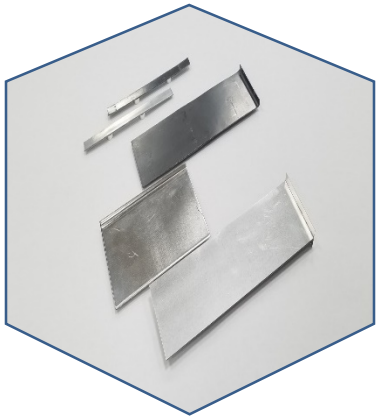
Graphene Composite Fin (GCF™)Technology – Advanced Energy Storage Thermal Management

General Information



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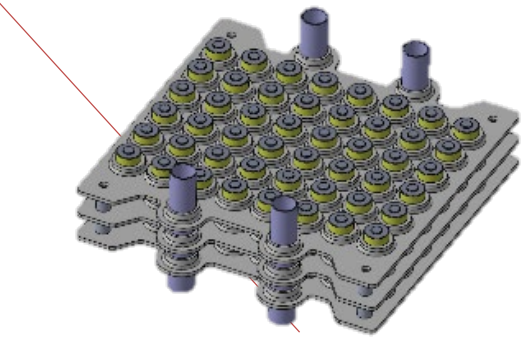
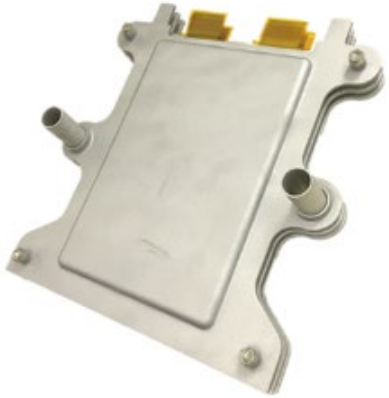
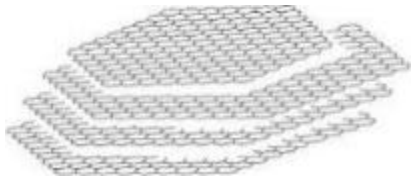
HDS Graphene Composite Fin (GCFTM)Tech Summary

- 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 (GCFTM) - 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

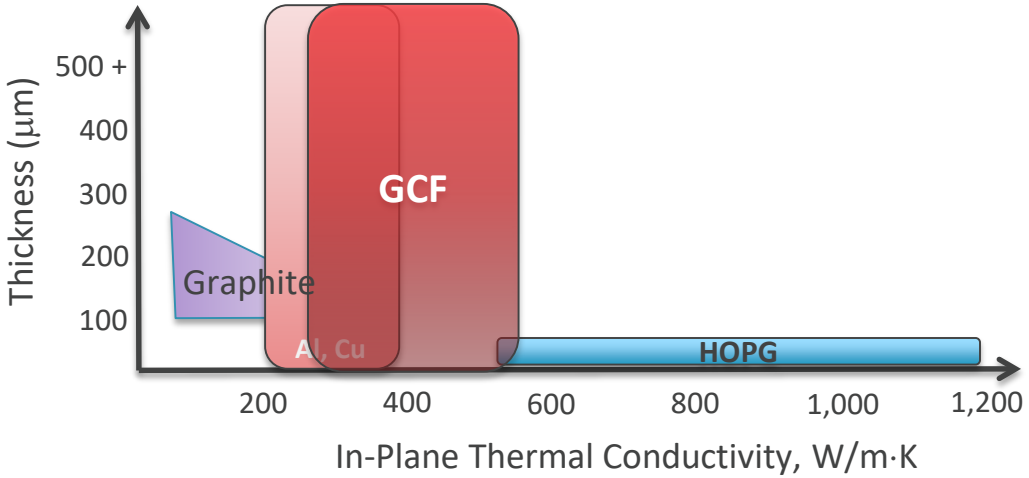
GCF™ vs metal foil:

