

The Zinc Air Battery and the Zinc Economy: A Virtuous Circle

How the Automotive Industry Could Adopt Zinc-Air Technology to overcome Peak Oil and Global Warming A Policy White Paper

[2025: This paper is provided for historical context to illustrate progress in the EV industry since the launch of the GM Volt in 2007].

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Executive Summary

Oil Demand must be reduced greatly over the next 10 years in line with declining oil supplies and to reduce CO₂ emissions. The only practicable way to achieve this is to electrify Road Transport and replace petroleum with Electric Propulsion. The Lithium Ion battery has become the prime candidate to power electrified road vehicles in the near future.

Lithium supply and future production may not be sufficient to sustain global electric vehicle production. The current focus on Lilon batteries to the exclusion of all other batteries is a potential error that may lead to EV and PHEV production becoming uneconomic due to insufficient Lithium supply.

The Automotive Industry should also investigate the Zinc Air Battery and Fuel Cell technologies as alternatives. Zinc Air Batteries have the highest specific energy and lowest cost of any Electric Vehicle rechargeable battery technology and are therefore suited for mass market introduction in millions of electric automobiles. The Zinc Air Fuel Cell has even higher specific energy than the ZnAir Battery. The ZnAir Fuel Cell is an electric propulsion technology that could permit very quick recharge times comparable to refuelling a conventional vehicle with petrol. Due to its low weight, ZnAir technology is a viable contender to power large trucks and heavy commercial vehicles which would require batteries 10 times as large as a car. Zinc production is the third or fourth highest of all metals – it is therefore the cheapest and most abundant battery metal. Indeed, Zinc is an industrial metal which can already sustain large battery production in the volumes required by the Global Automotive Industry.

Zinc Air batteries must be equipped with a filter to absorb CO₂ from the entry air. Therefore vehicles equipped with this technology can be designed to permanently reduce atmospheric CO₂ levels, contrary to conventional vehicles.

In light of the logistical, temporal, environmental and financial constraints with which the world is faced, National Governments should prioritise the development of Zinc Air Battery powered automobiles and the development of a refuelling infrastructure for Zinc Air Fuel Cell powered commercial and utility vehicles. A “Zinc Economy” using already available and simple technology presents a viable, practicable and implementable path for society to transition from oil power to renewable electric power, to maintain the essential transport infrastructure on which society depends and lay a foundation for further more advanced developments in Electric Propulsion technology to follow.

Introduction

The Global Automotive Industry is now committed to the biggest challenge it has ever faced – the transition to Electric Propulsion. After three decades of missed opportunity, the industry is being forced to finally embrace Sustainable Mobility by the twin exigencies of Peak Oil and Global Warming. The greater needs of Human Civilisation mean that this transition must be achieved as quickly and effectively as possible to maintain the critical transport infrastructure on which we all depend.

In the last few years, the Lithium Ion battery technology has emerged as the major contender to enable effective Electric Propulsion. The USA is undergoing a sea-change in attitudes as public awareness and imagination is fired by the idea of the Plug in Hybrid Vehicle – a car that will take the commuter to work and home again on electric power, while still giving him the range of an Internal Combustion Engine for longer journeys. The growing success of the Toyota Prius sowed the seeds of this phenomenon. The presentation by GM of the Chevrolet Volt Series-Hybrid PHEV concept in January 2007, to be powered by a 16kWh Lilon battery, has injected new impetus into PHEV development.

The major car manufacturers have all but abandoned other battery technologies. Lithium Ion is seen as the only viable technology and as the best technology to enable Electrified Vehicles. Around the world, universities and research establishments that undertake battery research are focused almost exclusively on Lilon.

But as we have shown at length in our recent analysis¹, this unique focus on the Lilon battery may be unfortunate. It is a mistake which could have profound negative consequences if other battery technologies are not also pursued.

