

Next Generation Battery Technology

The eVTOL Show
Palo Alto, October 24, 2023



The advent of electric aviation

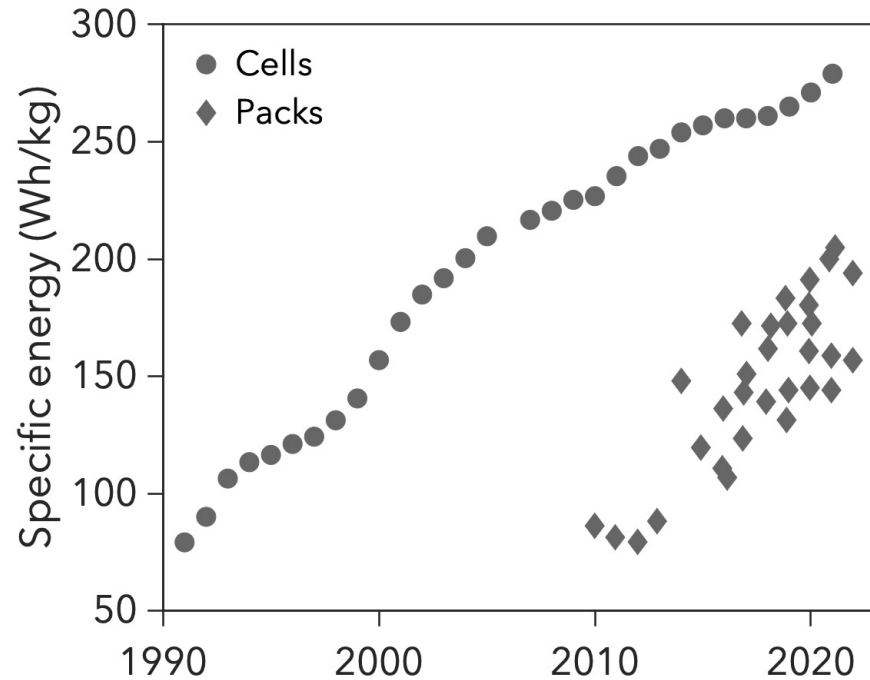


Source: Lilium, Eviation, Electra.Aero

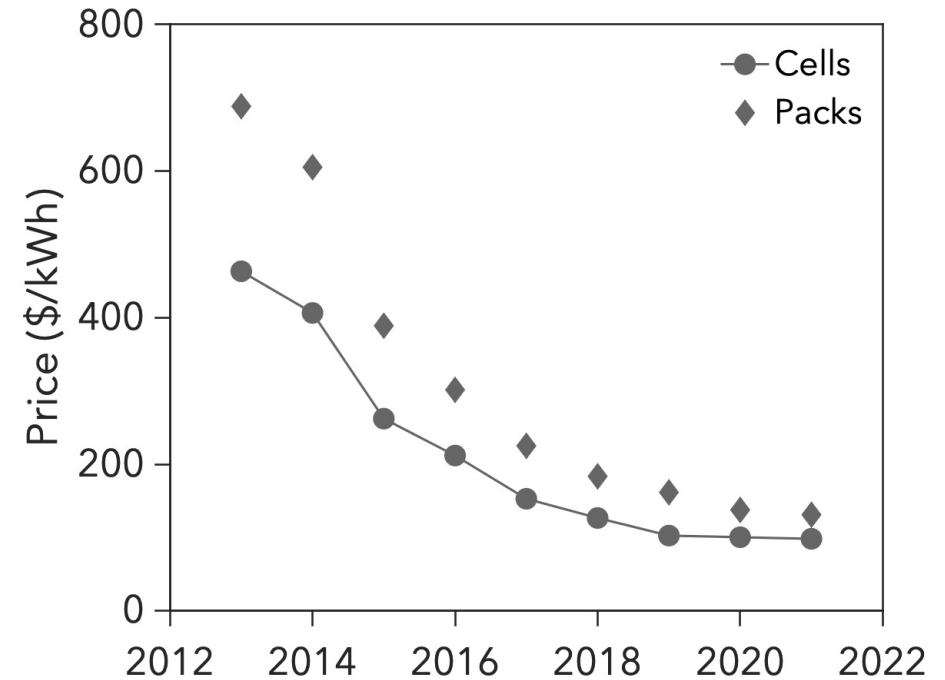
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AND BATTERY AERO

The state of battery technology



Cells: ~6 Wh/kg per year to ~300 Wh/kg
Packs: ~12 Wh/kg per year to 200 Wh/kg



~80% decline over the last decade
Cells: US\$100-120/kWh
Packs: US\$140-160/kWh

Sources: T. Placke, R. Kloeppel, S. Dühnen, and M. Winter, J. Solid State Electr., vol. 21, no. 7, pp. 1939-1964, 2017. US Department of Energy, "FOTW 1206, Oct 4, 2021". Bloomberg New Energy Finance, "2022 lithium-ion battery price survey," 2022.



