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*Standard Form 298 (Rev. 8-98)*
Prescribed by ANSI Std Z39-18
# Agenda

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<tr>
<th>Item</th>
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<td>Welcome</td>
<td>Marta Tomkiw</td>
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<tr>
<td>TARDEC overview</td>
<td>Dr. Grace Bochenek</td>
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<tr>
<td>OnPoint Overview/ Background:</td>
<td>Mr. Jason Rottenberg</td>
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<td>Portfolio/who they are working with and why</td>
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<tr>
<td>Ground Vehicle Power &amp; Energy Strategy</td>
<td>Jennifer Hitchcock</td>
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<td>Hot topics:</td>
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<tr>
<td>On Board Power</td>
<td>Marta Tomkiw</td>
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<td>Energy Storage</td>
<td>Sonya Gargies</td>
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<tr>
<td>Common Modular Power Management System</td>
<td>Rakesh Patel</td>
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<td>Current program discussions</td>
<td>All</td>
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<td>Recap of any actions</td>
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**MISSION:** Provide full service life cycle engineering support to our TACOM LCMC Customers (PEO GCS, PEO CS&CSS, ILSC) and PM FCS (BCT), to develop and integrate the right technology solutions to improve the effectiveness of the current force and realize the superior capability of the future force to facilitate Army transformation.

**VISION:** Be the first choice of technology and engineering expertise for ground vehicle systems and support equipment – today and tomorrow.
Strategic Technology Areas

Power & Energy
- Advanced Power Systems
- Energy Storage
- Fuel Strategy

Vehicle Electronics
- On-board Prognostics/Diagnostics
- Condition-based Maintenance
- Logistics

Unmanned Ground Vehicle Robotics
- Robotic Follower
- Unmanned Ground Systems
- Small Unmanned Systems

Survivability
- Ballistic Protection
- Detection Avoidance
- Hit & Kill Avoidance

Wind and Solar Power Provide Electricity
Grid and Alternative Energy Generate H₂ via Electrolysis

TARDEC FOCUS
Performance Evaluation

**TARDEC DIRECTOR**

- Metrics
  - Technology Metrics
  - Business Performance Metrics
  - Workforce Development Metrics
- Technology Quality
- Responsiveness to Customer
  - Customer Feedback Surveys
  - Identified Focal Points for Daily Interaction
  - PEO Technology Summits
  - Continuous Interactive Feedback Process
  - Senior Scientists’ Role
  - Independent Tech Panels
  - Industry and Scientist Peer Review
  - Army Science Board “Rigorous” Review
TARDEC Power and Energy Thrusts

Power and Energy

Ground Vehicle Power & Energy

21st Century Basing
Hot Topics
Power Spectrum

- Electronics
- Residential
- Automotive
- Heavy Vehicle
- Marine
- Industrial
- Commercial Bldg.
- Locomotive
- Soldier Power
- Sensors, Unmanned Vehicles
- Vehcles Mobile Generators
- Ship Service Propulsion

Power Spectrum

- 10 W
- 100 W
- 1 KW
- 10 kW
- 100 KW
- 1 MW
- 10 MW
- 100 MW

TARDEC

Power, Watts

10

Climbs steep hills
Negotiates steep ditches
Organizational Thrust Areas

Advanced Power Systems
   Engine
   Fuel Cells
   Air, Thermal and Power Management
   Power Trains
   Non – Primary Power Systems (APU’s, On Board Power Generation)

Hybrid Electric and Energy Storage
   Drive Components (motors, generators)
   Power Electronics
   Energy Storage

Testing, Evaluation and Assessment
   Modeling and Simulation
   P&E SIL
   Electronic Architecture SIL
   Propulsion Lab, Air and Cooling Lab (Future Power and Energy Lab)
   Vehicle Testing and Experiments
Platform Power and Energy Needs – Initial Identification

**Abrams**
- Thermal Management
- IAPU with improved batteries

**Bradley**
- Engine up-power
  - Electric power/Electrical Power system upgrade
  - Improved double pin track
- Transmission

**Stryker**
- Power management

**M113**
- Mobility upgrade

**CS/CSS**
- JP8 & low sulphur engines
- Improved Power trains
- Improved oil/air filters
  - Hybrid drive systems
- Exportable Power
  - More power

**FCS**
- Hybrid Electric Development
- Power and Energy System Integration and Experiments
- Engine development

*From TG information 9/28/06*
Strategic Ground Vehicle Needs

Non-Primary Power
- Thermal
- Communications
- Survivability
- Etc...

