Aviation Propulsion Battery Challenges and EPiC Solutions

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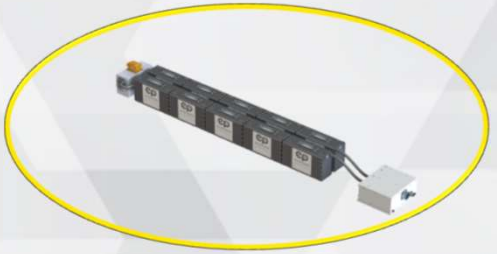
Outline

- **Electric Power Systems Introduction**
- **Electrified Aviation Obstacles**
  - Cycle Life
  - Cost
  - Performance/Mass
  - Containment: Thermal Runaway (TR)
- **Thermal Runaway – EPS Process**
  - Chaos Management
  - Thermal Management
  - Venting
- **EPIC Ecosystem Solutions**

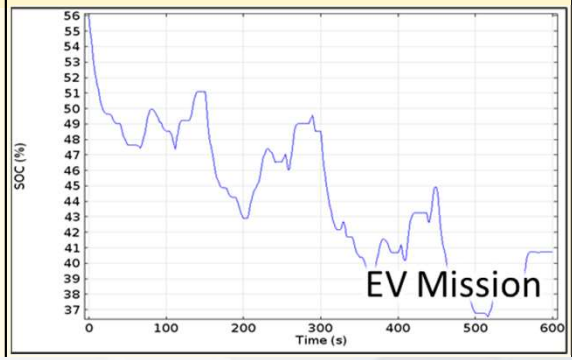
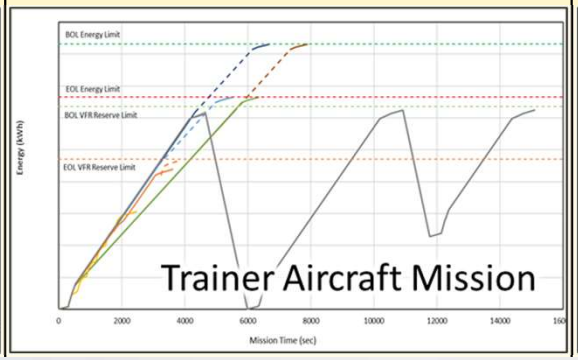
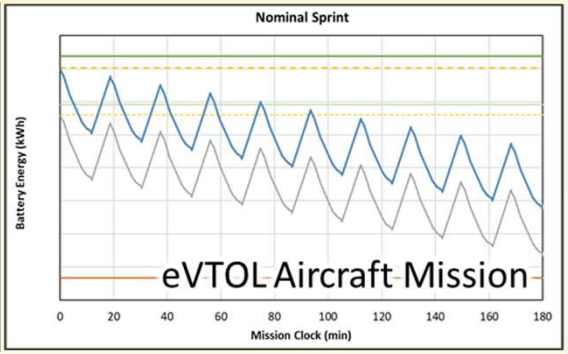
EP-SYSTEMS HIGHLIGHTS



