Polaris Range EXtender Technology (REX)

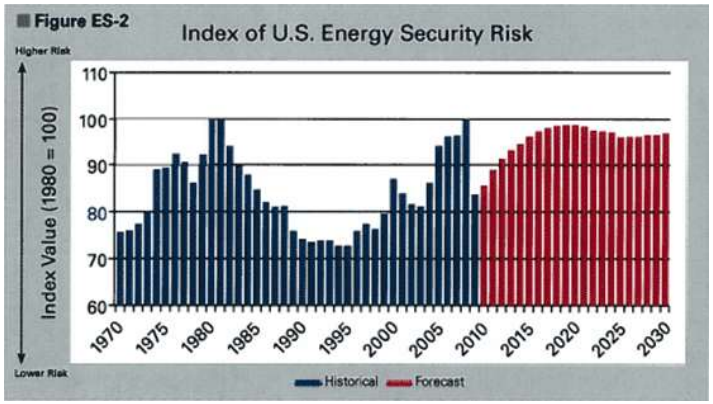
National Defense Industrial Association

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-6

Feb 2011 - PM-JLTV: Fully burdened cost of fuel in Afghanistan is $330/gallon

IMPACTS of Saving 1% Fuel

$5-82B
Fewer Dollars Spent on Fuel

6,444
Fewer Soldier Trips

37
Fewer Casualties

GEN Dunwoody, TWV Conference, 2011

The Warfighter's Load Problem

2001-ongoing

Soldier Weight and Equipment Increases

2005-2010

IEDs force supply lines off roads – aviation used to ship supplies

"Clear and Hold" Strategy moves into more rugged terrain

2007- Iraq;
2009 - Afghanistan




- **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

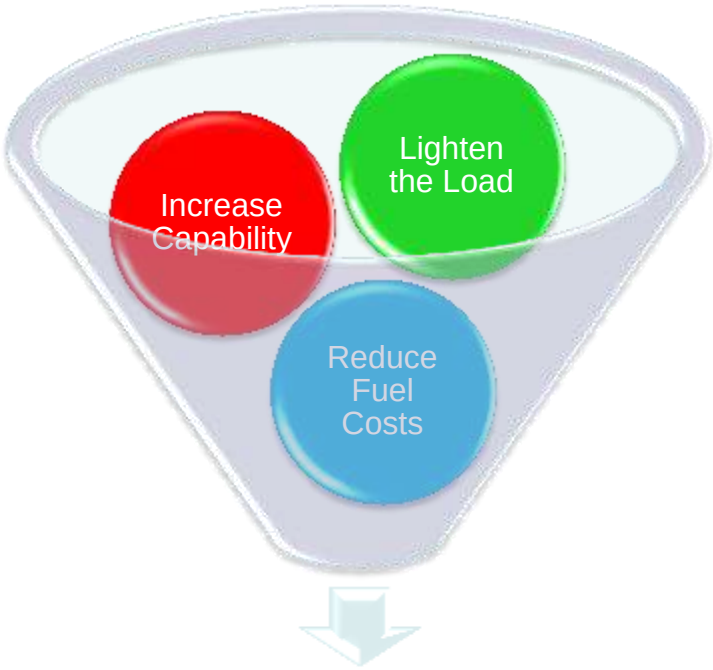
- ✓ 1992: 1st use of ATVs by the military
- ✓ 2002: TF Dagger requests 1st Militarized ATV
- ✓ 2007: 1st Militarized Side-by-Side Class Vehicle – IDF incorporates into TOE and Doctrine
- ✓ 2009: 1st Militarized strike / recon platform for JSOTF-A
- ✓ 2010: 1st Militarized LSEV
- ➢ 2011: The REX Technology






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



Highly mobile, capable and efficient platform

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

2010
Ford Triton V8
5.4 liter displacement
310 hp
365 Ft lb Torque
14/20 mpg

2011
Ford EcoBoost V6
3.5 liter displacement
365 hp
420 Ft lb Torque
16/22 mpg

Current Technical Paths to Reduce Emissions and Fuel Consumption

- Engine downsizing
  - Reduced displacement and cylinder count
- Turbocharging
  - Increase power density
- Driveline efficiency Increase
  - Reduced parasitic losses for accessories
  - Reduce friction in engine
- Engine start/stop capability
  - Integrated starter/generators
- Driveline electrification
  - Battery powered electric vehicles
  - Parallel and serial hybrids