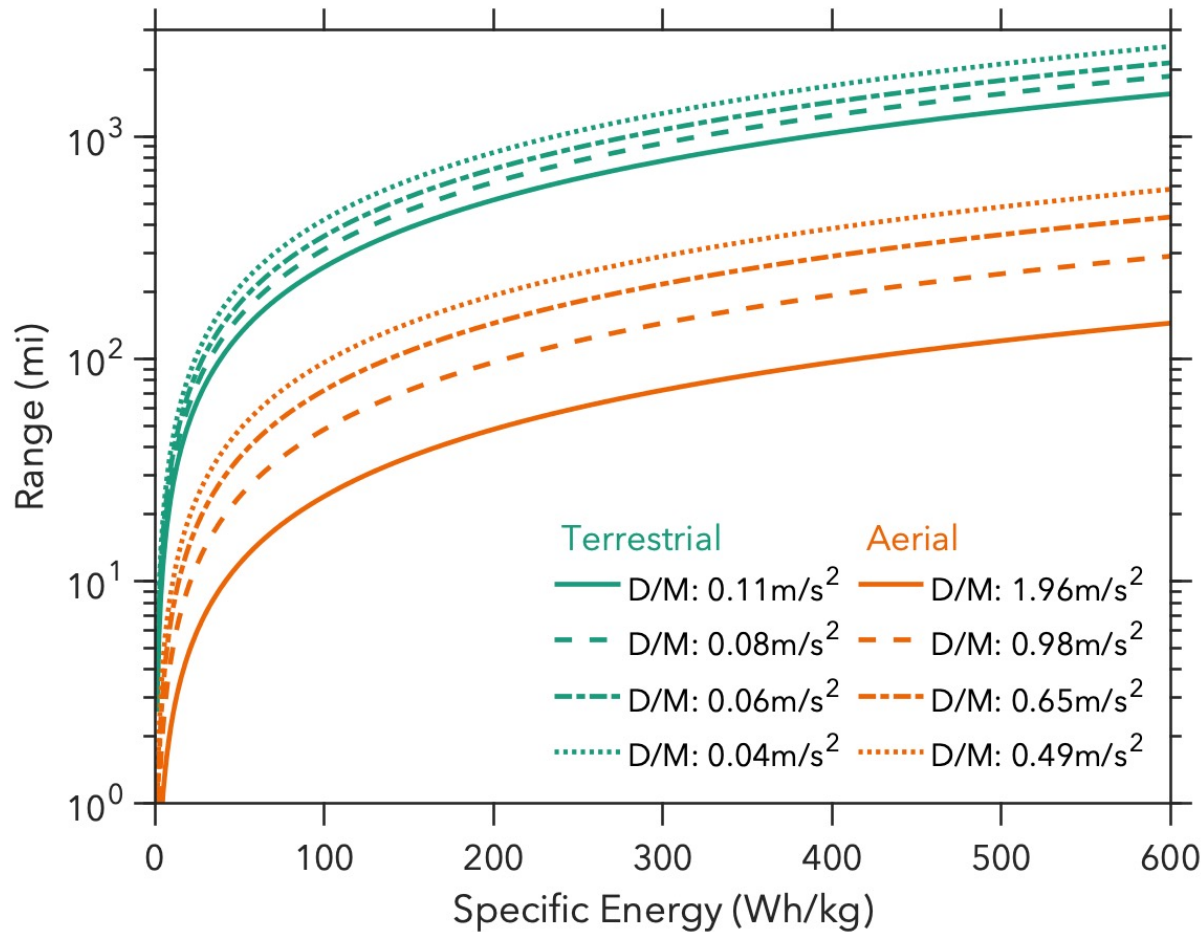
EV batteries for aircraft?

Sources: Tesla

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Battery electric range (terrestrial & aerial)