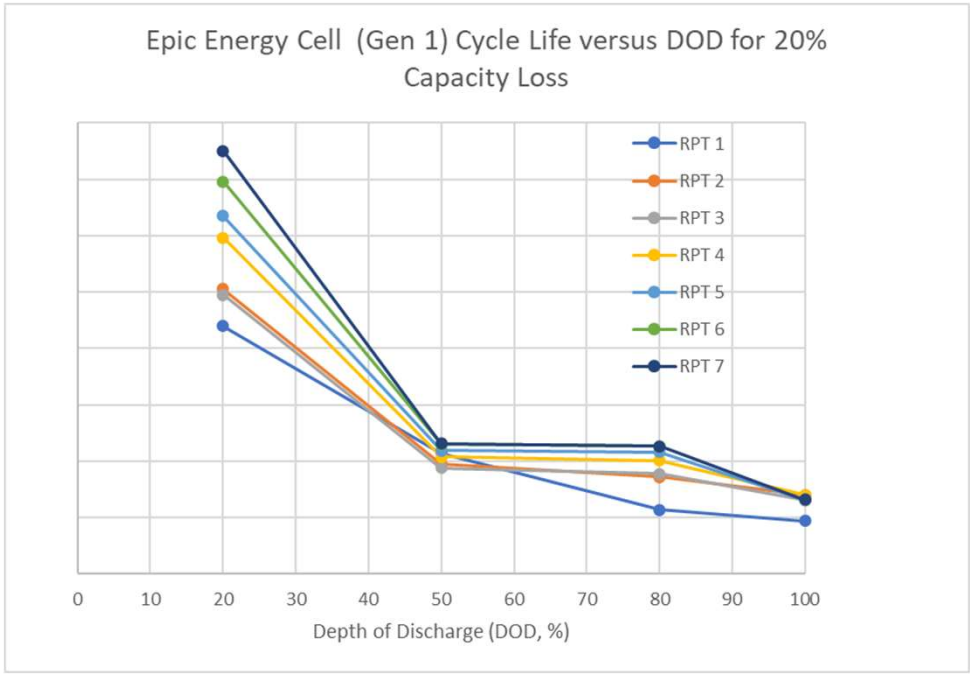
> 20	6	16,000 SQ FT	> 2 MWh	25,000 SQ FT	TSO-C179B
UNIQUE AEROSPACE BATTERY PROPULSION SYSTEMS IN DEVELOPMENT	ALL-ELECTRIC DEMONSTRATORS FLYING WITH EPS BATTERY SYSTEMS	LIMITED PRODUCTION AND HQ FACILITY COMPLETION AND OCCUPANCY	EXPERIMENTAL FLIGHT BATTERIES DELIVERED PER YEAR	MFG. FACILITY IN DEVELOPMENT	LAUNCHED FAA CERTIFICATION EFFORT FOR PROPULSION BATTERY

Unique Challenges for eVTOL Batteries

	Automotive EV	Part 23 Fixed Wing	eVTOL - AAM
Charging:	Low-Rate Charging	Fast Charge	Extreme Fast Charge
Discharging:	Energy Cell	Moderate Power Cell	High Power Cell
Energy Density:	Current Cell Technology	Near to Mid-Term Cell Technology	Mid to Long-Term Technology Targeted
Thermal Management:	Environment Dominated Thermal Constraints	Low to Moderate Thermal Constraints	High Thermally Taxing Mission Segments Bookend the Mission
Depth of Discharge:	Low Nominal Depth of Discharge	>50% DoD on Each Flight Cycle	~25% DoD for Each Mission Leg
Usage Profile:			

