to foster sustainable electrification
Xiao-Guang Yang • Bairav S. Vishnugopi • Partha P. Mukherjee • Wenwei Wang • Fengchun Sun •
Chao-Yang Wang

Long-Range EVs/Big Batteries Are Unsustainable

- 600+ mile range vehicles need 150 kWh battery regardless of energy density, meaning formidably high cost to consumers even at $150/kWh, again regardless of energy density, and huge consumption of critical raw materials (Co, Ni, Li)

- Vehicle warranty is 100k miles, meaning 150 cycles of the 150kWh battery. Loading up a car with 150 kWh battery and retiring it after 150 cycles do not make sense. Utilization of BIG batteries for EVs is very low.

50kWh EV Batteries are Sustainable & w/o Range Anxiety

- If 50kWh sustainable batteries is new norm for mass-market EVs, what is not to love about LFP batteries?
- 10-minute fast rechargeable LFP of 50kWh is an ideal solution for sustainable and affordable EVs, as found from our 2-yr study (2018-2020).

Yang et al., *Nature Energy* 6, 176–185 (2021)

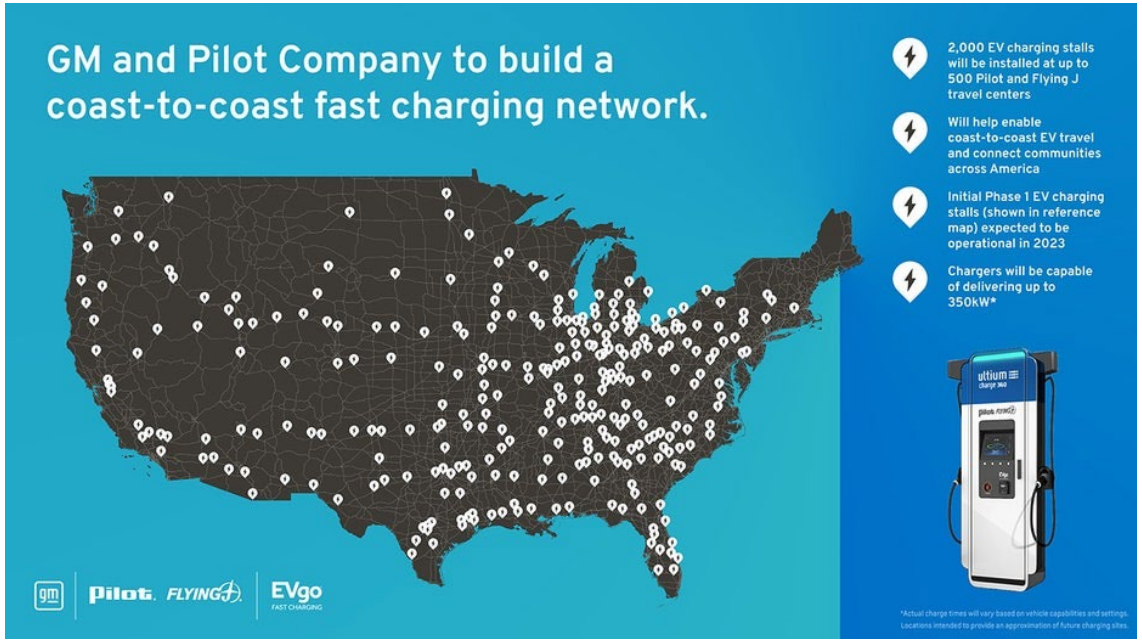
Fast-Charging Infrastructure Is Available

CHARGE! —

Electrify America will deploy 2,000 350kW fast chargers by the end of 2019

484 new charging sites, split between 17 metro areas and highways in 39 states.

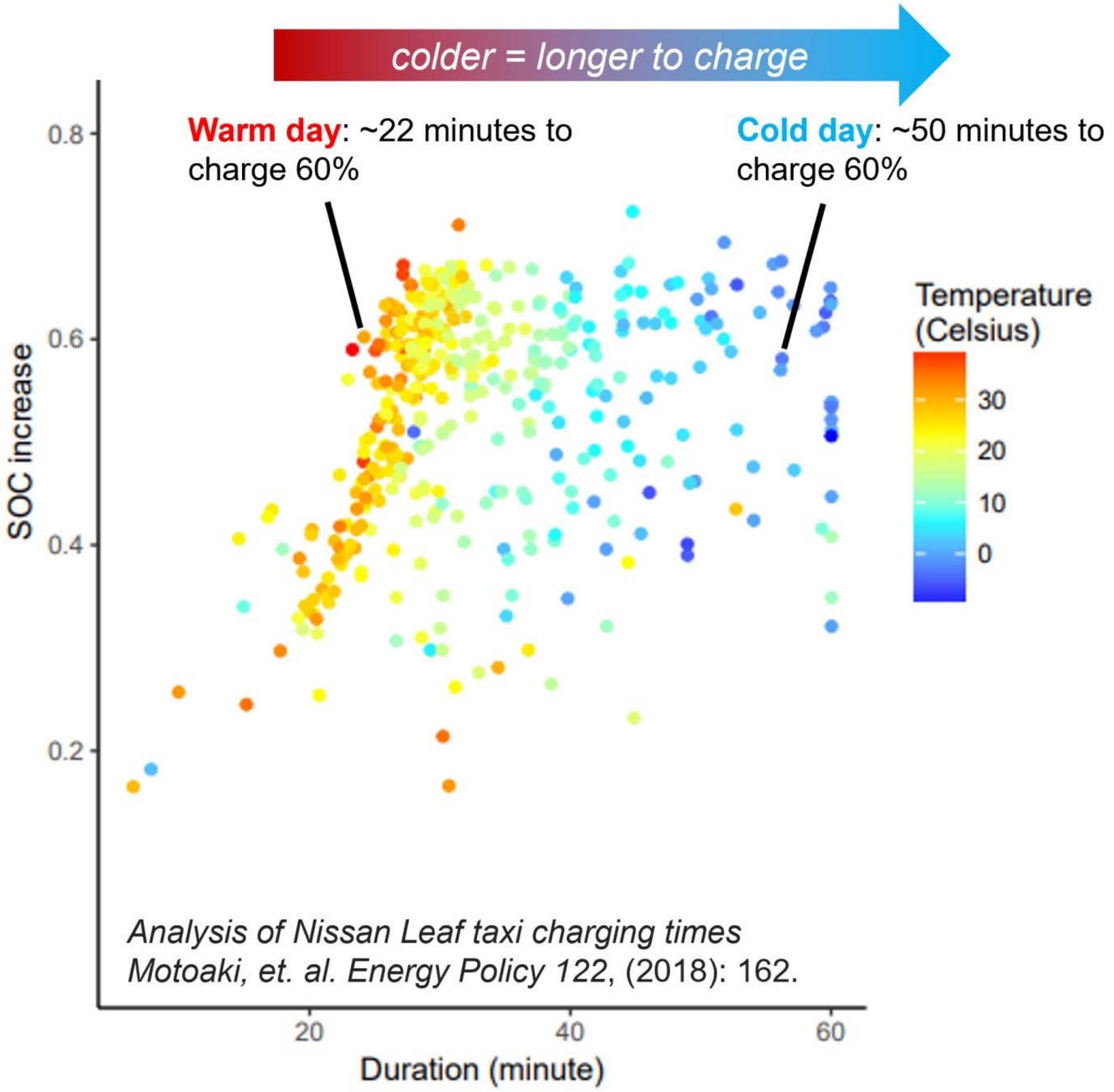
JONATHAN M. GITLIN - 4/20/2018, 11:13 AM