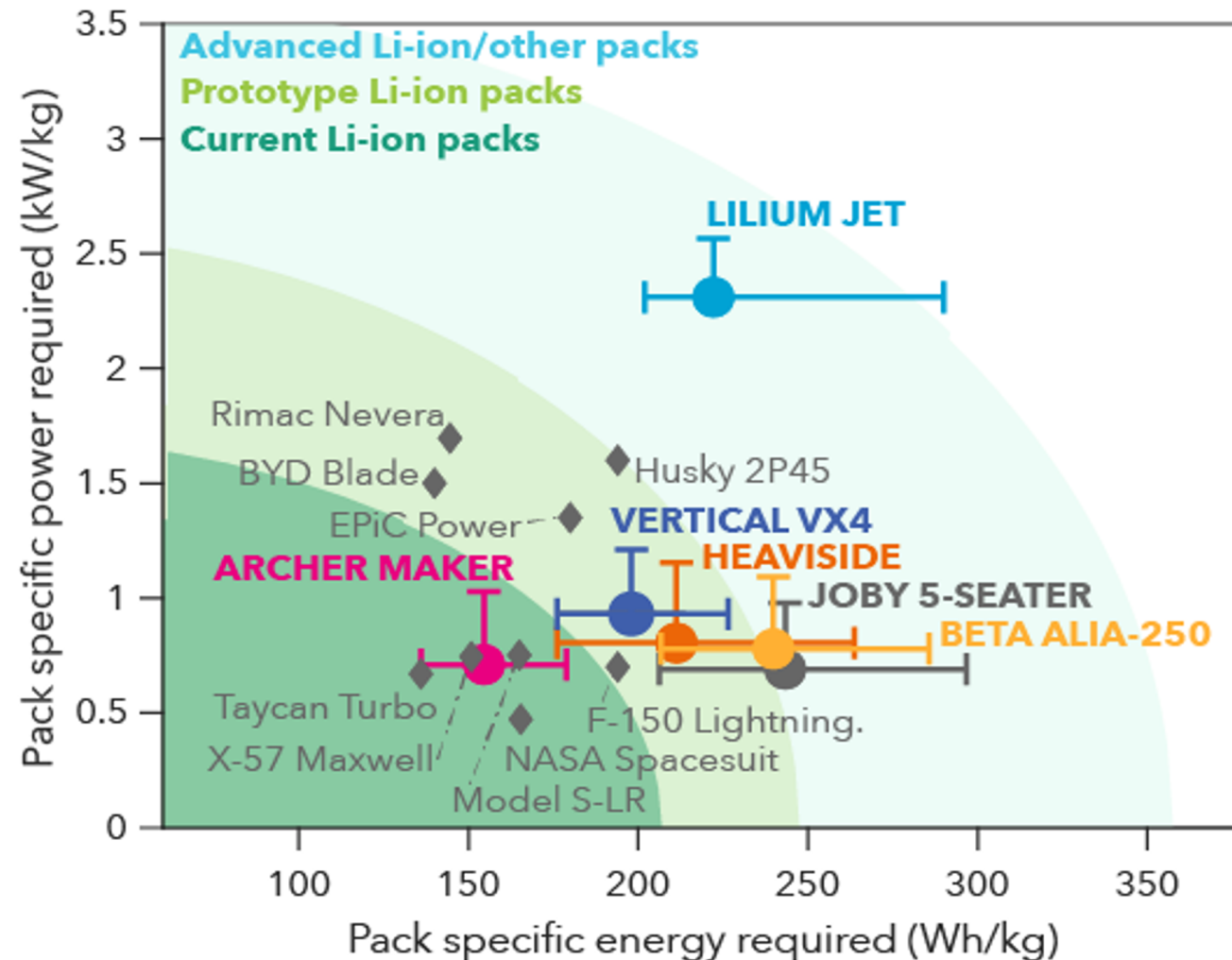


- Terrestrial vehicle range depends on the D/M ratio which increases with v^2
- D/L has a minimum at a certain speed
- Aircraft are limited to 100-250 mi with 200-300 Wh/kg. (battery fraction = 0.3) 600Wh/kg enables up to 500 miles of range

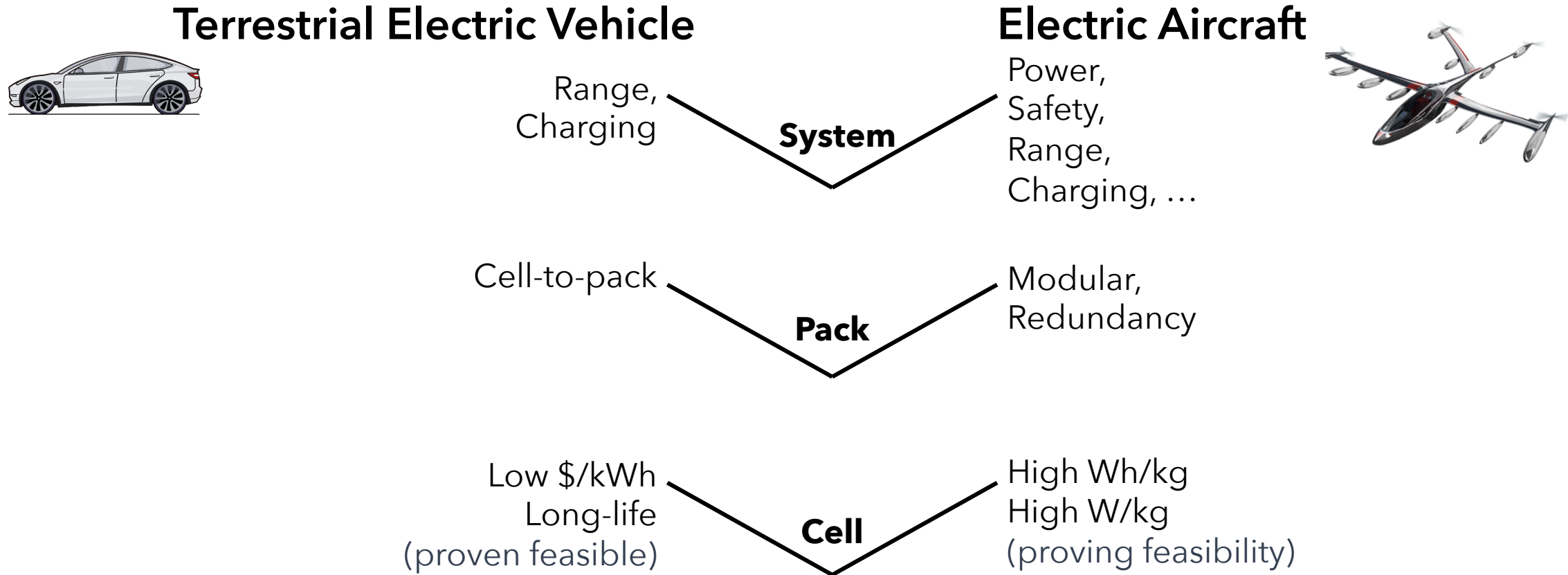
Sources: 600 Wh/kg: V. Viswanathan, A.H. Epstein, Y-M. Chiang, E. Takeuchi, M. Bradley, ..., Nature, (2022) 601 (7894), 519-525.