DoD vs Cycle Life

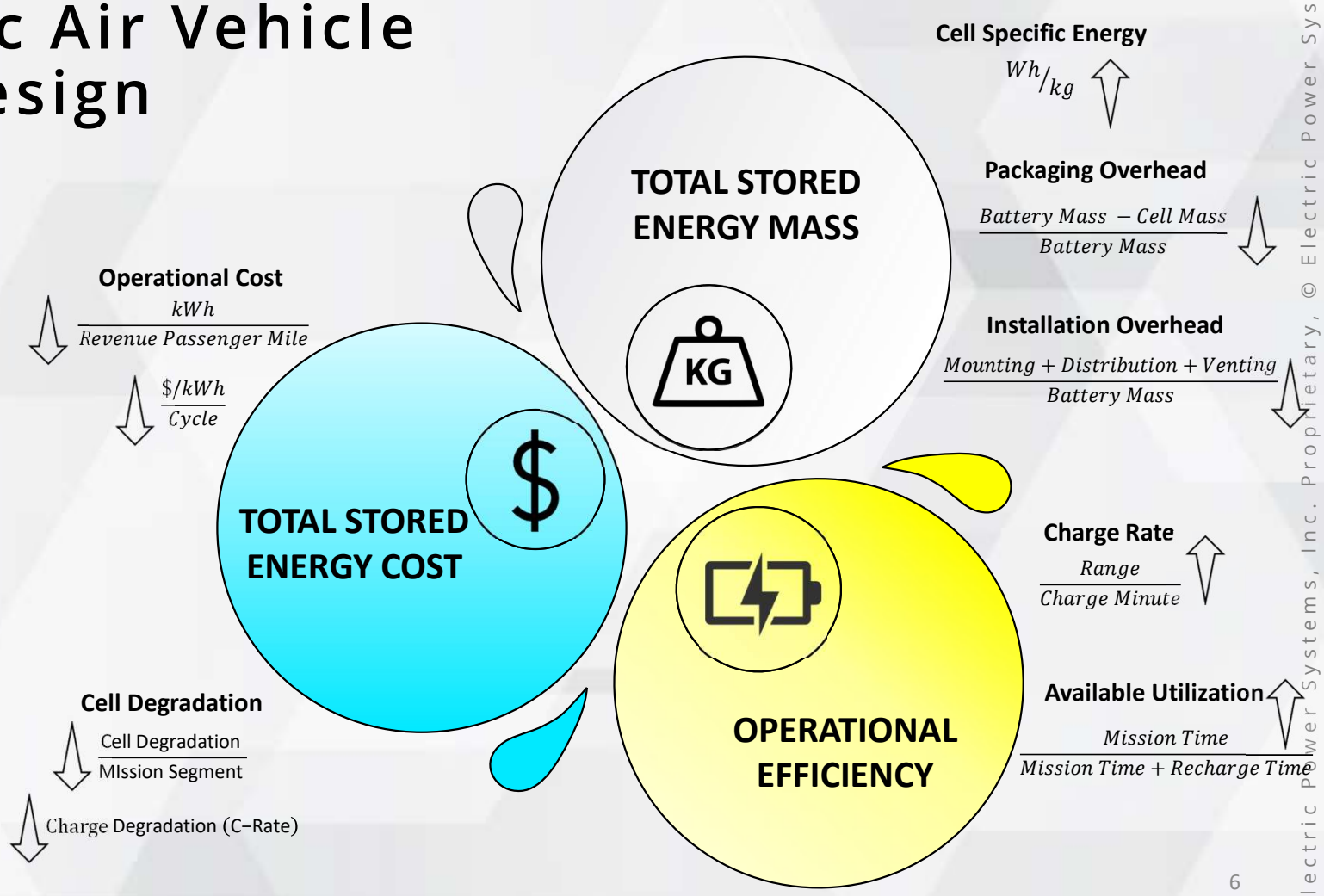
- For 20% Capacity loss, preliminary testing expects ~2000 cycles for 80% depth of discharge
- Testing based on 1C/1C profiles at 25°C



Key Measures of Effectiveness for Electric Air Vehicle Battery Design

Battery and Battery Installation Design is a Process of Multi-Objective Optimization

- Focus on the value to operator
- Understand the interaction between technology constraints
- EPS has industry leading Operational Costs with the EPIC system



Thermal Runaway Mitigation

How EPS Engineers Thermal Runaway Management

EPS Thermal Runaway Design Process

Containment Approach

- Single Cell Containment
- Module Containment
- Explosion Containment

Containment approach directs thermal runaway design focus.

Thermal Management

- Cell Characterization (calorimeter data)
- Hand Calculations
- FEA/CFD Thermal Model
- Component level TR testing

Chaos Management

- Cell Characterization (TR cell failure mode)
- Previous program lessons learned
- Cell protection design review (CAD)
- Component level TR testing

Venting

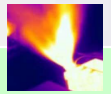
- Cell Characterization (gas emission)
- Cell Characterization (burn behavior)
- Previous program lessons learned
- Hydraulic diameter path review

Thermal runaway is stochastic. Sufficient sample sizes for cell characterization is needed.

Full Module TR Test

Process is iterated until specification compliance is achieved.

