Providing Vehicle OEMs Flexible Scale to Accelerate Adoption of Electric Drive Vehicles

Principle Investigator: Jeremiah Shives  
Presenter: Dane Carter

Remy Inc.

Date: May 10th, 2011  
Project ID: ARRAVT025

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Overview

Timeline
Start: December 17th, 2009
End: December 16, 2013
Status: Approx. 24% complete

Barriers and Risks
• Market Acceptance Timing
• Manufacturing Expansion
• Supply
• Application Integration

Budget
Total: $120,400,000
DOE Share: $60,200,000
Contractor Share: $60,200,000

Partners (subawardee)
Phoenix International
(division of John Deere)
Project Lead: Kevin Larson
Objectives

• Accelerate the adoption and use of electric drive vehicles in the market by developing a standardized platform of lower cost, higher performance hybrid electric motors and controls

• Invest in the expansion or refurbishment of U.S. based manufacturing facilities, as well as new product tooling and engineering, production and test equipment, and product commercialization
Approach

Technical Feasibility:
• The new motor and inverter products proposed in the project are based on an extension of existing product and process technology.

• Remy has been producing rotating electrical products for over 100 years and hybrid electric drive motors since 2003.

• Phoenix has been producing electronic controls for over 20 years.

Ability to Complete Facility:
• Manufacturing processes, including site expansions and supply chain management, are well-established at both Remy and Phoenix International.

• Phase I of the project began with the refurbishment of existing facilities to support initial production capacity.

• Phase II of the project includes the addition of capacity in a second existing facility to support high volume production.
Approach

Ability to Deliver Commercial Ready Product:
• For this project, many of the target customers are Remy’s existing customers in both the automotive and heavy duty market where Remy has the leading share of rotating electrical products in North America.

• These customers have been very enthusiastic regarding Remy’s new approach to reduce costs through creating a family of standardized electric drive motors, and have launched new product development efforts with Remy.

Ability to Estimate Costs:
• Remy’s facilities planning group continues to provide direction for the manufacturing site costs based on several previous plant relocations in the United States.

• Phoenix International has very current costs for site expansion and equipment having commissioned a new power electronics facility in January of 2009.

• New product designs are extensions of existing products.

• Material prices are reviewed by global purchasing and supplier quality teams at both companies.
Approach

Ability to Recycle:
• Remy is the largest U.S. remanufacturer of starter and alternator products, recycling and refurbishing 4 to 5 million units per year in its two U.S. facilities in Virginia and Oklahoma.

• Planning for such recycling of hybrid motors is already underway in joint meetings between Remy, its customers, and its suppliers.

• Remy has standard workflow procedures in all of its manufacturing operations which define and control the segregation and recycling of various scrap raw materials used in its process, including byproduct materials and nonconforming products.

• Phoenix International’s recycling plan is to leverage Remy’s existing capability in the product recycling area.

• If re-manufacturing is called for, the inverter parts could be returned to Phoenix facilities for rebuild or Phoenix could supply the required subcomponents back to Remy to facilitate the remanufacturing.

• In cases where scrapping of the inverter is called for; the housing and bus bar metals are recyclable.
Approach

Environmental Impact:
• Existing facilities are being utilized for all phases of the project so that no new construction will be required.

• Phase 1 production does not require any new environmental permits.

Phase 1 Manufacturing Facility
This project has helped to fund 152 direct jobs at Remy and our sub-awardees.

Another 730 jobs are estimated to have been funded at our suppliers and vendors.

### Key Milestones for 2010

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Stage Motor Hardware Available</td>
<td>COMPLETE</td>
</tr>
<tr>
<td>Phase 1 Production Facility Complete (Low Volume)</td>
<td>COMPLETE</td>
</tr>
<tr>
<td>Inverter 1 Rev 1 Hardware Available</td>
<td>COMPLETE</td>
</tr>
<tr>
<td>Inverter 2 Rev 1 Hardware Available</td>
<td>COMPLETE</td>
</tr>
</tbody>
</table>
Production Intent Design Motor Samples:
Multiple configurations of the HVH410 and HVH250 motors have been produced.

