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What can we learn from Battery Benchmarking?

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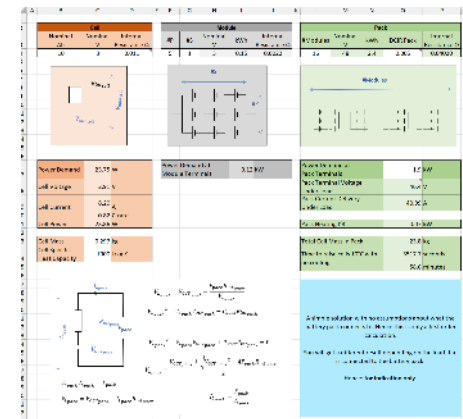
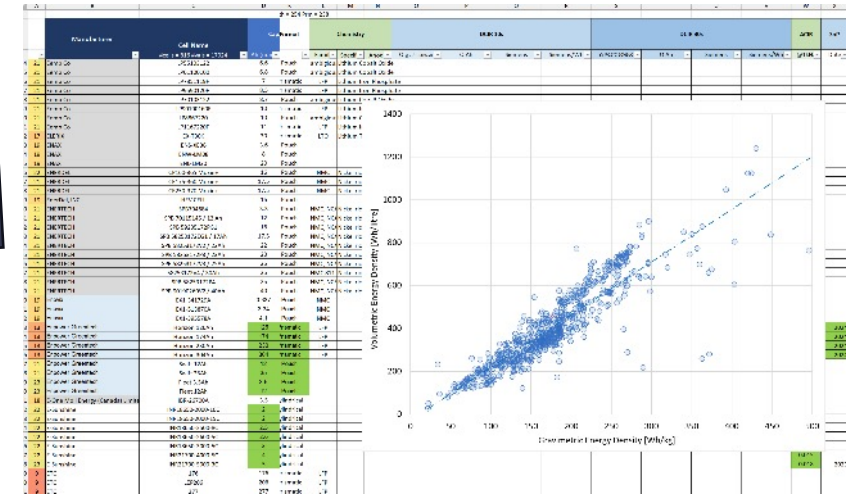
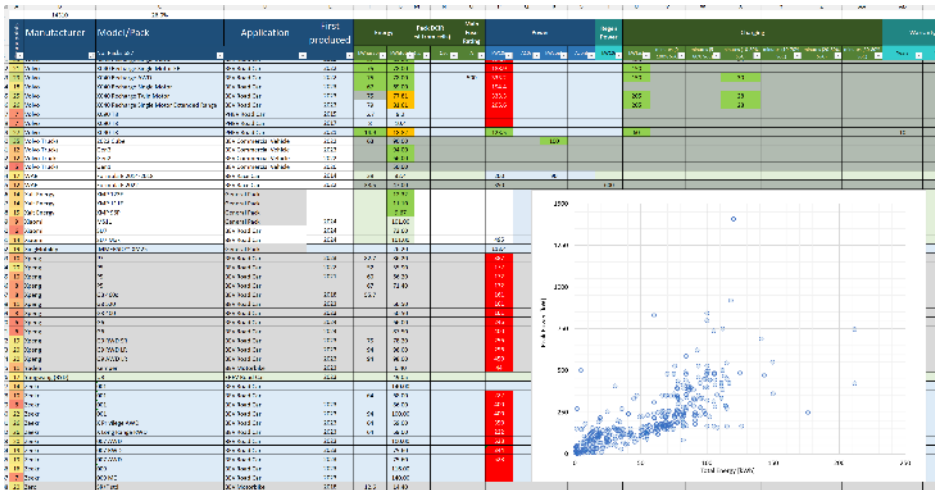
What can we learn from Battery Benchmarking?

We don't have the resources to take batteries apart, but there are lots out there who do and they share lots of data.

Data => Estimations / Limit Cases => Calculations

pack database

cell database



calculations



Tesla 2022 Model Y 4680

Early model teardown and weight of pack + interior trim and seats.

⇒ Create parts list => estimate mass => estimate 4680 pack mass

⇒ Compare to Model 3 21700 based pack

Tesla Model Y 2022 4680		References
Pack		1 https://electrek.co/2022/06/10/tesla-model-y-4680-cells-faster-charging/ 2 https://www.torque.news.com/15475/what-difference-weight-do-tesla-4680-cells-make
Total energy	71.5 kWh	ref 1
Usable energy	67.5 kWh	
Usable window	94.4%	
Nominal pack voltage	340.4 V	
Nominal pack capacity	210.15 Ah	
Maximum pack voltage	386.4 V	
Minimum pack voltage	230 V	
Configuration		
s	92 s	
p	9 p	
Pack mass	445 kg	
Cell mass	294 kg	
Cooling		
Cost	\$ 5,000.00	
Discharge		227 kW @ motor
Peak power	252 kW _{10s}	
Continuous power	kW	
Charging		
5 to 80%	minutes	
peak charge power	kW	
motor regen max power	kW	
Module		
#modules	4	
#cells per module	207	
s	s	
p	p	
Cell		
#cells	828	
Nominal voltage	3.7 V	
nominal capacity	23.35 Ah	
total energy	86.40 Wh	
Maximum voltage	4.20 V	
Minimum voltage	2.5 V	
cell mass	0.355 kg	
Continuous power	W	
Peak power	304.6 W _{10s}	
Wh/kg	161 Wh/kg	
W _{10s} /kg	W/kg	
Cell to pack mass ratio	66%	
S/kWh	\$ 69.90	


s	p	Total Pack Energy kWh	Usable Energy kWh	SoC window
92	6	47.7		
92	7	55.6		
92	8	63.6	67.5	106.13%
92	9	71.5	75.9	106.15%
92	10	79.5		

20lb less at car level
-9 kg at car level

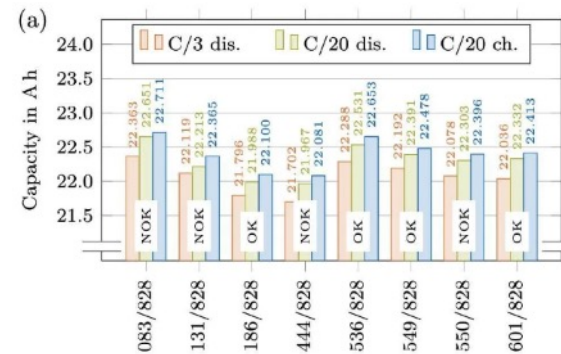
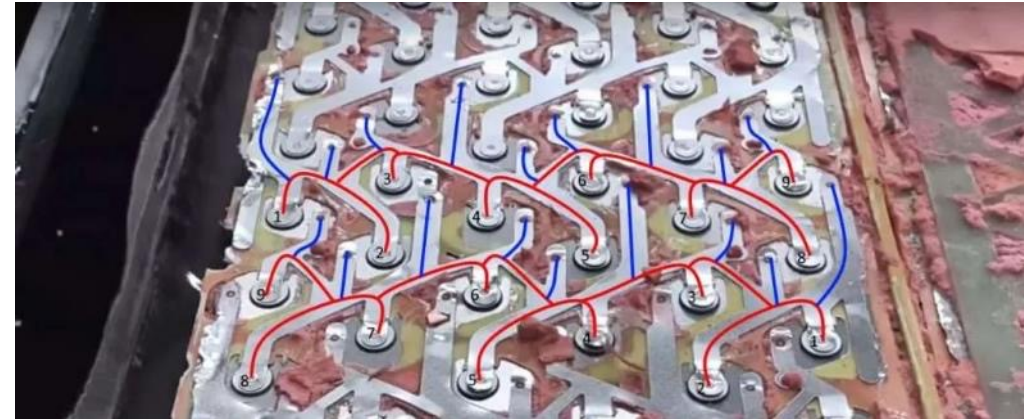
Tesla Model Y with 4680 cells weighs 4480lb and with 2170 cells weighs 4500lb [ref 2]

Weight Estimate		
Battery+seats+console+carpet	1198	lb
Model 3 Front seat	543.4	kg
Front seat rails	44.8	kg
Carpets + underlay	10.6	kg
Centre Console	23.5	kg
Inner floor structure	10.8	kg
Wiring	8	kg
	0.5	kg
Battery	445	kg

Note: Model 3 battery weight 481 kg



Pack capacity from declared cycle testing. Cell configuration from teardown.



