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The Tesla Battery Report

Tesla Motors: Battery Technology, Analysis of the Gigafactory, and the Automakers' Perspectives

Menahem Anderman

Advanced Automotive Batteries

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Web: www.advancedautobat.com

Email: menahem@advancedautobat.com

Outline

1. Tesla's Sudden Success and the Direction of the EV Market
2. EV Battery Technology Background
3. EV Battery Technology: Tesla vs. Conventional
4. Tesla Battery IP by Subject Matter and Significance
5. The Gigafactory: Investment, Challenges, Benefits
6. Tesla Battery Annual Production Cost Estimate (Japan/U.S.) vs. Volume from 2013 to 2024
7. Tesla's Impact on the EV/Battery Industry
8. EV Market and EV Battery Market Forecast to 2020
9. Conclusion: Likely Scenarios for the Gigafactory and Tesla's Future

Tesla has already shattered many of the industry's deep-rooted convictions…

- ➢ That it is almost impossible for a newcomer to break into the automotive business
  - Tesla became the #2 EV seller in the U.S. in 2013
- ➢ That practical EVs must be limited to a range of 100-150 miles
  - Tesla designed and produced a >240-mile EV, which is 2-3X the range achieved by everyone else
- ➢ That EVs are more suitable as small urban vehicles
  - Tesla is producing and selling a large luxury EV
- ➢ That EVs are hard to sell and that customers will not pay extra $ for them
  - In 2013, in the U.S., Tesla sold more $90K+ sedans than well-established brands such as Mercedes and BMW
- ➢ That EVs imply a financial loss for carmakers
  - Tesla almost broke even during the first year of mass production

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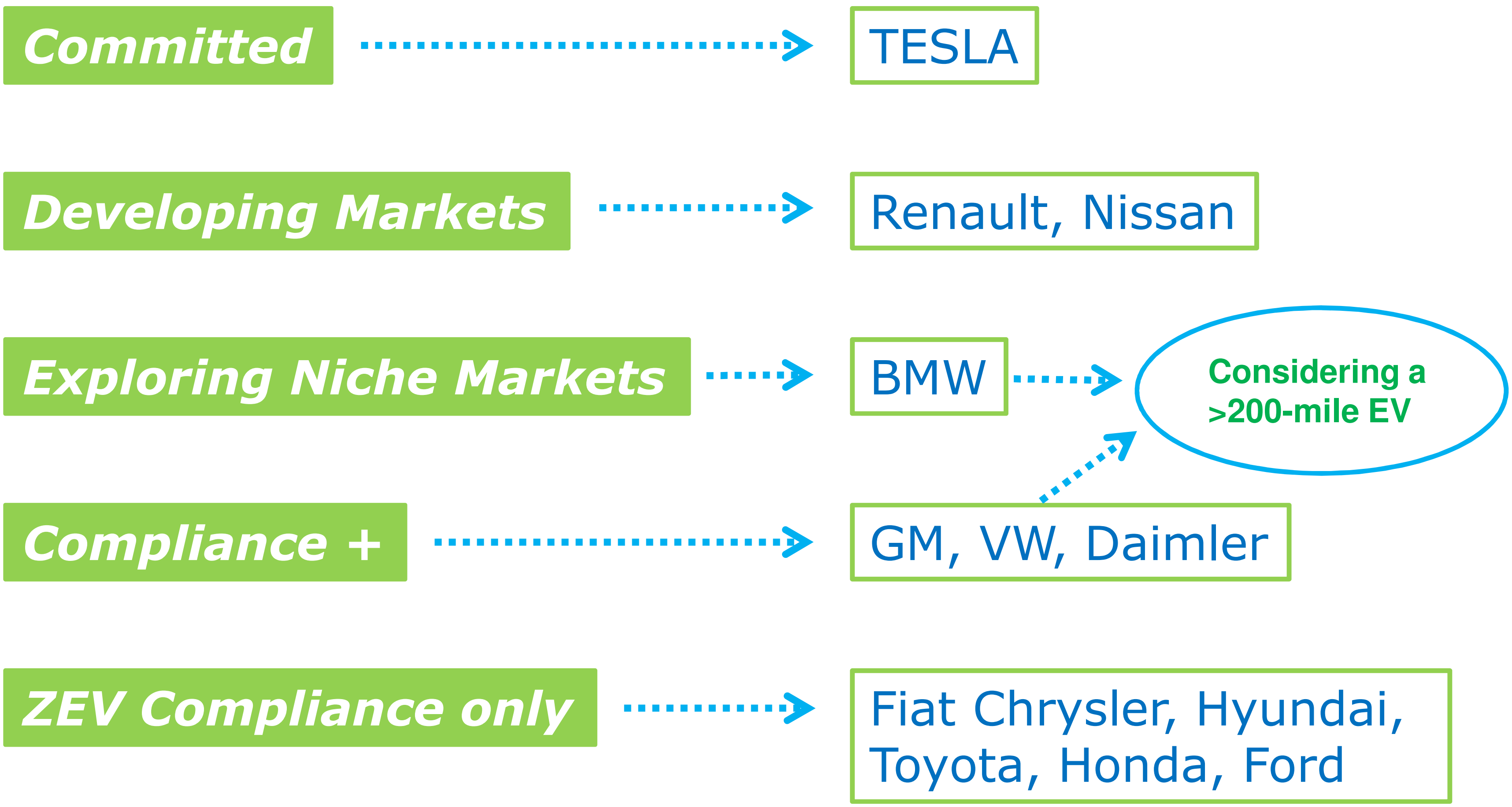
Why do most automakers question the current viability of EVs?