Power Needs

Mobility

FY02 FY12

Estimated Electrical Power Growth

<table>
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<th>Year</th>
<th>Electrical Power (kw)</th>
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<td>Current</td>
<td>Future</td>
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<td>JLTV</td>
<td>FCS</td>
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Actual Growth 1985-2007
Objectives

• Develop an integrated strategy to meet the power and energy requirements of current and future modular force.

• Allows science and technology investments to be prioritized and focused on products that can transition.

• Allows program managers to plan and resource for technology insertion.

• Allows the development of the required people, tools and facilities.
Major Components

Strategy

- Workforce
- Requirements Analysis
- Facilities & Tools
- Projects
- P&E Conference
Requirements Analysis

- Linking technology development to requirements allows effective technology transition
- PEO-GCS, PEO-CS&CSS, PM FCS-BCT, JC-UGV are part of the strategy development team
- First version of Ground Vehicle P&E Strategy planned for 30 Apr 07
Requirements - Functional Decomposition

Ground Vehicle Power and Energy

Prime Power
- Engine
  - Diesel
  - Brayton
  - Otto
  - Stratified Charge
- Drivetrain
  - Electrical
  - Mechanical
  - Driveline Components
  - Mobility Components

Non Primary Power
- Diesel
- Turbine
- Fuel Cell
- Battery
- Generators

Energy Storage
- Batteries
- Capacitors
- Flywheels
- Fuels

Power & Thermal Management
- Power Management
  - Power Generation
  - Energy Storage
  - Power/Thermal Control & Distribution
- Thermal Management
  - Power Plant Cooling
  - Power-Electronics Cooling
  - Climate Control
Power & Energy Thrust Areas

**Advanced Power Systems**
- Engine
- Fuel Cells
- Air, Thermal and Power Management
- Power Trains
- Non – Primary Power Systems
  (APU’s, On Board Power Generation)

**Hybrid Electric and Energy Storage**
- Drive Components (motors, generators)
- Power Electronics
- Energy Storage

**Track and Suspension**
- Lightweight track
- Elastomer Research
- Advanced suspension

**Testing, Evaluation and Assessment**
- Modeling and Simulation
- P&E SIL
- Electronic Architecture SIL
- Propulsion Lab, Air and Cooling Lab
  (Future Power and Energy Lab)
- Track Research Lab
- Vehicle Testing and Experiments

Key Platforms

- PM FCS
- Robotic
- PEO-GCS
- PEO-CS/CSS

Key Power & Energy Technologies for Robotics

- PEM, SOFC Fuel Cells
- System and Component Thermal Management
- Power monitoring, improved diagnostics,
  fault management,
  automatic/semi automatic load control,
  Auxiliary Power to include
  small IC engine, small generators

- Drive Motors/Generators
- Converters/Inverters
- Advanced Batteries
  (Li-ion,Ni-mh)
- Capacitors

- Band Track
- Hybrid Steel Track
- MR Suspension
- Semi Active Suspension

- Mobility M&S
  Laboratory and vehicle
  Evaluation and testing
Workforce, Facilities & Tools

- Developing workforce to provide P&E support to LCMC
- Define and develop tools to execute P&E strategy
- Approved MILCON support strategic thrusts for P&E
  - Fuel Cells
  - Power Management
  - Thermal Management
  - Pulse Power
  - Tactical Vehicle Mobility
How can you help us?

Oversight on the P&E Strategy development

Assist in identifying solutions to our “gapped” technologies

Where is our current investment strategy at risk?

