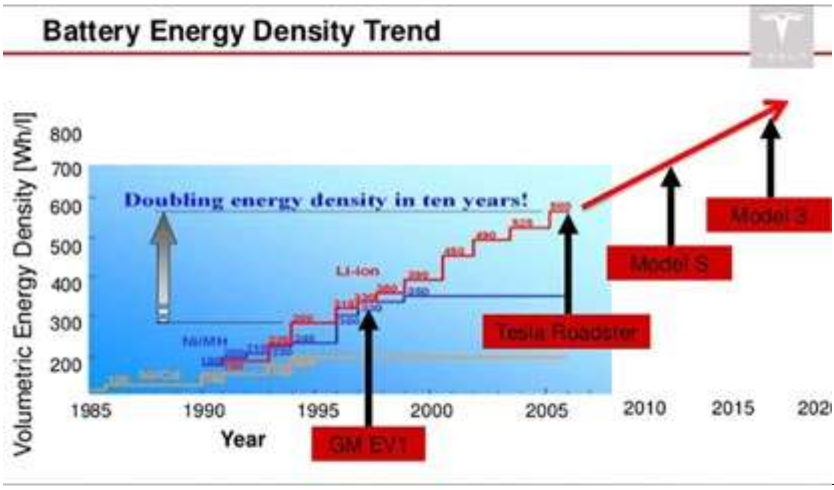
Aircraft Power Sources

There have been a recent flurry of announcements of new projects to develop ‘green’ passenger-carrying hybrid or all-electric aircraft technology demonstrators. **BILL READ FRAeS** asks battery manufacturers whether the current state of battery technology is equal to the task of powering these new larger aircraft and will they be as environmentally-friendly as hoped for?

Airbus, Rolls-Royce and Siemens recently announced plans to use a BAe 146 as a hybrid electric aircraft test bed. (Airbus)

The past few months have seen the announcement of a number of new projects to develop large passenger-carrying all-electric or hybrid electric aircraft. For some or all of their flight times, such aircraft will rely on on-board batteries to power electric motors. But is current battery technology equal to such a challenge? How reliable are batteries to power such a large platform as an aircraft? How easy are they to recharge between flights? Will they be safe to operate in adverse flight conditions? How environmentally friendly are they? To answer these and other questions, *AEROSPACE* talked to three representatives from the battery manufacturing industry - Brett Williams, Director of Engineering from True Blue Power in Wichita, Kansas, USA; Jean-Marc Thevenoud, Marketing Manager, Aviation from TTG Division, Saft Batteries in France; and Claude Chanson General Manager from RECHARGE - The Advanced Rechargeable & Lithium Batteries Association in Brussels, Belgium.

Technology breakthroughs



A prediction from electric car manufacturer Tesla on how battery energy density has improved in recent years and how to may continue in the future. (Tesla)

AEROSPACE**:** *There have been some remarkable improvements in battery technology in recent years in terms of battery size, weight, power, duration. What have been the main advances and how has they been achieved?*

BW: The advances have come in the form of either improved anodes or cathodes (the two opposite polarity elements that shift electrons from positive to negative and back again). Anodes are traditionally made from some form of graphite while cathodes can vary widely. The chemistry associated with the cathode side generally defines the behaviour of the battery with regard to more power and energy or to improve or safety but making the batteries less volatile.

J-MT: In the 1990s Saft developed ULM (Ultra Low Maintenance) nickel-cadmium (Ni-Cd) batteries with a longer lifetime, that increase the time between maintenance stops by up to 50%. While Ni-Cd technology continues to be the first choice for many aviation programmes, new battery technologies, such as lithium-ion (Li-ion), are beginning to be applied to aviation needs which offer high energy and power density, enabling lightweight battery systems to be designed that can provide up to 30% of weight savings in a low maintenance package. However, these ‘emerging’ technology batteries are not yet ‘off the shelf’ and consequently require more development effort.

CC: The visible part of the iceberg is the development of Li-ion batteries: the main progress for this technology have been incremental progresses in active materials and cells/batteries design, thanks to a large increase of the manufacturing (automation and process control). In parallel, a lot of new batteries technologies have been explored, opening a high probability of success for a post-Li-ion technology in the future.