- During 2010-2013, most automakers brought sub-compact/compact EVs with EPA-rated ranges of 75-80 miles to the market
  - Battery parameters: 22-24 kWh, 550 lb, **$8,000-$14,000** (depending on volume)
- 2017 compact EVs from major automakers will be capable of 110-140 miles
  - Projected 2017 battery parameters: 30 kWh; 600 lb, $9,000 - $12,000
- How about a 240-mile C-D Class EV in 2017 (competitor of Tesla Model 3)?
  - Likely battery parameters: 70 kWh, 1,100 -1,400 lb, **$15,000 - $20,000** (depending on volume)
- Cost, weight, and volume are challenging
- And then, there is still:
  - Refueling time
  - Durability, safety, and reliability
  - Operation at low and high temperatures

So major automakers developed EVs predominantly to meet government mandates

Battery EV Efforts by Major Automakers



Committed → TESLA

Developing Markets → Renault, Nissan

Exploring Niche Markets → BMW → Considering a >200-mile EV

Compliance + → GM, VW, Daimler → Considering a >200-mile EV

ZEV Compliance only → Fiat Chrysler, Hyundai, Toyota, Honda, Ford

Vehicle Electrification:
The Perspective of Major Automakers

1. For the next 10+ years, no viable mass market for EVs due to battery cost and size, and charging time; HEVs and/or PHEVs are a more effective way to reduce the CO_2 footprint
    - *Shared by most automakers excluding Renault-Nissan*
2. In the longer term, fuel-cell (FC) vehicles are more appealing than battery EVs due to the shorter fueling time and longer driving ranges
    - *Shared by Toyota, Honda, and Hyundai (less uniformly by Daimler and GM)*
3. In the short term, we make EVs predominantly to meet California's Zero-Emission Vehicle (ZEV) Mandate
    - *Shared by most companies excluding Renault-Nissan, who explore international markets, and excluding Toyota, Honda, and Hyundai, who, even in the short term, favor FC vehicles*

4a. We will offer the lowest-cost EVs we can build and hopefully sell at least in ZEV states

- *Was shared by most automakers prior to Tesla's success*

4b. Our expected losses associated with ZEV-compliance costs for selling larger EVs with longer driving range may be lower than for smaller EVs with shorter range

- *The current position of about half the automakers (GM, Audi, Daimler, Chrysler), who shifted their EV development focus after Tesla's success*

Section Outline

2. EV Battery Technology Background
    - Cell Design
    - Key Materials
    - Module and Pack Design

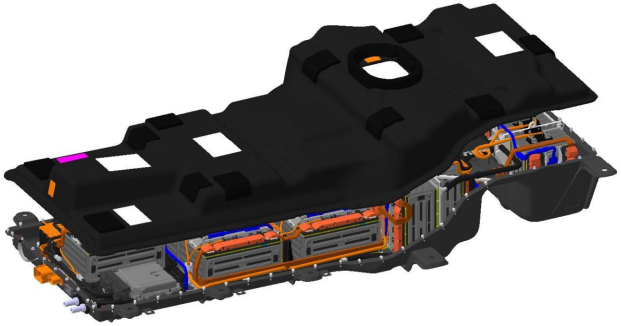
More on Battery Packs

Custom-vehicle design allows for simple battery construction

BMW i-3

Tesla Model S

Conversion of ICE platform requires customized (and more expensive) battery construction



Fiat 500

Chevy Volt

Li-Ion Cells Employed in Current EVs

	Cell Maker	Chemistry	Capacity	Configuration	Voltage	Weight	Volume	Ener dens	Spec Ener	Used in:	
		Anode/Cathode	Ah		V	Kg	liter	Wh/liter	Wh/kg	Company	Model
1	AESC	G/LMO-NCA	33	Pouch	3.75	0.80	0.40	309	155	Nissan	Leaf
2	LG Chem	G/NMC-LMO	36	Pouch	3.75	0.86	0.49	275	157	Renault	Zoe
3	Li-Tec	G/NMC	52	Pouch	3.65	1.25	0.60	316	152	Daimler	Smart
4	Li Energy Japan	G/LMO-NMC	50	Prismatic	3.7	1.70	0.85	218	109	Mitsubishi	i-MiEV
5	Samsung	G/NMC-LMO	64	Prismatic	3.7	1.80	0.97	243	132	Fiat	500
6	Lishen Tianjin	G-LFP	16	Prismatic	3.25	0.45	0.23	226	116	Coda	EV
7	Toshiba	LTO-NMC	20	Prismatic	2.3	0.52	0.23	200	89	Honda	Fit
8	Panasonic	G/NCA	3.1	Cylindrical	3.6	0.048	0.018	630	233	Tesla	Model S

Tesla-Panasonic's current cell offers specific energy 50% higher than the competition. This is primarily due to the use of highly reactive NCA cathodes and high-density electrodes. The gap will shrink to 20-25% in the next 3 years.

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Automotive vs. Consumer Li-Ion Cells

- For automotive applications, the design drivers are:
  1. Safety, reliability, and life
  2. Energy per unit weight and volume, and cost
- Safety is more challenging with larger cells
- Larger cells were introduced in 2010-12 with very conservative designs due to life and safety concerns
- As the industry gains more confidence, next-generation cells for 2016-2017 will use more energetic materials in a better optimized package and will see energy density enhanced by 40%
- Current high-energy 18650 cells deliver 50% higher energy per unit weight than current large cells. In the future, the main opportunity for energy density enhancement and cost reduction in 18650 cell construction is in the implementation of materials with higher capacity and/or lower cost; there would also be some benefit in moving to slightly larger cells (20700 or so)
- We assume similar chemistries will be developed for both large cells and 18650 cells before the end of the decade
- We project that by 2018, the 18650 approach will only offer 15-20% better energy per unit volume and similar cost to that of the large-cell pack
- In the longer term there is better opportunity for cost reduction with larger cells due to economy of scale

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Tesla's Liquid-Cooled Module features 444 '18650' cells per module

