Balancing Shipboard Energy with Warfighting Needs

Naval Postgraduate School: Defense Energy Seminar

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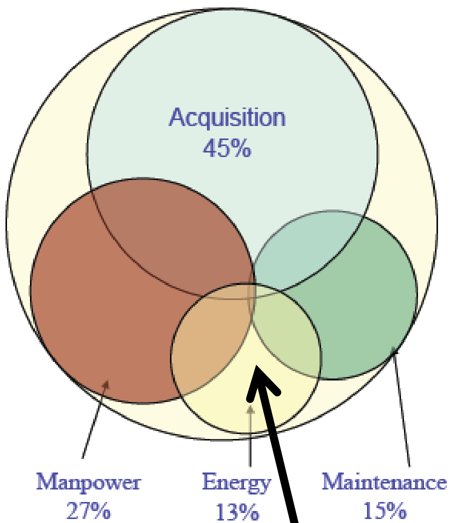
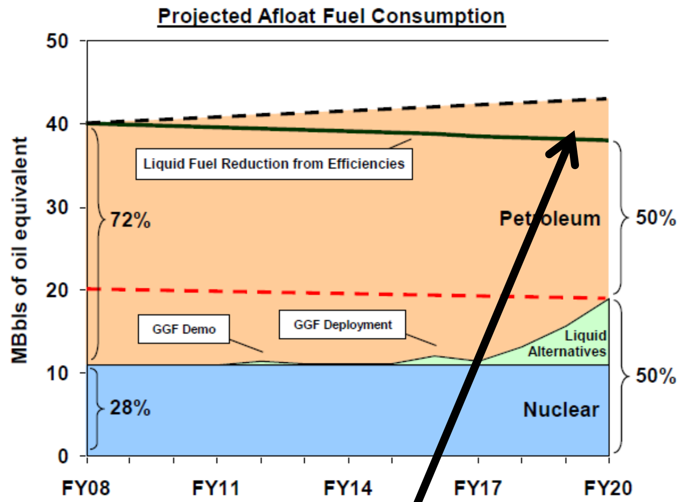
TWH: Future Power and Energy Storage Architectures, SEA 05Z35

The Situation

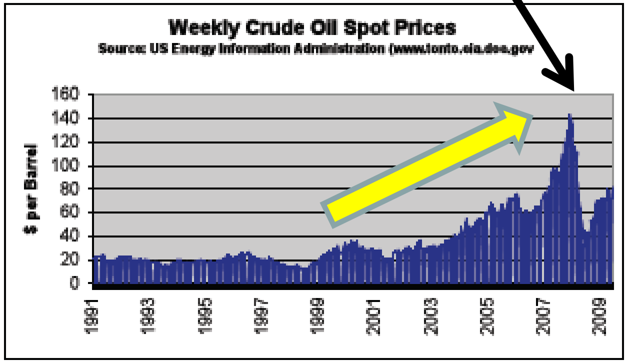
Typical Surface Combatant
Total Ownership Cost

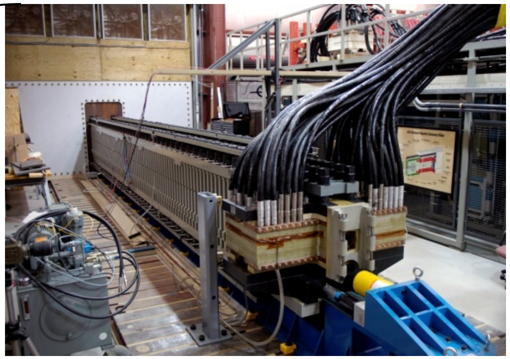


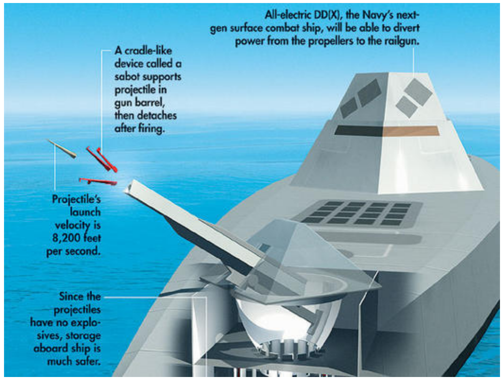


Energy is a substantial
And growing cost element

Energy management critical to controlling cost and maintaining capability in light of new load requirements.