Lithium is a niche industrial material. Its production is very limited and any realistic achievable future production will be too constrained to permit its viability as the backbone strategic material for the global automotive industry². Production is already struggling to keep up with global demand for portable electronic items. Lithium's geological distribution is even more limited. In only two places in the world is Lithium found in significant quantity – the Andes and Tibet. The history of 20th Century Oil Politics does not bode well for South America if Lithium battery technology becomes the prime means of motive power for global road transport.

In our recent analysis of the Lithium situation, we recommended that extra research and development be urgently prioritised into the alternative battery technologies of Zinc Air and Sodium Nickel Chloride (Zebra).

The Zebra Sodium Nickel Chloride battery is a mature technology. It is rugged, proven, safe, durable and affordable. On the prime metric used to measure batteries for Electric Vehicles, its Specific Energy or Energy Content per Unit Weight is significantly higher than any other rechargeable EV battery available today, including Lilon. The Zebra battery is in effect the only dedicated Battery Electric vehicle (BEV) battery in production in the world. It could be adopted quickly and widely, particularly in the important fleet utility, delivery and public transport sectors. The Zebra battery could be the backbone for spearheading the introduction of Commercial Electric Vehicles, along with or followed by private vehicles.

However, the Zebra battery will become affected by its Nickel requirements once production reaches a few million units. 10 million 10kWh sized PHEV Zebra batteries would require 10% of current global Nickel production. The price of Nickel has already tripled in recent years. This issue can be addressed, by replacing the Nickel with Iron. However, this potential Sodium Iron Chloride variant of Zebra technology has not yet been pursued actively. Therefore while we recommend that research into the NaFeCl Zebra variant should also be prioritised urgently we should not rely on the Zebra battery chemistry alone.

The Zinc Air Battery and Fuel Cell technologies have attracted significant interest for a similar period of time to the Zebra, since the 1960s. There are two overriding reasons for this: Zinc Air provides the highest practical Energy Storage per Unit Weight at the Lowest Cost of any known battery technology. There are a number of other powerful features of this technology which mean that research into overcoming its weaker points should be

1 "The Trouble with Lithium", William Tahil, Meridian International Research, January 2007;
www.meridian-int-res.com/Projects/Lithium_Problem_2.pdf

2 This was well before large lithium deposits such as Manono, Siberia or Thacker Pass were known.

prioritised so that Zinc Air technology can be introduced as quickly as possible.

Highest Specific Energy

The main factor which has restricted the appeal of Electric Vehicles is their limited range. The range is governed by how much electrical energy the battery can store and the weight of the battery.

Therefore the most important performance metric for EV batteries is the amount of energy the battery can store per unit weight. This is called its Specific Energy and is measured³ in Watt – hours per kilogram (Wh/kg). The amount of energy that can be stored per unit volume is also important, since the available space in an automobile is limited.

For instance, Lead Acid batteries are inexpensive but because Lead is so heavy, they only store about 30Wh of electrical energy per kg of weight. The NiMH battery used in a number of EVs in California in the late 1990s can now store about 60 – 70Wh/kg. Nickel-Zinc is similar. The Zebra NaNiCl battery stores 100 – 120Wh/kg. The Lilon batteries used in consumer electronics can store 120 – 150Wh/kg, but these are not safe enough for EVs. Different safer Lilon chemistries must be used instead⁴ and these can only store the same amount of energy as NiMH i.e. 70 – 80Wh/kg.

The Zinc Air battery however has the highest Specific Energy of all. In existing “fuel cell” batteries where the battery is recharged by physically replacing the Zinc anodes, rather than by plugging it into a socket, **the Specific Energy is 220Wh/kg**. Electrically Rechargeable ZnAir batteries deliver 100 – 150Wh/kg.

There are other factors that have to be taken into account but the Zinc-Air technologies have long been recognised as attractive for this reason. Zinc-Air has such high Specific Energy because one of the reactants is external to the battery – the Oxygen in the air. Therefore the vehicle does not have to carry that material on-board in the battery, greatly reducing the weight.