- 250kW Tesla Supercharger can power 5C charging of 50kWh and serve 5 EVs per hour
- 350-kW DC charger can power 7C charging of 50kWh and serve 7 EVs per hour

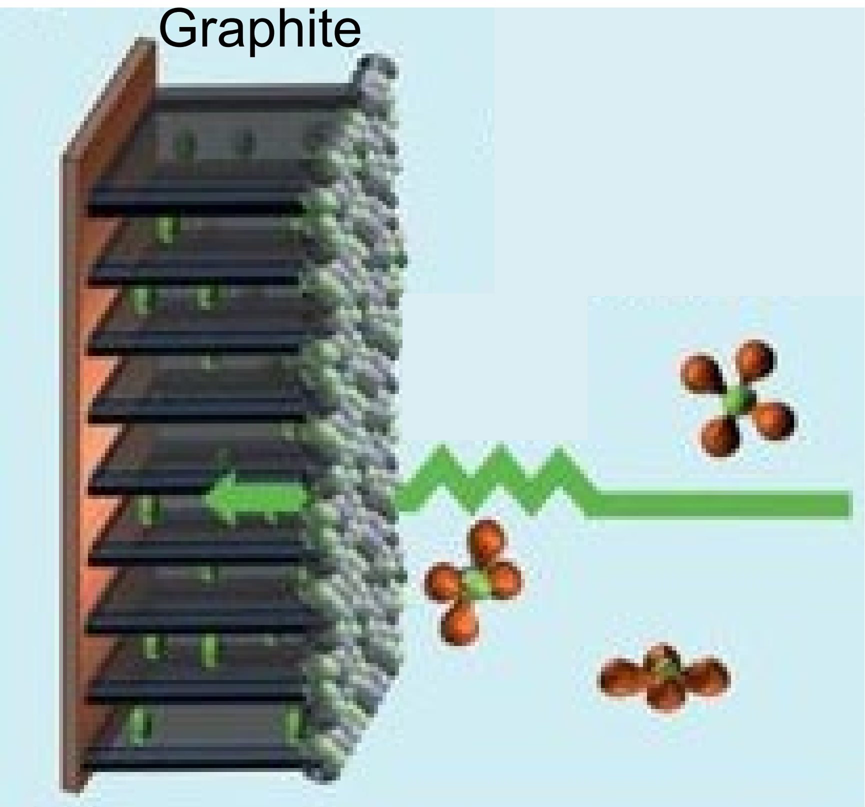
The Challenge: 10-min Charging at All Temperatures

How **much** energy was added during the charge (state-of-charge (SOC) increase)



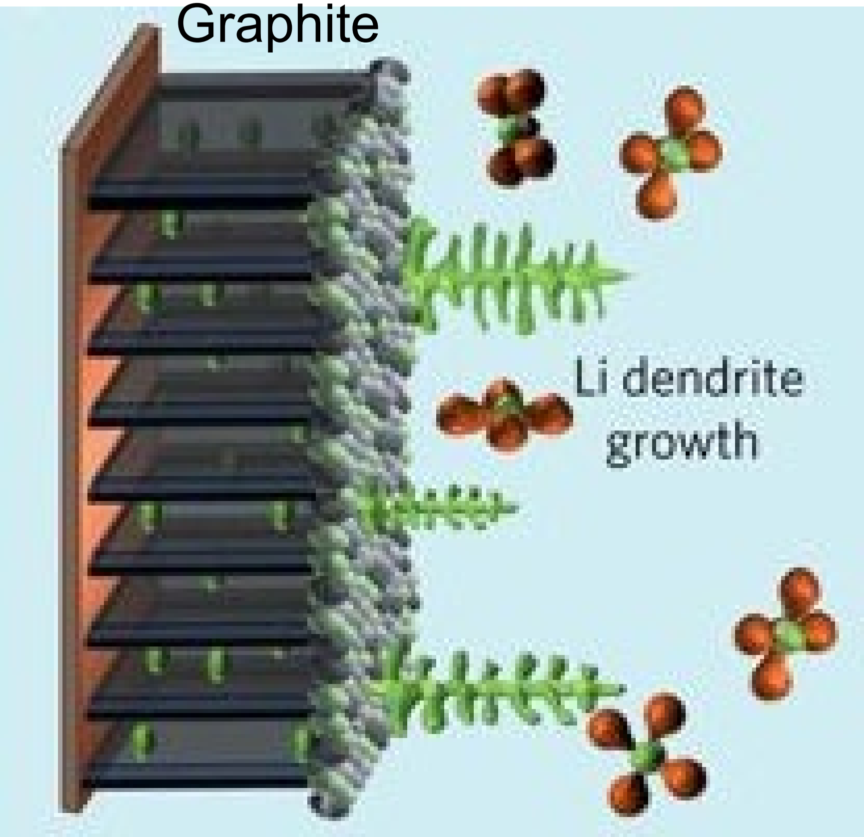
How **long** it took to add that much energy

Critical Science: Li Plating



Li intercalation into graphite:

$$C_6 + Li^+ + e^- \underset{\text{de-intercalation}}{\overset{\text{intercalation}}{\rightleftharpoons}} LiC_6$$



Li plating reaction:

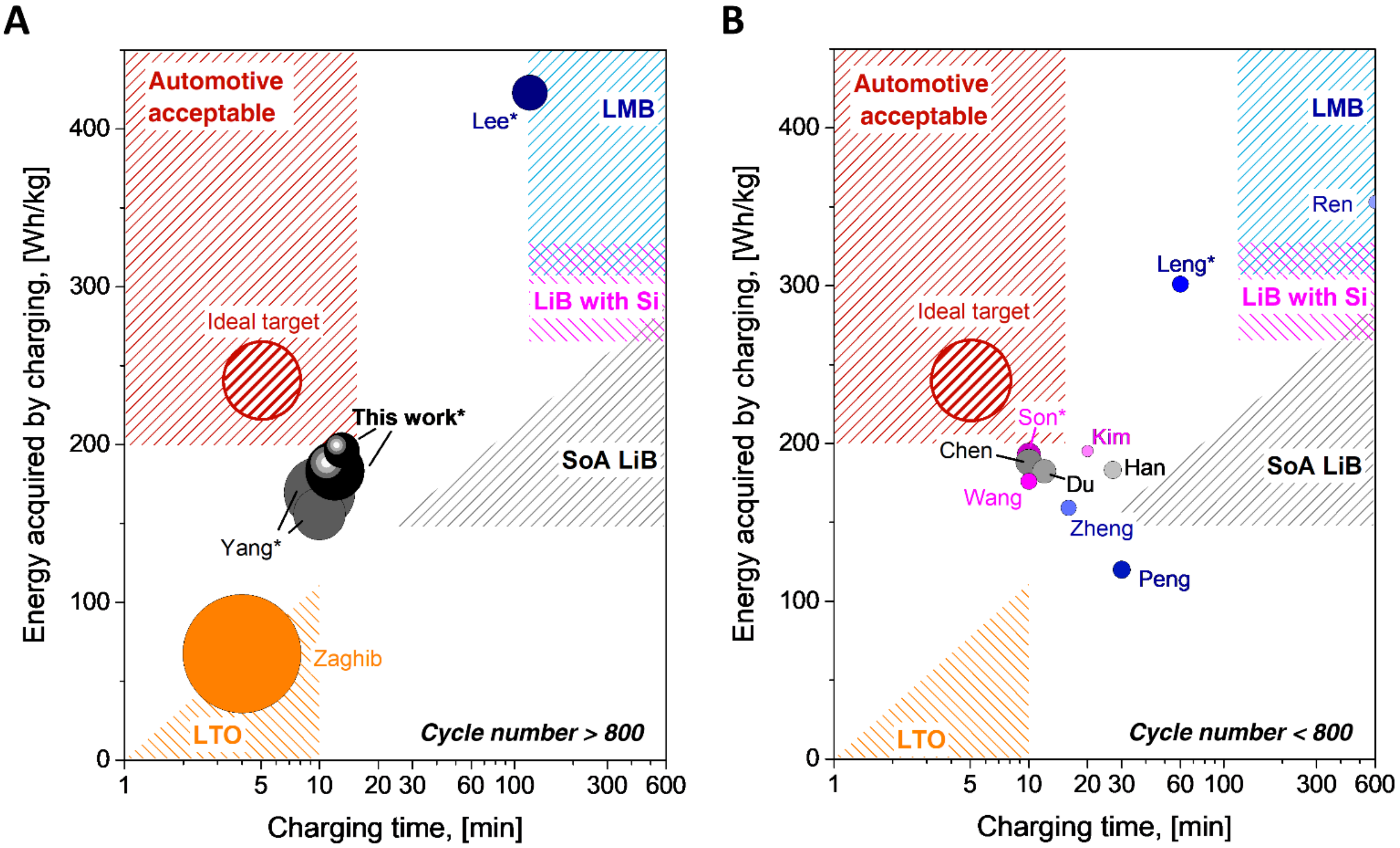
$$Li^+ + e^- \xrightarrow{plating} Li(s)$$

Li plating is prone to occur at:

- high charge rate
- low temperature
- High areal capacity (or high energy density)

Nature Energy 2, (2017): 17108.

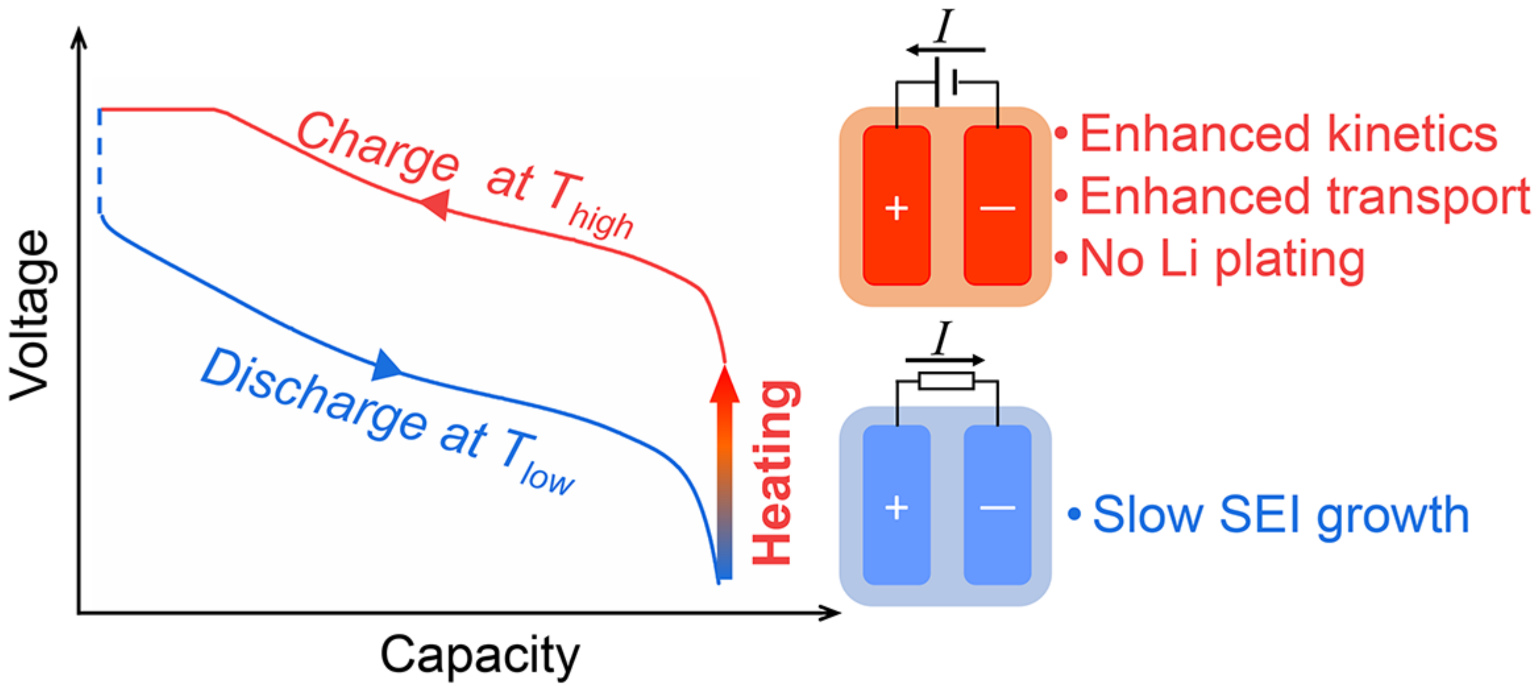
Figure of Merit for Fast Charging & Current State



Wang et al., *Nature* 611, 485-490 (2022)

ATM Approach

- **Asymmetric Temperature Modulation (ATM)** method: charge at a high temperature (~60^{o}C) to prevent Li plating, and discharge at ambient temperatures
- The cell stays at high temperature only during fast charge (~10-min per cycle) to avoid severe degradation due to high T.
- Rapid preheating prior to charging made possible by a self-heating structure; heating time is <1-min (heating speed >1^{o}C/sec)

