Subject:

The Use of Graphene Batteries to Power Aircraft

August 2024

A Report on the Potential Impact of Graphene-Based Batteries on Electric-Powered Aircraft

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AERONAUTICA WINDPOWER

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Report on the Potential Impact of Graphene-Based Batteries on Electric-Powered Aircraft

While the thought of using electric batteries to power aircraft is nothing new, advances in energy density using light-weight graphene batteries are now achievable. This paper studies the state of the art for electric flight and the role that graphene batteries being developed by MEP World Group of Florida may play in it.

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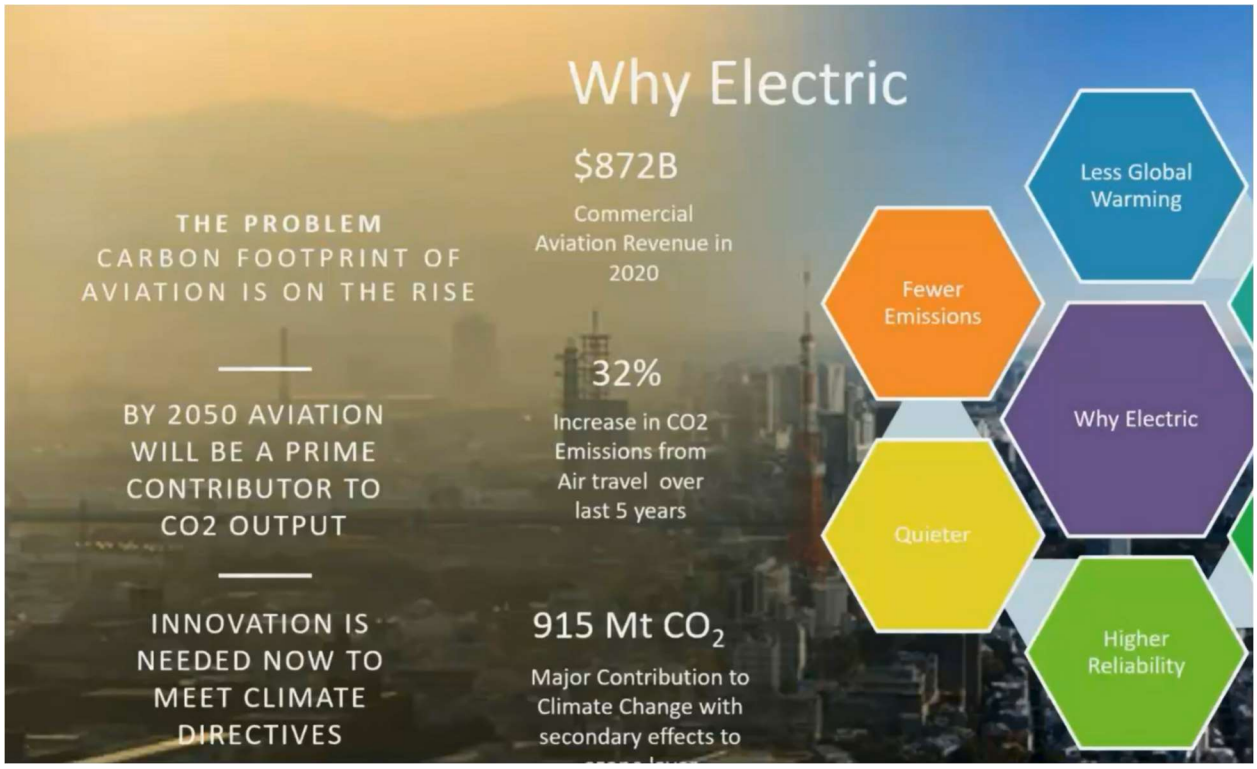
Slide Graphics credit to Anita Sangupta, AnitaSangupta.com

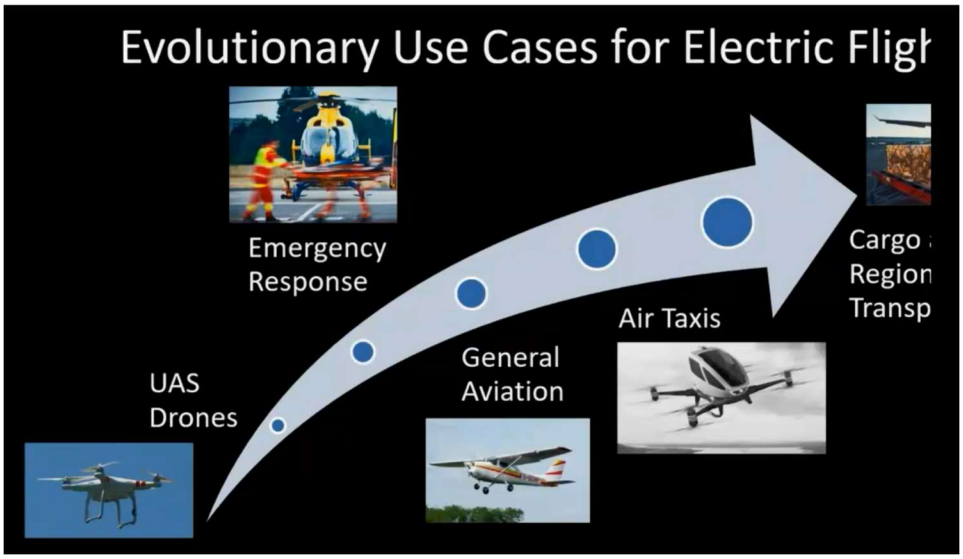
Introduction

Electric-powered flight has captured the imagination of engineers and innovators for over a century. As the world moves towards sustainable energy solutions, the aviation industry faces increasing pressure to reduce its carbon footprint. The advent of electric aircraft promises a greener alternative to traditional fossil fuel-powered planes. However, one of the most significant challenges in realizing this vision has been the development of batteries with sufficient energy density and specific power to make electric flight practical on a larger scale.