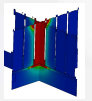
THERMAL MANAGEMENT EXAMPLE

Containment Approach	Requirement	Thermal Management 	Chaos Management 	Venting 
Single-Cell Containment *(DO-311A 2.4.5.4, JSC-20793)*	*Cell to cell propagation prohibited*	Highly Critical Cell to cell propagation prevention dependent on heat TMS	Highly Critical Violent cell ejecta can damage other cells propagating TR	Critical Typically, low volume of exhaust. Vent path can heat other cells
Module Containment *(DO-311A 2.4.5.5)*	*Module to module propagation prohibited*	Critical Cells expected to propagate. Need to consider adjacent module propagation	Critical TR cannot damage the containment of the module	Highly Critical High volume of exhaust if full module propagation occurs
Explosion Containment (DO-311A 2.4.5.6)	*Structural fragments prohibited (typically in a fire zone)*	Critical Bat teries are expected to propagate. Damage to vehicle structure to be considered	Critical Damage to vehicle structure to be considered	Critical Highest volume of exhaust, fire zones can have large exhaust ports

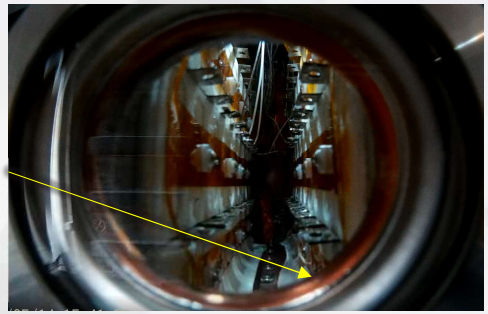
CHAOS/THERMAL MANAGEMENT

FINAL DESIGN

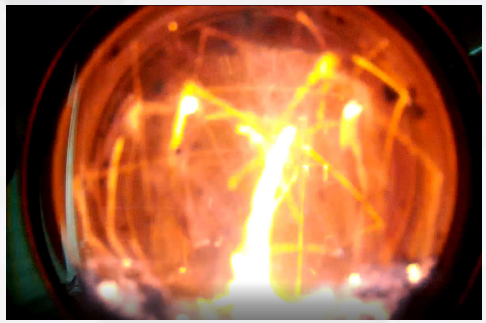
- 35% packaging overhead
- Certified to DO-311A Single Cell Containment
- Proprietary Single Cell TMS Technology



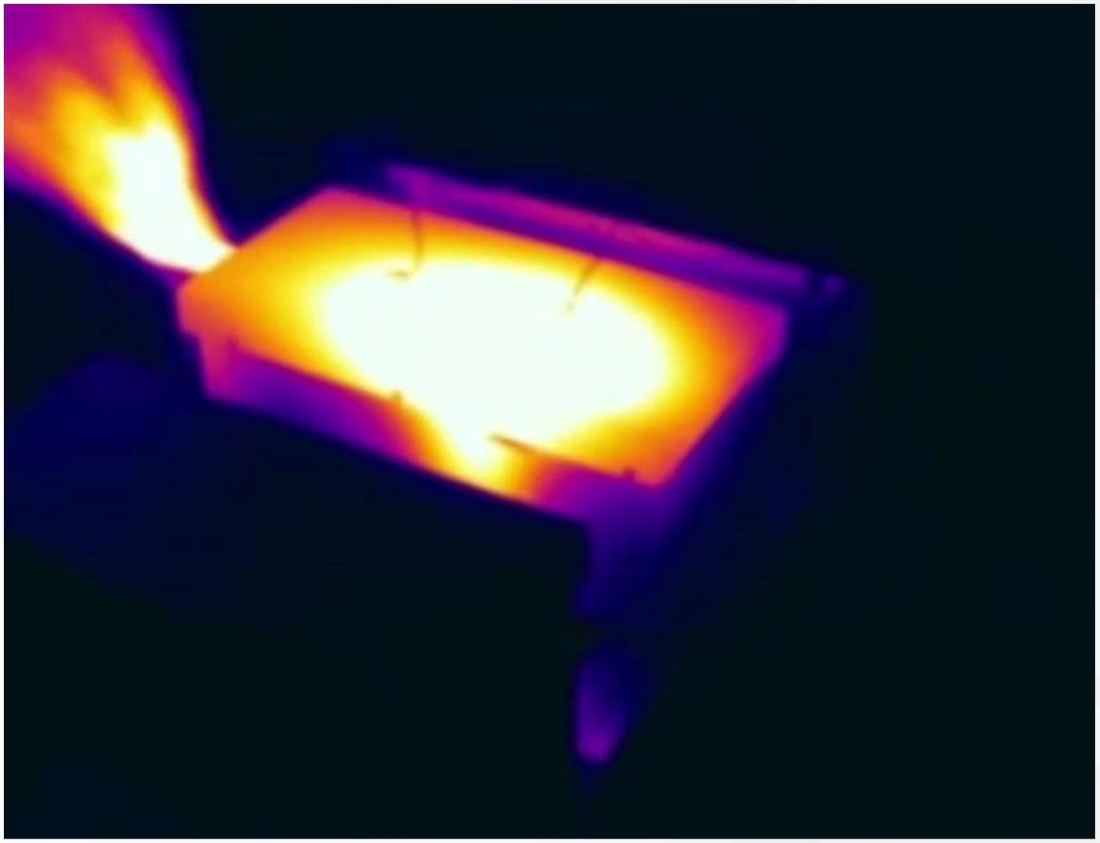
Trigger cell heating.



