An Analysis on Sub-stoichiometric Germanium Selenide for Lithium-Ion Battery Anodes Capable of Charging in Seconds

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Executive Summary

This Quicklook analysis looks at a Germanium-Selenium (GeSe) composition technology that has proven itself at the chemical level to increase the life of a battery charge while decrease the amount of time needed for a battery to fully charge.

At the base level, this technology looks promising, however after analyzing the battery markets, talking with the inventor, and conducting subject matter expert interviews with a wide range of individuals, we conclude this technology, while impressive at the chemical level, is not commercially viable either through a company based patented technology or through licensing to battery manufacturers.

We recommend no new funding go toward improving this individual technology or to file patent protection in the U.S. or worldwide.

Technology Description

A team of researchers, led by Dr. Buddie Mullins with the McKetta Department of Chemical Engineering at the University of Texas at Austin have developed and demonstrated an anode material Germanium-Selenium composition that can be used as the active material in Lithium-Ion (Li-ion) battery anodes.

The GeSe composite is an alternative to current materials used to comprise anodes such as graphite. This technology exhibits a quick charge, high coulombic capacity, which is also known as the level of battery output in volts, and a better charge cyclability. The use of GeSe for the Li-ion anode has been successfully tested for thousands of cycles and the results have been published in journals, most recently in 2014, in The Royal Society of Chemistry journal.

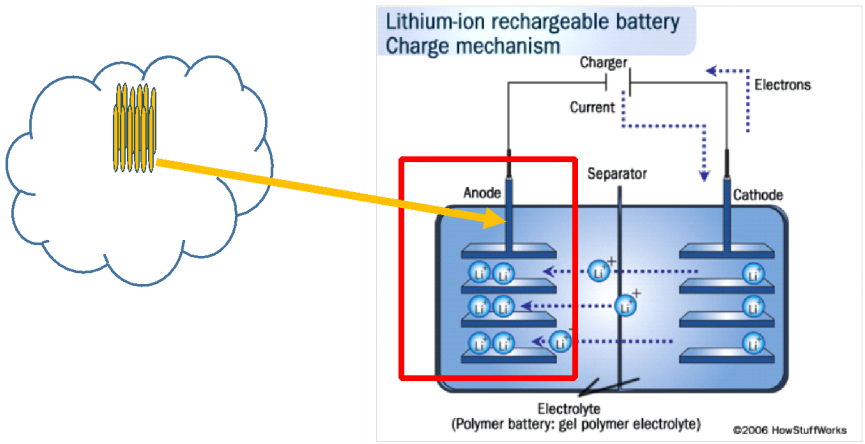

Figure 1. How a Lithium-Ion Batter Works[1]

Current limitations of power management with Li-ion batteries are tied to the charge time of anodes and overall battery size. The common denominator limiting technology design innovation is the size of battery and the ability to maintain charges over long periods of time. Form factor characteristics in the technology industry are shrinking exponentially across components with the exception of the battery power source.

When compared to the standard lithium-ion battery with graphite, a battery running with the GeSe composite technology would be expected to run 2.5X longer, require 3X less space, and able to reduce charging times threefold. Although the potential in the small battery market is boundless, the focus of our research has been through the Li-ion requirements as part of a licensing deal to battery manufacturers.

There is an extensive market that caters to the consumer electronics and commercial application for battery use and reaches into many different industries due to consumer demand for higher efficiency batteries.

Potential Advantages and Benefits

Battery technology is over 2,000 years old, but it has been the bottleneck for the progress of electrical devices and technology. GeSe anodes could revolutionize how batteries are made and enhance their capabilities to meet an ever-increasing demand for mobile energy. This technology is in the incubation stage and because of this it is difficult to determine the impact, but there are some clear niche markets that would have a strong commercial demand for this product.

The following list of benefits is based off of laboratory observations in a controlled environment. It is assumed the rate of charge and overall capacity would remain the same if scaled up in size. *See chart below on where GeSe batteries fit into the battery market space*.

