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Energy Storage Saves Fuel For Forward Operating Base

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Sandia National Laboratories

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OVERVIEW

- Project Objectives
- Sandia Initial Testing and Assessments
- Energy Storage Analysis
- Major Findings
- Future Analysis

Project Objectives

- **Description**
  - *Evaluate energy storage systems within the force provider microgrid*
- **Develop Request for Information (RFI) with Product Manager Force Sustainment Systems (PdM FSS) for available energy storage systems that can meet Army standards**
- **Burn-in testing at Sandia Distributed Energy Technology Laboratory (DETL) and Energy Storage Test Pad (ESTP)**
- **Performance testing at Base Camp Integration Laboratory (BCIL)**
- **Develop models in Matlab/SIMULINK and System of Systems Analysis Toolset (SoSAT) to evaluate energy storage potential**

Base Camp Integration Laboratory (BCIL)

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Sandia Testing

- **10 energy storage vendors responded to RFI**
- **Down selected to 5 vendors based on ability to meet Army standards and Technology Readiness Level (TRL) 6**
- **4 Vendors were tested and assessed at Sandia DETL and ESTP for Functionality**
  - GS Battery, EPC Power (Lead Acid, 150kW / 51kWh)
  - Raytheon kTech (Zinc Bromide, 30kW / 120kWh)
  - Princeton Power (Lithium Ion, 100kW / 60kWh)
  - Milspray (Lead Acid, 15kW / 75kWh)
- **Testing and Assessments Performed**
  - Safety Assessment
  - Capacity
  - Command Response
  - Frequency Response
  - Voltage Response
  - Combined Frequency and Voltage Response
  - Total Harmonic
  - Round Trip System Efficiency

Sandia Energy Storage Test Pad (ESTP)

Distributed Energy Technologies Laboratory (DETL)

Sandia Testing

- **The following reports have been published and are unlimited release at http://www.sandia.gov/ess/pubs_tech.html**
  - Test Report: GS Battery, EPC Power Hybrid Energy System, Rugged Energy Storage Containment Unit (HES RESCU)
  - Test Report: Raytheon/Ktech RK30 Energy Storage System
  - Test Report: Princeton Power Systems Prototype Energy Storage System
  - Test Report: Milspray Scorpion Energy Storage Device