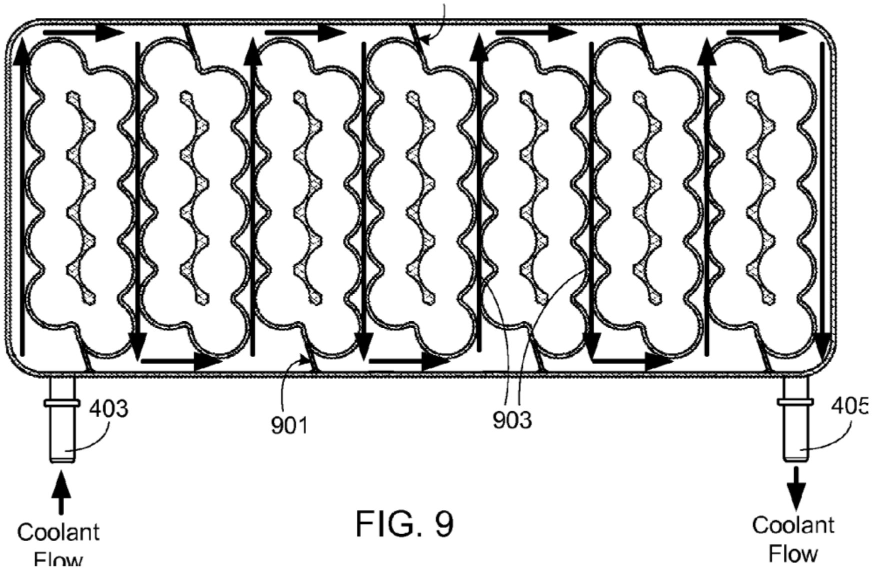

FIG. 9

From US Patent 8,647,763 B2

Two unique module design elements:

1) A small wire is welded to each cell terminal on

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2) A complex rectangular aluminum tube is used

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Tesla 85 kWh Battery Breakdown

Tesla 85 kWh battery	**Rated**	**Actual**
Cell Capacity, Ah	3.25	3.1
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Total # of cells in series in pack	96	96
# of modules per pack	16	16
# of cells in series per module	6	6
# of cells in parallel in module/pack	74	74
Total # of cells in module	444	444
Total # of cells	7104	7104
Battery Capacity, kWh	**85**	**80**

EV Vehicle and Battery Technology - Tesla

- ✓ Custom EV platforms allow for the implementation of larger batteries
- ✓ Larger batteries allow for the use of low-power computer cells
  - ✓ Low average power-to-energy ratio
  - ✓ Large thermal mass
  - ✓ Currently lower cost per Wh
- ✓ The depth of discharge per cell is lower on larger batteries
  - ✓ On EVs with a 200-mile range, 600 full cycles correspond to 120,000 miles
  - ✓ On vehicles with a 75-mile range, 600 full cycles correspond to only 45,000 miles
- ✓ Tesla recommends less than full charge for normal use
  - ✓ **Due to the greater range, normal charging can be to 80% SOC or lower, which greatly enhances battery life**
- ✓ Tesla’s module design with many cells in parallel allows for single-cell failure without bringing the whole battery down
  - ✓ Thus the Tesla pack is more robust against single-cell failure
- ✓ Tesla has developed significant know-how in module, pack, and vehicle integration and the small-cell approach presents some advantages
- ❖ However, cycle life is lower and utilizing a very large number of cells and four welds per cell is unattractive from the standpoint of reliability

Tesla Battery Life
Promise and Challenge

- Max. charge voltage, high battery temperature, and low charging temperature have a notable impact on life
  - ✓ **If most users only charge to 80% or less and avoid fast charge** most of the time, >800 cycles , >10 years, and 100k miles are perhaps possible in moderate climates
  - ❖ Hot climates reduce life and cold charging can induce imbalances that also reduce life

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Automakers and the 18650 Cells

- Most automakers have evaluated the cell and pack designs and decided against using them in their EVs
- This is true even for new vehicles with ranges >200 miles
- One advantage of the 18650 cells is the low profile (height) which allows for the integration of the battery below the axle
- The analyses of most automakers, supported by estimates from Korean battery makers, show that a pack based on a large pouch will achieve cost parity with the 18650 design in 2-3 years, with better potential for lower cost in later years

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3.1-Ah 18650 Cell Price

150 Million Cells (2 GWh), 2013

3.1 Ah 18650 Cylindrical, 2 GWh, 2013 US plant			
NCA 85,15,5 Cathode, Annual Volume, 200 Million cells			
Component	$	$/kWh	% of cost
Cathode	0.70	62	30%
Materials	**1.41**	**126**	**61%**
Depreciation	*Available with Report Purchase*		
Labor			
Utility			
Manuf ovhd			
Yield losses			
R&D			
SGA			
Cell cost			
Profit, 8%	0.18	16	8%
Price	2.48	221	108%

3.4-Ah 18650 Cell Materials Cost

500 Million Cells (7 GWh—Japan Plant), 2016

3.4 Ah 18650 Cylindrical, 7 GWh, 2016 Japan plant				
NCA 85,15,5 Cathode, Annual Volume, 600 Million cells				
	Units	**Amount**	**$/unit**	**$/cell**
Cathode Active Material	kg	0.0210	31	0.65
Anode Active Material	kg	*Available with Report Purchase*		
Separator	m^2			
Electrolyte	kg			
Copper Foil	kg			
Can, Headers & Terminals	cell			
Other: Al, Al2O3, binders, carbon additives	cell	1	0.11	0.11
Total Materials				**1.274**
$/Wh				**0.106**

3.4-Ah 18650 Cell Price 2016

600 Million Cells (7GWh Japan), 2016

3.4 Ah 18650 Cylindrical, 7 GWh, 2016 Japan plant			
NCA 85,15,5 Cathode, Annual Volume, 600 Million cells			
Component	$	$/kWh	% of cost
Cathode	0.65	53	33%
Materials	**1.27**	**104**	**66%**
Depreciation	0.24	19.6	12%
Labor			
Utility			
Manuf ovhd			
Yield losses			
R&D			
SGA			
Cell cost			
Profit, 8%			
Price			

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42-Ah EV Pouch Cell Price

3.7-GWh Plant, 2016

42 Ah EV Pouch Cell Price

NMC 6,2,2 Cathode, Pouch, 24 Million 42-Ah EV Cells / Year

Component	$	Per kWh	%
Materials	18.3	118	59%
Factory Depreciation	4.7	30	14%
Manufacturing Overhead	*Available with Report Purchase*		
Labor			
Un-yielded COG			
Scrap, 4%			
Yielded COG			
Company Overhead			
Burdened Cost			
Warranty & Profit			
Price	**33.1**	213	**127%**
Gross Margin	5.9		18%

EV Battery Cost Estimate:

Pack, Cell, and Cell Materials

For a 70-kWh Battery, 2016 FY

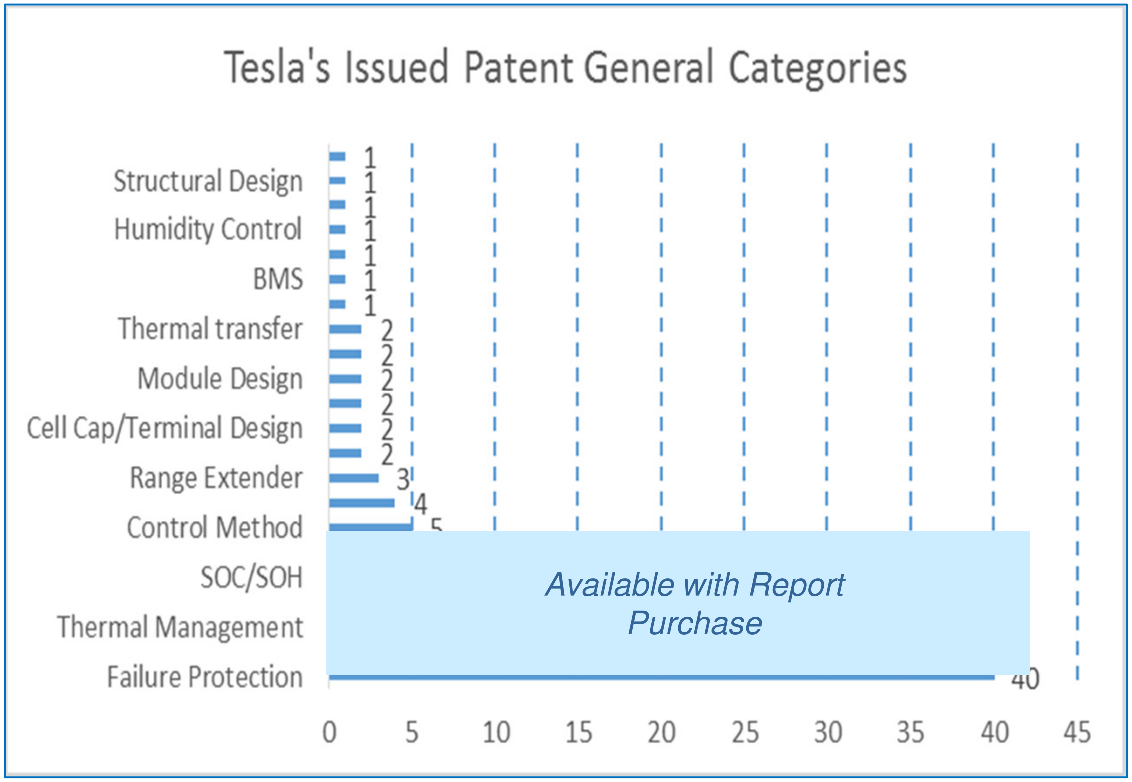
Volume	Cell Materials	Cell Price	Pack Price
Cell Technology	$/kWh	$/kWh	$/kWh
Pouch cells, 3.7GWh plant	118	*Available with Report Purchase*	
18650 , 7GWh plant	106		

Tesla Patent Summary

Issued Patent Breakdown

104 Issued Battery related Patents

- Most Common Function Was Failure Protection, Mitigation and Handling
- Many Patents Issued on User Interface To Vehicle (customization, network connection to vehicle, etc.)
- Patents Do Not Cover Cell Chemistry, but Battery System Design, Application and Vehicle Integration



Tesla's Gigafactory Challenges

- Tesla's 35-GWh plant will be about 10X larger than any existing plant
  - In existing 1-3 GWh plants there are already many process steps performed on parallel lines. The benefits of installing 20-50 parallel lines may be limited
  - Expanded machine size and throughput will mean more upfront engineering, longer startup time, and higher cost, and will present higher risks but perhaps better potential rewards
- Production in Reno Nevada is somewhat attractive due to the low humidity and relatively low labor and utility costs, and to a synergetic effect with solar energy (the latter not necessarily for cost reasons). Economy of scale will only be realized if the factory works at close to full utilization
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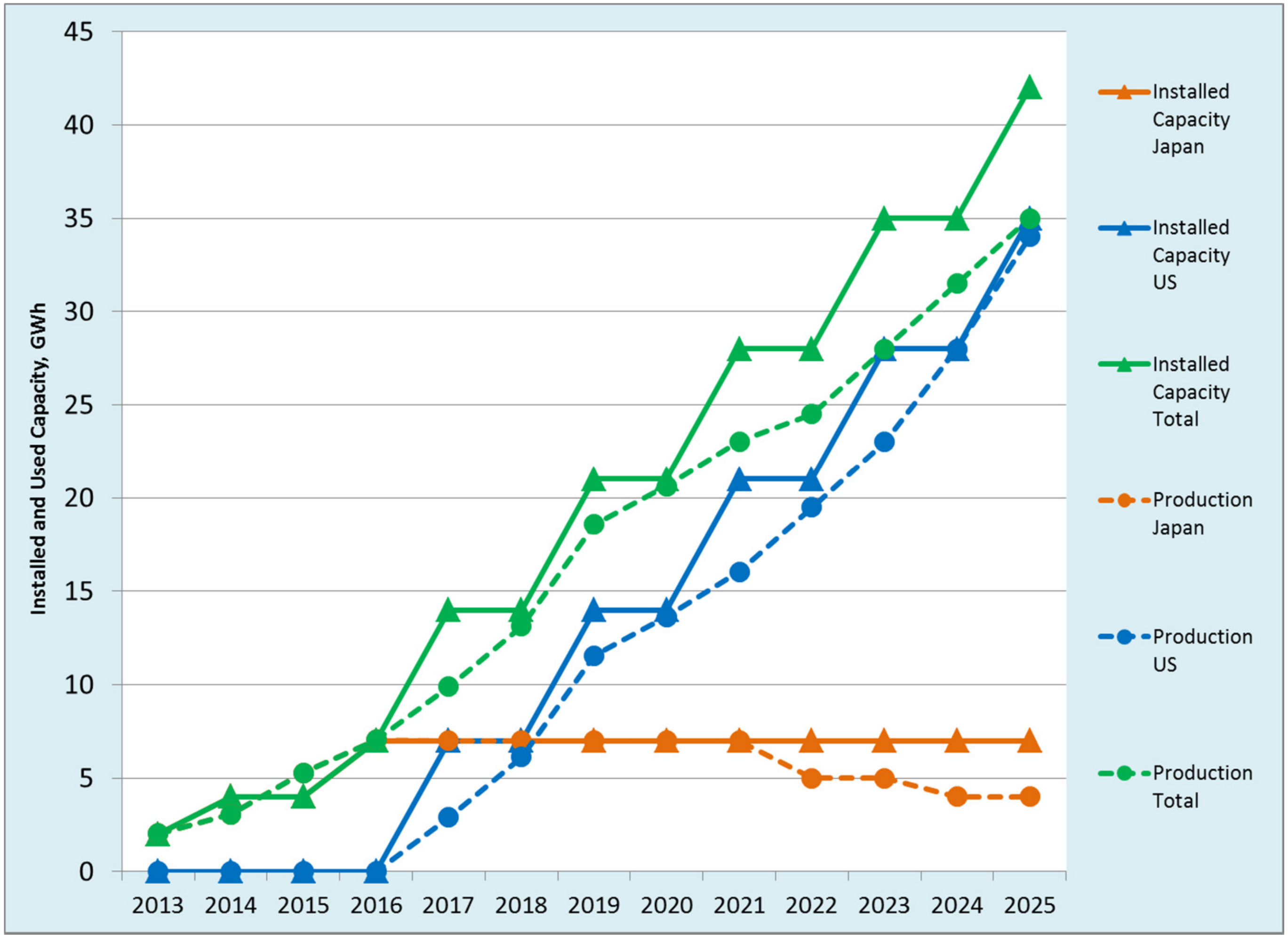
Gigafactory Cell Production

