ARPA-E/ASD(R&E) Hybrid Energy Storage Module (HESM) Applications

19 May 2011

Mr. John Heinzel
HESM IPT
NSWC Philadelphia

The Challenge

National Power & Energy

- **Critical to**
  - National security
  - Economic growth
  - Public health & safety
- **Current/Future demands**
  - Greater reliability/resiliency
    - Increased situational awareness
    - Faster response to faults/failures
    - Higher intrinsic reliability
  - More flexibility
    - Shift from centralized to market driven command and control
  - Increased energy security
    - Shift away from dependence on foreign oil

Military Power & Energy

- **Critical to**
  - Power projection
  - Base security & operations
  - Warfighter health & safety
- **Current/Future demands**
  - Greater reliability/resiliency
    - Increased situational awareness
    - Faster response to faults/failures
    - Higher intrinsic reliability
  - More flexibility
    - Shift toward integrated power systems
    - Shift toward increased automation for command and control
  - Increased energy security
    - Shift away from dependence on foreign oil
    - Reduce risk to Warfighter

The Military and National power and energy systems face many of the same challenges

Diverse Applications

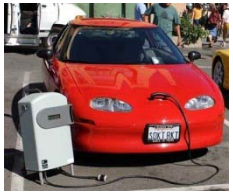
Commercial

Heavy Vehicle

Commercial Marine

Electronics

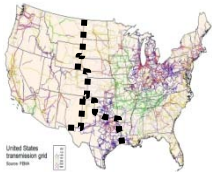
Residential



Automotive

Industrial, Dist. Gen

Locomotive

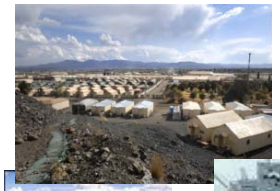


.01 .1 1 10 100 1,000 10,000

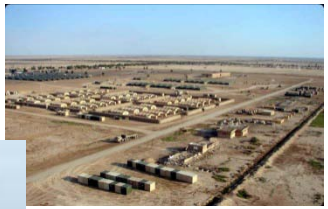
POWER (kWe)

Pulse Loads:
High rate pulse applications found at all power levels

Tactical Power



Distributed Power

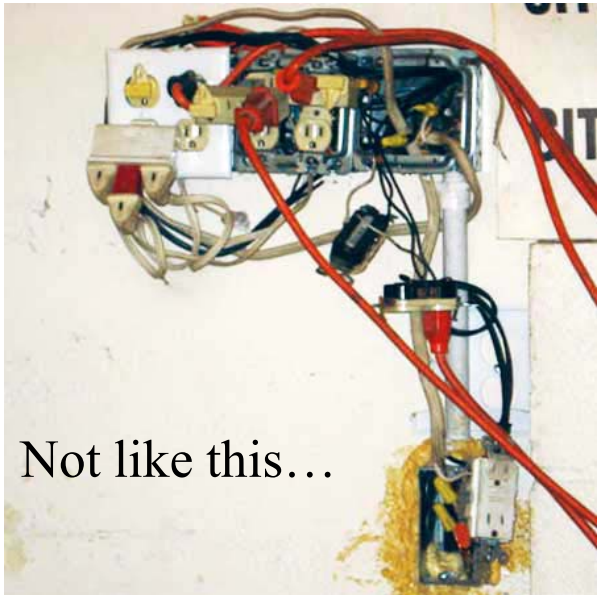


Military

Military Perspective
Looking Forward

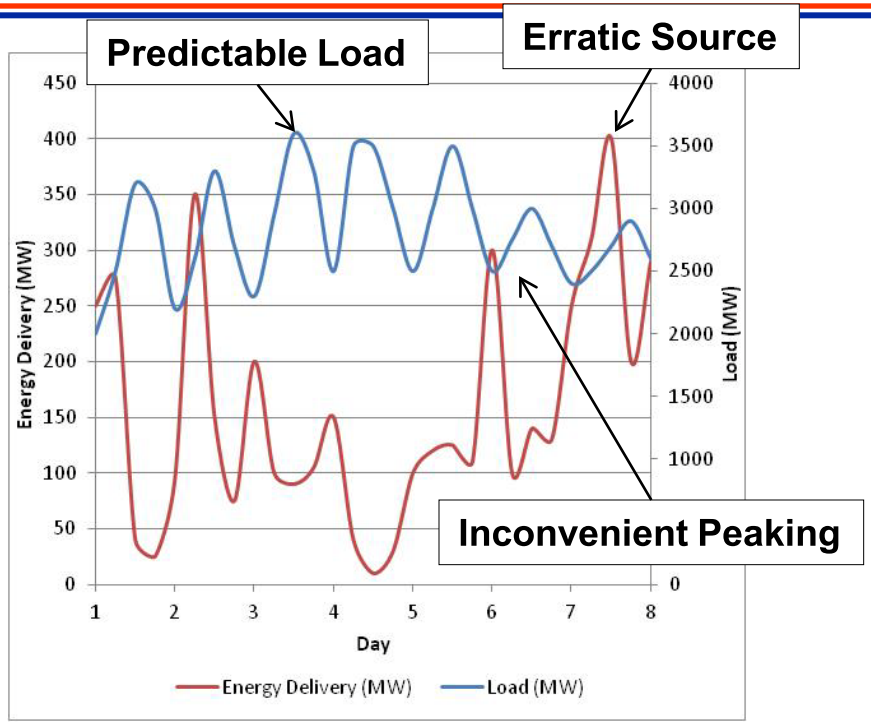
New threats and technology development are leading to better and more power hungry solutions in sensors and weapons.

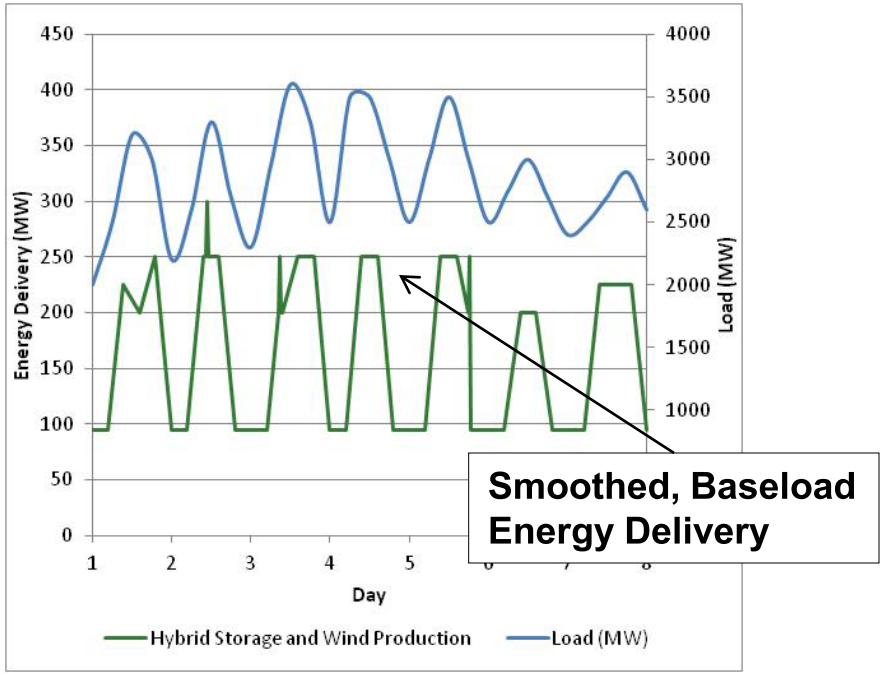
How do you address this on both current and future platforms?

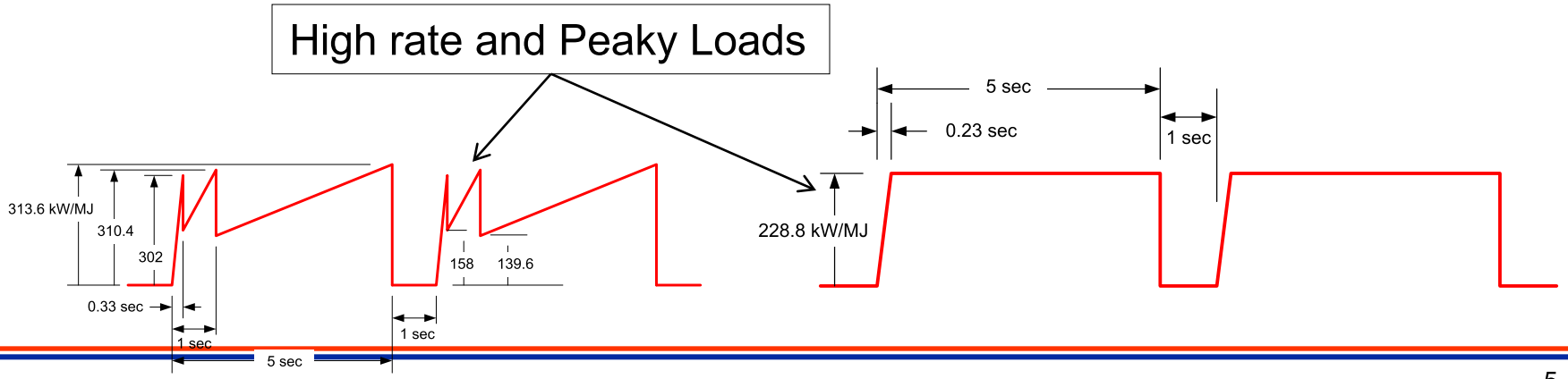


Fuel Efficient Solutions Needed to Satisfy Both Power Growth and Reduction of Logistics Lines