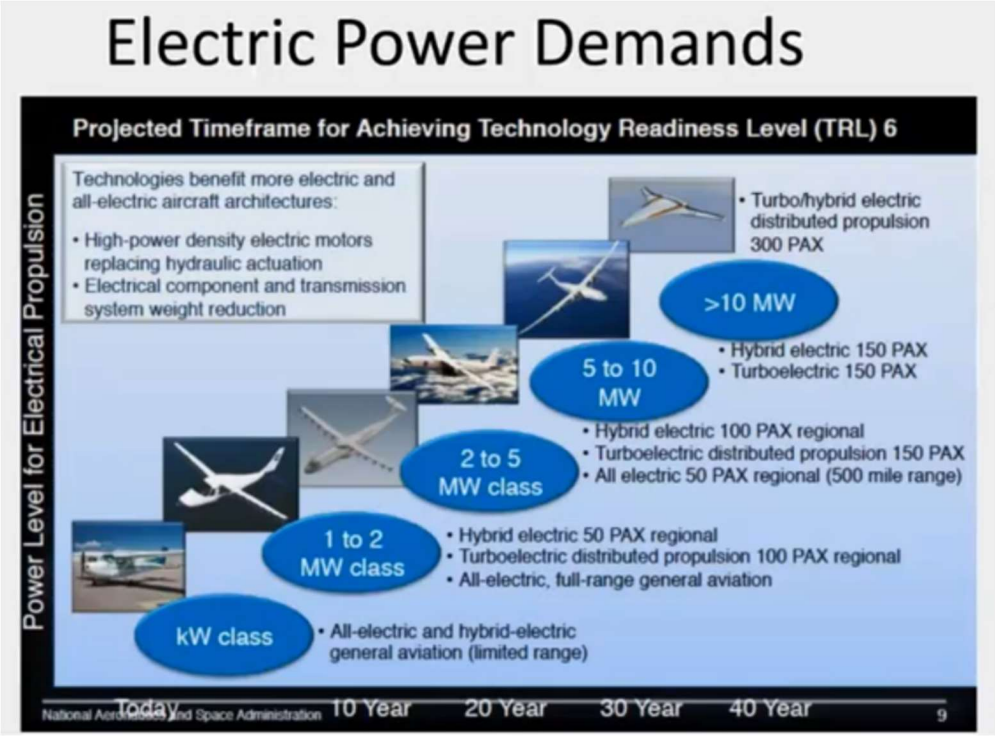
A Brief History of Electric-Powered Flight

The concept of electric-powered flight dates back to the late 19th century, with some of the earliest experiments involving tethered electric models. It wasn't until the 1970s and 1980s that serious attempts were made to create manned electric aircraft. The pioneers in this field faced numerous challenges, primarily due to the limitations of battery technology. Early electric aircraft relied on lead-acid batteries, which were heavy and offered limited energy storage. Despite these limitations, several successful flights were conducted, proving the potential of electric propulsion.



In the following decades, the introduction of Lithium-ion (Li-ion) batteries marked a significant improvement. These batteries offered better energy density and were lighter, making them more suitable for electric flight.

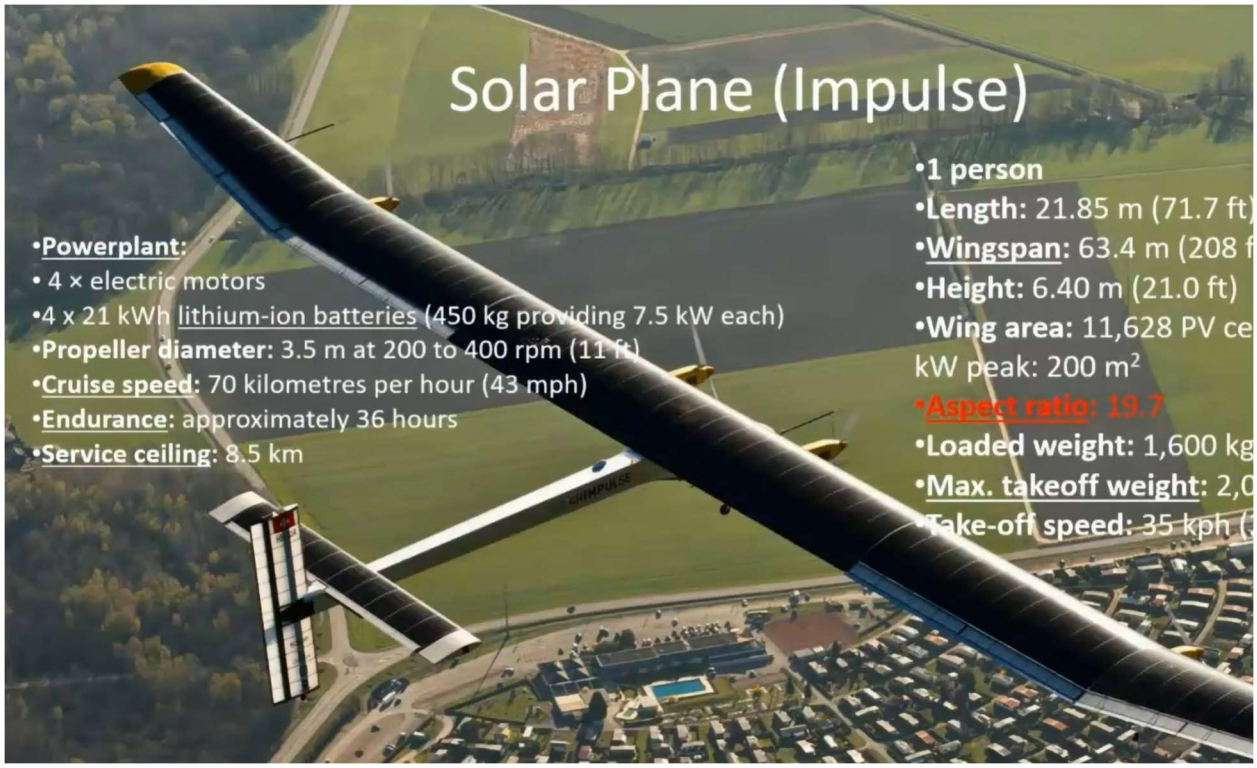
However, even with Li-ion batteries, the energy density and specific power remained a critical bottleneck, restricting the range and payload capacity of electric aircraft. Consequently, electric flight has primarily been limited to small, short-range aircraft and drones.