Higher energy density

AEROSPACE**:** *What have been the main drivers to improve battery technology?*

BW: The critical factor that battery manufacturers are attempting to optimise is ‘energy density’- that is, the most energy per unit weight. This is typically expressed as kilowatt per kilogram (kW/kg). Size improvements also come along with better energy density. Of course, aerospace is more concerned with more power and energy per unit weight but it has less leverage to drive technology than higher volume markets.

J-MT: The main drivers for the aviation market are weight saving, reduced maintenance time and, most important of all, safety. By using only four Li-ion batteries on the A350, Airbus reduced weight by more than 80kg, while replacing the regular checks, periodical check and general overhaul needed with other types of batteries with a single check every two years. Furthermore, the Li-ion technology allows real-time monitoring of batteries' charge and health.

CC: Batteries have always been competing for higher energy density. A competitive advantage in this field not only allows larger market shares but also for new applications to start.

Electric cars lead the way

Lithium-ion batteries fitted on a Nissan Leaf electric car. The development of the electric car has been a major driver in the development of more efficient batteries. (Wikipedia)

AEROSPACE**:** *Which other industry sectors have helped with the advancement of battery technology?*

BW: The automotive industry has certainly been a major driver of battery technology with the goals of going further (and/or faster) on a single charge, plus quick charging. The size of the market for electric automobiles has enticed dozens of battery manufacturers to push the technology forward faster to capture that opportunity. However, supply has generally outpaced demand as the electric or hybrid vehicle market is still maturing and this has caused a number of battery players to fall to the wayside and narrowed the field to the major competitors. Consumer products are also generating opportunities for better batteries, although with a consideration towards physically smaller batteries with equal or more energy.

J-MT: The development of electric-powered cars by the automotive industry has led to a new and large usage of Li-ion batteries which offer cost reduction and energy density improvement. This has also proved to be a good way to increase the Li-ion market acceptance for large applications.

CC: Although the market for electric-powered vehicle has only recently increased significantly, studies and development for automotive applications started in 1975 with Ni-Fe and Ni-Cd technologies. Since that time, interest has increased and the amount of R&D invested over the past years is very important. However, it is the IT sector which has mainly contributed to the industrial development of the technology, particularly the Li-ion technology now enabling electric-mobility.

A new generation of batteries

AEROSPACE**:** *Batteries have been used on aircraft for many years to power certain systems and more recently on more-electric aircraft, such as the Boeing 787. Do these batteries differ from those used in vehicles or on the ground to allow for particular conditions encountered during flight (such as extreme temperatures, motion or adverse weather?)*

BW: In some cases, yes, aircraft battery cells may be optimised specifically for an aerospace environment. However, other applications utilise standard commercial grade cells but constructed within a battery or battery system in a way that helps them be more robust or reliable over their life. They may be designed with vibration or shock, temperature and extreme temperature variation, moisture exposure, or flammability concerns in mind. Additionally, they would be validated against electrical requirements for power quality, radio frequency (RF) interference or susceptibility, and protection against lightning effects.

CC: The technical requirements for batteries used on aircraft are not very different from those of many other applications. The technology used is similar but some specific designs are modified to increase the robustness of the product. As aviation usage requires a high level of reliability and quality control (including years of testing records), this may reduce the pace on innovation introduction for this application.

AEROSPACE**:** *Could the same type of batteries be used to power an all-electric aircraft or would they need to be completely redesigned?*

BW: It’s possible that similar cell technology could be used for the propulsion of an all-electric aircraft. However, it would need to be constructed into a battery system that absolutely maximised the energy and power while minimising the weight.

J-MT: Batteries in aviation are currently used for such important functions as starting the auxiliary power unit (APU), as well as providing the minimum level of back-up energy required to get information to a pilot in an emergency. The emergence of more-electrical aircraft hasn’t change the overall function of the batteries, as they are solicited during a limited time for specific actions. However, the function of the battery is dramatically changed for an all-electric aircraft, as the battery is used constantly to power the aircraft. Nevertheless, the technology can still be Li-ion, with targeted cell performances, dedicated thermal management and specific design to allow battery swapping if needed.

CC: Batteries for aircraft motor power supply would need a new specification but this would be mainly about the technical design, not about the chemistry technology. It is clear that the performance expectation of such specifically designed batteries would certainly limit the usage, as the energy density of Li batteries is much less than that of fuel.