Another important measurement for Electric Vehicles is how quickly the energy in the battery can be released – Specific Power or power delivery per unit weight. The highest power demands on the battery are when the vehicle is accelerating, climbing a hill or cruising at high speed. In these situations, we want the battery to give up its energy more quickly. Unfortunately, batteries are less efficient when they do this and while they deliver the energy more quickly, they lose capacity – they cannot deliver as much of it in total. This applies to all battery technologies. The high energy storage Lilon batteries are greatly affected by this, which is one reason why in reality Lilon batteries can only deliver 70-80Wh/kg when used in EVs.

The energy capacity of Zinc Air batteries also drops significantly when High Power is required. This problem can be resolved however, either by having a large battery to start with, which gives the vehicle long range and still provides adequate power, or by using Ultracapacitors with the battery to deliver high power bursts when needed. This is called a Hybrid Battery System.

Zinc Air Fuel Cell Quick Recharge

Extensive research, development and field trials have been carried out in Europe and the USA into versions of the ZnAir battery that can be completely recharged in a few minutes like a conventional petrol vehicle by pumping into the vehicle a liquid slurry of electrolyte and Zinc particles or physically replacing the Zinc when the battery has run down. Instead of having a fixed Zinc anode, separated from the cathode by the potassium hydroxide (KOH) electrolyte, the anode consists of a slurry of small Zinc particles suspended in the electrolyte that are pumped continuously past a metal bed, the anode current collector. As they roll along the metal bed, they react with the electrolyte to produce electricity until they are consumed. When all the Zinc particles have reacted, the battery has discharged.

³ The commercial “Unit” of electricity is 1 kiloWatt-Hour or 1,000 Watt-Hours (1000 Wh).

⁴ i.e. Lithium Iron Phosphate, which was the intention in 2007.

To recharge, the driver would pull into a service station, insert a nozzle to pump out the exhausted slurry of spent Zinc Oxide and electrolyte and then pump in a fresh charge of new Zinc pellets and electrolyte. In this way, a 30kWh battery that would take 10 hours to completely recharge at home from the mains, can be “recharged” in 10 minutes.

This “refuellable” Zn Air technology is the only technology in the world that can allow such fast recharging of EVs. Although it is claimed that new Lilon battery technologies can be recharged in 10 minutes or less, there is a major problem. The mains electricity supply required to do so would have to have extremely high power. For instance, to recharge a small 10kWh battery in 6 minutes would require a 100kW power supply. Most houses are limited to 5 – 10kW total power draw at the most. Such fast recharging would only be possible at special dedicated recharge facilities and then the question arises of many EVs wanting to fast recharge simultaneously. The total power requirements could equal those of a major industrial facility, which may not be practical for urban “Service Stations”.

If we consider Heavy Goods Vehicles, the issue becomes even more significant. While a PHEV car requires at least a 10kWh battery to provide useful All Electric Range (AER) of 30 miles, the heaviest trucks would only travel half a mile per kWh. A 200kWh battery would give only 100 miles AER, for a vehicle that travels 60,000 – 80,000 miles per year. With current generation Lilon batteries, a 200kWh unit would weigh 2.8 tonnes. With Zebra units, it would weigh 1.7 tonnes. With some existing ZnAir Fuel Cells, it would weigh 900 kgs. At that weight, one can envisage having 400kWh of ZnAir capacity housed under the trailer, to give a useful 200 miles AER. By using either the mechanically rechargeable or slurry refuellable technologies, refuelling would then take no longer than with diesel. Long distance trucks would operate best as Series Hybrids, with an on-board generator to keep the battery charged and provide peak power when required.

Zinc-Air is the most viable battery technology for large trucks because of this very high energy requirement. The other technologies would all weigh too much to provide significant energy.

The company Metallic Power Inc. pioneered the development of this refuellable Zinc Air Fuel Cell between 1998 and 2004. The technology was originally developed at the Lawrence Livermore National Laboratory. The technology rights are now owned by the Teck Cominco Mining Company, the largest Zinc producer in the world. The realisable Specific Energy of this technology is about 140Wh/kg.