Violent ejections of the “jelly role” can produce projectile motion of debris in the module.



VENT MANAGEMENT EXAMPLE
FINAL DESIGN



x64 playback

Before TR

TR Venting
Acceptable Exhaust
Behavior

TR Cool Down
Module Contained

EPiC Battery Solution

How a modular battery approach can overcome these issues.

A Solution for Every Application

ALL-ELECTRIC HYBRID-ELECTRIC MICRO-HYBRID

EPiC ENERGY

TRAINER | THIN HAUL | EVTOL

SYSTEM: 205WH/KG

20% PACKAGING OVERHEAD

2000+ CYCLES @ 80% DoD

10C DISCHARGE

3C CHARGE RATES

EPiC POWER

HYBRID | EVTOL | MILITARY

SYSTEM: 180WH/KG

23% PACKAGING OVERHEAD

2000+ CYCLES @ 80% DoD

30C DISCHARGE

3C+ CHARGE RATES

EPiC ULTRA

HYBRID | APU | REGIONAL | MILITARY

SYSTEM: 115WH/KG

25% PACKAGING OVERHEAD

7500+ CYCLES @ 80% DoD

70C DISCHARGE

4C CHARGE RATES

40, 60, 80AH APU

ELECTRIC PROPULSION ION CORE (EPiC) Module

VENTING

DO-311a Venting Category B
Gang Vent Attachment Points and Sealing Interface
Optional Gang Vent with Attachment Hardware
Module-to-Module Propagation Mitigation

DATA/COMMS CONNECTOR

Complex Wiring Elimination
Less Wiring Leading to Reduced Mass
Redundant Communication Signals
EMI Protected

ENCLOSURE

DO-160G Structure & Environmental Compliance
High-Temperature Composite Case
Low Sidewall Temperature During Thermal Runaway
No Additional Vehicle Firewall Needed

THERMAL MANAGEMENT

Embedded Thermal Management
Minimal Coolant Volume Requirements
Low-Maintenance Connection Ports
On-Board/Off-Board Reservoir Integration