The aircraft are examined at (L/D) ratios of 5, 10, 15, and 20, corresponding to a (D/M) ratio of 1.96, 0.98, 0.65, and 0.49 m/s² respectively

Electric aviation requires high specific energy and high specific power



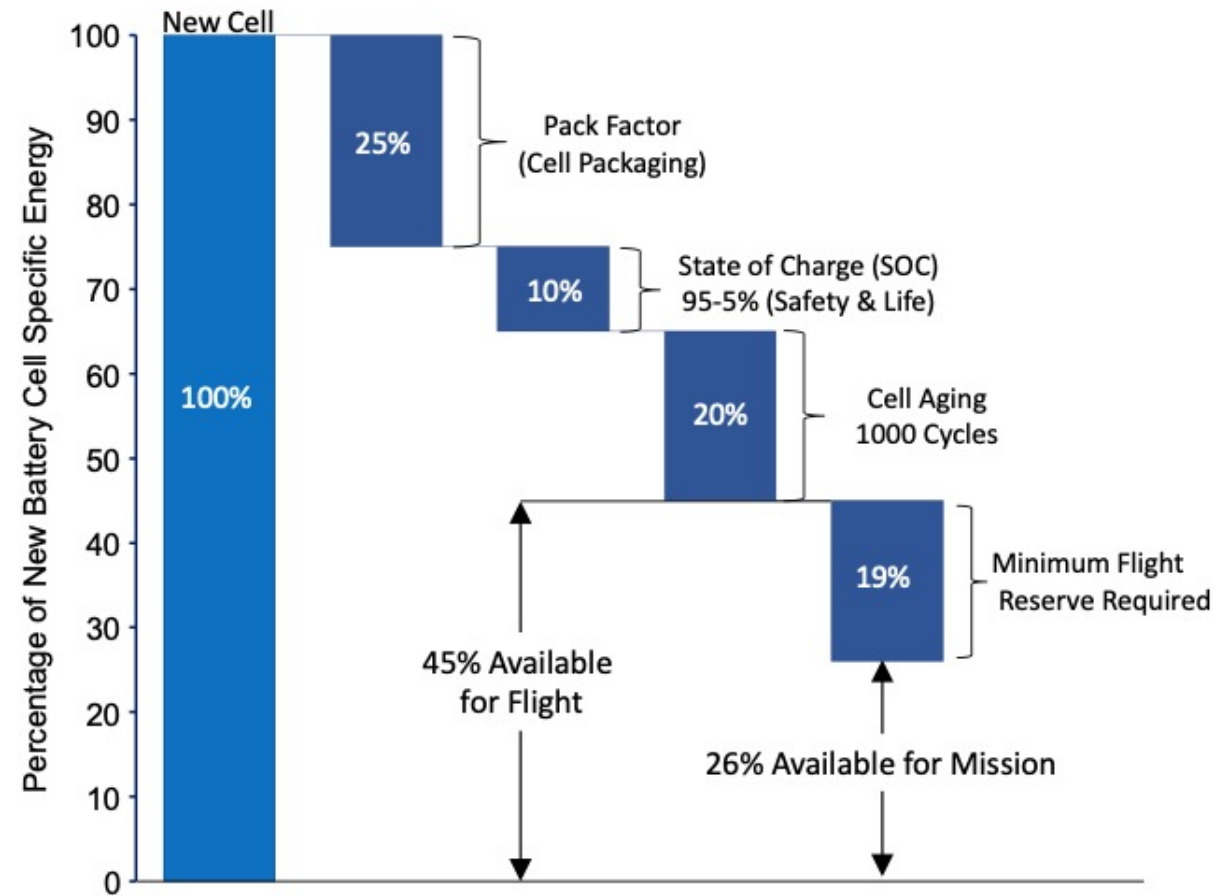
EV and electric aviation requirements are diverging





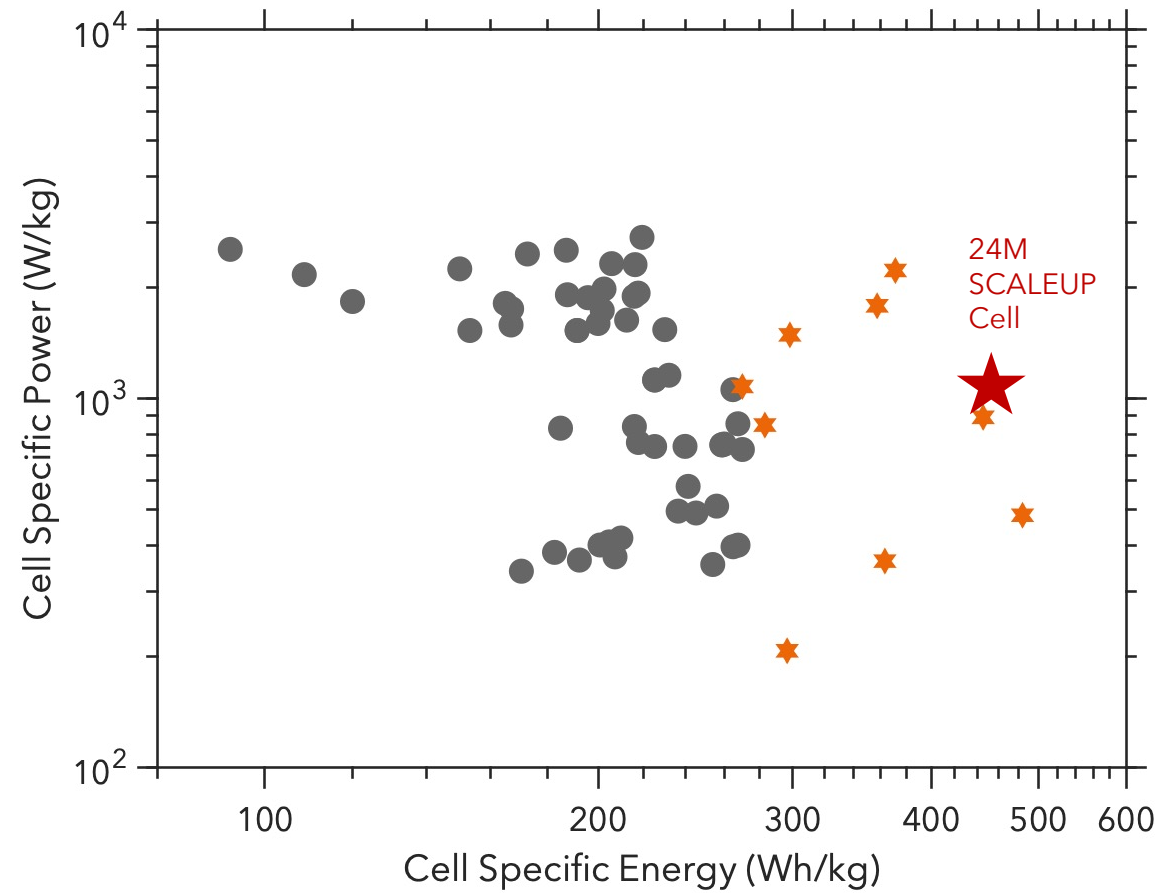
Development of new batteries for aviation