Irregular Sources And Loads



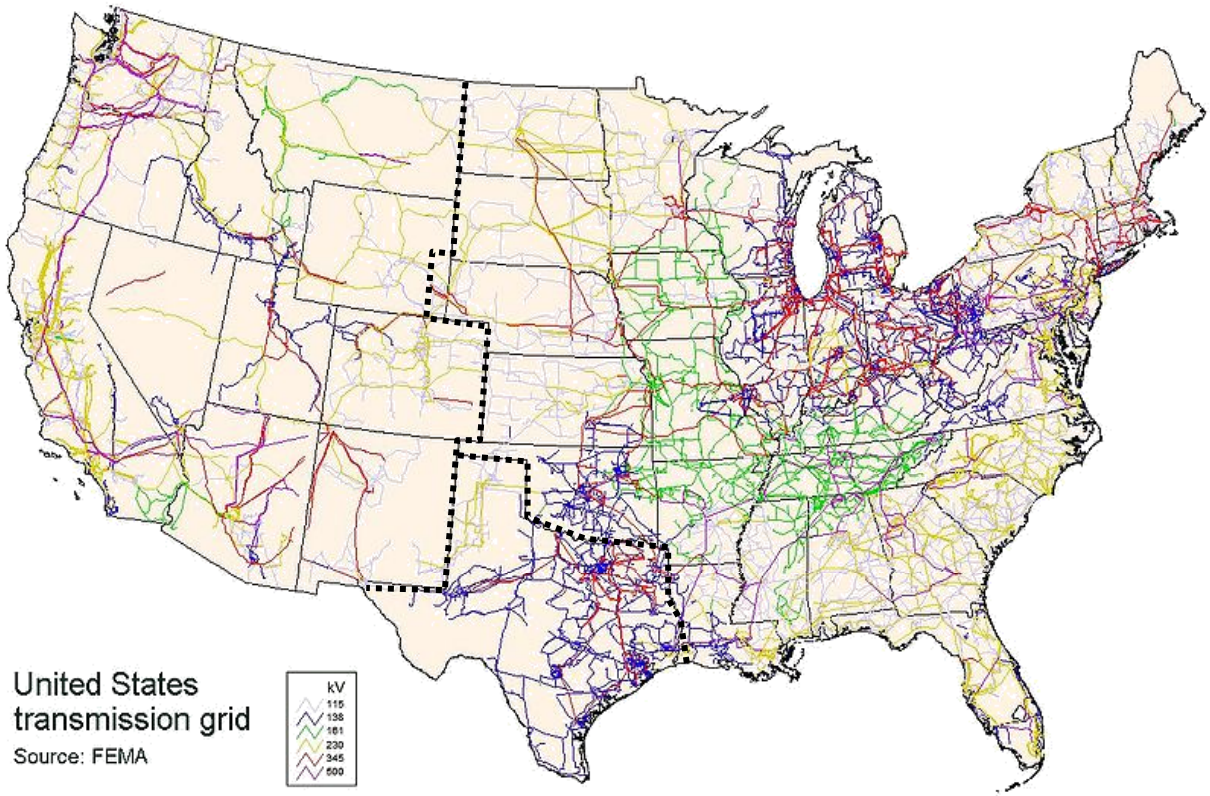




Commercial Perspective
Looking Forward

Electric Grid: Premier Achievement of 20th Century [NAE]

Harness Renewable Power: #1 Challenge for 21st Century

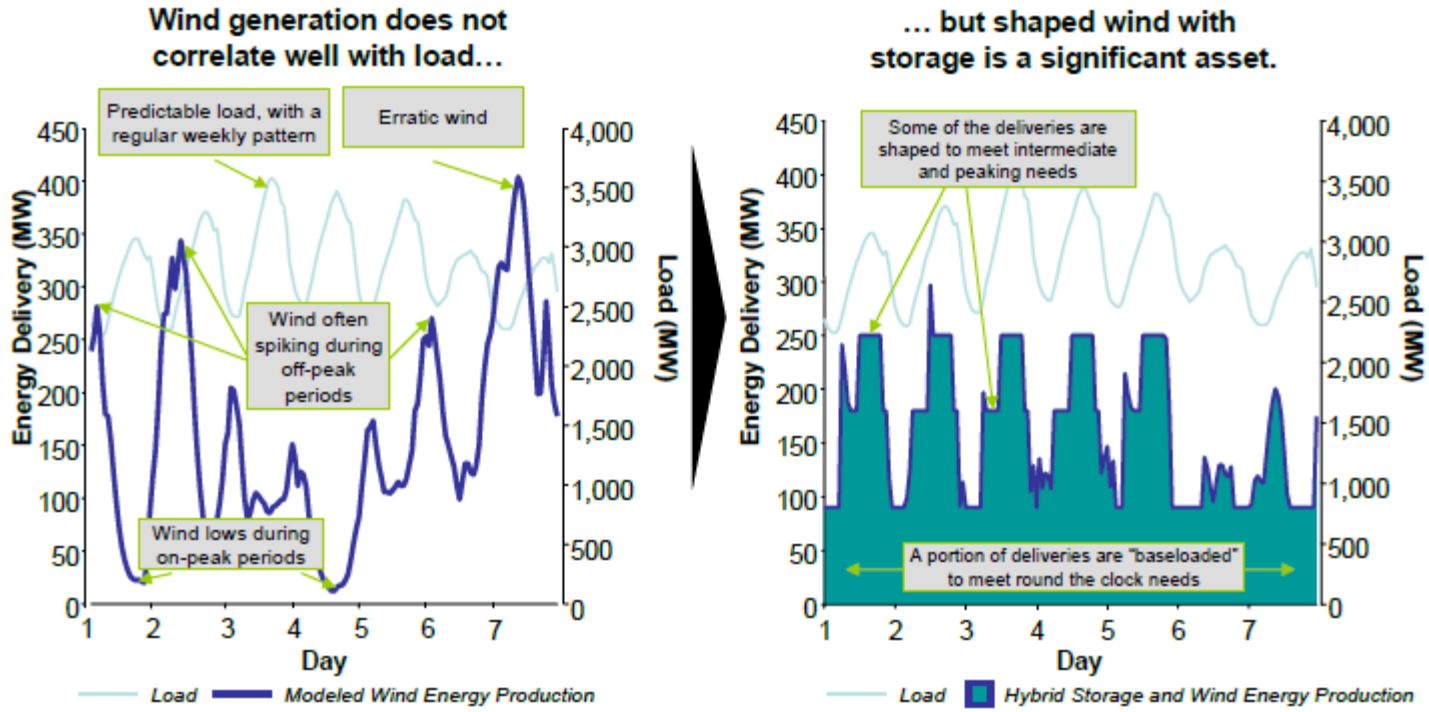


Storage Separates Electric Generation and Load in Space and Time

Grid Storage Workshop Findings

Energy Storage is required to confer reliability to renewable energy sources and to produce power when the load occurs

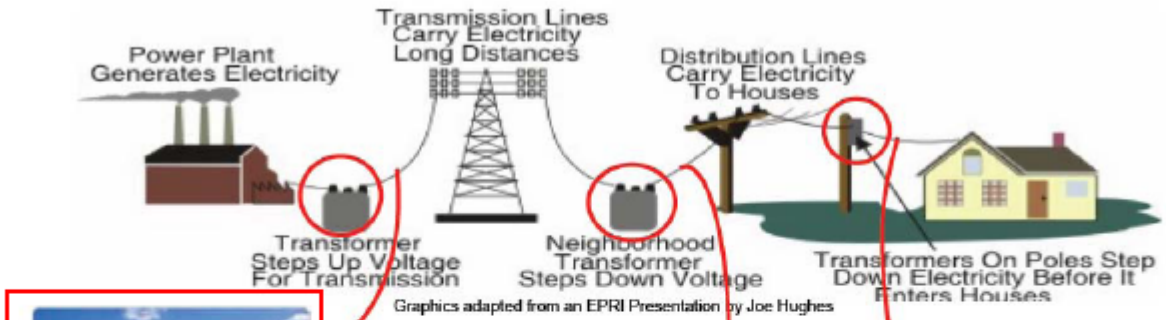
Texas Panhandle Example



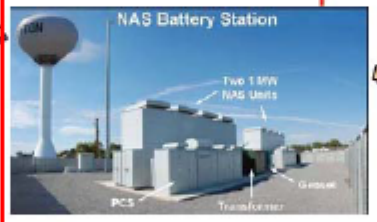
Notes: 400 MW of wind in Texas Panhandle modeled in conjunction w / local storage facility. Grid storage parameters – 400 MW of capacity

Grid Storage Workshop Findings

Workshop participants from utilities believed that storage is headed toward wide utilization from generation points to individual homes



Large Central Units



Substation Batteries

Storage at Grid Edge

"Residental generation from renewables has doubled every year for the last decade". A. Nourai - AEP

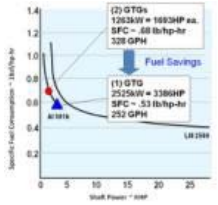
… each technology has technical challenges, and room for development within ARPA-E.

