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HALLGARTEN & COMPANY

Sector Review

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Antimony Molten-Salt Batteries

The New Metal in Mass Storage

Antimony-based batteries

Solid Science & Big Backers

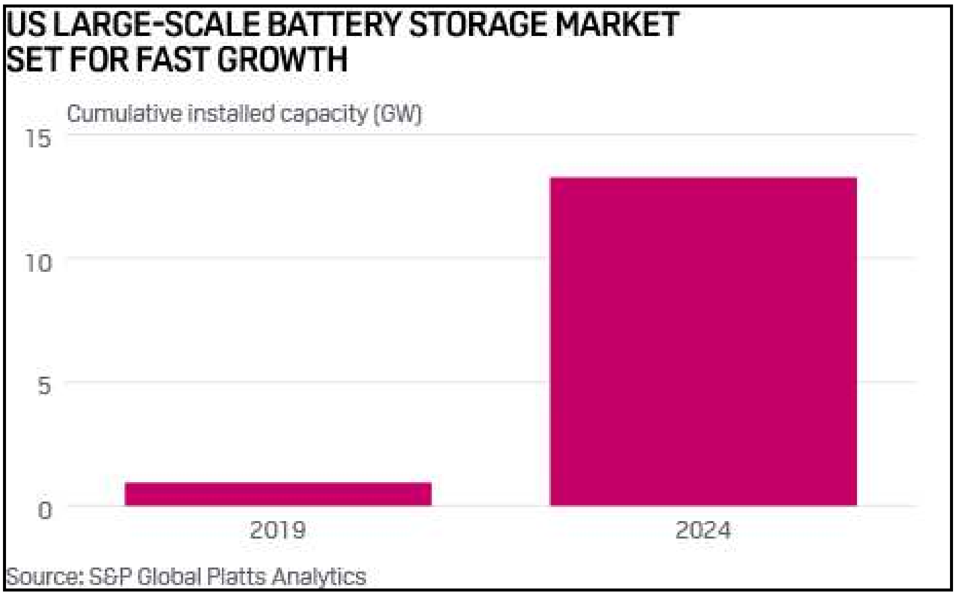
- + The last decade has seen major advances in utilising molten salts in liquid metals batteries for energy storage in grid (and off-grid) applications
- + The new technologies offer the potential to provide high-value new usages for Antimony
- + Prominent backers, Bill Gates, have got behind the Ambri venture
- + Chinese dominance in Antimony is fading due to overexploitation and long-term predatory pricing
- + Antimony prices are staging a swift rebound which is good news for Sb miners but bad news for adoption of new technologies if the price spikes
- + There are many currently unexploited non-Chinese Antimony deposits that could be reactivated
- ✖ Corrosion remains an issue that academics are grappling with
- ✖ Antimony supplies are finite and constrained and greater usage would likely surge prices and maybe price out storage applications
- ✖ Antimony supply is currently dominated by China
- ✖ Technical problems, mid-decade, derailed Ambri's advancement for several years
- ✖ Uptake is slow thus far

Conjuring with Liquids

Battery technologies have been proliferating in recent years like mushrooms after the rain. Despite this there are batteries and batteries. Many of the newly invented storage devices have specific usages and one new application is not necessarily a replacement for an existing type of battery.

Most of the buzz in the mainstream media is about battery options that extend the life of cellphones or laptops and other PDAs or with regard to hybrid or electric vehicles. However the really great economic leap forward has to do with mass storage devices which mesh with energy grids to provide off-peak storage of electricity. Industrial or natural gas has been stored since its inception in the industrial revolution in massive tanks, caverns or gasometers, while a solution to massive electricity storage has been much more elusive. With conventional dry-cell battery using two electrodes separated by an electrolyte, it would require thousands of individual cells, the size of soft drink cans, to be strung together in a massive installation to create a mass storage battery of any usefulness to be attached the grid.

The relevance of this has been heightened with the burgeoning of alternative energy sources (wind and solar) that are irregular in their generating periods and do not always coincide with peak demand. As the chart below shows, S&P Global's estimates show that demand for mass storage devices is growing geometrically.