Capacity tests from a number of cells [7]:

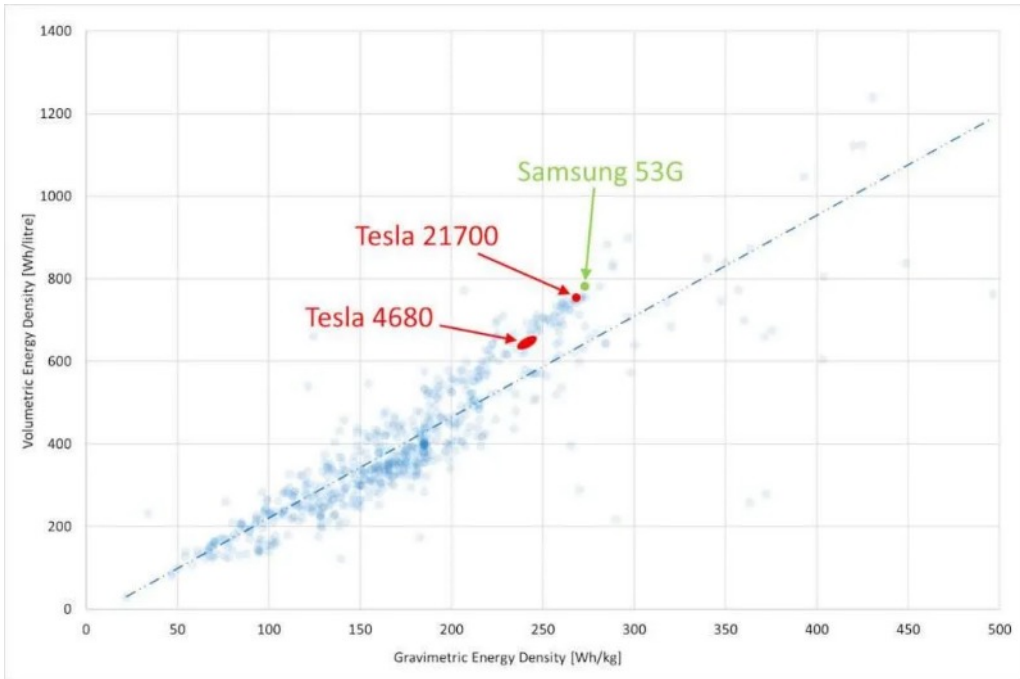
- Capacity: 22.31Ah at C/20 discharge
- Capacity: 22.41Ah at C/20 charge
- Capacity: 22.08Ah at C/3 discharge

Ank, Manuel, Sommer, Alessandro, Abo Gamra, Kareem, Schöberl, Jan, Leeb, Matthias, Schachtl, Johannes, Streidel, Noah, Stock, Sandro, Schreiber, Markus, Bilfinger, Philip, Allgäuer, Christian, Rosner, Philipp, Hagemeyer, Jan, Röfle, Matti, Daub, Rüdiger, Lienkamp, Markus, [Lithium-Ion Cells in Automotive Applications: Tesla 4680 Cylindrical Cell Teardown and Characterization, Journal of The Electrochemical Society, Volume 170, Number 12](#)

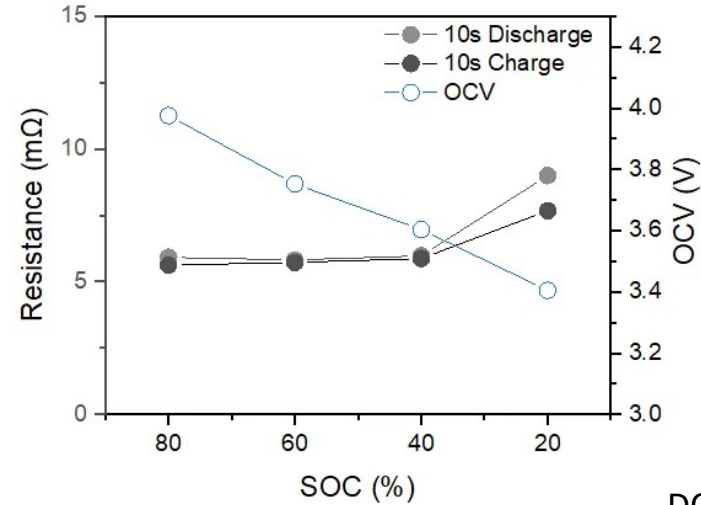


Tesla 4680 Cell

How does this cell compare?

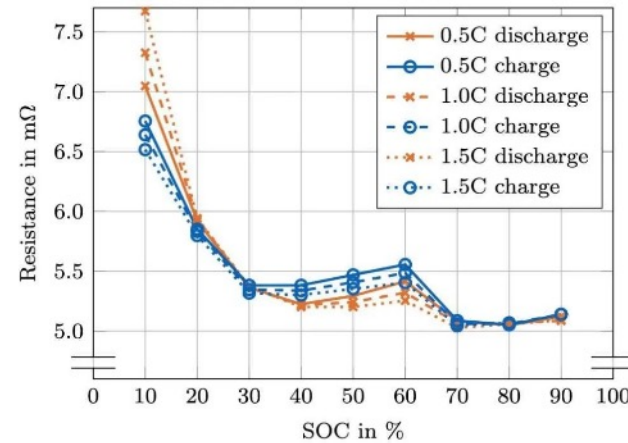


This was an early cell and we know that it is all about lowering the cost.



UC San Diego analysis, [The Limiting Factor](#) & [Laboratory for Energy Storage and Conversion](#), UC San Diego, [Ying Shirley Meng](#), UC San Diego

