Battery Form Factor

Kriss Motors White Paper

October 2011 version 1.1 (10-09-2011)

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Introduction

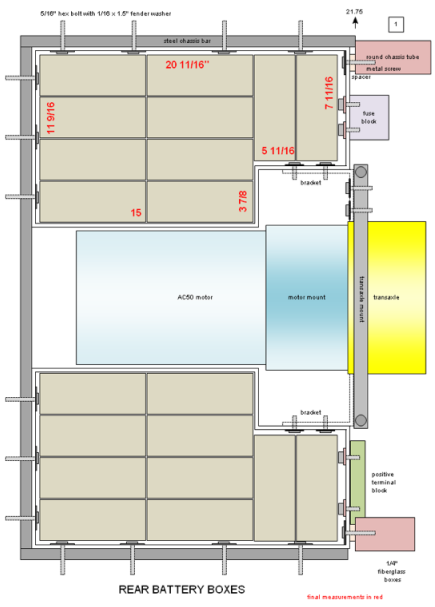
At the onset of emerging markets, a sort of Cambrian Era explosion takes place where strange, odd, and wonderful new products fight for space in the new business niche.

After a time, the dust settles; many offerings go extinct, while others adapt, eventually leading to product maturity in the industry.

It seems we are at a stage now with $LiFePO_4$ battery cells in electric vehicle applications where a technical summary of battery form factor status can help clear away some of the Cambrian dust. The following material concentrates on the large prismatic form factor typically characterized by Lego-like plastic cases.

Test fitting 71mm cells (form factor A) into the front battery box

Enclosure design



Since batteries hold much less energy per volume than gasoline, the task of physically fitting sufficient cells into a vehicle becomes a primary design task.

An optimum profile of system voltage and amp-hour storage capacity must be matched to the space available. The challenge is not unlike playing with blocks in nursery school; how many can you fit into a specific box?

Battery enclosures, or boxes, require careful layouts, but this design is totally dependent on the selected form factor. An iterative approach may be necessary to achieve a balance between voltage/storage, space, appearance, and maintenance access.

The drawing shows a rear pack installation design with 71mm width (factor A) cells. Use of a different form factor would trigger a complete enclosure redesign, a time-consuming and expensive step.

Form factor options

The following table summarizes current Chinese $LiFePO_4$ prismatic cells available for sale in the U.S.

Brand	SKU	Ah	Width	Length	Height	Factor	Density	Comment
CALB	SE180AHA	180	71	182	279	A	49.9	
Hipower	HP-CT-180AH	180	72	183	286	A	47.8	
Sinopoly	SP-LFP180AHA	180	71	182	282	A	49.4	
Sinopoly	SP-LFP200AHA	200	71	182	282	A	54.9	
CALB	SE100AHA	100	67	142	218	B	48.2	
Sinopoly	SP-LFP90AHA	90	67	142	220	B	43.0	
Sinopoly	SP-LFP100AHA	100	67	142	220	B	47.8	
Winston	WB-LYP90AHA	90	61	143	218	BB	47.3	width variant
CALB	SE60AHA	60	51	142	218	BB	38.0	width variant
Sinopoly	SP-LPF60AHA-S2	60	34	139	222	BB	57.2	width variant
CALB	SE70AHA	70	61	113	206	C	49.3	
Hipower	HP-PW-60AH	60	61	114	203	C	42.5	
Sinopoly	SP-LPF60AHA	60	61	116	183	C	46.3	
Winston	WB-LYP60AHA	60	61	115	203	C	42.1	
CALB	SE40AHA	40	46	182	116	D	41.2	
Sinopoly	SP-LPF40AHA	40	46	182	116	D	41.2	
Winston	WB-LYP40AHA	40	46	183	116	D	41.0	
Hipower	HP-PW-100AH	100	51	278	163	n/a	43.3	non-conforming size
Winston	WB-LYP160AHA	160	65	209	280	n/a	42.1	non-conforming size
Winston	WB-LYP100AHA	100	62	179	218	n/a	41.3	non-conforming size

The **Brand** column indicates the name of the Chinese trading company. At this time, there are four major players who represent an assortment of quasi-independent factories throughout China.