A similar Zinc-Air fuel cell design that has undergone extensive testing and development since 1990 is the mechanically rechargeable ZnAir system. This was developed by the Israeli company Electric Fuel Ltd. (now Arotech). It demonstrates high specific energy of 220Wh/kg at low to medium power rates. In this system, the Zinc metal anodes are physically removed and replaced when the battery is discharged. This would be suited to vehicle fleet operators such as municipalities, urban public transit operators, taxi companies and large national haulage companies. Recharge time is similar to the liquid electrolyte slurry system but not so convenient.

Carbon Dioxide Reduction

Before the Industrial Revolution, the concentration of CO₂ in the atmosphere was about 290ppm. By 1995, it had reached 360ppm. Today, it is about 410ppm and rising. The situation is becoming critical.

Replacing petroleum with electric propulsion reduces CO₂ emissions enormously. In the USA, Light Duty Vehicles emit 270g of CO₂ per km. In Europe, new cars emit some 160g/km. This is an astronomical amount. If one considers that US cars drive 12,000 miles per year, each of the 220M automobiles in the country emits over 5 tonnes of CO₂ per year. That is about 3 - 4 times their own “body weight” in CO₂ per year.

Since US cars drive 2.6 trillion miles per year, total US CO₂ emissions from LDVs alone reach 1.1 billion tonnes per year.

Total US CO₂ emissions in 2005 were 6 billion tonnes. Transportation of all types accounts for one third of this or 1,958 million tonnes of which 82% is by Road Transport – 1.6 billion tonnes.

Road Transport accounts for 27% of US CO₂ emissions.

In the UK, all transport accounts for 25% of CO₂ emissions.

Road Transport must be electrified because of the global decline in oil production which is now occurring. In addition, replacing Road Fuel with Electricity⁵ would eliminate 27% of US CO₂ emissions and about 20% of equivalent European CO₂ emissions. The electricity required can be gained from straightforward domestic and industrial efficiency measures – no new generating capacity is required. This is an enormous benefit.

In other words, Road Transport Petroleum Consumption can in effect be replaced for free by existing electricity production. However, in countries dependent on Natural Gas and Coal for electricity generation, Renewable Electricity generation must also be prioritised to assure security of supply as natural gas supplies will also soon become more constrained. Electricity production from Coal must be phased out as well to reduce CO₂ emissions to acceptable levels.

However, the Zinc Air Fuel Cell and battery technologies have another advantage in the situation in which we now find ourselves. To achieve acceptable life and durability, the Zinc Air battery must be supplied with air that has had the Carbon Dioxide removed. The CO₂ is removed by passing the inlet air through a “scrubber” of inexpensive hydroxides (Soda Lime) where it is fixed into carbonates – in effect, the common minerals chalk or limestone.

This requirement has heretofore been seen as a disadvantage of Zinc Air technology. No other battery requires a filter to remove the atmospheric CO₂. The filter will have to be periodically removed and replaced, depending on how much the vehicle is driven.

However, times have changed. In fact, this is now a significant advantage and positive factor of the Zinc Air battery. Not only does it eliminate the extremely high CO₂ emissions that petrol driven vehicles produce – it absorbs Carbon Dioxide from the atmosphere.

To summarise, the Zinc Air Battery, in common with the other batteries for Electric Propulsion, can replace petrol effectively for free from existing electricity generation and eliminate 20 – 30% of western CO₂ emissions. But in addition, the Zinc Air battery has the unique capability to remove CO₂ from the atmosphere and therefore actively to reduce CO₂ levels.

Zinc Cost and Availability

Any battery technology that is to be used by hundreds of millions of motor vehicles must use cheap and abundant materials. The cost of batteries has always been and continues to be the major obstacle to the widespread introduction of Electric Vehicles.

The only battery in volume production with an affordable cost is the Lead Acid (PbA) battery, first invented in the mid-nineteenth century. Lead is an inexpensive metal. However the PbA battery is too heavy and its cycle life too short to be viable in mass market EVs. The supply of Lead would also be insufficient to meet EV/PHEV demand on the scale of the global automotive industry, not to mention the environmental hazards of this technology.