Assumptions for the Analysis

- Panasonic will increase capacity in Japan from 4 GWh today to 7 GWh by 2016
  - Or, alternatively, Tesla will fill the gap with cells from Samsung or LG Chem of Korea
- Tesla will build the infrastructure for a 35-GWh plant but will furbish it and install production lines in stages. The first stage on the order of 7 GWh will be completed by the end of 2016
- The gigafactory will expand in several stages in increments of 7 GWh every two years to reach 35 GWh in 2025

Panasonic-Tesla Projected 18650 Installed Capacity and Production

Japan & U.S. - 2013 to 2024



Tesla-Panasonic Plant Depreciation for Stepwise Expansion

Tesla's Panasonic Production Cost Analysis	Japan 18650 Cells			US Giga Factory 20700 Cells	
	2013	2014	2015	*Available with Report Purchase*	2020
Cars sold, 000'	23	35	60		250
Growth rate		52%	71%		11%
Production, '000 packs	25	39	66		275
Installed Capacity Japan	2	4	4		7
Installed Capacity US	0	0	0		14
Installed Capacity Total	2	4	4		21
US Investment to date	0	0	400		1940
Annual Depreciation, US plant*	0	0	0		243
Production Total	2	3	5		21
Production Japan	2.0	3.1	5.3		7.0
Production US	0	0	0		14
Production, Million cells, Total	184	257	440		1409
Production 18650, Million cells, Japan	184	257	440		583
Production 20700 Million cells, US	0	0	0		826
Depreciation Charges per cell, $	0.33	0.3	0.27		0.29

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70-kWh
Pack Cost
2018

70 kWh Tesla Pack	100k packs / year 2018		
Cost of module components	per module (6s42p)	per pack (102s42p)	in $ per kWh
Enclosures	*Available with Report Purchase*		
Cooling components			
Others, fasteners, interconnects			
electronics			
Subtotal non-cell components			
Cells (4.5 Ah)			
Module integration			
NRE			
CapEx*			
Overhead			
Labor			
Subtotal integration cost			
Total module cost			
Pack components			
Mechanical			
Electrical			
Thermal			
BMS			
Subtotal			
Pack integration			
NRE			
CapEx*			
Ovhd			
labor			
Subtotal integration			
Total pack cost		**$ 14,902**	**213**
Pack minus cells		**$ 2,965**	**42**
Profit and warranty, beyond cells	8%	$ 237	3
Pack price		**$ 15,139**	**216**