Princeton Power

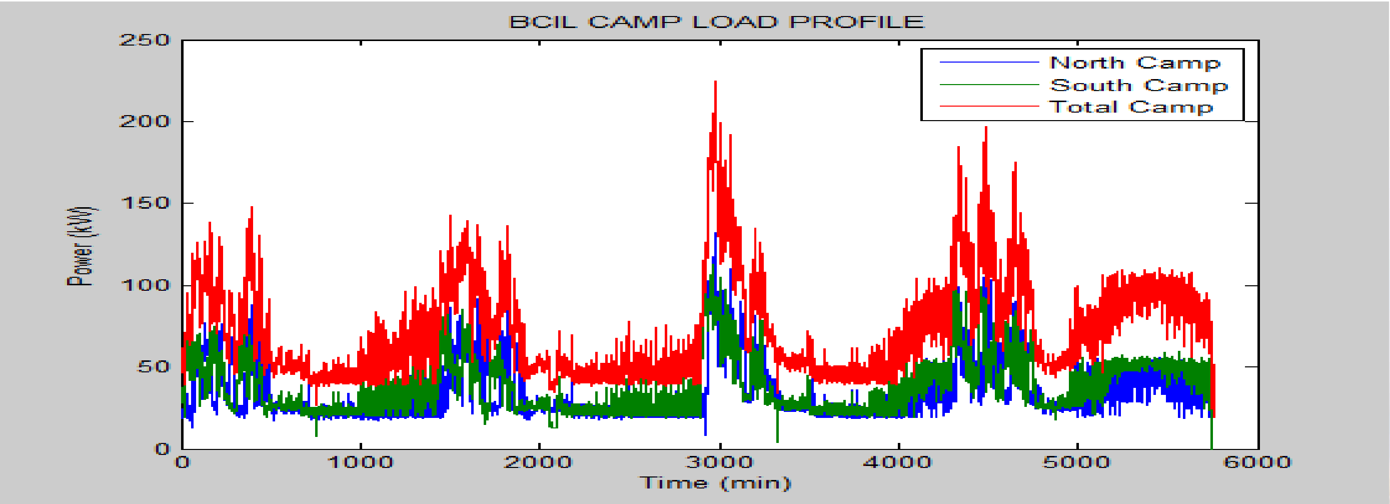
Milspray Scorpion

GS Battery / EPC Power

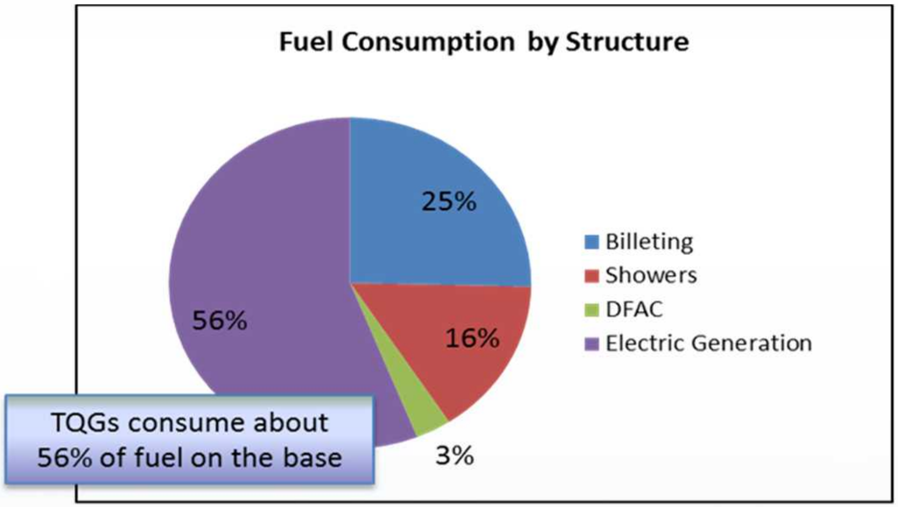
Ktech RK30

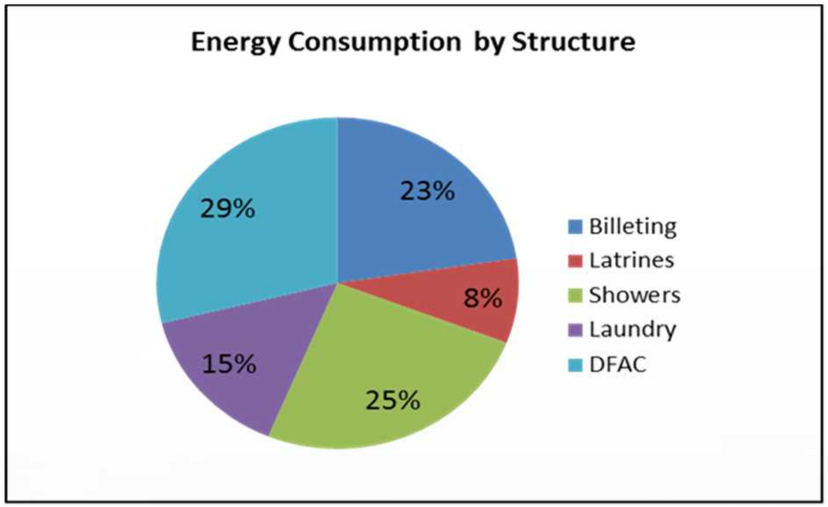
Energy Storage Analysis - BCIL

- **BCIL**
  - Located in Fort Devens, Massachusetts
  - Two Side-by-side 150 person (PAX) Force Provider base camps (one is a control/baseline FOB and the other is an experimental FOB)
  - Proving ground for new Forward Operating Base (FOB) technologies
  - Forward Operating Base training for soldiers
- **Electrical System for BCIL Microgrid (2 - 150PAX)**
  - Generation (6 x 60kW Tactical Quiet Generators)
  - Load Demand (Peak – 127 kW, Average – 28 kW, Average Load Demand per day – 612 kWh)