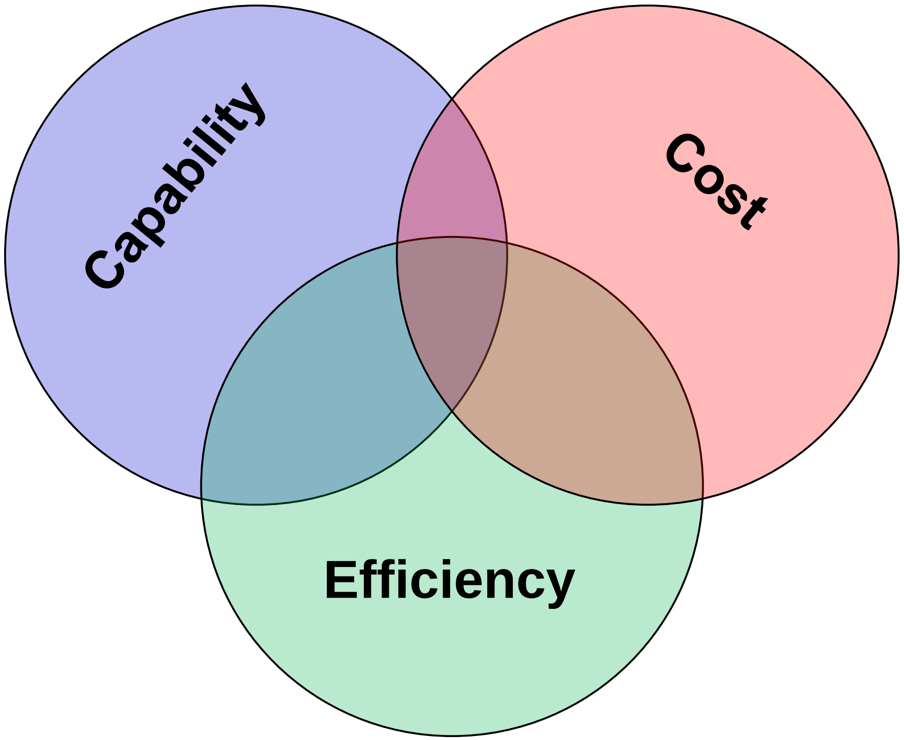






Energy is an Optimization Function

- Power
- Speed
- Size
- Weapons
- Sensors



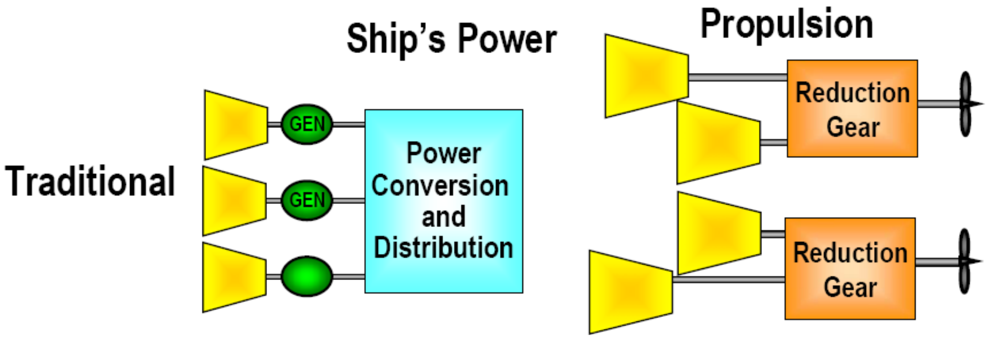
- Acquisition
- Maintenance
- Operational
- Reliability

- Fuel Burn
- Endurance Range

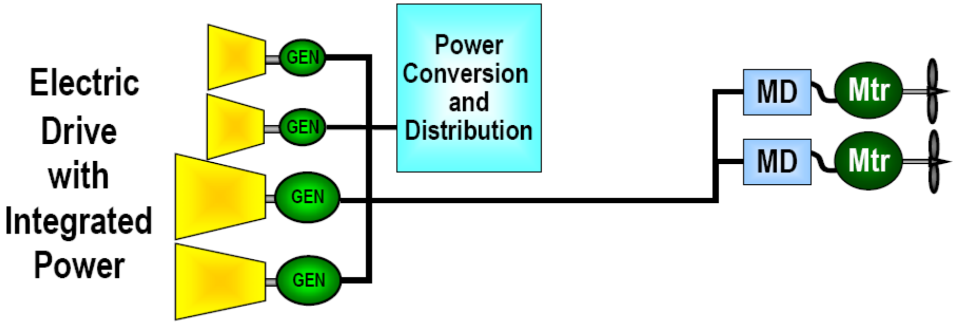
Significant Engineering is Necessary to Find the Right Cross-Section

Don’t Ships Have Lots of Power?

DDG-51 Flight 2A:
~9MW installed electric power; ~75MW installed mechanical propulsion

