CARPENTER ELECTRIFICATION®

Transforming the Future of Aerospace

Advanced Materials for Electrification

INDUSTRY LEADER

The electric aviation revolution is here, promising a new era of cleaner, more efficient air travel. At the core of this transformation is the need for advanced materials to meet the demanding requirements of electric aircraft propulsion. With over 134 years of specialty alloy innovation, Carpenter Electrification is at the forefront of this challenge.

Our cutting-edge electric motor stack materials, particularly the Hiperco® family of iron-cobalt alloys, are redefining what's possible in aircraft electrification. Carpenter's innovations enable motors with higher power density, improved efficiency, and reduced weight, overcoming key obstacles in electric and hybrid aircraft design. These advancements aren't just improvements — they're reshaping the future of aerospace.

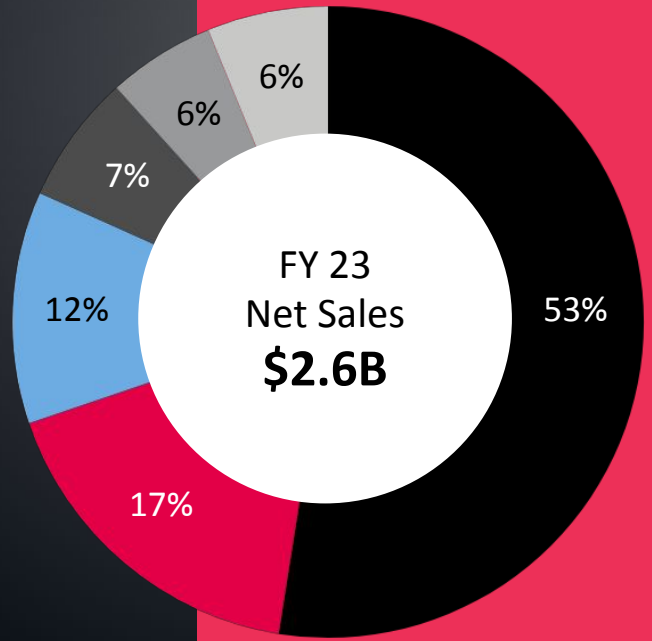
Carpenter Technology, Preferred Solutions Provider to the Aerospace Industry

Partner to OEMs & Tiers across end-use markets in solving critical needs

- Energy 6%
- Distribution 6%
- Transportation 7%
- Medical 12%
- Industrial & Consumer 17%
- Aerospace & Defense 53%

NYSE: CRS $60.89[1]

$3.0B market cap[1]



[1] As of 2/2/2024 Percentages reflect sales ex-surcharge. Quarter ending June 30, 2023.

Carpenter Technology, Preferred Solutions Provider to the Aerospace Industry

134 years of specialty alloy product and process innovation leadership

500+ Alloys

- Nickel-based
- Cobalt-based
- Titanium
- Stainless Steels
- Soft Magnetic
- Other Specialty Alloys

Product Forms

- Ingot / Billet
- Bar
- Powder
- Wire
- Stacks & components
- Strip

Aerospace Quality Systems

- “Original JENQC Melter” on the Jet Engine Nickel Quality Committee, formed under the auspices of the FAA
- AS9100 Certification

Carpenter Technology, Preferred Solutions Provider to the Aerospace Industry

A global footprint with ~4,000 employees

Facility locations

Athens, AL
Rancho Cucamonga, CA
Clearwater, FL
Chicago, IL
Dundee, MI
Raleigh, NC
Elyria, OH
Vienna, OH
Wauseon, OH

Franklin, PA
Kutztown, PA
Latrobe, PA
Orwigsburg, PA
Philadelphia, PA
Reading, PA
Washington, PA
Hartsville, SC
White House, TN

Belgium
Liverpool, UK
Monterrey, Mexico
Mexico City, Mexico
Ontario, Canada
Singapore
Seoul, South Korea
Suzhou, China
Torshälla, Sweden
Taipei, Taiwan

The Electrification Challenge: Balancing Power and Efficiency

Manufacturers face significant challenges in optimizing aircraft performance as the aerospace industry shifts towards more sustainable and efficient propulsion systems. The primary obstacles include:

1. Weight reduction without compromising structural integrity
2. Maximizing power density to enhance range and payload capacity
3. Improving overall system efficiency to extend flight times
4. Ensuring reliability and safety in increasingly complex electrical systems

Carpenter's advanced materials, such as our Hiperco® iron-cobalt alloys, directly address these challenges by offering superior magnetic properties that translate into tangible performance gains for electric and hybrid aircraft.