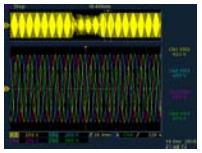
Source: A. Nourai, American Electrical Power, Inc. presentation at EESAT 2009, October 4-7, 2009

Role of Energy Storage Systems

Fuel Savings: Energy Mgt

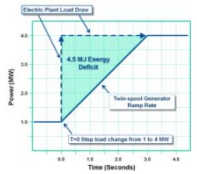
- Single Generator Operations
- Generator load scheduling





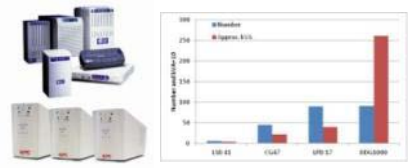
Power Quality

- Transient ride through
- Load changes outside of design space for prime movers



Energy Surety

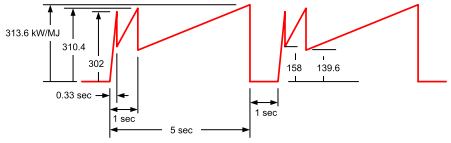
- Backup power
- UPS protection of sensitive devices



Increasing UPS and Batteries

Advanced Loads

- Pulsed applications
- Highly transient loads

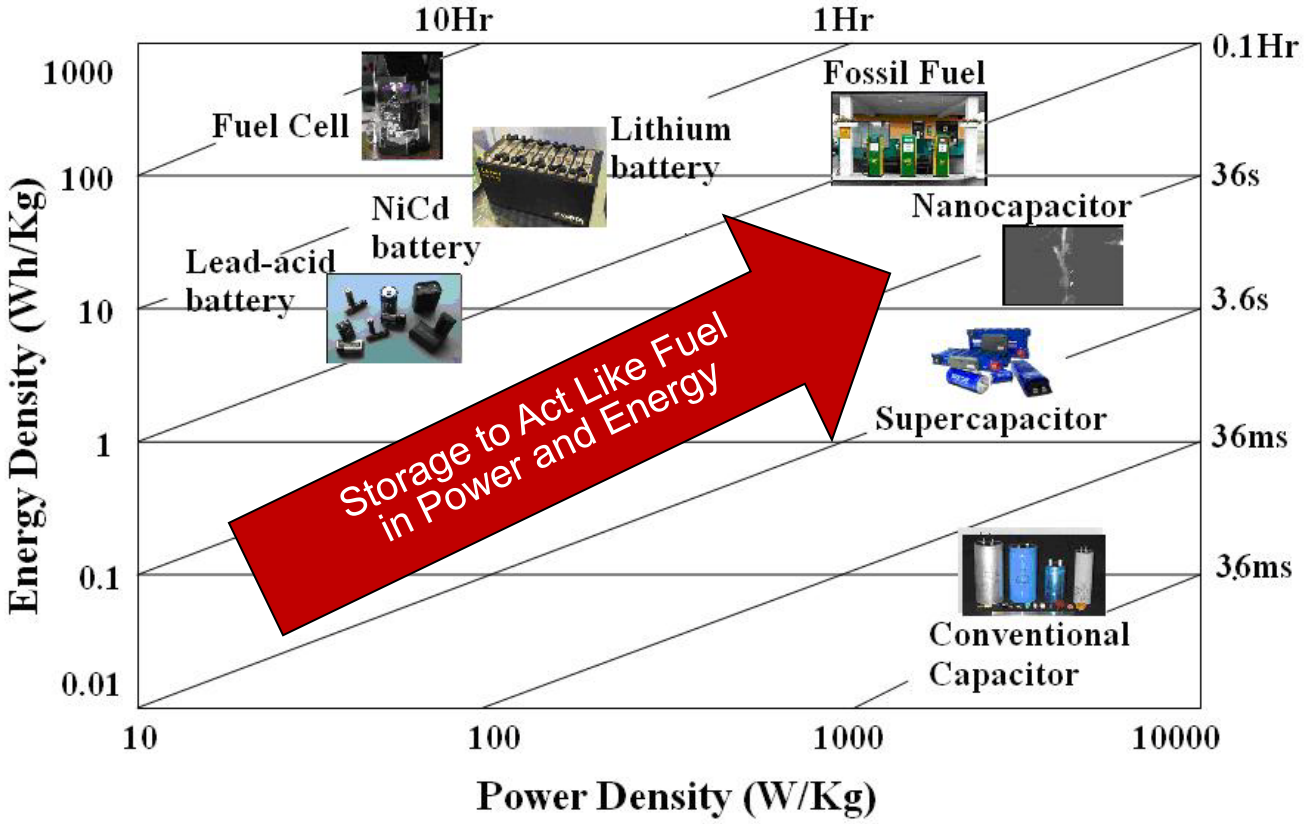


Potential EMRG Load Profiles

Need for Energy Storage is changing beyond traditional Energy Surety role to meet reduced fuel demands and increase capability within installations/platforms

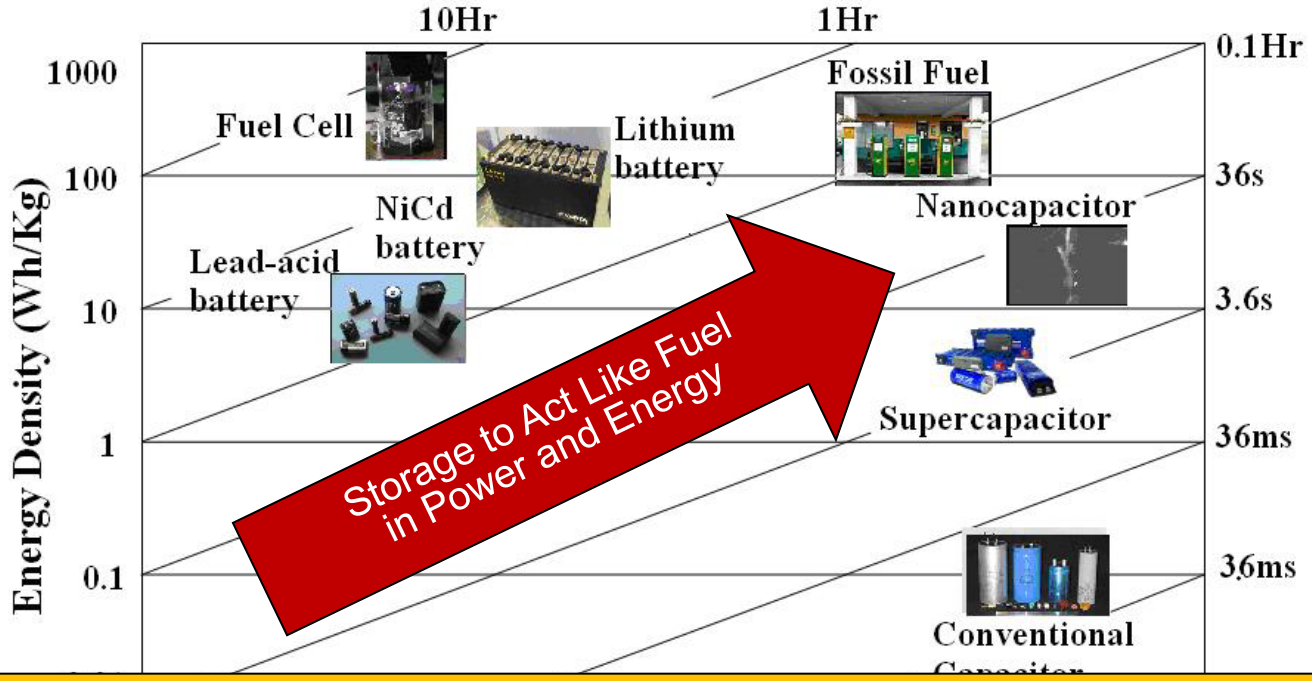
Technical Gap Area for Hybrid Energy Storage

Military and Grid storage "systems" will be supplied by a combination of technologies with varied power and energy storage capacities



Technical Gap Area for Hybrid Energy Storage

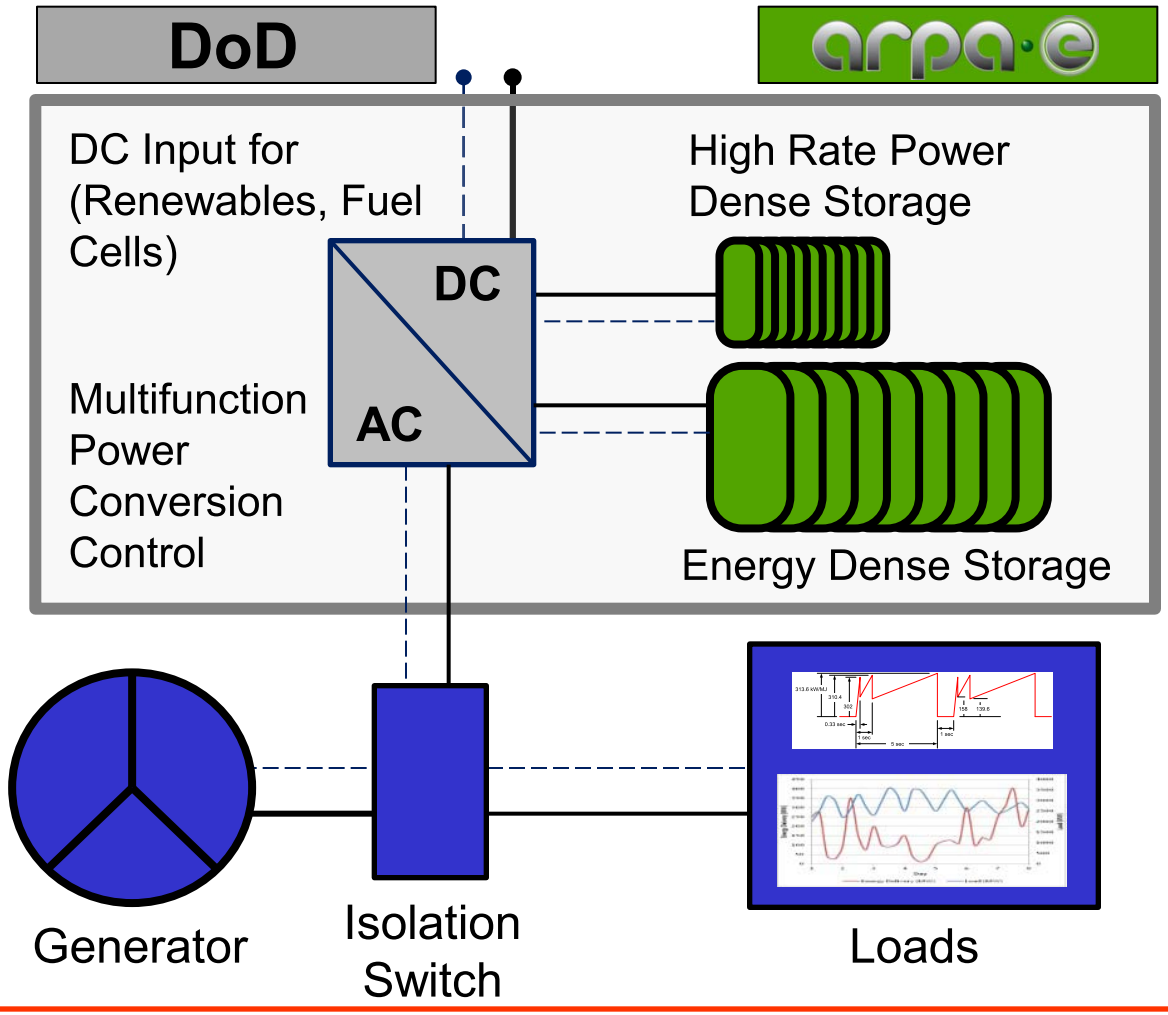
Military and Grid storage "systems" will be supplied by a combination of technologies with varied power and energy storage capacities