Sampling of Existing Electric Airplanes

Today's electric airplanes are limited to small, light-weight airframes, with little payload capacity. A direct analogy can be drawn with the trucking of long-haul freight.

Some aircraft designers have tried to tackle the problem of electric flight by going after the aircraft aerodynamics issues involving lift and drag. Many designs incorporate solar panels into the wings to enhance milage. And with the recent advancement of drone technologies, multi-rotor helicopters with electric motors are being designed.

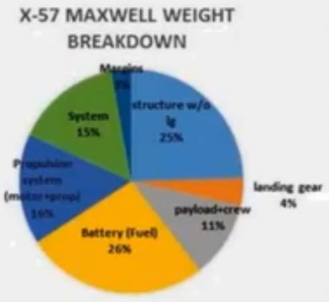


NASA has been experimenting with electric planes as well. Note the novel engine configuration which provides larger props for takeoff and smaller, more efficient motors for cruising. The common motivation for most designs appears to be the ability to take advantage of lower priced electric 'fuel' which can be derived from many sources (both renewable and otherwise), along with less complicated and inexpensive mechanical equipment.

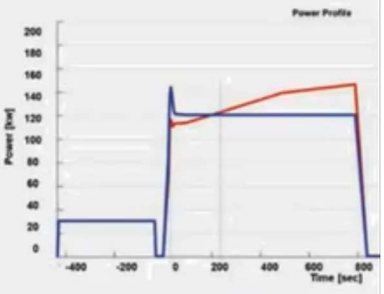
NASA Maxwell 57 ETP

Weight	1364 kg
Payload	151 kg (2 p
Energy	121 Wh/kg
Power	12 x 14 kW
Range	1 hours (10
Propulsion	DEP 14 e-n
Span	9.4 m
AR	15