See *Chinese Battery Manufacturing – Commentary*, a white paper available from KrissMotors.com, for more details about the structure of the $LiFePO_4$ industry. Current brand names are used instead of the more familiar pre-2010 names like Thunder Sky and Sky Energy. Sky Energy cells now fall under the CALB brand. Thunder Sky split into two brands – Winston and Sinopoly – but the situation is under Chinese legal review.

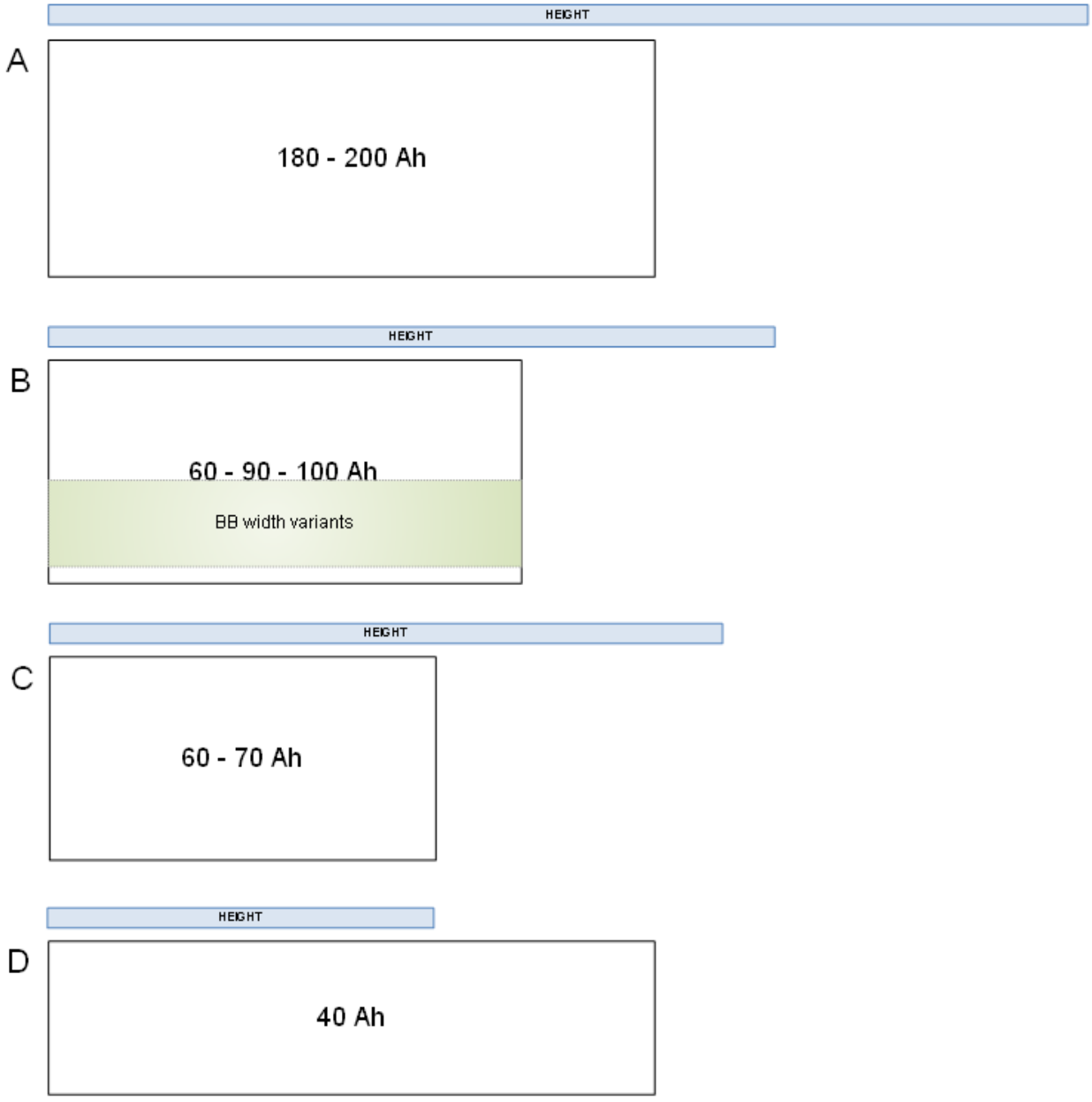
The **SKU** column lists the battery factory model designation. The next four columns describe the cell physically: amp-hour capacity (**Ah**) and outside dimensions in millimeters. The **Density** column measures milliamp-hours per cubic centimeter, a way to gage cell packaging efficiency (higher density is better).