Total systems approach is required including energy storage devices, multifunction controls, power conditioning, thermal mgt to satisfy needed requirements and operational conditions

Hybrid Energy Storage Module (HESM)

HESM Unit



Technologies

- **Storage**
  - Advanced Energy Storage Device(s)
    - High Rate Batteries
    - Metal Air Batteries
    - High Energy Flywheels
    - Flow Batteries
    - Capacitors
- **Multifunction Power Conversion Control**
  - Multi Rate Control & Energy Storage Management
  - Thermal Tolerant Power Conversion for Continuous Operation
  - Energy Storage "Agnostic" Interface
- **HESM System Design**
  - Lightweight System Safety & Containment
  - Robust Thermal Architecture & Interface

Overall Benefits

- **Simplify integration of advanced distribution systems**
  - Standardized interfaces for multiple “hybrid” energy storage and power source inputs
  - Minimize reliance on redundant generator operation for fight through power
  - Reconfigurable power
  - Support different power types input and outputs
  - Reduction of storage size
  - Reduction of reactive power flow
  - Eliminates piece components (reduces overall system vol, weight)

- **Fuel Reduction**
  - Integrated control of generator scheduling, alternative energy source (renewables/fuel cells, etc) buffering
  - Optimization of source operation (baseloading)

- **Enables future loads**
  - Rate control (High transient applications)

Draft Output of Requirements Workshop
Product(s) Demonstration Areas

Tactical Energy Storage (kW to 10's kW)

- Operation close to power generation source
- Functionality: Energy Mgt, Power Quality
- DC Input for High Efficiency Renewables, Fuel Cell Generators

Commercial Application: Home Energy Management
DoD Application: Patrol Base, Combat Outpost

Distributed Energy Storage (100's kW to MW)

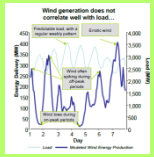
- Operation distributed in electric architecture
- Functionality: Energy Mgt, Power Quality
- DC Input for High Efficiency Renewables, Fuel Cell Generators

Commercial Application: Utility Distributed Generators
DoD Application: FOB, Super FOB, Ships


Pulse Energy Storage

- Operation for specialty applications
- Functionality: Energy Mgt, Power Quality, High Pulse Capability

Commercial Application: Utility Grid Level Storage
DoD Application: Ships, Aircraft, Vehicles

Tactical Energy Storage

- **Concept: Compact, light, integration of generators and renewables with controlled operation to support loads**

- **Military Benefits:**
  - Optimized small generator loading
  - Common interface point to support renewables & fuel cell integration to generator
  - Consistent power quality and controlled source under transient input
  - Multiple generator input allows system to operate like larger PU/PP

- **Commercial Benefits:**
  - Coordinate renewables integration to local electrical system
  - Localized high-efficiency generation/CHP tie-in
  - Storage for online buffering and utility ridethrough
  - Peak-shaving and load scheduling for optimized utility rate billing

Draft Output of Requirements Workshop
Product(s) Demonstration Areas

Tactical Energy Storage (kW to 10's kW)

- Operation close to power generation source
- Functionality: Energy Mgt, Power Quality
- DC Input for High Efficiency Renewables, Fuel Cell Generators

Commercial Application: Home Energy Management
DoD Application: Patrol Base, Combat Outpost

Distributed Energy Storage (100's kW to MW)

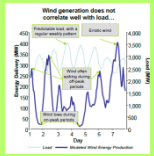
- Operation distributed in electric architecture
- Functionality: Energy Mgt, Power Quality
- DC Input for High Efficiency Renewables, Fuel Cell Generators

Commercial Application: Utility Distributed Generators
DoD Application: FOB, Super FOB, Ships

Pulse Energy Storage

- Operation for specialty applications
- Functionality: Energy Mgt, Power Quality, High Pulse Capability

Commercial Application: Utility Grid Level Storage
DoD Application: Ships, Aircraft, Vehicles



Distributed Energy Storage

- **Concept: Parallel storage capability to operate with single or reduced generators.**
- **Military Benefits:**
  - Grid-tied storage enables high generator baseload with full transient capability.
  - Extends generator power utility range
  - Serves as interface for large-scale renewables and fuel cell tie-in to broader distribution network
  - Interface for large FOB applications at high voltage interface point, 4160VAC capable with advanced step-up devices
  - Potential VAR compensation to support optimized generator loading
- **Commercial Benefits:**
  - Scalable 480VAC interface with storage subsystem allows for simplified storage and backup generator interface for sensitive applications
  - Controls and supports 480VAC standard generators, for microgrid and load scheduling
  - Provides buffered interface for renewable tie-in to facility main power

Draft Output of Requirements Workshop
Product(s) Demonstration Areas

Tactical Energy Storage (kW to 10's kW)

- Operation close to power generation source
- Functionality: Energy Mgt, Power Quality
- DC Input for High Efficiency Renewables, Fuel Cell Generators

Commercial Application: Home Energy Management
DoD Application: Patrol Base, Combat Outpost

Distributed Energy Storage (100's kW to MW)

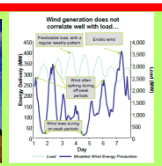
- Operation distributed in electric architecture
- Functionality: Energy Mgt, Power Quality
- DC Input for High Efficiency Renewables, Fuel Cell Generators

Commercial Application: Utility Distributed Generators
DoD Application: FOB, Super FOB, Ships


Pulse Energy Storage

- Operation for specialty applications
- Functionality: Energy Mgt, Power Quality, High Pulse Capability

Commercial Application: Utility Grid Level Storage
DoD Application: Ships, Aircraft, Vehicles

Pulse Energy Storage

- **Concept: Support high transient operations at substantial power levels with large energy requirements.**

- **Military Benefit:**
  - Supports high-rate sensors and weapons without substantial power diversion from generation system
  - Provides capability prior to additional generation coming online
  - Hybrid function supports alternate lower-rate operations under other conditions
  - Electrical actuation and “accumulator” functionality

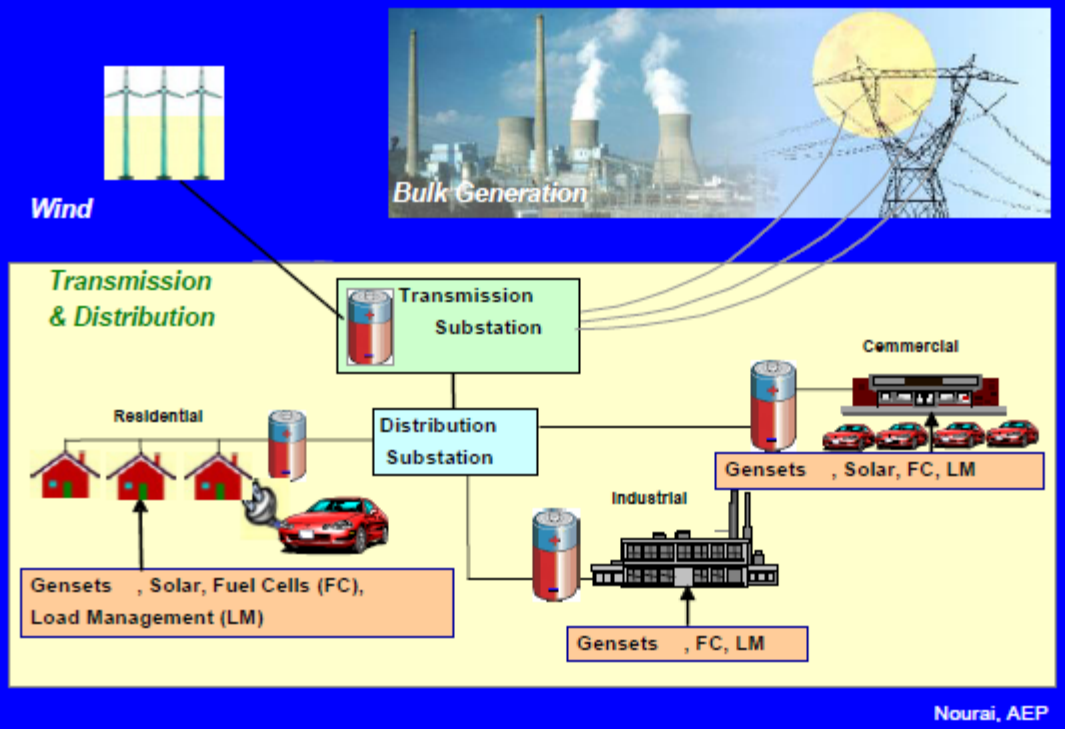
- **Commercial Benefit:**
  - High peak capability allows for fast response to dispatch cycles