POWER CONNECTOR

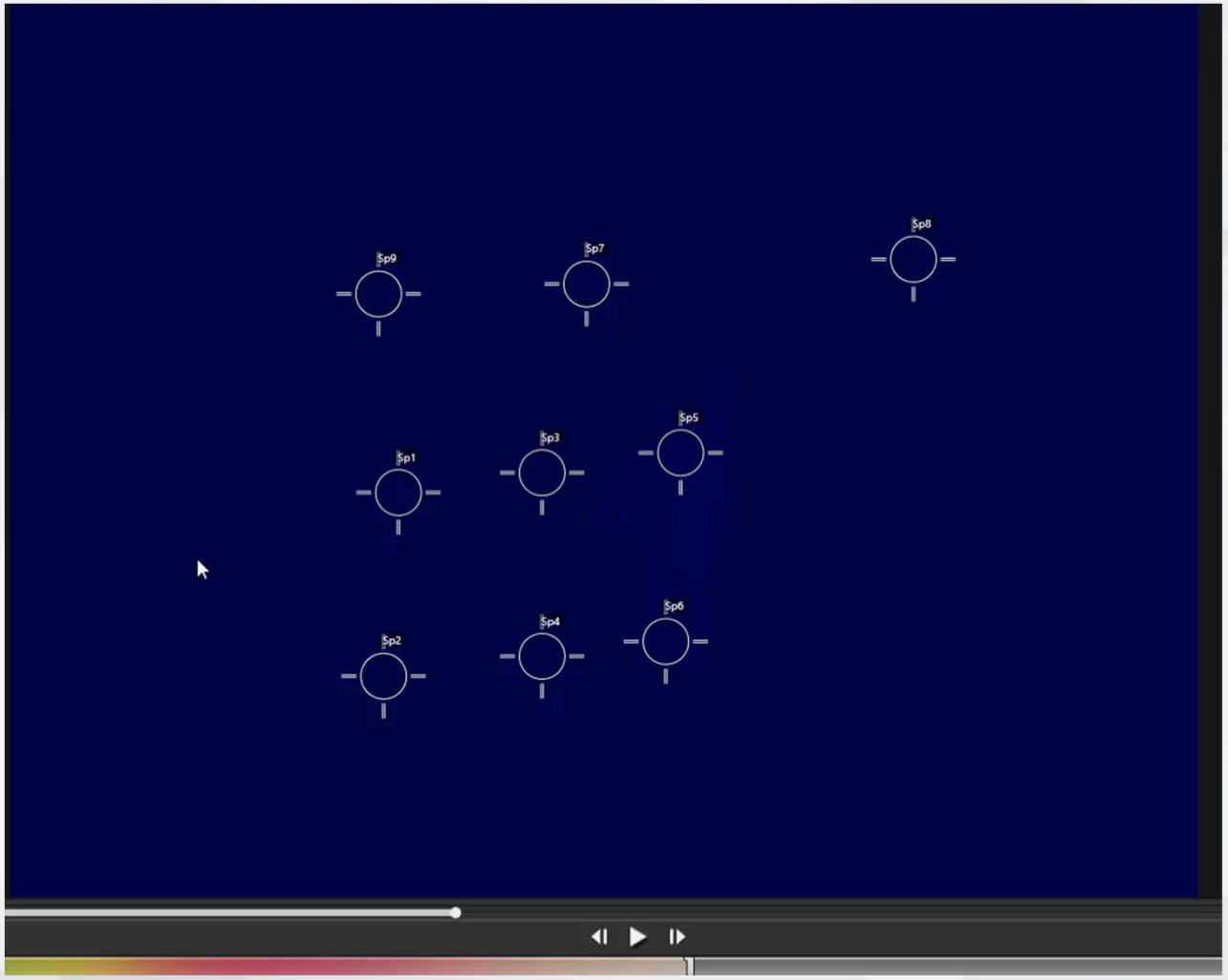
Patented Module-Module Connector
Complex Wiring Elimination
High-Current Capabilities
Robust Thermal Runaway Survivability
Finger-Safe for Handling

MOUNTING LOCATIONS

Configuration in Any Orientation
Mounting in Any Direction
Space-Claim Flexibility
Mounting Hardpoints in All Corners
16 Total Mounting Points

Containment

EPiC FAA Abuse testing

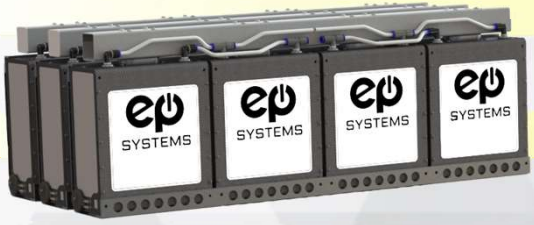


- 20% packaging overhead
- Certified to FAA Standards
- Proprietary Technology

EPiC Module Enables Integrated Ecosystem

Questions?

Numerous Applications



eVTOL

RETROFIT

TRADITIONAL AERO

FIXED WING