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

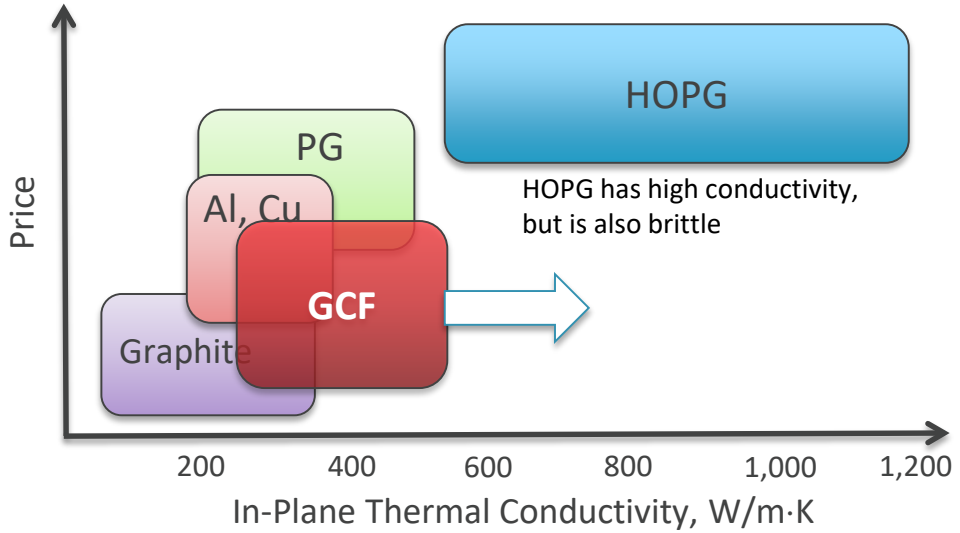
Product	Description	In-plane Thermal Conductivity (W/m·K)
Graphene used in GCF™	Anisotropic – controlled heat transfer in 2D Tailored wettability and chemical resistance	> 500
GCF™	Anisotropic – controlled heat transfer in 3D Tailored thickness, strength, physical, thermal, and electrical properties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