Mass Storage Devices

The important consideration is that mass storage devices do not even need to be connected to the grid and thus can be in the middle of nowhere bridging the infrastructure gap (and cost) that weighs on emerging economies (and isolated minesites).

And then there are liquid metal batteries…

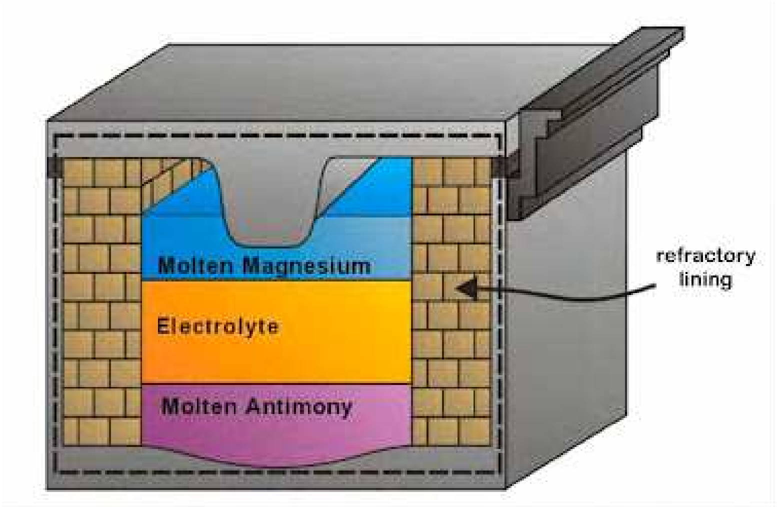
Molten Salts

One of the greatest remaining challenges is storing electricity that interacts with the grid. The latest technology to grapple with this issue is the liquid metal battery with relies upon the field of the study of molten salts. The origin of using these salts for storing energy goes back to the Second World War.

Molten salt is salt which is solid at standard temperature and pressure but enters the liquid phase due to elevated temperature. A salt that is normally liquid even at standard temperature and pressure is usually called a room temperature ionic liquid, although technically molten salts are a class of ionic liquids.

Liquid Metal Batteries (LMBs)

Liquid metal batteries use an electrolyte that is solid and inactive at ambient temperatures. They can be stored indefinitely (over 50 years) yet provide full power in an instant when required. Once activated, they provide a burst of high power for a short period (a few tens of seconds to 60 minutes or more), with output ranging from watts to kilowatts. The high power is due to the high ionic conductivity of the molten salt, which is three orders of magnitude (or more) greater than that of the sulphuric acid in a Lead–acid car battery.

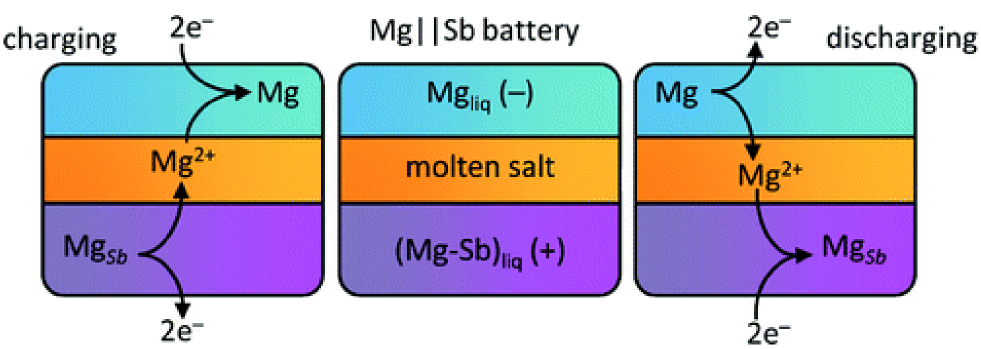


It seems most new battery innovations emerge from academia rather than commercial R&D. Researchers at MIT (led by Professor Donald Sadoway) have been working on a liquid battery system that could enable renewable energy sources to compete with conventional power plants. The research was funded to the tune of $15mn by the likes of Bill Gates, energy giant Total, the US Department of Energy's Advanced Research Projects Agency and Khosla Ventures (run by Sun Microsystems co-founder Vinod Khosla).