Backup Slides

HESM IPT

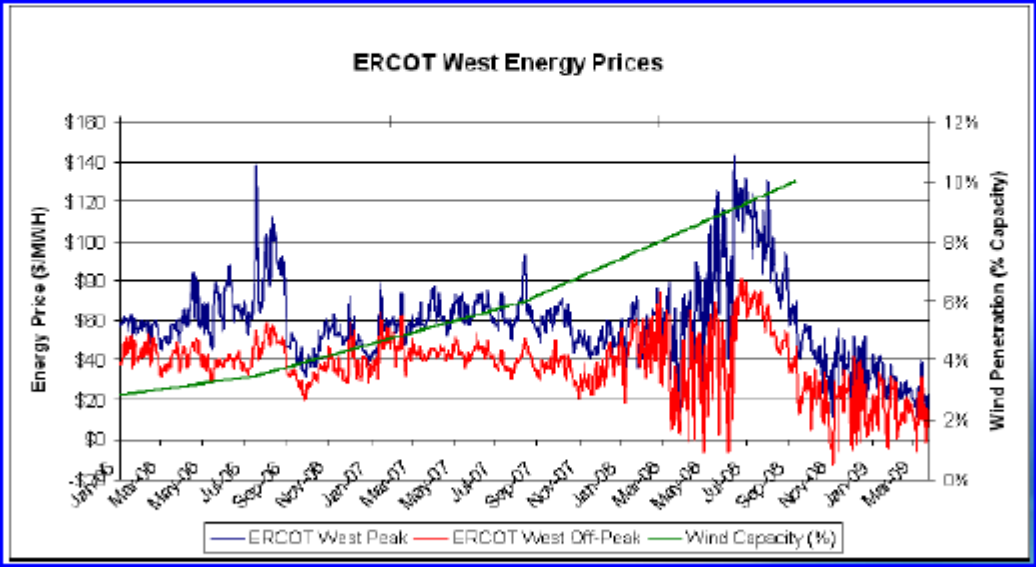
Co Leads: Don Hoffman (DoD PM)/Mark Johnson (ARPA-E)

- **ARPA-E**
  - Srinivas Mirmira
  - David Danielson
  - Rusty Heffner
  - Leshika Samarasinghe
- **DoD**
  - Jack Taylor, ASD(R&E)
  - Jack Price, ASD(R&E)
  - Jillyn Alban, ASD(R&E)
  - Adam Rosenberg, ASD(OEPP)
  - John Pazik, ONR, Chair – EPCOI
  - Ed Shaffer, ARL
  - John Heinzel, NSWC Philadelphia
  - Erik Kallio, TARDEC
  - Miguel Maldonado, AFRL WPAFB, ASD(R&E)
  - Marcus Smith, AFRL Tyndall



Distributed Storage, Distributed Generation, and Distributed Intelligence will be essential for the Grid of the Future

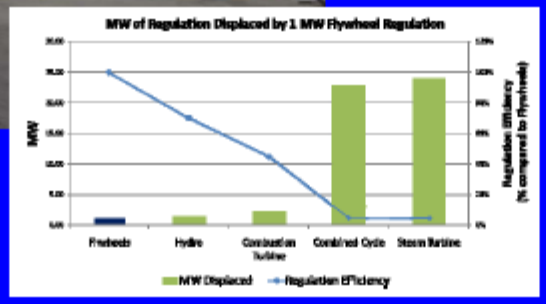
In Texas on Feb. 26, 2008 Wind Power dropped 1400MW in 10 Minutes. Blackouts were avoided by massive Load shedding by industrial Customers



March 08, there were 933 Negative Pricing Intervals = 38% of 15min. intervals
Max. Price = $2303; Min. Price = -$1983 $/MWh

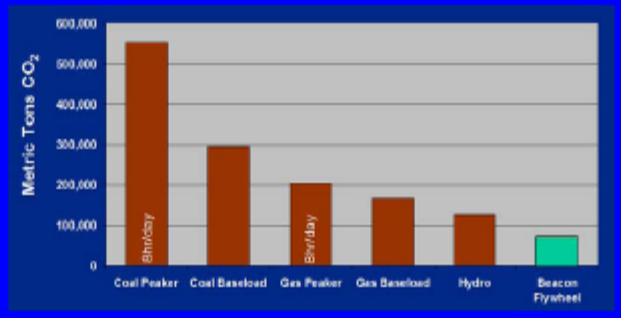
2x 100kW/15 min Flywheel systems

CEC / DOE and NYSERDA / DOE



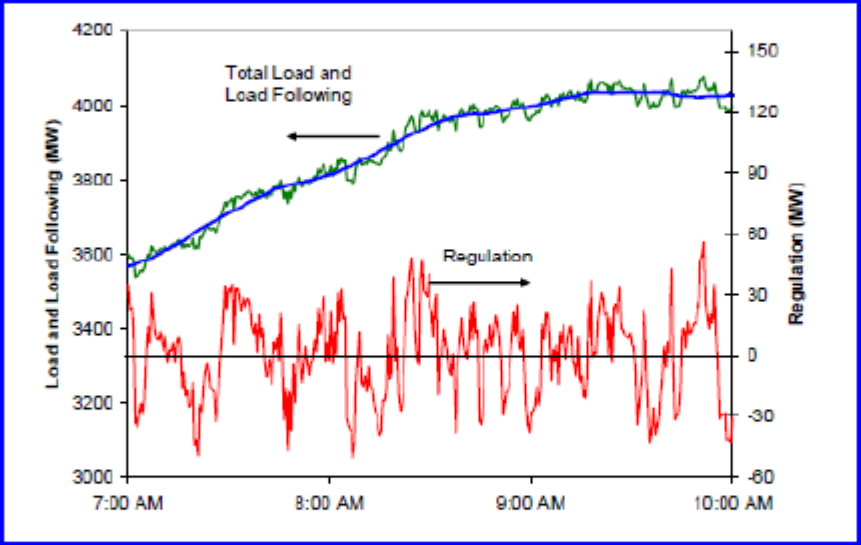
Regulation by fast storage may be twice as effective than gas turbines and 20 times more effective than steam turbines.
(Y. Makarov, PNNL,)

Flywheels represent a 70-80% reduction in CO2 emission over present methods (Fioravanti, KEMA, 2007)



Frequ. Reg. Needs will Double with 20% wind

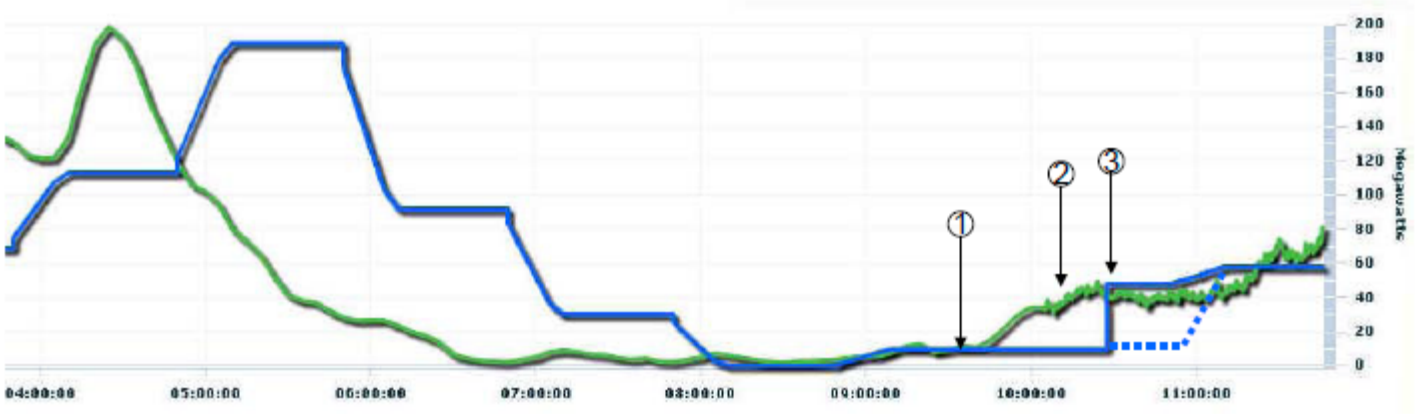
Grid Frequency Regulation with Fast Storage:



Kirby 2004

Current method to balance constantly shifting load fluctuation is to vary the frequency and periodically adjust generation in response to an ISO signal. Fast storage can respond instantaneously!

Inaccuracy in Wind Generation Forecasts Increase the Need for Other Generation Resources to Maintain Reliability



Legend

Total Schedule without Intra-Hour

Total Schedule With Intra-Hour

Total Generation

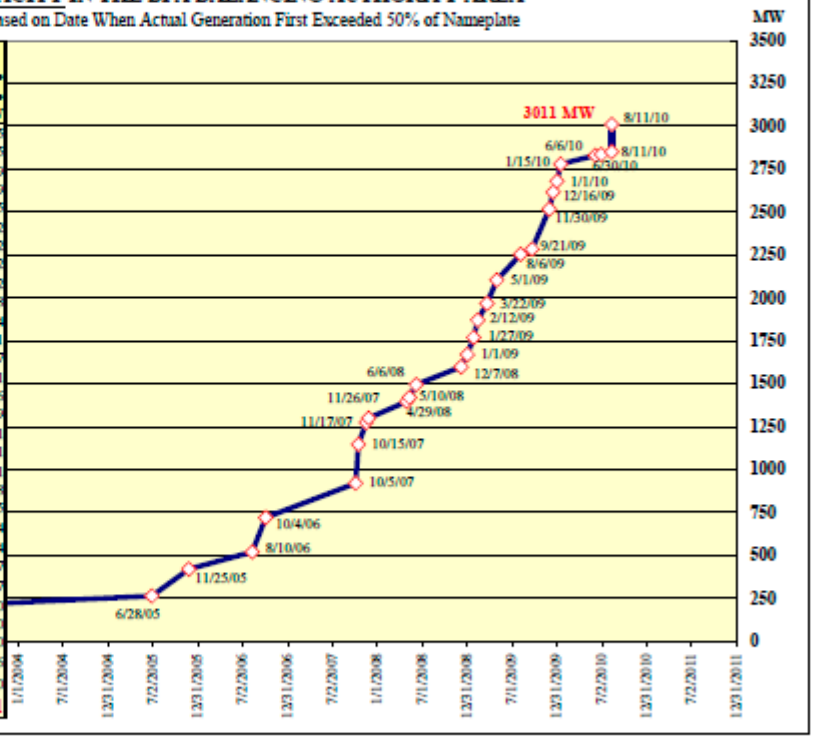
1. Hour Ending 11 scheduling window closes
2. Hour Ending 11 intra-hour scheduling window closes
3. Hour Ending 11 intra-hour schedule