NASA Maxwell 57 ETP (test flight in 202

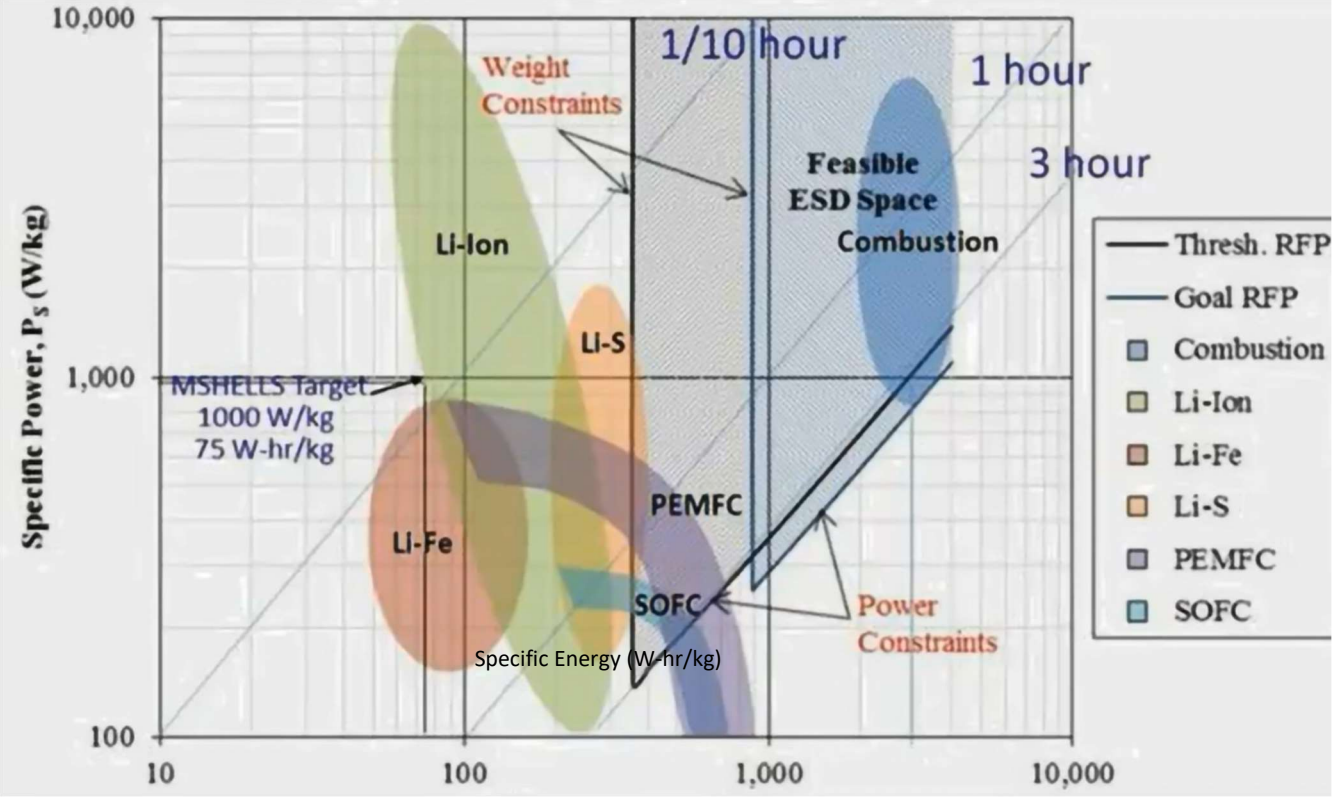


Category	Weight %	weight (lb)	weight (kg)
structure w/o lg	25%	738 lb	335 kg
landing gear	4%	119 lb	54 kg
payload+crew	11%	333 lb	151 kg
Battery (Fuel)	26%	790 lb	358 kg
Propulsion system (motor+prop)	16%	480 lb	218 kg
System	15%	460 lb	209 kg
Margins	3%	86 lb	39 kg
Total	100%	3006 lb	1364 kg



The Importance of Energy Density in Electric-Powered Flight

Energy density, measured in watt-hours per kilogram (Wh/kg), is a critical factor in the viability of electric-powered flight. It determines how much energy a battery can store for a given weight, directly impacting the aircraft's range and payload capacity. Specific power, measured in watts per kilogram (W/kg), is another crucial factor, indicating how much power the battery can deliver relative to its weight (lift). Together, these metrics dictate the overall performance of an electric aircraft. For commercial aviation, where long-range and large payloads are essential, current battery technologies like Lithium-ion fall short, as may be seen in the graph below.



The energy density of Li-ion batteries typically ranges between 150-250 Wh/kg, which is sufficient for the demonstration of small, light aircraft but inadequate for larger, more demanding applications and a general market. To achieve parity with traditional jet fuel, which has an energy density of around 12,000 Wh/kg (including the efficiency of combustion engines), batteries with significantly higher energy density are required, as will be seen below.

The Potential of Graphene-Based Batteries

The introduction of *MEP World Group's* new graphene-based battery appears to greatly improve the opportunities for electric planes. This new graphene-based battery, offering 1680 Wh/kg of both specific power and energy, represents a significant leap forward in battery technology. Graphene, a single layer of carbon atoms arranged in a two-dimensional lattice, is known for its exceptional electrical and thermal conductivity, strength, and light weight. These

properties make it an ideal material for advanced battery applications, such as the aircraft industry.

Although the MEP graphene battery is still in prototype stages, early indicators point to characteristics that far surpass other batteries. A simple comparison was done between the MEP prototype and a Lithium Ion battery from CosPowers, Inc. Specific Energy and Specific Power for the graphene battery appear to be more than an order of magnitude greater than the Lithium units, as seen in the table and graph below.

Energy and Power Characteristics for Graphene Batteries in Aircraft

Comparative Manufacturers:		CosPower	MEP	Delta
Specific Energy	w-h/kg	86.25	1680.00	19.48
Specific Power	w/kg	50.00	1680.00	33.60
Volumetric Density	kWhr/L	0.05	0.47	9.76
Gravimetric Density	kWhr/kG	0.09	1.68	19.48

CosPower Stats:

Energy Size	2,070 kWhrs DC/container	
Weight	24 t (assumed metric ton, or 1000 kG)	
Power Size	1200 kW	
Volume	42.70 cubic meters	42698.35 Liters

Above is for their 1 MW x 2MWhr container with PCS

MEP Graphene Stats:

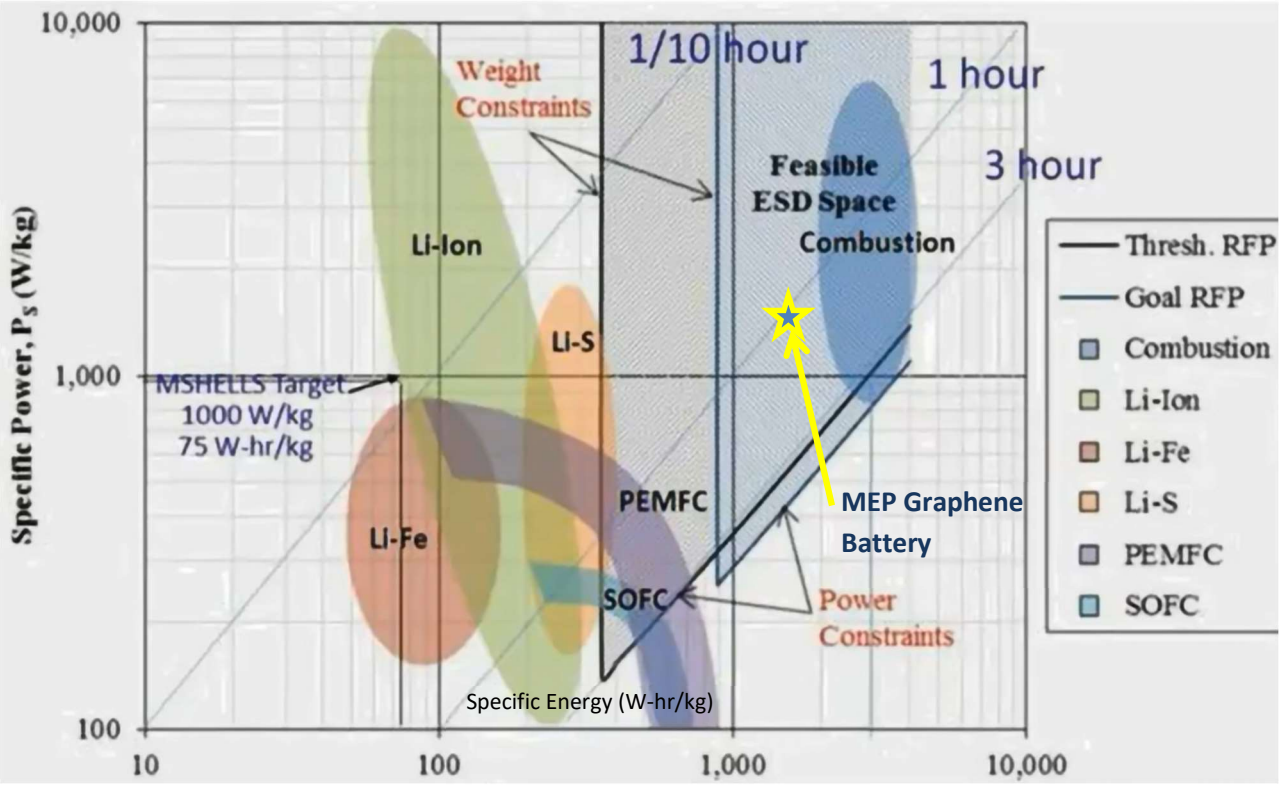
Energy Size	1.680 kWhrs DC/8 cells (1kG)	
Weight	1150 kG/8 cells includes 14% BOP	
Power Size	210 watts/cell	1680 watts/kG
Volume	2.26 cuft for 30.24 kWhrs	63.958 Liters

Above based on 1kg = 8 cells, each cell is 210wh. Prototype has 144 cells to yield 30.24 kWhrs at C of 1. Weight is 125g/cell plus BOS.

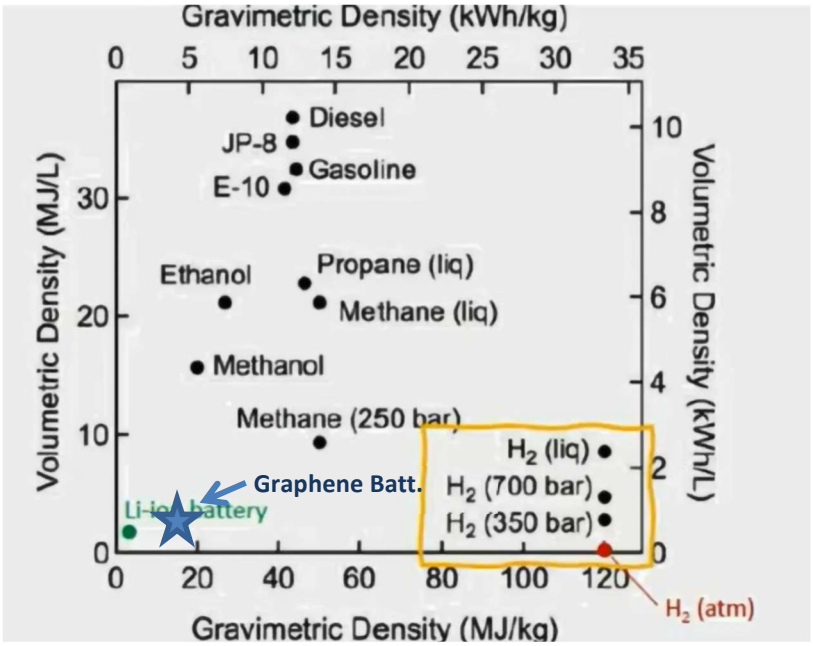
The 1680 Wh/kg energy density of the graphene-based battery is many times greater than that of current Li-ion batteries. This increase in energy density could enable electric aircraft to achieve much greater ranges and carry heavier payloads, bringing electric flight closer to commercial reality. The high specific power of the battery also means that it can deliver the necessary power for takeoff and sustained flight without adding excessive weight.

When plotted against current existing batteries, the advantage to the graphene battery stands apart from all other battery architectures, as can be seen in the following graph which shows the addition of the graphene battery characteristics.

Note that the Power and Energy attributes fall within the Feasible ESD range envelopes for both power and weight constraints.