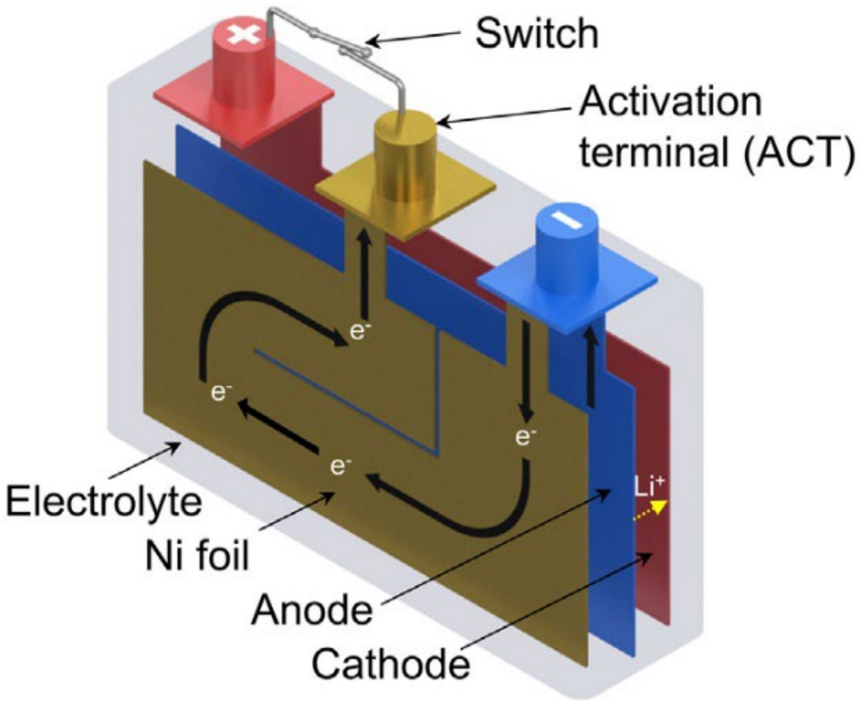


For more details, see:
Yang et al., *PNAS* 115, 7266-7271 (2018)
Yang et al., *Joule* 3, 1-18 (2019)

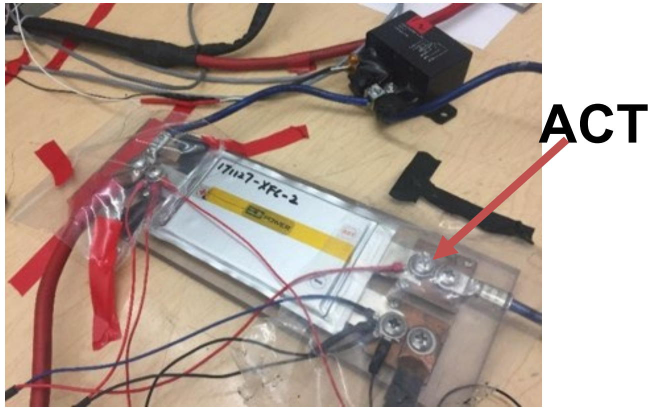
Rapid Intracell Heating is Key to ATM

Conventional external battery heating: 0.5-1°C/min, Preheating ~60 min

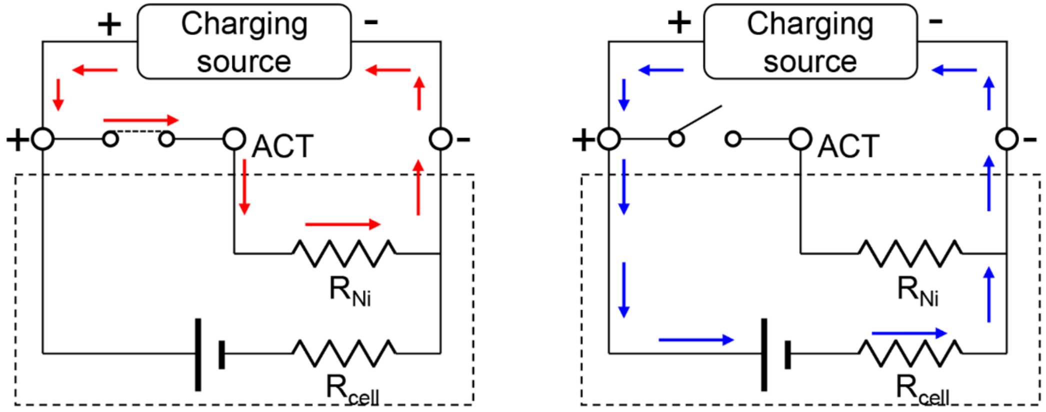
Self-Heating Structure: ~100°C/min, <30 sec preheat



Wang et al. (2016) Nature 529 (7587), 515.