Wind power is growing fast

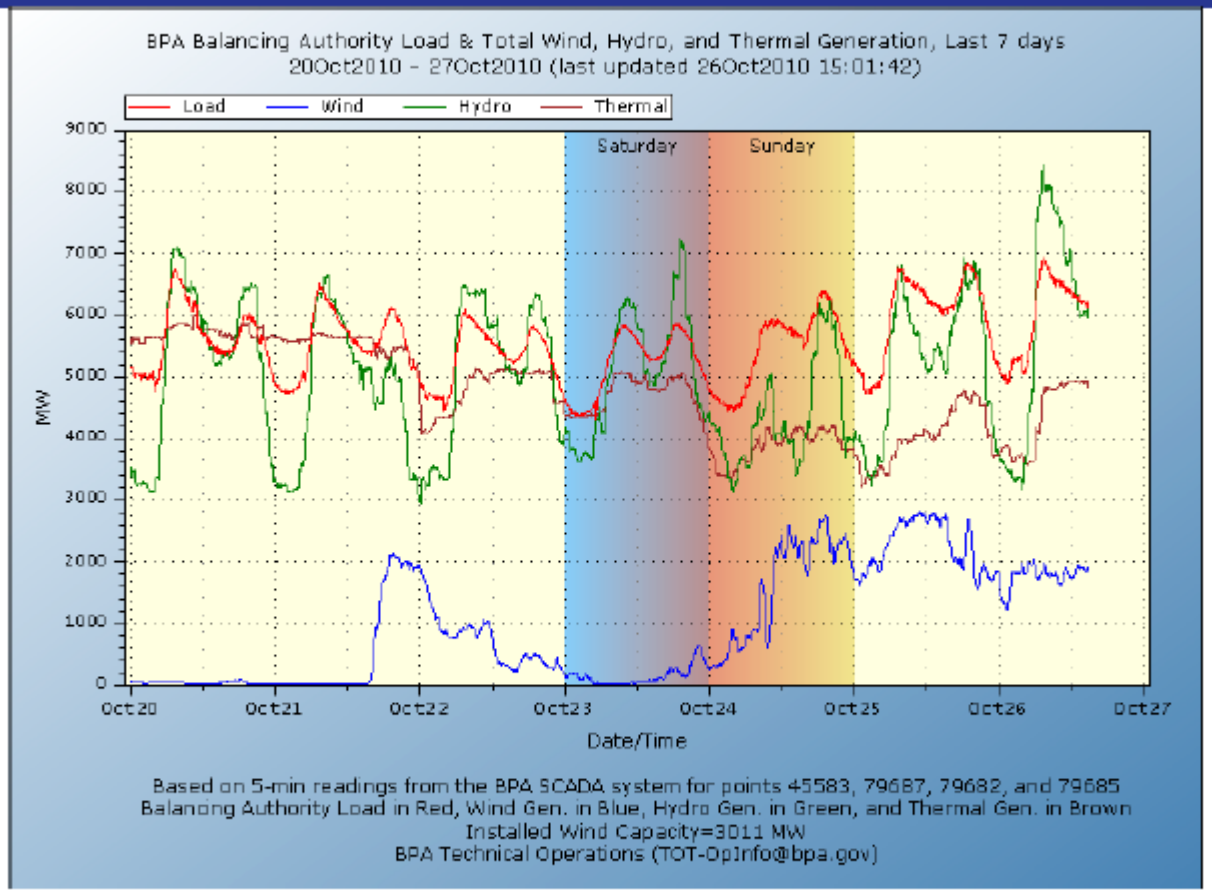
WIND GENERATION CAPACITY IN THE BPA BALANCING AUTHORITY AREA

Sequential Increases in Capacity, Based on Date When Actual Generation First Exceeded 50% of Nameplate

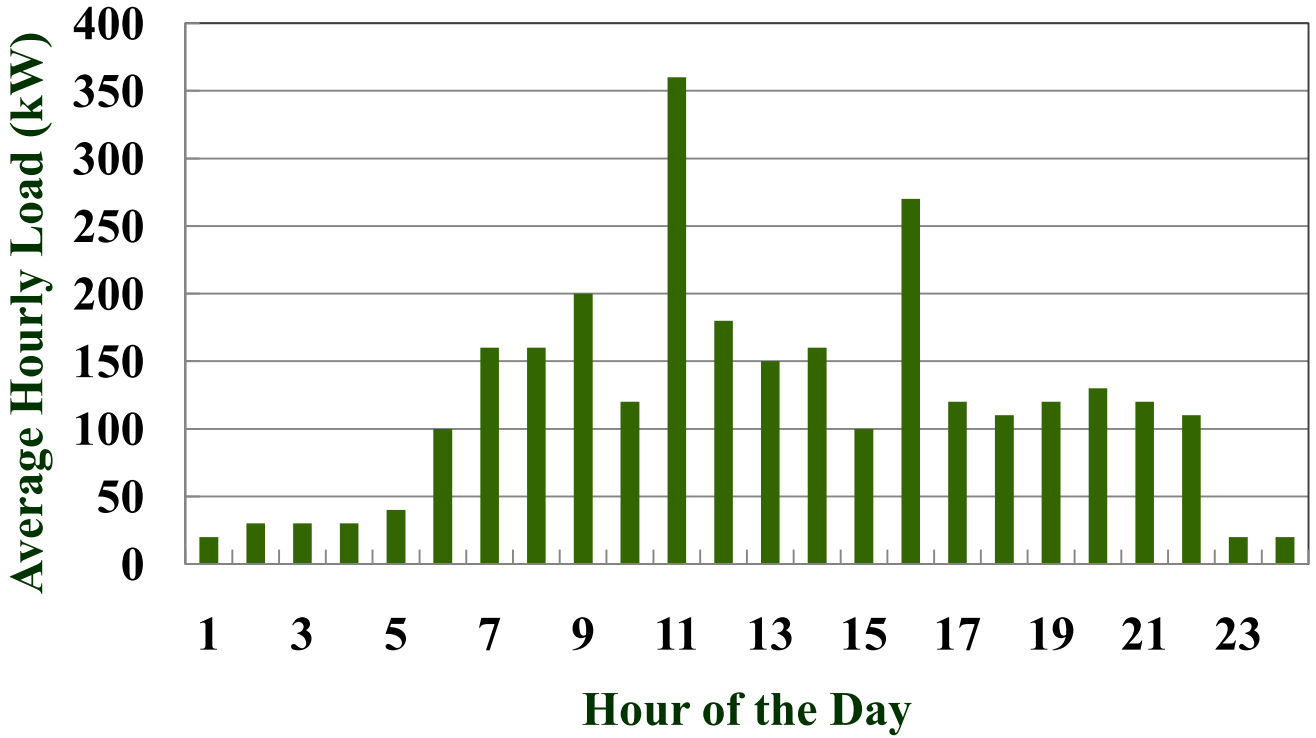
Plant	Nameplate Capacity MW	Date When Actual Gen First Exceeded 1/2 of Current Nameplate Capacity	Cumulative Nameplate Capacity MW
Vansycle	25	10/25/1998	25
Stateline	90	12/18/2001	115
Klondike I	24	1/16/2002	139
Condon	50	6/18/2002	189
Klondike II	76	6/28/2005	265
Hopkins Ridge	157	11/25/2005	422
Leaning Juniper	100	8/10/2006	522
Big Horn	200	10/4/2006	722
White Creek	200	10/5/2007	922
Klondike III	226	10/15/2007	1148
Biglow Canyon	126	11/17/2007	1274
Nine Canyon @ 28%	27	11/26/2007	1301
Goodnoe Hills	96	4/29/2008	1397
Nine Canyon @ 52%	24	5/10/2008	1421
Klondike 3a	75	6/6/2008	1496
Arlington	103	12/7/2008	1599
Willow Creek	72	1/1/2009	1671
Pebble Springs	100	1/27/2009	1771
Hay Canyon	100	2/12/2009	1871
Wheatfield	97	3/22/2009	1968
Tuolumne	137	5/1/2009	2105
Biglow Canyon Phase 2	149	8/6/2009	2254
Windy Flats Dooley (phase 1)	30	9/21/2009	2284
Windy Flats Dooley (phase 2)	233	11/30/2009	2517
Harvest	100	12/16/2009	2617
Combine Hills	63	1/1/2010	2680
Star Point	100	1/15/2010	2780
Linden Farm	50	6/6/2010	2830
Coastal Energy	6	6/30/2010	2836
Biglow Canyon Phase 2 (addl)	14	8/11/2010	2850
Biglow Canyon Phase 3	161	8/11/2010	3011



