Expert Call: Electric Vehicle Batteries
Sowing the seeds of an energy revolution

Equities

Global
Chemicals

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EV demand driven by regulation not consumers; bullish on battery cost decline

We hosted a call with Robert Feldmaier, ex-Chief Engineer of the Tesla Model S. He sees EV demand as largely driven by regulations not consumers, and believes that based on current CAFE standards ~30% of vehicles will need some form of electrification long-term (~3% now). These penetration levels are also consistent with EU targets of 95gr of CO_2 emissions by 2020. However, the CAFE rules will be re-assessed in 2017, and this could significantly impact the demand outlook. Robert sees the current 4-5%/year reduction in battery costs as sustainable and views the US Advanced Battery Consortium's (USABC) target of $200/kWh as achievable.

Battery chemistry still evolving; Fuel cells distribution challenge

Though lithium ion is the most promising today, over time other chemistries could win out. He noted that lithium sulphur, lithium-air, and solid state batteries all have similar characteristics with lithium ion. He is cautious on the infrastructure cost of fuel cells as a hydrogen station would cost over $1m (vs. just thousands for EV charging stations).

Tesla read-throughs: Chemical partnerships not out of the question

He thinks that Tesla will be able to launch its Gen 3 vehicle at a base price in the mid-$30k range; however, part of the cost reduction will come from using a smaller battery pack, which lowers range. Battery chemistry may change in time; the initial selection was largely driven by availability. Battery re-use and use extension into renewable energy and in particular could be significant game changer for utilities and solar markets. Lastly, he did see an opportunity in stationary storage, though said that these batteries may require a different chemistry. Given Tesla's limited battery component know how, he believes they are likely to work with partners in the medium term on its Gigafactory, creating opportunities for battery material producers

Chemical companies best exposed to the battery materials fundamentals

Umicore for Cathode Materials, Hitachi Chemical for Anode Materials, Solvay, Asahi Kasei & Arkema for separators, Ube for Electrolytes, LG Chemical for electrolytes and battery assembly, BASF, Johnson Matthey and Clariant for future battery technologies..

Contents

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The following is a transcript, edited for clarity, of the conference call we hosted with Robert Feldmaier, ex Chief Engineer of the Tesla Model S.

Electric cars dominated the auto industry at the turn of the 20th century

Electric cars are not a new phenomenon

In the 1890s, electric cars dominated the global market. That was the very early formative years of the auto industry. Gas was used, and steam as well.

But by 1905, gasoline cars made up 86% of the market. Electric cars had 7%; steam, 7%. Why? First, gasoline was very cheap and readily available. And the cost of electricity at that time was high. That has changed over time. Today, gasoline is more expensive and electricity less expensive. The electrical industry was very fragmented and from my perspective, I think, it still is.

Electric vehicles used lead-acid batteries and had a fairly short range (40 miles), but they were still better than steam (10-15miles). Gasoline cars had to make frequent stops for water at the beginning because they didn't have closed cooling systems. People didn't like gasoline cars because they were noisy, smelly, and hard to start. You had to hand-crank them.

Gasoline was adopted due to lower cost and significantly greater driving range

But one big thing changed that, and that was the electric starter. And the other thing was a Model T, which was a gasoline engine that then went with an assembly line, got the cost down so that normal people could start to buy cars, and then gasoline predominated.

Evolution of battery technologies

Lead-acids are the only battery that was commonly used for a long time.

Back in the 1980's, there was work on nickel cadmium batteries and then nickel-metal hydrides. Nickel-metal hydrides actually came into real commercialization more in the late 1990's. And they offered about twice the energy of lead-acids. So that was a significant improvement. Then people were playing with zinc air. What's really happened more recently in the last 10 years or so is the lithium-ion battery, which again doubled the energy from nickel-metal hydrides.

The big question from batteries is what's next, what will be the next battery chemistry beyond lithium-ions. Quite frankly, that question is not yet answered.

Today, the electric vehicle market is small but growing fast

Electric vehicle sales continue to grow, but it's still a very small fraction of sales in North America. This is also true in Europe in that they have fairly low sales volume. Hybrid vehicles have been picking up a little bit of interest, but they're still only at around 3 percent of total new vehicles sales.

Hybrids could be 30% of the market in the future

What I'm seeing happening in the future on this is that the pure battery electric vehicles are still going to remain a niche market. It's going to be a low percent, something in the couple percent range. But from what I am hearing from the auto companies is that some type of electrified vehicle, a hybrid, could be in the 30% range in order to meet regulatory requirements.

And that's the thing that everyone needs to be aware of. The basic thing to understand is that electric vehicles are not being consumer-driven. It's really regulatory-driven. It's really fuel economy in the U.S., emissions in Europe. In California, it's the zero emission standard.

The market for EV is regulatory-driven, not consumer driven

There has not been a huge explosion in sales of electric vehicles. But in order for the companies to meet these new regulatory requirements, they are going to have to do a lot more electrified vehicles. And this is where it gets a little tricky trying to predict well how many.

The auto companies have a lot of different levers to pull. They are downsizing engines or turbo-charging. They're going to eight- and nine-speed automatics, aerodynamics downsizing, weight reductions – all kinds of things are being done to meet these regulations. Electrification tends to be an expensive way of getting there. It's also a very productive way because it gets you very large increases in miles per gallon, but it does come at a cost.

Auto companies have different levers to pull to meet new regulatory requirements

There are some conferences that I've gone to where a Chrysler and a Ford Powertrain executive both said the same thing, that they are not going to know until they get up to 2017 what the real percent [of cost reduction] is going to be, and it's going to be based upon what other kind of improvements they get.

What's the issue with electric vehicles and its energy storage?

When you look at the energy that you can put on board with batteries and electric vehicles, it's a lot less than gasoline. So that's the basic problem, and it's just physics that you're dealing with. And then you have storage considerations for batteries looking at safety, durability, specific energy, specific power and cost.

There are a many different kinds of electrified vehicles. There is something called a mild hybrid, which is basically a stop-start system. These are starting to become very popular in Europe, and they're starting to gain a little bit of traction. I think you're going to be seeing a lot more of them in the US.

A parallel hybrid system is one where you operate the vehicle with both the gasoline engine and electric drive. You can typically drive these vehicles for short distances at low speeds and in pure battery electric mode. And as you increase your speed or discharge the battery, the motor kicks on and you're driving with both the motor and the engine. That's why it's called a parallel system.

Some of the vehicles had a single mode previously. And there have been a number of two-mode systems where you have two motors – one that operates at low speeds, and another at high speeds. These two-mode systems give you fuel economy improvement and higher speeds [versus single mode systems].

And there's a series hybrid where you're driving all the time through the electric drivetrain, but there's also a gasoline engine on board to recharge the batteries. The gasoline engine basically serves as a generator. But it still feels like you're driving an electric vehicle because you're driving through the electric drivetrain.