HDS GCFTM – Competitive Positioning - II

Thickness vs. Performance

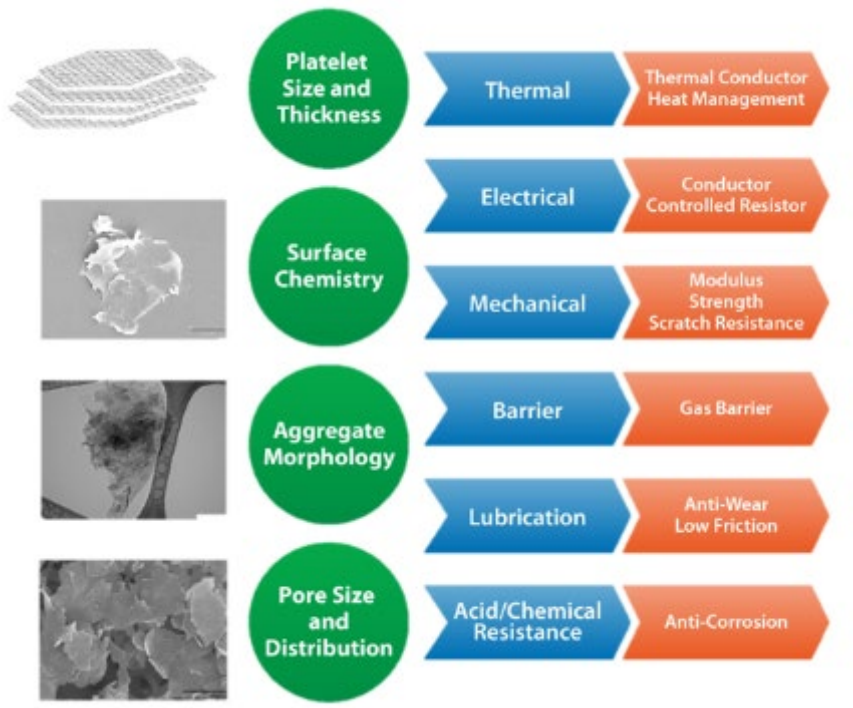


Price vs. Performance



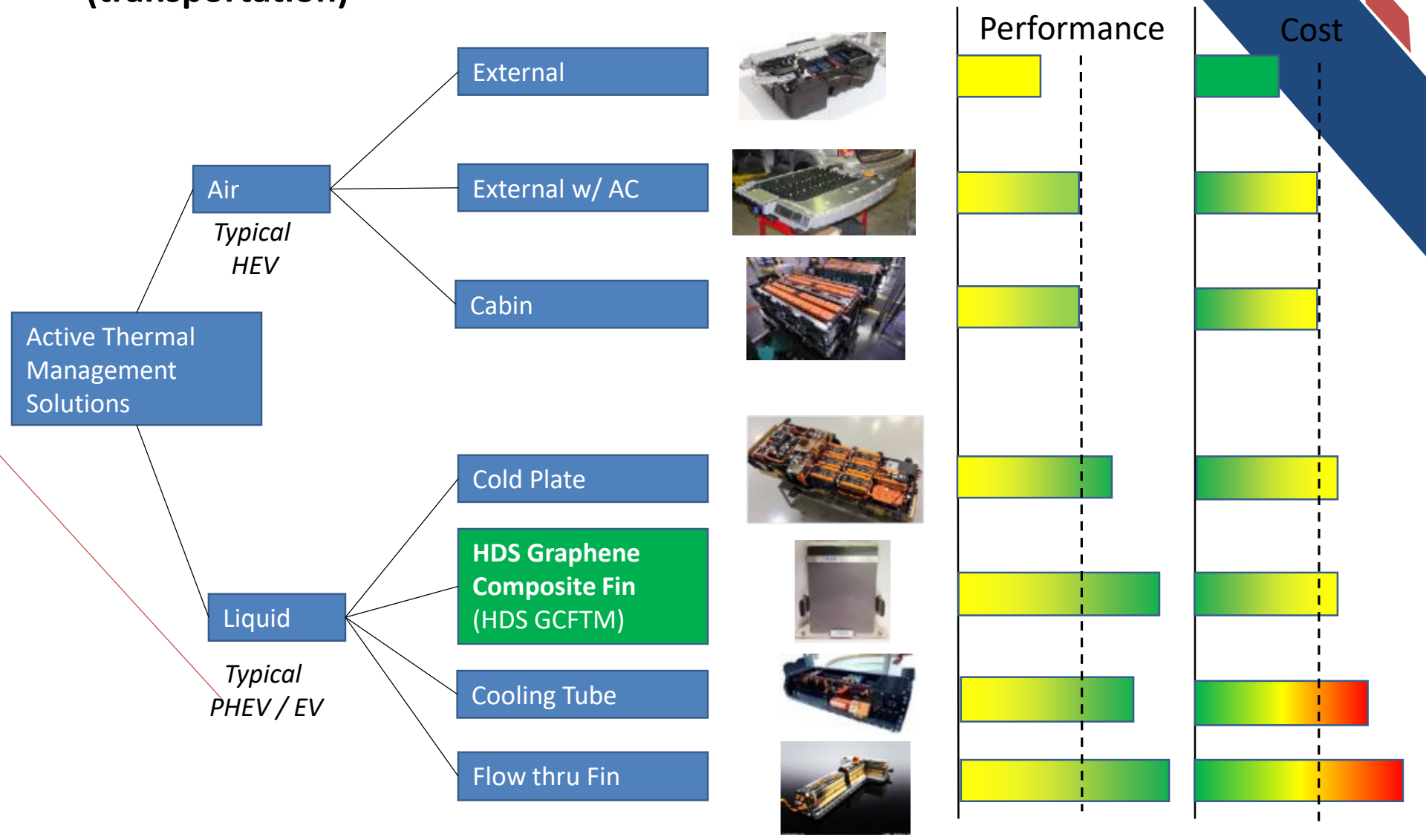
GCFTM – Tailoring Properties for Unique Applications