Specific energy improvements have an outside impact on aircraft range

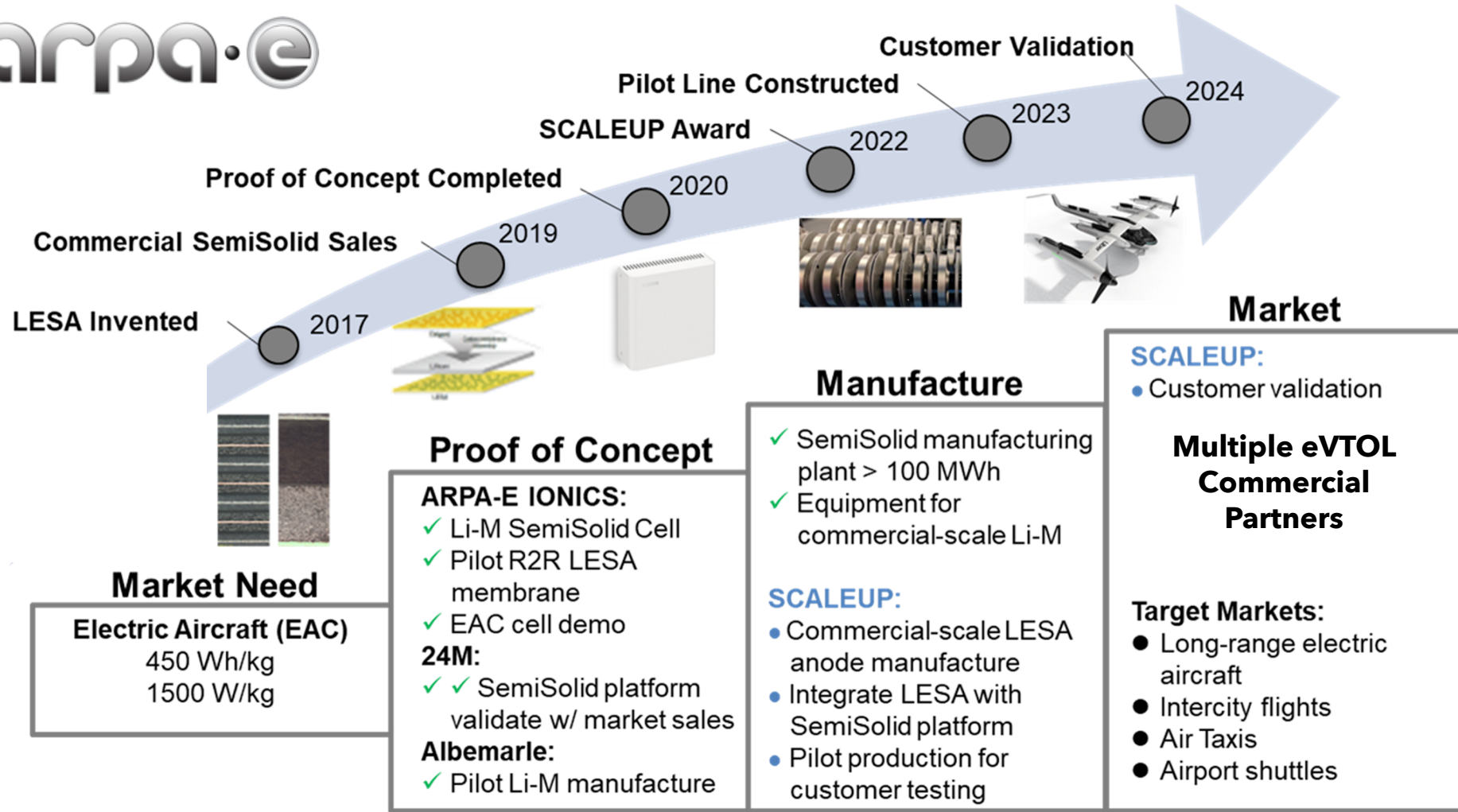


Sources: V. Viswanathan, A.H. Epstein, Y-M. Chiang, E. Takeuchi, M. Bradley, ..., Nature, (2022) 601 (7894), 519-525