Still room for improvement?

easyJet is also working on its own electric aircraft concept. (easyJet)

AEROSPACE*: *Studies of future large electric powered aircraft often say that they will only be possible if there are future advances in battery power storage technology. What scope is there for such further technological enhancements to improve energy/weight ratios?

BW: This will certainly represent a challenge. Right now, lithium-ion technology represents the best possible solution for practical large-scale energy storage and delivery on aircraft. However, even the best lithium-ion cells have an energy density in the neighborhood of 250Wh/kg, although there may be some a little higher. However most of the research seems to indicate that the potential for practical electric flight doesn't become possible until at least 300Wh/kg, and possibly as high as 500Wh/kg. While research in university labs are always pushing towards these kinds of advancements, nothing in that range appears to be on the horizon of commercial viability.

J-MT: A battery is a pack of one or more cells, each of which has a positive electrode (the cathode), a negative electrode (the anode), a separator and an electrolyte. Using different chemicals and materials for these affects the properties of the battery – how much energy it can store and output, how much power it can provide or the number of times it can be discharged and recharged (also called cycling capacity). Battery companies are constantly experimenting to find chemistries that are cheaper, denser, lighter and more powerful. Today's battery technology makes it possible to power small electrical aircraft for a short duration, typically 30 minutes. To power large electric aircraft for long-haul flights would require an important breakthrough in battery technology, as batteries have low energy density compared with aviation fuels, without considering the challenge of high voltage bus architecture that is required for such application.

In addition to improving current technology there are several areas of research, including lithium-sulphur and solid state. In Li-ion batteries, the active materials are layered between the lithium ions in stable host structures during charge and discharge. In lithium-sulphur (Li-S) batteries, there are no host structures. While discharging, the lithium anode is consumed and sulphur transformed into a variety of chemical compounds; during charging, the reverse process takes place. A Li-S battery uses very light active materials: sulphur in the positive electrode and metallic lithium as the negative electrode. This is why its theoretical energy density is extraordinarily high: four times greater than that of Li-ion. That makes it a good fit for the aviation and space industries. Li-S technology needs further research and development work to improve its life expectancy and to continue to increase specific energy density.

Solid-state batteries represent a paradigm shift in terms of technology. In modern Li-ion batteries, ions move from one electrode to another across the liquid electrolyte (also called ionic conductivity). In all-solid-state batteries, the liquid electrolyte is replaced by a solid compound which nevertheless allows lithium ions to migrate within it. This concept is far from new, but over the past ten years – thanks to intensive worldwide research – new families of solid electrolytes have been discovered with very high ionic conductivity, similar to liquid electrolyte, allowing this particular technological barrier to be overcome. The first huge advantage is a marked improvement in safety at cell and battery levels: inorganic solid electrolytes are non-flammable when heated, unlike their liquid counterparts. Second, it permits the use of innovative, high-voltage high-capacity materials, enabling denser, lighter batteries with improved safety performance and better shelf-life as a result of reduced self-discharge. As the batteries can exhibit a a high power-to-weight ratio, they may be ideal for use in electric vehicles. Several kinds of all-solid-state batteries are likely to come to market as technological progress continues. The first could be solid-state batteries with graphite-based anodes, bringing improved energy performance and safety. In time, lighter solid-state battery technologies using a metallic lithium anode should become commercially available.

CC: The energy/weight ratio has been for years the target of performance increase of batteries. The access to the aircraft market is a new challenge. In a similar way to the electric road mobility market, hybrid systems or specific new small systems may be the way to introduce electrical energy as a power source for air transport.

Which comes first - the battery or the motor?

AEROSPACE**:** *Is the key to developing larger electric aircraft to gain more power supplied by the batteries or reduce the power required by the motors?*

BW: This is hard to say as I can't speak about this with any real knowledge on the topic of motor technology. Motors are advancing but I feel like the industry is expecting the solution to come from better batteries. However, it could also come, in part, from neither. Companies such as Aurora Flight Science (recently purchased by Boeing) are making advances in composite materials and aerodynamic design to make aircraft lighter and more efficient, reducing the burden on battery or motor advancements. Brett Williams

J-MT: As a battery manufacturer, we are looking at ways to reduce battery weight or improving the battery performance for a given weight. It is often claimed that saving one kilogram on each flight could save roughly 1,700 tons of fuel and 5,400 tons of CO_2 per year for the whole of air traffic. For example, 85kg have been saved by replacing Ni-Cd batteries with Li-ion batteries on the A350.