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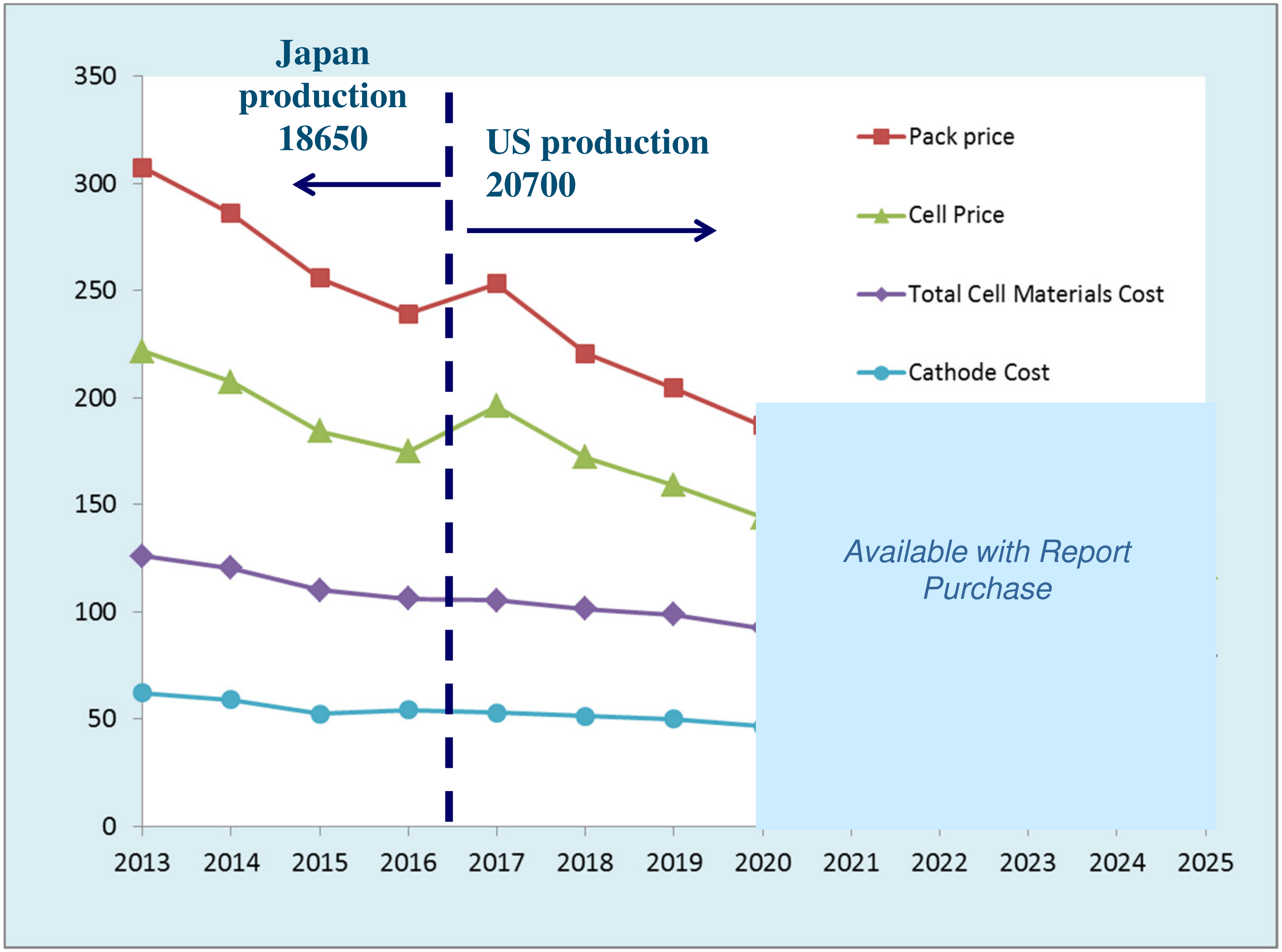
5-Ah 18650 Cell Price

2 billion Cells per Year, 2025
35-GWh U.S. Production

5 Ah 20700 Cylindrical, 35 GWh, 2025 US plant			
NCM 8,1,1 Cathode, Annual Volume, 2 billion cells			
Component	$	$/kWh	% of cost
Cathode	0.68	38	35%
Materials	*Available with Report Purchase*		
Depreciation			
Labor			
Utility			
Manuf ovhd			
Yield losses			
R&D			
SGA	0.075	4.2	3.8%
Cell cost	1.95	108	100%
Profit, 8%	0.16	8.7	8%
Price	2.11	117	108%

Cathode, Total Materials Cost Cell and pack price per kWh Cost 2013 to 2025



Tesla's Gigafactory - Synopsis

- It represents a huge risk and a tremendous amount of cash investment
- It depends largely on Panasonic's willingness to invest
- If 35 GWh are indeed installed and utilized, our assessment shows that pack pricing for the 2025 time scale could be as low as $167/kWh, $8,400 for a 50-kWh battery and $11,700 for a 70-kWh pack
- Battery cost per kWh will go up slightly in 2017 due to high depreciation charges, but larger capacity per cell will neutralize the increase by 2018

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- Pack cost much below $200/kWh is unlikely before 2020, which brings the cost of the proposed 70-kWh pack for a 240-mile D class EV to $14,000 (or higher). Tesla could offer an entry-level version with 45-50kWh (at $9K to $10K per pack) but such a vehicle would not quite attain 200 miles per charge in most real-life driving conditions

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Tesla's Impact on the EV / Battery Industry

- *Available with Report Purchase*
- Whether or not the 18650 approach has a lasting life, EV batteries with higher capacity, lower power/energy ratio, and lower cost per kWh are now viewed with renewed interest
- If the gigafactory is built at a faster rate than proposed in this analysis—and possibly even at the rate of this analysis—overcapacity is likely to happen again
- The supply chain cannot ignore a company that became the largest user of Li-Ion batteries in the world overnight and is planning a 20X expansion in 5 years
  - Some production of materials will be established in the U.S.
  - Volume expectations are up but cost targets for cells and materials are down

Major Materials and their Suppliers

Cathode

- **Lithiated Nickel-Cobalt-Aluminum Oxide**: $LiNiCoAlO_2$ (metal ratio Ni/Co/Al (80/15/5))
- **Aluminum** may be replaced in the future with Manganese or Magnesium, which show potential for a better balance in cost/life/performance/safety
- **Supplier**: Sumitomo Metal Mining Co., Japan
- **Raw Materials**: Nickel sulfate (or nickel nitrate) cobalt sulfate (or cobalt nitrate) lithium hydroxide
- **Process**: High temperature sintering (about 700° C)
- **Investment** estimate $90 million per 7 GWh
- **Other Potential Suppliers** to the U.S. gigafactory:
  - Umicore
  - 3M
  - Toda America
  - Nichia Corp.
  - BASF
  - Later from China