- Faster charging times
    - Test results show a 3X decrease in charging time
    - (Example: Current lithium-ion technology 3 hours ~ 1 hour GeSe battery)
- Greater capacity
    - Test results show a 3X increase in total capacity
    - (Example: “AA” GeSe sized battery would have 3X the life of existing technology)
- Battery size
    - Technology could allow for decrease in size of batteries relative to capacity

[1]Brain, Marshall. "How Lithium-ion Batteries Work" Nov. 14, 2006. HowStuffWorks.com. Accessed Jun 3, 2015. http://electronics.howstuffworks.com/everyday-tech/lithium-ion-battery.htm

- Environmental Health and Safety
    - There is no increased risks around EHS compared to existing lithium-ion batteries
- Potential market size
    - The forecast 2015 global battery sales are $74 billion with Li-ion having approximately $10 billion share or at 37% market share.

Because this technology is in its infancy there are some potential disadvantages that could restrict the market readiness of this technology. Below is a list of potential concerns:

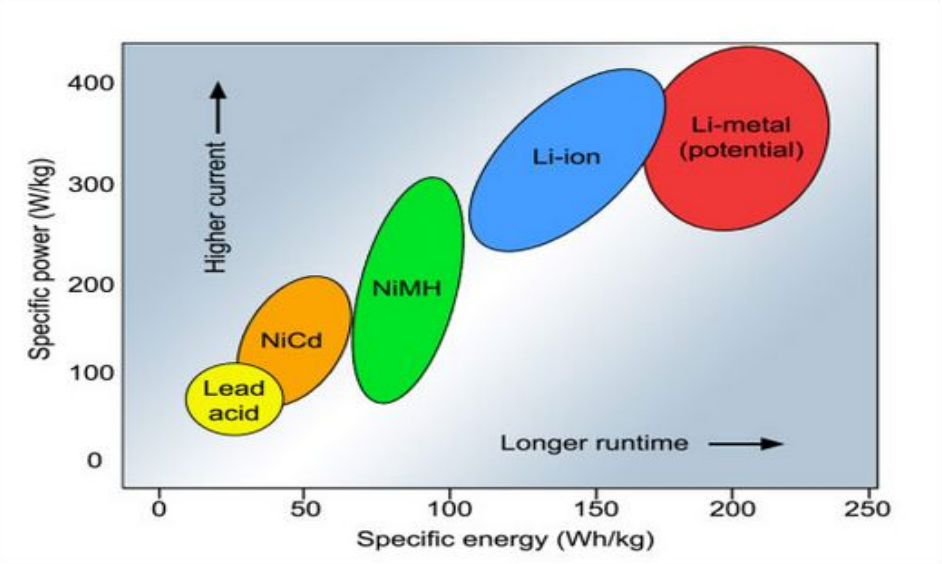

Figure 2. Specific Energy and Power for Rechargeable Batteres[2]

- Ratio of Germanium to Selenium is chemically unstable
    - The material has extraordinary capabilities, but the ratio of Germanium to Selenium is extremely unstable. Because of this instability, the material starts to break down very quickly and consumes the available lithium.
- Cost of Germanium
    - Germanium is a rare earth metal and the current market rate is approximately $2,000 per kilogram. Of note, graphite is approximately $10 per kilogram.
- Manufacturing GeSe material
    - The GeSe material is very difficult to make. It has only been created in very small amounts and in controlled laboratory experiments. The equipment needed to scale this operation would be extremely expensive.

Potential Commercial Markets

The commercialization potential for this technology could be vast and extremely profitable considering the size of the market. The segment that GeSe batteries could compete directly in is the Li-ion space.

The chart below shows the approximate percentage of sales based on type of battery technology and clearly demonstrates a huge potential market for this technology.

The advancements in technology continues to raise the demand for higher performing batteries and is represented by the growth of Li-ion batteries gaining 37% market share in a $74 billion industry.

