

Graphene Composite Fin (GCF™)Technology – Advanced Energy Storage Thermal Management

General Information

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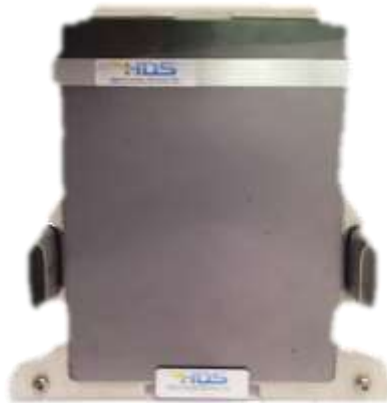
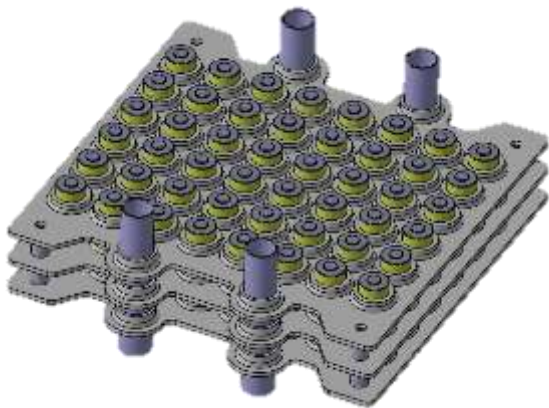
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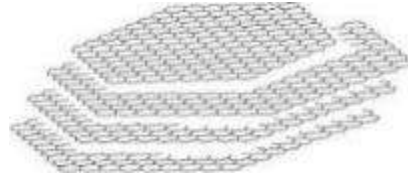
WORLD CLASS ENGINEERING AND PROTOTYPING SOLUTIONS

HDS Graphene Composite Fin (GCF™)Tech Summary

- Patent-pending Technology
- Outperforms thermal performance of passive Al or Cu plates
- Offers thermal performance similar to complex liquid cooling systems
- Reduced Size, Weight, and Power Consumption (SWaP)
- Is lightweight and non-corrosive
- Is easy to manufacture and assemble



Graphene and Nano Carbon Materials



**Graphene
Nanoplatelets**

HDS designs use a domestically-sourced, low-cost graphene nanoplatelet material, manufactured via a non-oxidizing process to produce an exceptionally pure material whose size, shape & edge chemistry can be controlled to customize properties.

The graphene nanoplatelet materials are laminated, bonded, or mixed with other base materials to provide the required thermal and structural performance.

Graphene Composite Fin (GCF™) - Competitive Positioning - I

GCF™ vs graphite foil:

- Better electrical or thermal properties
- Tailored compositions consisting of graphene nanoplatelets
- Can include selected additives or coatings designed for specific properties
- Better two-dimensional anisotropic properties

GCF™ vs metal foil:

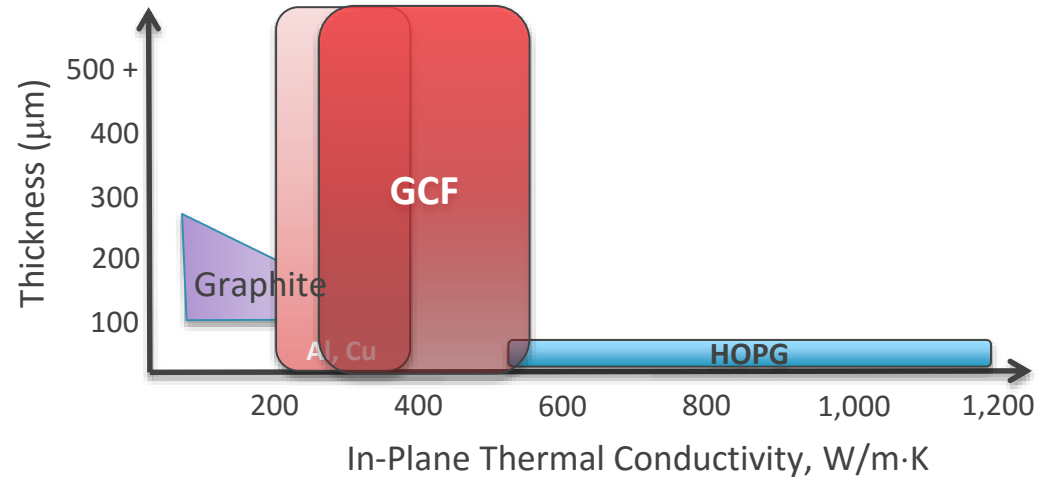
- Lighter
- Does not corrode
- Better thermal properties
- Much better two-dimensional anisotropic properties
- Tailored wettability and chemical resistance