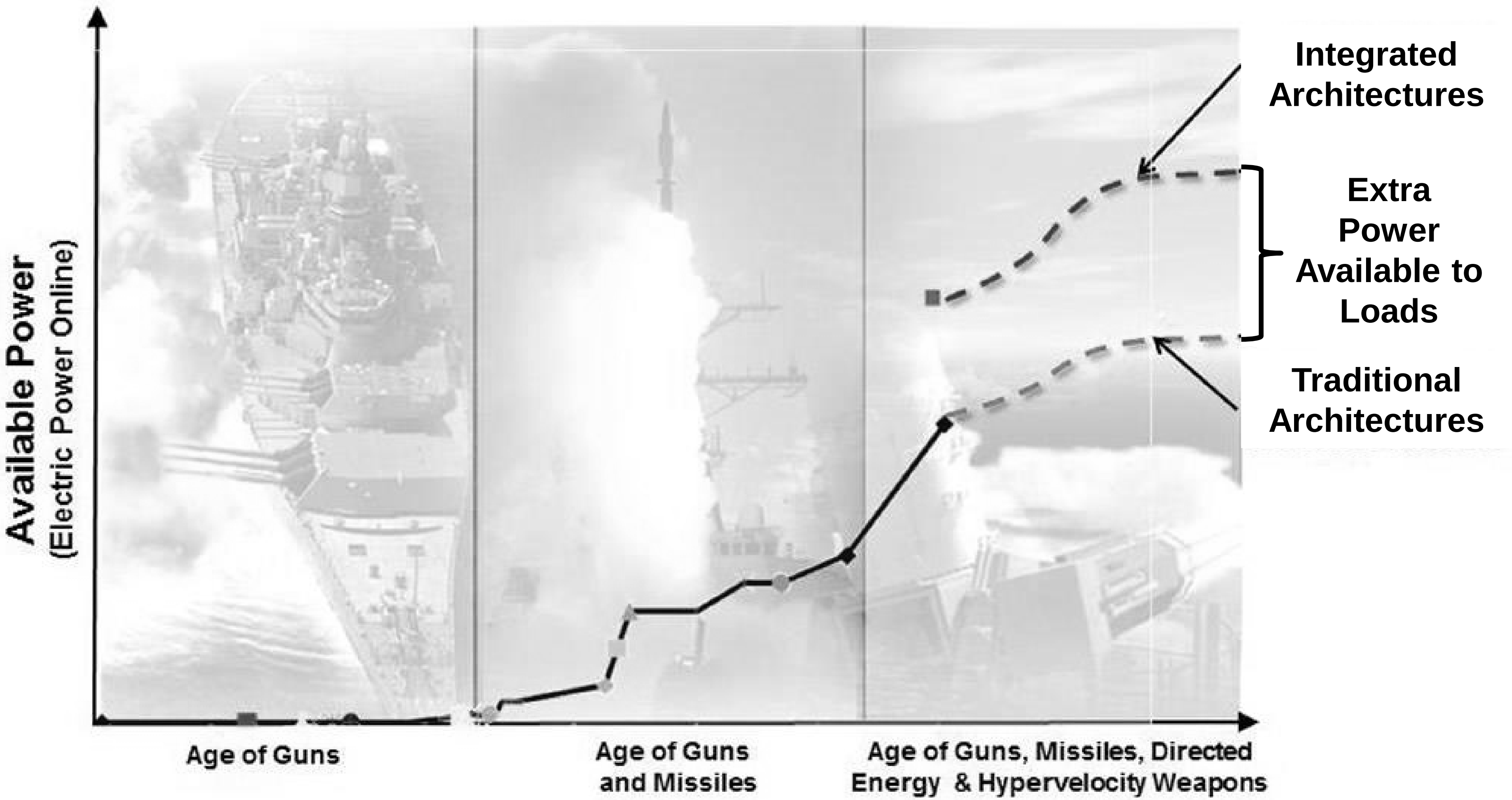


DDG-1000: ~78MW installed electric power



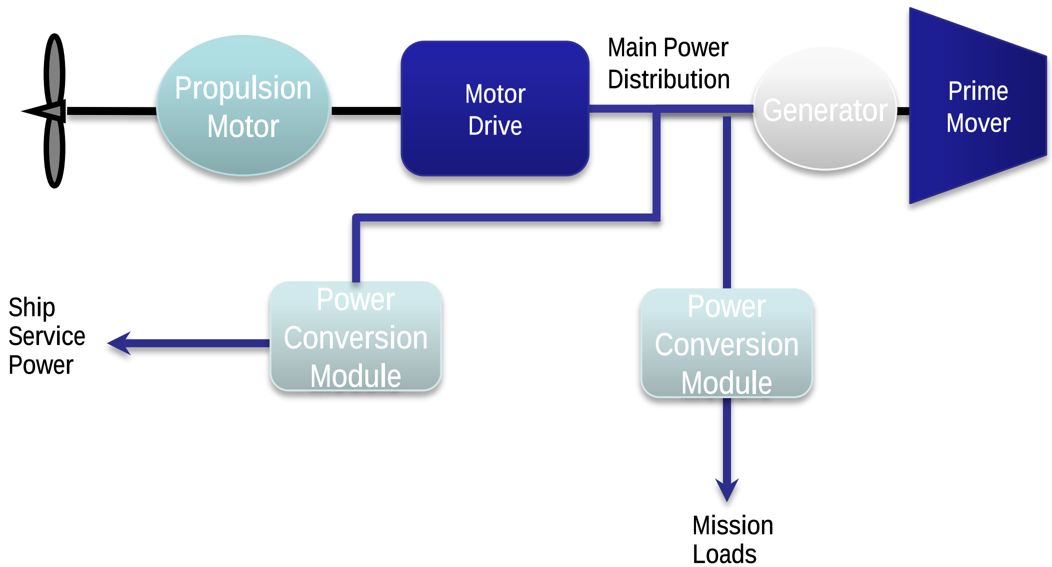
Accessing Power is Key…

Shipboard Electrical Power to Meet Mission Loads



Adapted from http://www.navsea.navy.mil/Portals/103/Images/TeamShips/PEOShips/ESO/Integrated_Architectures_figure2ex.jpg