Energy Storage Analysis – BCIL Baseline



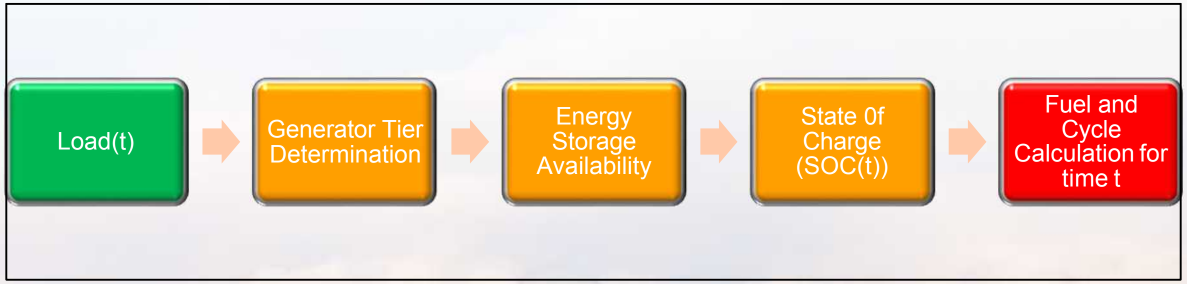


Consumable	Average 30 Day Consumption
Fuel	14,995 gal
Energy	85,805 kWh

TQG- Tactical Quite Generator
DFAC- Dining Facility

Energy Storage Analysis - Matlab/SIMULINK

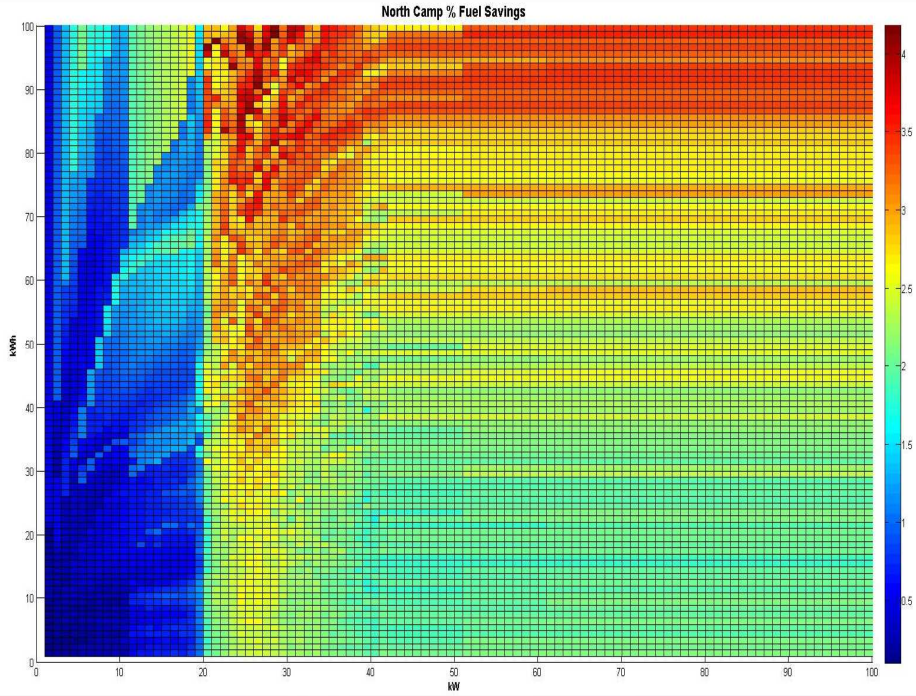
- **Energy Storage Applications**
  - ***Generation Deferral***
    - Discharge energy storage system to provide power when load demand is greater than 80% of generators' ratings online
    - Charge energy storage system when load is between 40% and 80% of generators online
  - ***Spinning Reserve (Insurance)***
    - Run generators at a higher efficiency at 45% and 90% and use energy storage when load exceeds 90%
- **Model Inputs**
  - ***Energy Storage System***
    - kW Rating, kWh Rating, State of Charge Range, Round Trip System Efficiency, Max Charging Rate, Max Discharging Rate (All parameters are based on vendor data sheet values)
  - ***Generators (60kW TQG)***
    - kW Rating, Operational Limits (40% and 80%) unless ESS in spinning reserve
  - ***Base Camp Load***
    - kW and kVAR every second for all buildings within the FOB