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

A Better Bridge

Traditional Parallel Hybrids

- 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

Current Hybrid Solutions Tend to be *ENGINE DOMINANT*

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

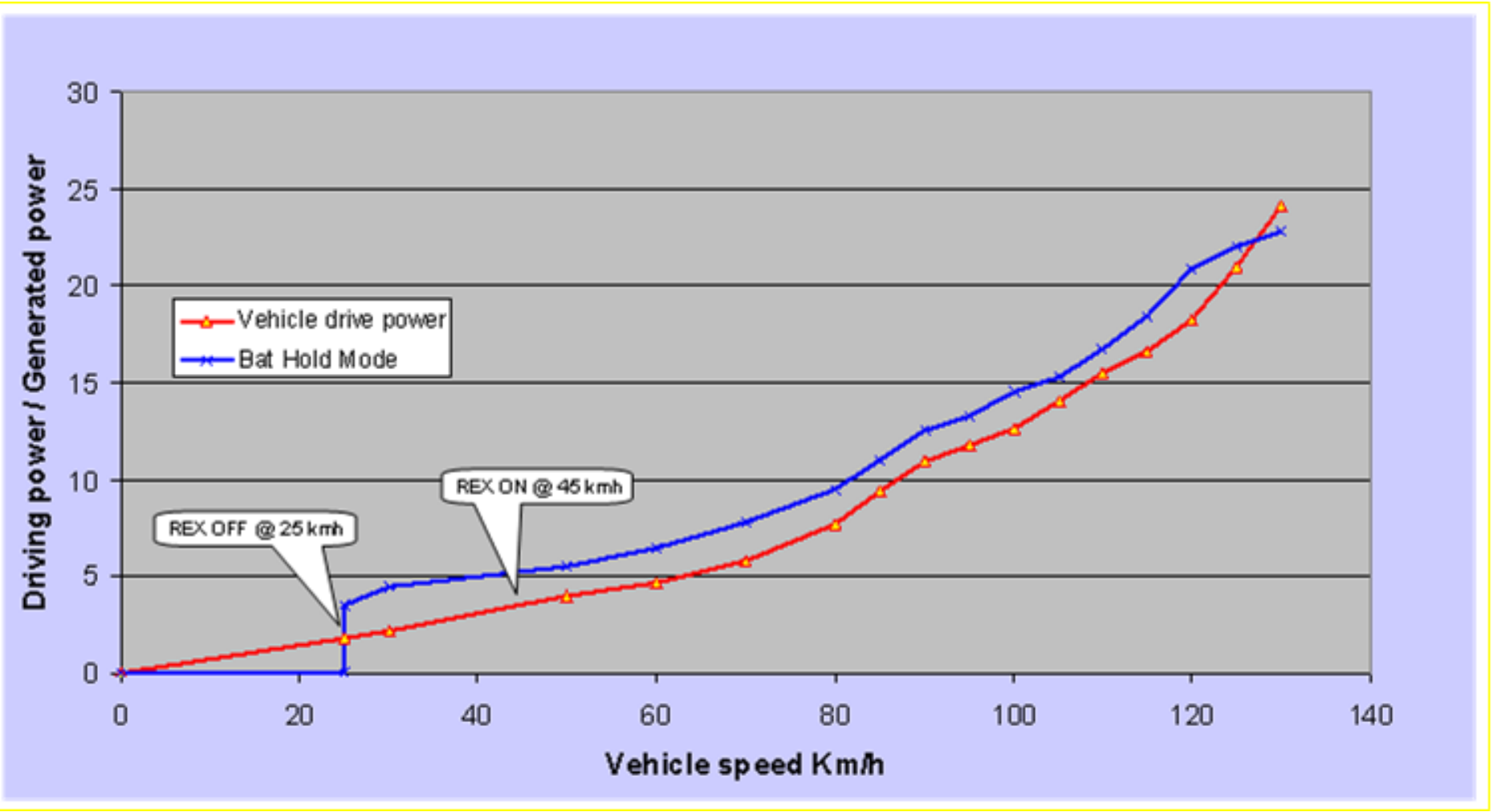
Technology Demonstrator

- 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

Polaris Electric Vehicle REX Strategy

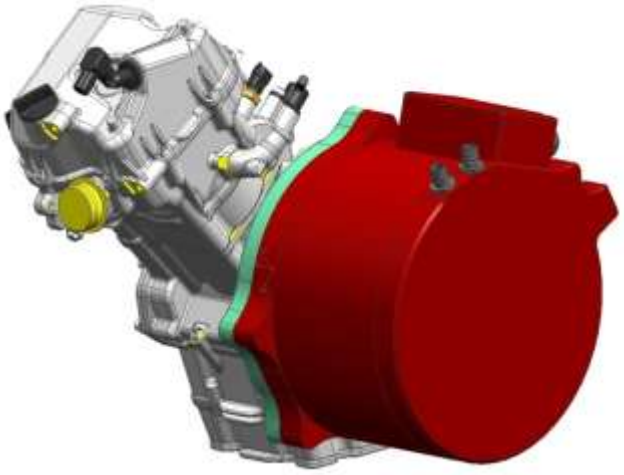
- Powertrain and battery pack is sized for the needs of typical duty cycle
- Transient acceleration needs are met with the battery
  - Partially recovered with regenerative braking
- REX generator sized to slightly exceed average vehicle power needs in typical usage
- No need for remote charging infrastructure
  - 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



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

