Polaris Range EXtender Technology (REX)

National Defense Industrial Association
Joint Service Power Expo
Myrtle Beach, SC
May 5th, 2011
The Fuel Efficiency Problem

**ESR Index Established - 2008**

- Afghanistan: “…each gallon of fuel costs 7 gallons to transport”
- FOB use of fuel, 2004-2009: 50M to 500M gallons
- Fmr CIA Director Woolsey: “getting gas to an M1A1 in Fallujah…costs up to $100 a gallon or more”
- “70% of the tonnage delivered to deployed forces is fuel” – Rep. Roscoe Bartlett, R, MD
- Feb 2011 - PM-JLTV: Fully burdened cost of fuel in Afghanistan is $330/gallon
The Warfighter’s Load Problem

- Soldier Weight and Equipment Increases
- IEDs force supply lines off roads – aviation used to ship supplies
- “Clear and Hold” Strategy moves into more rugged terrain

- Combat Load in 1991: 60lbs; Today: 130lbs
- Batteries for a 3 week patrol, Marine Squad: 700lbs
- Doctrine in 1991: Air/Land, Force on Force; Today: Asymmetric, IED-laden LoCs, avoid the heavy vehicles on predictable roads of travel
Case Study: Military Use – ATV/UTVs

✓ 1992: 1st use of ATVs by the military
✓ 2002: TF Dagger requests 1st Militarized ATV
✓ 2007: 1st Militarized Side-by-Side Class Vehicle – IDF incorporates into TOE and Doctrine
✓ 2009: 1st Militarized strike / recon platform for JSOTF-A
✓ 2010: 1st Militarized LSEV
➢ 2011: The REX Technology
Convergence of the Problem Sets

- All-terrain, on/off-road, load bearing tactical vehicle
- Quiet, stealth modes
- Longer range (fossil & EV)
- Increased auxiliary power requirements
- Unmanned building block options
- Stand alone, dismounted power generation
- Quick, COTS technology with low fuel costs

The Polaris REX Technology
Emissions and Fuel economy
Trends in the Automotive Powertrains

- Emissions reduction and fuel economy needs are driving a fundamental shift in Internal Combustion Engine efficiency and power density

- Trend toward reduced emissions, same power from smaller engines

<table>
<thead>
<tr>
<th>Year</th>
<th>Model</th>
<th>Displacement</th>
<th>Horsepower</th>
<th>Torque (Ft lb)</th>
<th>Fuel Efficiency (mpg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Ford Triton V8</td>
<td>5.4 liter</td>
<td>310 hp</td>
<td>365</td>
<td>14/20</td>
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<tr>
<td>2011</td>
<td>Ford EcoBoost V6</td>
<td>3.5 liter</td>
<td>365 hp</td>
<td>420</td>
<td>16/22</td>
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<tr>
<td>Technical Path</td>
<td>Description</td>
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<td>--------------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Engine downsizing</td>
<td>- Reduced displacement and cylinder count</td>
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<tr>
<td>Turbocharging</td>
<td>- Increase power density</td>
<td></td>
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<tr>
<td>Driveline efficiency Increase</td>
<td>- Reduced parasitic losses for accessories</td>
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<tr>
<td>Engine start/stop capability</td>
<td>- Integrated starter/generators</td>
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<tr>
<td>Driveline electrification</td>
<td>- Battery powered electric vehicles</td>
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<tr>
<td></td>
<td>- Parallel and serial hybrids</td>
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Limitations on Electric Vehicle Utility

- Vehicle range is limited by battery capacity
- Vehicle utility is limited by recharging time
- Relatively poor power density for batteries
- No widespread recharging infrastructure
- Add-on cost of batteries
- Weight and packaging considerations of batteries
- Range Anxiety presents obstacle to increased adoption of electric vehicles for on-road use

Hybrids are a bridging technology between pure electric and internal combustion powered vehicles
Polaris REX Technology

- Combines advances in powertrain downsizing and efficiency with electric vehicle technology to increase vehicle utility
- Uses existing, proven technology
- Allows for the best combination of vehicle range and emission reduction and fuel efficiency
- Leverages existing fuel infrastructure for electric vehicles with ‘instant’ recharging capability
• Internal combustion engine is sized to handle transient acceleration loads
• Engine nearly as large as engine in traditional internal combustion powered vehicles
• Due to its size the engine runs in a low efficiency region for much of its operating range
• Engine size compounds vehicle packaging challenges
• Engine size increases vehicle cost
A New Approach