Leveraging ALL Installed Power

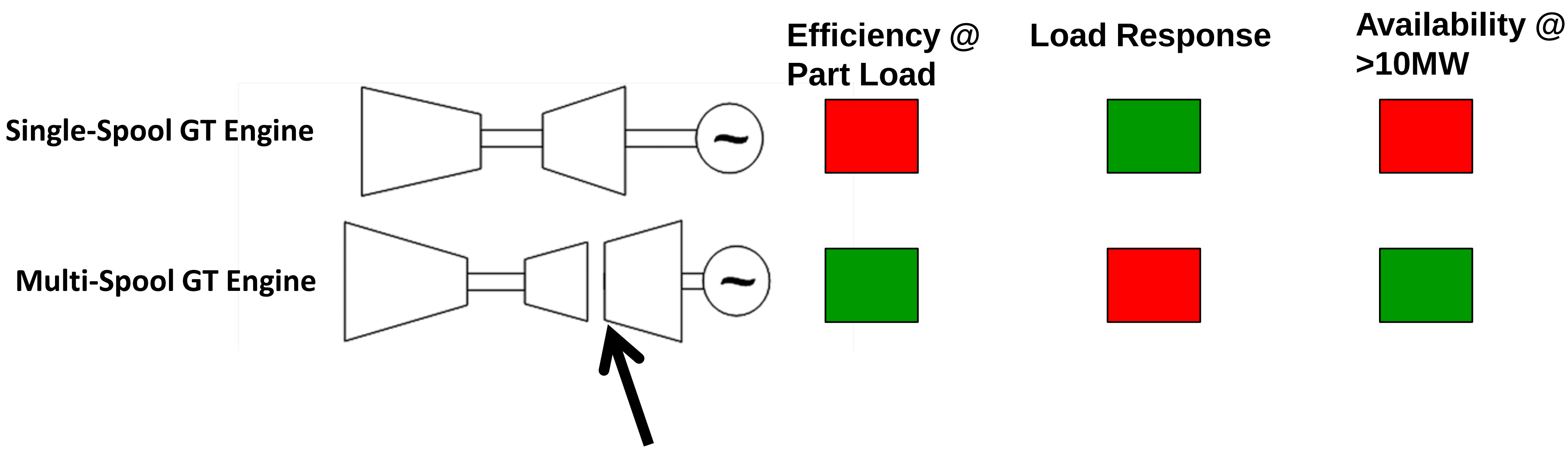


Power availability by ensuring all prime movers are accessible to all loads offers:

- **Additional and larger mission loads**
- **Power flexibility and optimization of plant loading**
- **Enhanced survivability if reconfigurable**

Gas Turbine Generator Transient Response

Accessing Power is Key…Not just the ratings



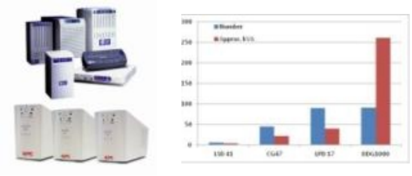
Aerodynamic couple in two-spool GTG makes transient concerns greater; however, available large GTGs all use this architecture.

Makes energy storage buffers necessary…

Energy Storage: A Means to Get Fuel Savings and Operational Capability

Energy Surety

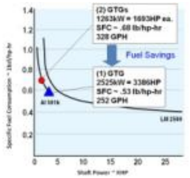
- Online storage devices for backup power
- UPS for protection of sensitive devices
- Closed, signature-free energy source



Increasing UPS and Batteries

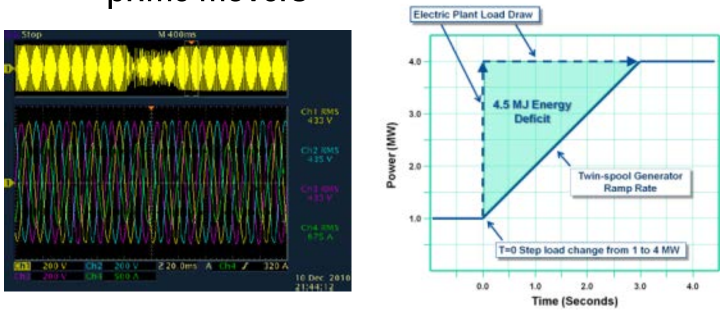
Fuel Savings

- Single Generator Operations (Shipwide UPS)
- Generator load optimization/scheduling
- Minimization of spinning assets
- Terrestrial distributions (microgrids)