The table is sorted by a form **Factor** category which has been invented for this purpose. In general, the categories are defined by length and width dimensions within a 3mm threshold; for example, form factor A cells are all within 1mm in width and length. Height is a somewhat less critical dimension.

There are four basic form factors – A, B, C, and D – and three related width variants that are named BB signifying a subset of factor B. The 3 cells at the bottom of the table do not share dimensions with other cell sizes and are therefore labelled "n/a". Selecting a non-conforming form factor means that

product substitution is more difficult and dependent upon a single trading company.

The following chart shows the footprint of the prismatic form factors drawn to scale along with a blue bar that indicates cell height. Width variants for factor BB are indicated by a shaded green box.



Market share

EValbum.com maintains a listing of 3400 worldwide EV projects based on user-supplied data. About 6% of these projects involve a 4-wheel vehicle converted with large prismatic $LiFePO_4$ cells *and* sufficient information to determine the battery brand and form factor.

This following market share information is derived from 194 *EValbum* project listings as of October 8, 2011. While certainly not a comprehensive survey, some useful insights can still be inferred.

FORM FACTOR MARKET SHARE		
Factor	Projects	Share %
A	41	21.1%
B	66	34.0%
BB	1	0.5%
C	11	5.7%
D	6	3.1%
obsolete	35	18.0%
non-conforming	34	17.5%
TOTAL	194	100.0%

Over half of all $LiFePO_4$ projects selected the factor A or B, while about a third of the projects used batteries that are no longer manufactured, or non-conforming cells as defined in this paper. The *EValbum* data is something of a moving target since many of the reported EV projects date back several years and this market share does not necessarily represent *current* decision making.

Another useful perspective is market share by amp-hour (Ah) capacity.

AH SIZE MARKET SHARE		
Capacity	Projects	Share %
40	6	3.1%
60	12	6.2%
90	26	13.4%
100	53	27.3%
160	31	16.0%
180	19	9.8%
200	25	12.9%
other	22	11.3%
TOTAL	194	100.0%

The most popular capacity is the 100Ah cell. The second most popular choice has been an intermediate

size – the 160Ah cell – but this will probably fade in popularity as share moves to either 100Ah or 200Ah sizes. Winston is the only trading company that offers the 160Ah cell and it is produced in a non-conforming form factor adding to its vulnerability. If 160Ah market share were evenly divided between 90-100Ah and 180-200Ah cells, the resulting market share would be:

Hypothetical market share without 160Ah product

Small cells (40-60)	9% share
Medium cells (90-100)	49%
Large cells (180-200)	31%
Other	11%

The view by trading company brand market share reveals a concentrated structure that was disrupted by the sale of Thunder Sky and its subsequent breakup into two separate companies, Winston and Sinopoly.

