# Testimony of Jay Whitacre
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## HOUSE SCIENCE COMMITTEE HEARING:
## "INNOVATION IN BATTERY STORAGE FOR RENEWABLE ENERGY"

Mr. Chairman and members of the Committee, thank you for inviting me to speak today on innovation in grid-scale energy storage. I also want to acknowledge the Bipartisan Policy Center's American Energy Innovation Council for working with your staff on setting up this hearing.

My name is Jay Whitacre, and I am the Founder and Chief Technology Officer of Aquion Energy. I am also a Professor of Materials Science & Engineering at Carnegie Mellon University.

### About Aquion

At Aquion Energy, I set out to solve the problem of making large-scale energy storage systems that are high performance, safe, sustainable, and cost-effective. The solution we developed is an Aqueous Hybrid Ion intercalation battery, which uses a saltwater electrolyte, manganese oxide cathode, carbon composite anode, and synthetic cotton separator. It's safe and sustainable—the water-based chemistry results in a nontoxic and non-combustible product that is safe to handle and environmentally friendly. It performs remarkably well—providing long-duration discharge of up to 20 continuous hours while maintaining performance over thousands of cycles, and thus many years of operation. The system is modular and can be scaled to right-size applications. And the system is tolerant to abuse and requires no thermal management or regular maintenance.

Aquion's batteries are thus suited for long-duration, daily cycling applications. In addition to enabling the integration of variable generation from renewable power sources, Aquion's batteries provide back-up and off-grid power, grid reliability services, and load-shifting for customers wishing to avoid peak electricity rates or demand charges.

Aquion is currently manufacturing a completely novel product that is shipping to paying customers after being produced in a factory established in a refurbished automobile factory about 35 miles east of Pittsburgh. To date, Aquion has created over

150 full-time jobs and lured numerous highly trained individuals and families to the Pittsburgh region. In mid-2014, the first generation of the Aquion AHI technology was commercially launched and global sales have been increasing since then. Multiple megawatt hours of energy storage have been produced at Aquion's factory and shipped all over the world.

Aquion's batteries are being installed in (among other places) Australia, Malaysia, the Philippines, Germany, Hawaii, and California. An additional compelling aspect of this market (that is projected to grow into a multi-billion dollar industry in the next 5 years) is that the use cases and locations will provide excellent data as the technology continues to mature and cost down to the point where it is relevant for large-scale grid-tied installations. As such, Aquion is taking a classical approach to cultivating a disruptive technology: identify or create a smaller market (distributed PV solar/battery hybrid systems in this case) that has characteristics of the larger desired market and dominate that smaller market while selling at lower volumes and higher price points.

## The Beginning

I initially developed the concept for Aquion's battery technology when I arrived at Carnegie Mellon University (CMU). My previous position was that of Senior Staff Scientist at NASA's Jet Propulsion Laboratory (JPL), where I learned a tremendous amount not only about functional materials for energy technologies, but also about systems engineering and risk assessment. When I arrived at CMU, I set out to apply my knowledge, largely gained while working for seven years at one of the premier national lab environments in the world, to solve a key and pressing problem. I asked the question: "What is most needed in the world that I could potentially contribute to such that it will result in near-term impact?" After several months of surveying the landscape of "energy devices that rely on electrochemically functional materials," I concluded that the technology most lagging behind market needs was stationary energy storage for use in applications ranging from distributed microgrids in developing countries to large scale grid-tied installations around the world.

With the knowledge that a strong economic underpinning is required of any successful energy technology, I first performed a basic techno-economic analysis to arrive at the key metrics that would then inform any experimental work. For stationary energy storage, energy density requirements can be set aside, and so the primary metrics become specific cost in $/kWh. Specifically, for stationary storage to be economically viable, the capital cost of the storage itself should be less than $200/kWh and should approach $100/kWh to be truly disruptive. A simple analysis suggests that as the cost of the materials increase, it is very difficult to approach the cost goals without having exceedingly high energy density. The challenge at hand when considering existing technologies was then evident: only a handful of battery chemistries have specific energy values in excess of 100 Wh/kg at the device level. Any storage technology that has a specific energy <100 Wh/kg must have a total mass-normalized cost of goods sold (COGS) of less than $10/kg to meet the $100/kWh target. This specific cost value is substantially lower than the well-documented mass-averaged COGS for nearly every battery system. With this in mind, I set out to survey all possible materials sources and related processes to identify what, if any, materials might be low cost enough to enable the technology we sought to develop. While this preliminary process did not directly result in any specific inventions, it was critical to informing the innovation path that followed. Without it, my work would not have been able to so directly respond to a key global technological hole. As result of my training at JPL as a systems engineer, I recognized that technological and economic context are paramount, and that any innovation or invention can have little meaning or impact without it.