Power Quality

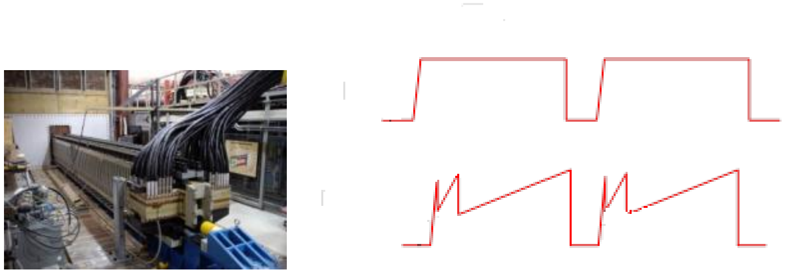
- Advanced GTG Transient ridethrough
- Load changes outside of design space for prime movers



Power Quality Surety Under Two-Spool GTG Application

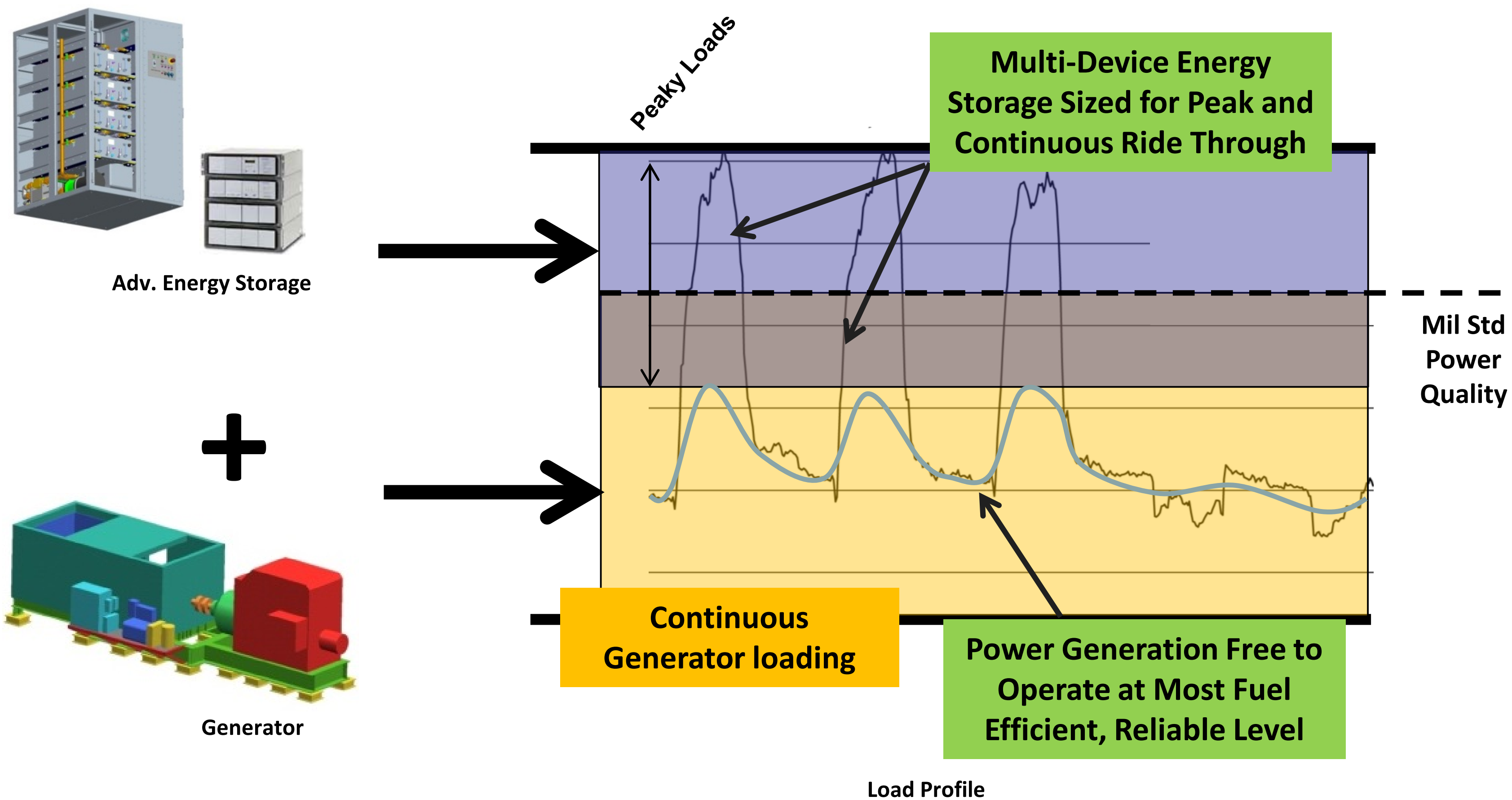
Advanced Loads

- Pulsed applications
- Highly transient loads
- Cyclic load requirements



Potential Mission Load Profiles

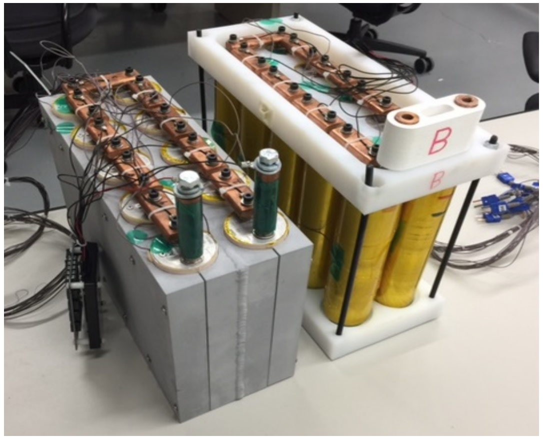
Future Operational Mode



Optimize storage buffering prime movers to enable continuous Directed Energy Weapons operations with optimized, efficient loading of spinning assets…

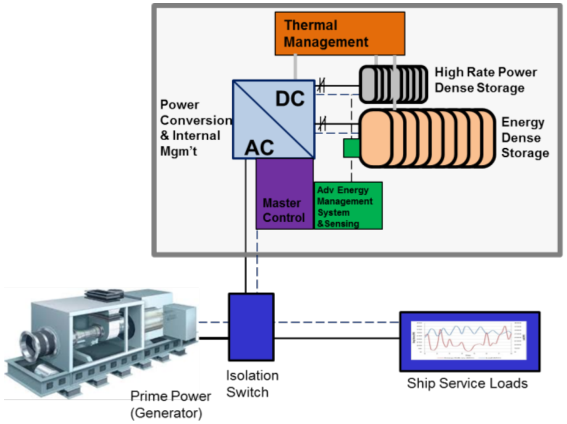
Energy Storage Approaches

Batteries



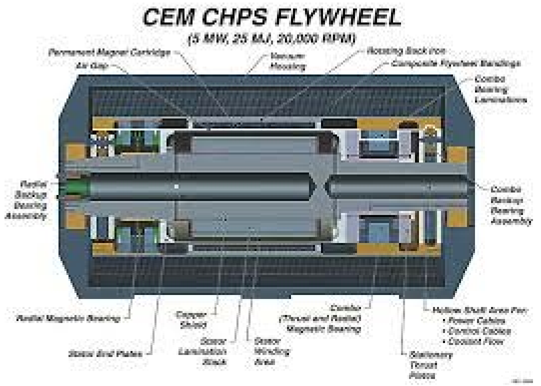