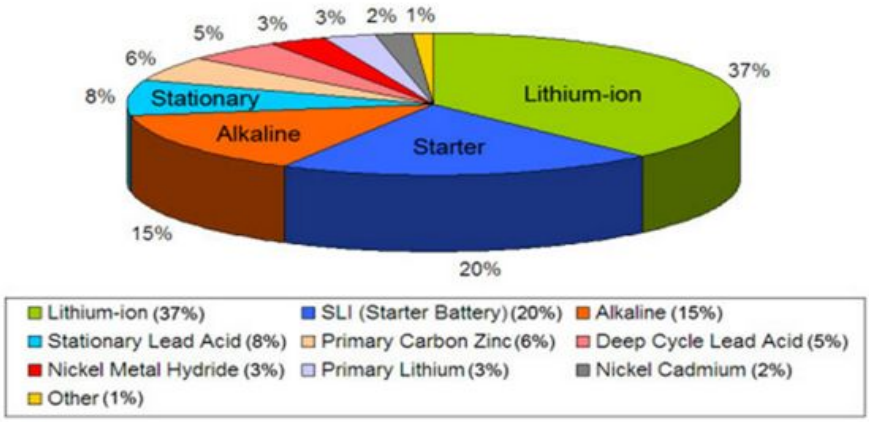

Figure 1: Revenue contributions by different battery chemistries

Figure 3. Market Share of Different Batteries[2]

This growth has been primarily driven from the consumer electronics sector, but battery technology is applicable in nearly every industry. However, due to excessive costs and potential complexities in manufacturing, the GeSe batteries may need to compete in a much tighter specialty niche market.

Key Market Applications

Currently the costs associated with GeSe could limit the market applications. Due to the excessive material and manufacturing costs, the GeSe batteries market segment may need to focus on highly technical applications where function and capability override the prohibitive costs. Potential industries include aerospace, military, and consumer electronic applications.

Growth Indicators

The growing demand for higher capacity batteries continues to outstrip the actual capabilities of the market place. Li-ion batteries represent the best commercially available

[2] Battery University. "Global Battery Markets." 2015. Accessed June 7, 2015. http://batteryuniversity.com/learn/article/global_battery_markets

technology on the market with expected growth to reach $15.6 billion in the U.S. by 2020 (see growth chart below).

- U.S. growth between 2001 and 2015 (36% annualized)
- U.S. growth between 2015 to 2020 expected to grow by (12% annualized)
- Declining growth expected as Li-ion now represents 37% of the market
- Li-ion batteries continue to gain market share
- Shows huge potential growth of GeSe batteries

