November 2006 Phase 2 Progress Report: 100kW LOW COST ENERGY STORAGE INVERTER

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Sandia National Laboratories

Background

Rinehart Motion completed Phase 1 R&D activities July 2003 thru April 2004

- In Phase 1 we worked on the Inverter hardware, substantially reducing the size and cost of future Inverters

Phase 2 activities began in July 2004 and were scheduled to end June 2006 (a 9 month no-cost extension has been granted)

- Phase 2 work is focused on the Inverter / PCS system design

The Phase 2 work plan includes:

- Determine the scalability boundaries of the technology. Target down to 30kW and up to 1MW
- Generate credible inverter performance and reliability data for power and thermal cycling at full product ratings

Background

Phase 2 work plan continued:

- Investigate various approaches for optimized baseplate pin-fin design, considering performance, materials (both conventional and advanced) and manufacturing methods
- Develop technology for a closed-system heat exchanger (radiator) for applications where cooling fluid is either not available or cannot be practically implemented
- Investigate water, glycol, and alternate engineered fluids for the cooling media
- Develop appropriate manufacturing processes for full-scale production of the inverters. These include producing high quality circuit subsystems, making reliable seals for the liquid cooled heatsink structure, and providing for effective testing
- Using pre-production tooling, fabricate, test and deploy alpha test units with various customer R&D programs

Phase 2 Status to Date

Inverter systems engineering

- Control systems design and firmware development
- Multiple PCS, Inverter and Drive system packaging concepts

Capital equipment purchase and integration into facilities

- Design and Analysis software and training
- Equipment installation and training

Commercialization activities

- PV systems customer discussions
- Southwest utility customer visits
- Failure to engage a utility or Storage System customer
- Engagement with early adopters – US Military Hybrid Electric Vehicles

Key vendor relationships - building on Phase 1 work

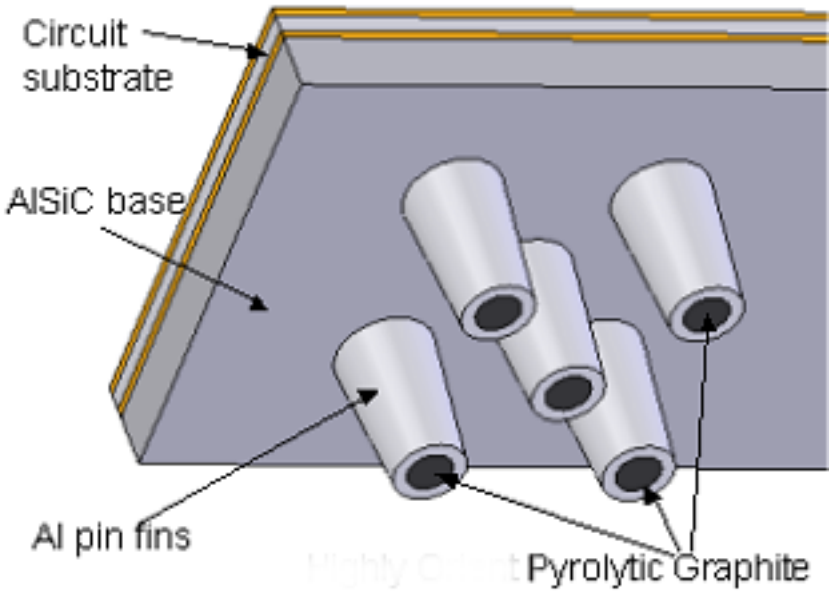
- Follow-on communications with Materials and Electrochemical Research, Ceramic Process Systems and Aztex - metal matrix materials vendors
- Selection of MIM Cu supplier Amulaire Thermal Technologies

Advanced Thermal Management

Continuing the work done in Phase 1, we have explored new and emerging thermal management materials with the potential to reduce cost and improve reliability of the inverter package

- AlSiC composite
- Al-Graphite composite (you may recall our Phase 1 failure with Cu-Graphite composite…)
- 3-D woven Graphite fiber
  - In-situ cast in the AlSiC base, or
  - Direct to fluid heat exchanger
- Novel pin-fin and folded-fin designs using low cost materials
- Cu Metal Injection Molding Processes

These alternatives have been explored in detail, and MIM Cu has been selected for lowest cost



Down Selection of Thermal Base Materials

The AlSiC baseplates work exactly as expected, and offer superior long term reliability.