Configurations include:
• Oil Cooling
• Water Cooling
• 3 motor lengths
• Multiple Winding Patterns
• Customer Specific Assemblies
Technical Accomplishments and Progress

Production Intent Design Samples:
• Sample motors have been tested to meet initial performance and durability targets.
• Validation to customer specific specifications has also been complete.

Motor Test Stands
Technical Accomplishments and Progress

**Specifications**

<table>
<thead>
<tr>
<th>Measurements</th>
<th>HVH10-075-FOCS</th>
<th>HVH10-150-FOCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Length (mm)</td>
<td>125</td>
<td>210</td>
</tr>
<tr>
<td>Stator Outside Diameter (mm)</td>
<td>410</td>
<td>410</td>
</tr>
<tr>
<td>Rotor Inside Diameter (mm)</td>
<td>289</td>
<td>289</td>
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<tr>
<td>Mass Complete Motor (kg)</td>
<td>59</td>
<td>91</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Performance</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Continuous Power Output (kW)</td>
<td>92</td>
<td>185</td>
</tr>
<tr>
<td>Peak Power Output (kW)</td>
<td>133</td>
<td>275</td>
</tr>
<tr>
<td>Continuous Torque Output (N-m)</td>
<td>580</td>
<td>1110</td>
</tr>
<tr>
<td>Peak Torque Output (N-m)</td>
<td>830</td>
<td>1670</td>
</tr>
<tr>
<td>Max Input Current Continuous/Peak (Amps)</td>
<td>240/480</td>
<td>240/480</td>
</tr>
<tr>
<td>Peak Efficiency (%)</td>
<td>See Efficiency Map</td>
<td>See Efficiency Map</td>
</tr>
<tr>
<td>Max. Operating Speed (rpm)</td>
<td>6,000</td>
<td>6,000</td>
</tr>
<tr>
<td>Base Speed (rpm)</td>
<td>1750</td>
<td>1750</td>
</tr>
<tr>
<td>Operating Voltage (VDC nom.)</td>
<td>650</td>
<td>650</td>
</tr>
<tr>
<td>Max. Temperature Limit</td>
<td>CLASS H (180°C)</td>
<td>CLASS H (180°C)</td>
</tr>
<tr>
<td>Internal Oil (ATF) Cooling</td>
<td>70°C Oil Inlet Temperature</td>
<td></td>
</tr>
<tr>
<td>Conductor Type</td>
<td>High Voltage Hairpin</td>
<td>High Voltage Hairpin</td>
</tr>
</tbody>
</table>

1. Continuous data reflects stator temperature held at 180°C and 70°C oil flowing at 10 LPM.
2. Actual performance dependent on application and cooling system.
3. Inverter control method is six-step for peak performance, and space vector for continuous performance. 5% voltage drop allowance.
4. Remy Motors insulation system can operate at 700VDC.
5. Optional content available: resolvers, housings, AC induction motor, & high-speed motor.
6. Other vector type configurations are available, consult your nearest representative.

Optional Content Available: Resolver, Housings

Based on active magnetic material.

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**Patented Hairpin Stator technology.**
Highest output, efficiency and power density available.

**HVV410 Standard Performance (600 VDC)**

**HVV410-075 Efficiency Map @ 650Vbus**

Efficiencies recorded at temperature of 140°C. Lower temperatures would yield higher efficiencies.
# Technical Accomplishments and Progress

## Specifications

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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Overall Length (mm)</td>
<td>147</td>
<td>180</td>
<td>147</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Stator Outside Diameter (mm)</td>
<td>242</td>
<td>242</td>
<td>242</td>
<td>242</td>
<td>242</td>
</tr>
<tr>
<td>Rotor Inside Diameter (mm)</td>
<td>132</td>
<td>132</td>
<td>132</td>
<td>132</td>
<td>132</td>
</tr>
<tr>
<td>Mass (Complete Motor) (kg)</td>
<td>43</td>
<td>43</td>
<td>33.5</td>
<td>43</td>
<td>43</td>
</tr>
</tbody>
</table>

