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STORMCROW

"Fool Sells" and Other Fuelishness

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Zero Emissions with Zero Compromises

In this issue we discuss:

- **Prices Still Moving the Right Way** By no means are we believers in 'higher prices are always better', but for the lithium industry to continue to grow, it's inevitable that lithium chemical and spodumene prices must rise from present levels. This is what they are doing.

- **A (Longish) Diatribe on Fuel Cells** It's apparently fashionable in some circles to discuss how the only possible alternative to using internal combustion engines in vehicles (ICVs) is to cram a vehicle full of lithium batteries (BEVs). Well, no, that's not true as the "series hybrid" design may have a say in all this, providing a compromise-free solution that ends up being cheaper than any alternative. Now, we completely understand that there are barriers in the way of adopting hydrogen fuel cells tomorrow, but we hope you enjoy a current perspective from of someone who has looked at the fuel cell space for about 20 years and was a complete and utter skeptic back in 2001.

As a Matter of Introduction…

This is our fifteenth (semi)monthly newsletter! Maybe. Plus or minus one or two. Time flies when you are having fun, and critical materials and the connected industries are, at least to us, fun. While we never produced a newsletter filled with cautions about the "best cure for high prices being high prices " during the lithium heyday that extended through the middle of 2017, those who sat in on Stormcrow talks at conferences know that we were out there saying it. However, we feel even more strongly that the old maxim about the "best cure for low prices being low prices" is every bit as true, and given some pessimism around the battery materials market now, we believe that some realism (along with a little hope that is finally being sprinkled with some evidence) is required.

First, for those who don't know, Stormcrow deals with the markets for critical materials. Generally speaking, what amounts to a critical material is in the eye of the beholder, but we think of them as materials that are essential to making a product with the properties intended by its designers, even if those materials are not anything like the highest-cost item on a bill of materials. As an example, think about lithium in the battery of your cell phone. That lithium costs pennies as a raw material, but if your cell phone manufacturer was forced to do without it then the resulting cell phone would bring with it a very, very different operating experience than it currently does.

Over the coming months, we are going to deal with our views of the market prospects for some critical materials, and interesting facts about others. We will talk a little (or in this newsletter, a lot) about technology and the impact, both good and bad, that it can have on demand for critical materials. We hope you find this interesting and worthwhile! Note that when not writing newsletters like this one, Stormcrow Capital functions as a corporate adviser (capital markets / financing / M&A) in the critical materials sector. We are registered as an Exempt Market Dealer in Canada *(additional disclosures included at the end of this note, for those who need help getting to sleep).*

Those Green Shoots are Growing!

Last month we referenced the changes in prices as "little green shoots" coming up. We might be into winter in North America, but lithium chemical prices continue to show signs of life. Between the beginning and end of November, the chemicals looked like this:

Battery-grade $LiOH \bullet H_2O$ down 2.0%

Battery-grade Li_2CO_3 UP 4.7%

Battery-grade $CoSO_4 \bullet 7\ H_2O$ UP 1.4%

Battery-grade $NiSO_4 \bullet 6\ H_2O$ UP 1.1%

This month, three up in China and one down, except that the one price that is down on average has been flat for essentially 6 weeks and seems to have found its bottom. Given, in China, the feedstock for lithium hydroxide is lithium carbonate, price gains for carbonate will eventually be reflected in price gains for hydroxide, too.

With battery demand continuing to rise, prices are continuing to move. Since the start of December, spodumene, lithium carbonate, cobalt sulfate and nickel sulfate prices are all moving higher. Lithium hydroxide is flat, still, but it was always expected to lag. Now, we don't believe lithium carbonate prices are going back to historical highs in 2021, that would not be a good thing for the market. But more robust pricing will help bring a healthy level of supply to the market and maintain interest in the space.

"Fool Sells" May Have Their Day

First, let's outline why we are interested, at all, in matters of technology like fuel cells. The main reason is that technology moves the demand for critical materials, both in good and bad ways. For example, the advent of PET scanners used in cancer treatment and diagnosis has resulted in a real and valuable market for the rare earth lutetium because the material lutetium orthosilicate makes a great detector for the gamma rays emitted in a PET scan. On the other hand, the market for the rare earth yttrium was crushed because the lighting industry has moved to LEDs and away from fluorescent bulbs. Keeping an eye on technology is the only way to avoid getting blindsided when you are interested in relatively small markets for specialty materials.