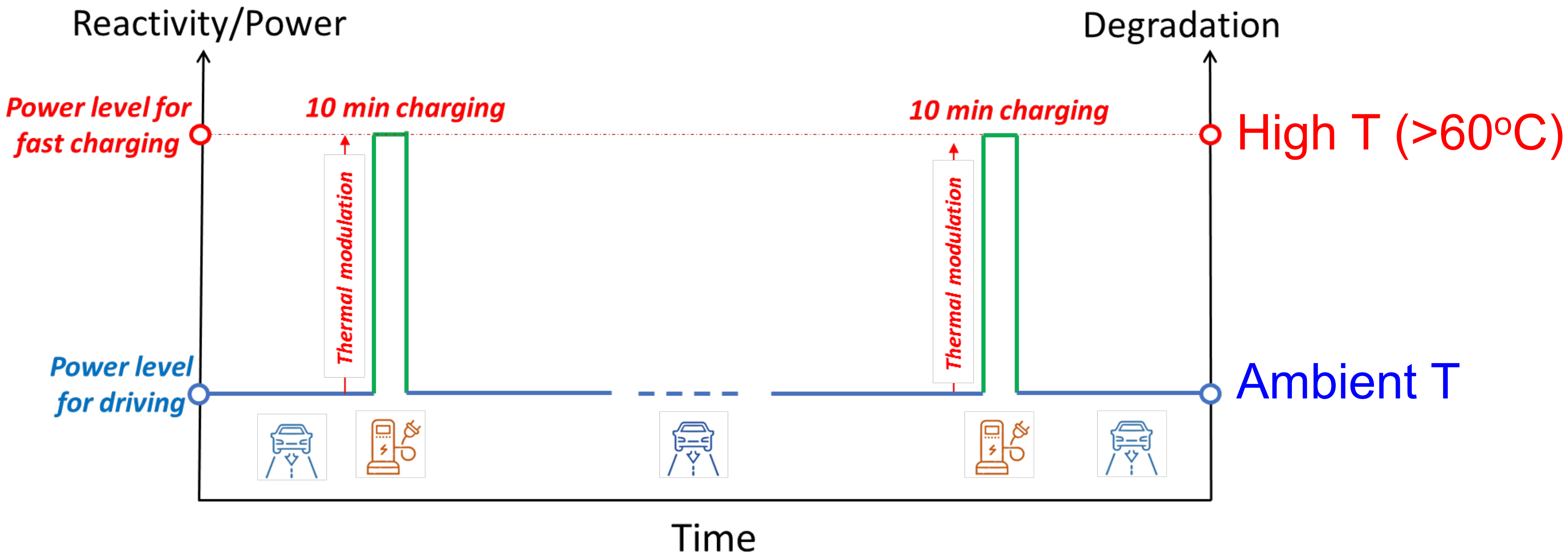


10.5-Ah Gen-1 XFC cell



Switch ON: heating   Switch OFF: charging

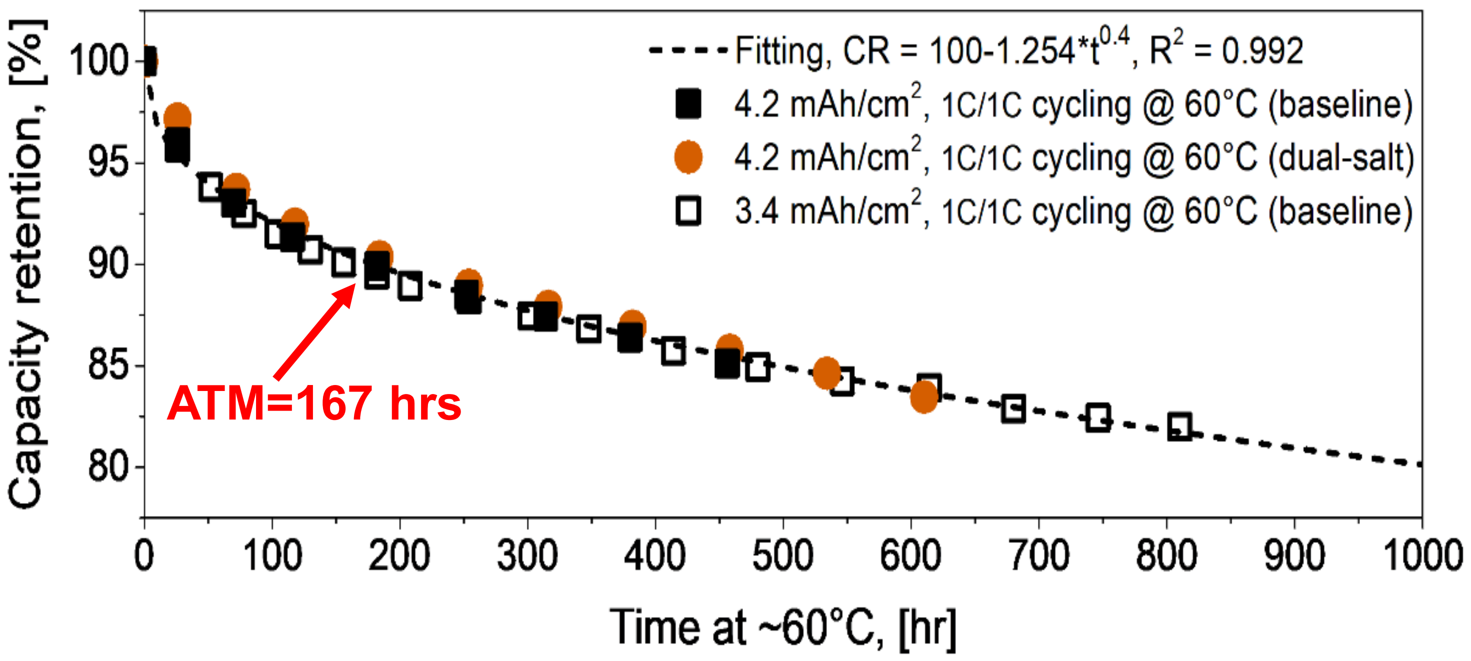
ATM Eliminate Li Plating while Limit SEI Growth



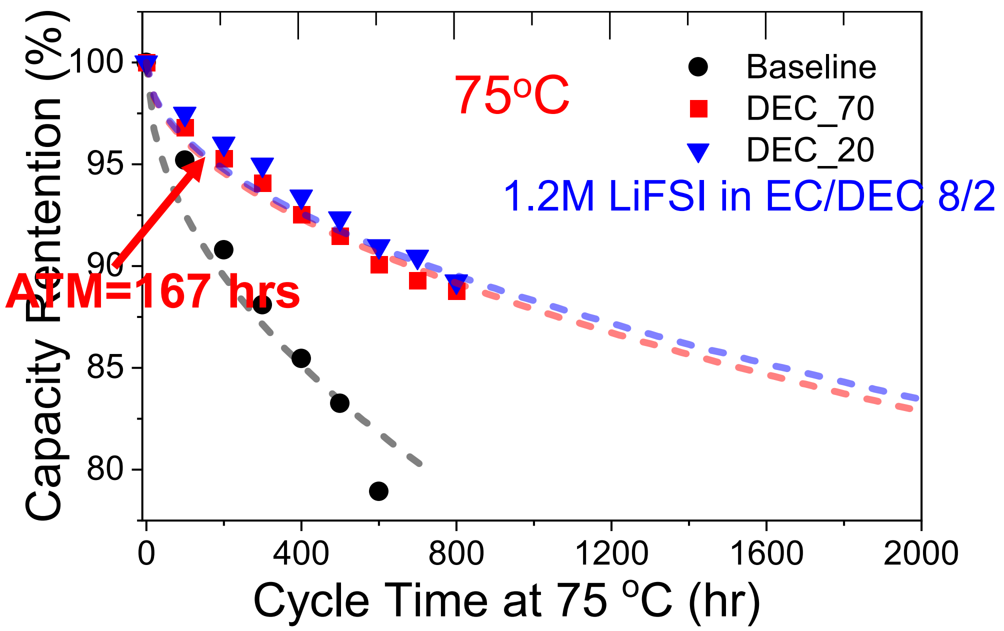
Capacity Retention = *fn*(SEI growth @ 60°C, Li plating, misc. others)