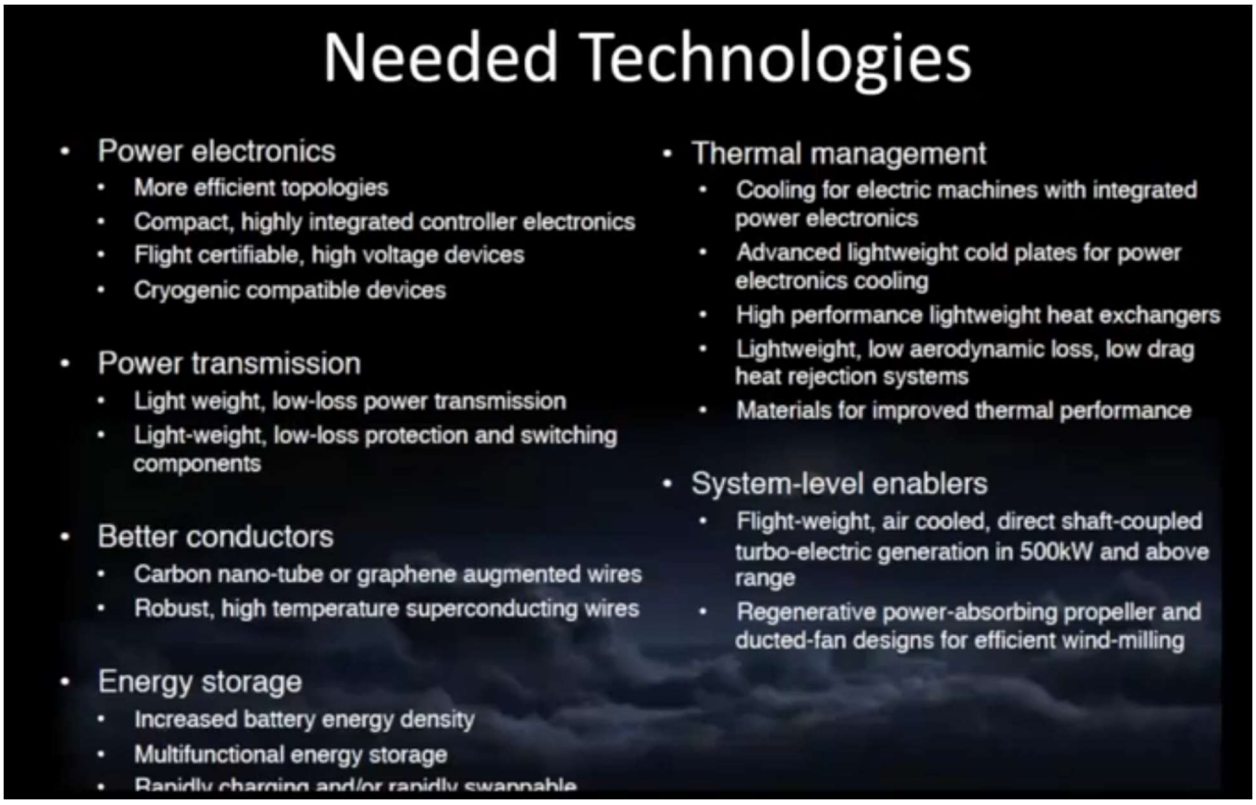
We also look at the relative power and energy that battery systems offer in comparison to more traditional fuels. In the graph below we can see that Lithium Ion, and even the Graphene battery, have a very low energy density (both volume and weight) than traditional fuels.



Implications for the Aviation Industry

If successfully commercialized, graphene-based batteries could revolutionize the aviation industry. Here's why:

1. **Extended Range**: The significant increase in energy density could allow electric aircraft to fly much longer distances, making them competitive with traditional aircraft for regional and even some international flights.
2. **Increased Payload Capacity**: Higher energy density means that electric aircraft can carry more weight, which could include more passengers, cargo, or additional equipment. This could make electric aircraft viable for a wider range of applications, including larger commercial airliners.
3. **Reduced Environmental Impact**: By enabling longer-range electric flights, graphene batteries could help reduce the aviation industry's reliance on fossil fuels, leading to a significant reduction in carbon emissions.
4. **Lower Operating Costs**: Electric aircraft powered by graphene-based batteries could offer lower operating costs compared to traditional aircraft, primarily due to lower fuel costs and reduced maintenance requirements, as electric motors are simpler and more reliable than jet engines.



Economic Analysis: Graphene Electric Battery vs. Traditional Aircraft Fuels

In assessing the economic viability of graphene-based batteries in electric-powered aircraft, it's essential to differentiate between capital costs and operational costs. Based on discussions with MEP, let us assume that the graphene battery will cost approximately $120 per kWhr delivered. The $120 per kilowatt-hour (kWh) price of the graphene battery represents a capital investment, unlike the operational cost of jet fuel, which is consumed and must be replenished for each flight. This section revisits the economic comparison, taking into account the battery's reusability and the long-term financial implications of adopting this new technology in aviation.

