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Liquid Metal Batteries as a Solution to Renewable Energy's Intermittency Issues

I. Introduction

Despite massive strides in cost reduction and efficiency, renewable energy sources only produced 13% of the US's total electricity production of 4.1 billion megawatt hours in 2014[1]. The sparse adoption of renewables can, at least partially, be attributed to intermittency issues associated with renewable sources since solar and wind power fluctuate wildly. For example, strong winds at nighttime will generate electricity that goes unused due to low demands for electricity, or solar panels on a home will produce wasted power during the day if nobody is home. The simple, straightforward solution to the intermittency issue is storing excess power from peak production hours—high wind speeds for wind power or midday for solar—in a battery and using that power when demand surpasses production. There is some current capacity for storing excess power, but it is limited to specific cases and appears poorly suited for widespread application. A recent breakthrough in battery technology from MIT presents a potential solution for large scale storage by using high-temperature liquid metal batteries to store grid-level quantities of electricity. In this paper, I will seek to address the pitfalls of current storage technologies and the economic feasibility of liquid metal batteries for widespread use in mediating the intermittency issues of renewable energy sources.

II. Current Storage Technology

There are two prominent options for storing large amounts of electric power. Hydroelectric pumped storage is by far the more prevalent option. Hydroelectric pumped storage uses a system of two water reservoirs at different elevations connected by a pump and turbine, as shown on the right. When electricity demand is

[1] https://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3

low, excess grid power pumps water up from the lower reservoir to the higher reservoir. Then, when electricity demand is high, the water from the upper reservoir can be passed through the turbine to the lower reservoir to produce electricity[2]. Hydroelectric pumped storage benefits from extremely high capacity limited only by the size of the reservoirs and from the ability to rapidly switch from storage to production by turning pumps off and turbines on. US pumped storage capacity is currently around 20 GW[3]. The obvious constraint around hydroelectric pumped storage is its size and cost. The two-reservoir system is very large and must either be built into a hillside or have a hillside constructed around it, both of which are expensive options—though some projects have been proposed that could take advantage of abandoned mines to function as the lower elevation reservoir[4]. As a consequence, hydroelectric pumped storage is only suitable for areas that can accommodate the elevation requirements.

The second, more recent to arrive storage option is high-capacity lithium-ion storage batteries, which store energy in individual homes rather than for a full electrical grid. Tesla's Powerwall battery has a storage capacity of 6.4 kWh and is available for $3000[5]. The Powerwall is specifically designed for in-home use, with one battery's full charge powering a typical American home for a day. The battery, shown to the left, is wall-mounted, about three feet wide, a little over four feet tall, seven inches deep, and weighs 220 lbs. Tesla designed the battery for use with solar panels, produced by Tesla's sibling company Solarcity, as a solution to solar power's intermittency problems. The Powerwall was met with such enthusiasm that only a week after its announcement in April 2015, the battery had sold out until mid-2016, totaling roughly $1 billion of sales[6]. Though Tesla's battery appears

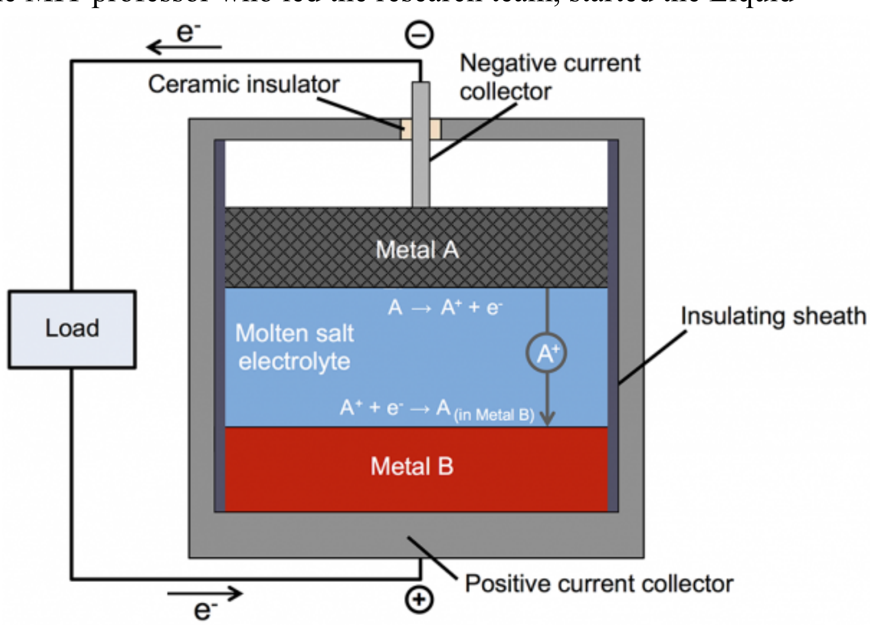
[2] http://www.ferc.gov/industries/hydropower/gen-info/licensing/pump-storage.asp
[3] http://www.hydro.org/tech-and-policy/technology/pumped-storage/
[4] http://energystorage.org/energy-storage/technologies/sub-surface-pumped-hydroelectric-storage
[5] https://www.teslamotors.com/powerwall
[6] http://ecowatch.com/2015/08/06/tesla-battery-sold-out/

wonderfully suited for home-sized electricity storage, particularly solar-powered homes, it seems ambitious to use these batteries in every house-hold in a wind-powered region as an answer to wind's intermittency issues. Furthermore, the batteries may be poorly suited for industrial use, where peak electricity demand vastly exceeds the Powerwall's capacity of 6.4 kWh. The batteries require cooling systems, which scale poorly to larger sizes.