And then there's something called a BEV, which is a full battery electric. There's no gasoline engine. It's electric only.

What's important about these different electrifications is that they drive different kinds of battery requirements. For a stop-start, you usually put regenerative braking in, and therefore you're looking for a battery that has some high power to it but low cost.

Energy storage requirements are a function of end vehicle performance requirements

When you go to the parallel hybrid, you're looking at high power, high efficiency, and long cycle life at a shallow depth of discharge. Those vehicles tend to operate on a depth of discharge ranging in the 40% to 60% range.

Nickel-metal hydrides are predominantly used here, and they work pretty well for parallel hybrids. So you will probably continue to see some of these parallel hybrids with nickel-metal hydrides. A lithium-ion battery gives you the opportunity for weight savings and improved space utilization because the volume of the battery is smaller.

And then for plug-in hybrids you want to have high specific energy, but also with a reasonably high-power level. Some of this depends upon how much range you're trying to get in a pure electric, so that's something the car company has to set as a functional objective as they're designing the vehicle.

Pure battery electric vehicles require high specific energy and moderate power. The specific energy is important in order to get the maximum range out of the vehicle. With the electric motor you already get good power and performance, so the power of the battery is not as important.

Managing the trade-off between power, energy, and life/cost

The conundrum that you're dealing with is to try to find the sweet spot in the trade-off between power, energy, and battery life and cost.

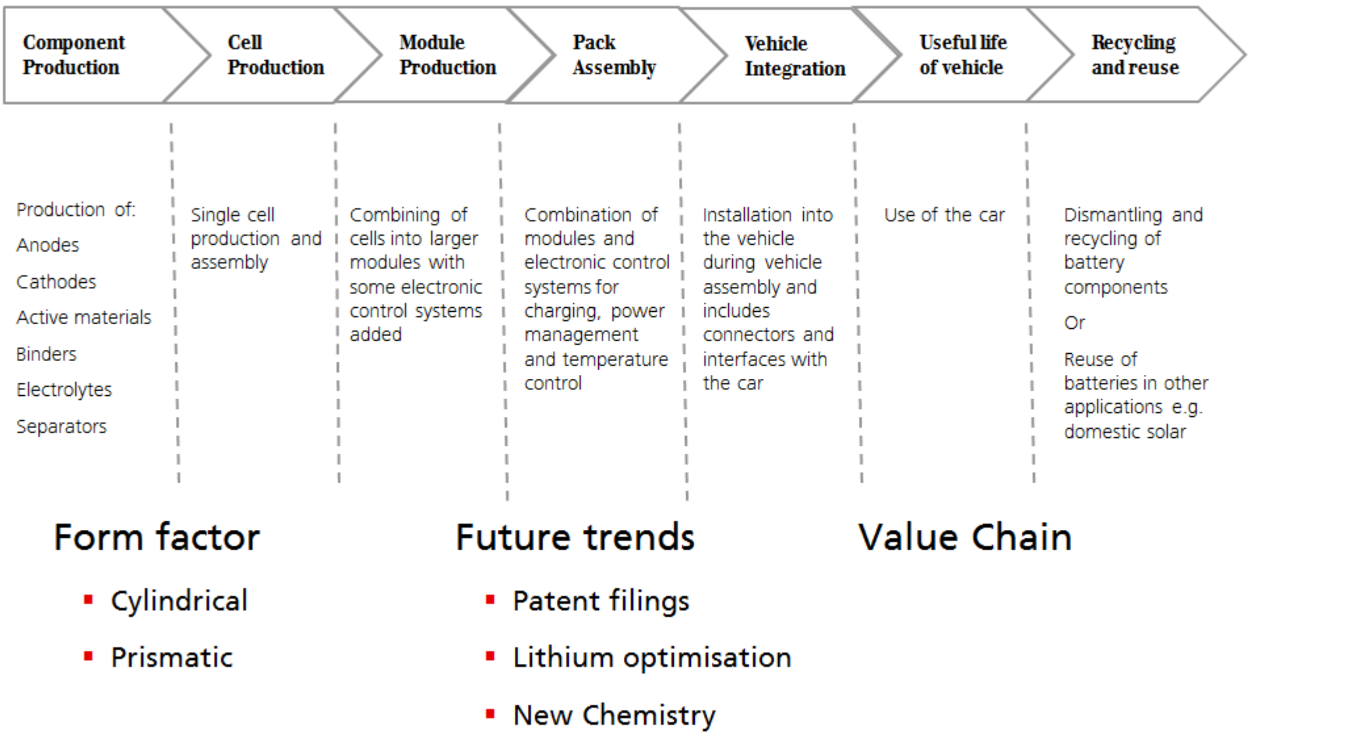
The dilemma:

- Things done to optimise power will generally decrease energy, and vice versa;
- Things done to optimise power or energy will generally sacrifice cycle life;
- Things done to optimise power or energy will generally increase cell cost.

So there are balances and trade-offs that you have to look at as you decide on your battery chemistry and other design considerations. That's the reason why there aren't necessarily winners and losers in the different kinds of battery chemistries that are out there.

What you have to then also realize is that there are different things going on with the batteries from a value chain standpoint.

Figure 1: The 7-step electric battery value chain



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There's something called the form factor of the battery, which is basically the size of the battery per unit output. And there are different configurations you can make the cells, from cylindrical to prismatic.

Looking at the whole production starting with components that you make and then making a cell, the cells are usually then made into modules as modules go into a pack, which also includes your battery management system, and cooling, and so forth. You have to integrate that into the vehicle, you have the lifetime use of it, and ultimately, the batteries need to be recycled.

There's a lot of battery research going on, a lot of patents being filed, and all kinds of optimization on lithium chemistries. My feeling is that ultimately somebody is going to invent a new chemistry beyond lithium. If you look at what's happened from lead-acids to nickel-metal hydrides to lithium, there is a possibility for a new battery chemistry to come about that will surpass lithium at some point in the future.

From a whole value chain standpoint of how automakers build their battery packs, will they buy complete packs; will they buy modules or buy cells? Different companies are doing that in different ways.

My long term prediction is that a lot of companies will end up buying modules and build the packs themselves because the battery pack is a very large item. It's very expensive to ship. And as volumes increase, I think they're going to find the economies of scale are to actually build a battery pack in their own assembly plants. That's what the Chevy Volt does now, and that's my prediction on where things will end up in terms of the best way to build a battery.

Then looking at the different kinds of batteries – I want to qualify that I am not a battery expert, I'm a car guy. But having worked around electric vehicles for 20 years, I've picked up a fair amount of knowledge about batteries and different kinds and so forth.

First of all, looking at how you build the cell itself.

There's a bobbin cell, which is basically the type of battery that you use for a lot of consumer electronics. Bobbin cell production is a very highly automated process, which helps reduce the cost. It has a high energy density and a pretty high ratio of active to inactive materials. It's relatively low power due to the limited electrode interface area, but it also has low self-discharge, which is very important for the longevity of the battery.