CC: Not being a motor specialist, I cannot comment about the progress margin available for motors. It is clear that the laws of aerodynamics will not change with electric power and that the energy/weight ratio of batteries needs to be improved. However, as with the invention of the jet engine, we can wonder if a fundamentally new approach for electrical engine may not be useful? We also may try to think out 'of the box' for an innovative approach of the usage of electrical energy for air propulsion (for instance, a number of electric motors activating ‘mobile’ wings which significantly change the aircraft aerodynamics from take-off condition to flying conditions…)

Hybrid vs all-electric aircraft

AEROSPACE**:** *One of the hurdles to be overcome to enable flight certification of a large electric aircraft is the risk of the batteries running out during flight. How practical is it to fly a large aircraft powered by batteries alone or would a hybrid design be safer and more practical?*

BW: If there was significant margin in the amount of energy available, then it could be possible to envision a purely electric aircraft. Of course, with safety as the highest priority, a backup system will always be necessary. That backup could come in the form of reserve batteries for the primary system or it could come from an independent power source, such as a reserve fuel supply. In the short-term, due to the current state of battery technology, hybrid solutions will be the only option until we bridge the gap towards an all-electric solution.

J-MT: Whatever the application, safety is the first parameter to be considered. For large aircraft, the full-electric aircraft is not yet possible which is why the hybrid solution is the preferred one. For small aircraft (2 to 4 people), full electrical solutions already exist as prototypes. When these aircraft go to production, safety must be well considered, as well as reliability, cycling capability and life duration. What is acceptable for a proof-of-concept might not be suitable for production.

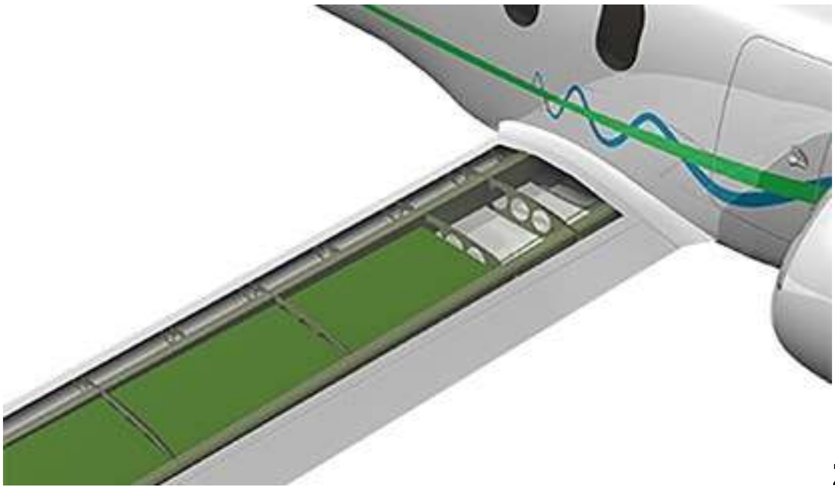
CC: I don’t think that the risk of running out of batteries is less under control than the risk of running out of fuel. On the contrary, the automotive industry is now discovering how much more simple and reliable are the electric-vehicles when compared to the internal combustion engine. Nevertheless, it is realistic to envisage a transition period where hybrid designs (although more complex) would provide a back-up of known technologies - as well as being required from a performance point of view.

AEROSPACE**:** *Is it practical to use batteries for take-off, given the large amount of power required?*

BW: In theory, yes. Batteries could be used for take-off, climb, and sustaining cruise. It does take a lot of power but for high-energy systems configured electrically in parallel, large amounts of power can be generated. The primary challenge is not in generating the power but in having enough energy left to complete a mission of any significant length. Again, this problem can only solved by having much higher energy densities than are available today. Some of the smaller all-electric aircraft demonstrators are circumventing the issue of initial power requirements by using take-off assist systems similar to a catapult systems on aircraft carriers.

CC: It is clear that the design of high power batteries (when compared to high energy batteries) require more mass for the electrically conductive parts. Therefore, it reduces the energy/weight ratio, which is already a limiting factor. This has certainly to be taken into account when assessing the whole aircraft design and expected autonomy.

Where would the batteries go - fuselage or wings?



Zunum Aero is proposing to store the batteries for its new electric aircraft design in bays for modular battery packs within the in the wings. (Zunum Aero)

AEROSPACE*: *Would it be most practical to fit batteries inside the wings on an aircraft - as with liquid fuel - or would they be better inside the fuselage?