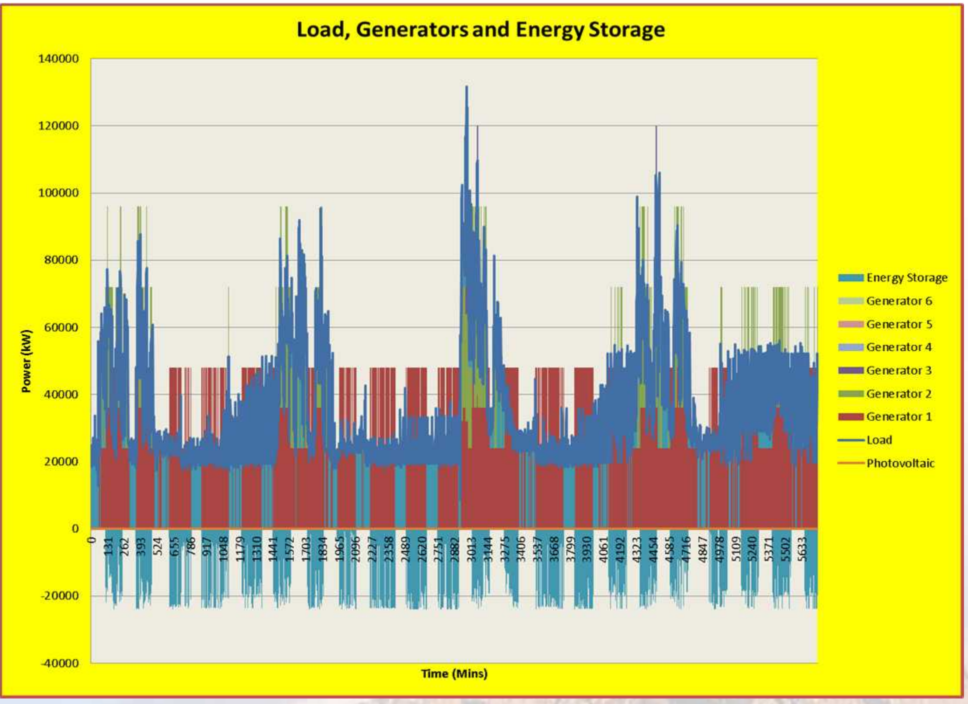
Matlab/SIMULINK Program Flow Diagram

Matlab/SIMULINK Analysis Results

- **Fuel Savings**
  - **FOB Camp (150 PAX)**
    - 3.5% - 5.8%



150 Person Fuel Savings



150 Person Generation and Load Profile

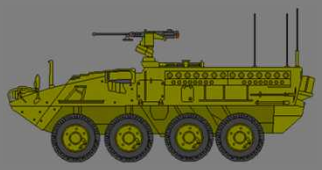
System of Systems Analysis Toolset (SoSAT)

- The System of Systems Analysis Toolset (SoSAT) is a stochastic simulation that has been used extensively to evaluate mission performance of military system of systems (SoS) across multiple interdependent functions and measures of effectiveness (e.g. sustainment, function availability, survivability, etc.)
- SoSAT has been verified and validated (V&V) by the US Army Material Systems Analysis Activity (AMSAA) organization
- Government capability that has been transitioned: SoSAT Analysis cell at Tank and Automotive Command (TACOM) Cost and Systems Analysis group (Sandia provides periodic training sessions)
- Current SoSAT applications:
  - U.S. Army Brigade Combat Team Modernization
  - U.S. Army Contingency Basing & Operational Energy
  - U.S. Navy Remove Multi-Mission Vehicles (RMMV), Littoral Combat Ship (LCS)
  - U.S. Marine Corps Expeditionary Energy Office (E2O)
  - U.S. Air Force Electronic Warfare

SoSAT Highlights

- **System State Model**
  - Multiple user defined functions/operations
  - Multiple Function States
  - System interdependencies
  - Impacts of external factors (weather, terrain, combat, etc.)
- **Model system behavior by defining:**
  - States for all subsystems/components/functions
  - How transitions are made between states
- **States can change through:**
  - Normal processes (failure, repair, etc.)
  - External conditions (weather, terrain, combat, etc.)
  - Changes in functional states of other systems

Platform as a "System State Model"