The MIT team's Mg||Sb liquid metal battery is comprised of three liquid layers (as shown at right) and operates at 700 °C.

During charging, Mg is electrochemically extracted from the Mg–Sb alloy electrode and deposited as liquid Mg on the top (negative) electrode. During discharging, the Mg electrode is consumed, and Mg is deposited into the Mg–Sb liquid bottom (positive) electrode. During charging, the battery consumes energy and upon discharge, the battery supplies energy.

The schematic that follows shows a Mg||Sb liquid metal battery and the chemical reaction between the different elements and how it first stores then releases the charge.



Source: Bradwell et al.

The music to our ears in all this is the use of Antimony, and seemingly in quantity, thus providing an important new application for the metal.

The Innovation

More recent MIT battery designs substitute different metals (mainly Lead and Lithium) for the molten layers used in the team's previously developed battery with a strong Magnesium component.

The latest iteration involves a Lithium/Antimony/Lead liquid metal battery comprising a liquid lithium negative electrode, a molten salt electrolyte, and a liquid Antimony/Lead alloy positive electrode, which self-segregate by density into three distinct layers owing to the immiscibility of the contiguous salt and metal phases. The difference in composition between the two liquid metals gives rise to a voltage.

Their latest formula replaced the Magnesium with Lithium and allowed the battery to work at a temperature more than 200 degrees Celsius lower than the previous formulation. The all-liquid construction confers the advantages of higher current density, longer cycle life and simpler manufacturing of large-scale storage systems (because no membranes or separators are involved) relative to those of conventional batteries.

The researchers found that while Antimony could produce a high operating voltage, and Lead gave a low melting point, a mixture of the two combined both advantages. In addition to the lower operating temperature, which should simplify the battery's design and extend its working life, the new formulation will be less expensive to make. However when they make that comment it leaves us wondering whether they are factoring in how much Antimony, which has a delicate supply/demand balance might rise if suddenly a new application that absorbs more metal starts to get traction.

Reports of the extensive testing indicate that even after 10 years of daily charging and discharging, the system should retain about 85% of its initial efficiency. This would be a major attraction for electric utilities, who have been largely watchers, rather than initiators, in new battery technologies. The MIT team has speculated that it may be possible to build giant batteries using 50-100 fewer individual cells this way, than would be possible with a conventional battery array, reducing cost and complexity.

AMBRI

In 2010 Donald Sadoway, David Bradwell and Luis Ortiz co-founded the Liquid Metal Battery Corporation with seed money from Bill Gates, Khosla Ventures and the French energy company, Total S.A. The offices were in Cambridge, Massachusetts and so they named the company AMBRI, lifting the middle letters out of the suburb's name. The goal was to create a safe, affordable electrical storage solution utilizing liquid metal batteries formats that might change the way electric grids are operated worldwide.

Key Metrics

The standard module has the footprint of a 10-foot shipping container. Some of the key parameters are:

Capacity: 400-1000 kWh, up to 250 kW

DC Efficiency: exceeds 80% under wide range of use cases

Response time: <500 milliseconds

Voltage: 500 —1500 V

At room temperature, the cell is non-conductive and its active materials are solid metals and a solid electrolyte. Upon heating to 500˚C temperature, the battery systems operate at maximum performance level no matter the external temperature and require no power-hungry air conditioning. This obviously makes them attractive for desert environments (where solar is at its best) and functional also in super-cold environments (where wind may be power source of choice). It should be recalled that Lithium-ion batteries rapidly lose charge in frigid conditions).

The cells generate their own heat during use, eliminating the need for auxiliary power for temperature control. The company, in a colourful turn of phrase, has said that its systems "like to be used" meaning that a full charge/discharge cycle at least every two days will keep the system at its operating temperature and higher duty cycles will not increase degradation.

The Cost Benefits

The use of Sb as the positive liquid electrode in a liquid metal battery offers a low-cost chemistry, below the threshold cost required for broad-scale adoption of a large-scale electricity storage technology. *Bradwell et al.* in their paper noted that Antimony could potentially drop the cost of the active components by a factor of five (Table S3), while providing similar voltages for analogous chemistries.