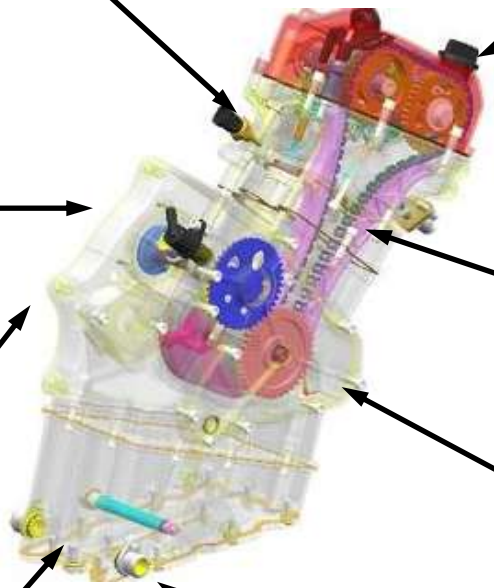


Polaris REX Engine

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 WEIGHT - Generator acts as flywheel, dynamic balancer, and starter for engine

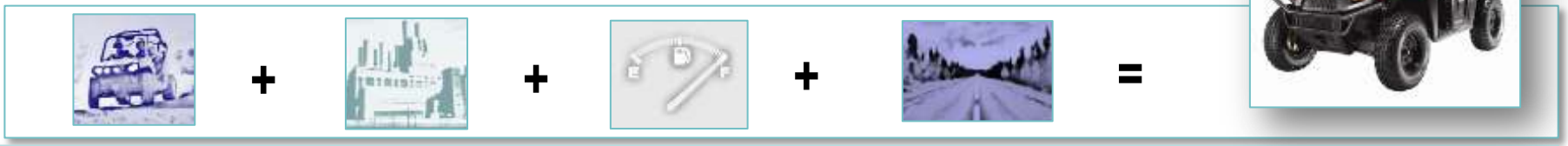
INCEASED EFFICIENCY - Small 325cc displacement allows engine to run at its lowest consumption range

REDUCED PARASITIC LOSSES - No oil pump

LOWER EMISSIONS – Oil sump preheated by drive motor coolant

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



Polaris Off-Road Capability + Stationary Power Generation + Fuel Economy + Extended Range = *RANGER™ Hybrid!*

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?

Mr. Stacey Stewart
Director, Powertrain
stacey.stewart@polarisind.com

Mr. Brian Gross
Program Lead, Engineering
brian.gross@polarisind.com

Mr. Patrick Weldon
Manager, Business Development
patrick.weldon@polarisind.com