Past, Present and Future

Aircraft Electrification

Commercial Jet Aircraft
(1950s – present)

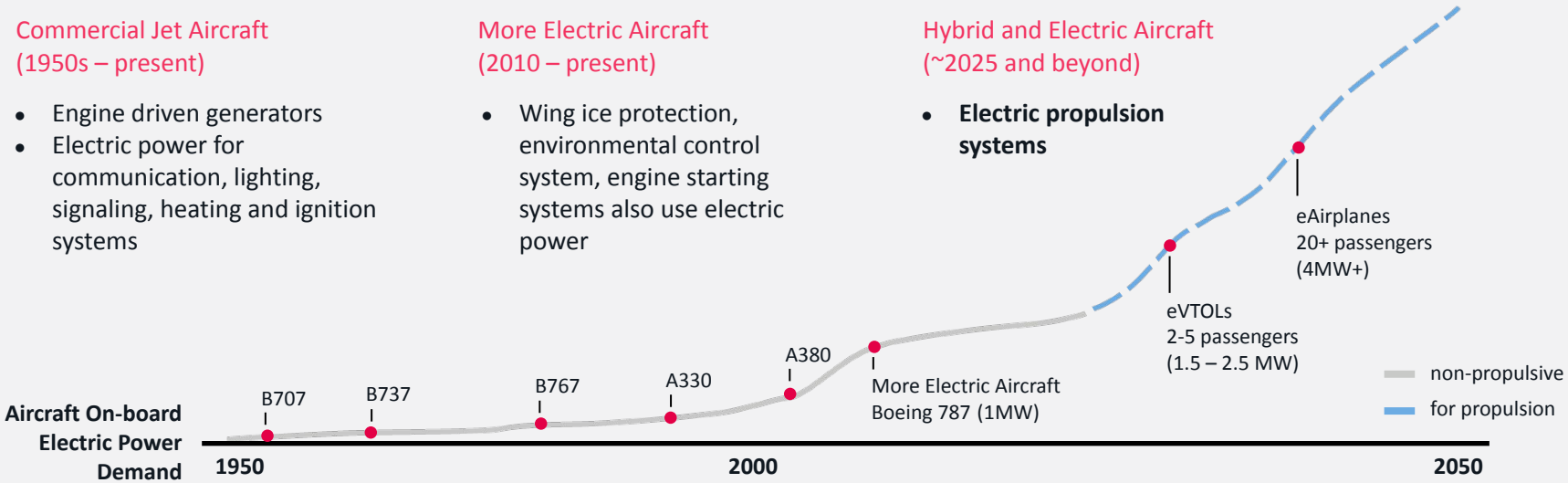
- Engine driven generators
- Electric power for communication, lighting, signaling, heating and ignition systems

More Electric Aircraft
(2010 – present)

- Wing ice protection, environmental control system, engine starting systems also use electric power

Hybrid and Electric Aircraft
(~2025 and beyond)

- **Electric propulsion systems**



Hiperco® Iron-cobalt Alloy is the Leading Choice for Generator and Apu Stator Stacks

The Rise of Electric Propulsion in Aerospace

The trajectory of aircraft electrification is clear and accelerating. From the early days of electric power in commercial jets for auxiliary systems to today's More Electric Aircraft (MEA) designs, the industry is rapidly progressing towards fully electric and hybrid propulsion systems. This evolution is driven by the need for more efficient, environmentally friendly, and versatile aircraft.

Emerging applications for electric motor propulsion systems span a wide range of aircraft types, including:

- eVTOL (Electric Vertical Takeoff and Landing) aircraft for urban air mobility
- Small electric airplanes for regional air mobility
- Larger electric/hybrid aircraft for short-haul commercial flights

By 2030, the demand for these electric aircraft is projected to soar, with estimates suggesting the market to reach $37 billion annually. This surge in demand underscores the critical need for advanced materials to meet electric propulsion systems' rigorous performance requirements.

