Advanced In-Wheel Electric Propulsion Technology

April 2011
Introduction
Protean Electric: Company Overview

Protean Electric:

• Clean technology company
• Leading global supplier of in-wheel electric motor technology

Product Offering:

• In-wheel electric motor designed for high-volume manufacturing as simple, low cost solution, featuring built-in inverter and control electronics

Performance and Design Opportunities:

• Suitable for 2 and 4-wheel drive, commercial vehicles, pickups, SUVs and family passenger cars – vehicles customers prefer and OEMs profit from
**Company Overview**

<table>
<thead>
<tr>
<th>Corporate Structure</th>
<th>U.S. holding company, operating subsidiaries in UK, US and Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employees</td>
<td>83 (73 engineers)</td>
</tr>
<tr>
<td>Products</td>
<td>Protean Drive™ In-Wheel Motors with Integrated Inverter. System ECU (SECU) Independent Motor Control Software</td>
</tr>
<tr>
<td>Test Vehicles</td>
<td>Volvo ReCharge Plug-in SHEV Ford F150 EV Vauxhall Vivaro PHEV GAC Trumpchi EV</td>
</tr>
<tr>
<td>Funding to Date</td>
<td>Oak Investment Partners</td>
</tr>
</tbody>
</table>
Wheel Assembly – Exploded View

- Vehicle Suspension
- Stator
- Wheel Bearing
- Rotor
- Conventional Wheel Rim
- Coils and Power Electronics/Micro Inverters
- Permanent Magnets
### Protean Drive Power & Torque

#### Projected Performance

<table>
<thead>
<tr>
<th>PD18-3</th>
<th>Power (kW)</th>
<th>Torque (Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak/Continuous</td>
<td>81/64</td>
<td>800/500</td>
</tr>
<tr>
<td>Peak/Continuous</td>
<td>110/86</td>
<td>590/370</td>
</tr>
<tr>
<td>Diameter x Width</td>
<td>420 x 115</td>
<td>16.5 x 4.5 inches</td>
</tr>
<tr>
<td>Mass</td>
<td>31 kg</td>
<td>68 lbs</td>
</tr>
</tbody>
</table>

**380Vdc, inlet coolant @30 deg C, flow rate 8l/m**

---

www.proteanelectric.com
Unique Distributed Drive Architecture

Sub-Motor Architecture

Sub-Motors = Multiple autonomous motors each with its own micro-inverter and sharing a common rotor - Patent granted
System Control Architecture

Vehicle ECU (SECU)

Protean High-Integrity System Control Software. ISO26262 Process for Safety Certification

Accelerator, brake, gear select, vehicle speed, battery status etc.

Torque Demand

Motor 1
Motor 2
Motor 3
Motor 4

www.proteanelectric.com
Conventional IC Engine Vehicle Layout
Conventional Electric Vehicle Layout
Protean Drive Vehicle Layout

Protean Drive

Battery Pack

Protean Drive
Competitive Advantages
Key Advantages

○ **Power and Torque**
  - Unique patented distributed drive architecture
  - High torque direct-drive (no gearing)
  - Scalable to support wide range of vehicles

○ **Safety**
  - System redundancy through distributed architecture
  - Order of magnitude benefits compared to alternative solutions

○ **Packaging Integration**
  - No need for additional power electronics (inverter integrated in motor)
  - No need for additional mechanical components (e.g. gears, differential, drive-shafts)
**Key Advantages**

**Cost**
- Reduced part count for total vehicle
- Less complex, reduced assembly costs
- Total system equal to conventional drive train cost
- Enables new design paradigms for future EVs, further reducing costs

**Compatibility, Validation and Time to Market**
- Integrates easily into existing vehicle platforms, limited chassis modifications
- Through-the-road hybrid (TTRH) configurations for light commercial and performance vehicle applications
- Selectable driving modes (conventional ICE, blended and EV) addresses market concerns over reliability, performance and range
### Key Advantages

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Protean</th>
<th>Competitors</th>
</tr>
</thead>
</table>
| Torque Density       | - 26Nm/kg & 53Nm/l for motor + inverter  
                    | - Highest torque density EV motor available                                                      | UQM 6Nm/kg; 13Nm/l  
                    |                                                                                                 | ACP 5Nm/kg; 5.5Nm/l |
| In-wheel             | - Designed for in-wheel deployment                                                                | Not suitable for in-wheel deployment                                          |
| Direct Drive         | - No gearing required  
                    | - Reduced part count  
                    | - Improved safety and reliability                                                           | Gearing required to increase torque |
| Safety               | - ISO26262 functional safety  
                    | - Multiple levels of redundancy  
                    | - No single failure can cause unsafe condition (enabled by sub-motor architecture)      | No known competitor offers ISO26262 safety compliance for multi-motor applications and no clear way for standard 3-phase motors to achieve this. |
| Integrated electronics| - Enables sub-motor modularity  
                    | - Compatibility with volume production processes                                                 | Separate inverter with no sub-motor modularity; large power components not compatible with automated production |
| Ease of Use          | - Can be fitted to existing vehicle platforms                                                    | Major vehicle tear-up required for retrofit                                         |
| Patent Protected     | - Broad patent portfolio                                                                          | Little innovation in core motor technology                                         |
**Packaging: Fully-Integrated Solution**

<table>
<thead>
<tr>
<th>Conventional Solution</th>
<th>Protean Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>2WD Drive-train Volume (litres)</td>
<td>92.08 (in chassis)</td>
</tr>
<tr>
<td>2WD Drive-train Weight</td>
<td>110kg</td>
</tr>
</tbody>
</table>

**Separate power electronics**
7.3” x 12.3” x 30”

**In-board motor**
12" diameter x 15” deep

**Integrated power electronics**
8 units, 3” x 2.5” x 0.5” each

**In-wheel motor**
16.5” diameter x 4.5” deep
Packaging: It Fits with Room To Spare

Conventional Solution

Motor  Gearbox & Differential  Driveshaft

Protean Electric

Protean Drive™ motor with Integrated Inverter and control electronics

AC Propulsion power electronics (AC Propulsion test vehicle)

Protean Electric in-wheel motors (Volvo ReCharge)

www.proteanelectric.com
Development History
New Technology?