As an aside, lithium-ion batteries are very good for not having memory effects. That was one of the big problems with nickel-cadmium batteries that have made them fall out of favour.

Cylindrical cells have high-speed manufacturing capability. They have automated winders and assembly equipment, very good mechanical strength that helps with internal pressures, and low cost sealing. But cylindrical cells have poor thermal characteristics. Auto companies tend not to like thermal events in their batteries. Also, the cylindrical shape is not really optimal for packing density because you have a lot of airspace in between.

One of the other battery shapes that have been looked at is sort of flat-wound. They're also called prismatic. They have the ability of being manufactured with high speed processors in winders, have good thermal characteristics, and you have the opportunity of packing these tighter into the module for better packaging efficiency. On the downsides though it does require some fairly expensive laser welding equipment and some glass ceramic cells.

Types of lithium ion battery technologies

There are multiple types of lithium-ion technology, each with different kinds of pros and cons. Examples of lithium chemistry include:

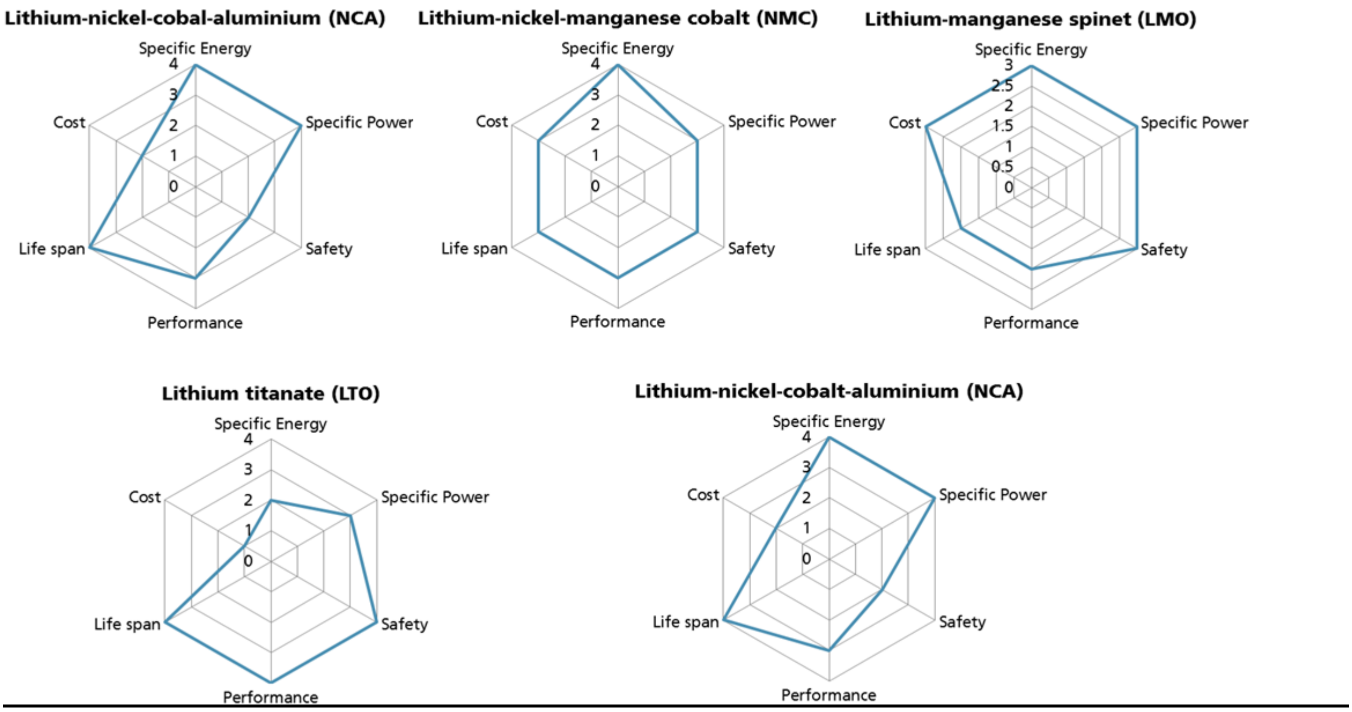
- Lithium Nickel Cobalt Aluminium (LiNCA)
- Lithium Nickel Manganese (LiNMc)
- Lithium Manganese Spiral (LiLMO)
- Lithium Titanate (LiLFP)
- Lithium Iron Phosphate (LiLFP)

The last one is the battery that's used a lot in consumer electronics.

No one battery chemistry dominates the market

[Figure 2] shows you what some of those different trade-offs are as you're selecting a battery based on the key performance characteristics of specific energy, specific power safety performance, lifespan, and cost. As you can see, there isn't any one battery that says – wow, this is it. It's the best in all categories. You have different trade-offs that you have to make.

Figure 2: Battery technologies – several options available with varying capabilities



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As you're designing a car, you have to make a consideration on is what's most important to you. Is it safety? Is it cost? Is it life? Is it specific energy? And look at the trade-offs of those.

Some aspects, particularly the safety aspect, are important because of thermal events. Some of the batteries that are very good for safety are actually just using an air-cooled system thereby reducing cost for the total system. Other batteries that are a little more thermally challenged use liquid cooling systems. But going from an air-cooled to a liquid-cooled system add some cost to the total battery system within the battery pack. So again engineers have to think about trade-offs in battery selection.

Today, lithium-ion, lithium cobalt oxide ($LiCoO_2$) chemistry continues to dominate the market place because that's the battery that's used in handhelds, and that's still the largest use of batteries.

There has been a lot of stuff out in the media with issues on safety. There is the Boeing 787 that had an incident that got a lot of media coverage. And a number of years ago, there were some laptops that were catching on fire. So the safety thing is a big consideration and one that's gotten some media play. That's one that's gotten some play with Tesla as well from a couple of accident situations. These have been accidents, so not from normal use situations.

Opportunities for improvements in batteries

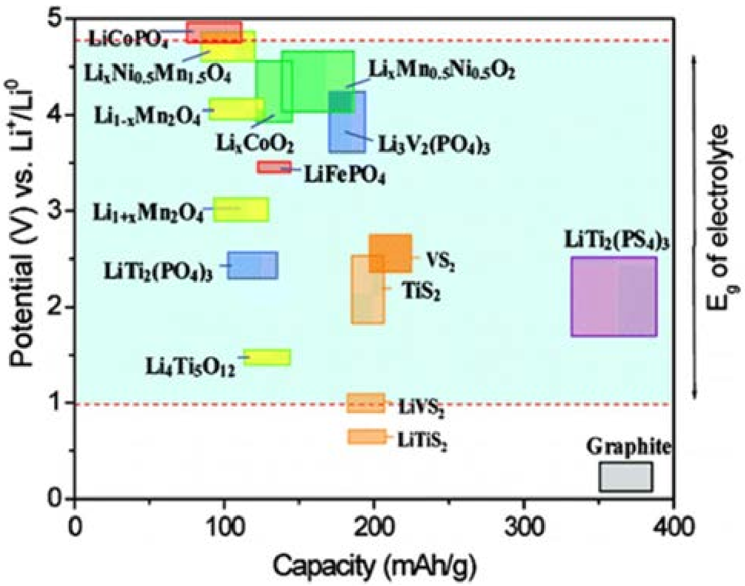
Cathodes offer the biggest opportunity for improvement

The cathodes, I think, offer probably the biggest opportunity for improvement. There are some concerns over the life cycle and temperature stability of lithium manganese, but they do offer very low cost. Nickel manganese cobalt is becoming fairly popular. And it has mixed oxides of nickel, manganese, and cobalt.