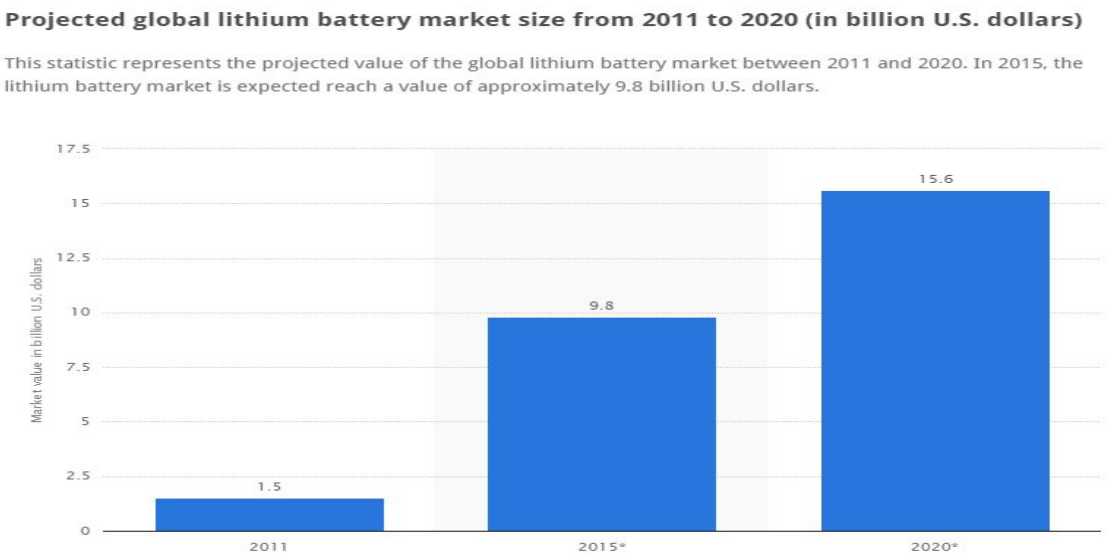

Figure 4. Projected Growth in the Global Lithium Battery Industry[3]

Market Interest

Overall, demand for lithium-ion batteries is expected to continue to grow till the year 2020. Small electronic manufacturers, the grid and renewable energy storage segment, along with a greater increase in the battery market by automobile manufactures; specifically Tesla and Toyota all will drive the growth of the battery market. In 2013, for example, worldwide sales for plug-in vehicles amounted to 400,000 units – which grew to over 700,000 in 2014. A 75% increase in just one year[4].

[3] Berger, Roland. "Projected global lithium battery market size from 2011 to 2020." Statista. 2011. Accessed June 8, 2015.
http://www.statista.com/statistics/235316/global-lithium-battery-market/

[4] Sullivan, Frost. "Global Lithium-ion Market to Double Despite Recent Issues." Frost & Sullivan. Feb.21, 2013. Accessed June 9, 2015.
http://www.frost.com/prod/servlet/press-release.pag?docid=274194514

The continued push for legislative action and consumer demand for electric vehicle production is increasing as more consumers focus on alternative and renewable forms of energy. While pending Environmental Protection Agency regulations restricting carbon emissions and booting auto fuel consumption rates will act as a catalyst to stimulate market demand.

The grid and renewable energy storage energy segment will likely provide the battery market robust growth opportunities for the next 5- 7 years. Vendors such as Tesla Motors and Daimler Benz are now selling modular configurable battery storage for homes and businesses. Reflecting these developments, Frost and Sullivan predict that the market for high-capacity batteries, such as Lithium Ion, will grow from $35 billion in 2016 to $80 billion in 2020, a 128% increase in just four years[5].

With regards to the consumer electronic market, Moore's Law dictates that technology will become cheaper while becoming more robust and efficient – between 2006 and 2014, the cost per Kilowatt/Hour declined by over 70%, and this trend shows little evidence of slowing[6].

Using this as a foundation, the consumer electronic market will develop lighter, smaller, and more efficient batteries for the coming "Internet of Things," wearables, and other such technologies.

Technology Development Status

Dr. Mullins and his research team have conducted numerous tests with the GeSe developed as the active material for the Lithium-ion battery anode material. The team has been able to successfully complete thousands of cycles of testing; with each cycle one charge and one discharge. The testing has been conducted at varying rates of speed for charge/discharge. They have validated the proof of concept for the potential of improved Li-ion battery performance with their testing.

However, this testing has been conducted in a small-scale lab environment. To date, this technology has not been licensed nor extended to any third party agency to determine viability for continued testing and development.

The biggest challenges tied to the scale up of testing and continued development of this technology would be the dependency on Germanium, a costly and rare commodity and the transition of the technology into a commercial application that can be scaled to be mass

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[5] Sullivan, Frost. "Innovation Across Key Industries to Quadruple Revenues for Lithium-Ion Batteries." Frost & Sullivan. Sept. 4, 2014. Accessed June 10, 2015. http://ww2.frost.com/news/press-releases/innovation-across-key-industries-quadruple-revenues-lithium-ion-batteries/

[6] Chen, Allan. "New Studies Find Significant Declines in Price of Rooftop and Utility-Scale Solar." Berkeley Lab. Sept. 17, 2014. Accessed June 4, 2015. https://newscenter.lbl.gov/2014/09/17/new-studies-find-significant-declines-in-price-of-rooftop-and-utility-scale-solar/

manufactured for an industry application. The inventors and team have proved the technology works at the atomic level through chemical reactions, but have not reached a point where the technology is efficient on a manufacturing level.