The Lithium Ion battery has become the favoured technology of the battery industry. Lilon batteries are currently very expensive and even in volume EV production they are not expected to fall below \$500/kWh to the end user. However, as stated above, analysis of realistic future Lithium availability and production shows that Lithium supply would be completely inadequate to meet the needs of the global automotive industry, which currently

⁵ See “2007 Peak Oil: The EV Imperative”, Meridian International Research, 2005 P186 for the analysis which shows that electricity consumption efficiency gains could save enough electricity to power the entire US and European Road Vehicle fleets – no extra electricity production is required.

produces 60 million vehicles per year.

The NiMH battery is very expensive and requires large quantities of the metal Nickel. Nickel is produced in relatively limited quantities and is expensive but it is still an important industrial metal. 70% of the Nickel produced is used in the manufacture of stainless steel and production could be expanded significantly if required.

The Zebra Sodium Nickel Chloride battery uses one third of the amount of Nickel as NiMH and has double the specific energy capacity. Therefore there need not be major material availability constraints until NaNiCl production was expanded to a few million units per year. However, Nickel prices or availability would become an issue at production of 10 million Zebra units per year. In this case the Zebra technology would allow substitution of the Nickel with Iron, with some loss of performance, but producing a **very affordable battery that could be manufactured in unlimited quantities**. Research should be carried out into this alternative version of the battery as a precaution and to ensure its long term sustainability.

However, Zinc is the metal produced in the fourth greatest quantity in the world after Iron, Copper and Aluminium. Its current price is less than 4% of that of Nickel. 6 times as much Zinc as Nickel is produced per year. An established global Zinc recycling industry exists to reclaim Zinc from its myriad of industrial uses, including the ubiquitous Alkaline battery. Zinc has widespread availability and accessibility throughout the world. It is not a strategic metal. It is distributed in (for our purposes) unlimited quantities in the Earth's crust. There are now some 900M motor vehicles in the world; 21 months of Global Zinc Production would be sufficient to produce 1 billion 10kWh Zinc Air batteries. In comparison, 10 years of Nickel production would be required to do the same with Zebra batteries. As for Lithium – over 180 years of current Lithium production would be required with Lilon technology.

The Zinc Air battery uses the cheapest and most available metal of all the battery types. It is non toxic, already widely used in the battery industry and throughout society. It is a common material.

In 1998, the Lawrence Livermore National Laboratory estimated that their refuellable Zinc Air fuel cell could be produced for \$60/kWh. NiMH and Lilon are unlikely⁶ to fall below \$500/kWh, even in volume production. This cost level effectively renders them prohibitive for mass market adoption.

Zinc Air is therefore by far the least expensive and least material constrained of all the EV Battery technologies. In fact, it is the only affordable and viable mass market EV battery technology.

Safety

There are still significant safety concerns with Lilon battery technology. The technology used in consumer and portable electronics cannot safely be used in cars and safer Lilon alternatives have been developed instead. These have the disadvantage that they store no more energy than NiMH battery technology. Therefore the higher energy storage capability of consumer electronics Lilon batteries, which is still less than Zinc-Air, is lost in EV applications.

Even the safer Lilon chemistries that would have to be used in EVs are not entirely safe. Unlike all of the other battery technologies – NiMH, NiZn, PbA, Zn-Air, Zebra – the Lilon battery requires much more extensive electronic monitoring and control to keep it within safe operational limits. The safer Lilon chemistries still require this.

The biggest danger with a battery is that it might short circuit in the event of a car crash. In this situation, it completely discharges very quickly and becomes extremely hot. With Lilon batteries, this can cause a fire and Lithium itself will then burn fiercely. Other batteries may produce large quantities of hydrogen gas and burst or explode. They can all create an electrical danger for the emergency services.