DCIR ~5.4mΩ to 7mΩ @50% SoC



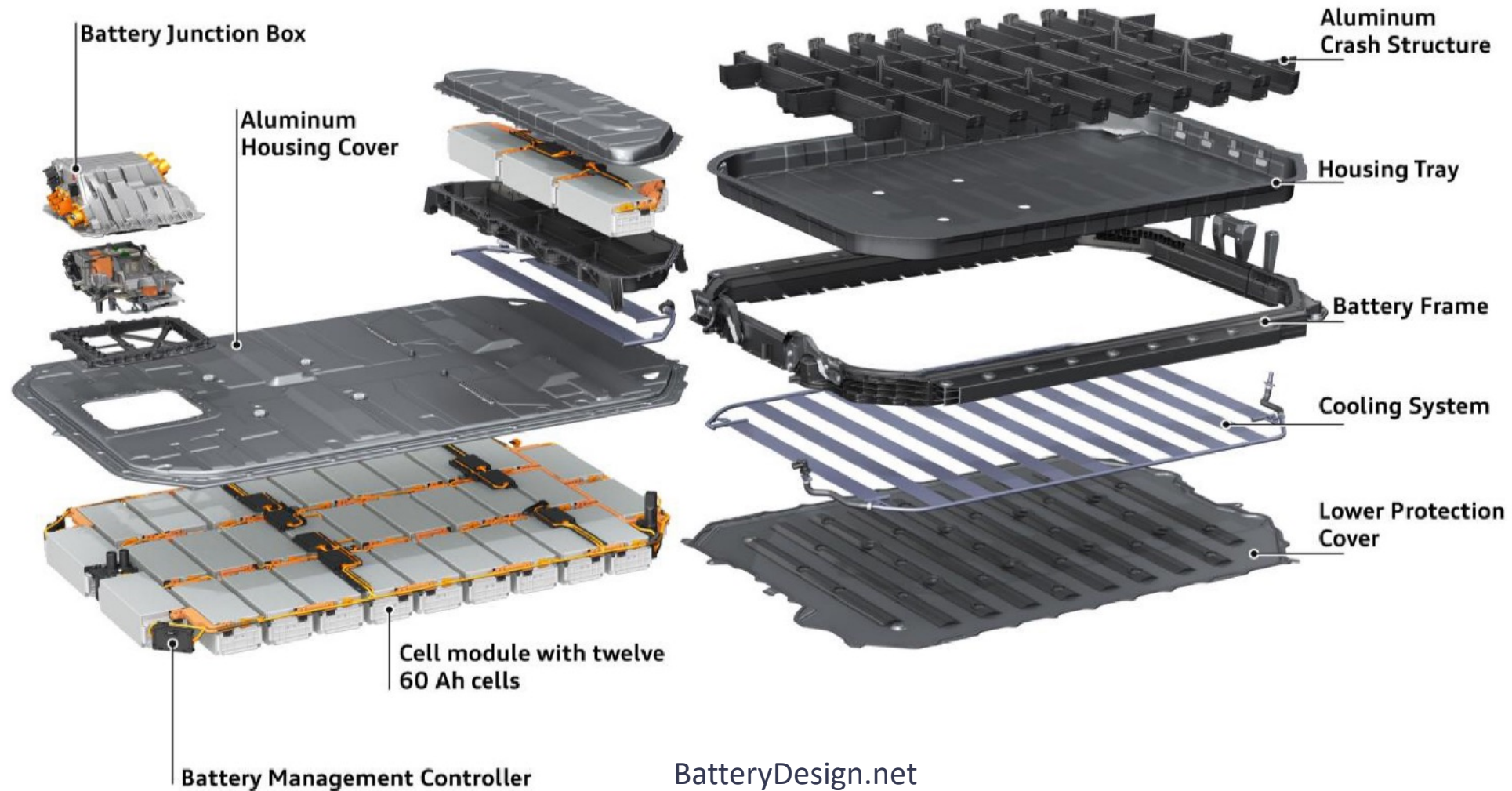
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If we know the cell DCIR we have the ability to then look at discharge limits and to estimate heat rejection requirements.

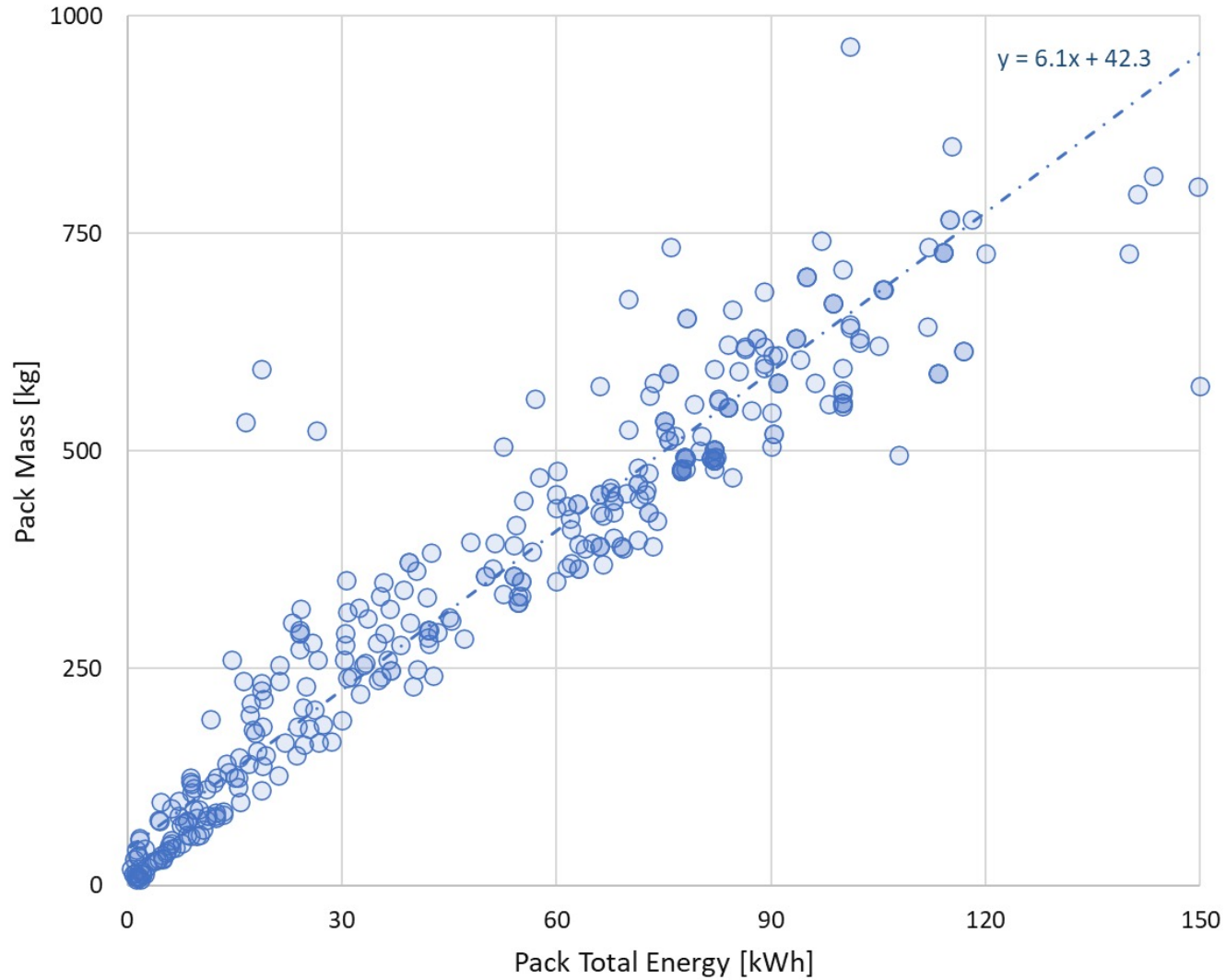


What can we learn from Battery Benchmarking?