After a deep survey on relevant academic and intellectual property literature on similar fields yielded some compelling directions, I decided that the most appealing electrolyte system would be sodium-ion based and have a neutral pH aqueous electrolyte. Sodium is chemically similar to lithium, but is ubiquitous and extremely inexpensive. The next step was to identify or create electrode materials that could reversibly interact with sodium ions in an aqueous electrolyte in a similar fashion as observed in Li-ion batteries, a process known as intercalation or insertion reactions. At that time, no one had investigated or reported a sodium-ion intercalation battery electrode material that was stable in an aqueous electrolyte. After a significant amount of materials screening, the first of several key electrode materials were identified and proven; the little-explored solid-state ceramic material $Na_4Mn_9O_{18}$. Not only was it demonstrated to be functional and stable, this particular phase of sodium manganite could be made by mixing two extremely inexpensive precursors and heating them in air: electrolytic manganese dioxide and sodium carbonate (or sodium bicarbonate), for a total potential materials cost of under $2/kg. This result was documented and protected in a provisional patent application in the spring of 2008 and as I continued my search for other similarly functional materials, I started to engage potential sources of funding, and was successful in securing a seed-round investment from a prominent venture capital to conduct technology incubation in his lab at CMU. This somewhat unusual arrangement is a testament to the promise and strength of the preliminary results as well as the promise that the technology holds.

Top-tier venture firms invest only in ideas or companies that are capable of having transformational impact, and once they commit, they seek to provide their company founders with as much support as possible. During the incubation phase (June 2008 to late 2009), nearly everything changed; several more sodium-compatible intercalation compounds were discovered and a range of device configurations were screened. The proof-of-concept device that was tested by a third-party lab in late 2009 was found to have excellent stability and very low materials and processing costs; the company was ready to spin out of the university.

At the same time, we applied for and received funding from the Department of Energy (DOE), which was matched by private investors, to prototype battery units, build a pilot-scale production line, and demonstrate performance in a grid-connected environment. Additionally, that funding supported continuing basic research at CMU, the results of which helped us refine the technology at Aquion.

In the following 4 years, the chemistry and the device changed substantially beyond the design proven at CMU. The novel battery chemistry is now known as the "aqueous hybrid ion" or "AHI" system, a moniker based on the fact that multiple functional ions ($Na+$, $Li+$, and $H+$) work in a hybrid fashion in the electrodes and electrolyte to participate in the energy storage reactions. The AHI chemistry uses ultra-low cost manganese dioxide based cathode material and anode comprised of both $NaTi_2(PO_4)_3$ ("NTP", which is made from pigment-grate $TiO_2$ and common chemicals used by the fertilizer industry) and high surface area activated carbons. One key recent development in the AHI chemistry was the discovery that the NTP anode material can be stabilized for long term use by the addition of other kinds of carbons that are in intimate local contact within the electrode. These carbons can serve to mediate the local pH conditions and stymie degradation reactions that can occur on the surface of the NTP. This concept is at the core of my most recent granted US patent.

Ten additional patents were issued around the world; all aspects of this new technology are novel and are protected, from the fundamental chemistry to the packaging design. This process established Aquion as a leader in next generation stationary energy storage technology field, and of the 10 to 15 new North American battery companies attempting to transition into full-scale manufacturing, only Aquion has succeeded. Data from batteries and systems deployed around the world show that the technology is highly functional and is able to deliver the services desired by the various customers. In 2015, several multi-MWh installations will be integrated in the Philippines, Hawaii, and Florida. See, for example, Aquion's recent announcement of a planned deployment in Hawaii: http://globenewswire.com/news-release/2015/01/07/695641/10114491/en/Aquion-Energy-Enters-Agreement-for-Major-Microgrid-Battery-System-Deployment-at-Bakken-Hale-in-Hawaii.html.

These early large-scale installations are a critical stepping-stone for Aquion, since the effectiveness and versatility of the technology as proven in these kinds of use cases will make our products more marketable.

**Academic Openness**

A cornerstone of Aquion's technology development and product communication efforts has been one of intellectual and academic openness. My staff and I have published many papers in the peer review literature that describe both the fundamentals behind the technology as well as product and systems-level performance. This openness has created international academic interest in the AHI technology and has encouraged others to investigate similar approaches and materials systems. While this might be seen as encouraging competition, the synergy that comes from sharing ideas and results is very beneficial to the company and outweighs the risk of creating competitive threats. Furthermore, this openly available information has allowed the AHI chemistry to gain marketplace credibility more rapidly, since the technical community consumes, scrutinizes, and accepts the results that are put forward.

**Marketability**

One key market-creating technical attribute of the AHI technology is the product's extraordinary robustness; in the early days of this project, we demonstrated that the materials could be charged/discharged over 5,000 times without losing function; this attribute has been a cornerstone of the AHI value proposition, since being able to promise over 10 years of daily cycles without requiring significant recharging is extremely attractive to all markets and allows them to compete favorably against most other technologies (especially those with a similar price per kWh).