6 "Status and Prospects of Battery Technology for Hybrid Electric Vehicles including Plug-in Hybrid EVs", 26/1/07, M. Anderman, Briefing to the US Senate Committee on Energy and Natural Resources

The ZnAir system is the only battery that is inherently short-circuit proof. If a short circuit occurs, its chemistry shuts the battery down. It cannot operate and discharge with a short circuit. No danger can occur.

In the ZnAir battery one of the reactants is external to the battery – it is the air itself. If the air supply to the battery is shut off by a valve, the reaction stops and the battery shuts down. In all other batteries, both reactants are contained within the battery itself and cannot be separated in this way. This gives two independent ways to shut down the electrical power in an emergency – with a switch and by physically shutting off the air supply. With its inherent resistance to short circuit, ZnAir is therefore by far the safest of all battery technologies.

Other Operational Aspects

The Zinc Air battery can be overcharged and overdischarged without safety or damage implications, unlike Lilon batteries. The battery can also be reconditioned by deep discharging to take all the cells down to zero charge, to rebalance the whole battery pack. This fundamental operation which helps to maintain performance and extend the life of the battery cannot be performed with Lilon batteries.

All EV batteries require cooling due to the heat they generate when high power demand is placed on them. Other battery technologies use a dedicated air or water cooling system to do this. The ZnAir battery and Fuel Cell work most effectively if the electrolyte is pumped through the battery and air must be pumped through the battery casing to ensure adequate air flow. These flows can be used to cool the battery – therefore a separate cooling system is not required.

The main weakness and criticism of rechargeable Zinc Air batteries is their low cycle life. This is limited to about 600 100% cycles at C/3⁷. High voltage drop occurs under high power loading but the same effect also occurs with Lilon batteries optimised for energy storage, not power delivery. Ultracapacitor Hybrid Systems are proposed to solve this issue for both Lilon and ZnAir and would have other performance benefits.

600 charge and discharge cycles would be sufficient for 2 years operation of an EV that completely discharged its battery every day and recharged at night. In a Plug In Hybrid, battery charge would be maintained by the generator to extend battery life. Set against this low cycle life is the overriding factor of Cost. The ZnAir technologies are so potentially inexpensive that low cycle life is not cost prohibitive. Low cost also allows large 30kWh units to be affordable for cars. With high energy capacity, only partial discharge would occur each day extending the cycle life to over 1000 cycles. As indicated above, ZnAir batteries can also be periodically reconditioned, during an annual service for instance. There are other operational ways to address this issue.

Solar Thermal Zinc Production

The need to reduce CO₂ emissions and fossil fuel dependence in all spheres of industrial activity is rapidly becoming an imperative. The smelting of ores into the desired metal – iron, copper, zinc, nickel etc. - is a very energy intensive process and produces large quantities of Carbon Dioxide.

For instance, Zinc metal is produced by first roasting its ore to produce Zinc Oxide and then reducing the oxide to Zinc metal with Carbon. The Carbon removes the Oxygen from the oxide and is converted into Carbon Dioxide.

Large amounts of fossil fuel are therefore required, first to heat up the ore and then to heat it with Carbon to reduce it to Zinc. The Carbon used is coke, made from coal. A large volume of CO₂ is of course produced by this process.

Some 60 million cars are now manufactured each year⁸. If they were all equipped with a 30kWh Zinc-Air battery, 2.88 million tonnes of Zinc would be required, 30% of existing global Zinc production. Some of this could be

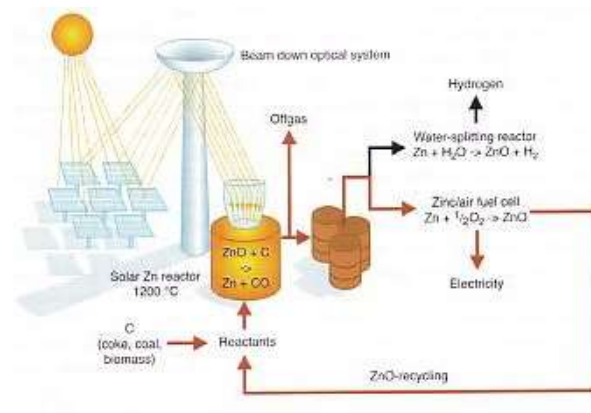
⁷ C/3 means the battery is discharged in 3 hours. This is the standard rate at which EV batteries are measured.