Through the course of our interviews, the inventor stated that he had stopped working on advancing the battery technology and was instead focusing on a different direction to increase battery efficiency.

Patent Status of Technology

No patents have been granted for this technology, however there are two patent applications pending, but have not been reviewed by the US or an international patent office. Thus, the strength of these applications is unknown.
1 PCT application filed: WO2015057678A1[7]
1 US application filed: US20150102257 A1[8]

The patent has been published in full as of April 2015. Significant patent fee expenditures for filing, translation, and attorney fees will be required in 2016 when the PCT application enters the national phase. The possible expenses to be incurred on these two patents, if the PCT application is filed in 9 countries, could exceed $430,000 over the lifetime of the two patents as determined by the U.S Patent and Trademark Office. The US and PCT disclose similar information, however the US application has 20 claims, while the PCT application has 80 claims. Because there is no patent on the technology currently, a failure to proceed with the patent application will result in the technology being unprotected due to its public disclosure.

Competing Technologies and Competitors Notes

This technology will compete against many firmly established technologies and new technologies looking to improve the performance of already established battery technologies. In fact there are more than 30 different battery technologies currently in production that serve numerous consumer and commercial applications. Many of them utilize distinct natural earth metals through a combination with other atomic elements to create batteries, such as the ones listed below[9]:

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[7] World Intellectual Property Organization. "Sub-Stoichiometric, Chalcogen-Containing-Germanium, Tin, or Lead Anodes for Lithium or Sodium Ion Batteries." April 23, 2015. Accessed June 5, 2015 https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2015057678

[8] US Patent & Trademark Office. "Sub-Stoichiometric, Chalcogen-Containing-Germanium, Tin, or Lead Anodes for Lithium or Sodium Ion Batteries." April 16, 2015. Accessed June 5, 2015. http://appft1.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PG01&p=1&u=/netahtml/PTO/srchnum.html&r=1&f=G&l=50&s1=20150102257.PGNR.

[9] Wikipedia. "Lithium-Ion Battery" March 26, 2003. Accessed June 5, 2015. http://www.wikiwand.com/en/Lithium-ion_battery

- Standard disposable batteries
- Standard rechargeable batteries
- Nickel Metal Hydride batteries
- Lithium Ion batteries
- Numerous other battery materials and Germanium-based materials
- Automobile Battery Manufacturing (Tesla and Toyota)

Note: These are just a few of the many different types of batteries our technology would compete against, which leaves buyers in the battery market many choices

Of the established technologies, Zinc-carbon is the standard single use battery in most small electronics, and nickel-cadmium battery is the standard rechargeable battery used in small electronics.

Companies are working on technology to enhance the performance of the established battery technology. One such technology is a reusable attachment claiming to make batteries last 8X longer[10]. Additionally, BASF has developed technology to double the energy storage of Nickel Metal Hydride batteries, making this technology more advantageous on a per cost basis[11]. BASF is currently licensing the technology to numerous major battery manufacturers[12].

In addition to these competing technologies and companies, the inventor is currently working on a new competing battery technology and Tesla is making their electric car battery technology available to the world for free[13].

Finally, there are many competing Germanium based battery technologies. Two years ago Germanium was *the* new material that would revolutionize battery technology. Because of the interest in the material, many researchers began working on technologies utilizing Germanium. This has led to many patents and technologies using Germanium for batteries[14]. However, no Germanium-based technologies have caught on with manufacturers to date.