Limit SEI Growth at Elevated Temperatures

NMC811/Gr cells cycling in constant 60^{o}C oven

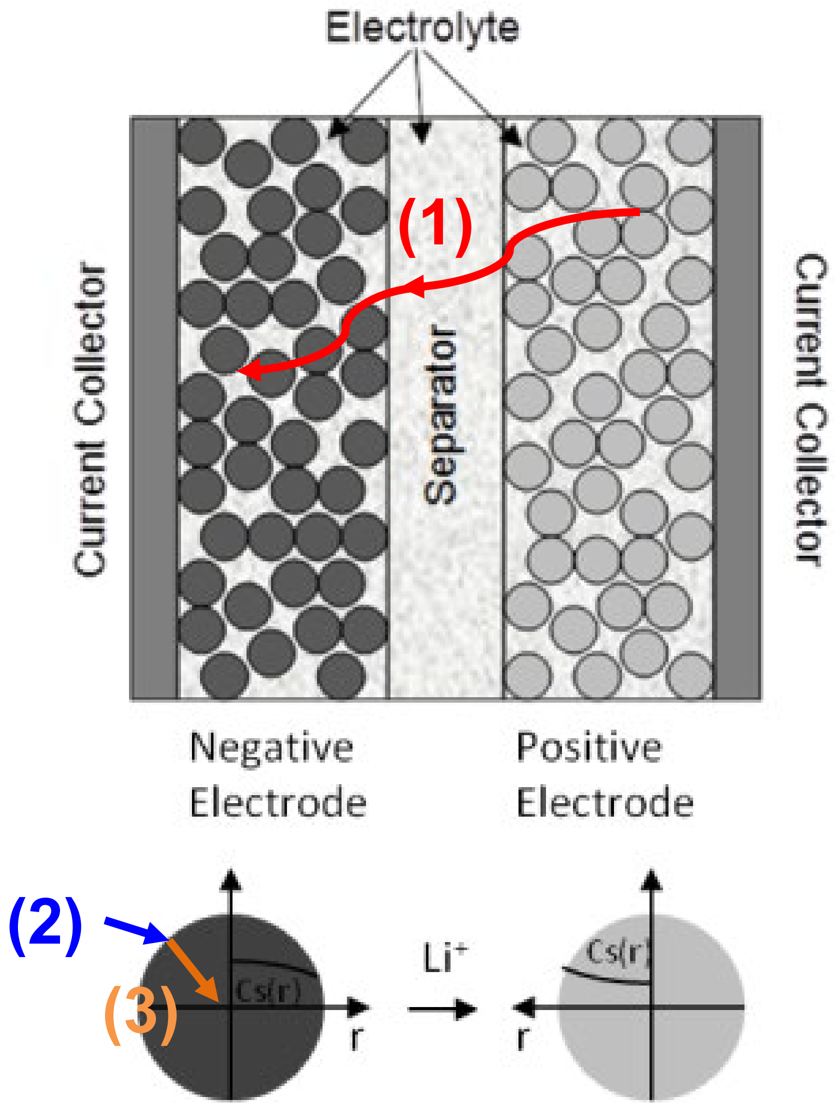


LFP/Gr cells cycling in constant 75^{o}C oven



- ATM-enabled UFC: 1000 fast-charges @ 60^{o}C means
  - 1000*10 min*1hr/60 min=166.7 hrs @60^{o}C
  - Time @ Elevated Temp is only 0.167% of battery lifetime (1000 cy ~ 200k miles ~ 12 yrs)