- The critical issues are thermal performance and cost
- k = 180W/mK
- $60 for the test coupon used (projected volume cost)

A new process, Metal Injection Molding of powdered Cu has been investigated

- Cost is very low
- Material in 98% Cu dense after sintering
- k = 370W/mK (compared with pure Cu = 393W/mK)
- Fin densities are >10x possible with AlSiC
- $6 for the test coupon used (projected volume cost)

We've come Full Circle

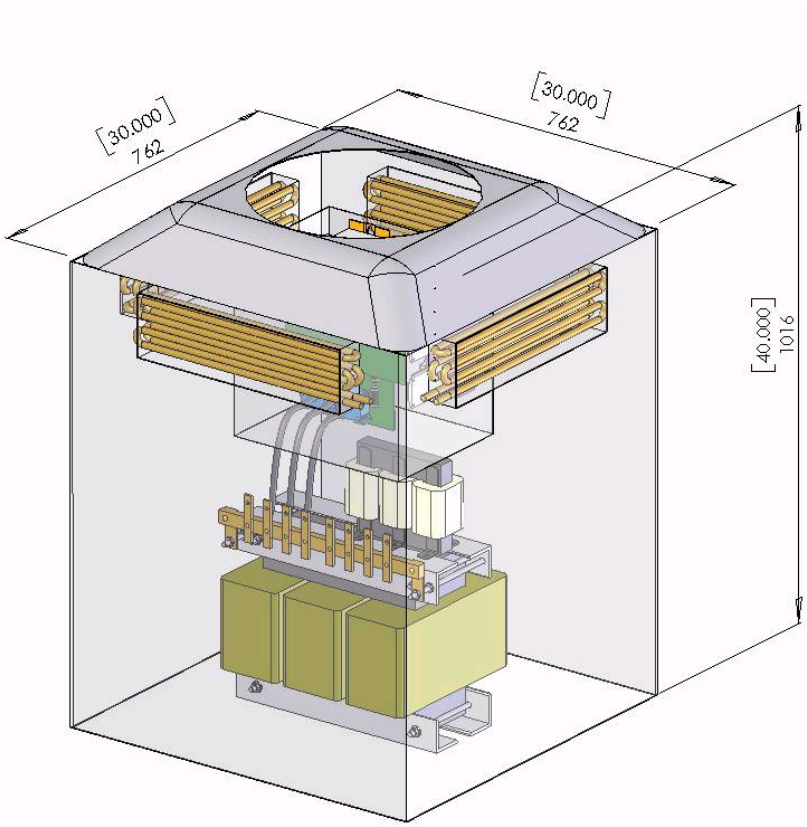
Starting Point:

The ordinary use of exotic materials

Today's Approach:

The exotic use of ordinary materials

PCS Assembly - Concept meets Reality



The inverter measures 28 x 28 x 36 in and 760lbs:

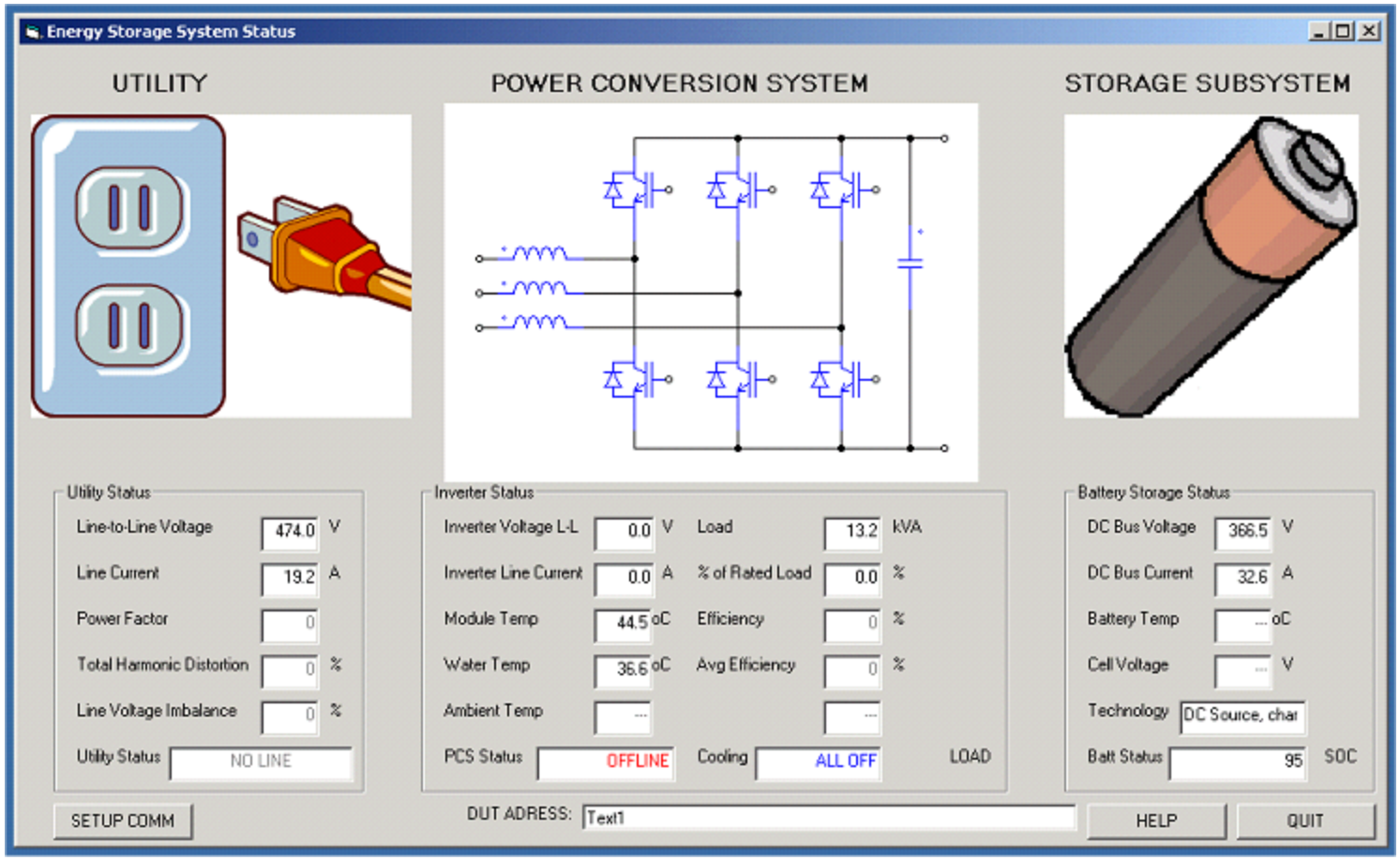
0.216 kVA/L

0.29 kVA/kg

Full PCS System in a box - not just an inverter

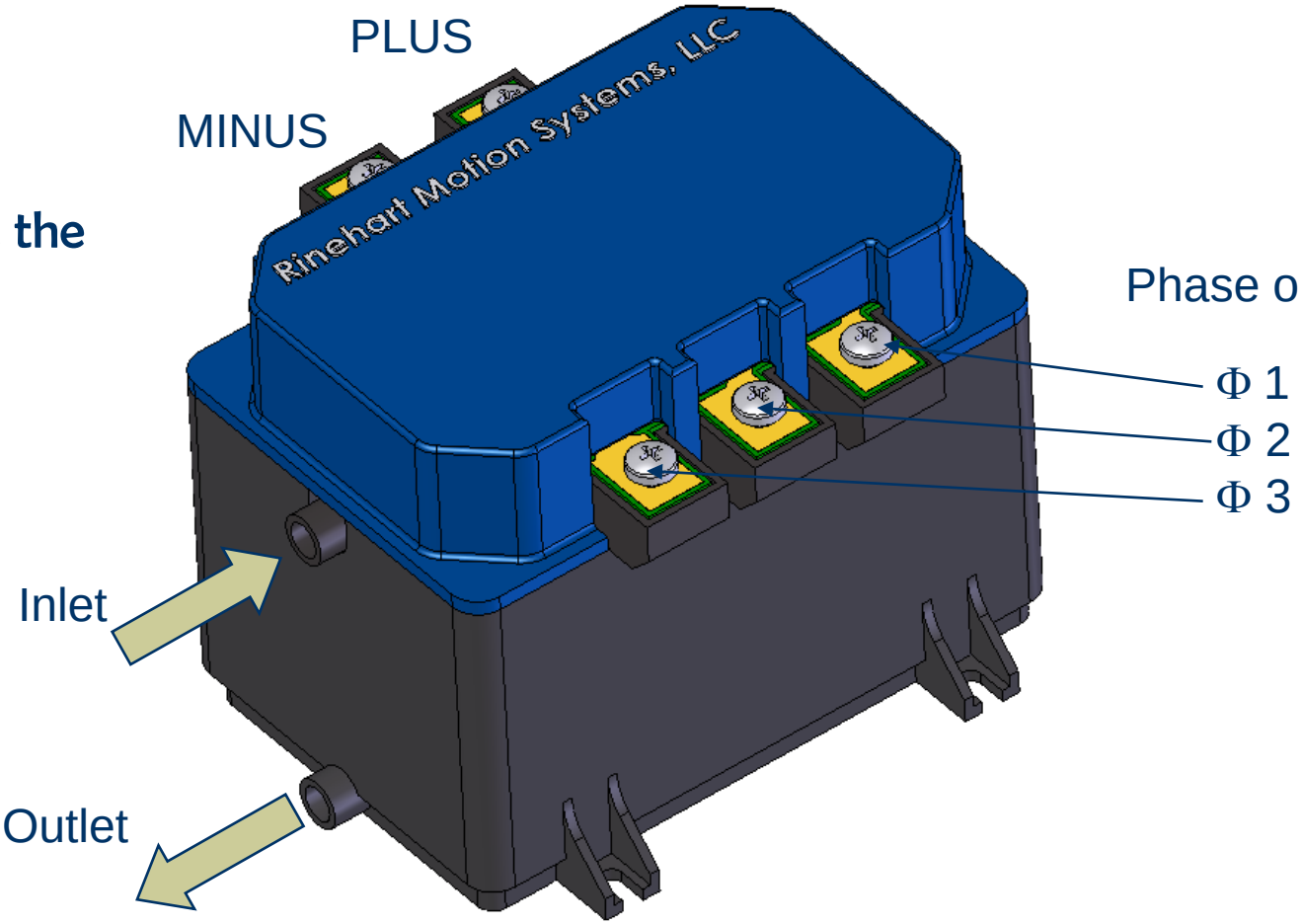
- system level circuit protection devices (including AC and DC disconnects, fast fault-limiting fuses, circuit breakers, etc.);
- line-frequency isolation transformer (660 lbs of our total, and the single largest cost item in the system!);
- closed fluid cooling loop, including power module heat exchanger, flow and temperature monitoring, and cooling radiators;
- graphical user interface and monitor, including local PC-based and Internet WAN-based communications;
- control power and housekeeping functions.