Wind Generation Experiences Significant Ramps

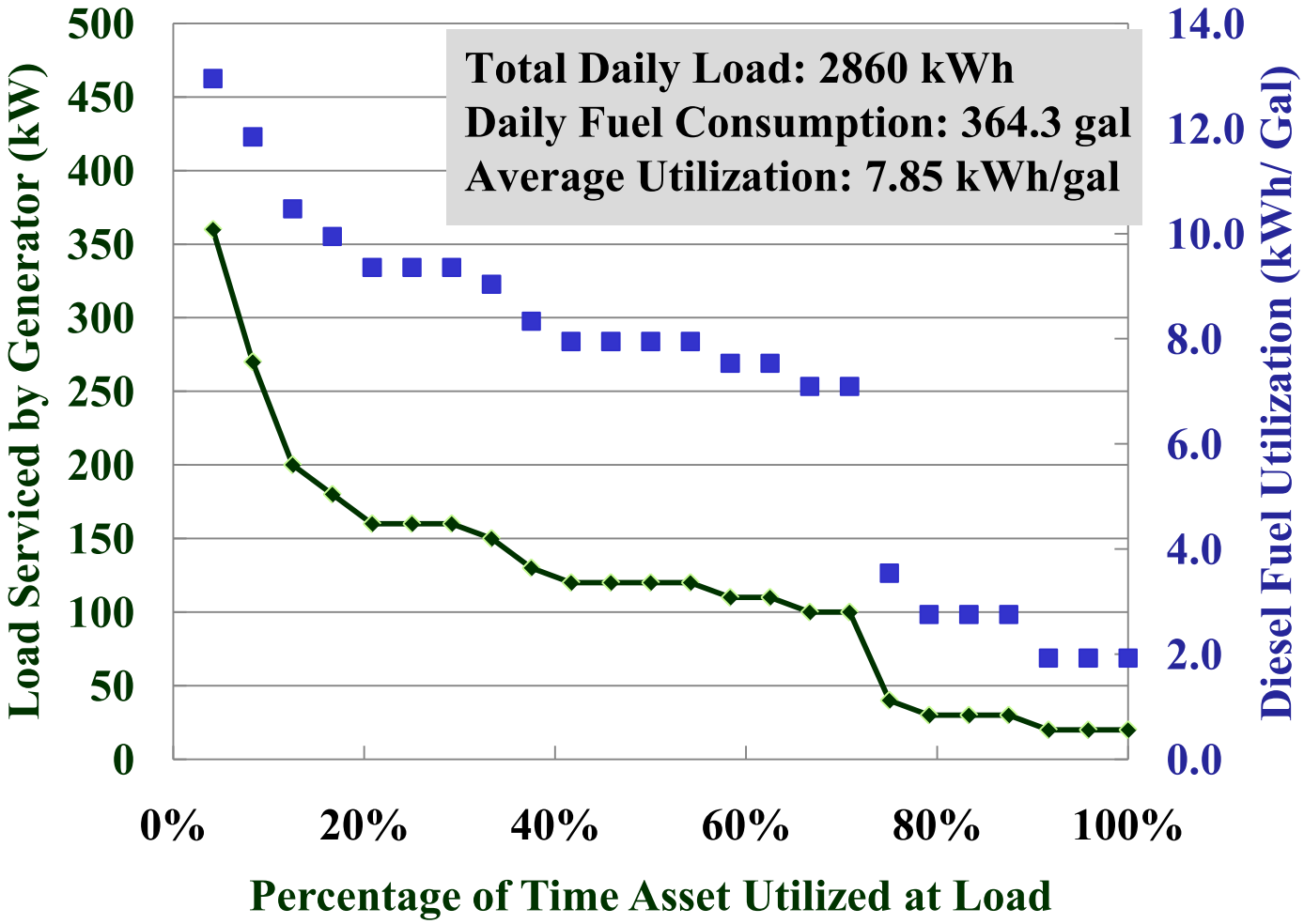


Service Loads Supported by Single Diesel Generator Through Day – Modesto, CA

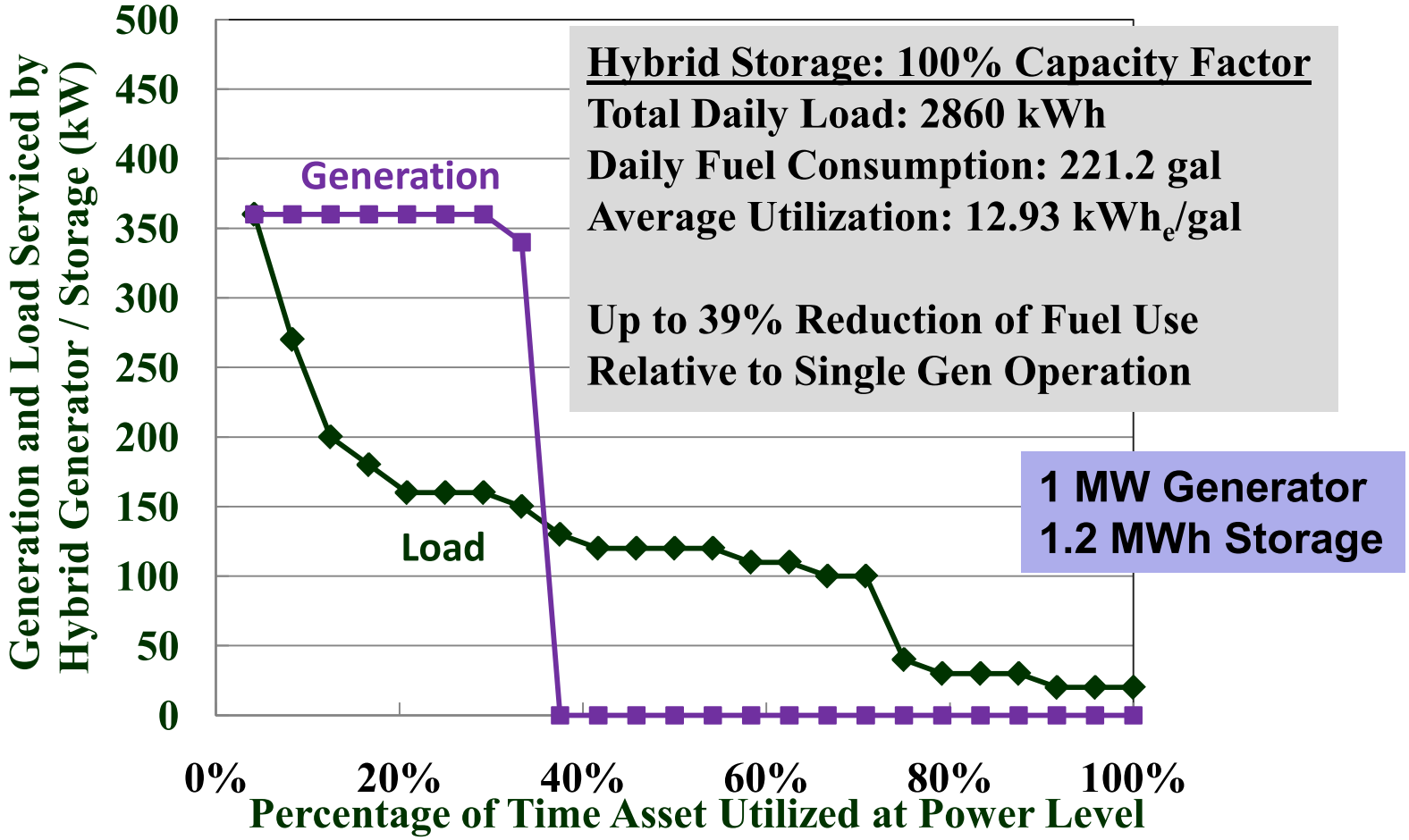


Commercial Data for Single Generator Operation From Primus Power
Need Similar Data for DoD Applications

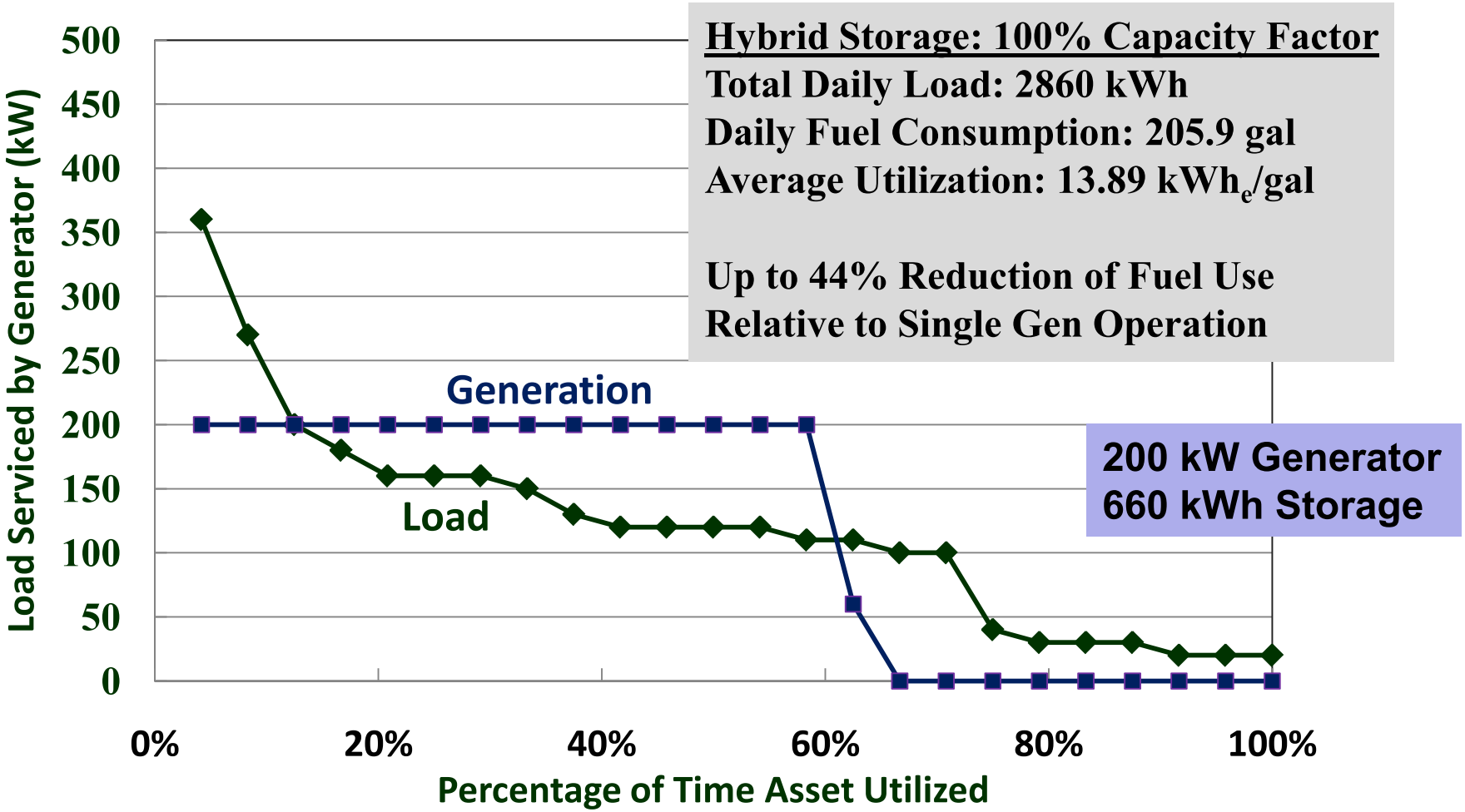
Load Duration Profile
1MW Diesel Single Generator Ops