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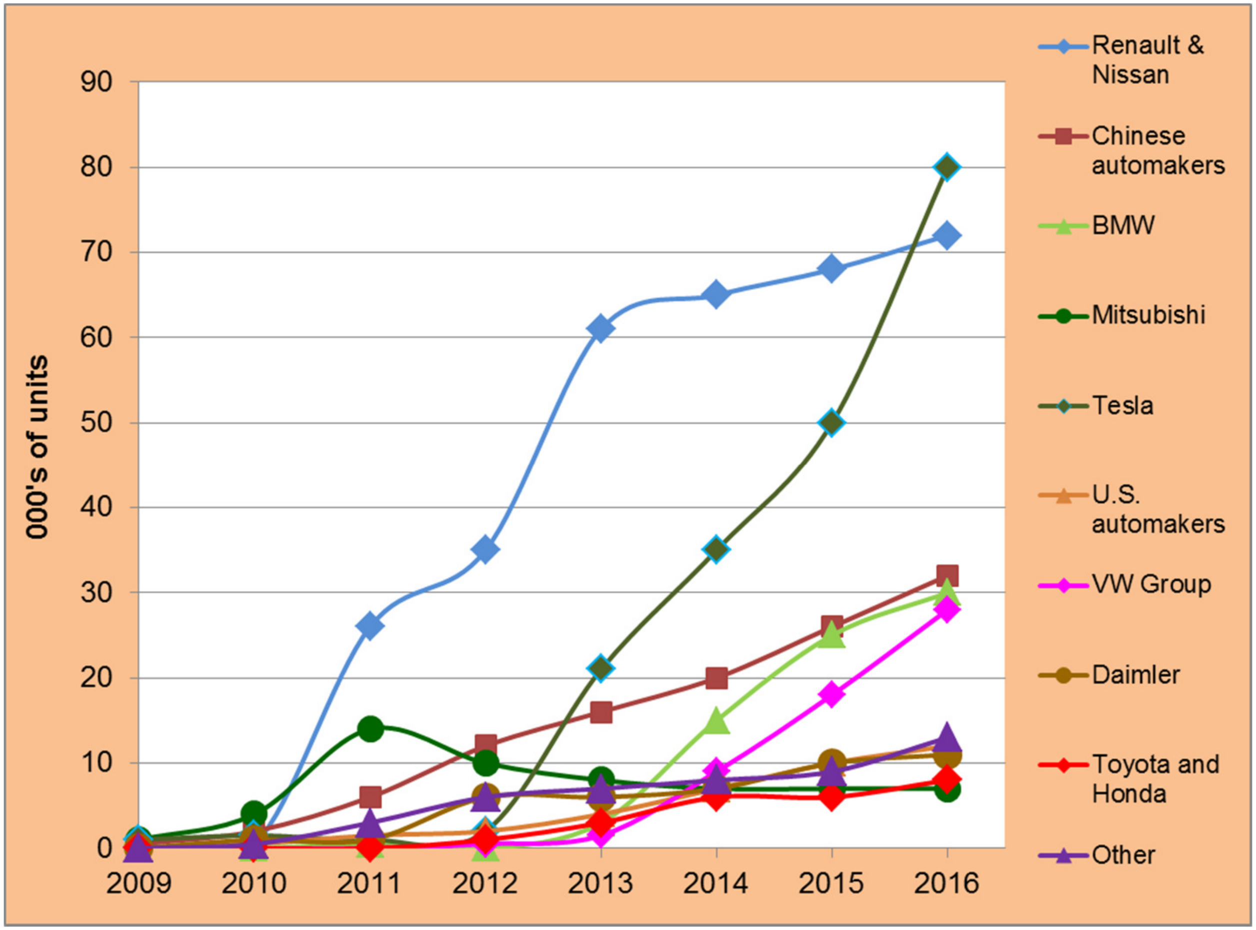
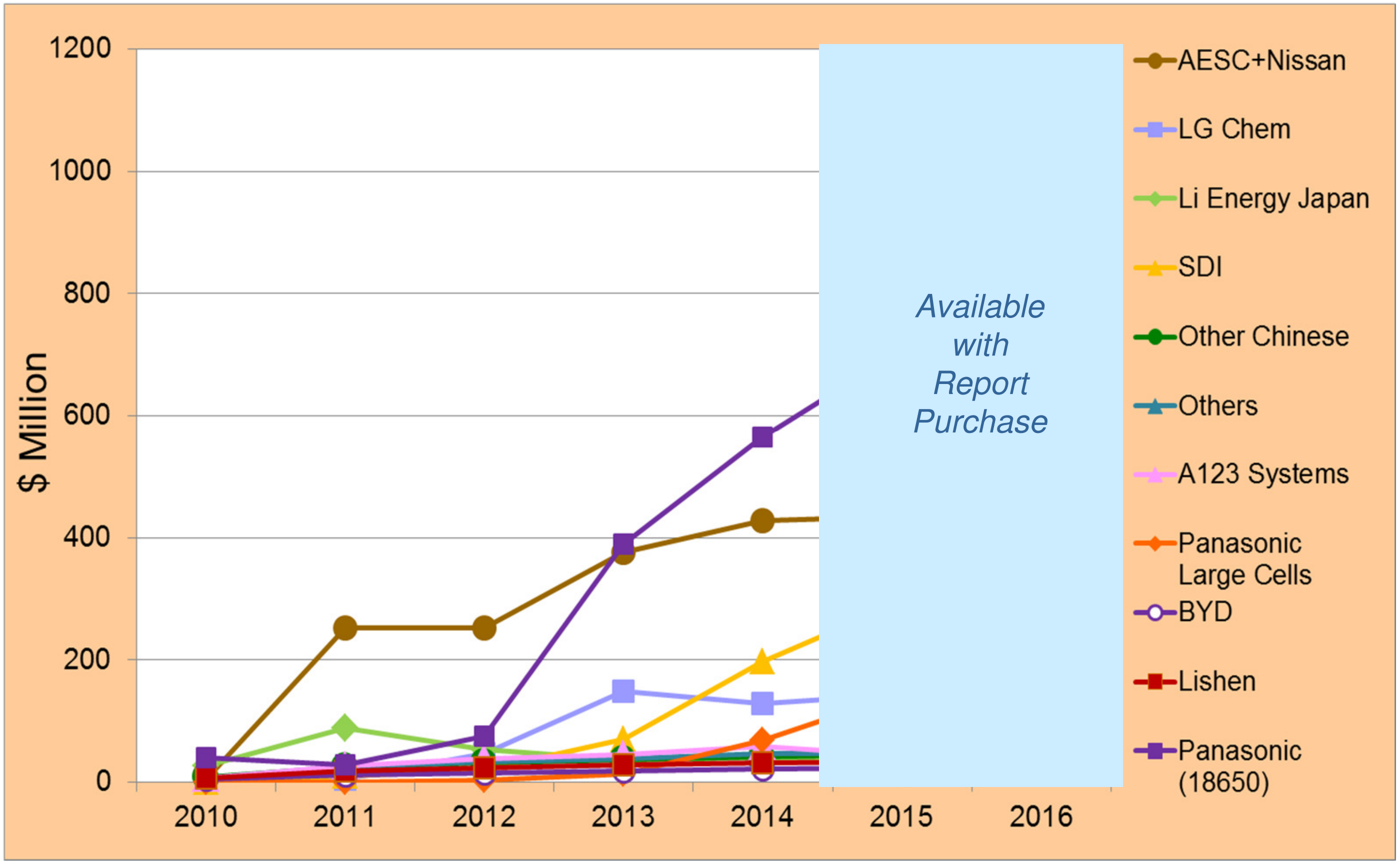
EV Market Forecast by Producer