Wheeled Vehicle Model

Example Elements

Suspension

FBCB2 Communications

Engine

Fuel

Example Operations

Operability

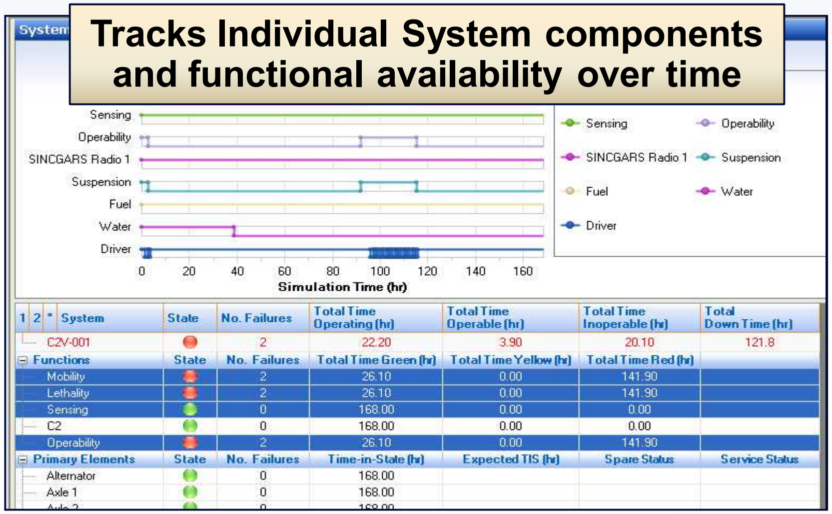
Lethality

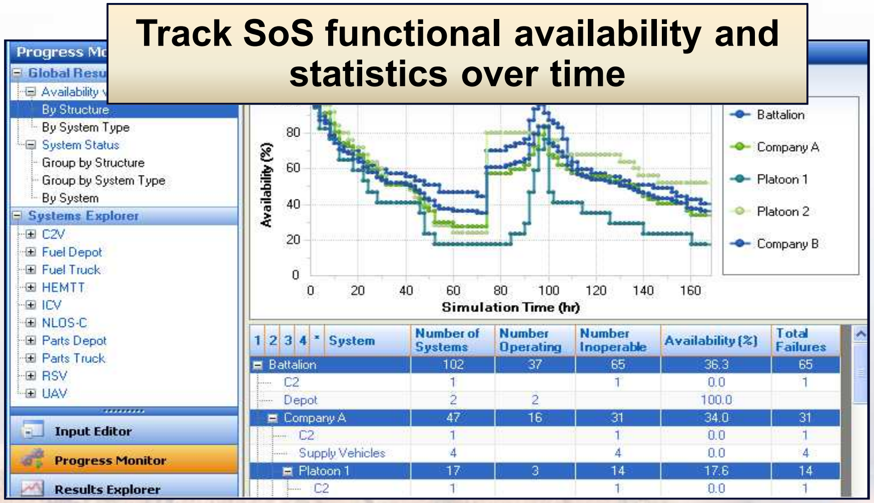
Mobility

The System State Model is an intuitive way to capture system behavior and is building block for systems in the simulation

SoSAT Features and Outputs

- **Provides analysts a scenario-based capability to:**
  - Simulate *any or all* of a system of systems (SoS) organizational structure
  - Simulate multiple mission segments for a SoS
  - Provide data to assess SoS performance objectives
  - Support business decisions and trade-offs
- **Basic Modeling Features**
  - System element reliability failures
  - Consumable usage and depletion
  - Maintenance activities including any required spares or services
  - Supply reorder for consumables and spare inventories
- **Advanced Modeling Features**
  - Damage effects modeling
  - Network modeling
  - Prognostics and Health Management
  - Human performance
  - Time-based changes to model attributes
  - System Referencing (interdependencies)