How could we mitigate the risk?
On-Board Vehicle Power

OnPoint Technologies Visit
28 February 2007

Ms. Marta Tomkiw
Team Leader of Power
**System Engineering Approach to the solution**

**Establish System Power Requirements**
- Comprehensive systems list developed
  - Electrical loads determined
    - Peak, nominal, standby (amps)
    - Voltage (DC or AC 50/60/400Hz)
  - Data provided by system "owners"
  - Focus on designated platform

**Identify “System of Systems” Power Requirements**
- Determine realistic power reqms (peak vs nominal vs standby)
- Simultaneous operations
- Assume “worst case” required loads
- On-board batteries support short duration power spikes (common approach)
  - Supplemental battery charging
  - Actual combinations of systems “UNKNOWN”

**Power Requirements**
- Minimums – **155 amps**

**Identify “System of Systems” Power Requirements**

**Decision Factors**
- Amps generated
- Environmental impacts
- Excess capacity
- Complexity (# of mods reqd)
- Availability in Army system
- Schedule & technical risk
- Development cost
- Acquisition cost (Operational
  - (impact on soldiers)
- Potential for spiral improvements

**Determine Feasible Hardware Solution Sets**
- Variety of Alternator upgrades
- Fielded items:
  - 260A: Pending use on FMTV
  - 280A: Used on Stryker
  - 400A: Used on other HMMWV
- Alternate item
  - Fisher 400 V
  - Dual VI PER (Lockheed Martin)
  - USMC 30kW OBVP program
- Combinations of:
  - Standard or enhanced pulley ratios
  - Standard or high idle

**Recommended Solutions**

**Consensus Review**
VRLA Batteries

• 6TMF used on 95% of the Army’s Vehicles

• A 6T size, VRLA battery looks to be the next step in offering the soldier improved power in support of on going upgrades

• VRLA will offer the following:

Advantages:
- Maintenance Free
- Air shippable
- Life Cycle laboratory simulation testing at TARDEC has shown nearly 2X the life value
- Improved Deep Cycle Capability

Disadvantages:
- Increased Weight (+14 lbs per battery)
- Sensitivity to recharging – easily overcharged and damaged
- Currently @ 2.5 X the cost
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<th>VRLA</th>
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<td>40.5 kg max</td>
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<td>(discharge time to 7.2 volts)</td>
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<td>725 amp 30 sec</td>
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<td>Retention of Charge: (min)</td>
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<td>Deep cycle capacity (min)</td>
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Energy Storage Research
Team Projects

OnPoint Technologies Visit
28 February 2007

Ms. Sonya Gargies
Team Leader of Energy Storage
**Program: High Energy Lithium Ion Manufacturing Technology Program**
- High power, high energy Li-ion battery pack production for HEVs
- $115K per 30kW-hr pack (per vehicle) to $58K
- Accelerate the technology and automate the manufacturing process
- Parallel ATO will improve the technology in temperature stability, improve safety and performance and develop enhanced materials. (FCS Energy Density: >120 Wh/Kg, Power Density: 1-2 kW/Kg @ 2sec, Cycle Life (50% DoD) > 10,000, Temp: -40°C/+65°C)
- MTO will produce affordable battery packs for HEV dash mobility, silent watch, and pulse power for weapons.

**Program: SAFT Prismatic Lithium-ion batteries and Integrated Liquid Cooling**
- Develop prismatic lithium-ion cells that are optimized for liquid cooling.
- Investigate and implement a liquid cooled Li-ion battery module using the high energy and high power VL30P cells (from MTO development) and develop flat would prismatic cells.
- Demonstrate feasibility of managing the heat transfer
- Extend operating temperature range
**Program: TJ Technologies LFP**
- R&D project targeted towards a new energy storage cathode material Lithium-iron phosphate (LFP).
- A new material is being investigated and scaled up for hybrid electric vehicle applications to improve safety and performance for lighter, more affordable batteries.
- LFP module will be scaled up and the batteries will be put in a module for testing and evaluation.
- Improve safety and reliability of lithium-ion batteries, and expand operational temperature ranges.