actually



Battery Pack Weight

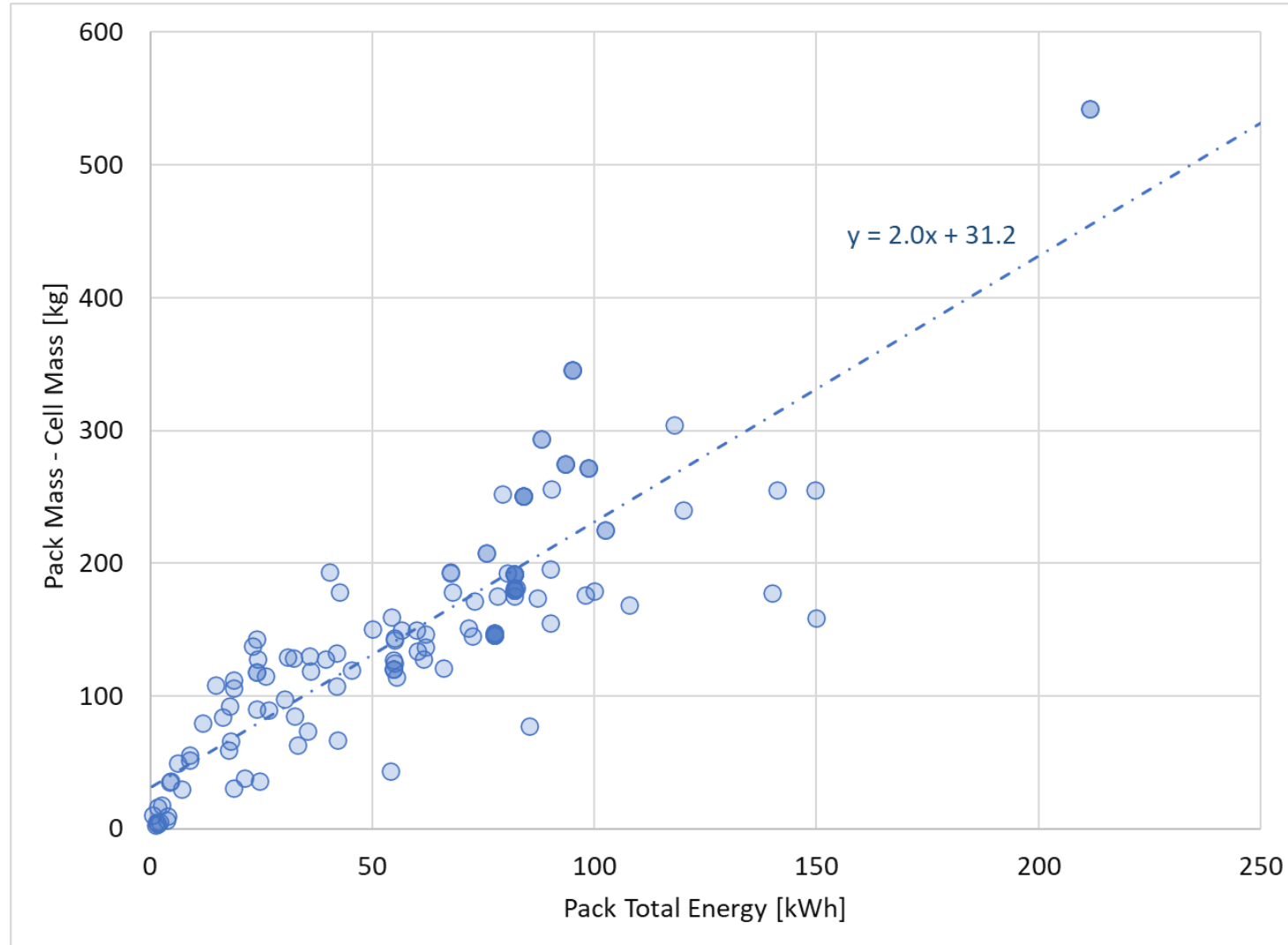


Lots of data >400 values in database.
A spread of ~200kg @100kWh in pack mass across the various applications.

Battery Pack Weight

Cells +

- modules
- thermal
- HV electrical
- LV harness
- sensors
- BMS
- HV control
- connectors
- case
- mounts

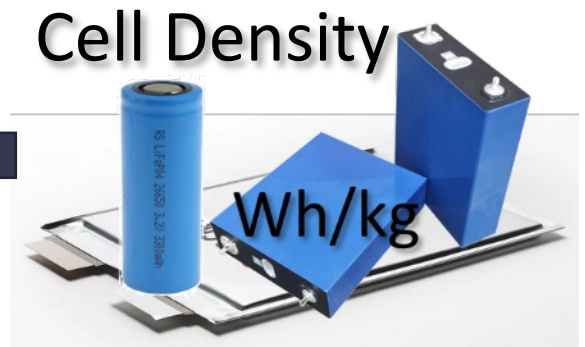
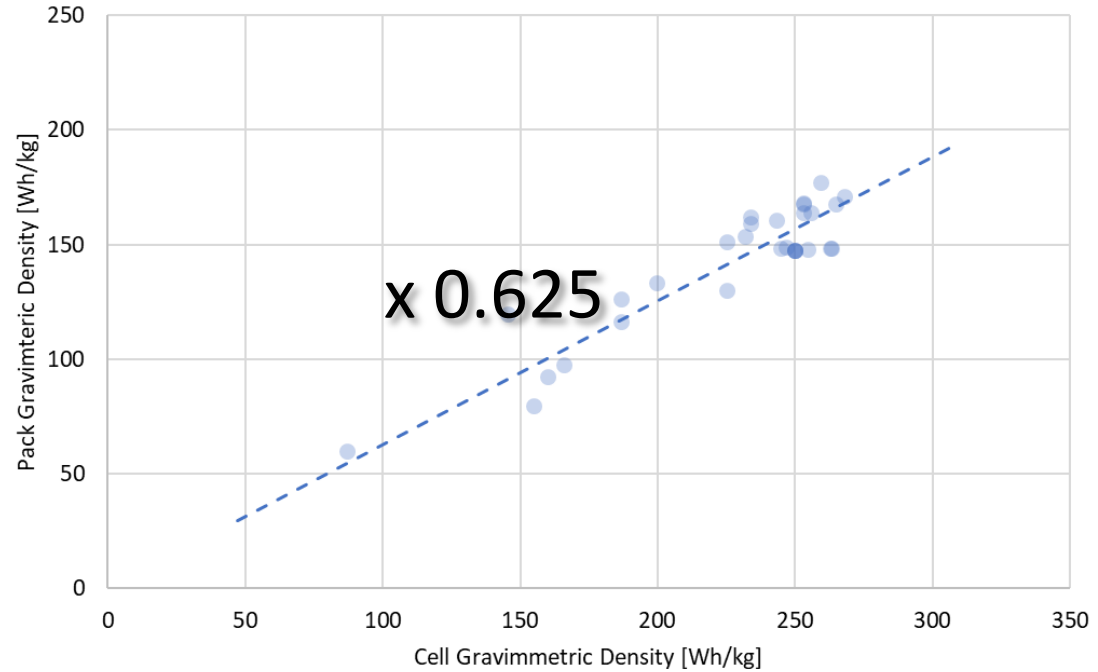
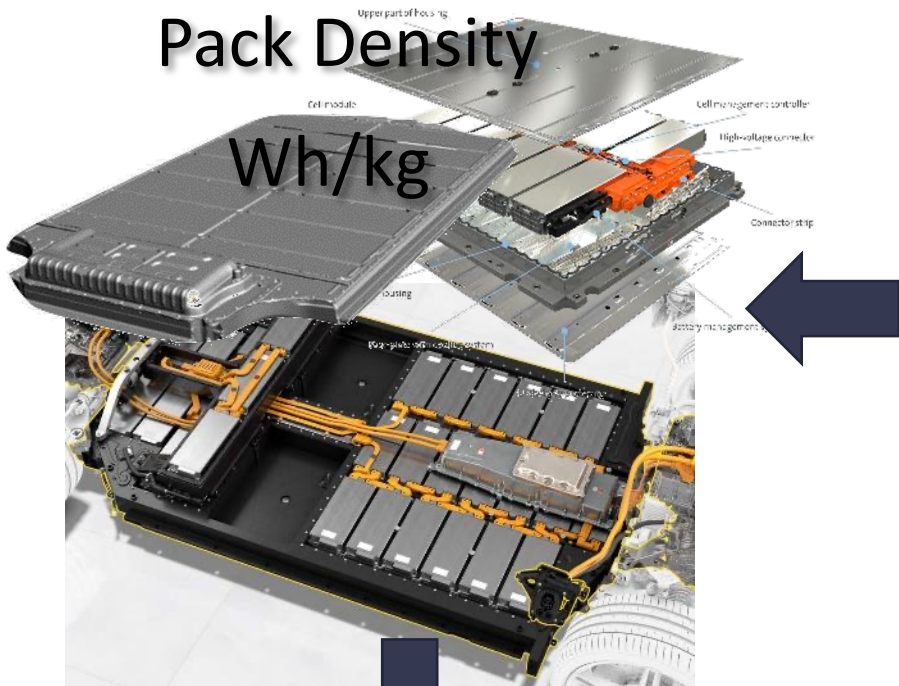


On average: 31.2kg for the BMS, connectors, fuses, contactors.