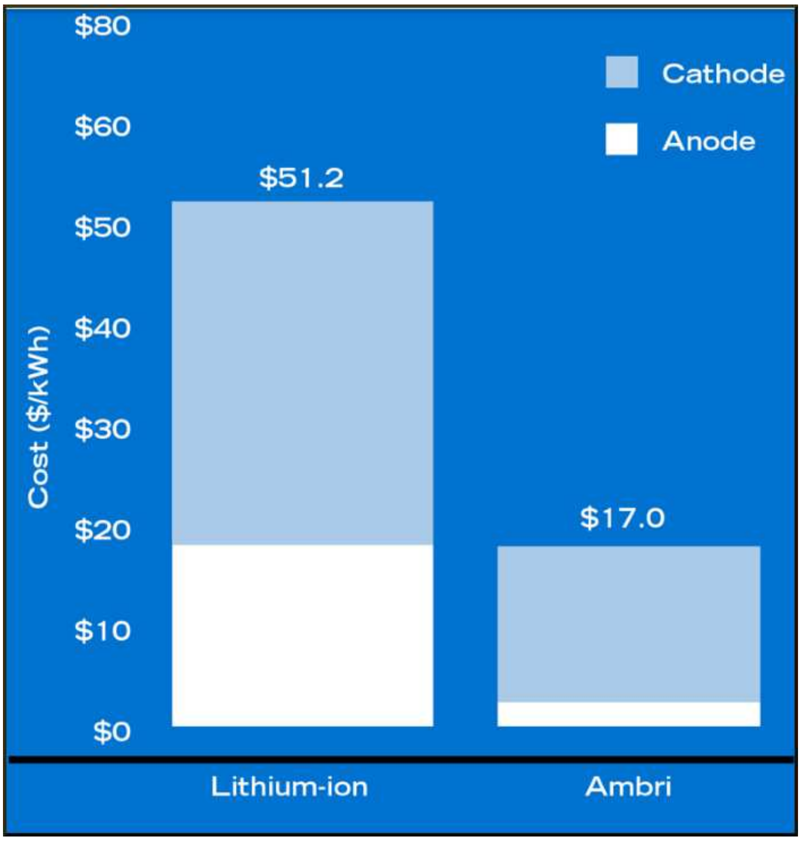
Bradwell offered a summary of the candidate electrode material costs and world reserves. The price data though is somewhat old from 2012 information collected from USGS Mineral Commodity Summaries.

Metal	Electrode	Cost ($/kg)	Cost ($/mol)	World reserves (10^3 tons)
Li	negative	65[13]	0.4	9,900
Na	negative	1.6[14]	0.04	>1,000,000
Mg	negative	5	0.13	>1,000,000
Bi	positive	24	4.4	330
Te	positive	150	19	21
Sb	positive	7	0.74	2,100

Some of these metals are now even cheaper than they were then. It is interesting to note the potential usages for Bismuth and Tellurium as well.

Inexpensive molten chloride salts, such as $MgCl_2$, KCl, and NaCl are suitable as the electrolyte, providing high conductivity, a suitable density and liquid range, and stability with reactive metals.

It is interesting that Ambri claims that its cells utilize commonly available electrode materials that the "calcium and antimony electrodes in Ambri cells are less than one third the cost of the lithium, nickel, manganese and cobalt in the most common lithium-ion cells". It's not clear though when this price assertion was made as Antimony Trioxide was bumping along the bottom (below $6,000) for 18 months until the recent sudden turn upwards. As we shall note further on the price has now risen from the dead. Still the savings, if they are 2/3rds of the cost of a Lithium-ion alternative, are not negated by the recent rise in Sb prices. Indeed, with Lithium hydroxide itself having risen in recent times, the "ratio of viability" between the two formats are moving, if not proportionately, at least in the same direction.



The manufacturing of Ambri cells, so it claims, is far simpler and requires 1/3 to 1/2 the capital expense per MWh of production than lithium-ion.