Second, I (Jon Hykawy) am a technologist by training and started looking at the fuel cell market and its participants in 2000. At the time, I was a complete skeptic and said so publicly because fuel cells were (a) too expensive, (b) ill-suited for use in light-duty vehicle applications, (c) had no refueling infrastructure available, (d) used a fuel (hydrogen) that was just too expensive and (e) had a refueling problem of their own. But things change, and 20 years later it might be time to revise my opinion.

We recently had a chance to read a screed by another group of analysts. Their report centered on why fuel cells will be a complete commercial failure for at least the next 20 years. And then, in truly comical fashion, an announcement was made by the Chinese that hydrogen fuel cells will figure prominently in their nation's development plan for transportation. Apologies for length, but describing what we now think and why will take a few pages to explain.

Let's assume that the argument we are having is about the broader topic of transportation, including light-duty, medium-duty and heavy-duty applications, everything from passenger cars to large transport trucks. Also, let's assume that everyone at all levels of decision-making shares two common goals, which is that they want to help limit the emissions created by the automotive industry and by the use of the vehicles the industry manufactures, but that they also realize that that this can only be done if they allow the automotive industry to sell vehicles to its buyers that the buyers want, that fit the needs of the buyers and that can be sold for a price greater than their manufacturing cost. All of this is probably nuts, I know, but humor me.

The argument the mainstream is having is whether it will be battery electric vehicles (BEVs) or fuel cell-electric vehicles (FCEVs) that replace those dinosaurs of the past, internal combustion-powered vehicles (ICVs). A BEV is a vehicle where the sole form of on-board energy is electricity contained in a battery, usually a lithium cell pack. A FCEV is one where the sole form of energy used is electrical energy generated by consuming hydrogen in a fuel cell that generates the electricity. We all know about ICVs because most of us use them regularly. Mainstream thought seems to be that BEVs will replace ICVs, while fuel cells (or, as the completely unbiased Elon Musk refers to them, "fool sells") will play a minor role.

We aren't nearly as sure of that, for what we believe are also simple reasons. Batteries are not cheap. While they have become cheaper, there is a limit to cost reduction and a diminishing return effect to engineering efforts. We've seen "Moore's Law" invoked when discussing batteries, which is like invoking Darwinism when discussing what you want for dinner; Moore's Law and batteries have, literally, nothing to do with one another. And we think there has been an artificial dichotomy imposed on the discussion of what, if anything, will replace ICVs.

Let's look at costs, and let's initially limit our discussion to light-duty applications. These are applications where the vehicle is going to be used for a small fraction of the hours in a day. In other words, our personal vehicles and not a taxi or a passenger bus or delivery van or, God forbid, a long-haul semitrailer cab. Let's also assume that the fondest hopes of those touting the new BEV Age are correct (and they are not, at least not yet) and lithium batteries for use in BEVs now cost USD$100/kWh to make. Note this is manufacturing COST. Not market price, not what they are sold for, COST. We also know that a light-duty ICV drivetrain, because of the huge volumes and quantity of R&D done on them, has a cost of about USD$45/kWh. Today, plenty of the analysts in government concerned with such things will tell you that, with reasonable production quantities, the cost of a fuel cell system would be USD$50/kWh. So, the immediate response should be "case closed; by your own rules the FCEV will be more expensive than the ICV, and we are done". Not so fast, play along for a little while longer, please.

Let's further assume we need a battery energy capacity of 80 kWh to drive a light-duty SUV down the road for an acceptable number of kilometers per charge. If so, then the cost of that battery today would be about USD$8,000, assuming what we outlined above. If we assume a few levels of a 25% markup, then the commercial price for that battery could easily be USD$16,000 or more. Meanwhile, an SUV has a powertrain, today, that produces perhaps 200 hp, or 149 kW. That means the full ICV drivetrain has a cost of USD$6,700. Commercial cost as included in the ICV is obviously higher, but overall margin on ICVs is not that big, part of what makes the automotive industry a tough place to be.

Discussing the equivalent FCV cost takes a little work. The combined heat and electrical efficiency of a fuel cell is likely in the range of 65% with respect to fuel energy, but the electrical efficiency alone is only around 45%. However, the mechanical efficiency of the internal combustion drivetrain is a lot worse than that, perhaps 25% compared to fuel value. Power is a different matter, but when we buy a 200 hp/149 kW internal combustion engine, only a fraction of that power is actually getting to the wheels, a portion of it is wasted as heat from the engine, in the transmission and differential and elsewhere in the drivetrain. What this comes down to is that, to get the same amount of power to the wheels, a fuel cell needs to generate less electrical power compared to a mechanical drivetrain. In our case, something like a 149 kW internal combustion drivetrain will be comparable to a 70 kW fuel cell. That fuel cell system alone, no electric motor attached yet, might have a cost of USD$3,500. Compared to the other options, this doesn't look too bad.