The current options for electricity storage are either too large (hydroelectric pump storage) or too small (lithium ion batteries) for broad-reaching adoption. An effective solution to intermittency issues will have to be a more medium sized option: larger than lithium ion packs so that one won't be necessary for each household, but smaller than hydroelectric pump storage plants to avoid large construction costs and geographical constraints.

III. Liquid Metal Batteries

The liquid metal battery project began at MIT with the objective of producing a cost-effective grid-scale form of electricity storage, and it resulted in a 2012 American Chemical Society publication that determined batteries comprised of molten magnesium and antimony could operate as efficient storage cells when operated at high temperatures (700 ºC)[7]. Magnesium and antimony because of their low melting points, low cost, and low and high electronegativity. Magnesium costs $5.15/kg and antimony costs only $7/kg, and both are very abundant, so there is little obstacle to their widespread use in electrical storage cells. After the study, Dr. Donald Sadoway, the MIT professor who led the research team, started the Liquid Metal Battery Corporation—now called Ambri—to further develop the batteries for potential market applications by exploring new battery chemistries for greater storage capacity and charging efficiency.



7 http://pubs.acs.org/doi/pdf/10.1021/ja209759s

Liquid metal batteries are comprised very simply of a layer of magnesium (the anode) and a layer of antimony (the cathode) sandwiching a layer of molten salt electrolyte, which transfers charged particles. To deliver charge, the magnesium layer donates electrons to the antimony. The magnesium ions then flow through the electrolyte to bond with antimony and form an alloy. To charge the cell, current is applied to the cell, which breaks apart the magnesium-antimony alloy into uncharged magnesium and antimony[8]. In a solid state battery, this movement of magnesium from the anode to the cathode would cause the anode and cathode to shrink and expand, potentially causing cracking, one of the main sources of decay in solid-state batteries. However, because the metals are in the liquid state, the metal can flow from anode to cathode without complication since the liquid cell will always take the shape of its container. Additionally, the liquid state eliminates the need for separation membranes since the magnesium, electrolyte, and antimony will naturally separate themselves by density.

Ambri has since reduced the battery's cost and operating temperature by adding lead to the batteries, bringing the operating temperature down to 500 ºC. Using a lead-antimony alloy for the cathode results in a lower melting point without reducing cell potential because the positively charged ions from the anode will preferentially bond with antimony ions. 500 ºC is far from ambient conditions, but the high operating temperature actually presents a pricing advantage. Though ambient-temperature devices are conventionally thought of as more efficient, high load batteries tend to heat up from large flows of power, so high temperature occurs incidentally. As a result, the temperature control used in liquid metal batteries is an insulating layer of ceramic rather than a cooling system, which is substantially cheaper and simpler to produce.

Ambri's base storage unit is called the Ambri core (size depicted to the left), an aggregate of 768 8-inch liquid metal cells. The cores each have a capacity of 200 kWh and are designed to be further aggregated into systems of up to 1 MWh[9]. This 1 MWh system has an equivalent capacity to 156 Tesla Powerwalls. To be cost effective, the

[8] https://www.technologyreview.com/s/511081/ambris-better-grid-battery/
[9] http://static1.1.sqspcdn.com/static/f/1497163/26724787/1449674657127/Project+Imua+-+Storage+and+Renewables+in+Hawaii.pdf?token=%2BC%2Bfo7yS7SqPcldf4LHGwHBUE6Q%3D

1 MWh system should be roughly as expensive as 156 Tesla Powerwalls, which were successful enough to sell out for a year in advance when announced. At $3000 per unit, 156 Powerwalls cost $468,000, so this is a reasonable target cost for a 1MWh system, and a price lower or approximately equal to this figure will indicate market viability.

The battery's design is remarkably simple, consisting only of metal disks and salt sealed inside an insulator, which means that the cost of assembly should be very low, and can be minimized with scale. The more widely adopted the batteries, the cheaper and more efficiently the batteries can be produced. The bulk of the cost of the batteries will be tied up in the raw materials. Ambri is constantly testing new chemistries for greater efficiency and lower cost, and the company doesn't release the exact chemistry of their batteries to protect the startup. Because of this, we will (crudely) estimate the price of the materials using the original cell composed of magnesium, antimony, and a magnesium chloride electrolyte. As stated earlier, magnesium costs $5.15/kg and antimony costs $7/kg, or $5150/metric ton and $7000/metric ton, and magnesium chloride can be purchased for $13.78/metric ton[10]. Because magnesium has a +2 oxidation state and antimony has a -3 oxidation state, the battery will likely use 3/2 as many moles of magnesium as antimony. Using their respective molar masses of 24.305 and 121.76 g/mol, we get that there will be 3.34 times as many tons of antimony as magnesium. It is difficult to predict how much magnesium chloride electrolyte is used, but its cost is so much lower than the cost of the metals that it can probably be ignored, especially since Ambri's current battery chemistry has likely reduced cost in some way that offsets this minor cost. The 1 MWh system is reported to weigh 50 tons[11]. Using the 1:3.34 magnesium to antimony weight ratio, we get that the 1 MWh system has around 11.5 tons of magnesium and 38.5 tons of antimony, which translates to 10.4 metric tons of magnesium and 34.9 metric tons of antimony. Using the cost per metric ton of magnesium and antimony, we get that the cost of the system is just under $300,000. This figure falls significantly below $468,000, the cost of equivalent storage in lithium ion batteries. Better still, this cost estimate leaves significant room for the cost of assembly and other parts, such as the insulator and electrolyte, while still falling within a competitive price range.

[1643 words], citations is URL form for now

10 http://www.alibaba.com/showroom/magnesium-chloride-price.html

11 http://www.greentechmedia.com/articles/read/Slideshow-Update-on-Ambris-Liquid-Metal-Grid-Scale-Battery