BW: I can't really comment on this but my guess is that, given the number of batteries required, there would be no choice but to put them in the aircraft's wings.

J-MT: This is more a question for aircraft manufacturers but putting the batteries closest to where the application they are need for would seem the best solution to save weight on the quantity of cables needed. In current aircraft designs the batteries are usually located in an electrical cabinet which is pressurised and, most of the time, at room temperature. This is not always the case for other applications, such as helicopters; and so, the temperature specifications are in the range -55ºC to +70ºC which is more constraining that for automotive applications.

CC: There are certainly some thermal management issues to be addressed if the batteries in the wings but it may be the best solution to save room in the fuselage, particularly if battery cooling is needed during flight.

Swap or recharge?

In August 2017 Pipistrel inaugurated its first electric charging station which takes on hour to recharge one of its Alpha Electro trainers. But how practical would it be to recharge a large passenger-carrying commercial aircraft at an airport and how long would it take? (Pipistrel)

AEROSPACE**:** *How quickly could a large electric aircraft be 'refuelled' after a flight?*

BW: Lithium-ion batteries have a very low internal impedence that allows them to be charged very quickly. So, it could be reasonably fast. However, based on the size/amount of the batteries needed, having a power source to charge them at their maximum rate may be impractical. Even electric cars at this point take between 9-10 hours to fully recharge. Higher power may be available at airport electric charging stations but the batteries will be much, much larger. It is likely that it would not be anything near the short refuel and turn-around time expected by airlines today between flights.

J-MT: Today, on the A350, the BattCare, Saft GSE (ground support equipment) allows a very quick charge, from 20% of state of charge to 90% in fewer than 45 minutes.

CC: A battery's recharging rate is defined by the its power. Increasing battery power has some energy performance drawback but the benefit is the high rate charge. In addition, in the case of hybrid systems, high power batteries would most likely be a technical requirement. Such type of batteries could possibly charge in 15-30 min, depending on the charging station power and battery size.

Boeing Phantom Works' electric-powered demonstrator was powered by a hydrogen fuel cell and a lithium ion battery located inside the fuselage. (Boeing)

AEROSPACE**:** *Would it be more practical to charge up the batteries again or swap them out for fresh ones?*

BW: The idea of battery swapping has been tried before with minimal success, although it has been on smaller electric UAVs. However, with cars this did not prove practical. Given the size and number of batteries needed to power an aircraft, the time and logistics for removing and reinstalling batteries quickly would be even more challenging.

J-MT: Both options are feasible and have advantages and disadvantages. The charge up of the battery on the ground between two flights would need time and would immobilise the aircraft whereas swapping batteries would require a dedicated logistics team and handling equipment.

CC: Swapping batteries has not been proved being successful for large batteries in the past, due to too many technical constraints.

Battery life and duration

A Saft Ni-Cd aviation battery. (Saft)

AEROSPACE**:** *How many times could such batteries be recharged?*

BW: Different battery technologies have different cycle life capabilities - the amount of times a battery can be full charged and discharge or a 100% DOD (depth of discharge). Some batteries on the cutting edge of university lab research have achieved incredible energy densities, only to be unusable after a few charge and discharge cycles. However, for the most practical and readily available battery cells, they can be charged and discharged for hundreds, sometimes thousands of cycles. I would expect that aircraft batteries would need to be capable of many thousands of cycles to be of any financial and practical value.

J-MT: Li-ion batteries for aviation can typically being recharged several thousands of times.

CC: The number of charges ('cycles') for a battery depends on its usage. Typically, Li-ion batteries for professional-controlled usage are achieving around 1,000 full cycles.

True Blue Power TB46 advanced lithium-ion battery for aviation products. (True Blue Power)

AEROSPACE**:** *What limits are there on the time a battery could operate to power an aircraft?*

BW: The amount of time a battery can operate is only limited by the amount of energy it has and the amount of energy the aircraft consumes. In theory, there are ways to recoup some energy to reduce the load on the batteries or even recharge them in flight to extend their duration. This would be similar to some electric or hybrid cars, which use regenerative braking to put energy back into the system. However, with aircraft this concept is more difficult to achieve. Anything that is used to generate electricity also increases drag or loss of efficiency, thus requiring the batteries to work harder.