There's some tailoring that you can do with that chemistry to do some trade-offs between energy, power, and safety.

One that's been getting a lot of interest recently is lithium iron phosphate. It's got some improved safety to it. It offers the potential of some lower cost, but it's not a good conductor and there are some additives or nanotechnology that's used, and it's really the nanotechnology part of that that probably offers a lot of opportunity yet in this area for improved performance. But it does have a little bit lower voltage per cell relative to nickel manganese cobalt.

Figure 3: Continued development of high voltage cathode materials



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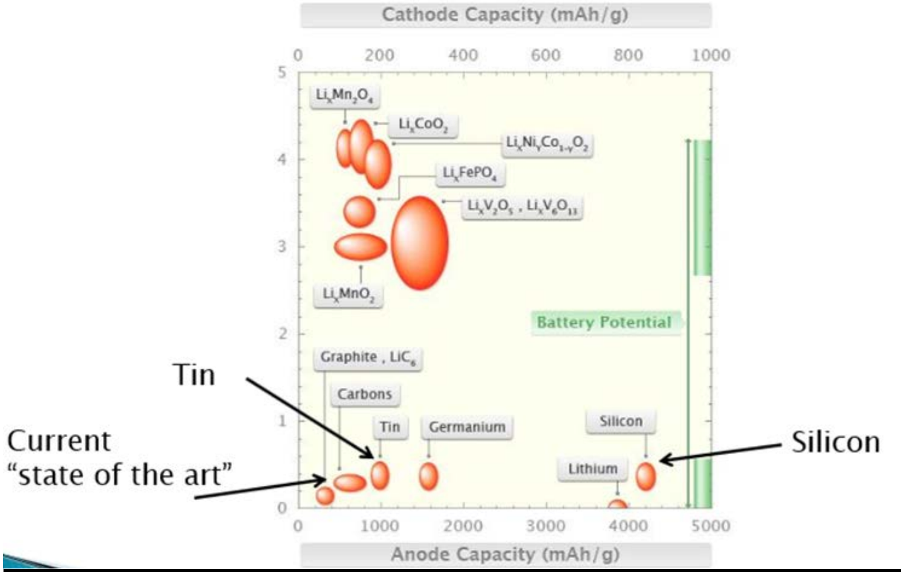
[Figure 3] is a little graph that shows all the different chemistries that are being looked at and the potential from a voltage standpoint, a capacity standpoint, and then the type of electrolyte. It's a rather busy chart, but it gives you a picture that there are all these different kinds of chemistries and each one again has some different trade-offs on performance as you're making those selections.

Figure 4 looks at the different kinds of anodes that are available. There are a lot of anode developments that are going on.

Tin is one that is starting to show some interest because of the low cost of tin. But the one that looks like it maybe has some better long-term opportunity is silicone. This is really more in the laboratory development stage, but it's showing real promise for really improving some of the anode capacity. It will be interesting to see how that plays out as you get into more commercialization.

Figure 4: Anode developments



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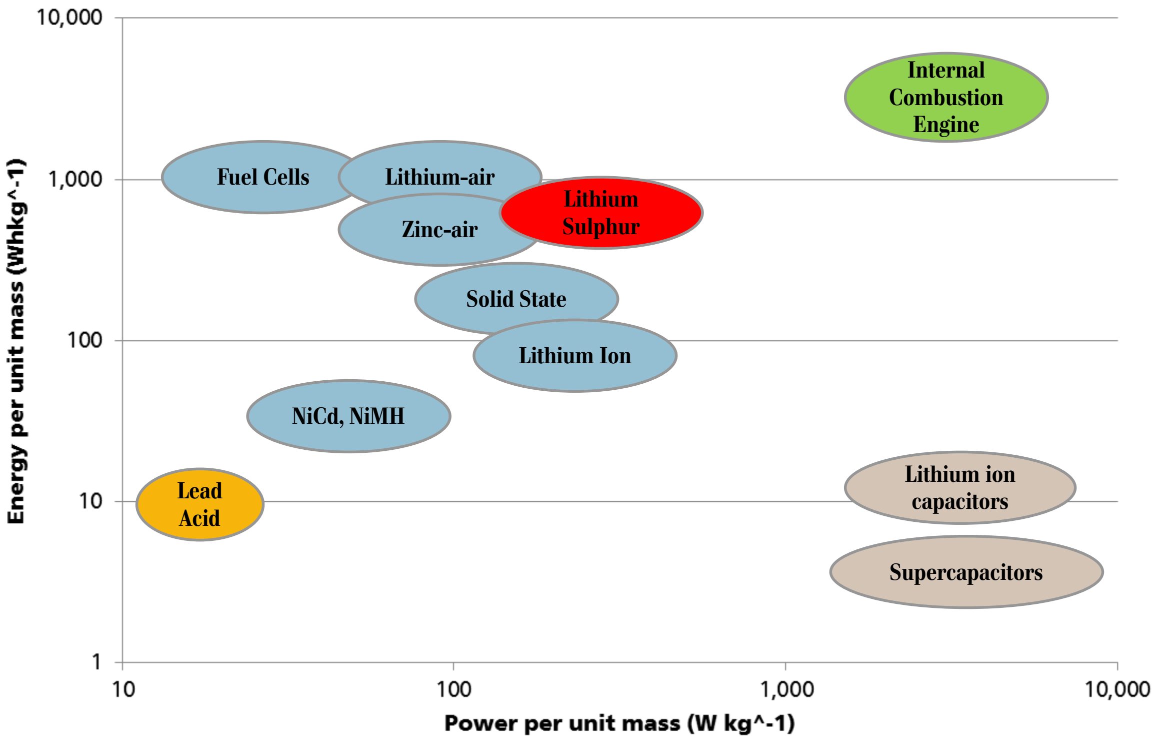
You also have to consider the separator material in batteries. When you look at separators, what you use for some of the smaller batteries that are used in handhelds and consumer electronics are not necessarily the same choice that you use for the larger cylindrical or prismatic batteries. You have to look at what's happening with the operating voltage and thermal profiles in operating environments that are very different in an electrical vehicle than it is on a consumer electronic device. The shut-down function may not operate exactly the same for large format cells either.