Product	Description	In-plane Thermal Conductivity (W/m.K)
Graphene used in GCF™	Anisotropic – controlled heat transfer in 2D Tailored wettability and chemical resistance	> 500
GCF™	Anisotropic – controlled heat transfer in 3D Tailored thickness, strength, physical, thermal, and electrical properties	300-475
Natural Graphite	Limited thermal conductivity	150 – 400
Copper	Lower thermal conductivity, heavy	< 400
Aluminum	Much lower thermal conductivity, corrosive	< 240

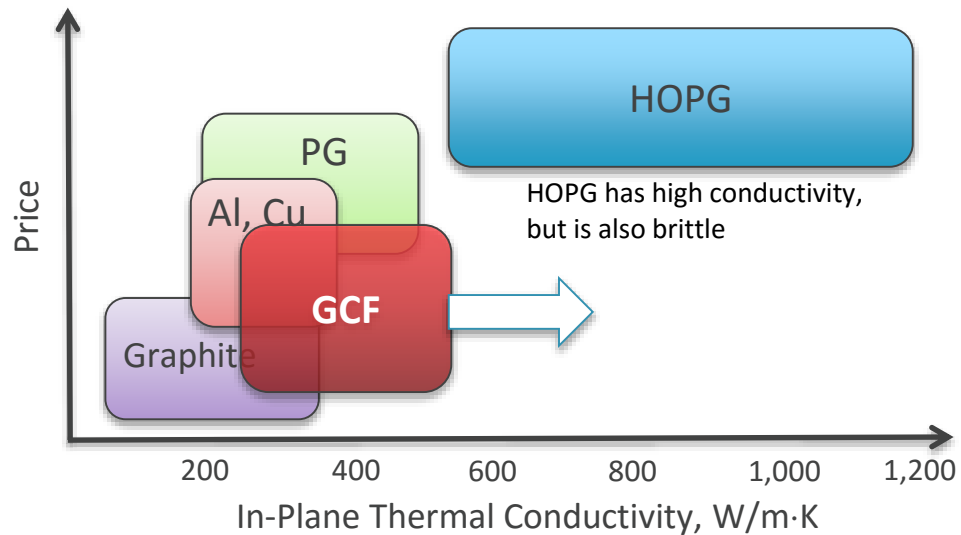


HDS GCF™ – Competitive Positioning - II