Each GWh of Ambri batteries requires less than 1% of current annual production of these (calcium and antimony) anode and cathode materials. This is the closest we have to divining how much Antimony that the Ambri product line might consume if it gains traction. Current Sb production is around 170,000 tonnes per annum, implying that a Gigawatt of Ambri cell utilizes 1.7 tonnes of Antimony.

In another giveaway, the company commented that its cells are projected to be priced at less than lithium-ion cells for commercial deliveries starting in 2022. This might imply that the batteries are currently not achieving the target of being one-third of the cost of Lithium-ion batteries to manufacture.

Finally we would note that scarcely any Antimony is currently recycled (excepting the small amount that goes into lead-acid batteries), however (while Ambri claim a 20-year life for each cell) the entirety of the Sb should be recyclable at the End-of-Life for the electrodes.

Moving into the Realm of the Real

In November 2020, Ambri announced that they had come to an agreement to deploy its energy storage systems at a data centre under development near Reno, Nevada. This deal was inked with TerraScale, a developer of sustainable infrastructure solutions for the energy and digital technology sectors.

TerraScale is engaged in developing a 3,700-acre project called Energos Reno near the city of Fernley in the Reno-Sparks metropolitan area. The site will include a microgrid with more than 500MW of renewable energy capacity powering a data centre that TerraScale anticipates will be used by government and commercial clients.

The renewable resources driving the Energos Reno project will be solar and geothermal: there is already 10MW of solar generation built at the site, which TerraScale intends to bring up to 500MW and 23MW of active geothermal power with a rated capacity of 48MW. While the first phase of the project is the buildout of roadways and utilities to enable the sustainable data centre to be sited there, TerraScale said in a press release that it hopes the data centre and its microgrid will be built and completed within 10 years.

The agreement includes delivery of 250MWh of Ambri systems to the Energos Reno project site, starting in 2021.

Terrascale have stated that their choice was made as the Ambri systems are particularly well-suited for high-desert operations, for the shifting of the project's large amounts of renewable solar load, and for the storage technology's grid-system peak shaving capability. Terrascale claimed that "without need for air conditioning or fire suppression," there was "no question that liquid metal battery can undercut lithium-ion," and that the technology "offers resistance to capacity fade and immunity to thermal runaway while constructed of ethically sourced materials. All at the lowest price point". Fulsome praise, indeed.

NEC drops the ball

In 2019, Ambri was selected by the Massachusetts-headquartered energy storage system integrator arm of the Japanese major, NEC, as a potential technology solution for projects that required more than four hours' duration of storage, with NEC Energy Solutions announcing a minimum purchase order of 200 MWh of cells from Ambri in 2019.

However despite its theoretically strong position in the energy storage space, in mid-2020, NEC abandoned its efforts in the space. This was obviously a setback for Ambri as well as a key adopter departed the scene.

Antimony - Let the Benefits Flow

The liquid metal battery potentially brings a new major use for a metal of interest to us, Antimony. This metal, in particular, could do with attracting more innovative high-tech uses. The main traditional use was as a hardening alloy with lead in bullets and ammunition as lead batteries. The “newer” innovation was as a fire retardant, but there has been scarcely any new application of note for several decades.

We are well-known as unalloyed (pardon the pun) fans of Antimony but it must be admitted that while in a critical supply situation (which puts it near the top of most strategic metals rankings) the applications for Antimony are scarcely “high-tech” in the way Rare Earths are.

China has a very strong position in Antimony and long has had. Indeed this is the metal it has been dominant in for the longest (since the 1800s). However, like so many other resources this dominance has been squandered through overproduction, predatory pricing and high-grading. China now finds its domestic share of global production plunging and to prop up its dominance it has become a leading importer of artisanal and “conflict” ore from all around the world. This is demonstrated by its neo-colonialist efforts in Burma.

It then processes this imported ore/concentrate and manages to maintain the optics that it still holds a dominant position in processed end-product Antimony Trioxide and other products.

Antimony is in the critical metals listings of the BGS, EU and USA. But is the metal strategic? Thus far it does not have the type of applications that other high-tech metals possess but it is still a key component in the things it is used for and its long term application as an alloy with Lead in ammunition has not gone away.