### Performance

| Continuous Power Output (kW)            | 60                                               | 63                                               | 176                                              | 185                                              |
| Peak Power Output (kW)                  | 76                                               | 78                                               | 297                                              | 305                                              |
| Continuous Torque Output (N·m)          | 275                                              | 325                                              | 225                                              | 288                                              |
| Peak Torque Output (N·m)                | 320                                              | 408                                              | 320                                              | 408                                              |
| Max. Input Current Continuous/Peak (Amps)| 200/300                                          | 200/300                                          | 300/600                                          | 300/600                                          |
| Peak Efficiency (%)                     | See Efficiency Map                               |                                                  |                                                  |                                                  |
| Max. Operating Speed (rpm)              | 10,600                                           |                                                  |                                                  |                                                  |
| Base Speed (rpm)                        | 2300                                             | 1600                                             | 4000                                             | 3000                                             |
| Operating Voltage (VDC num.)            | 320                                              | 650                                              |                                                  |                                                  |
| Max. Temperature Limit                  | CLASS H (180°C)                                  |                                                  |                                                  |                                                  |
| Internal Oil (ATF) Cooling              | 70°C Oil Inlet Temperature                       |                                                  |                                                  |                                                  |

1. Continuous data reflects stator temperature held at 180°C and 70°C oil flowing at 10 LPM
2. Actual performance dependent on application and cooling system.
3. Inverter control method is on-shelf for peak performance, and space vector for continuous performance - 9% voltage drop allowance.
4. Remy Motors run at 720VDC system voltage.
5. Optional content available: Resin/filled, water-cooled, housing, AC induction motor, and high-speed motor.
6. Other motor sizes/configurations available. Contact your Remy representative.

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**Standardized and scalable solutions for seamless customer integration.**

**Typical Production Motor Output Curves (HV250 Standard Configuration)**

- Torque
- Efficiency

**HV250-410-5 Efficiency Map @ 320Vbus**

Efficiencies recorded at temperature of 140°C. Lower temperatures would yield higher efficiencies.
Inverter Samples:
• Concept stage sample inverters have been produced by Phoenix International.

• Production intent design samples will be available Q2 2011.
Collaborations

Phoenix International:
• Remy has collaborated with Phoenix International as a subawardee to this grant.

• The inverters will be developed and put in production by Phoenix International at a location in Fargo, ND.

• The inverter sizes required will match the motor sizes needed in the marketplace.

• The motors and inverters are typically matched to various customer requirements such as peak power of the motor and available voltage of the DC source.

• Inverter development will follow the same typical steps as the motor development with the delivery of prototypes and production devices availability at the same time.

• This will provide the customer with a matched set of motor and inverter drive systems.
Future Work

2011:
• Complete development stage hardware validation for base motor and inverter products
• Expand production capacity at the Phase 1 facility
• Forecast market demand for additional production capacity

2012:
• Complete production stage hardware validation for base motor and inverter products
• Start production at Phase 1 production facility

2013:
• Expand production capacity to a Phase 2 facility based on market demand
### Future Work

<table>
<thead>
<tr>
<th>2010</th>
<th>2011</th>
<th></th>
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<tbody>
<tr>
<td>Oct</td>
<td>Nov</td>
<td>Dec</td>
<td>Jan</td>
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<td>Mar</td>
<td>Apr</td>
<td>May</td>
<td>Jun</td>
<td>Jul</td>
<td>Aug</td>
<td>Sep</td>
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- CV build and validation
- DV design iterations
- Customer application definitions

- DV component sourcing
- Phase I capability and capacity improvements

- Justification for Phase II capacity increase

- Continuous Improvement
- Introduction of new products

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**Go No/Go Decision Point:** Phase II facility will be required for capacity above 20K units per year.

**Challenges/Barriers:** Market maturity and volume forecasting. System integration for each application.
Summary

• Accelerating the adoption and use of electric drive vehicles in the market.

• Developing a standardized platform of lower cost, higher performance hybrid electric motors and controls.

• Building on the proven success of existing product and process technologies.

• Matching product features and production capacity to real market requirements.

• Delivering technical accomplishments on time.