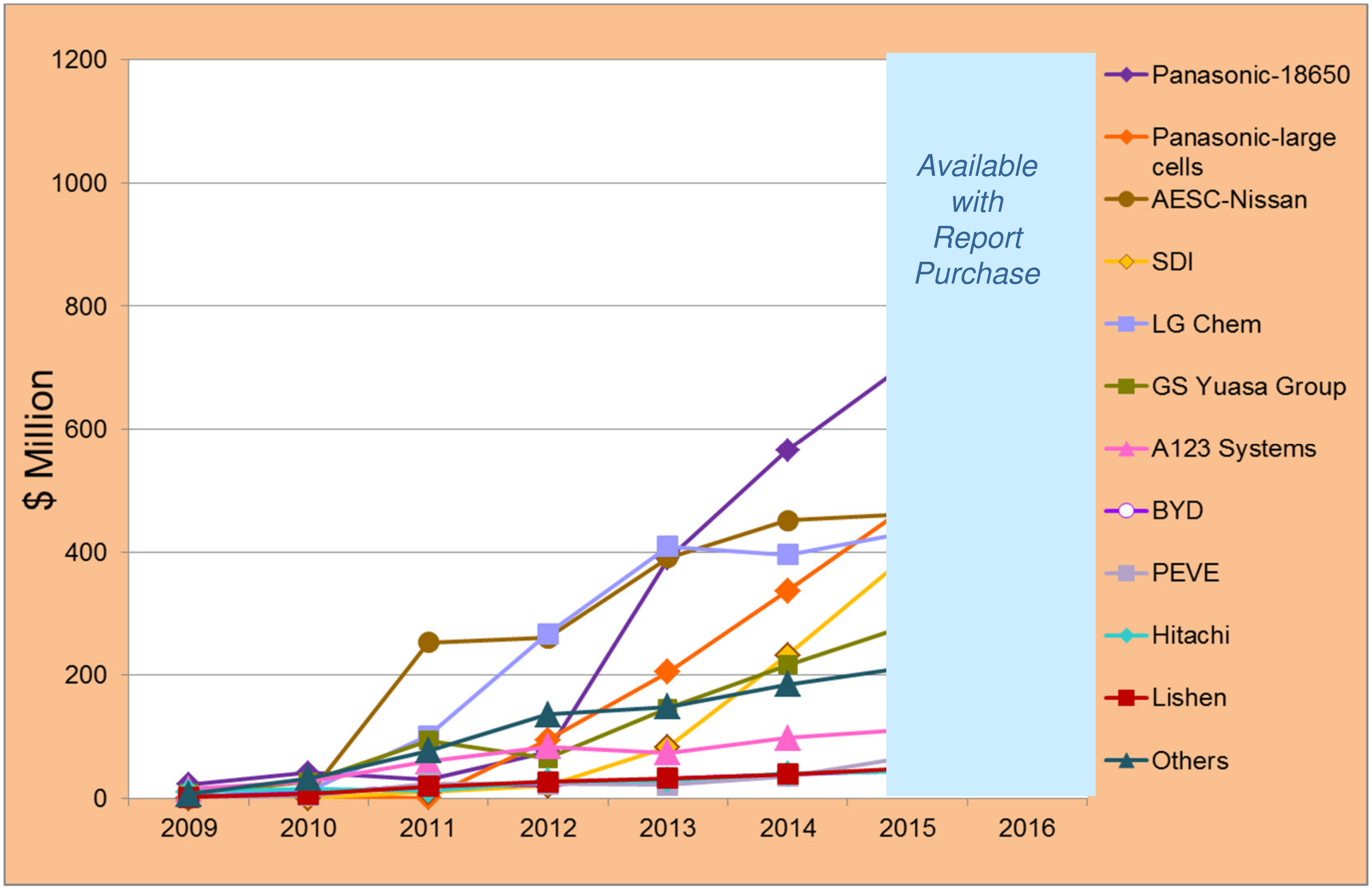
EV Battery Cell Business

Panasonic leads due to Tesla



But LG Chem and SDI are positioned to rapidly increase their market share after 2016

Combined xEV Battery Cell Business by Producer



Government Credits are a Bigger Deal than is Generally Acknowledged

- ***California ZEV credits and federal incentive programs could be more important to Tesla's profitability than discussed publically***
  - *Available with Report Purchase*
- **Tesla will establish volume in vehicle, powertrain, and battery production and will thus be competitive in each of the areas in which they can sell**
  - **Cars**
  - **ZEV credits:** *Available with Report Purchase*
  - **Powertrain**: *Available with Report Purchase*
  - **Batteries**: *Available with Report Purchase*

The Major Risk Factors

1. **The market is not really there yet.**

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2. **Government policies are becoming less supportive**
3. **China is demanding that Tesla invest in China earlier rather than later**

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4. **Battery life and vehicle (including battery) reliability**

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5. Any of the above can **slow down investment by partners** . Uneven investment may hinder the projected aggressive growth

Our Projection: the Most Likely Scenario…

- Tesla and Panasonic will most likely reach an agreement by which Panasonic's investment in the U.S. will happen in stages, 5- to 10-GWh plants at a time
- Tesla will not see much cost reduction from the gigafactory until 2018 or later
- The price of the 2017 new model (prior to government incentives) will be in the range of $45-75K; this is the market segment of sporty mid-luxury sedans such as the BMW 5 series

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- If sales in China are significant, the total sales number for Tesla may exceed 200k by 2020 but Tesla will have to shift some production to China

Tesla's Future and the Gigafactory

Tesla may succeed in accomplishing what the U.S. Government failed to achieve, which is to establish a domestic Li-Ion battery industry—which can be viewed as a huge success in itself, but:

- Will it be profitable?
- Will materials suppliers join the project?
- Will it support the highly lucrative EV business projected by analysts?

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