Electric Motor Propulsion Systems

Emerging Applications

eVTOL/UAM

Aircraft Specifications	
Passengers	2 - 5
Payload (lbs)	500 - 1,000
Range (miles)	50 - 100
Speed (mph)	80 - 200
Propulsion power (MW)	0.9 - 2.4
Engine Specifications	
Power Per Engine (kW)	125 - 250
Propeller speed (rpm)	1,500 - 2,600
Energy source	Battery
Production Expectations - 2030s	
eVTOL demand (annual)	5,000+
Propulsion e-motor demand (annual)	45,000+

Emerging Applications

Small Airplane/RAM

Aircraft Specifications	
Passengers	4 - 10
Payload (lbs)	800 - 2,500
Range (miles)	200 - 400
Speed (mph)	150 - 250
Propulsion power (MW)	0.5 - 1.5
Engine Specifications	
Power Per Engine (kW)	≥ 500
Propeller speed (rpm)	1,500 - 2,600
Energy source	Battery, hybrid
Production Expectations - 2030s	
eVTOL demand (annual)	300 - 500
Propulsion e-motor demand (annual)	400 - 600

Electric Motor Propulsion Systems

Emerging Applications

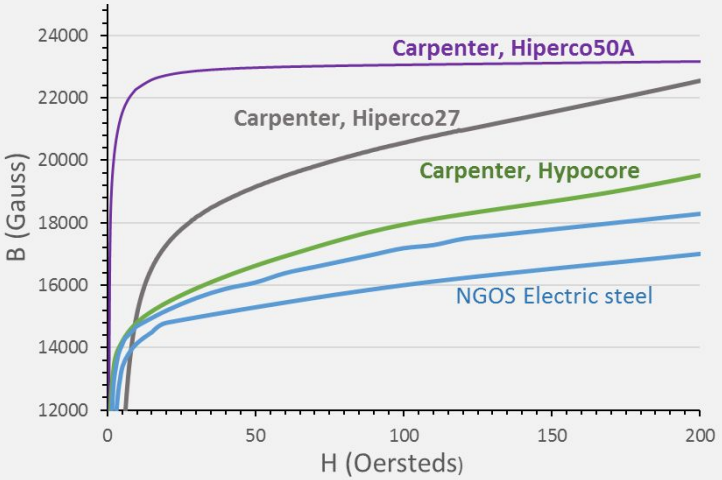
Airplane/Short-haul

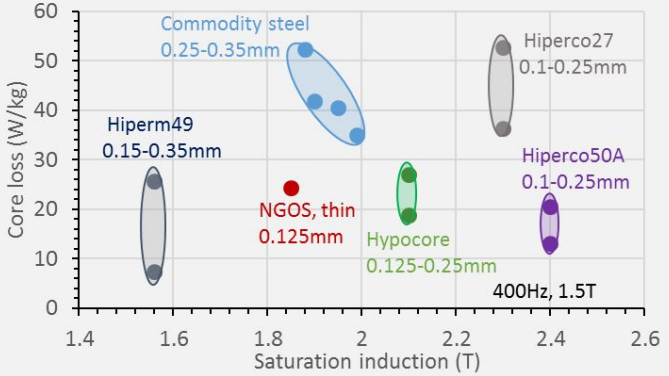
Aircraft Specifications	
Passengers	10 - 50
Payload (lbs)	3,000 - 15,000
Range (miles)	250 - 750
Speed (mph)	215 - 350
Propulsion power (MW)	1 - 5+
Engine Specifications	
Power Per Engine (kW)	≥ 1,000
Propeller speed (rpm)	1,500 - 2,600
Energy source	Battery, hybrid, hydrogen
Production Expectations - 2030s	
eVTOL demand (annual)	100 - 200
Propulsion e-motor demand (annual)	200 - 400

Ideal Choice for Power Dense Electric Generators & Motors

Hiperco® provides the highest induction for a soft magnetic material while exhibiting good permeability and core loss properties