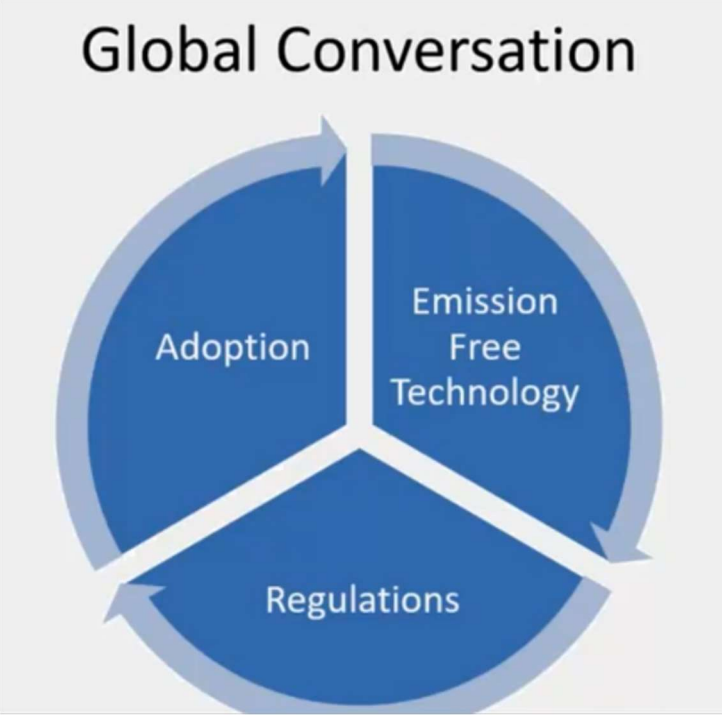
Cost Comparison: Graphene Battery vs. Jet Fuel

1. **Capital Cost of Energy Storage**:
    - The $120 per kWh figure for the graphene battery is a capital cost, reflecting the initial investment needed to purchase the battery. This cost covers the storage capacity, which can be recharged and used multiple times over the battery's lifespan.
    - In contrast, jet fuel is an operational expense. The cost of jet fuel is typically around $2.50 to $3.00 per gallon, translating to approximately $0.07 to $0.09 per kWh. However, jet fuel is a consumable resource; it must be continually purchased and replenished for each flight.
2. **Battery Lifespan and Reusability**:
    - Graphene-based batteries are expected to have a lifespan of several hundred to potentially thousands of charge cycles. If we assume a lifespan of 1,000 charge cycles, the effective cost of energy from the battery can be distributed across its entire operational life.
    - For example, at $120 per kWh and 1,000 charge cycles, the capital cost per kWh per cycle effectively reduces to $0.12. This is higher than the per-kWh cost of jet fuel but must be considered alongside the operational efficiency and other savings provided by electric aircraft.
3. **Operational Costs**:
    - **Fuel vs. Electricity Costs**: The cost of recharging a graphene battery depends on the local electricity price, which varies but is often cheaper than jet fuel on a per-mile basis due to the higher efficiency of electric motors (typically above 90% compared to 30-40% for jet engines). This efficiency reduces the actual energy required for flight, further mitigating the apparent cost difference. Electricity can also be created from a large number of fuel sources, including solar and wind energy, and may be locally sourced.
    - **Maintenance**: Electric aircraft are expected to have lower maintenance costs due to fewer moving parts in electric motors compared to jet engines. This leads to lower operational expenses over time, contributing to the overall economic advantage of electric propulsion.
4. **Total Cost of Ownership (TCO)**:
    - When evaluating the Total Cost of Ownership, the initial investment in graphene batteries should be weighed against long-term savings in fuel, maintenance, and operational costs. The ability to recharge and reuse the battery over many cycles

reduces the effective energy cost, potentially lowering the TCO compared to traditional aircraft.
    - Electric aircraft could also benefit from more stable electricity prices compared to the volatility of oil prices, reducing financial risk over the aircraft's lifespan.

Long-Term Financial Benefits

1. **Market Competitiveness**:
    - As production scales and manufacturing scale matures, the cost of graphene batteries is likely to decrease further, making them more competitive with traditional fuel-powered aircraft. The higher upfront costs of electric aircraft may be offset by lower operating costs over time, particularly on routes where electricity is cheap and abundant.
    - Airlines that adopt electric aircraft early could gain a competitive advantage in markets where environmental regulations are becoming more stringent, and where there is a demand for greener flight options.
2. **Infrastructure Costs**:
    - While electric aircraft require investment in charging infrastructure, these costs may be partially offset by savings in fuel storage and handling facilities, which are necessary for traditional jet fuel. Moreover, the modularity and potential upgradability of batteries could reduce long-term infrastructure expenses.
3. **Environmental and Regulatory Factors**:
    - The environmental benefits of electric aircraft, powered by graphene-based batteries, could result in economic incentives, such as tax breaks, subsidies, or avoidance of carbon taxes. These factors could further reduce the effective cost of operating electric aircraft, enhancing their economic appeal.



Conclusions

The introduction of MEP's graphene-based batteries with an energy density of 1680 Wh/kg could be a game-changer for the aviation industry. By addressing the critical limitations of current battery technology, these batteries have the potential to make electric-powered flight a practical and sustainable option for a wide range of applications. As the technology continues to develop, we may soon see electric aircraft capable of rivaling traditional planes in both range and capacity, ushering in a new era of cleaner, more efficient aviation.

The economic use case for graphene-based batteries in electric aircraft hinges on a nuanced understanding of capital and operational costs. While the initial investment in these batteries is higher than the per-unit cost of jet fuel, the ability to recharge and reuse the batteries over thousands of cycles significantly reduces their effective cost over time. When combined with the higher efficiency of electric propulsion, lower maintenance costs, and potential environmental incentives, graphene batteries offer a compelling economic proposition that could make electric aircraft a viable and competitive alternative to traditional fuel-powered planes. As the technology evolves and costs decrease, the adoption of graphene batteries could play a pivotal role in the future of sustainable aviation.

However, as with other sales comparisons that contrast a capital investment such as a battery against a fuel-based alternative, one must consider that the consumer is making an investment. In order to not limit sales to 'early adopters', the economic valuation of the batteries needs to be made clear and affordable.