Thickness vs. Performance

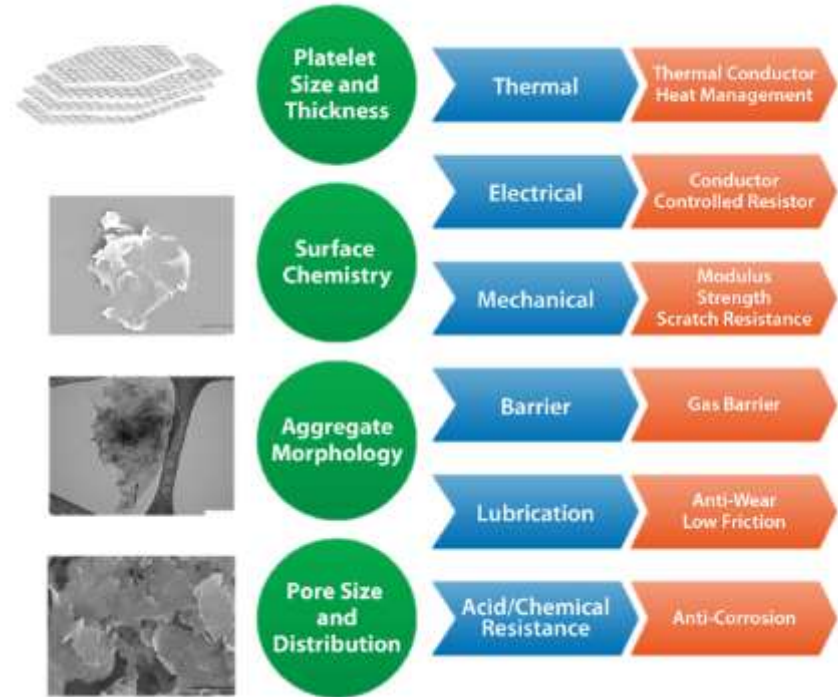


Price vs. Performance



GCF™ – Tailoring Properties for Unique Applications

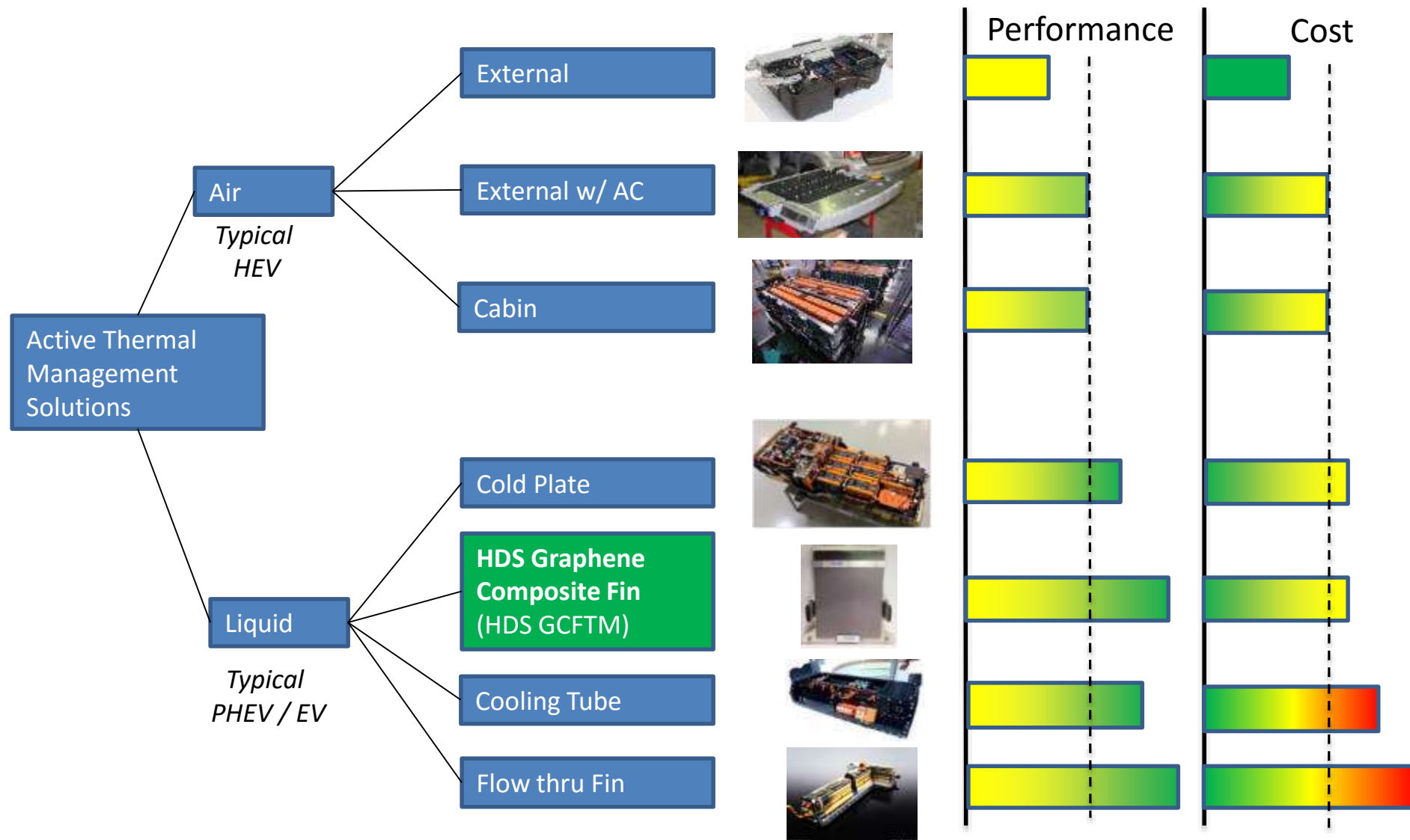
- Strength & Formability
- Conductivity at elevated temperature
- Low/High Pressure Operation
- Low/High Temperature Operation
- Coatings
 - Adhesive
 - Abrasion
 - Electrically insulating
 - Thermal conducting
- Lamination
- Minimum bend radii, Bend cycling
- Surface properties (hydrophobicity, etc.)
- Processing Capability