Tackling Li Plating Controlled by 3 Processes

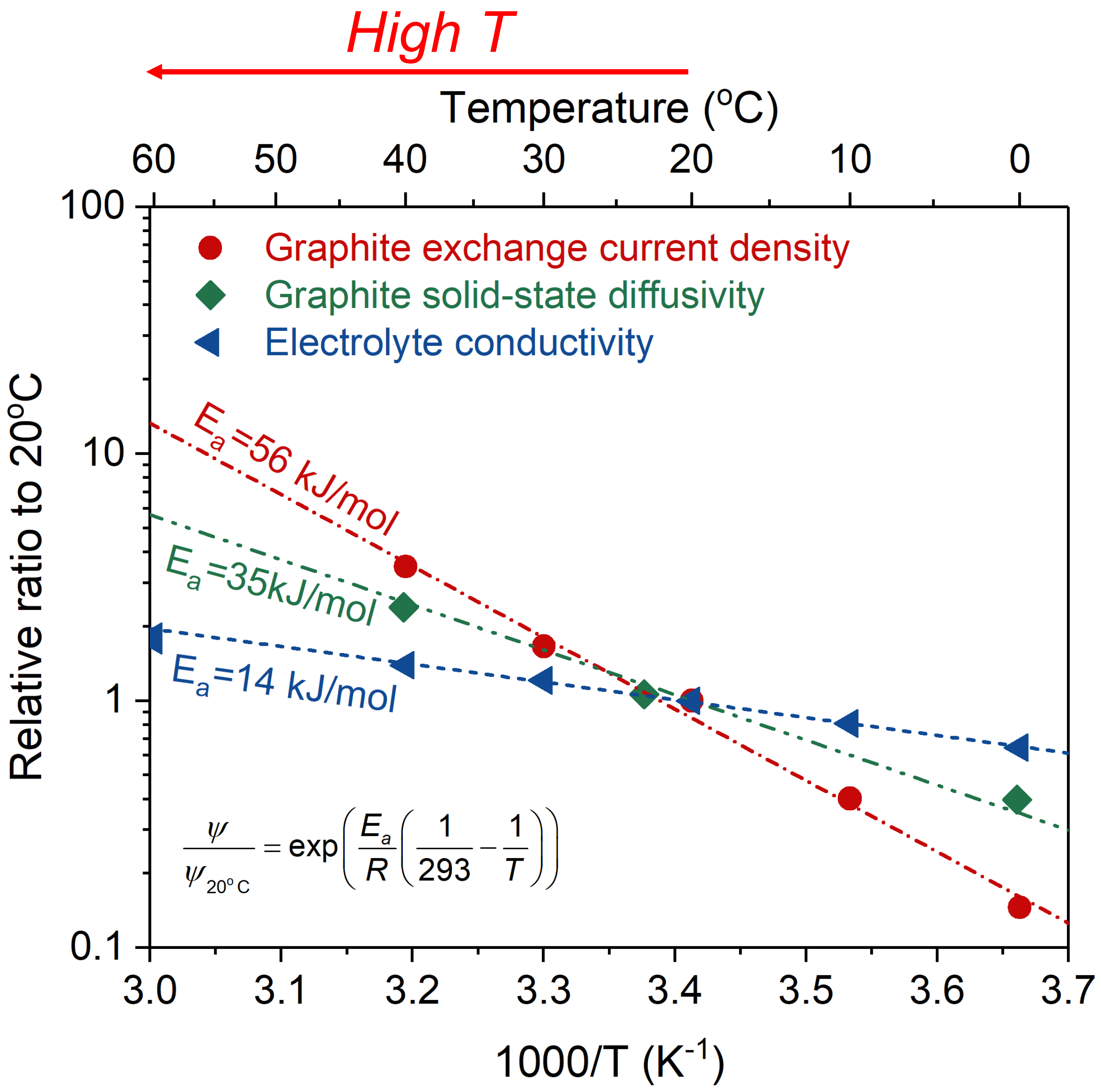


(1) Ion transport in the electrolyte

(2) Reaction at graphite interface

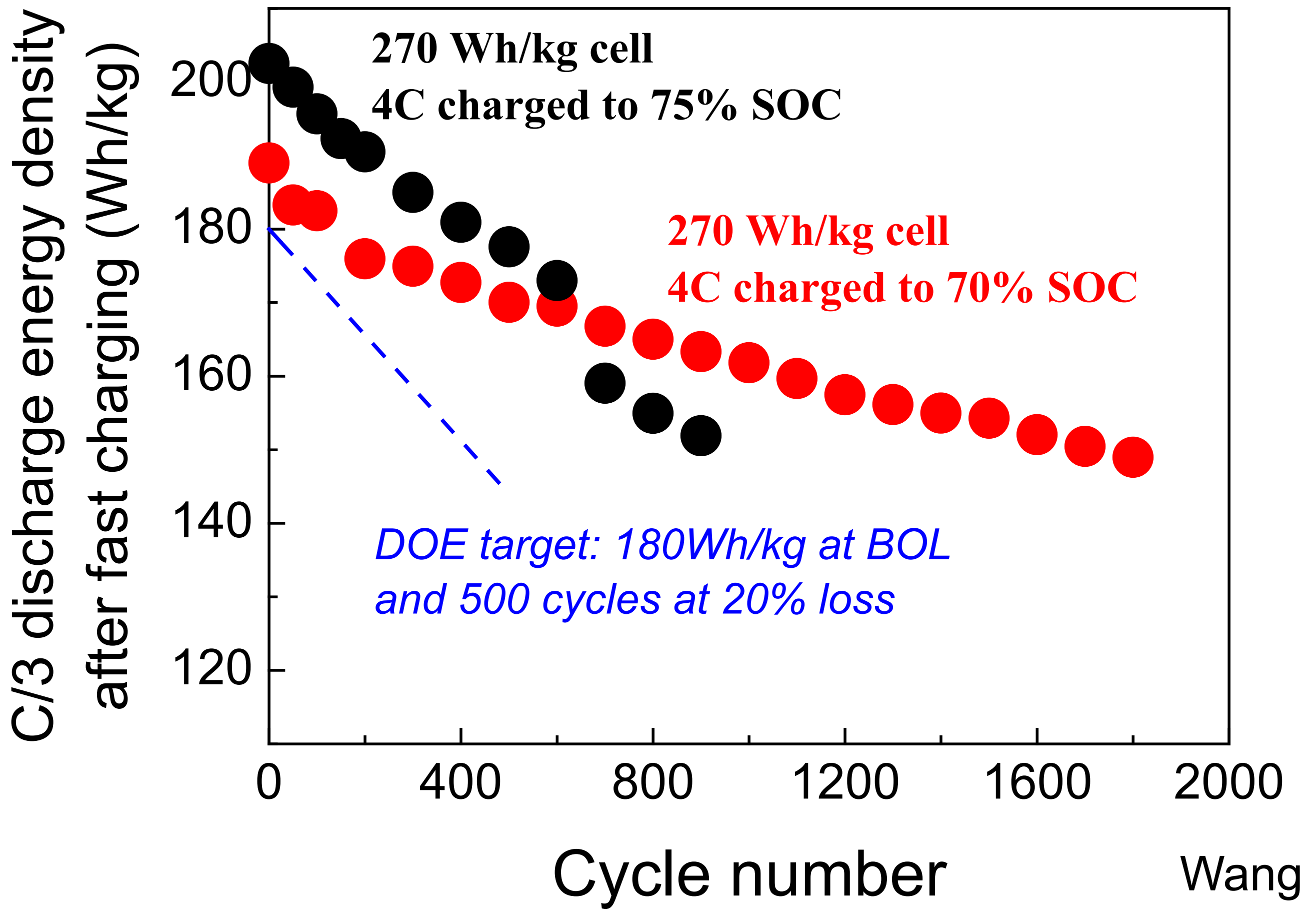
(3) Solid state diffusion within graphite

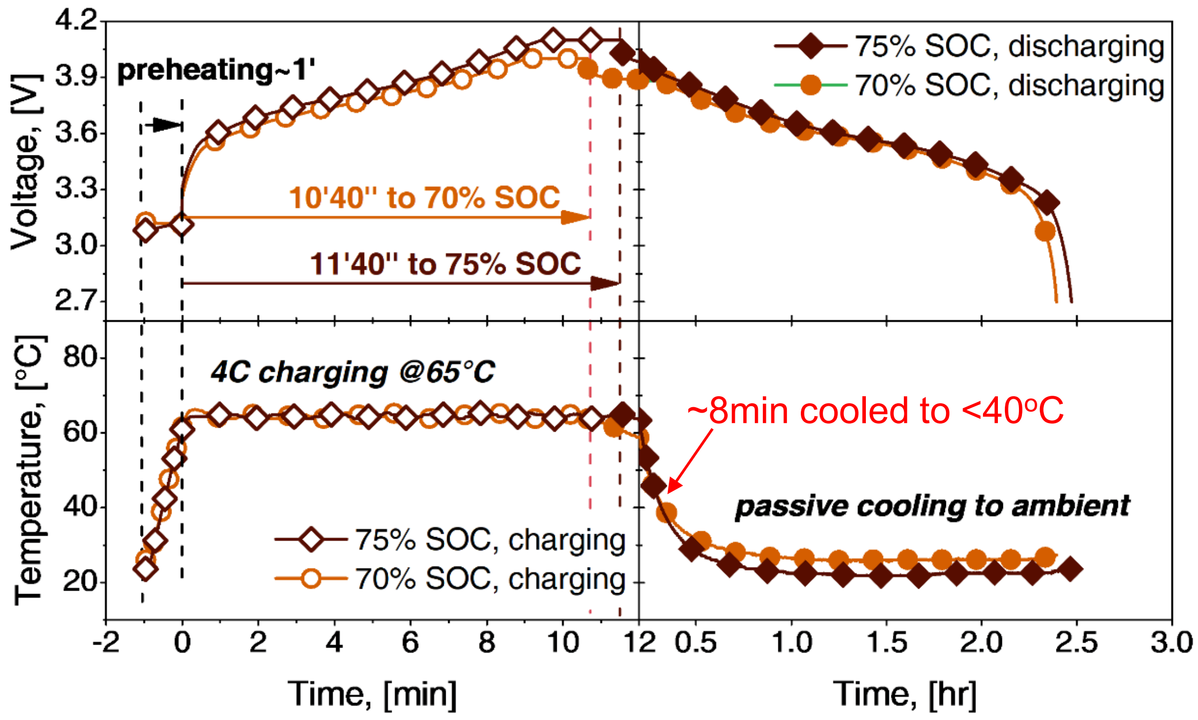
High-T Boosts all 3 Processes & Eliminates Li Plating



Temperature	20 -> 60°C	20 -> 90°C
Electrolyte conductivity	2x	3x
Li Diffusivity in Gr	6x	16x
Charge transfer kinetics on Gr	12x	84x

270 Wh/kg NMC811/Gr Cell Fast Charging





Wang et al., *Nature* 611, 485-490 (2022)

270 Wh/kg Cell Fast Charging: 10-min + 200 Wh/kg + 1000+ cycles + passive cooling

Takeaways

- **Less is more!** It is time to design a car with a small UFC battery that can be quickly and conveniently recharged.
- UFC cars can already achieve cost parity with gasoline cars; in particular, the LFP-powered UFC car is the only way to kill all 4 pains: charging, range, safety, and cost anxiety.
- ATM approach is chemistry and material agnostic: Li-ion, Li Metal, all solid state,…
- ATM method is scalable, with the maximum plating-free charge rate depending on tolerable temperatures (60-90^{o}C).
- ATM method is reconfigurable during usage, with BMS controlling charge temperature (RT for slow charging, MT for 4C charging, and ET for 6-10C charging).