Module, case, cooling, busbars ~2x Total kWh



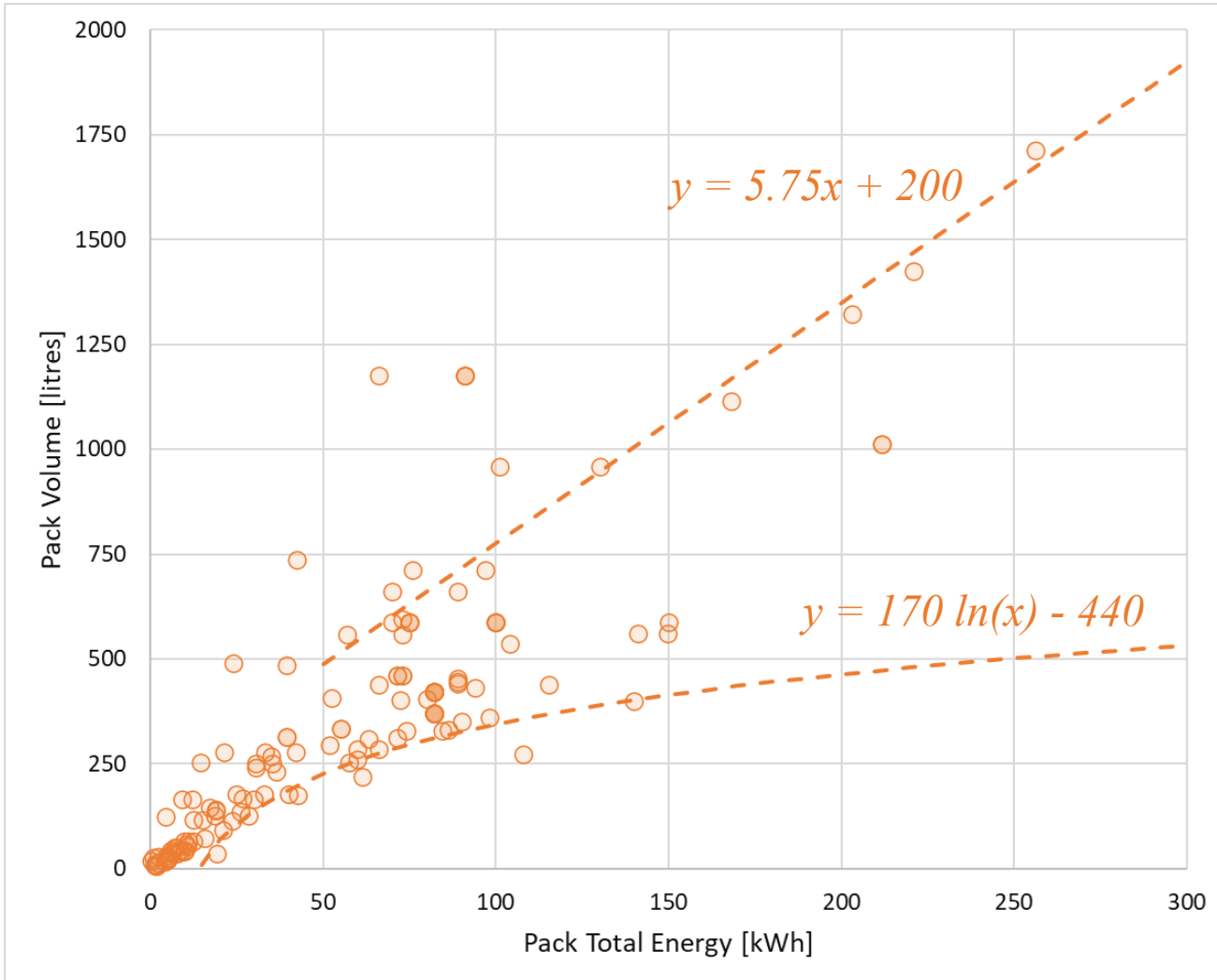
Pack Mass Estimation



$$\text{Pack Energy} / \text{Pack Density} = \text{Pack Mass}$$



How big are battery packs?

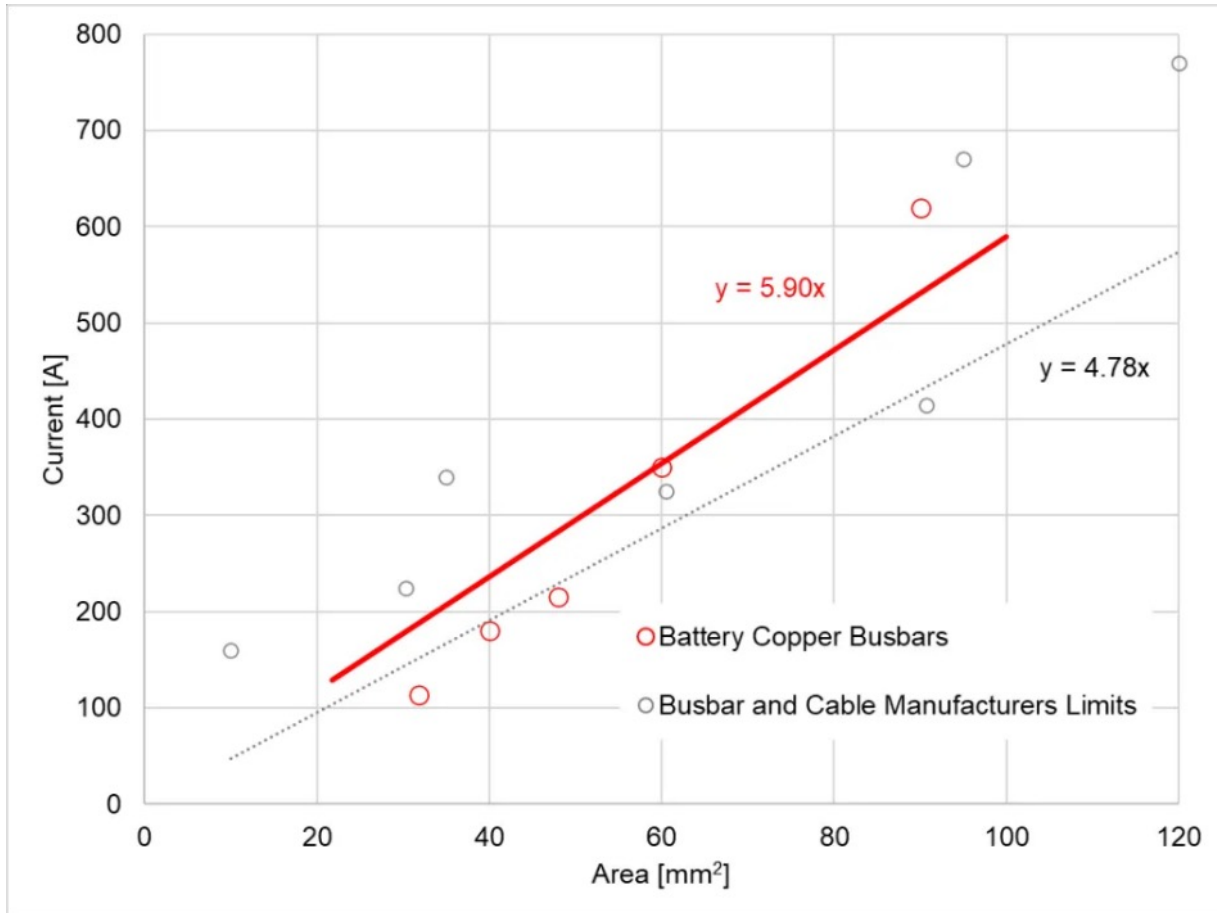


We can see a range and the trend of those limits.