TRADING COMPANY MARKET SHARE

Old brands	Projects	Percent	New brands	Projects	Percent
SkyEnergy	47	24.2%	CALB	47	26.0%
Thunder Sky	124	63.9%	Sinopoly	91	50.3%
GBS	8	4.1%	Winston	33	18.2%
HiPower	9	4.6%	HiPower	9	5.0%
Voltronix	5	2.6%	Other	1	0.6%
Other	1	0.5%			

Thunder Sky dominated the pre-2011 brands with a 64% market share, followed by SkyEnergy, now called CALB. Translated into 2011 brand names (and this assumes a theoretical static picture), Sinopoly holds the dominate position with over half the market.

However, if non-conforming form factor products are eliminated, the market share picture shifts dramatically:

Hypothetical market share with form factor only products

Sinopoly	72%
CALB	26%
Winston	1%
HiPower	1%

Competitive assessment

Based solely on form factor, two Chinese trading companies, Sinopoly and CALB, appear to enjoy a technical advantage. Both firms cover all Ah capacities and offer a range of form factor. CALB uses a factor BB for its 60Ah cell but offers a factor C 70Ah cell; Sinopoly deploys a factor C for its 60Ah capacity level.

In contrast, Winston does not offer a compatible factor A or B, the most popular sizes. Its factor BB cell has a non-conforming width of 61mm. Winston is more competitive at the low capacity end – 60 and 40 Ah cells – but these are less useful for EV applications and have less than a 10% market share. Winston's share historically has rested on the 160Ah non-conforming size, and this vulnerability will put increasing pressure on Winston's market position in 2012.

Hipower currently offers no intermediate factor B.

Competition *within a form factor* is critical from an EV conversion point of view. Since the time and costs associated with battery enclosure design and construction are considerable, reliance on a single supplier introduces business risk and possible premium pricing. Non-conforming sizes run the risk of product discontinuation which would then trigger a significant redesign effort.

Future trends

Battery energy density tends to increase over time with the experience curve effect of applying many incremental improvements. Rather than continually change outside physical dimensions, battery manufacturers may increase the Ah capacity of existing form factor cells. Thus, the popular factor A 180Ah cell has already been bumped up to 200Ah capacity by Sinopoly. In the future, this factor may evolve to a 220Ah cell, followed by a 240Ah version, and so on.

Non-conforming sizes will probably disappear over the next year or two unless they find a foothold in a special application or OEM design. Winston appears particularly vulnerable in this regard as previously noted.

Form factor conformity pressure may cause either "multiples" of popular sizes or dimension modification to better mesh with different capacity cells. For example, Sinopoly's S2 version of its 60Ah cell is only 34mm wide (factor BB). This means two S2 cells, with a 68mm combined width, would fit into the 100Ah factor B footprint. This creates the possibility of a 120Ah dual battery unit, wired in series or parallel, that could theoretically replace a single 100Ah cell. Such a "multiple" of width increases the application range of the product.

Battery retail prices will continue to decline, but factor A will likely enjoy the most favorable reduction on a *dollar per amp-hour basis* due to lower case cost per cell. The plastic enclosure and fittings must be amortized across a lower value capacity in the small sizes, thus making them marginally less efficient and more expensive. Note that the 40Ah factor CC cells are about 10-15% less dense than factor A batteries. As EVs develop, these smaller sizes will become less desirable.

In general, form factor A is poised to become a clear frontrunner as it absorbs the 160Ah size and begins to invade the larger Ah capacity cell market. Some applications will need smaller capacity cells wired in series to achieve desired system voltage levels. But for a majority of future conversions, factor A may well become to be the size of choice. Winston does not have a factor A entry at this time and risks falling behind as a leading vendor to the EV community.

The rationalization of form factor offerings generally precedes declining unit prices. As manufacturing becomes more standardized, costs are easier to manage, and natural competitive pressures usually translate into better deals for the end user, which expands the market and permits more investment. Also, as SKUs decline, warehouse operations increase their efficiency.