The applicability of the graphene battery to the aircraft industry appears to be technically feasible. The harder task may be one of marketing: to sell the product under an 'investment' model. This is not a new challenge. The same was true with the housing market, where home ownership did not 'take off' until affordable financing methods (mortgages) were developed for the middle class. Large pieces of expensive equipment are often leased rather than sold to farmers who lack commercial credit. The automotive industry is learning this lesson now with electric cars. Sales resistance stemming from high sticker prices is still experienced and may require additional reductions in the cost (as well as additional charging stations) in order to make electric cars ubiquitous.

A Marketing Opportunity

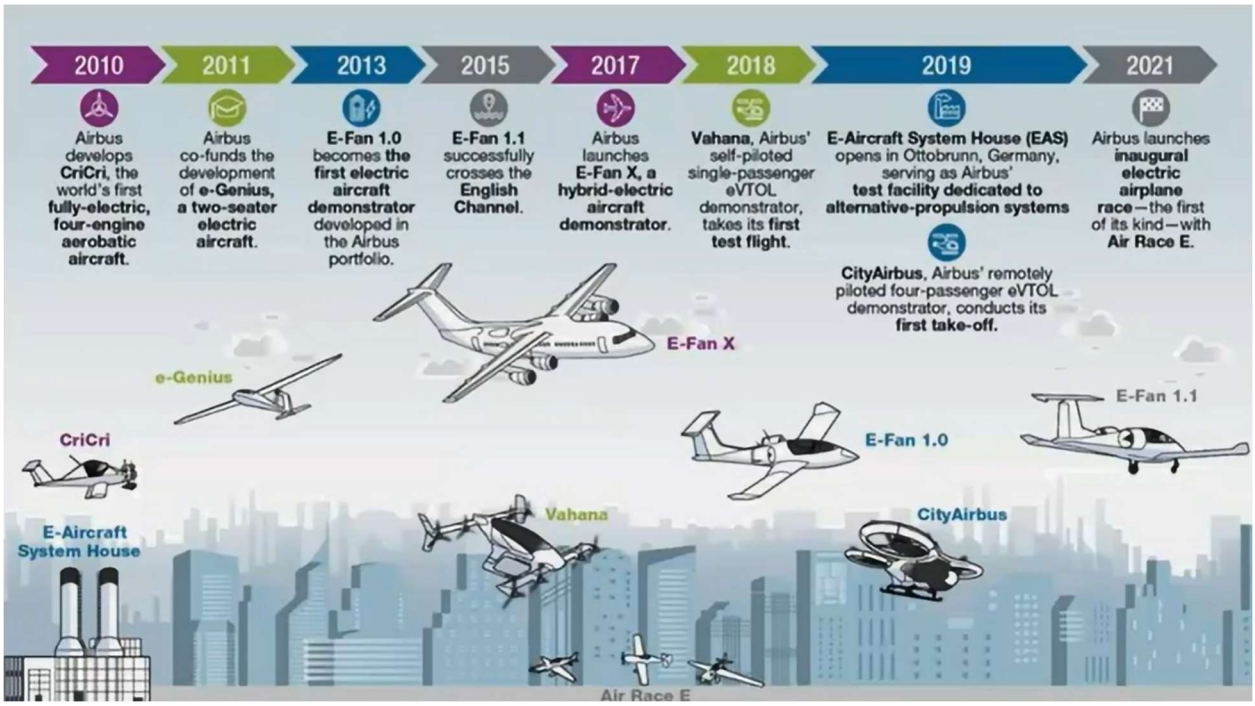
Aeronautica Energy Sales

One interesting note is that Associated Energy Developers, LLC – the authors of this report – are related to another corporation that has manufacturing, sales and marketing experience in just this sort of product. Aeronautica Windpower, LLC was a company owned by the author who manufactured sub-megawatt scale wind turbines from 2006 to 2016. The plans for the company are to manufacture and market an entire line of renewable energy equipment, including wind turbines, solar panels, and storage equipment.

The company is still capable of manufacturing and marketing under the *Aeronautica* brand (a fitting name for the Aircraft market) a battery for this dedicated market. It understands the sales cycle, financing techniques and other techniques needed to stimulate this market niche and is interested in negotiating a position with MEP Worldwide to do just that.

About the Author

Brian D. Kuhn is the Founder and a Principal of both Associated Energy Developers *and* Aeronautica Windpower *of Plymouth, MA, and a 40 year veteran of the Renewable Energy industry. Associated Energy Developers is a renewable energy project analysis and development company specializing in solar and wind systems for clients in the Commercial and Industrial as well as Utility scale markets. Brian may be reached at Brian.Kuhn@AssocEnergy.com, or 508-364-9489.*



Government Technology Assessment

Estimated Benefits From Systems Studies

Boeing/GE SUGAR (baseline Boeing 737–800)

- ~60% fuel burn reduction
- ~53% energy use reduction
- 77 to 87% reduction in NOx
- 24-31 EPNdB cum noise reduction

NASA N3X (baseline Boeing 777–200)

- ~63% energy use reduction
- ~90% NOx reduction
- 32-64 EPNdB cum noise reduction

NASA CEPT for GA (baseline Tecnam P2006T)

- 5x lower energy use/cost and emission
- 15 dB lower community noise
- Propulsion redundancy, improved ride quality, and control robustness

Regulatory Couples to Technology Challer