Pack volume data is much harder to acquire and a lot of variation in how it is measured => lower confidence and the need for more data.



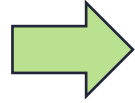
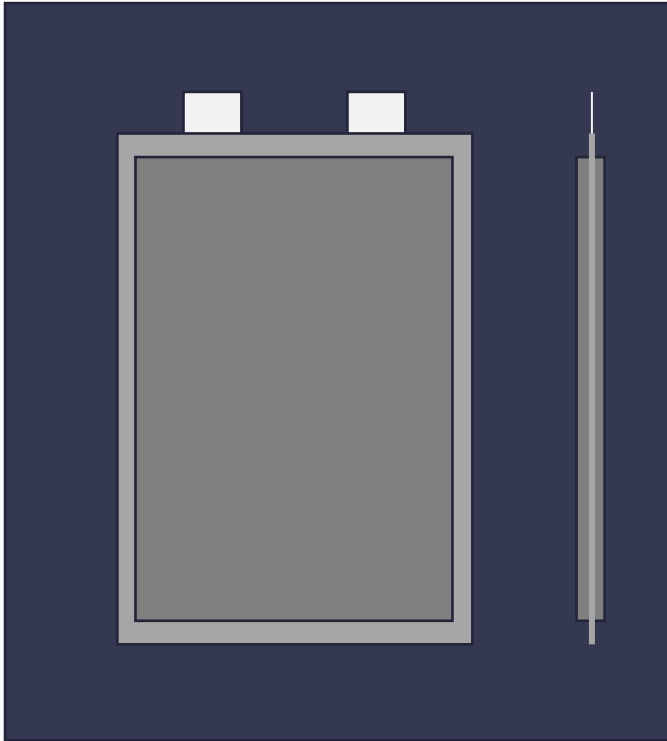
Busbar Sizing



Copper busbars in battery packs sized at around 5.9A/mm²

Pouch Cell Cooling Development

Top Tabs



Lower DCIR
More uniform discharge
Improved underfloor package

Opposing Tabs, reduced height to suit automotive underfloor



More robust wrap
Lower module height
Lower ΔT



One piece outer wrap, electrical tabs closer to cooling plate



Innovations: engineering design

Some innovations are subtle and an amalgamation of good engineering, eg **Hyundai Ioniq 5**, **Kia EV6**, **Genesis GV60 (E-GMP)**.



Plastic module case with no base.

Shared fixing bolts.

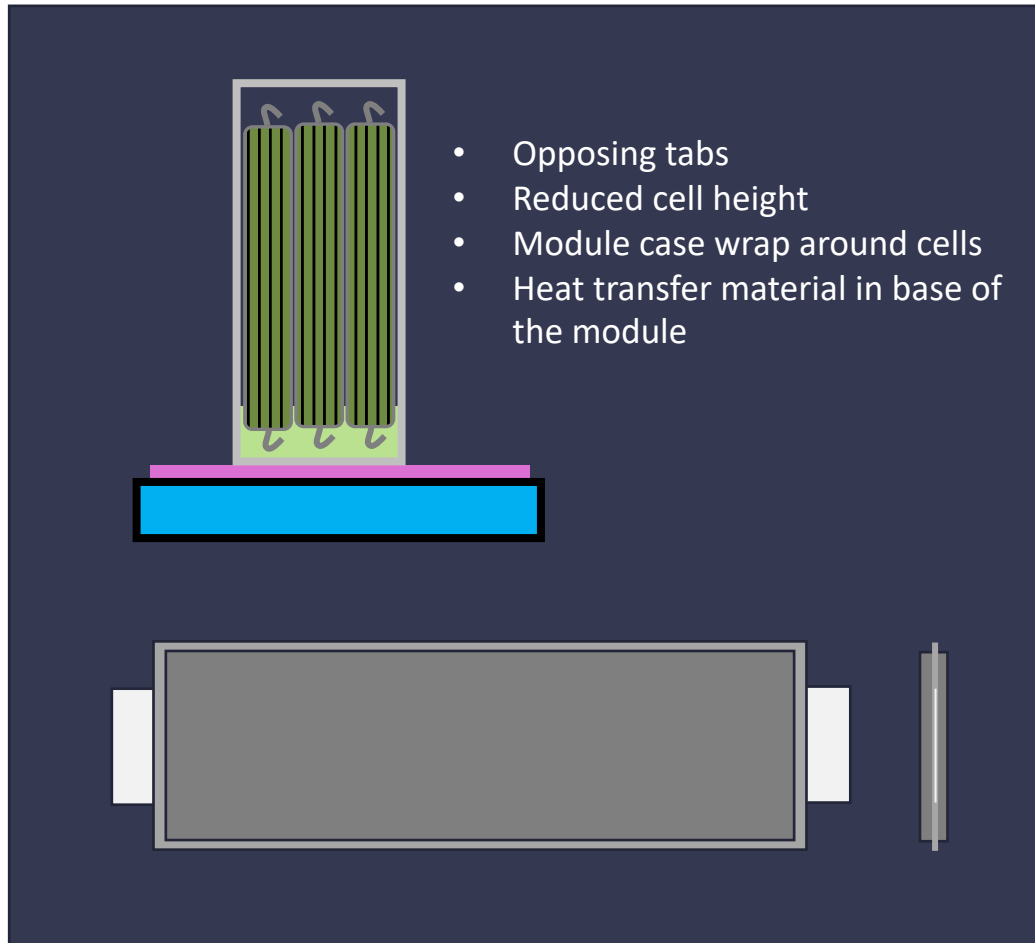
Bottom of cells interface directly with coolant plates.

Single outer cell wrap.