Now, let's think about real-world user ownership conditions. If you own an ICV, then you are used to getting the occasional maintenance work done, like oil changes. You are certainly used to refueling the vehicle every 400 km or so by stopping off at the gas station and spending five minutes pumping a highly flammable and carcinogenic chemical mixture called gasoline into a storage tank under the car.

If you switch to a BEV, a lot of periodic maintenance is a thing of the past, but not all (many modern automotive battery packs have liquid cooling, and coolant needs to be checked and changed over time). 'Refueling' is now recharging and can be done slowly at home. Problem is, if you get up one morning and decide you are going to drive 700 km to some destination, what was, let's say, a 8-hour trip on the highway using an ICV is now a 10+ hour trip using a BEV with the necessary 1-2 hour recharging stop. Is that a deal breaker? It might be, for some buyers, assuming that the higher capital cost of the BEV didn't stop the sale in the first place.

With a FCV, the refueling stop won't take longer than that for an ICV, assuming you can find a filling station that can provide hydrogen. The FCV might be sold at or near the cost of an ICV, but if you suffer constant headaches over where to fill up and how far you can get without having to be towed somewhere else for refueling, the user experience will leave a little to be desired. So, the major knock against fuel cells, currently, is cost and availability of hydrogen. I said the same thing 20 years ago, because I covered Ballard and Hydrogenics and other names in the first major go-round of fuel cells around 2001. I was a naysayer back then, when the story told on the street was that fuel cells were going to be in every single car in a few years. Didn't happen then, won't be happening now. But I think we can envision how it might happen, down the line.

The first mistake we think most people make is to draw the lines between ICVs, BEVs and FCVs, period. Instead of regarding the vehicles in this way, we prefer to think of vehicles of all types being short-range (SR) or long-range (LR). The difference is important because it can define the appropriate type of energy storage and drivetrain. The basic division between SR and LR is essentially the predictability and reliability of the route being traveled. If you drive your car to and from work each and every day, roughly 100 km total distance and you never really look to drive it much more than an hour on the highway before stopping for an extended period of time, you are a SR driver. If you drive anywhere between 10 minutes and hours at a time on different routes, then you are a LR driver.

The economically optimal design of a drivetrain for SR versus LR applications is different. For SR, the cheapest way to proceed is likely a BEV. If the vehicle in question is something like a city car, where the likelihood is that this passenger vehicle will be traveling less than 100 km total distance each day, then we can put perhaps 20 kWh of batteries onboard. The number of cells this will require still allows for us to generate the necessary voltage and current to provide more than enough acceleration, but the small battery size keeps costs down. This would mean roughly USD$2,000 cost in batteries, by our earlier assumptions. If such a city car needed even 100 hp, or 75 kW of power, this is still something like a USD$3,750 internal combustion drivetrain. Yes, we could easily design in an internal combustion drivetrain that can get you to work but could also drive continuously for 24 hours straight with only short refueling stops, since that's what most of us own as a vehicle. But that is not what this owner requires. A BEV in this application is cheap, cheerful and gets the job done.

And it is cheap. From our earlier assumptions, if this same vehicle needed a 120 hp (or 89 kW) internal combustion drivetrain, then that would cost something like $4,000. The batteries are definitely a cheaper way to go, providing the operational tradeoff is something that the owner can make. Best of all for the manufacturer, the difference in cost can be shared with the buyer, improving the gross margin on the sale.

Now, let's say you live 60 km outside a major city, running a business that has you traveling all around your local community but also regularly traveling into the city to pick up supplies or parts. This is decidedly an unpredictable and LR-type application. You might need, for example, to travel to the city in the morning to pick up parts, come all the way back, travel between customer sites and your office a number of times during the day, all without the luxury of being able to stop and sit for any significant length of time. As an example, something like the Tesla Model Y uses 265 Wh per km travelled. If ther average speed of this vehicle in a day is about 60 km/h, then we need average power of 16 kW. By designing in a 30 kW internal combustion engine turning an alternator and pairing that with a 20 kWh battery, we get a vehicle with all the acceleration of a BEV but with none of its operational limitations. And instead of the USD$9,000 for a high-powered four-cylinder gasoline engine and drivetrain, we start with less than USD$4,000 of small gasoline engine and batteries. Now the owner has a vehicle with entirely flexible operating characteristics, one that will, most days, operate as a zero emission BEV, something that ownership will encourage because it is the cheapest way to run this type of vehicle. But if they need to drive for eight hours straight through on the weekend, they don't need to plan where and when and how they will recharge, they just make sure there is some gasoline in their tank or that they remember to get some on the way.