Operator Interface and Communications



30kW non-Isolated Inverter Concept

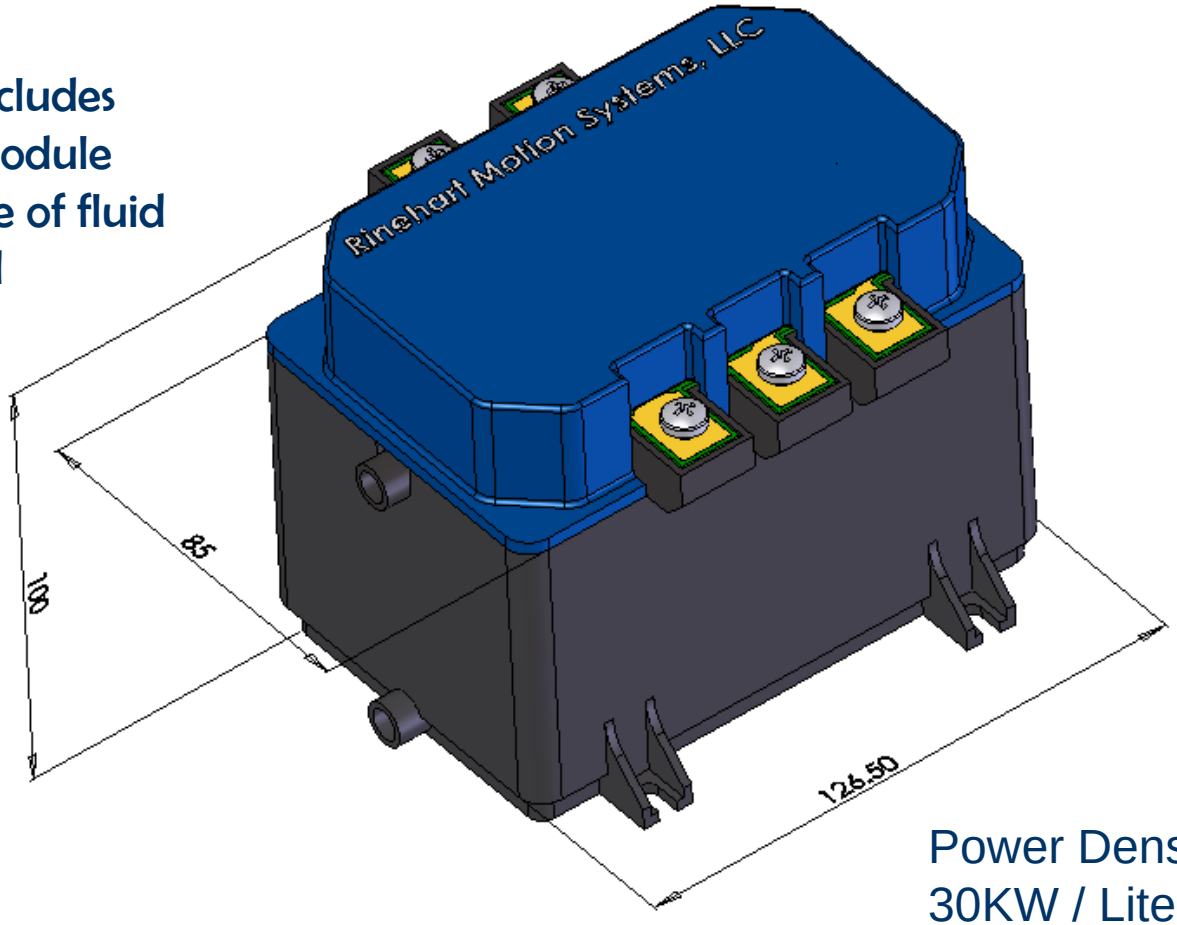
We started at the small end…



Estimated Size of the new Inverter

OVERALL DIMENSIONS: 85mm x 100mm x 126.5 mm = 1.07 liters

With a new concept that includes the Bus Capacitors in the module package, taking advantage of fluid cooling to decrease size and increase life