J-MT: There is no limitation with a proper thermal management. The constraint is linked to the weight of the batteries.

CC: Batteries age due to the cumulative effect of usage and time (particularly at high temperatures). It is difficult to anticipate what would be the thermal profile of the storage life of aircraft batteries which would also depend on their position in the aircraft. For reference, the usage duration in electric vehicles is in the range of ten years. - Claude Chanson

Safety

AEROSPACE**:** *Have there been any tests on the effect of ice, wind or rain on a distributed power aircraft fitted with multiple small electric engines?*

CC: All these multiple environmental impacts have certainly already been translated by the aviation industry into mechanical (shocks, vibrations, accelerations, etc) and thermal specifications, with which the batteries would have to comply. It is not considered that the environment they would encounter is more difficult than some of the extreme conditions in other applications where batteries are used with some, for example, oil drilling heads.

AEROSPACE**:** *There have been fire safety issues with batteries on more-electric aircraft, such as the Boeing 787. Have these problems now been solved?*

BW: This is still a significant concern. For specific issues, such as the 787, solutions have been found. Currently, the solution to the potential dangers of lithium-ion batteries has come in the form of electronic protection and containment. Electronic protection prevents an aircraft from overcharging or overdischarging a battery, which can cause failures. Containment systems are in place so that, if a battery experiences a failure, it will not adversely affect the aircraft structure, passengers or crew. However, ultimately, the cells themselves can fail, due to internal manufacturing or design defects, causing a thermal runaway of extremely high heat and the potential for high pressure, flames/fire, or even explosion. The safe use of lithium batteries on aircraft today is primarily concerned with protecting against and managing this kind of failure. It is not entirely solved but is evolving with better safety standards and testing to vet battery products before being approved for use.

J-MT: A very important point for lithium batteries is to ensure the desired level of security for the application. This is done by the choice of chemistry, thermal management, cell electronic management, successive barriers to protect against a cell failure, the propagation of the defect or assaults from outside. Due to the innovative nature of using Li-ion technology in commercial aviation, the regulatory authorities require an enhanced development assurance level to ensure the highest level of safety of the final product.

AEROSPACE**:** *In addition to the risk of the batteries running down during flight, are there any other potential safety risks with using batteries on a large electric aircraft - such as fire, lighting strikes, water ingress or motion during flight?*

BW: Loss of power and battery failure (or thermal runaway, as mentioned above) are probably the two primary concerns. Of course, as technology pushes for more energy in the same or less space, it becomes by definition, a significantly more volatile safety concern without additional advances to make them inherently fail-safe.

J-MT: As safety is a crucial element when developing a battery for an aircraft, all the potential risks are studied and are part of the development process, whatever the event, it has to be contained within the battery.

CC: It is probably not safety management which may hinder the development of the electric aircraft. This same safety question was raised during the development of electric-mobility vehicles but the more electric vehicles that are on the road, the less the concerns for safety seems to be justified.

Are electric aircraft really greener?

While an electric aircraft may not emit CO_2, the power station that generated the electricity for its batteries may have been powered by coal.

AEROSPACE**:** *Electric-powered aircraft are portrayed as 'greener' and have no adverse emissions compared to conventional jet aircraft. How much is this true - given that the electric power for the batteries has to generated from somewhere - including from coal and nuclear power?*

BW: This is true, as the power to recharge batteries traditionally comes from coal-fired power plants. The more electricity we use, the more coal we burn, emissions we create, fossil fuels we consume, etc. However, there are some benefits. Electricity provided over the grid is more efficient that transporting fuel in trucks (that also use fuel) but the source is similar. Electricity can also be supplemented with greener sources, like wind, solar, nuclear, and others - although not nearly enough. While it is true that an electric airplane could have little-to-no emissions compared to a conventional aircraft, when the total carbon footprint is considered, from source to use, it may decrease but is not eliminated by any means.