- Typically Lithium-Iron Phosphate for Shipboard use
- Future innovations welcome
- High power, low impedance variants necessary; Power density and thermal performance emphasized
- Safety behaviors are critical
- Solid BMS and sensing

Hybrids



- Battery-Capacitor; Battery-Flywheel and Battery-Battery variants offer benefits in various applications
- Supports high rate and high ripple/noise applications
- Superior dispatch characteristics
- Mix and match at the LRU level

Flywheels

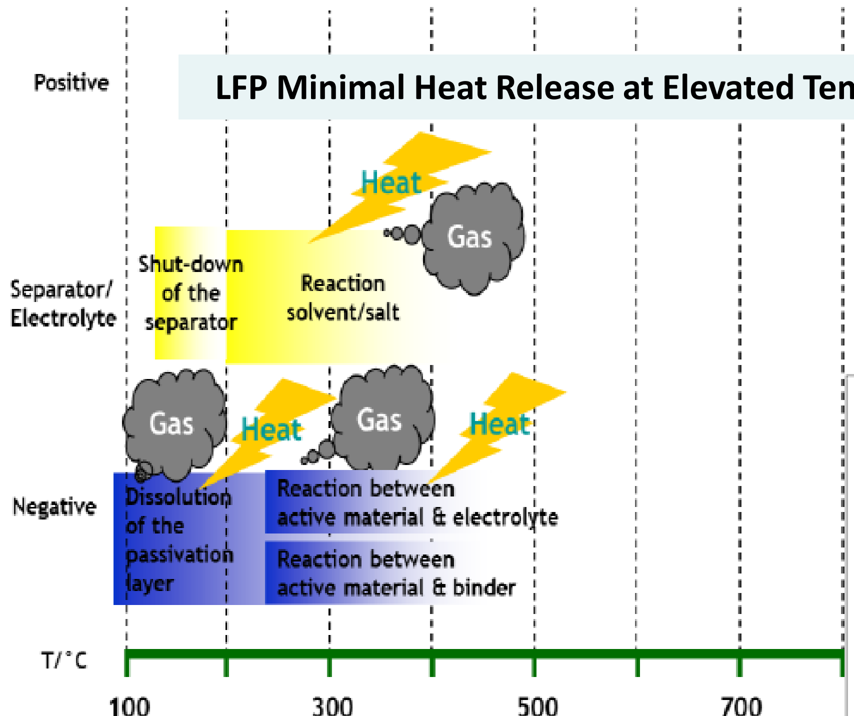


- Scales with square of rotational speed, which enables density advantages
- Efficiency, thermal management and safety are critical
- Advanced materials and shock tolerant designs are desirable to ensure life and performance