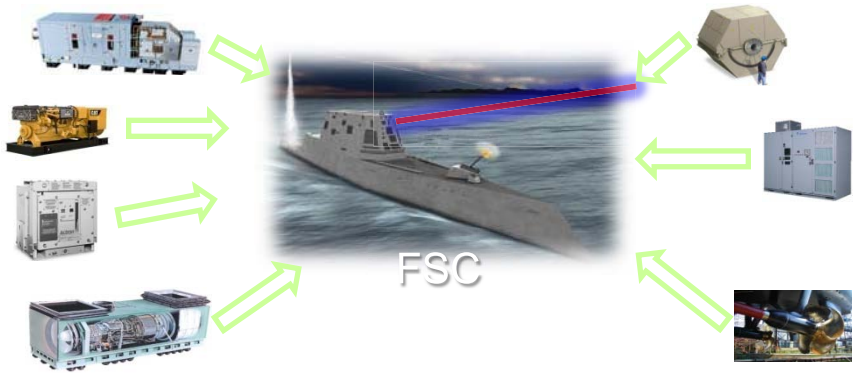
Load and Generation Profile
Ideal Hybrid Generator / Storage System

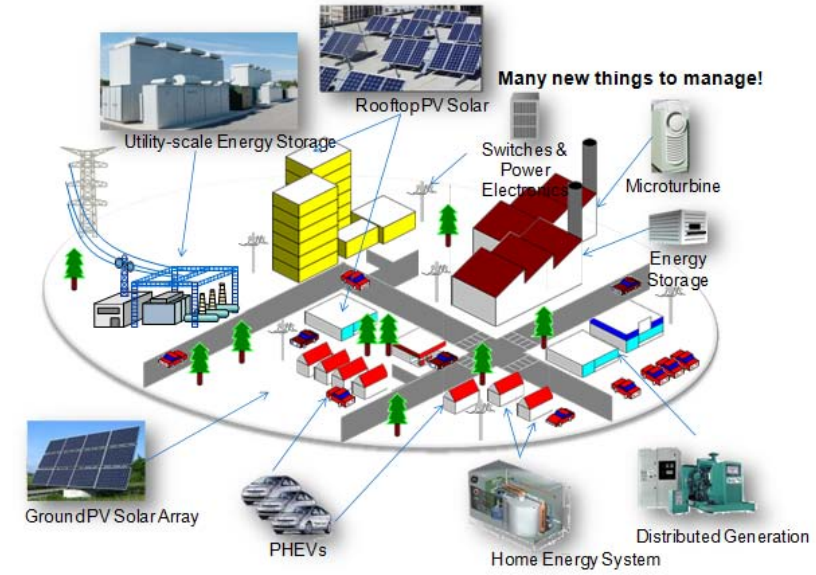


200 kW Generator + Hybrid Storage

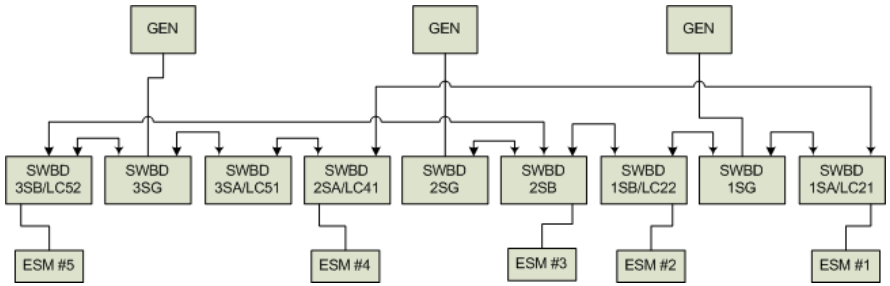


Technology Similarity – Land and Sea

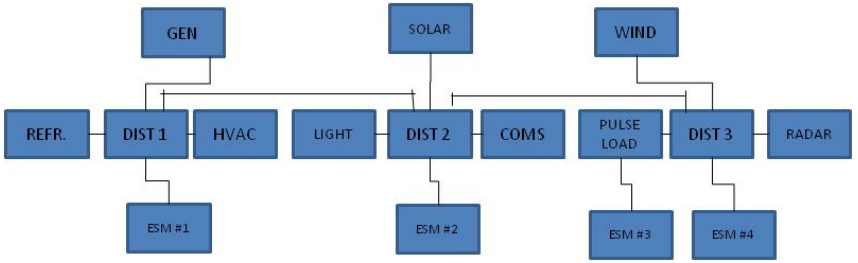




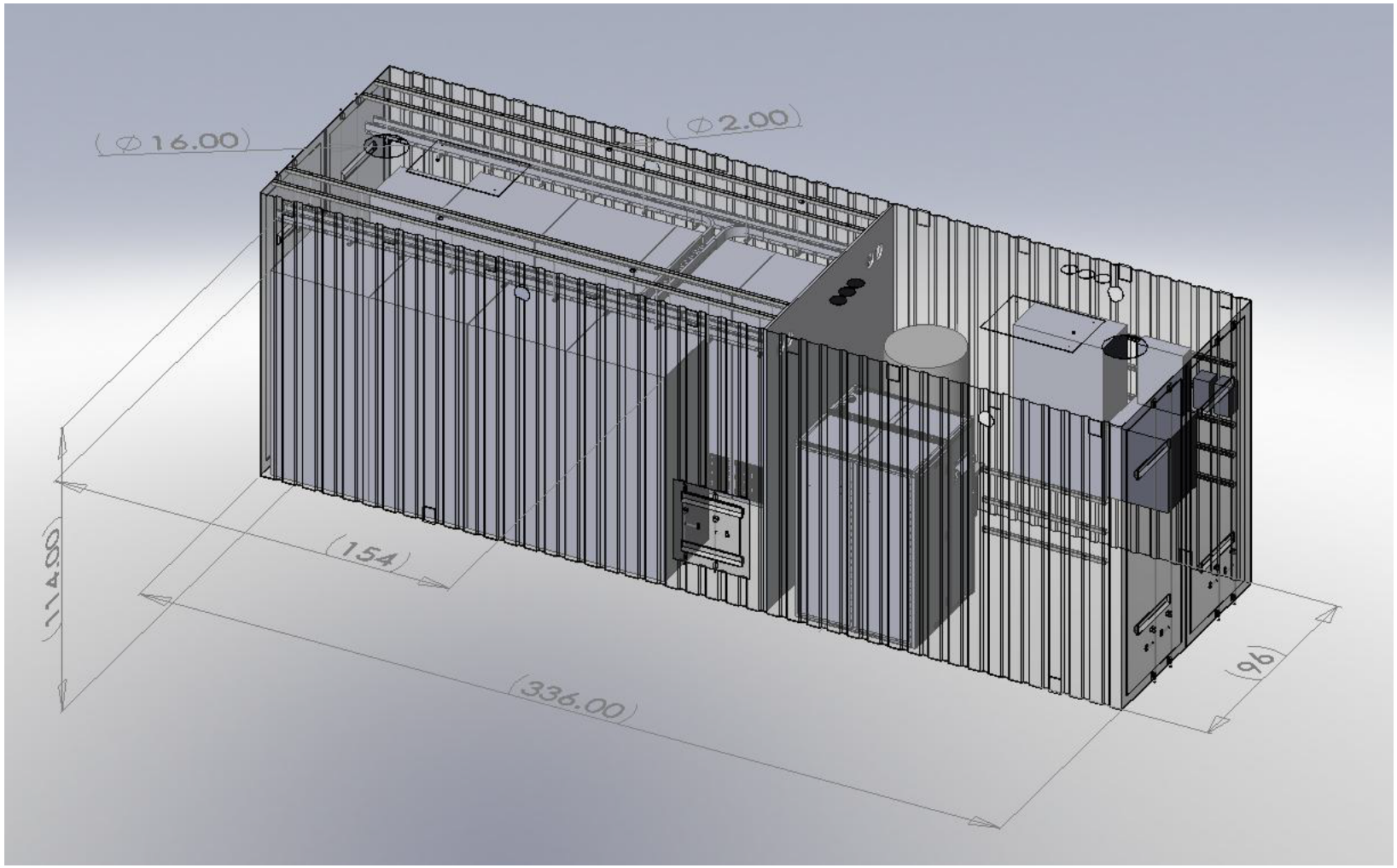
At Sea



On Land



ISO-Contained HESM



Dimensions not indicative of design approach