Developing a new generation of batteries for aviation



ARPA-E SCALEUP program roadmap

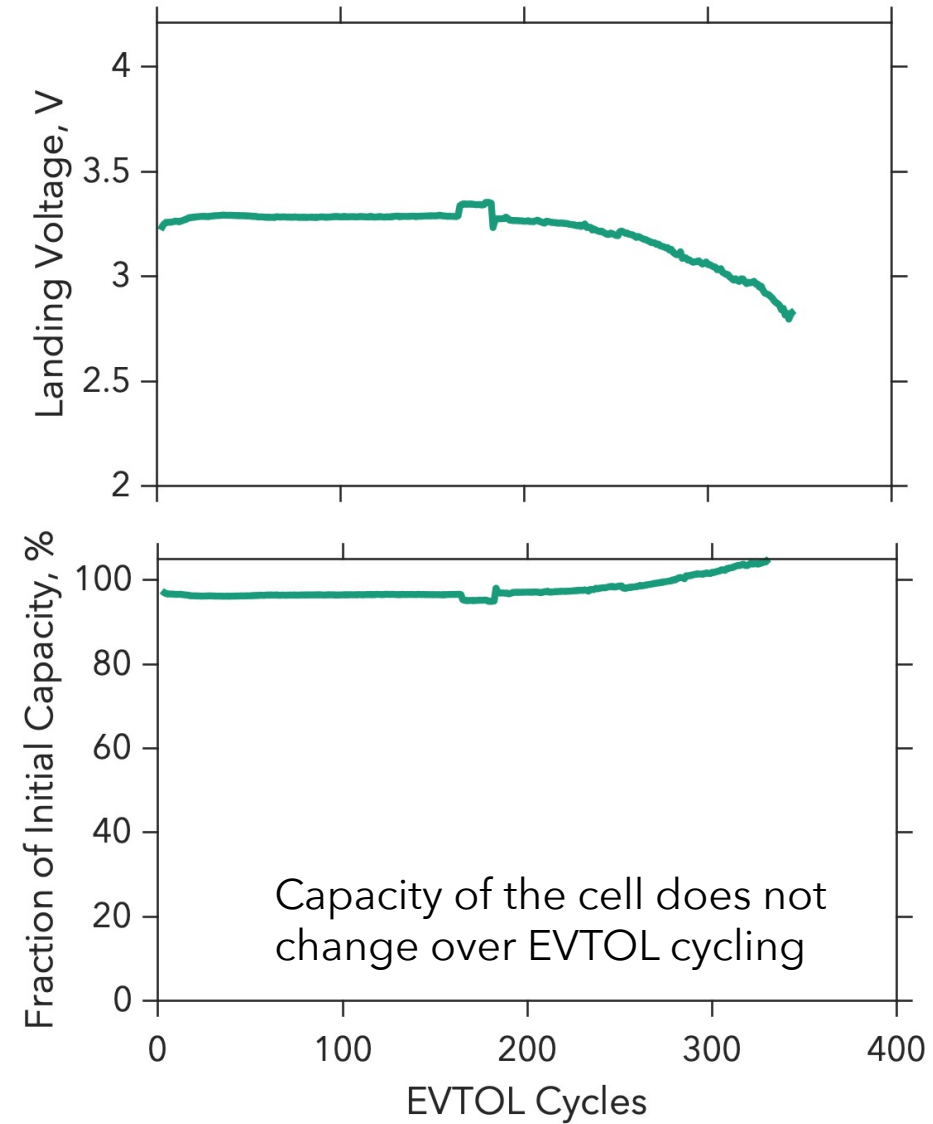
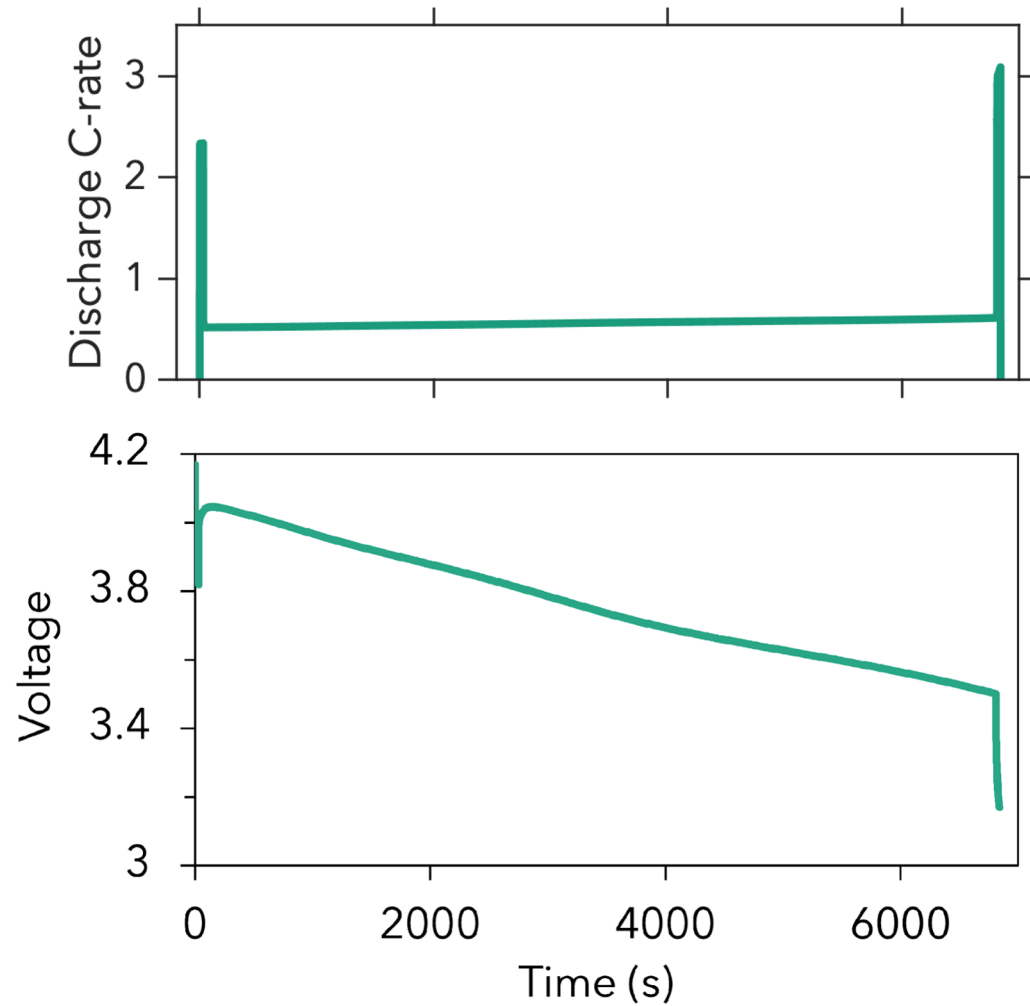