One option that is being looked at is some of the ceramic composite materials such as Al_2O_3. Panasonic, LG Chemical and SDI use standard separators with subsequent alumina coating. LG Chemical has a reinforced separator that employs a thick ceramic coating. One of the things this does is to improve the kind of the function from a cell standpoint of puncture-resistance, shrinkage, and internal shorts. = Internal shorts are one of the things that can cause those thermal events that we don't want to have happened.

In electrolyte development, the move to a solid state electrolyte is gaining interest because this is then non-flammable. The challenge you have is trying to get sufficient ionic conductivity at moderate to low temperatures, which again is very important for vehicle operation. There is also work being done around ionic liquids (a.k.a., low temperature molten salts), which suffer from poor voltage stability and are cost prohibitive at the current state of development.

Figure 5 is an overview of how some of the different battery chemistries stack up and how they compare to other alternatives.

Figure 5: How Batteries Stack Up – no battery can beat the energy density and power of petrol (gasoline)



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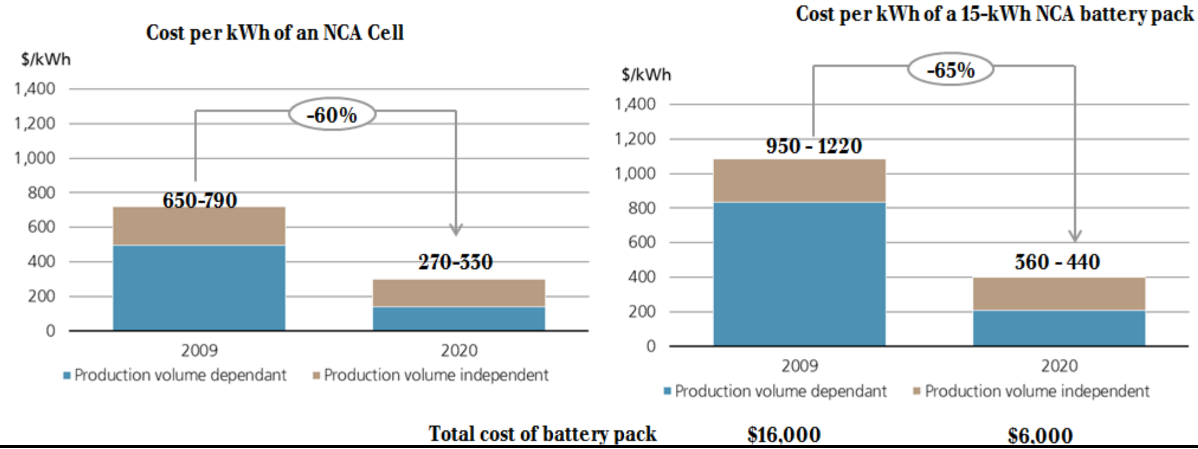
If you look at the bottom left, lead-acid to the nickel-metal hydride lithium-ion, as I mentioned earlier, each time there was a major battery chemistry change there were some very significant improvements. Within lithium-based batteries, there's still a lot of opportunity as we are talking about solid state and there's lithium sulphur and lithium air that are being looked at for future alternatives. So there's still, I think, a lot of improved performance opportunities within the 'general' lithium type of batteries.

There are super capacitors, which I don't see at this point as being something that is going to be real big commercially with automotive use. Internal combustion engines are still way up there on the top right in the chart.

Figure 6: Battery costs will decline 60 to 65% from 2009 to 2020



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Looking at what's going to happen – this [Figure 6] is actually a chart that I had from several years ago as I was starting to do some consulting work. It was about what was happening with battery cost and where it was predicted to go. And I've been finding that this is pretty much a trajectory we've been on.

Battery cost is critical relative to getting the cost of electric vehicles down. From my observations of the industry, battery costs have typically been coming down in the neighbourhood of 4% or 5% per year. That's been fairly constant and I don't see anything that I think is going to change that trend.

Battery cost is critical relative to getting the cost of electric vehicles down.

Some of the things that are causing that are manufacturing improvements with automation, the materials improvements we've been talking about, and then one is basic economics in that as you go to higher volume, you have a larger volume of products that you have to spread your fixed cost over. And one of the things you have to be very careful of if you're looking at battery cost, there's all kinds of cost information out there on cost comparisons. You have to know what you're talking about at the cell level, at the module level or the pack level because they're all very different from a dollar per kilowatt-hour standpoint.

People are managing to get cells down into the maybe $350/kWh range. The USABC [U.S. Advanced Battery Consortium] is trying to get down to or under $200/kWh.

If you project out the 4-5% per year long enough you would eventually get there. So it would be interesting to see how that ends up playing out over time. Will it be from the continuing improvements with lithium? Or will it be some major new battery chemistry that comes about that revolutionizes these things.

Tesla

The last topic I wanted to cover is one that everybody seems to have high interest in. I did work at Tesla. It was for about 10 months. I left Tesla because my job moved to California, and I elected to stay in Michigan. But Tesla is a very interesting company.

It does a lot of things differently than a traditional automotive manufacturer. And what you have to almost think of is that Tesla is not just a car company, it's kind of more of a technology company.

Going back into history, Tesla first started producing the Roadster in 2008. And they wanted to revolutionize what people thought of electric vehicles. They had made a proper decision that, in order to get the range and performance they were looking for, they needed a lithium-ion battery.

The only batteries that were available at that time, in any reasonable quantities, were the lithium-ion batteries that are used in laptops, the 18650 cell size. That's the reason they decided to do that. It wasn't that the cylindrical cells and prismatic weren't OK, it's just that they were not commercially available. And in order to get designs done, prototypes made and tested, they really had to make that decision back in about 2005. That's what really drove the reason for going to that particular battery configuration.

There are larger cell formats that are now available and there's really no clear winner on that. From my perspective, I think some of the larger cell configurations actually probably offer better long-term use in the automobile. Part of this is looking at the number of cells that you have to put into a vehicle. There's a lot of packaging materials that goes around those, and then all of the assembly that's required to put a 1,000 of these little cells together. We're still trying to find what the optimal form factor is.

The decision to go to Panasonic happened after I was there, so I don't know exactly what will happen, but I have to believe that Panasonic offered a very good deal.

One of the other things that Tesla gets out of that is also very good consistency in the cell. Back when they did the Roadster, Tesla was buying cells from different Asian sources. Now that they have one cell all the time, there is less production variation. But I have to believe that Tesla is also studying other alternatives for the future. It's a very technologically advanced company, and they're not going to be standing still.

From a historical standpoint, Tesla started out as more of an electric vehicle powertrain engineering company. They started developing electric powertrains and battery systems, and then decided to get into the car business. With the Roadster, they really didn't do the car; Lotus did that as a kind of rolling chassis and they put the electric drivetrain and batteries in it.