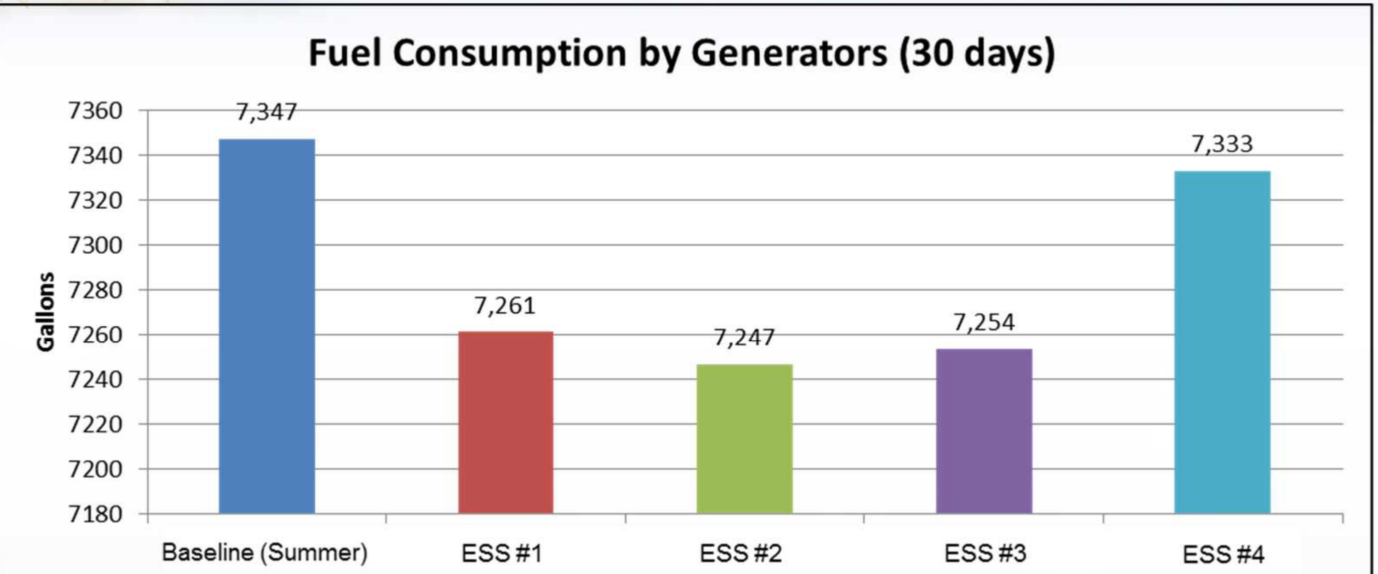




Energy Storage Analysis - SoSAT

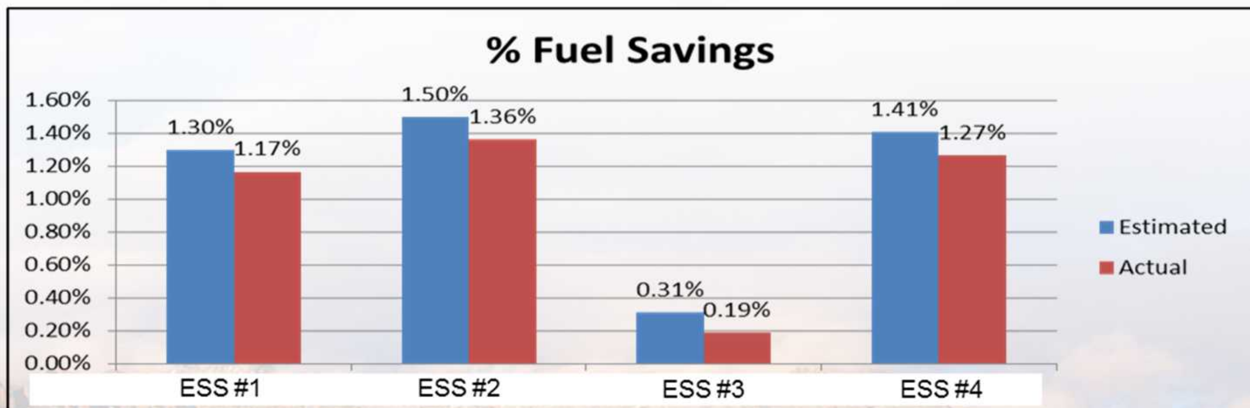
- **30 day scenario simulation/100 trials**
- **Leveraged data from another 1000 PAX modeling effort**
  - Based on Force Provider Containerized Systems
  - System loads, utilization rates and duty cycles leveraged from identical systems in 1000 PAX model
- **BCIL 150 PAX**
  - Number of soldiers on the FOB varies throughout the simulation
- **2 maintenance personnel for generators**
- **Microgrid configuration used for baseline**
- **Track fuel usage but fuel supply is not constrained**
- **Only the reliability of TQGs was modeled**