- 1898 Ferdinand Porsche designs the first hub motor driven car
- Fleet of 300 electric delivery vehicles, all using in-wheel motors
- 1901 Lohmer-Porsche race car – 4Wd electric using in-wheel motors

Hybrid car with electric motors in the wheels, and Porsche’s 1901 race car of similar design
Company History

1963
Company Established, pioneered printed armature motors

1989
Developed powered wheelchair motors and controllers

2001
Focus on high performance motors and drives

2003
Development focuses on wheelmotor technology

2004
First PML multi-wheel wheelmotor driven vehicle

2006
First public debut of the Hi-Pa Drive™ technology

2007
First Hi-Pa Drive™ equipped OEM vehicle shown to the public
2008
Wheelmotor development continues

2009
PML Flightlink splits

2009
New UK Protean Electric development centre

2010
New CEO, Expansion into US & Germany

2011.....
Example Vehicle Applications
**Example Vehicle Applications**

- **You don’t have to be small to be green!**
- **Complete range of family sized vehicles sedans, SUVs, light commercial and pick-up trucks, all profitable for OEMs**
- **Supports plug-in SHEVs, PHEVs, BEVs, Through-the-Road Hybrids**

---

### GAC Trumpchi
- 2WD EV
- 2 Protean In-Wheel motors
- Gross vehicle weight: 1,495kg (3,300 lb)

### Volvo ReCharge
- Plug in SHEV
- 4 Protean In-Wheel motors
- Gross vehicle weight: 1,640kg (3,616 lb)

### Ford F150
- BEV
- 4 Protean In-Wheel motors
- Gross vehicle weight: 2,472kg (5,450 lb)

### Vauxhall Vivaro
- Through -The-Road Hybrid
- 2 Protean In-Wheel motors
- Gross vehicle weight: 2,700kg (5,953 lb)

---

www.proteanelectric.com
GAC E-Trumpchi

- 2WD full electric drive vehicle version of the new GAC Trumpchi
- Uses 2 Protean Drive PD18 in-wheel motors
- Debuted at the 2010 Guangzhou Auto Show
- Gross vehicle weight: 1,495kg (3,300 lb)
- 220hp rear wheel drive all electric vehicle
Volvo ReCharge

- 4WD full electric drive vehicle conversion of a Volvo C30
- Uses 4 Protean Drive PD18 in-wheel motors
- Debuted on Volvo’s stand at the 2007 Frankfurt Motor Show
- Gross vehicle weight: 1,640kg (3616 lb).
- 0-60 mph in 5 seconds, over 130 mph top speed
Example Vehicle Application - Volvo ReCharge
Ford F150 Pickup Truck

- Full electric vehicle conversion of 4 wheel drive F150 pickup truck
- Uses 4 Protean Drive PD18 in-wheel motors
- Debuted on Ford’s stand at the 2008 SEMA show
- Gross vehicle weight: 2,472kg (5,450 lb)
- 100mph top speed, over 100 mile range
Example Vehicle Application - Ford F150
Joint project between Protean Electric and Millbrook Proving Ground (GM’s UK vehicle testing and evaluation centre)

2 Protean Drive PD18’s mounted to the rear rear in a Through-The-Road-Hybrid (TTRH) layout - enabling a hybrid mode to be added to any existing vehicle

55 miles pure electric range, over a 3x increase in fuel economy (114mpg in hybrid mode)

Debuted at the 2010 Low Carbon Vehicle Show

Three driver-selectable operating modes.
• IC engine only (front wheel drive).
• EV only (rear wheel drive).
• IC engine + Electric motors (four wheel drive).
Example Vehicle Application - Vauxhall Vivaro TTRH
Challenges
Challenges

Technology Development
- Torque density
- Motor control
- Packaging
- Software integration
- Environmental protection
- Brake integration
- Vibration resistance
- ABS, TC, stability control
- Torque/speed profile
- Design for manufacture

Customer Acceptance
- Unfamiliar technology
- Not invented here
- Ingrained prejudices
- Conservative industry
- Extremely large companies
- Established relationships
- Economic climate
- Time to Market

Company Development
- Funding
- Staff costs
- Time to market
- Rapid growth
- Personality conflicts
- Company culture
- Partner companies
- Economic climate
Solutions

Technology Development
- Experience
- Many iterations
- Testing
- Certification
- Specialists
- Improved design
- Time
- Partner Companies

Customer Acceptance
- Prove technology
- Demonstration vehicles
- Market reaction
- Internal champions
- Support at many levels
- Regulatory pressures
- Lack of choice
- Time

Company Development
- Culture shift
- Willing to accept change
- Pragmatism
- Commitment
- The right people
- Enthusiasm
The Potential
Concept Cars

Virtually every concept car being designed by today’s automotive designers and automotive design students use in-wheel motors...
www.proteanelectric.com

andrew.vallance@proteanelectric.com