J-MT: While they are being used, electric-powered aircraft are greener than conventional jet aircraft because there is no adverse emissions. It is the same with fully electrified vehicles which emit zero CO_2 when driving. However, for sure, it does not mean that there are no emissions during all the whole life cycle of electric aircraft

CC: There has been a lot of discussion on this question of comparing the CO_2 emissions between fossil fuel and electric vehicles, although I have no knowledge of any such study for electric aircraft. The question is very technical and requires an in depth understanding of the scope, the boundaries of the systems compared, and the equivalency of databases and model used. For this reason, most of the studies should be considered as non-conclusive, because of the lack of comparability. Nevertheless, the studies made by companies proposing comparison on a representative base are always showing the reduction of CO_2 emission in case of electrical vehicles. Indeed, the source of electricity can significantly hinder this benefit but we hope the Chinese model for producing electricity based on coal plants is not the world model for the future. RECHARGE has been involved in the European Commission project called "Product Environmental Footprint" pilot (http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm), and has acquired a significant experience in this field.

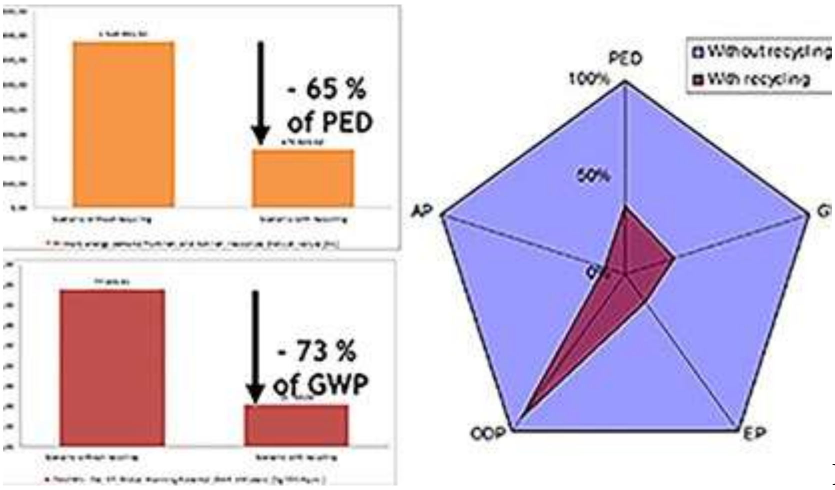

Nickel mine in West Australia. While the use of batteries may be ‘greener’, the process of extracting the minerals used to power them may have adverse effect on the environment.

AEROSPACE**:** *Have there been any studies into the environmental impact of the batteries used to power electric aircraft - which contain metals which have to be mined from somewhere?*

BW: Lithium tends to be preferred over lead-acid and nickel-cadmium batteries, the primary aircraft batteries used today, due to the lack of lead and cadmium they consume, which are environmental concerns. However, some lithium batteries also consume rare or ‘conflict-minerals’ like cobalt or other exotic materials. There are also discussions about the world’s supply of lithium. Some believe our consumption rate will tax the earth’s supply while others believe that it is plentiful for the long-term future.

J-MT: Saft is not aware of any such studies for electric aircraft but some have been published for electric vehicles. Mining impacts are taken into account as burdens in the extraction of raw materials but the battery recycling enables to produce secondary raw materials and to use again these metals, generating ‘environmental credits’, which lower the global environmental impacts of the battery along its total life cycle.

CC: This question refers to resources usage. The answer is highly dependent on the recycling requirement at the end of life of batteries. As batteries being mainly made of metals and metals compounds, they can be indefinitely recycled and reused. It is about the social model in each world country to decide how much economical resources should be devoted to this circular economy set up which will in the future determine the sustainable development of batteries.



PIC - Saft is actively involved in battery recycling. (Saft)

AEROSPACE: *Could such batteries be easily recycled?*

BW: Lithium batteries are generally allowed in local landfills and municipal waste systems, posing no significant environmental threat. They can be recycled for their useful materials, like their aluminum cases or nickel terminals, or possibly even for their thin copper and aluminum foil internals. But I do not know whether this is easy, practical or worthwhile.

J-MT: Yes, Li-ion batteries can be easily recycled and their recycling allows reduction of environmental impacts and preservation of natural resources,

CC: The batteries recycling technology is allowing today the recovery of all the metals contained in a battery. Unfortunately, not all countries are promoting a circular economy such as in Europe at the moment), and therefore, the level of the recycling industry for batteries is highly variable around the world. Nevertheless, we promote the implementation of a producer responsibility which would prevent the risk of a poor end of life management of the batteries. It is expected that the industrial actors of the air transport industry (most of them highly recognised companies) will endorse this responsibility.

Bill Read
12 December 2017

Royal Aeronautical Society

https://www.aerosociety.com/news/power-sources/