This system was not built, as customer demand was for higher power in HEV

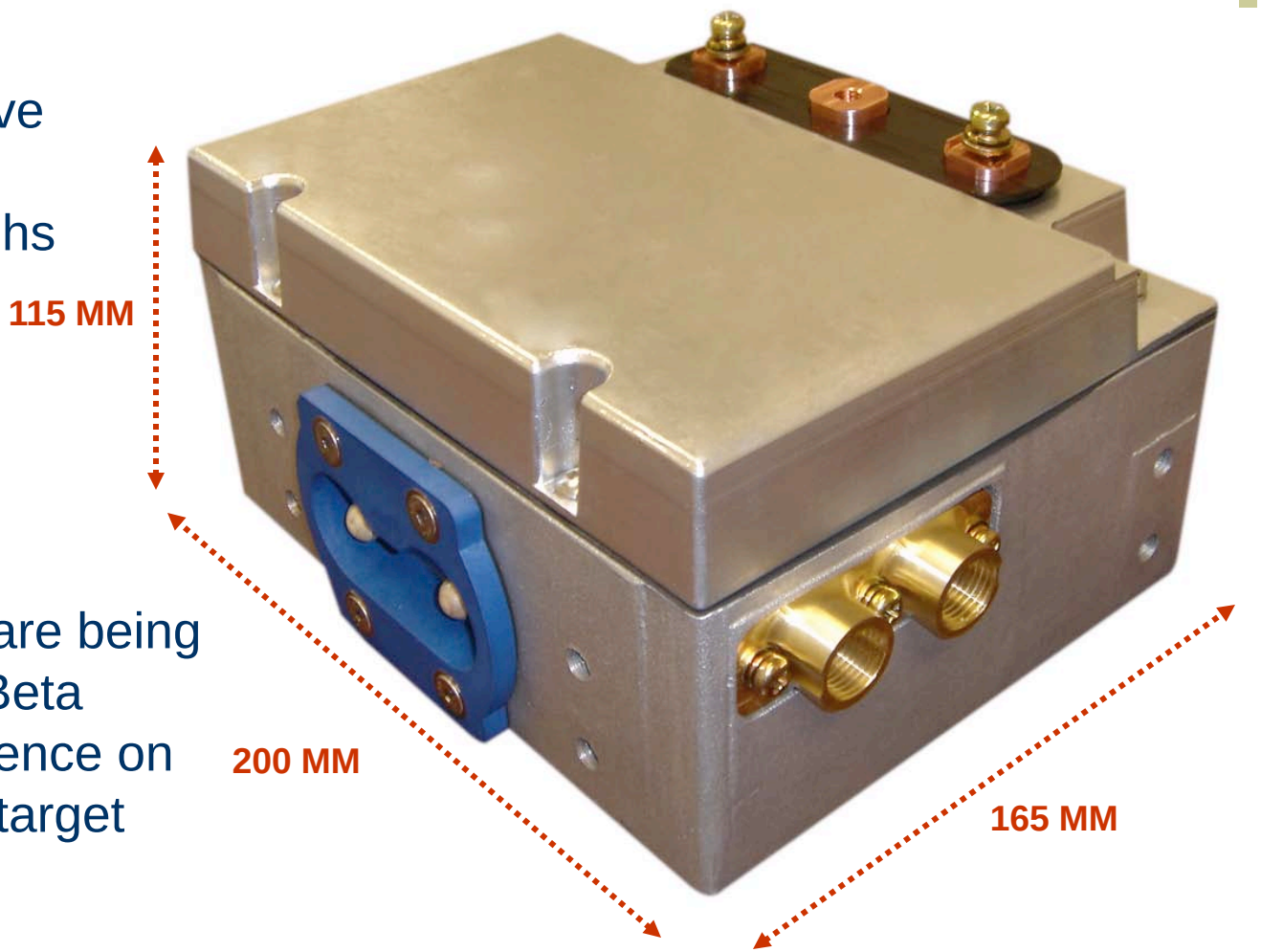
Power Density
30KW / Liter

Have progressed to 100kW

This Traction Drive occupies 3.5l of volume and weighs 6.5kg:

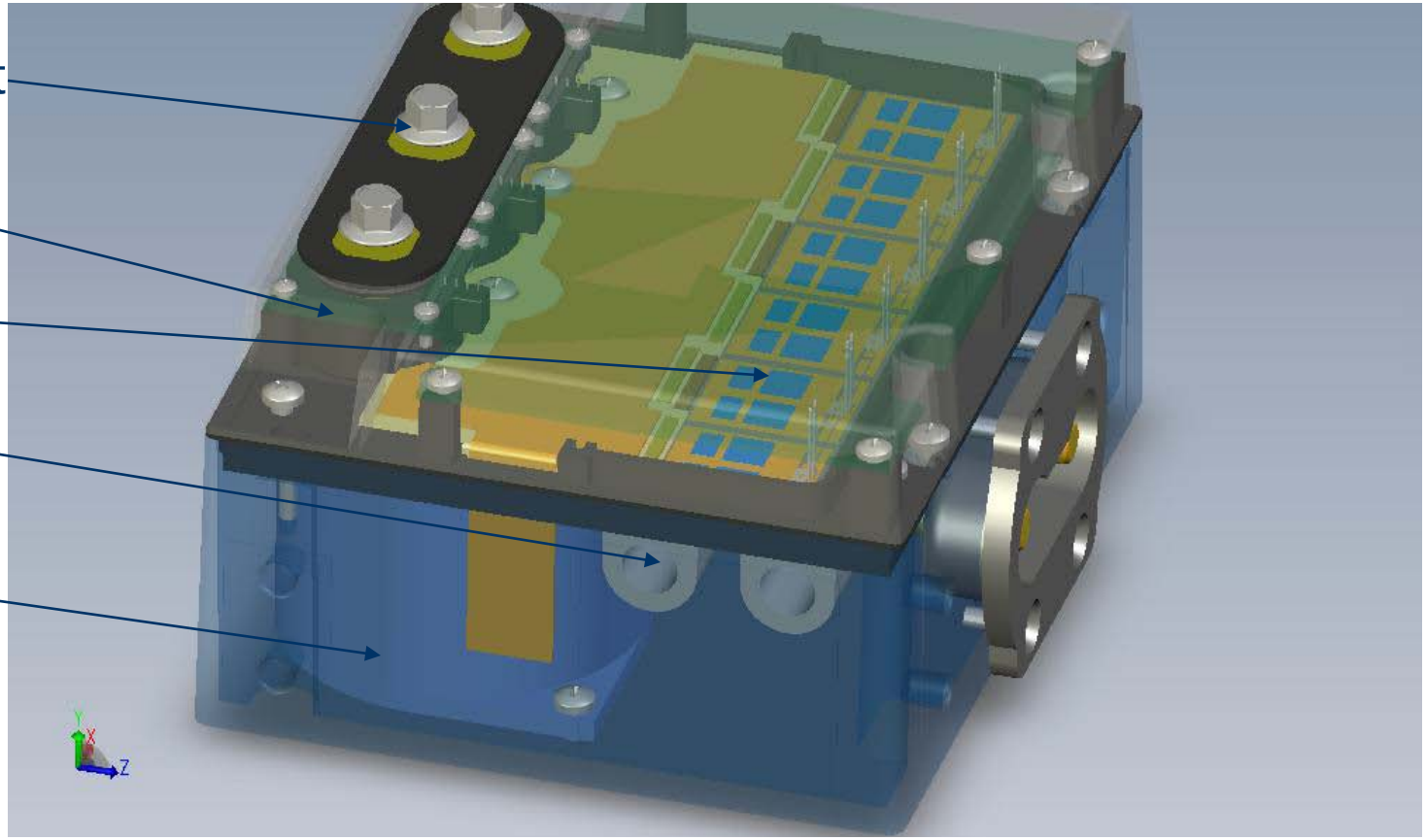
28 kW/l

16 kW/kg



Initial prototypes are being assembled, and Beta testing will commence on delivery to 3 or 4 target customers 2/07