Higher induction generates more motor power and torque per volume/mass of alloy

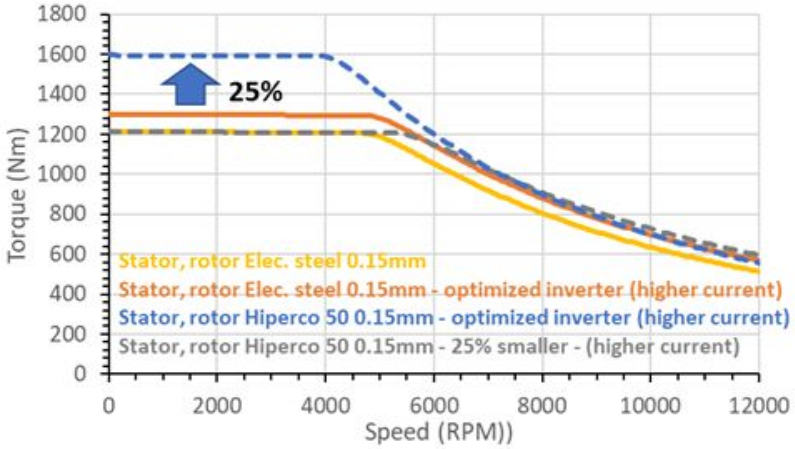




Hiperco Motor Performance Benefits

Power Dense Stator and Rotor Stacks Improve Motor Power and Aircraft Performance

- High torque density [15 – 25%]
- High power density [20 – 30%]
- High efficiency [up to 3% increase]
- Reduced motor size and weight [20 – 30%]
- Cooler operating temperature



Elevating Performance with Hiperco® Alloys

Our Hiperco® iron-cobalt alloys, explicitly engineered for high-performance electric motors and generators, including stator and rotor stacks, are at the core of Carpenter's offering. These advanced materials provide unparalleled benefits, such as:

1. **Unmatched Power Density:** Hiperco® alloys exhibit the highest induction levels among soft magnetic materials, enabling motors to generate more power and torque per unit volume.
2. **Exceptional Efficiency:** The superior magnetic properties of Hiperco® translate to efficiency gains of up to 3% in electric motors, particularly in stator and rotor stacks, a significant improvement that directly impacts aircraft range and operating costs.
3. **Compact Design:** Motors utilizing Hiperco® can be 20-30% smaller and lighter than those made with conventional materials, contributing to overall aircraft weight reduction and improved payload capacity.
4. **Thermal Management:** The increased efficiency of Hiperco®-based motors results in cooler operating temperatures, enhancing reliability and reducing cooling system requirements.

Aircraft System Level Performance Options to Improve Payload and Range

Common Aircraft Designs

Tilt Rotor eVTOL 

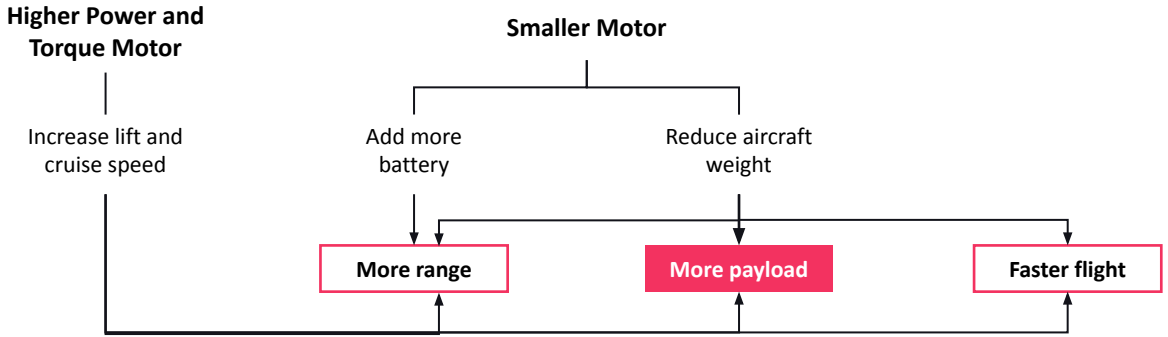
Lift + Cruise eVTOL 

Multi-Rotor eVTOL 

Vectored Fan eVTOL 

Fixed Wing airplane 

Hiperco® Motor Performance Improvements and Aircraft Design Flexibility



Tilt Rotor eVTOL Simulation (Empty weight 1790kg, Payload 380kg, 6 motors)

	Silicon steel motor	Higher power motor	Smaller motor
Total rated power (kW)	1,476	1,569	1,470
Total motor mass (kg)	315	317	294
Increased payload option		+92kg (24%)	+21kg (5%)
Increased range option		+15%[1]	+4%[1]