Battery Safety: Heat Release Under Abuse/Failure

Lithium Iron Phosphate (LFP) Identified as Near-Term Selection Li-ion Chemistry for High Power, Impedance and Safety

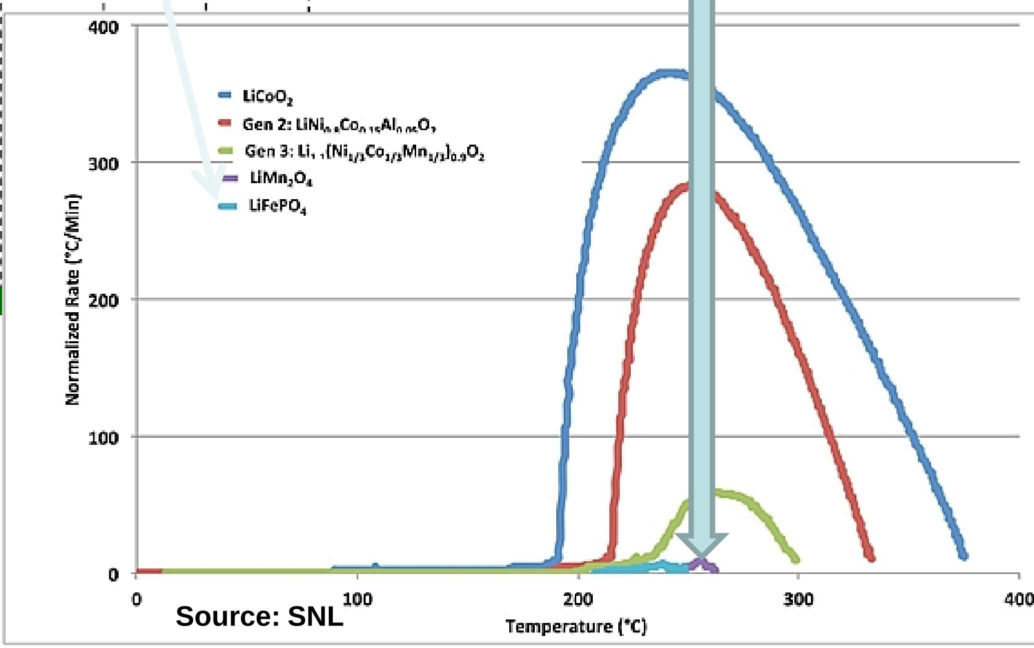
LFP Minimal Heat Release at Elevated Temps



Source: Saft

Electrolyte, separator and negative electrode are still thermal contributors

Minimal positive electrode contribution



Source: SNL

Similarity of Applications

Safe, efficient systems are critical to adoption and widespread use

Multiple-rate, high power/energy systems with appropriate thermal Characteristics are necessary for adoption

Commercial

Storage at Grids Edge

Transportation

Military

Aircraft

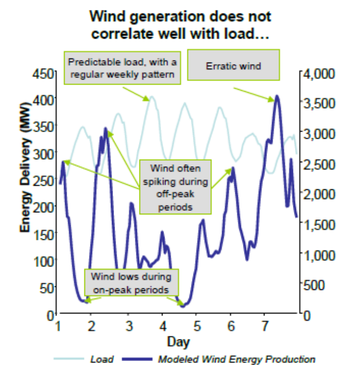
Ships

Subs

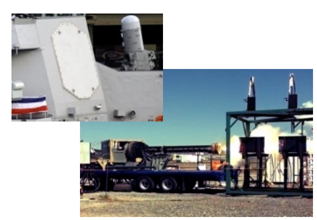
Vehicles

Commercial

Grid Stabilization



Military



High Rate Weapons & Sensors

Forward Operating Bases

Generator Ride Through

How to Balance Loads and Available Energy: Data and Decision Making

DATA SOURCES

eRM Sensors

- Fuel Flow Meters
- Electric Plant Load Sensors
- AC Plant

How much fuel is being used?
What power is being generated?