Now, a simple question with a simple answer: isn't it better for the environment and for consumers if a large fraction of vehicles on the road not only have the emissions of BEVs much of the time, but also cost less than both BEVs and traditional ICVs? I think so, and present large-scale vehicle manufacturers have publicly stated that they know how to get there without any need for subsidies and the use of taxpayer dollars to help drive new vehicle purchases. They just need government to get out of their way and stop trying to dictate what the correct solution is.

Now, where do fuel cells enter into this discussion? Well, let's say for our above SUV example, that we will replace the 30 kW generator set with a fuel cell. Remember that we have higher efficiencies with a fuel cell directly generating electricity than with an internal combustion engine turning an alternator. Our average power requirement was about 16 kW but we chose a 30 kW genset for safety's sake. With a fuel cell, let's ensure that our output is sufficient by using a 20 kW electrical output and pair that fuel cell with a 20 kWh battery. At scaled output costs for a light-duty fuel cell and our previous assumptions about battery cost, the cost of this power source is USD$3,000. This is slightly less expensive than the necessarily larger output from an internal combustion engine but comes at the cost of trying to source clean hydrogen fuel every time the fuel reservoir needs topping up, and this requires a lot more effort and more money than finding gasoline.

So the major impediments to the fuel cell being a major player in the transportation market, at just about any level, are related to the availability and cost of hydrogen. There are really two major ways to make hydrogen gas. One is to take clean water and use what is known as an electrolyser, in which electricity is used to decompose water into hydrogen and oxygen. This is essentially the opposite of what happens in a fuel cell. The hydrogen made this way is very pure, given the low level of impurities in clean water. That's a very good thing because most current hydrogen fuel cells can be permanently damaged by certain contaminants in their fuel gas, including carbon monoxide. Unfortunately, though, while this hydrogen is pure it is also fairly expensive, because there is a significant amount of electricity needed to generate the fuel. If an electrolyser is about 65% efficient, then making 1 kg of hydrogen requires 51 kWh of electrical energy. The average cost of electricity in the USA is USD$0.133 per kWh, as of October 2020. That 1 kg of hydrogen comes at an average electricity cost, alone, of USD$6.78, although it is also produced along with 7.9 kg of oxygen gas. Obviously if we collect the oxygen and sell it, we will defray some of our cost.

If the hydrogen described above is made using renewable energy, it's now known as "green" hydrogen, because it will meet a low-carbon production threshold and is somehow considered better than other hydrogen. If you make the same hydrogen using the same water and electrolyser but with electricity from a nuclear plant, then that hydrogen is referred to as "blue" hydrogen, which is clearly not as good in some way that I don't understand when compared to "green" hydrogen, even though it's the same hydrogen produced at the same price. For the reader, it's illustrative to do a calculation on how much of the Earth would need to be covered by 15%-efficient solar panels to generate enough electricity to replace all of our gasoline and diesel needs, planet-wide, using green hydrogen…

Unfortunately, the cheapest hydrogen gas we can make is "grey" hydrogen, hydrogen that doesn't necessarily meet the low-carbon threshold. Natural gas is mostly methane, CH_4. By exposing methane gas to hot steam, the products of the reaction are CO_2, CO and H_2 gases. Problem is, there is as much carbon dioxide generated by making hydrogen this way as there would be by burning the same amount of natural gas. The other problem is that the produced gas contains some carbon monoxide, CO, that is toxic to regular old fuel cells. To produce gas that is clean enough to use in a fuel cell, the impure hydrogen must be purified. Now, if the removed CO_2 and CO are captured and stored, this is a serious victory in the fight against climate change, but all of this makes the resulting H_2 gas more expensive. The carbon emissions from producing hydrogen this way would still be lower than what is emitted from burning gasoline or diesel in internal combustion engines, because of the higher efficiency of a fuel cell, but human beings seem to enjoy making 'perfect' the enemy of 'better'.