[1] from additional battery

Similar Benefits Observed Across Multiple eVTOL Configurations & Designs

More powerful Hiperco Motor

	Multi-copter	Tilt Rotor #1	Tilt Rotor #2	Lift + Cruise
Max take off mass-Si steel (kg)	900	2,219	2,941	3,347
Max take off mass-Hiperco (kg)	936	2,311	3,058	3,482
Payload increase (kg)	**36**	**92**	**117**	**135**
Payload increase (%)	**18%**	**24%**	**26%**	**21%**
Range increase (km)	**6.2**	**34.1**	**35.8**	**30.3**
Range increase (%)	**19%**	**17%**	**30%**	**12%**

Smaller Hiperco Motor

	Multi-copter	Tilt Rotor #1	Tilt Rotor #2	Lift + Cruise
Motor mass – Si steel (kg)	38	315	318	675
Motor mass- Hiperco (kg)	36	294	300	630
Payload increase (kg)	**2**	**21**	**18**	**45**
Payload increase (%)	**1%**	**6%**	**4%**	**7%**
Range increase (km)	**0.4**	**9.2**	**6.2**	**12.3**
Range increase (%)	**1%**	**5%**	**5%**	**5%**

Redefining Aircraft Performance and Economics

The implementation of Carpenter's advanced materials yields substantial performance improvements across various electric aircraft configurations. Here are some real-life designs and the results they've achieved:

- **For multi-copter designs:** Up to 18% increase in payload capacity and 19% increase in range
- **For tilt-rotor eVTOLs:** Payload increases of 24-26% and range extensions of 17-30%
- **For lift-plus-cruise configurations:** 21% greater payload capacity and 12% longer range

These performance gains offer aircraft manufacturers the flexibility to optimize designs for specific operational requirements, whether prioritizing payload, range, or a balance of both.

Opportunity for Significant Annual Operating Revenue From Each eVTOL

The achievable weight savings is equivalent to a passenger

"The new FAA standards will increase an average adult passenger and carry-on bag weight to 190 pounds (86 kg) in the summer and 195 pounds (89 kg) in the winter."

- Air Insight Group (May 11, 2021)

Significant increase in the realized passenger flight miles

x Average flight length (miles)[1]: 25

x Average flights per day (#)[1]: 25 - 40

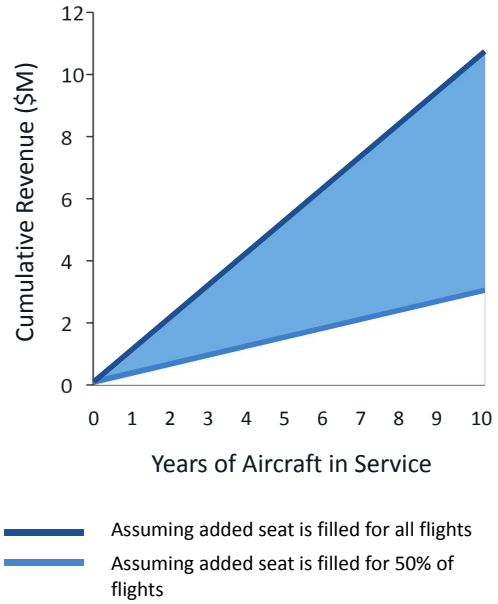
x Assumed daily usage factor: ~90%

= **Miles per year: 200,000 – 325,000**

x Average ticket price/mile[1]: $3 – 3.30

[1] Flying (October 22, 2021), per company reports from Archer and Joby

Up to $1.1M of additional potential revenue per eVTOL per year



Boosting Profitability and Operational Efficiency

The performance enhancements enabled by Carpenter's materials translate directly into economic benefits for aircraft operators. For example, you can expect benefits such as:

- **The additional payload capacity provided by Hiperco®-based motors is equivalent to adding an extra passenger seat in many eVTOL designs.**
- **This extra capacity could generate up to $1.1 million in additional annual revenue per aircraft, assuming the seat is filled for 50% of flights.**
- **Over a 10-year service life, this could amount to over $10 million in incremental revenue per aircraft.**