- 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)

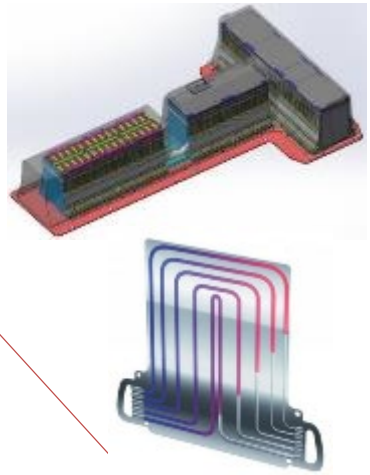


HDS Graphene Composite Fin* (GCF™)

Graphene Composite Fin* Advantages

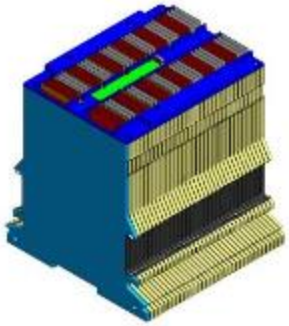
- Reduced parasitic energy consumption
- Fewer Fluid leak points
- Lower Complexity & parts count
- Lower System Cost

FROM:

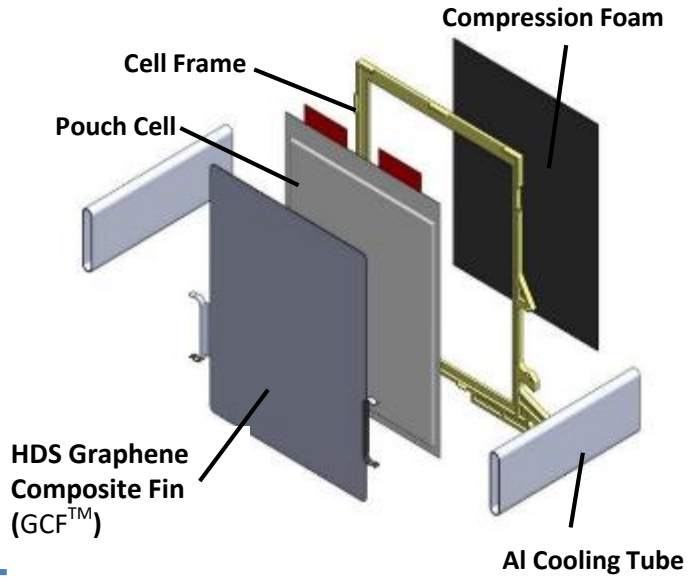


Current industry designs utilize circulating liquid which passes through a series of internal heat exchangers in the battery modules. Each 'fin' requires multiple seals/gaskets.

TO:



Module



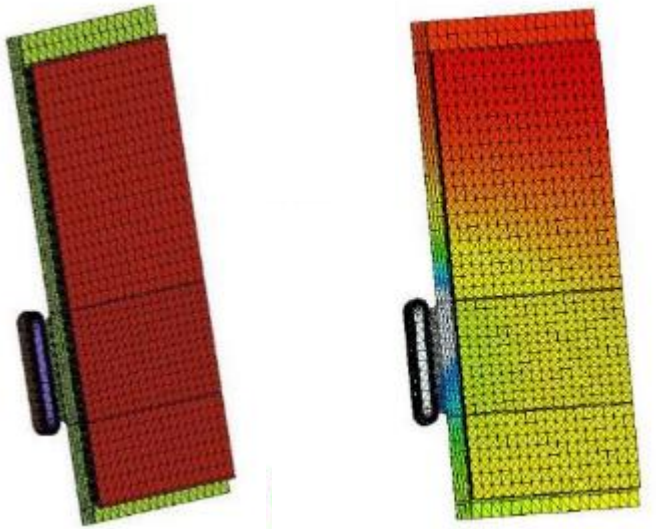
** Patent-pending*

GCF™ – Gen II Simulation Results

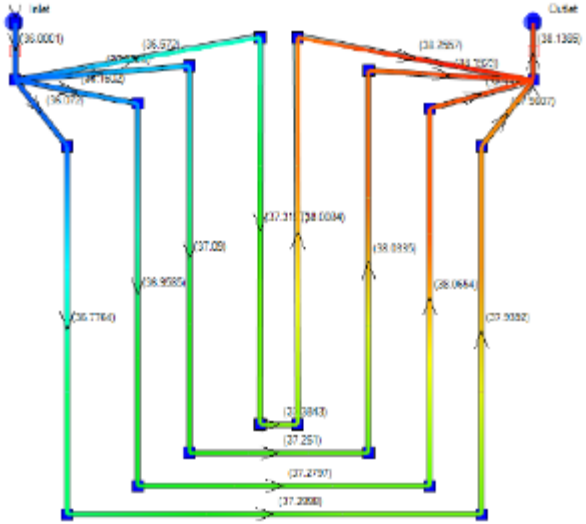
Gen II GCF Comparison to Flow through Fin

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)