So we can, theoretically at least, produce enough hydrogen because we have lots of water, electricity and natural gas. Unfortunately, the other major problem that arises is transportation and storage of hydrogen gas. If we need to carry some propane someplace, say from a filling station to a waiting barbeque, we can put liquid propane into an appropriate tank. The boiling point of propane is -42°C. There is not much problem with achieving a low enough temperature and high enough pressure to liquefy propane and then pump it and move it around. We do this every day. But the boiling point of hydrogen gas is -253°C. That is a considerably harder thing to achieve. Keeping hydrogen in liquid form is tough without very low temperatures being involved. The density of liquid hydrogen is only 0.07 g/cm^3, compared to the 0.75 g/cm^3 of gasoline, but it makes the difference up based on the much higher fuel value of hydrogen compared to a hydrocarbon. Unfortunately, the density of gaseous hydrogen is much lower than that. For example, if we push the edge of what can be done with modern storage containers and have a hydrogen pressure of 700 bar (or 70,000 Pascals or 691 times standard atmospheric pressure!) then the amount of hydrogen in a 72-liter volume, not far off the tank volume used in a current light-duty SUV to hold gasoline, increases to 0.042 g/cm^3 x 72,000 cm^3 or about 3 kg of hydrogen gas, compared to 56 kg of gasoline. Needless to say, more frequent refueling stops will be required, and I am not sure how comfortable I would be with an overstuffed bottle of shrapnel under my vehicle. But it can be done.

Critics of a hydrogen economy rightly point to the lack of a hydrogen infrastructure compared to the existing network of gasoline refueling stations or the ubiquity of electrical outlets. We can't refute that argument, although we will refer to a previous point we have made regarding the similarly fantastical possibility that, somehow, millions of BEVs will soon be looking to recharge in reasonable amounts of time while not blacking out the electrical grid (for example, if you have hope that your future Tesla Model Whatever will somehow manage to recharge 50 kWh of energy in, say, 5 minutes so that recharging can rival refueling with gasoline, then you need to explain how the grid can support average power draws of 600 kW all over the place, and also how the battery will avoid catching fire or at least being damaged over that five minute period). But we can posit two possibilities for how we can avoid much of the problem in trying to use hydrogen.

Both of these possibilities involve reforming a liquid hydrogen carrier onboard the FCEV. One option is to use a liquid hydrogen carrier that can be converted to very pure hydrogen, like ammonia (NH_3). Ammonia is not the nicest stuff out there, but then neither is gasoline. These days, the popular choices seem to involve using some sort of hydrocarbon like toluene to do the same thing, but I will take slightly toxic ammonia over flammable, toxic and carcinogenic toluene, any day.

It is technologically and chemically possible to take NH_3 and convert it to H_2 and N_2 gases. The fuel cell doesn't do anything with N_2, nitrogen gas is basically inert at normal operating temperatures. So we pass both the N_2 and H_2 though the fuel cell and turn the H_2 into water and electricity. NH_3 is a liquid that can dissolve in water and it would be possible to store it at existing refueling stations and pump it into FCEVs. Pump nozzles would need to be altered to help minimize the amount of ammonia vapor in the air, because ammonia is toxic (although so are all the components of gasoline, along with some of them being carcinogenic) but the possibility is there.

The density of saturated ammonia in water is 0.88 g/cm3, with about 308 g of NH_3 per liter of solution. This means a 72 liter fuel tank can carry 22.1 kg of ammonia, or about 3.9 kg of hydrogen, at least one third more than with gaseous hydrogen but with a much less expensive and safer fuel tank. Getting the ammonia out of aqueous solution involves heating it, nothing more. Breaking up the ammonia into H_2 and N_2 involves heating it up to its decomposition temperature of 450°C, or a much lower temperature if we use a catalyst. It's not simply throwing gasoline in a tank and spraying it into the engine but, again, it can be done.

The other option is to reform an available fossil fuel, like propane, gasoline or an alcohol, into impure hydrogen on-board a vehicle, but redesign the fuel cell to operate at a higher temperature than current, conventional proton exchange membrane-type fuel cells so as to become tolerant of contaminants in the hydrogen. We won't go into the details of how this might occur, but it would trade off using a new, potentially more expensive membrane material for reduced complexity in water management within the fuel cell and being able to tolerate CO in the fuel mix. Or maybe using a different type of catalyst that doesn't glom onto CO quite so aggressively. Surprisingly to some, both options might be feasible and so we might be able to directly lever our existing refueling infrastructure while using much less fossil fuel because we are using it much more efficiently.

Contrary to what we have heard from others, we fully expect fuel cells to play a significant role in transportation in the future. It will take a concerted effort, such as the one playing out in China, for this to happen, and it is likely to be driven, at least initially, by fleet use. For medium-duty or heavy-duty vehicles that operate out of a central depot of some kind, like city buses or municipal sanitation fleets, fuel cells represent a very significant way to reduce fuel consumption, carbon emissions and particulate levels while overcoming the lack of a distributed hydrogen infrastructure. There is clearly a difference of opinion on this topic, but to paraphrase Mark Twain, this is a free country where I am entitled to my opinion and others are entitled to be wrong(!).

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