With the Model S, they realized they needed to do the vehicle build themselves. The reason car companies make their own cars, is that it's a matter of economics. Buying a rolling chassis from somebody else, particularly shipping it from Europe all the way to California was not the least expensive way of building a car. So that was what drove the decision that Model S had to be built inside.

And the success of the Model S is in part because it's basically an incredible vehicle on its own regardless of the powertrain. It's a very good-looking vehicle; it's got very good space utilization; and has a lot of neat features, including the very large center stack. That was one of the things we were working on when I was there. It was a huge challenge trying to get that packaged in the vehicle, but it offers all kinds of features and interaction opportunities for the consumer, which again doesn't have anything to do directly with being an electric vehicle. It was just something that's very unique, and one that is getting very high marks from the people that are buying it, really liking it. It's very intuitive to use. Again, coming out of Silicon Valley Company, it's very advanced in that area.

One of the design challenges we had with Model S was trying to figure out how to put that amount of batteries into the vehicle without compromising the utilization of the vehicle. That's why the batteries are all packaged underneath, so there's no intrusion into the passenger requirement. And actually the battery pack housing itself is used to do some of the structural integrity of the underbody of the vehicle.

There's been a lot of interest in what's going on with this Giga Factory and why they are doing that. If you look at some of the stuff that Elon Musk has been talking about in the media for a while, if you project where Tesla wanted to be for sales volumes in the future, he was totally correct that they would become the largest consumer of these 18650 battery cells.

And Tesla is a very vertically integrated company. They make their own electric drive-trains; they make their own battery packs. On the Model S they actually make most of their own stampings. They're even doing some of their own injection moulding. For the size it is, it's tremendously vertically integrated.

So if you look at what is important going forward, batteries are critical in terms of costs and ability to get supply volume. I believe that what's driving the reason for doing the Giga Factory. What you have to also look at is that Tesla has not said exactly what kinds of batteries we're going to make there.

These would not necessarily have to be batteries for use in their vehicles. These could be batteries that they supply to other people or for other uses such as stationary storage. This is where Tesla has been doing some unique things. They're putting in their own fast-charge stations. They have been talking about getting more involved in the recycling of batteries ultimately. Part of this is taking away reasons why you wouldn't want an electric vehicle, but the other part of this is looking at the bigger picture as a technology company.

One way of being totally green with electric vehicles is using wind and solar power rather than coal-fired electrical plants. But one of the more efficient ways of doing that then is with stationary storage at those wind and solar sites. Remember, Elon also has another company called SolarCity. What's really an unknown is stationary storage. There's a little bit of it happening, but there's been actually more talk than action.

As vehicles start to come to their end-of-life because it's down to, say, 60 percent of its capacity, if you started off with something like a Nissan Leaf on a 100-mile range, you're now down to 60 miles. You're getting to the point where maybe the vehicle is not as usable for the customer. It still works, but maybe not to the point you need. And those batteries still have a lot of life left in them for other uses such as a stationary storage device.

But there's a lot of cost involved in dismantling those batteries and repurposing them. Is it actually going to be less expensive to do that or with battery costs coming down would it be less expensive just to put new batteries in? This is where the Giga Factory has another sales opportunity of providing batteries for stationary energy storage. So those are just some of the different things to think about in terms of where and how, you know, batteries could be playing out in the future.

Selected Q&A

Q. On [Figure 5] you have fuel cells approaching an internal combustion engine in terms of energy per unit mass. And Toyota seems to have been pretty vocal recently about moving in that direction. Could you tell us how that plays into this whole scheme?

A. Yes, I can at least to some extent. I've never done any direct work on fuel cells, but obviously I watched what's going on there.

We are probably a long way off in fuel cells

Fuel cells I think are a long ways off. There's a joke within the industry that when do you think fuel cells will have come about. If you asked me 10 years ago, it was 10 years. If you ask me now it's 10 years, although maybe now it's down to nine.

There is still interest in fuel cells because they do offer some very interesting opportunities for the future, in terms of having much better energy that you can have on board, and using hydrogen as a fuel source. But one of the problems is hydrogen and the infrastructure that you need to put hydrogen fuelling stations in.

Toyota is doing this as a demonstration fleet. That's where we were with electric vehicles 20 years ago. People were doing demonstration fleets when I was at Chrysler doing its electric vehicle program. We were building electric minivans. We started off with about 50 that we did on the old original minivan style and then switched to the later generation minivan and produced a couple of hundred of those in a demonstration fleet. The numbers that you're looking at are small, so they are basically trying to get some exposure and figure out how these actually work.

Toyota has not been big on going into full battery electric. They're doing that on a limited basis. They have been saying they're really interested in hybrids. So I think what you're going to see in the short-term for actually meeting regulations, Toyota is going to be doing a lot of hybrids and are really playing with the fuel cell as a way of developing this, getting them ready for long-term.

And remember, Toyota was really the first one to enter the market with hybrids. So I think they are putting some eggs in a long-term basket that maybe fuel cells are the way to go, but it's going to be long-term.

Q. We talked quite a lot about battery chemistries and the battery itself. To what extent do you see battery pack management systems or, for that matter, the electrical drivetrain having a big impact on the performance and the battery life?

I know from a Tesla point of view, they talk a lot about their proprietary battery pack management system. How important is that versus just the nature of the battery itself?

A. It is also extremely important. You can do a lot of optimizing of how much power you're getting, how much range you're getting and then what kind of life you get out of the batteries based on that battery management system. It is extremely important.

And yes, Tesla has done an outstanding job with their battery management. Again, they've got some very sharp electronics people from Silicon Valley who are working on this. But all of the other auto companies have people who are pretty good at that too.

You know, automobiles today are no longer mechanical systems. They are all electromechanical. Years ago, you used to have an engine controller and a transmission controller. Now, those are put into one. You have all kinds of different control modules that were within the body that are now all incorporated into one body control module. Auto companies have gotten very good on those control modules and that's how they're getting fuel economy improvements, by improving the combustion of the vehicle through electronic controls.

Even if you look at turbocharging, people are now starting to add electric motors on turbochargers so you don't get turbo lag, so you get the instant performance so that people will like the turbocharged smaller displacement engines.

So electronics are still a very significant area both in terms of performance but also in terms of cost production. If you look at all of the control systems, the motor control system, battery system and so forth, if you look at what's happened with consumer electronics, every time a new generation of parts comes out, they're smaller, lighter and cheaper.

The same thing happens with control modules in the automobile. As you get better at the electronic controls each time, the control modules get smaller, lighter and cheaper. So that's another area of cost reduction and performance improvement in the car that will be extremely important.

Q. It appears that the battery costs for renewable storage are much higher than that for electrical vehicles. Is the difference in the capacity of the batteries or the lifetime? How do you think research on one area, or volumes produced for one market, could impact the cost for the second?

A. Yes. It's interesting to see how that plays out. The use of a battery in stationary storage is quite different than in the vehicle. So the battery that you select may be a totally different kind of battery.