Acknowledgements

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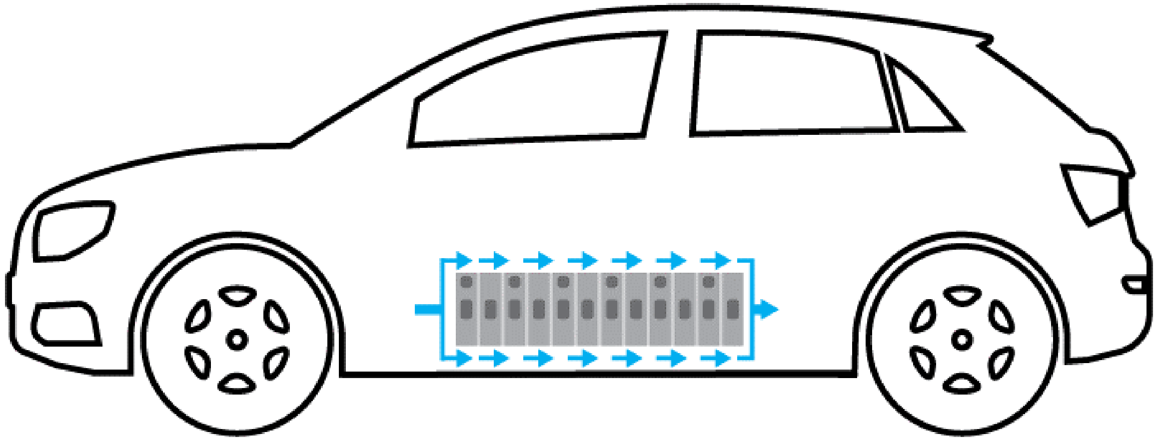
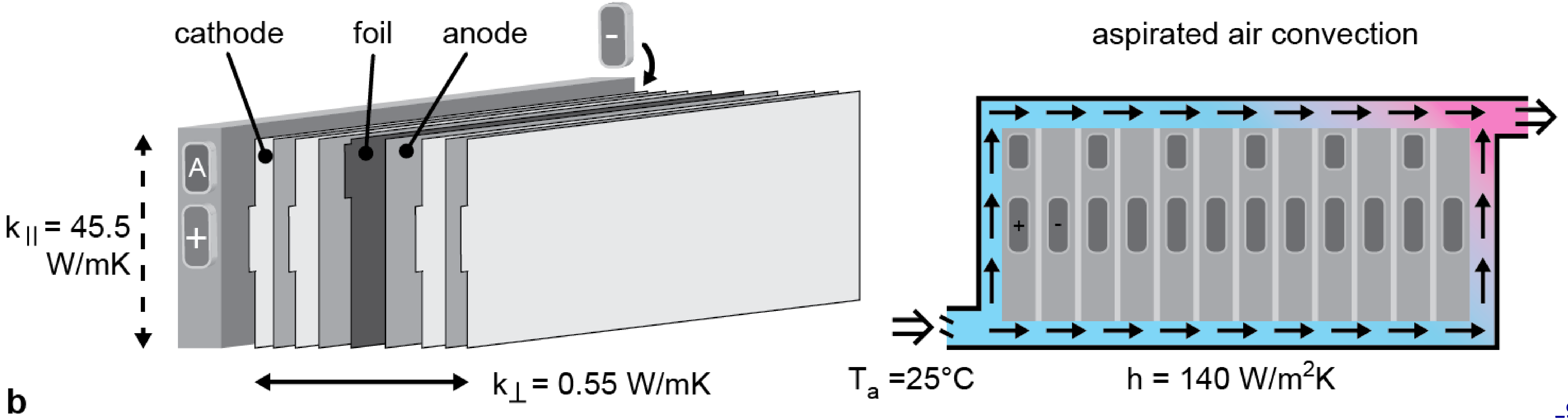
Air Cooling at Top and Bottom Surfaces

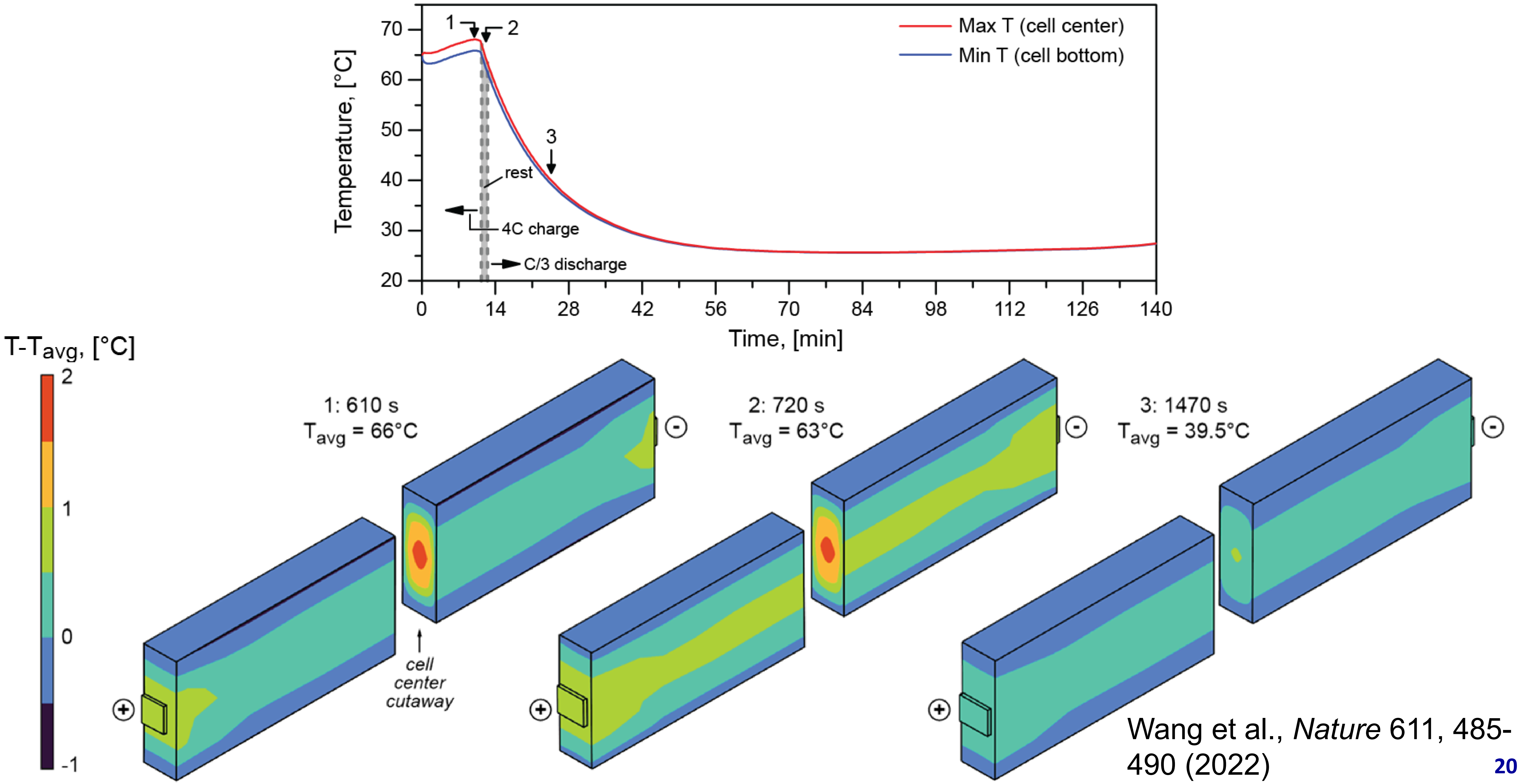
A digital twin of 12s1p module *with only air cooling*



- 150 Ah prismatic cell format
- Cooling just top & bottom cell surfaces



Air Cooling during Fast Charging & Subsequent Discharge



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