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[10] Reed, Brad. "This tiny $2.50 device extends your disposable batteries' lives by up to 800%." BGR.com. June 2, 2015. Accessed June 5, 2015.
https://bgr.com/2015/06/02/batteriser-battery-life-extension-device/

[11] Bullis, Kevin. "Old Battery Type Gets an Energy Boost." MIT Technology Review. Feb. 19, 2015. Accessed June 5. 2015.
http://www.technologyreview.com/news/535251/old-battery-type-gets-an-energy-boost/

[12] BASF. "Licensing Agreements." BASF. Accessed June 6, 2015.
http://www.catalysts.basf.com/p02/USWeb-Internet/catalysts/en/content/microsites/catalysts/prods-inds/batt-mats/NiMH-licenses

[13] Musk, Elon. "All our Patent are Belong to You." Tesla Motors. June 12, 2014. Accessed June 7, 2015.
http://www.teslamotors.com/blog/all-our-patent-are-belong-you

[14] Loveday, Eric. "Germanium-Based Battery Claimed to Double Range of Electric Vehicles." Inside Evs.com. April 29, 2013. Accessed June 8, 2015.
http://insideevs.com/germanium-based-battery-claimed-to-double-range-of-electric-vehicles/

Battery Market Analysis

Using Porter's 5 Forces Market Analysis, the overall competitive analysis for the battery industry is extremely high and any investment would have to be large in order to gain a foothold. This is due to a very high switching cost needed for a relatively untested scaled manufacturing of the Germanium-Selenium anode composition. There are also a large amount of competitors that offer different battery models and types for nearly every type of consumer and industry battery application.

One of the biggest barriers for the GeSe composition is the technology portion of it, as the inventor is already working on a different form of the battery, leading to little human capital investment in moving forward the technology to a position where it can be patented and licensed to a battery manufacturer.

There is a low to neutral threat of new entrants mainly due to the sophisticated manufacturing process needed to manufacturing the GeSe Li-ion battery. This would require a very large capital expenditure for companies to be able to integrate Germanium into their battery manufacturing process.

Another threat is the manufacturing agreements many consumer electronic and industry electronic companies sign with manufacturers to provide batteries for the electronic applications. Undercutting this process would require a relatively cheap manufacturing process, which unfortunately does not occur with the GeSe composition.

There is a high threat of substitution. The most important threat is the research and development units of large corporations that are already testing new ways to make batteries more efficient. There is also a large selection of batteries for almost every application, and whose ease will almost certainly make the GeSe li-battery hard to adopt.

The power of buyers is low to neutral because of the many different options with regards to battery applications. There are also very few manufacturers leading to few avenues for adoption. The increase in renewable and green technology in the future may provide an outlet by increasing the number of manufacturers who are willing to take a chance on a licensed battery technology.

There is a high power of sellers, because Germanium is a rare earth metal found in limited quantities with most being found in China. This is high risk because the supplies are not only subject to normal trade agreements, but can also be impacted by geopolitical issues within the region and worldwide.

Figure 5. A Porter's Market Analysis for the Battery Industry

Recommendation: Withdraw all patent applications and stop spending money on this invention

While there most certainly is a pain in the market with the lack of battery efficiency by consumers and commercial customers, the current available technology does not do a great job in meeting the needs of the market and we recommend the University of Texas at Austin Commercializing Office remove the technology from any pending patent applications and discontinue funding for it.

Through our market analysis, there is not enough of a pain point to overcome the distinct challenges in scaling the technology from a research laboratory setting to a battery manufacturing capable of producing thousands of batteries per day. The industry has numerous competitors and off the shelf solutions that can make a capital investment in this technology return little to no profit.

Germanium, by itself is a rare earth metal mined primarily in China, meaning the steady supply of the material is subject to normal trade agreements and geo-political tensions. While the U.S. has a strategic stockpile, it is not available for use in large quantities needed to manufacture this technology, since it has been reserved for U.S. military and defense company use to manufacturer night vision lenses.

Through our interviews with subject matter experts along with the inventor, we conclude this technology, while impressive at the chemical level, is not commercially viable either through a company based patented technology or through licensing to battery manufacturers. The inherent instability of the Germanium-Selenium ratio is troubling because it has the tendency to degrade the lithium ion after only a few charges. The difficulty in scaling the technology to a large quantity needed to gain market share within the battery industry will prove to be difficult if not impossible. Through the course of our discussions, we also learned the inventor has moved on to a different battery technology.