The lithium-ion offers very good performance and size and so forth but the lithium battery tends to still be expensive. And in stationary storage, size may not be as important as it is in a vehicle. In a vehicle, you're trying to optimize passenger space and luggage space. So you may go to a different kind of battery chemistry than for those stationary storages.

Where they can still gain from economies of scale is as manufacturing volumes go up, costs go down, and with the other material optimization that happens, if there are lower cost ways of doing cathodes and anodes, those cost savings from those materials could also translate to the stationary storage areas.

In my opinion the stationary storage thing is less developed than the automobile battery right now. It's still more in the, let's call it the beginning evolutionary stages.

Q. Bob, I had a question having to do with the competitive environment. And I wonder if you could, you know, give us an assessment of how big a lead you think Tesla has? And then while there are lots of car companies I'm sure that are doing some work in electrics, who in your mind is actually serious enough become a threat at some point in the future if anyone? Thank you.

A. Yes. Tesla is certainly shaking things up with what they're doing. And they are still a very minor player from a volume standpoint.

But if you go back to the early 1970s, the Japanese were not major players either in the United States or Europe and look what happened. So you need to pay attention because over time, these things can gain traction.

Tesla certainly got some attention at General Motors. I don't know how many of you seen this really interesting movie called the "Revenge of the Electric Car," which stars Bob Lutz from General Motors and Elon Musk from Tesla. There's a lot of interesting stuff in that movie about what caused General Motors to do the Volt. And Tesla is actually part of that, it was said, "Hey, if, you know, this little company can do electric vehicles, we ought to be able to also."

The difference there though is GM took the approach of doing a plug-in series hybrid as opposed to the pure battery electric that Tesla is doing. One of the questions I asked Elon in my interview back in September 2008 was, "Are you guys looking to get into hybrids?" He said, "No, we are going to be a pure battery electric vehicle company." So they are firmly committed to that, I believe.

Other auto companies, as I said, have to do electrification in order to meet the regulatory standards. What's going to be interesting on that though is how well they do at getting customers to buy them.

From what I'm seeing, there's going to be a large increase in electrified vehicles to meet the standards but there's nothing driving consumers to buy them. In the United States, there are something called a mid-term review in 2017. Elections for president are 2016, so the current administration is really big on electric vehicles. It would be interesting to see what happens with that mid-term review.

And that will also influence what auto companies do in terms of, let's call a direct competition to Tesla. General Motors again is one who stepped up to that. They now have a plug in hybrid series vehicle in the Cadillac which is starting to play more in the luxury car end where Tesla is.

But again, it's not a pure battery electric, so it's not head-on competition. And you know, they're doing that off an existing vehicle while the Model S is still very unique.

So the other players I think that will probably give Tesla some challenge will be the European luxury brands like Mercedes, BMW and Audi. That's really where Tesla is trying to position themselves in the marketplace. It will be interesting to see whether people want a Mercedes or people want a Tesla.

Q. I wanted to focus on the cost of batteries and whether it's really realistic for Tesla to be able to produce mass-market cars in three years?

I mean, you pointed out this is a fabulous car but also very expensive car. And as you also pointed out, the other major companies have not pursued all electric batteries. And it seems to me it's for good reason. I mean if Tesla is, you know, fully loaded $100,000 product, the battery pack of all in is running about $42,000. And using your numbers of 5% decline for the year in cell cost, you're still talking about a pack which in three years' time will still exceed $35,000 in cost, and that's just for the battery. So how does Tesla come off saying they're going to be able to deliver a mass-market car for $35,000?

A. OK, well, there are several things. First, I think you're probably a little high on your total battery pack cost. And remember, Tesla actually came out with the Model S with three different battery packs. There was 160-mile, a 230-mile and a 300-mile range pack, and there are significant cost differences between each of those. The cost you were talking about I think is more for the 300-mile pack but I think you're even still a little high there. I can't divulge what Tesla actual battery pack costs are but I think you're on the high side. But for the mass-market vehicle, they haven't said what that base vehicle range is going to be, have they?

Look at the Nissan Leaf. It is a vehicle that's in the mid-$30,000s. And it's only a 100-mile range vehicle. You know, what Tesla can do is offer a low range battery pack in that car and the also upsize an option for a larger battery pack for those who want to spend more money and get more range.

So don't look at it just in terms of the trajectory of battery costs but you have to think about how you can do marketing of this with different battery packs to get your entry costs down. And that's what this initial vehicle was.

If you remember, they said the Model S can be under $50,000 with the $7,500 government credit. And that was with the low range battery pack. That doesn't mean that you make full profit margin on that low end vehicle. Tesla is doing the same thing as every other auto company. You make some profit margin on your base vehicle, but it's your upscale vehicle, your fully optioned vehicle and so forth where you really start to make your profit.

Q. There has been news recently about Tesla open-sourcing its patents and other companies have expressed interest in them. How do you see this affecting the development in the electric car industry?

A. I'm not sure it has an impact. Tesla has already been doing work for other auto companies. They've been doing work for Daimler and Ford and Toyota. And they've been openly saying for a long time, you know, other manufacturers are interested in them doing electric powertrains and batteries and so forth. They're willing to do that for them.

You have to understand how auto companies tend to view what is important to them in its body and power train. The auto companies all do their own major stampings, they build the body and all the parts of the car mount to the body is what -- it's what you see, it's what sets up the structure.

The body is something that auto companies are going to do internally. Power train is considered the heart and soul of the vehicle, so they tend to do their engines and transmissions themselves.

If you take that and extrapolate into the future, it would say that they are going to want to control their own electric powertrains and batteries and battery management systems because that's what creates the function of the vehicle.

In the short term, there are some advantages. They're not spending a lot of money. Daimler and Toyota got electric vehicles into production at a much smaller development cost in order to meet the California ZEV requirements than trying to do it themselves. But I would be surprised to see all the auto companies coming to Tesla to do their electric vehicle power train and battery development for them.

Q. Do you think there's a potential for OEMs using the internal combustion engine just as a generator and then have an electric drive train? And given the efficiency improvements that we're seeing, there's more likely to be a way forward?

Well, yes, you can. In fact, that's really what – like on the Chevy Volt and, you know, the Ford has a focus that's a plug-in hybrid, they have the C-MAX plug-in hybrid... That's what those vehicles do. They use the engine as a generator.

To me, the plug-in hybrid is probably the best technical solution which you can get like on the Chevy Volt. You get 40 miles of range in pure electric. That suffices most people's daily use. So you can plug in at home or if you need to – you know, if you have charge station at work to plug in, you can drive in pure electric mode most of the time but when you need to go farther, you've got the internal combustion engine on board to take you any distance you want.