⁸ Global motor vehicle production is projected to reach 76 million by 2013

supplied from existing recycling capacity but using conventional smelting methods, fossil fuel use and CO₂ emissions would rise. Nickel based batteries would face a similar problem, though Lithium production with the methods now used does not produce CO₂.

Therefore when Zinc production rises to supply EVs, some of the CO₂ reduction gained will be offset by extra emissions from smelting and ore extraction.

However, over the last ten years research has been carried out into the production of Zinc using renewable Solar Thermal Energy. This has opened up the possibility of producing Zinc with no or greatly reduced CO₂ emissions.



The European SOLZINC project has built and tested a Solar Thermal Reactor in Israel which can reduce Zinc Oxide to Zinc metal by solar power. An array of mirrors focuses sunlight onto a collector which then directs the concentrated light into the reactor chamber containing Zinc Oxide and beech charcoal. The temperature reaches over 1600 deg C. The charcoal reduces the oxide to Zinc metal. If the charcoal is produced from sustainable forests, the net CO₂ emissions would be zero.

If the temperature is raised somewhat more, Zinc Oxide will thermally dissociate into Zinc metal and Oxygen under the action of heat alone, without the need for carbon. This higher temperature can be achieved in the SOLZINC reactor.

This system would allow a completely renewable energy, non polluting “Zinc Economy” cycle to be established. The Zinc produced would be used in ZnAir batteries or fuel cells to generate electricity and power motor vehicles. When the Zinc in the fuel cells is used up, it has been oxidised back to Zinc Oxide. The Zinc Oxide would be shipped back to the Solar Thermal Smelter and dissociated into Zinc and Oxygen, ready to generate electricity again. Unlike the so-called “Hydrogen Economy”, a Zinc Economy using Solar Thermal Energy would be an energetically viable system which could develop out of the existing Zinc Industry.

The areas of the world with plentiful sunlight would be the best locations to site these smelters. It would of course take years for an industry to become established and there are many other factors to consider but the SOLZINC demonstration shows what could be achieved in the future. In the meantime, all battery technologies require metal and increasing battery production will require energy to do it. Conversely, the energy required to make conventional engine blocks out of cast iron and aluminium will fall. Unlike Nickel or Lithium, there is sufficient margin in the existing Zinc industry to sustain significant development of ZnAir technology before new Zinc production would be required.

Conclusion

Zinc is the most affordable and most abundant material available for a practical mass market EV power source. ZnAir also displays the highest specific energy of any battery technology.

These three power source metrics – Cost, Material Availability and Specific Energy – are the three most important Critical Factors to enable the successful introduction and adoption of millions of Electric Vehicles worldwide.

Zinc Air technology is therefore by far the most effective, powerful and affordable EV Power technology available to us. It is in fact the only viable technology that can enable the Global Electrification of Road Transport.

The Zinc Air Fuel Cell is the only battery technology that would allow EVs to be recharged in minutes with a liquid “fuel” like conventional vehicles, thus in time giving pure EVs the same convenience and capability for long distance travel as petrol driven vehicles.

Unlike any other power source, Zinc Air technology acts to absorb Carbon Dioxide, therefore reducing ambient CO₂ levels and purifying the air. A Zinc Air powered vehicle has exactly the opposite environmental impact to an existing Internal Combustion vehicle.

Zinc can be produced with non-polluting, renewable Solar Energy with little or no emission of CO₂. This would ultimately allow the development from within the existing Zinc industry of a completely environmentally neutral Zinc Cycle which would power EVs and stationary Zinc Fuel Cells from the Sun.

Therefore on a balanced analysis of all factors, priority should be given to adopting the Zinc Air technology as widely and quickly as possible, to replace Road Transport dependence on petroleum and to reduce anthropogenic CO₂ emissions.