**Program: AeroVironment Battery Architectures**
- Develop, build, and test an advanced configuration hybrid energy module.
- Various architectures will be investigated along with a hybrid module with integrated dc-dc converters for power management control between the two sources of power and energy.
- Architecture will be compared with battery-only and/or ultra capacitors only systems and determine the feasibility of energy storage architectures.
**Program: Quallion Matrix Design (small cells)**
- Investigate the feasibility of a hybrid battery matrix composed of small D-sized cells for use in HEVs.
- Matrix battery packs will be composed of two types of cells (high power and high energy) and will be tested and evaluated after build of modules.
- This study demonstrates the feasibility of using smaller capacity cells for propulsion system.

**Program: Testing and Evaluation of Li-Ion battery pack in a HE-HMMWV**
- There are current tests being conducted on the HE-HMMWV in Aberdeen, MD with Lithium-ion battery packs.
- The vehicle will undergo many tests using a 15kW-hr battery pack.
Activity: Live Fire Battery Testing
- Live fire testing is being carried out by ARL on cells and packs from various battery suppliers.

Activity: Thermal Runaway (Bulgaria)
- The Bulgarian Academy of Sciences is assisting the US Army with the study of thermal runaway in lead acid batteries.

Activity: Abuse testing on small Li-Ion Batteries (CERDEC and Rutgers University)
- We are being assisted in the study of the thermal runaway effect in Lithium ion batteries by the staff at CERDEC with the cooperation of Rutgers University.
- CERDEC has the facilities to handle the destructive testing of Lithium cells.
- They have substantial experience with small lithium ion batteries by virtue of their long involvement with the Land Warrior Program.

Activity: Research Calorimeter (Rutgers U.)
- Rutgers University is building two calorimeters for us for making the essential thermal measurements for lithium ion modules.

Activity: Module Test Rig Development
- A test rig is being designed, integrated with the research calorimeter and built to allow local testing of the basic battery modules that are the building blocks of the full size battery pack.
Proposed Efforts/Long Term Objectives

**Zebra Battery**
- This is the highest energy density battery that is currently in pilot production in the UK. Since it is a fused salt battery, operation requires that the battery be maintained in a heated condition.

**NiMH**
- NiMH is the first fall back position after the Lithium Ion battery chemistry. It has a water based electrolyte system which makes it safer and can operate at lower temperatures.

**High Capacity Li-Ion Modules for APU Application**

**Advanced Lead Acid**
- Lead acid is the ultimate fall back position.

**Ni-Cd**
- Nickel cadmium batteries follow NiMH batteries in energy density. They are manufactured in a variety of cell sizes and have excellent low temperature performance.

**NiZn**
- Developments in the NiZn technology suggest longer cycle life is at hand. Energy density slightly lower than Lithium Ion but higher than Nickel Metal Hydride. Projected costs are at the high end of the lead acid batteries.
• Thermal Runaway (the fundamental process and its control)

• Cell Design Optimization
  – Power vs. Energy Trade-off
  – Cell Configuration
  – Manufacturing process development and cost control
  – Cell Safety & Reliability

• Battery Architecture Optimization
  – System energy vs. Power Optimization
  – Thermal management
  – System control and cell management
  – Power conditioning & Integration with DC/DC Conversion
  – System Reliability and Safety

• Alternative Anode, Cathode, Shutdown Separator, Electrolyte Improvements
• Integrated Prototype Vehicle Evaluation (Battery Integration and Field Testing)
• Hybrid Solutions (e.g., Capacitor Assisted Battery)
TARDEC Battery Roadmap

Technology Readiness Levels (Maturity)

1. Lead Acid
2. NiMH
3. Li-ion
4. NiZn

Advanced Lead Acid
Improved Li-ion

Production Lead Acid Battery
30-40 W-hr/kg
150 W/kg

30-60 W-hr/kg
250-800 W/kg

Power Cell
85-100 W-hr/kg
1 kW/kg
Energy Cell
120 W-hr/kg
400 W/kg

30-80 W-hr/kg
250-1000 W/kg
(In-Production)