Another key marketable attribute of the AHI technology is its environmental benignness. Unlike any other productized battery chemistries, the AHI battery has no environmentally toxic or hazardous materials, and the environmental impact of the manufacturing process is also extremely low. The units consist of recyclable polypropylene external packaging, saltwater electrolyte, inert ceramic powder active materials, carbons, and stainless steel fixtures. This single attribute of the technology is extremely appealing to some customers/markets, since there is a growing worldwide movement to incorporate and use cleaner and environmentally certified technologies, especially amongst leading corporations. The Aquion product line has received a full cradle-to-cradle audit/certification by the McDonough Braungart Design Chemistry Corporation, who have a widely accepted Cradle-to-Cradle (C2C) certification process. Aquion can now successfully market the first and only C2C certified battery chemistry. Specific customers who are interested in this certification include European ventures in reaction to the movement to remove lead from the consumer use stream, and also developing countries who have poor or even no recycling programs to deal with the normally very hazardous battery technologies commonly used (with lead acid being the biggest concern).

**Next Steps**

As Aquion continues to scale, we will be exploring the distribution of our manufacturing infrastructure such that active materials production is co-located with low-cost materials sources and potential customer bases. This includes the exploration of setting up operations in Asia, South America, Australia, and South Africa. The materials-intensive nature of the product combined with the ease of manufacturing results in a very significant opportunity to create not only a worldwide customer base, but also a worldwide materials-centric production base where the economies of scale and transport can be optimized to an extraordinary effect. Specifically, at full global scale with the appropriate manufacturing assets installed at optimal locations, it is very possible that the Aquion energy storage system can be produced and sold at or below \$100/kWh, which is a common "holy grail" price point that is often discussed as a figure that would disrupt the global electricity market because it can legitimately alter the way large format power systems are designed and implemented. If Aquion continues on our current commercialization/growth trajectory, it is estimated that we will be able to achieve this price/performance point sometime in the 2017/2018 timeframe which is close enough to interest key technology partners such as major US utilities and international energy companies: Shell, Total, Exelon, and multiple other North American utilities who are currently all partners and/or investors.

**Societal impact of the technology**

If the technology envisioned manifests as planned, the way the world (not just North America) uses electricity will be positively impacted. Specifically, scalable, inexpensive bulk storage of electricity provides: (1) a mechanism for integrating large quantities of wind and solar generation, (2) a way to remove peak demands for generation and increase the trough electricity demands to make generation demands more constant, thus better utilizing traditional power generation assets, (3) a method for increasing system reliability, and (4) through each of these actions, lower the cost of providing electricity.

Renewable energy technologies are in a delicately balanced situation currently; anything that can further increase the credibility and positive perception of this new technology is still badly needed. There is a core audience who has accepted that energy storage is the inevitable wave of the future and is necessary to decrease mankind's global carbon footprint. However, more recognition and media focus is needed to inspire the next generation of innovators as well as help current technologies mature to the point where they are able to reach their true potential.

Without the partnership with DOE, it would have been far more challenging, if not impossible to move out of the lab and into the market—and perhaps Aquion would not have made it this far. My decision back in 2007 to spin out a company had a lot of risks. I had to cross that "valley of death" when you have no revenue, you're spending a lot of money and time to turn your lab results into a working commercial energy technology (and the manufacturing process to make it), and that technology's ultimate performance is uncertain. It's challenging to find private investors who can stomach that risk-reward profile—a handful exist, but by themselves it's rarely enough to get new capital-intensive technologies done. The partnership I had with DOE was critical for getting across the "valley of death," from a research concept to a prototype battery and manufacturing process with proven performance. Specifically, without DOE investment, we would not have had enough patient capital to take us through prototype production. This is an excellent example of how having key funds at the proper moment can boost a project significantly. Furthermore, we continue to collaborate with the DOE, who are actively testing various generations of our products and who also have partnered with us to develop a large in-house test bed. This support is important to us as we build technical credibility and continue to refine our product offering.

What can be done by DoE/National labs to advance other breakthroughs? In some ways, the DoE has a solid track record of encouraging good ideas and funding projects that can result in significant impact. However, one key item that is often overlooked early on in the technology development process is the difficultly of scaling/manufacturing. Since all new energy technologies will be both materials and manufacturing intensive, having more focus on these aspects of the process would increase the success rate of translating lab results into market products. There is still a tremendous amount of important and interesting fundamental science and engineering to be done in the process scale-up and manufacturing side of any company that is developing a new solution. I would encourage the DoE/national labs to further recognize this importance and to work to insert the realities of scaled manufacturing early into the technology development process such that national labs and DoE are assets focused not only on *what* bench top solutions to make, but also on *how* to turn a bench top solution into a scaled, mass-produced and relevant technology.

Thank you for the opportunity to share Aquion's story with you, and the attention you are devoting to energy storage technology development.