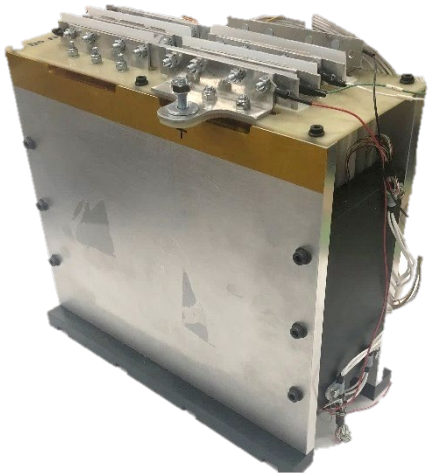


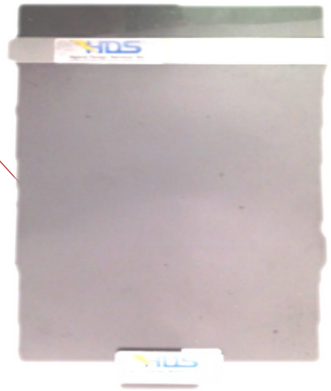
Cell Temp Rise ~ 2.0°C

✓ 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*

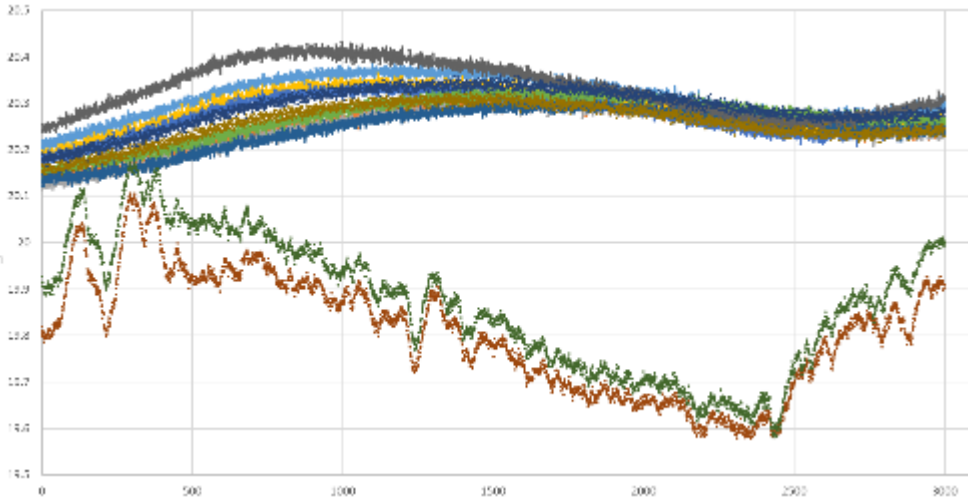
GCF™ – Gen II Test Results





Gen III GCF testing Underway

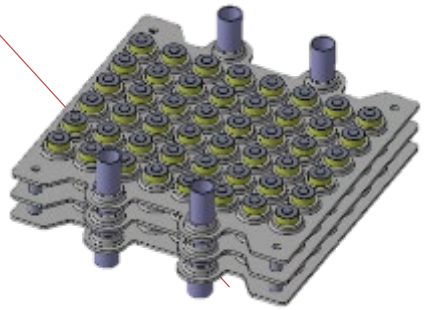
Gen II and III GCF Testing shows very good correlation with simulation results.



Test Results = 476 W/m-K

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

GCF™ Technology can benefit any application



HDS GCF™ Summary

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 Information

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.

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Web: www.HybridDesignServices.com

ISO 9001:2008 Certification: 8/19/2014

DUNS: 802293774

HDS Design, Engineering, Prototyping, & Testing

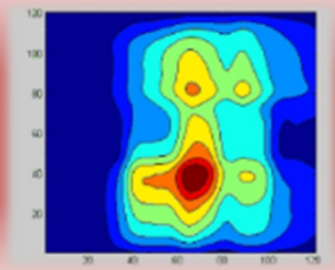
- Complete Vehicle xEV Drive Design, Development, Vehicle Integration, and Testing
  - Heavy-duty, Off-road, Marine, & Military Systems
    - Renewable Energy & Stationary Systems

Passenger & Cargo Vehicle Drive Systems

Heavy-duty Systems

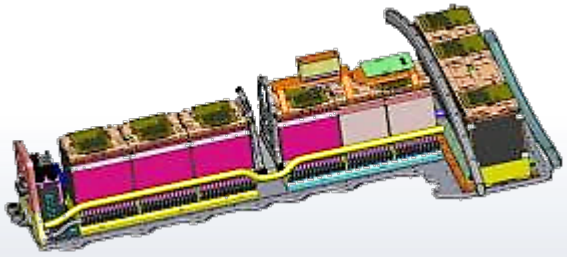
Renewable Energy & Stationary Systems

Testing and Simulation Services



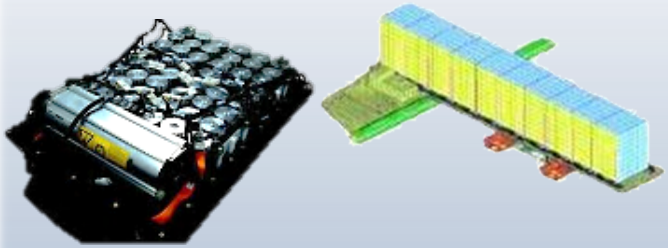
HDS Energy Storage Design & Engineering Expertise

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

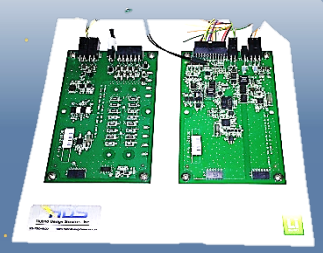
- Cell Thermal Model Correlation
- Module model development and correlation
- Module and Pack Thermal strategy development
- Module and Pack Structural System Design

HDS Products & IP

‘Smart’ Power Distribution Systems

Graphene Composite Fins

OTS Battery Management Systems



HV Sense Boards

EV and HEV Conversion Systems

Thank you!

Please contact HDS to learn more!

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