Power Cell
60 W-hr/kg
4.8 kW/kg
Energy Cell
200 Wh/kg
300 W/kg

Power Cell
60 W-hr/kg
8 kW/kg
Energy Cell
250 W-hr/kg
250 W/kg

Production Li-ion

80 W-hr/kg
400 W/kg
Improved Cycle Life

FireFly
400-800 W-hr/kg
500-2000 W/kg

Prototype demo
Projected longer cycle life. Reduction of grid corrosion by 40% using porous graphitic material

LFP cathode
Safer Less energetic materials

Parallel ATO & MTO Efforts

*Metrics are based on cell data

Combat Hybrid Power Systems (CHPS)
IV.GC.1999.01

Support Hybrid Electric FCS Program
ATO III.L.G.2004.03

Energy Storage Manufacturing
MTO-03-06

Advanced Energy Storage

FY00 FY01 FY02 FY03 FY04 FY05 FY06 FY07 FY08 FY09 FY10 FY11
Common Modular Power System

OnPoint Technologies Visit
28 February 2007

Mr. Rakesh Patel
Team Leader of Non-Primary Power
A joint PEO GCS/TARDEC initiative to develop a common modular power architecture to support future upgrades on HBCT and SBCT platforms.

• System Objectives:
  – Usable across multiple platforms: Abrams, Bradley, Paladin, and Stryker
  – Modular, reconfigurable, upgradeable and affordable over the system lifecycle
  – Able to support FCS spiral technology insertions and PEO GCS modernization

• Three Phases
  – Phase 1 - Evaluate vehicle power needs and develop a common power management Conceptual System architecture
  – Phase III – Develop detailed component level requirements, design, build and test a prototype CMPS for test and demonstration on a target vehicle (Stryker).
General
• Meet vehicle’s current performance specification for environmental and operational requirements

Power Generation
• 610VDC High Voltage per FCS standard 786-30299
• 28VDC per MIL-STD-704F
• 28VDC Non-primary Power System (NPS) requirements

Electrical Power Conversion
• Bi-directional 610VDC to 28VDC
• Bi-directional 110/208 three phase VAC to 610VDC

Power Distribution
• Point of load control, PWM/On/Off
• Protect against electric shock, over-voltage, over-current, reverse polarity, ground fault, shorts, and arc faults
• Controllable through CMPS network
• Monitor and report load voltage, current, and temperature
Power Management
• Manage power generation, energy storage, and power control/distribution components in order to maximize efficiency, increase reliability, and reduce crew burden.
• Ensure systems, subsystems, or components receive their required power based on crew input, mission derived priorities, system health, and/or tactical environment.
• Allow load shedding to meet final objective.
• Add battery management capability.

CMPS Data Network
• Dual CAN network (SAE J-1939/ISO11898)
• 1Mb/s main network, 250kbps engine network
• Connects to all power components and controls

Interface requirements
• Use 6TMF size batteries
• NATO Slave interface
• 610VDC interface
CMPS Proposed Stryker Implementation

Engine Power Pack Modifications
– Remove starter and alternator and replace with high voltage Integrated Starter Generator
– Electrify all engine accessories, belt driven and hydraulic
– Electrify air conditioning compressor (currently hydraulic)

Internal Vehicle Modifications
– Add CMPS CAN network
– Add DC/AC and DC/DC converters
– Replace power distribution panel with point of load controllers
– Electrify rear ramp (currently hydraulic)
– Add battery management system
– Add power management software to control and monitor loads
CMPS Shortfalls

Technical Issues:
- High voltage safety
  - In the crew area
  - Exporting power
  - OSHA standards?
- Cost effectiveness of hydraulic to electric conversion
- Appropriate efficiency requirements for DC/DC and AC/DC converters
- Small enough power control modules to perform point of load control
- Flat versus round copper wire
- Does not address battery chemistry or voltage
- Testing learning algorithms

Programmatic Issues:
- Financial resources for full integration
- Vehicle availability for integration timeline
- CMPS hardware acquisition strategy to maintain common components across all PEO-GCS vehicles where applicable