Pricing

The most recent high in Antimony Trioxide prices was early last decade when the price reached around $14,000 per tonne, which triggered a phase of replacement (or rather reduction in grade employed) by the fire retardant industry.

After a swoon that lasted several years, that sank the prospects of several Antimony wannabes, the price of Antimony started to uptick in 2016. It got to around $8,500 per tonne and then plunged again to around $5,500 on stories that the metal was about to be put in the penalty box by the EU (with its REACH program) and some American states (notably Massachusetts). This was linked to supposed toxic properties when used in fire retardants.

The picture was further complicated by the ever-looming liquidation of the FANYA stockpile, which amounted to around 19,000 tonnes, which was finally sanctioned by Chinese courts in mid-2019. The speculation of dumping in the marketplace proved unfounded as the FANYA stocks were bought by one of China’s largest Sb producers.

Prices bottomed in 2020 and are rising sharply on the back of low inventories, low production and revived restocking in the West. There is now considerable competition for scarce stocks between Chinese roasters and incipient power that is/was Tristar's roaster in Oman.

In recent weeks, demand has picked up dramatically with the metal strongly sought from US buyers according to traders, while European demand has been quieter.

Source: Argus Metals

Chinese production of the metal continues to decline due to over-exploitation and it has come increasingly to rely on supplies generated. All this achieves is to run down that source even more rapidly than would normally be the case for a well-priced and well-husbanded resource.

Higher prices are rather a "chicken-and-egg" issue for the likes of Ambri. To be sure of adequate supplies of metal higher prices are needed (probably over $8,000 at least) and yet if they go too high then viability of the economic equation is cast into doubt.

Risks

The principal risks for the evolution of this new format are:

- Spiking antimony prices
- Limited Antimony supplies as market is currently in balance
- Lack of advanced new Sb mining projects
- Slow uptake of the technology

Antimony has been in one of its swoons over the last year. The FANYA threat is behind us and the regulator threat against fire retardants is now a sleeper issue (but could come back to life). In the short term the SbO_3 price seems destined to continue its rebound as Chinese production continues to decline and low prices have stymied anything beyond small-scale production outside China.

A major new application, such as molten salt batteries, might have to fight it out with existing users for (currently) finite supplies.

Antimony mine developers are almost non-existent with the major non-Chinese supplier currently being the Costerfield mine of Mandalay Resources (TSX:MND) in Victoria, Australia. There are however sizeable known Antimony resources, many of them brownfield, scattered around the globe that could be reactivated at prices above $8,000 per tonne. However there are few developers in the mining space to do this.

Ambri have had their technology out there for nearly ten years now and it has taken almost as long to iron out problems and thus move to adoption.

Conclusion

VRBs have become a well-rehearsed discussion for energy storage and Elon Musk would have us believe that superannuated Tesla batteries have a “life after death” but we remain unconvinced on the latter.

However, if Liquid Metal Batteries become the killer application in grid-linked storage (or non-grid linked) then it potentially lights a fire under Antimony demand and pricing.

Chinese production of the metal continues to decline due to over-exploitation and it has come increasingly to rely on supplies from bitsy, irregular or dubious sources. All this achieves is to run down that source even more rapidly than would normally be the case for a well-priced and well-husbanded resource.

While the Antimony price has been in somewhat of a regulator-induced swoon in recent months, the main application in fire retardants has not gone away and in the wake of Grenfell Tower the regulators act against fire retardants at their own peril. So the marketplace is dry of product and the price is showing signs of upward creep with the next stop being $6,500. Short of regulator action it should be closer to $8,000 in the latter half of next year.

The issue though is the availability of metal supplies. Antimony has a seemingly finite supply at the moment and more likely a switch to using this metal, even in a limited way, would light a fire under currently depressed prices. If it rose too high (for instance over $12,000 per tonne) then it might choke off demand or usage as Vanadium did with its “own-goal” in 2018 when its price shot too high, too fast.

To mix some metaphors, molten salt batteries have flown under the radar thus far but definitely have a place in the evolving battery universe and hopefully will take the Antimony market along for the ride.

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