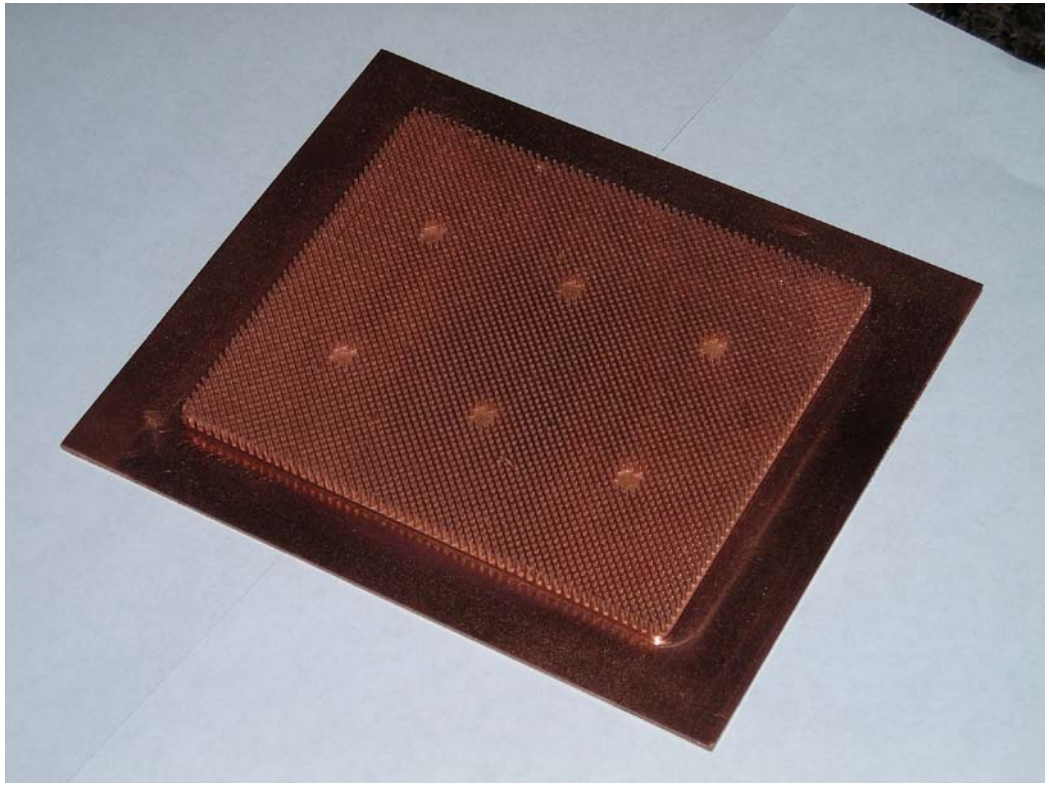
Complete Traction Drive for HEV



500kW Traction Drive Heat Exchanger

144mm x 122mm Cu base with >5,000 pin fins on a 2mm grid

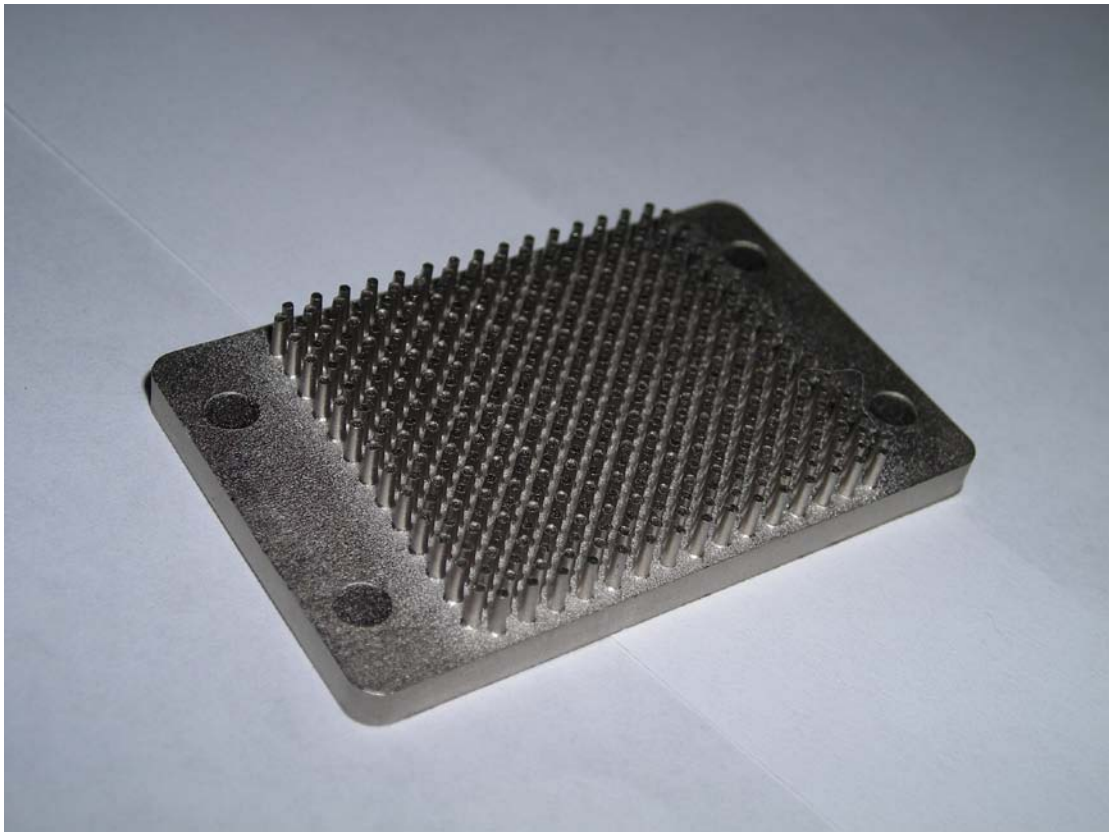
Removes more than 4kW of waste heat at 65oC temp rise



100kW HEV Module Heat Exchanger

46mm x 30mm Cu base. Pins are on a 2mm grid

450W of heat removal at 60oC temp rise



Summary

The INVERTER is the easy part - the Power Conversion System for an Energy Storage application is considerably more complex...

Paying customers are have been difficult to find for Storage System Inverter hardware

The US Military has become the early adopter, with 5 or 6 applications in Manned and UnManned Hybrid Ground Vehicles

- RMS will have booked in excess of $1M in contracts by year end

Commercial HEVs have become a target for the technology

RMS can achieve 3x the volumetric and 2x the mass density metrics that FreedomCAR has set for 2015 (assuming sufficient future funding)

- Engaging with FreedomCAR has proven difficult
- Presently negotiating a license with one of the major US semiconductor suppliers
- Will offer this drive to the smaller entities, for early beta test ~Feb 2007
- Presently engaging with EV, HEV and FCV Bus suppliers for 200kW drives

We would like to thank Dr. Imre Gyuk and the DOE Energy Storage Program for continued financial support; and Stan Atcitty and Sandia National Labs for the technical support that has allowed this program to succeed.