eLogBooks

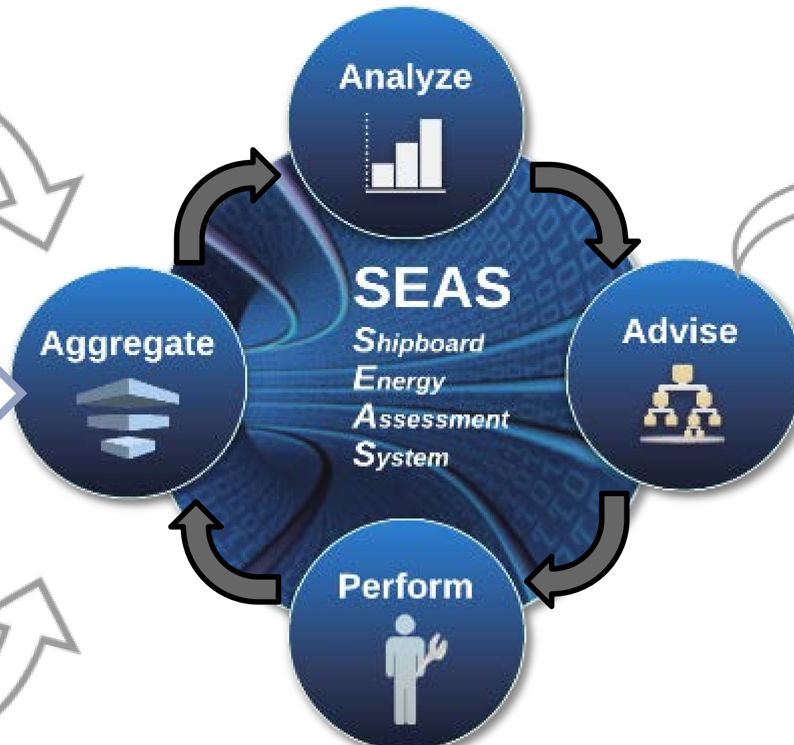
- Weather
- Sea

Why is energy being used this way?

Combat Systems

Future capability: What energy is required to accomplish the mission?

ENERGY MANAGEMENT: Advanced Controls and Decision Making



USERS

Shipboard

CO/ XO: Fuel penalty of delayed maintenance. Most efficient / ready watch team.

TAO: Availability of plant and resources to execute mission sets

CHENG: Impact of current material status on energy usage

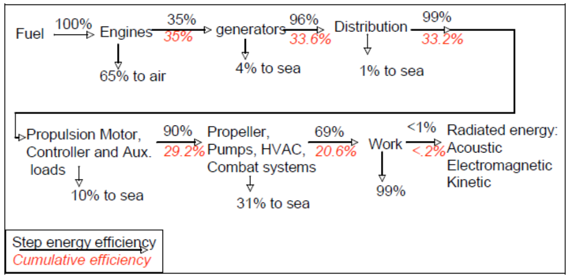
MPA: Energy savings for defouling

Combined Electric Ship With Storage

Plant Efficiency + Power Accessibility = Efficient , Available Power that is part of the Kill Chain

Optimization of Plant Genset Lineup and Loading

Future High-Efficiency Sources, e.g. Fuel Cells



Higher Efficiency of Power Utilization for Electrical and Propulsion Loads

Source: Doerry et. al, 2010

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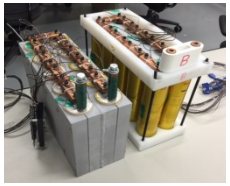
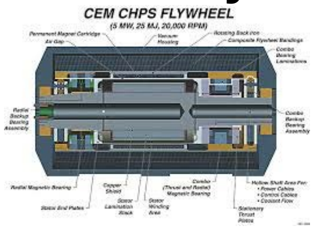
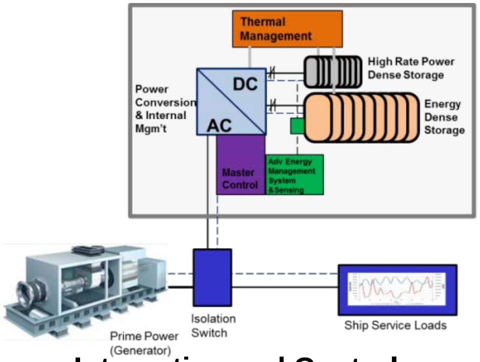




Storage Components



Integration and Control

Active Decision Making

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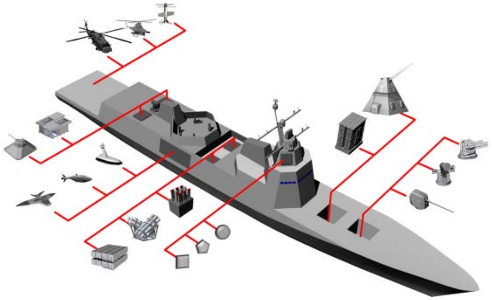

SEA 05D Rendition of a Notional Next-Generation Flex-Ship

Opportunities for Innovation

- Safe, common, affordable batteries, capacitors, flywheels and other storage innovations
- Compact and efficient power conversion
- Innovative means of managing highly transient loads
- New approaches to improve engine (diesel & GT) response rates
- Thermal management
- Commonality
- Control

Conclusions

- Present and emerging threats will continue to increase the electrical power demand on warships
- Management of generation, quality, and load will enhance or, perhaps *enable* the fight
- The ideal power management architecture will harness all installed power yet provide the maximum flexibility
  - Margin in the form of quantity
  - Flexibility to quickly switch electrical power use between propulsion, weapons, sensors and more
  - Efficiency under all operations

QUESTIONS?