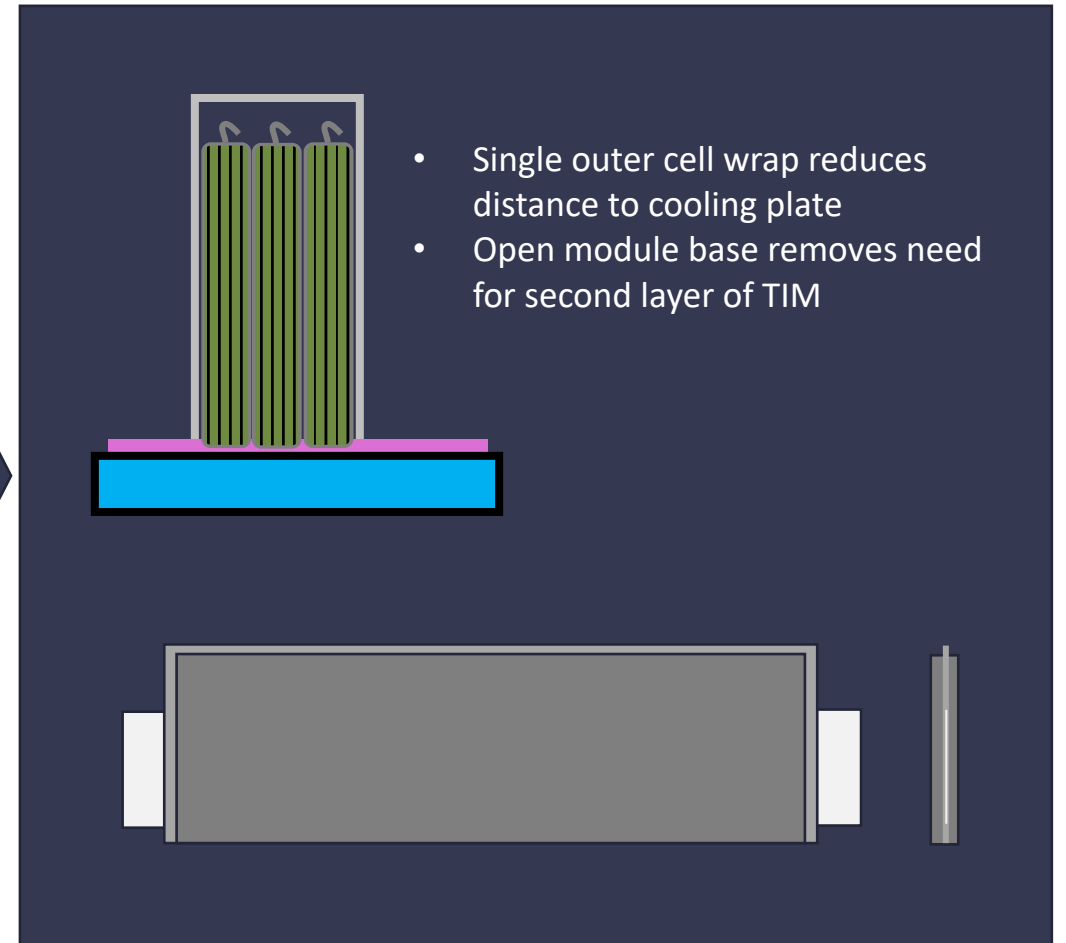
Shifted tabs down the cell, closer to coolant.



Pouch Cell Cooling Development

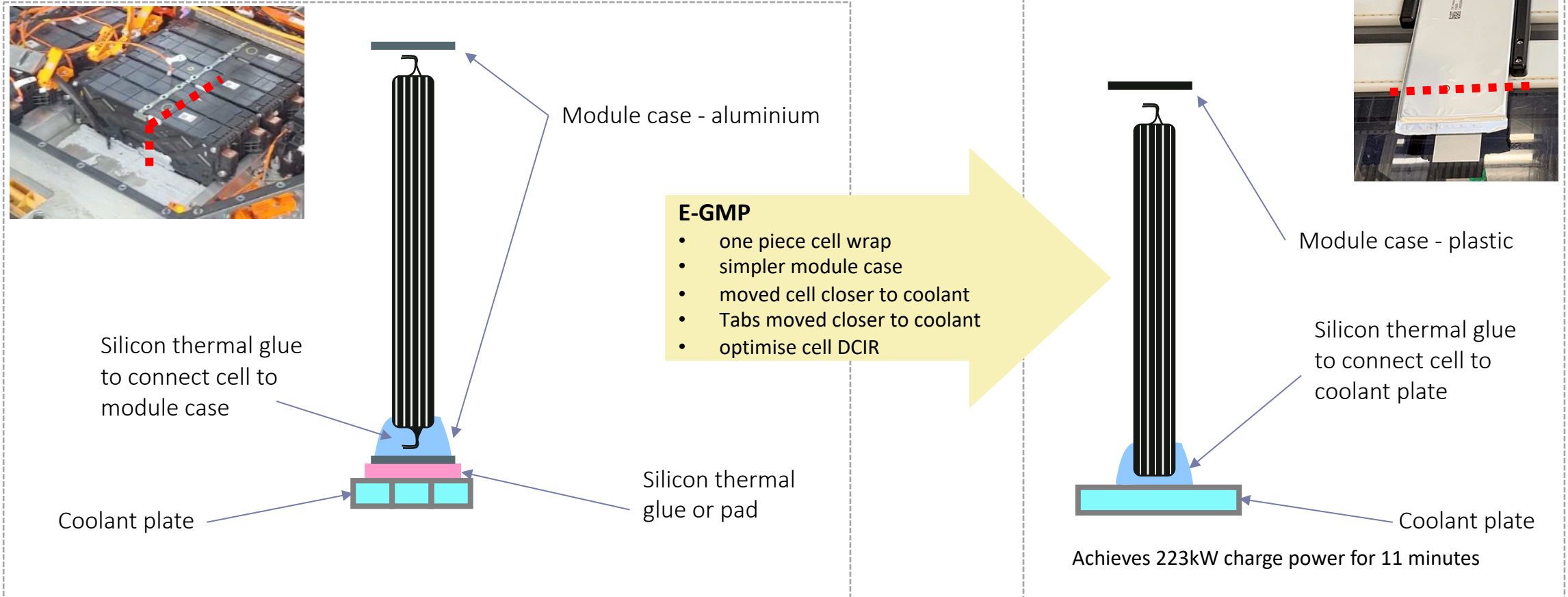


-
- Cheaper
 - Lower Z-height
 - Lower weight
 - Better thermal control

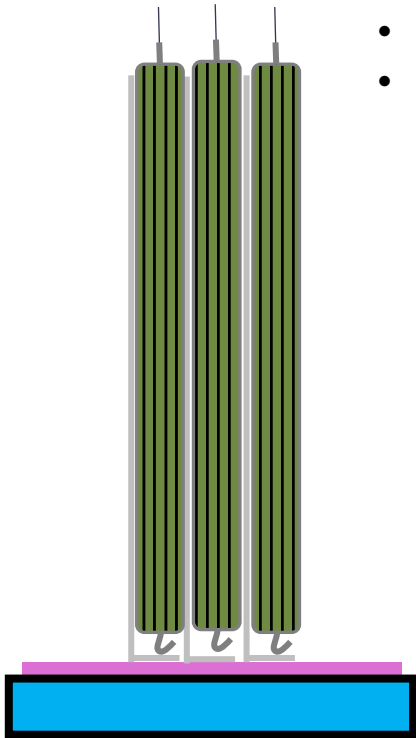


Innovations: engineering detail

Let's look at a section through the module and cell
Hyundai Ioniq 5 / Kia EV6 / Genesis GV60 (E-GMP)

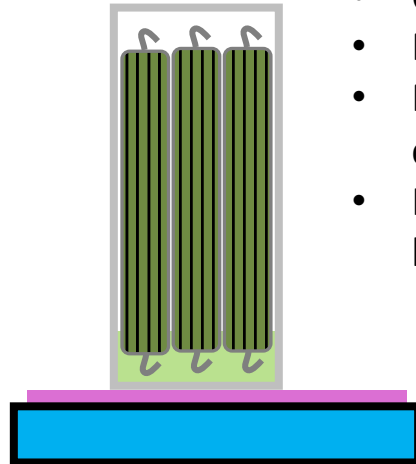


Pouch Cell Cooling Development



- Heat transfer plates
- Top tabs

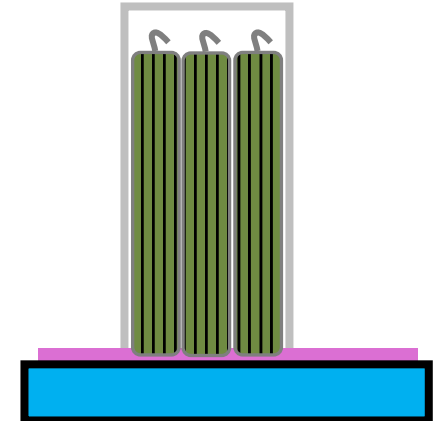
Lower ΔT
Lower mass
More compact



- Opposing tabs
- Reduced cell height
- Module case wrap around cells
- Heat transfer material in base of the module