GCF™ Energy Storage Example



Energy Storage Thermal Management Overview (transportation)

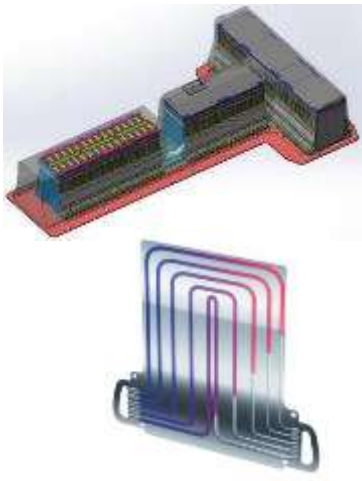


HDS Graphene Composite Fin* (GCF™)

Graphene Composite Fin* Advantages

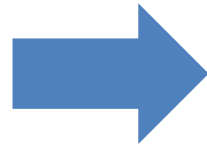
- Reduced parasitic energy consumption
- Fewer Fluid leak points
- Lower Complexity & parts count
- Lower System Cost

FROM:

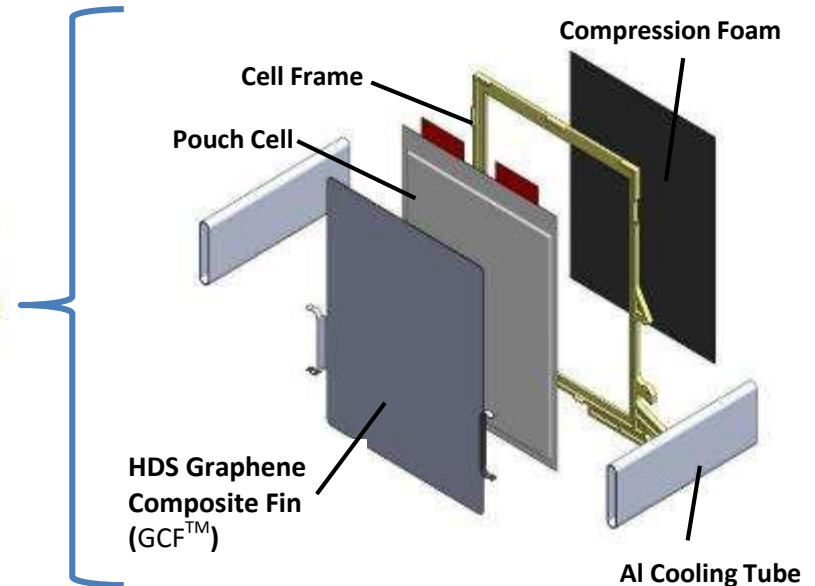


Current industry designs utilize circulating liquid which passes through a series of internal heat exchangers in the battery modules. Each 'fin' requires multiple seals/gaskets.