SoSAT Modeling and Analysis Results

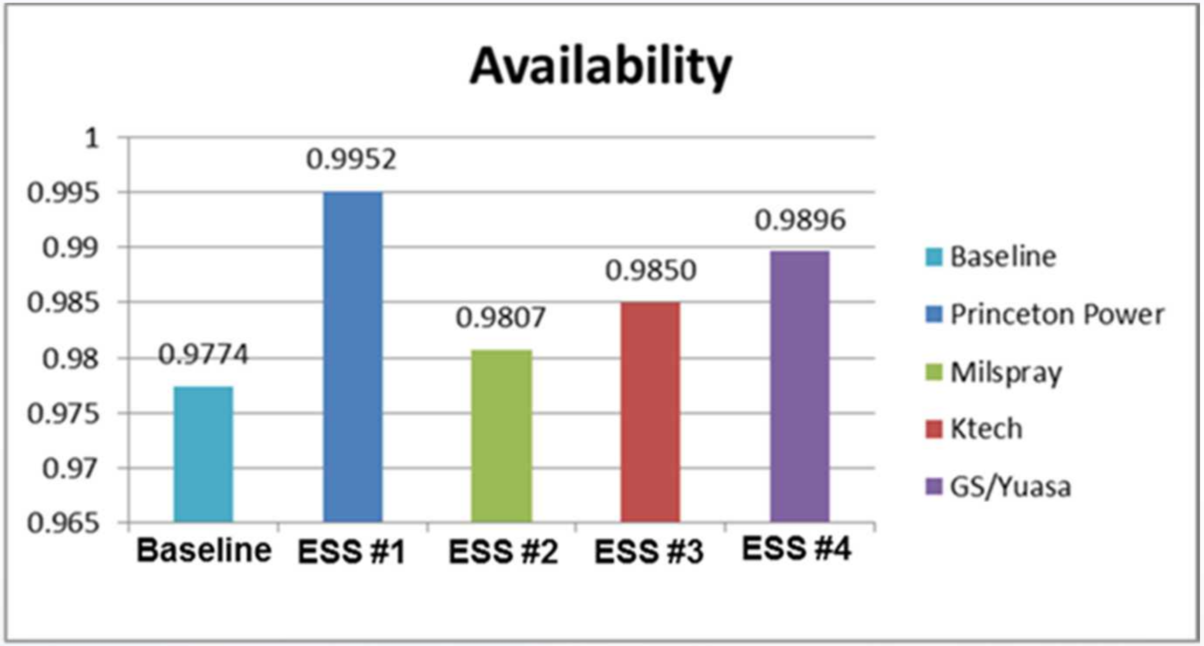


ESS #2 reduces fuel consumption by about 1200 gal/year

Expected fuel savings decrease when TQG startup time, TQG reliability and battery conditioning are modeled



SoSAT Operational Availability (Ao) Results



- **Availability improvement mostly due to energy storage supporting the load during generator startup**
- **Although ESS #4 has higher maintenance requirements than the ESS #3 system, its larger size leads to higher overall system availability**

Major Findings

- **Matlab/SIMULINK results show fuel savings of 3.5% - 5.8% when adding energy storage to a (150 PAX)**
  - Higher savings are due to turning off all generators when load is less than 18kW and using only the ESS to supply power than compared to the (300 PAX)
- **SoSAT results show an average of 0.19%-1.36% fuel savings when adding energy storage to a (150 PAX) FOB**
  - Expected fuel savings decreased from the Matlab/SIMULINK (1% - 3%) simulation when TQG startup time, TQG reliability and energy storage conditioning were modeled
  - Fuel Savings are not enough to reduce LOGPAC frequency
- **Generation availability improved from 0.9774 for the baseline to as high as 0.9952**
  - Reliability and availability are difficult to quantify
  - How much availability and/or reliability is required? (varies significantly with mission

Future Analysis Recommendations

- **Explore the benefits of energy storage for a system with renewable energy**
  - Energy storage can be used to increase the renewable integration capacity of a system
- **Represent the load profiles for power consuming systems more accurately**
  - Load profiles have an effect on system reliability and generator utilization and fuel consumption
- **Refine BCIL models as new test data becomes available**
- **Evaluate different energy storage technologies and applications**

Questions

THANK YOU!