Power Dense Stack Performance is Highly Dependent Upon Processing Methods

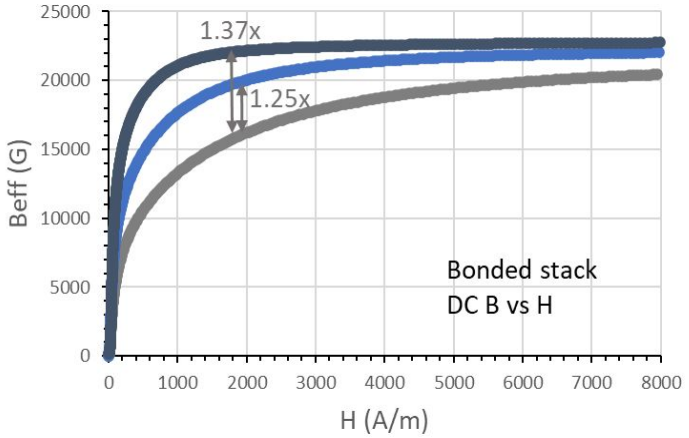
Material properties and processing techniques impact magnetic properties of Hiperco® stator and rotor stacks

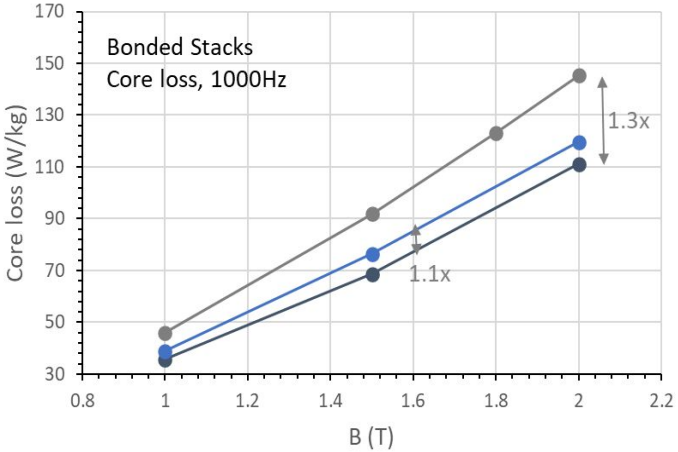
- Alloy quality (chemistry, strip process)
- Cutting process
- Growth
- Heat treatment
- Insulation
- Stress management

Getting the Most From Your Motor

Power Dense Stack Performance is Highly Dependent Upon Processing Methods

Significant improvement in finished stack magnetic properties from optimal processing of iron-cobalt alloys





Optimal processing

Improved processing

Conventional processing

Carpenter Electrification Stack Production Model

Integrated Production Capability and Capacity for Prototype and Volume Scale-up

01 → 02 → 03 → 04 → 05

Melting

- VIM (Vacuum induction melting)
- VAR (Vacuum arc remelting)
- Large VIM and VAR furnaces
- Largest VIM capacity

Rolling

- State-of-the-art hot strip mill
- Cold rolling mill
- Strip finishing – coat, slit, cut
- 0.05mm strip thickness

Cutting

- Stamping – high volume (partners)
- Laser Cutting – fast prototyping
- EDM – tight tolerance stacks

Stacking

- Automated system (2024)
- Printing & roller coating
- Bonding, interlocking, welding

Testing

- Stack magnetics
- Environmental
- Dimensional
- Strip magnetics


Ingot


Alloy Strip


Lamination


Stack

eVTOL Electric Propulsion Systems

Critical Factors for Stack Performance

Carpenter Electrification offers more than just advanced materials; we provide a comprehensive partnership to ensure optimal performance and seamless integration.

Performance

- High quality iron-cobalt alloys
- Control of material properties for optimum stack performance
- Stack processing expertise with Hiperco®

Agility

- Short lead-time
- Speed and schedule flexibility
- Capable of multiple stack processing approaches

Quality

- Finished stack magnetic testing
- AS9100 Certification
- Experience with quality requirements under the auspices of the FAA

Scale

- Production capacity for strip-melting & rolling
- Automated stack processing
- Scalable from prototype through volume production

PERFORMANCE

Partner With a Leader

Unlock the Future of Electrification

As the aerospace industry embraces electrification, partnering with a leader in advanced materials is crucial for success. Carpenter Electrification's unparalleled expertise in specialty alloys and electric motor stack materials positions us as the ideal collaborator for manufacturers pushing the boundaries of electric and hybrid aircraft design.

Ready to elevate your electric aircraft project?

Connect with our experts today to explore how Carpenter's advanced materials can transform your designs and drive the future of sustainable aviation.

Thank you

For additional information, please contact
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