TO:



Module



* Patent-pending

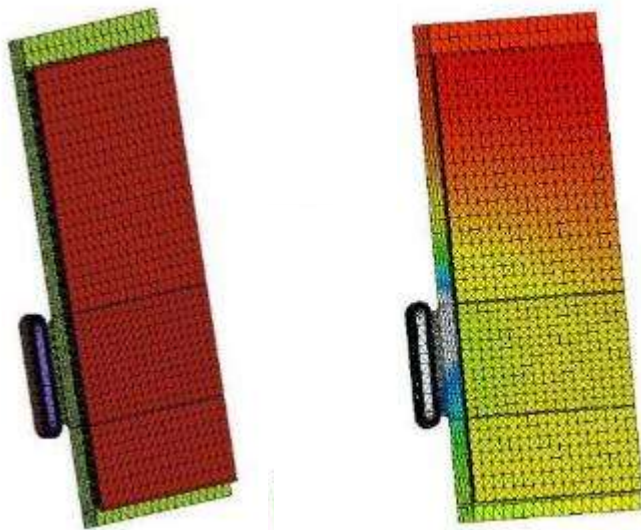


GCF™ – Gen II Simulation Results

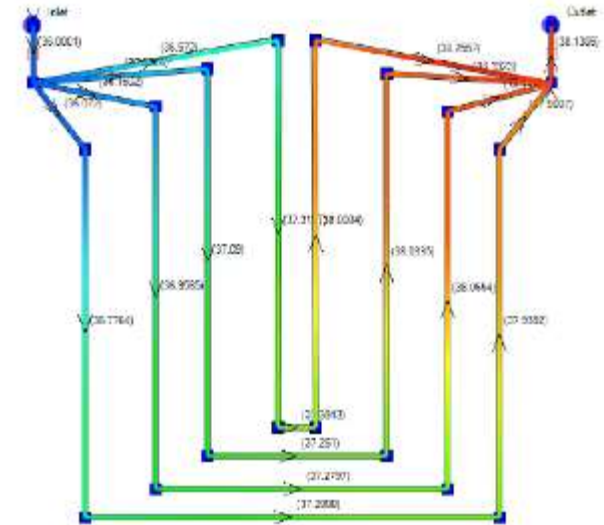
Gen II GCF Comparison to Flow through Fin

Comparable cooling performance (less than 3 deg. C rise) while improving:

- Manufacturing part count
- Complexity
- Leak paths (>500 O-rings → ~ 12),
- Pressure drop/ pumping losses on the 12Vdc system



Cell Temp Rise ~ 2.6°C (spot) / 2.3°C (area)



Cell Temp Rise ~ 2.0°C

✓ 3.7W/cell

✓ 10L/min

✓ 30° C Inlet Temp

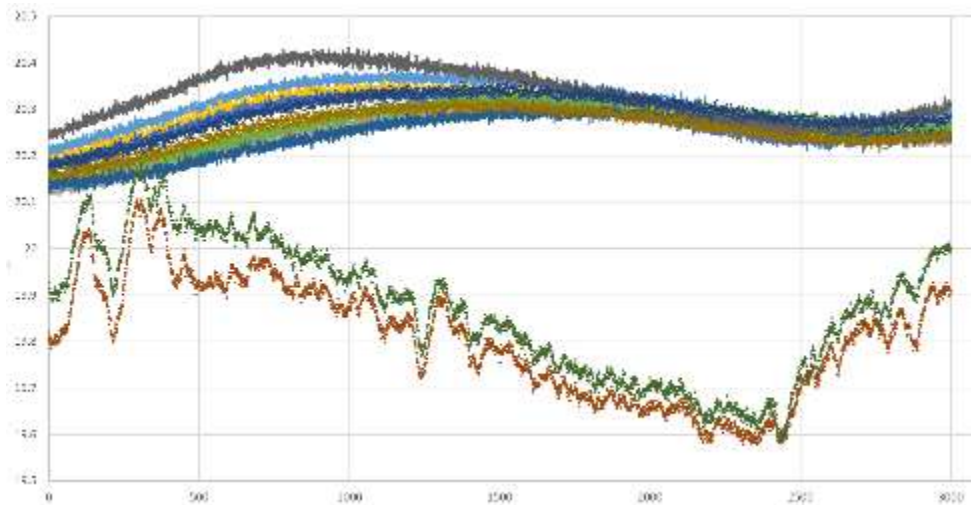
** Source: Variable Fidelity Methodology For Thermal Battery Modeling H.Lewis, B.Zandi, G.Lewis, & S.Ketkar*



GCF™ – Gen II Test Results

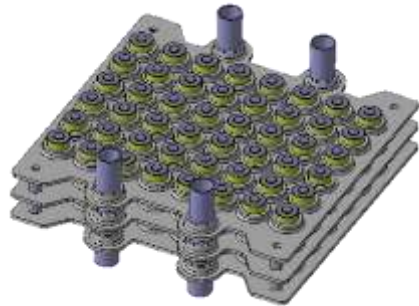
Gen II and Gen III GCF testing Underway

Gen II GCF Testing shows very good correlation with simulation results.