Thus without the support of the inventor needed to continue pushing the technology forward, a large amount of battery applications already in the market, and a difficult manufacturing process, we conclude this technology is not viable for the commercial battery industry.

However, if a process to efficiently manufacture Germanium within a Lithium-Ion battery is created, this technology may be worthy of revisiting. Although the inventor is pursuing another approach separate from this technology, this may be a stepping-stone to inventing a more efficient battery that could potentially be licensed to battery manufacturers.

In summary, until the technology to manufacture the GeSe Li-ion battery technology is further developed, no new funding should go toward improving this individual technology or to file patent protection in the U.S. or worldwide.

Interview Summaries

Interview #1: Phone and in-person interviews conducted week of May 25

Interview notes represent a compilation of two discussions:
Dell – former marketing director, End-User Computing
Dell – End-User Computing – Consumer PC Planning manager

Can you tell me about the general market conditions for PCs?

The slowdown in PCs that began at the end of last year continues, particularly in Commercial.

For 2015, we are expecting a contraction in the global PC business (all vendors/all types of PCs and all geographies) by over 6% in terms of number of total units sold and by at least 8-10% in terms of total revenue (ASP to end-consumers times units, not revenue to manufacturers).

Beyond 2016, we expect the total volume shipped for next several years (2017, 2018, 2019) to remain at 2015 levels, while the ASP per unit will drop by an average of 2% per year overall – more in Commercial.

How does the picture change when you split the market and compare market conditions for traditional desktops to laptops?

We expect declines in 2015 for both market segments; but desktops will suffer more – 10-12% declines in units vs. 4-5% for portables. We expect price erosion in ASP of about 2% per year for the foreseeable future for both.

Do you break down the notebook market into any further levels of granularity?

Yes, traditional laptops vs. ultraslim notebooks – sometimes called "ultrabooks" – which feature reduced dimensions and weight while offering mid-to-high levels of compute/display performance and battery life.

Can you give me insight into how these market segments are looking for the future?

As far as laptops go, ultrabooks are where its at. Everyone wants one. People are willing to sacrifice peripherals and ports for reduced size and a sexy form factor, even though all this comes at a significant premium. The new XPS 13 has 4 configurations, $800 to $1900 – with up to a 3200x1800 display and an i7 processor. It's just a bit under 2.5 pounds.

Compare that to a traditional "workhorse" laptop – like the Inspiron 5000. That laptop is more powerful and has more features than the entry-level XPS 13, yet costs a third more. It also weighs 2/3 more at almost 4.5 pounds. More importantly, the form factor for the ultrabooks is so much smaller. The XPS 13 is about 60% smaller by volume. This means a lot for anyone who wants to travel.

World-wide across all products, ultrabooks commanded a 50+% price premium over the average traditional laptop – although that's not exactly an apples-to-apples comparison. Even with the relatively rapid anticipated decline in ultrabook ASPs, we expect that average price premium to remain above 40% until the end of 2016.

The demand is clearly for the ultrabooks – you can tell even as a casual observer because of the higher price points and the relative lack of discounts on our web site for the XPS 13s.

(HWT note: as of 6/8, there are no discounts on the XPS 13 apparent on the Dell website, but the Inspiron 5000 includes a free Samsung or LG 32" LCD TV and a number of other value-add discounts like 3 years free premium support)

We are expecting world-wide demand for ultrabook units to be up by around 25% this year, and perhaps 15% the following year. This is a highly competitive segment, though, and we expect greater than average declines in ASPs going forward. In 2014, the ASP for an ultrabook was right about $1000, for this year, it's about $100 lower. For next year, probably $70-80 lower than that.

For 2015, ultrabooks should make up about a quarter of the WW market by units sold and about third of the market based on dollar value sold. By units sold, ultrabooks should grow to maybe 30% next year.

And Tablets – do you consider those to be ultrabooks or laptops?