Closer to coolant
Simpler cell wrap
Less TIM

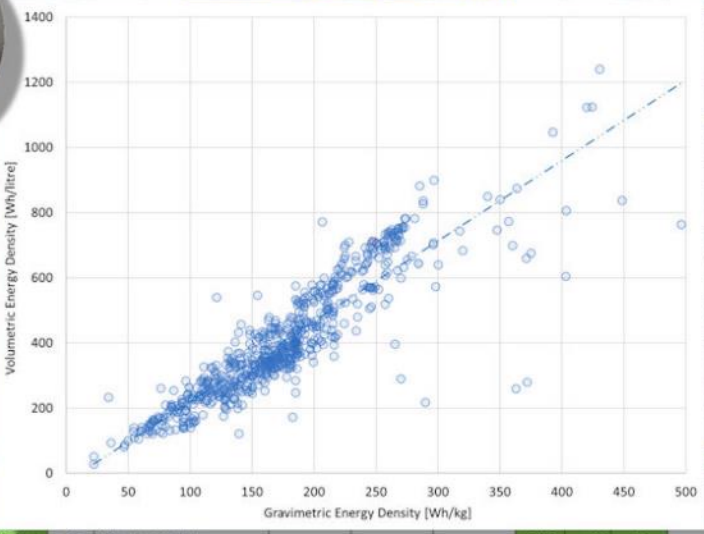


- Single outer cell wrap reduces distance to cooling plate
- Open module base removes need for second layer of TIM

What can we learn from Battery Benchmarking?

Cyl = 309 Pch = 244 Ptm = 239

Manufacturer	Capacity	Voltage	Energy	Mass	Format	Chemistry	DCIR 10s				ACIR	SoP	Dimensions [mm]			Volume		
Famil	Specif	Anodi	Q (atm) total	Q Ah	Siemens	Siemens/Wh	@ 10k	Date	W (or Di)	L	H	litre						
60 25 BAK					Cylindrical	NMC						0.03	2019	18.4	64.85	0.017244		
61 25 BAK					Cylindrical	NMC						0.07	2010	18.4	65	0.017284		
62 28 BAK					Cylindrical	NMC	0.022	0.0572	45.45454545	4.86				18.4	64.85	0.017244		
63 28 BAK					Cylindrical	NMC	0.021	0.0609	47.61904762	4.56				18.4	64.85	0.017244		
64 30 BAK														18.4	64.85	0.017244		
65 28 BAK														18.4	64.85	0.017244		
66 28 BAK														18.4	64.85	0.017244		
67 28 BAK														18.4	64.85	0.017244		
68 28 BAK														18.4	64.85	0.017244		
69 28 BAK														18.4	64.85	0.017244		
70 20 BAK														18.4	70.05	0.02461		
71 20 BAK														18.4	70	0.024245		
72 27 BAK														18.4	65	0.03451		
73 19 Battromia														18.4	70.75	0.025447		
74 20 BMZ / Sony		4.2	3.6	2.5	18.4	0.072								18.4	8.5	0.10115		
75 20 BMZ / Sony		4.2	3.6	2	14.976	0.072								18.4	70.3	0.024862		
76 20 BMZ / Sony	BMZ 21700 50EL	5	4.2	3.6	2.5	18	0.0685							18.4	69.8	0.024989		
77 20 BMZ / Sony	BMZ 21700 52EM	5.2	4.2	3.6	2.5	18.72	0.07							18.4	70.15	0.024529		
78 20 BMZ / Sony	BMZ 21700 52E	5.2	4.2	3.6	2.5	18.72	0.07							18.4	69.8	0.024989		
79 20 BMZ / TerraE	INR 21700 50 E	5	4.2	3.6	2.75	18	0.072							18.4	70.9	0.026221		
80 19 BMZ / TerraE	INR 21700 58 E	5.7	4.2	3.6	2.75	20.52	0.075							18.4	70.9	0.026221		
81 9 BYD	CA7F	102	3.2	3.2	326.4	2.3								18.4	49.9	0.369354		
82 23 BYD	CA9	100	3.8	3.2	2.5	320	1.96							18.4	80.5	0.137001		
83 11 BYD	Blade	202	3.2	3.2	646.4	3.92								18.4	120.6	0.205247		
84 21 BYD	FC680P	15.3	15	3.65	3.2	2	48.96	0.335						18.4	13.5	1.1664		
85 24 BYD	FC6820P	25	24.5	3.65	3.2	2	80	0.52						18.4	65	0.03451		
86 20 BYD	Blade 138Ah	138	3.8	3.2	2	441.6	2.63							18.4	46	0.629648		
87 20 CALB	24650FS3	3.6	3.65	3.2	2	11.52	0.089							18.4	26.5	0.382395		
88 21 CALB	CA40	40	3.65	3.2	2.5	128	1.5							18.4	41	1.1316		
89 23 CALB	L148N508	51.3	4.35	3.66	2.75	187.758	0.861							18.4	30	0.87075		
90 21 CALB	CA60	60	3.65	3.2	2.5	192	2							18.4	29	0.425952		
91 21 CALB	L135F72 (CAM72)	72	3.65	3.2	2.5	230.4	1.78							18.4	67	2.026482		
92 21 CALB	CAM72	72	3.65	3.2	2.5	230.4	1.78							18.4	49.9	0.369354		
93 9 CALB					330	2.17								18.4	53.7	1.934167		
94 21 CALB						3.4								18.4	71	3.56562		
95 21 CALB						1.97								18.4	71	3.56562		
96 30 CALB						1.795								18.4	71	3.56562		
97 21 CALB						3.984								18.4	71	3.56562		
98 21 CALB						5.6								18.4	71	3.56562		
99 9 CALB						4.25								18.4	71	3.56562		
100 21 CALB						13.6								18.4	71	3.56562		
101 28 CATL						0.37	Cylindrical	LFP	Lithium Iron Phosphate			0.0032	2020	34	184	0.167057		
102 14 CATL						0.53	Cylindrical	LFP	Lithium Iron Phosphate					40	145	0.240976		
103 30 CATL						0.402	Cylindrical	LFP	Lithium Iron Phosphate			0.0014		34	207	0.187939		
104 9 CATL						1.38	Prismatic	LFP										
105 26 CATL						182.5	0.85							2018	92	148	27	0.367632
106 18 CATL	60Ah	80	3.2	3.2	192	1.821								217	29	135	0.849555	
107 17 CATL	96Ah (Mini)	96.3	3.65	3.65	351.495	1.42								173	42	85	0.93761	
108 22 CATL	95Ah	95	4.3	3.67	2.5	348.65	1.42							35.7	180	102	0.855452	
109 31 CATL	100Ah CATL (LFP) 4	100	3.65	3.2	320	2.32								177	200	11	0.33829	



Brush-Film
Pouch cell

Aluminium-Gehäuse
Monobloc

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