Test Results = 476 W/m-K

HDS GCF™ – Gen III Designs: Pouch, Prismatic, & Cylindrical Cells



Source: Siemens, NASA, FIA Formula E, FedEx, Airbus



WORLD CLASS ENGINEERING AND PROTOTYPING SOLUTIONS

HDS Graphene Composite Fin Technology

- Outperforms thermal performance of passive Al or Cu plates
- Offers thermal performance similar to complex liquid cooling systems
- Reduced Size, Weight, and Power Consumption (SWaP)
- Provides superior heat spreading/distribution performance
- Is lightweight and non-corrosive
- Offers adjustable thicknesses and structural performance
- Offers reduced coolant pumping power, leak paths, and parts count
- Offers new design flexibility for thermal management system optimization
- Is easy to manufacture and assemble



About HDS



HDS Corporate Introduction

Hybrid Design Services, Inc. (HDS™) offers a full range of consulting, engineering, design, prototyping, and testing services, focusing on the advanced transportation and energy technology sectors.

Company Name: Hybrid Design Services, Inc.

ISO 9001:2008 Certification: 8/19/2014

Year Founded: 2004

DUNS: 802293774

Headquarters: 2479 Elliott Ave., Troy, MI 48063

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HDS Design, Engineering, Prototyping, & Testing Services

- Complete Vehicle xEV Drive Design, Development, Vehicle Integration, and Testing
 - Heavy-duty, Off-road, Marine, & Military Systems
 - Renewable Energy & Stationary Systems

Passenger & Cargo Vehicle Drive Systems



Heavy-duty Systems



Renewable Energy & Stationary Systems

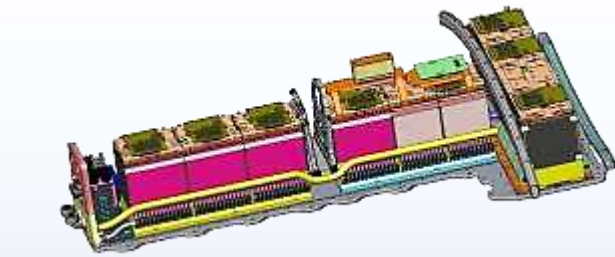


Testing and Simulation Services



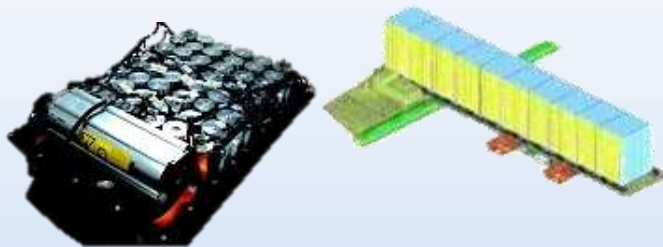
HDS Energy Storage Design & Engineering Expertise

Development, Design, and Prototyping



Pack Design and Optimization

- Module Size and configuration optimization
- Pack Electrical, Mechanical and Thermal Interface
- Vehicle Packaging & Environmental Protection
- BMS Development and Integration



Module Design and Optimization

- Cell Selection
- Module Packaging
- Cell carrier and Interconnect strategy
- Module V/T sense
- Thermal System Integration



Prototype Development

- Module Builds
- Pack Builds
- Incoming and End-of-line testing
- Supplier Management



Thermal and Structural Analyses

- Cell Thermal Model Correlation
- Module model development and correlation
- Module and Pack Thermal strategy development
- Module and Pack Structural System Design

HDS Products & IP

'Smart' Power Distribution Systems



Graphene Composite Fins



OTS Battery Management Systems



HV Sense Boards



EV and HEV Conversion Systems



WORLD CLASS ENGINEERING AND PROTOTYPING SOLUTIONS

Thank you!

Please contact HDS to learn more!

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