The problem with that is the cost because you have the cost of an electric motor, batteries, the battery management system, controllers, but you still have a gasoline engine which requires a fuel tank and exhaust and so forth. So it's really difficult to get the cost of that plug-in hybrid vehicle to be competitive with an internal combustion vehicle. It's always going to be higher cost but then you as a consumer have to decide if you get enough operating cost savings to make that initial purchase cost worth it. The cost of electricity versus gasoline at least in the U.S. is about a fourth or a fifth per mile. So if you're able to drive most of the time in pure electric, you can have a very large operating cost savings, but you also have to drive enough miles per day in order to make that pay off.

So that's where I kind of see things. You know, like I said, I think the correct technical solution is the plug-in series hybrid but it's got some costs problems to it.

Q. With their Giga Factory, do you think that Tesla ultimately want to own the proprietary technology, particularly on things like cathodes and some of the key components? Or do you think they're going to continue to be a company that's going to be prepared to work with partners?

A. Well, they will certainly want to have at least partial ownership of that technology. Tesla hasn't played its whole hand here on what all they're going to do with production out of that Giga Factory.

They have obviously opened the door for other battery manufacturers to jointly work with them and that's not surprising because Tesla really up till now has not been a battery manufacturer and there's an awful lot of education that goes into being one.

But there's a lot of education that went into becoming a rocket ship plant too, and Space Exploration did it and they successfully been sending rockets into space. So it's not to say that Tesla could not develop a battery on their own. But that's a long-term project. It takes a lot of time going from the laboratory to upsizing into commercialized sales and then doing all of the testing that's required to get that ready for production. So I think that's why they're looking for some partners, to help get things going quicker for initial production. But that doesn't mean that long term they couldn't be investing in their own battery chemistry and doing their own unique batteries there.

Q. Early in the call, you made the point that volume production and mass-market [of EVs] were incompatible. But I would remind everyone, please tell me if you disagree, I believe Daimler and BMW and Audi each make very nearly 2 million cars a year. The average selling price for each is well north of $25,000. So I don't think there's any compatibility issue there. And then if I'm not mistaken, Tesla hasn't disclosed precise numbers based upon consensus estimates of their current battery cost. They have come out and said that the Giga Factory will get them almost in a step function cost of 30% or more, lower than what they are currently, which suggests, something like a 60 kWh battery five or six years from now in a base car with a base price of $35,000 pre-option. You're looking at battery cost somewhere in the neighbourhood of $15,000 rather than $40,000. Do you disagree with any of that?

A. I guess – on cost reduction, I thought it was more 20% than 30% but I might be wrong. But that's also long term. It's not when they start production of the batteries. That was, as I recall, sometime like 2020 or later, that they were saying that they could get cost down by that amount.

If you look at, again, 5% per year, it only takes you six years to get to 30 percent. So I don't think that's a totally unrealistic kind of percentage to get to at some point in time in the future.

I think your other question was about the mass-market thing again. You know, one of the things on the mass-market with that is going to be interesting to see if you could actually achieve those sales volumes of pure battery electric vehicles. If you look at sales today, it would tell you that just from a marketing challenge, that's going to be significant to sell that number of electric vehicles.

But as I said, the regulations are going to be driving more electric vehicles and the question remains if people will get interested. There was a J.D. Power survey that was done, I don't know, a year and a half, two years ago, and consumers were saying they didn't think they want electric vehicles because they're going to be slow and not fun to drive. That's because people haven't driven them. It's totally the opposite. Electric vehicles have instant torque and constant torque. They're actually a lot of fun to drive. So as you get more electric vehicles out there and people start to understand, ultimately, there will probably be some more consumer acceptance, but I think it's going to be, you know, slow developing now.

Q. I'm curious as to why you feel that way because my understanding is Tesla is able to sell every Model S than what they can do here. Presumably every Model X, they will be able to make with long waiting lists and zero marketing from consumers cross-shopping them with similar drives from Porsches and BMWs, etc.

A. When Tesla started production of the Roadster they had a long waiting list. Towards the end of production, it didn't have. Model S, I'm predicting will probably have a little bit of that same phenomenon. There are a lot of early adopters and I don't know what kind of a waiting list time there is on the Model S now but I'll bet it's less than it was three years ago.

And that's what I mentioned, that the challenge that Tesla will have is going up against the other premium brands like Mercedes, BMW and so forth in the future that are also offering electric vehicles.

A lot of this is branding. There are people who are going to look at Tesla as being something unique and say, "Well, I'd rather be driving the Tesla than a Mercedes". The jury is still out on that. Tesla hasn't had that kind of direct competition with upscale brands. And that's where I think the challenges will be, are they really going to be able to be able to sell at the volumes that they're talking about? That to me is the bigger challenge than trying to get the base cost of the vehicle in the, you know, $30s.

Q. I'm curious as to your view of whether it is possible for ZEV credits to be a very meaningful kicker for Tesla in the future?

A. Yes, Tesla is not doing this because they have to. They're doing it as a business proposition and trying to make money from building and selling electric vehicles. For the other auto companies, they have a little different basic cost situation. They already have a large organization set up for internal combustion engines. So they have to look at the cost of doing an electric vehicle versus an internal combustion engine, and looking at profit margin of one versus the other.

The challenge then is also from a brand standpoint, Tesla has done in my opinion a wonderful job of doing an upscale brand image and therefore people are willing to pay a premium to be driving the Tesla. Chevy, Ford and Chrysler don’t have that luxury of being able to, to do a Tesla Model S vehicle and call it a Chevrolet and sell it for $60,000 to $100,000 because people wouldn't pay that much for a Chevrolet.

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Asahi Kasei[5]	3407.T	Neutral	N/A	¥774	11 Jul 2014
BASF SE[14]	BASFn.F	Buy	N/A	€83.74	10 Jul 2014
Clariant[5, 18b]	CLN.VX	Buy	N/A	CHF16.88	10 Jul 2014
Ford Motor Co.[6a, 6c, 7, 16]	F.N	Buy	N/A	US$17.30	10 Jul 2014
General Motors Company[2, 4, 6a, 6b, 6c, 7, 16]	GM.N	Buy	N/A	US$37.75	10 Jul 2014
Hitachi Chemical	4217.T	Neutral	N/A	¥1,626	11 Jul 2014
Johnson Matthey	JMAT.L	Neutral	N/A	3,009p	10 Jul 2014
LG Chemical	051910.KS	Buy	N/A	Won284,000	11 Jul 2014
Shin-Etsu Chemical	4063.T	Neutral	N/A	¥6,075	11 Jul 2014
Solvay	SOLB.BR	Neutral	N/A	€123.50	10 Jul 2014
SUMCO	3436.T	Neutral	N/A	¥957	11 Jul 2014
Tesla Motors[13, 16]	TSLA.O	Neutral	N/A	US$219.46	10 Jul 2014
Ube Industries	4208.T	Not Rated	N/A	¥172	11 Jul 2014
Umicore	UMI.BR	Buy	N/A	€34.10	10 Jul 2014
Wacker Chemie[18a]	WCHG.DE	Buy	N/A	€82.58	10 Jul 2014

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