Well, tablets can mean a lot of things. I can only tell you about Windows-based tablets – and for the sake of the discussion, that includes tablets and "convertible" or 2-in-1 tablets. But I consider them to be separate. But Increasingly there is less-and-less distinction between a Windows ultrabook and a Windows Tablet/convertible.

Growth worldwide is strong for tablets – up perhaps 50% this year based on volume. So it's faster growing than the ultrabook market. These client machines tend to be much lower performing machines than the ultrabooks and much less appropriate for commercial usage. However, for home and the BYOD market (*HWT note: BYOD – bring your own device, where corporate users bring their own devices to work and use them for work purposes)*, it's significant. Still, in 2015, that overall market represents around 10% of the overall laptop market on a units-sold basis, and less than that on a dollars-sold basis. The typical tablet is maybe half the cost of the typical ultrabook.

So where is the "Client computing" focus?

Well, PC's and Laptops of all sorts are bread-and-butter, so to speak. They are core drivers of revenue.

Focusing in on the portable computing part of this, what are the key drivers in product design and marketing? By this, I'm really asking "what's important to the customers".

That's a complex question, but fundamentally the most important thing is performance. It needs to be fast, the display needs to be great, and it needs to run for a long time on batteries. All that is considered "Performance" to the end-user.

Secondarily, the perception of build and design quality (and the perception of durability that goes with that) is critical. That's part of the reason why so many of these ultrabooks look like they were carved out of a single piece of metal. It's really important to look well-built, sturdy, and reliable.

The third most important thing is price.

Everything else is of considerably less importance – audio quality, webcam, cellular connectivity, etc.

Focusing in on the battery aspect of performance – how important is that?

Battery life isn't nearly as important as overall "speed", but it's about as important as display quality.

How interested would you be in a technology that would allow Lithium Ion batteries to hold more charge in a smaller volume of space – and recharge in a small fraction of the time versus traditional Li-ion batteries used today in Laptops?

Well, we aren't looking to manufacture batteries. We might be interested in batteries that we could source that fit that description, but I can't give you a "yes or no" answer on that. Consumers are more interested in "small" versus "light", though. A few grams in weight savings isn't a big deal. If the laptop can be made significantly smaller, that's important.

Can you be a bit more specific on that?

For traditional laptops – the "big heavy ones", this isn't something we'd be likely to pursue. Many of those machines have extra room in the chassis and can already be configured with extra-large batteries. Also, things like the DVD can be swapped out for a second battery. And the batteries are easily removable – so you could have any number of batteries. Those buying this class of laptops already accept bulk and weight. A little more isn't a big deal. And these batteries are relatively inexpensive – which is important for these customers.

Ultrabooks are where this might be interesting. Consumers are willing to "pay more for less", so to speak. And this class of consumer is wants a system with a high degree of mobility.

But realistically speaking, this concept might have been a lot more interesting a few years ago – when battery life was much much less than it is now.

What do you mean by that?

It's not 2005, where 90 minutes was considered pretty acceptable.

We've made huge strides in solving the battery life problem.

The industry has been looking to solve the issue of battery life by looking to more power-efficient hardware – not better batteries.

About once a year, Intel comes out with a new chipset architecture that offers better performance and lower power consumption. And SSD disks make a huge difference – they use almost no power at rest. Even Windows 8 and 10 have contributed to better power efficiency.

The Haswell-based systems will last almost twice as long as the older Ivy Bridge systems on the same battery. And they run cooler, and are more compact. The newer Broadwell chips deliver maybe an extra 90 minutes and are lighter and thinner.

With up to a 15 hour capability for the standard version and up to 11 hours for the touch-panel XPS 13, I'm not sure that consumers would be highly interested in (or would pay more for) a laptop that lasts longer or recharges in say 10 minutes.

What about "fast recharge time"?

I'm not aware of "recharge time" being a particularly important consideration. Intuition tells me that if the battery can already last an entire workday, then it hits the mark. It takes 3 hours to charge – people can charge it in their cars, on the desk, I'm not aware of this being an issue, given that the current batteries last so long.