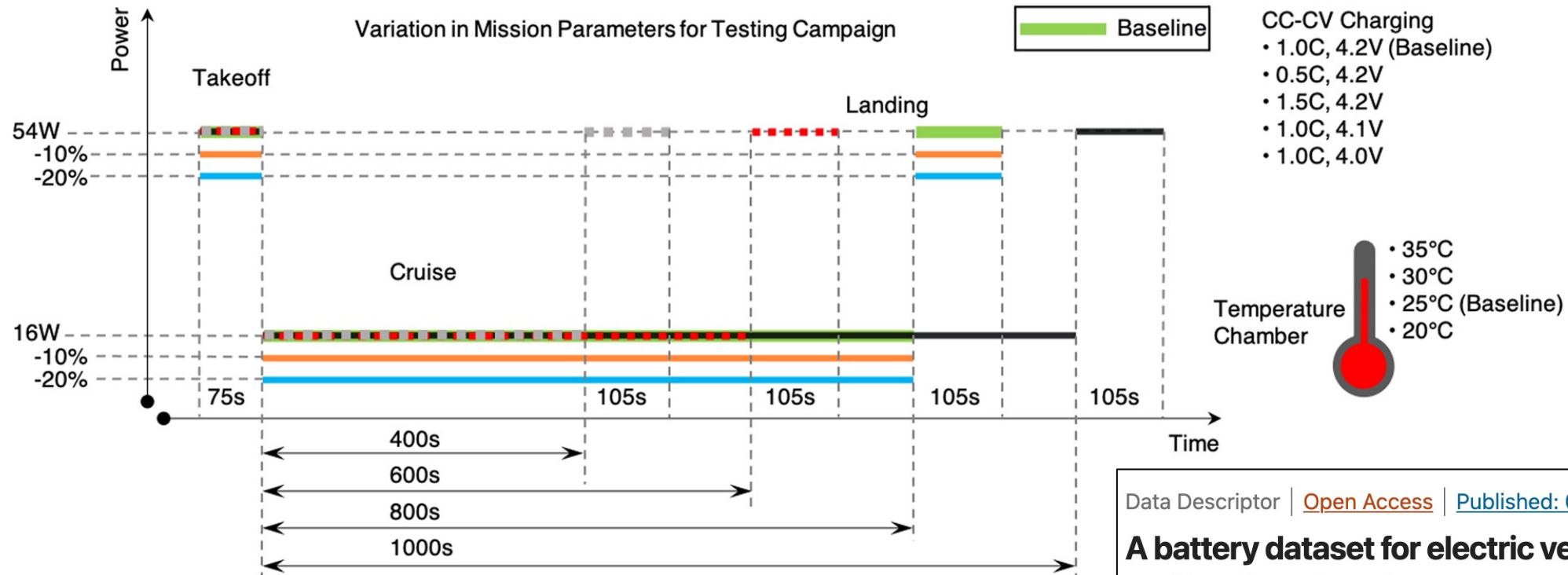
How to validate new battery technology for aviation?



eVTOL Cycling Data



The largest eVTOL battery cycling dataset



Data Descriptor | [Open Access](#) | [Published: 02 June 2023](#)

A battery dataset for electric vertical takeoff and landing aircraft

[Alexander Bills](#), [Shashank Sripad](#), ... [Venkatasubramanian](#)

[Viswanathan](#)  [+ Show authors](#)

[Scientific Data](#) **10**, Article number: 344 (2023) | [Cite this article](#)





Technology Divergence

Aviation batteries build on EV developments but weight matters much more.