• Create a *battery dominant* hybrid electric vehicle
• Utilize battery for transient acceleration needs
• Size the engine to maintain battery SOC during steady-state driving
  – Incorporate aggressive regenerative braking strategy
• Utilize engine downsizing technology to provide best combination of high power density and small package size for the internal combustion engine
  – Engine maintains battery SOC only
  – Series hybrid
Technology Demonstrator

• Polaris REX technology demonstrator based on a European-market VW Polo
  – Up to 500 miles operating range
  – Emissions certification levels lower than a Chevy Volt or Toyota Prius
  – Aerodynamic improvements to reduce ‘pure losses’
  – Aggressive braking regeneration strategy
• Powertrain and battery pack is sized for the needs of typical duty cycle
• Transient acceleration needs are met with the battery
  – Partially recovered with regenerative braking
• REX generator sized to slightly exceed average vehicle power needs in typical usage
• No need for remote charging infrastructure
  – The existing gasoline infrastructure is utilized for ‘instant’ battery recharging via an on-board ICE REX recharging system
• On-board REX recharging system is downsized in displacement as much as possible to increase the efficiency, minimize emissions, and maximum fuel economy
• The battery capacity is reduced from that of a pure electric car since the REX system provides increased range.
• Battery capacity is sized to receive the maximum benefit from the ‘electric only’ range for the emissions certification.
• Battery reduction strategy also has the benefit of reducing cost and vehicle weight
Drive Strategy

- Vehicle drive power
- Bat Hold Mode

- REX OFF @ 25 km/h
- REX ON @ 45 km/h
Polaris Range Extender Package

- Single cylinder
- Integrated generator
- 325cc displacement
- 38 kg weight
- 22kW electrical output
- Port fuel injection
- Low friction design
- Compact space saving design
Polaris REX Engine

**INCREASED EFFICIENCY** - Nikasil cylinder coating for improved heat transfer and dormant state capability

**REDUCED FRICTION** - All rotating members mounted on roller bearings

**REDUCED WEIGHT** - Integrated crankshaft drive and mounting system for generator

**REDUCED PARASITIC LOSSES** - Crankshaft and cam chain distribute oil to cylinder head

**REDUCED PARASITIC LOSSES** - No oil pump

**LOWER EMISSIONS** - Oil sump preheated by drive motor coolant

**INCREASED EFFICIENCY** - Small 325cc displacement allows engine to run at its lowest consumption range

**REDUCED WEIGHT** - Generator acts as flywheel, dynamic balancer, and starter for engine
Application of REX technology to Off-Road Vehicles

- Technology demonstrator based on Polaris Ranger EV
- Utilize Polaris 22kW REX engine and generator
  - Relatively higher power needs due to poor aerodynamics and 4-wheel drive system
  - Drive strategy reconfigured for off-road use
- Results
  - 3X better fuel economy than gas powered Ranger 800
  - Up to 50 mph top speed
  - Reduced battery capacity
  - 10X driving range increase of base Ranger EV
Ranger Hybrid Operating Modes

- Three driving modes
  - Pure electric
    - Approximately 30 mile range depending on duty cycle
    - Reduced IR signature
    - Quiet operation
  - Extended range REX mode with power limit for fuel economy
  - REX mode with power boost for increased acceleration
- Stationary power generation mode
  - Up to 22kW power generation
    - Configurable in 12/24 V DC and 110/220 V AC
Future Developments

- V-twin gas engine for higher power needs
- Heavy fuel engines up to 45 hp
- Apply REX Hybrid concept to higher capability vehicle platforms
  - Ranger Crew
  - RZR 4
- Develop 300V applications for higher efficiency and generation capacity
Conclusion

• Problem Statements are clear!
  – Increase Efficiency
  – Increase Capability
  – Lighten the Load

• REX Offers a Polaris-solution, based on 16 years of work with the US and Worldwide Militaries and Special Forces

• Outside the Box thinking, rapid prototyping, and the use of COTS technology make this possible
Questions?

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