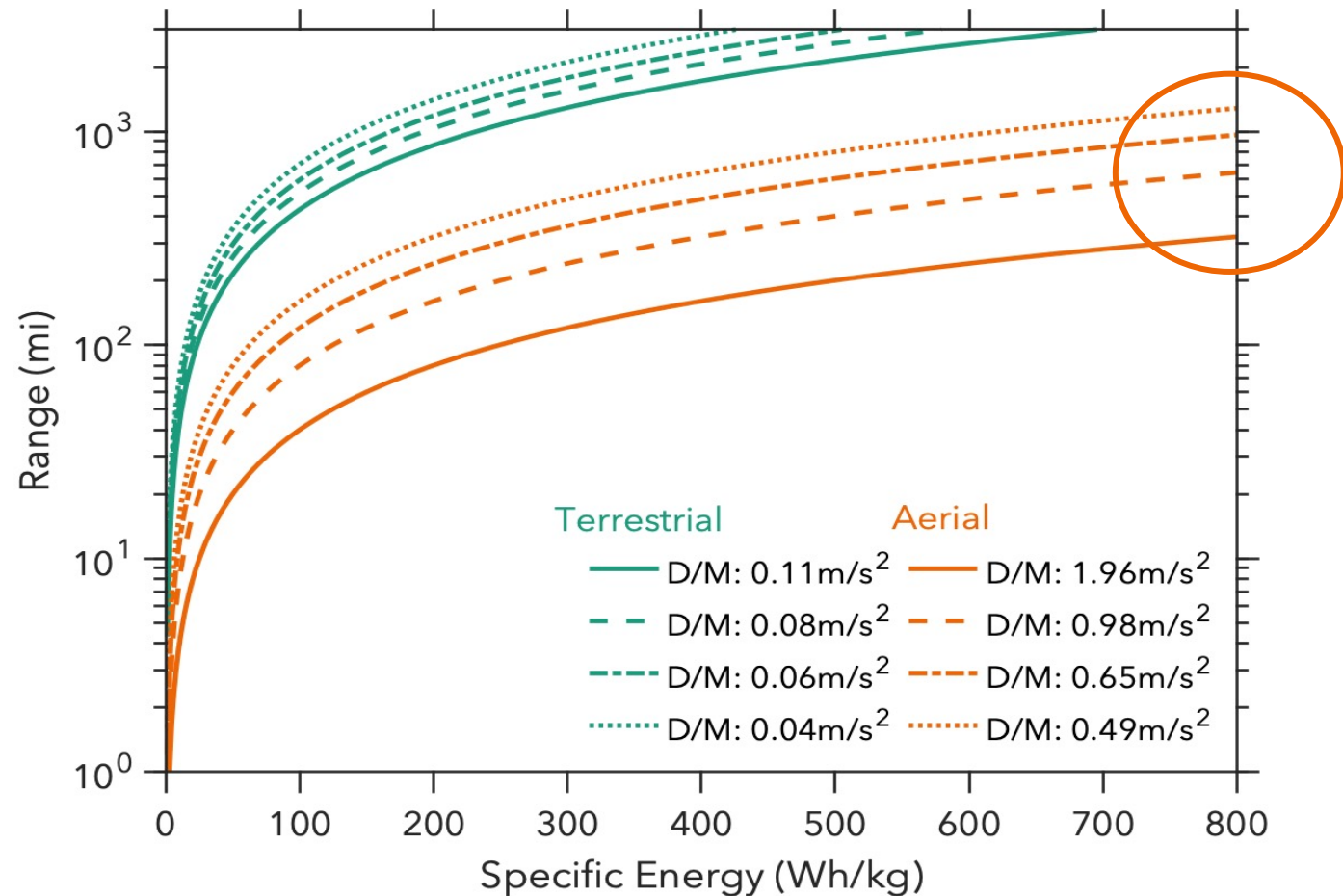
Next Gen Batteries

Today's batteries achieve 100-250 miles. Over the next decade, we will reach 500 miles with current aircraft designs.

Testing & Validation

Batteries need to be validated for aviation specific conditions including performance and safety.

What's on the roadmap?



Sources: V. Viswanathan, A.H. Epstein, Y-M. Chiang, E. Takeuchi, M. Bradley, ..., Nature, (2022) 601 (7894), 519-525.

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Approaches to >1000 Wh/kg systems



Chemistry	Voltage (V)	Electrons transferred	Theoretical capacity (mAhg ⁻¹)	Theoretical specific energy (Whkg ⁻¹)
Li metal				
CF _x	4	1	900	3,600
SF ₆	3.69	8	1,063	3,922
BF ₃		3	1,186	
SO ₂	3	1	419	1,257
SOCl ₂	3.6	2	450	1,620
SO ₂ Cl ₂	3.9	2	397	1,548.3
FeF ₂	2.63		571.2	1,306.8
FeF ₃	2.73	3	712.5	1,644
S	2.2	2	1,675	2,567
O ₂	2.96	2	3,350	3,505
I ₂	3.6	2	211	760
Br ₂	3.9	2	335	1,306
Cl ₂		2		6,294
Se	2.1	2	679	1,226
Non-Li				
Mg/O ₂	2.95	2	3,350	3,924
Zn/O ₂	1.64	4	662	1,086

PROPEL-1K

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Pioneering Railroad, Oceanic and Plane Electrification with 1K Energy Storage Systems

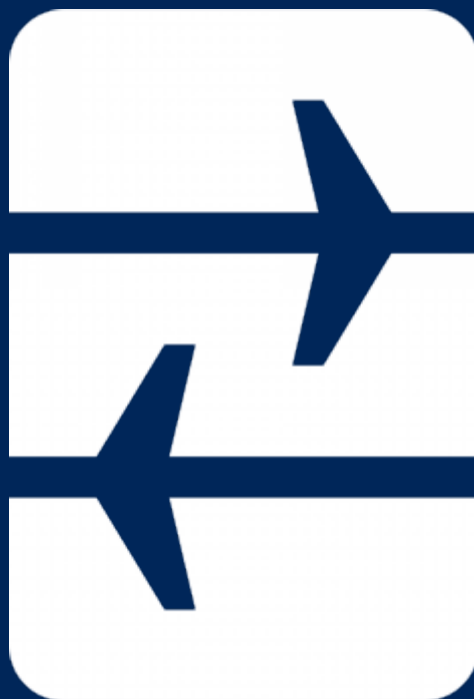
• Transportation • Transportation Storage

PRINT

* Status: Active

Release Date: 09/01/2023

Project Count: 0



Thank You