Next Generation Power and Energy

EXPONAVAL 2010

02 December 2010

Valparaiso, Chile

CAPT Lynn Petersen

Deputy Director

PMS 320 (ESO)

(Presented by: Dr. Peter Cho

ONR Global)

Report Documentation Page

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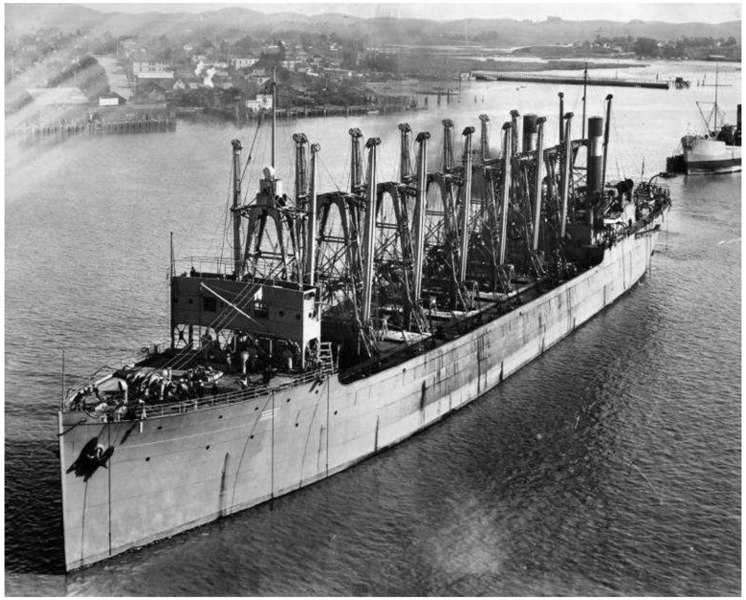
Outline

- **Brief History of Navy Electric Drive**
- **Challenges/Opportunities**
- **Next Generation Integrated Power System**
- **Open Architecture Business Model**
- **Intelligent Ship/Power Dense Technologies**
- **Hybrid Electric Drive (HED)**

Electric Ships Office
ESO
Directing the Future of Ships Power

Electric Drive

PEO SHIPS



USS Jupiter

Commissioned 1913

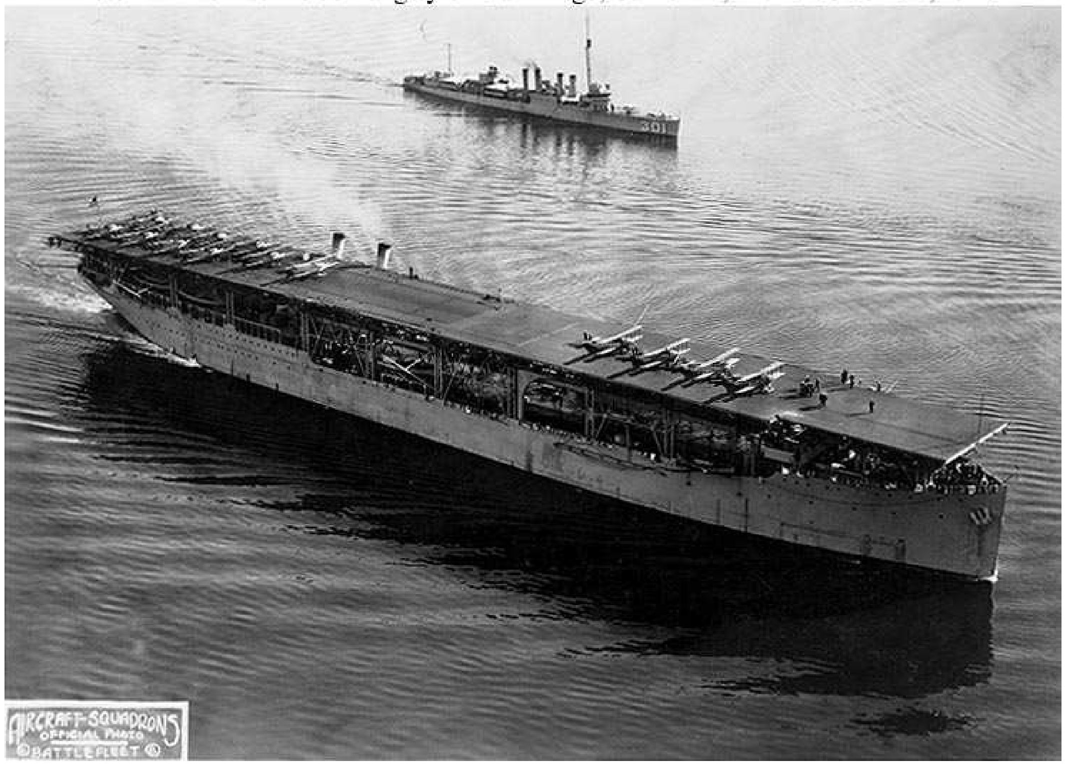
- Collier -

USS Langley

Recommissioned 1922

- First US Aircraft Carrier -

Photo # NH 81279 USS Langley off San Diego, California, with USS Somers, 1928



Today's Integrated Electric Ships

PLATFORM	RESULTS
	**Amphibious Assault (LHD 8)** ◆ The first U.S. Navy amphibious ship built with Gas Turbine Engines and Hybrid Electric Drive resulting in **significant fuel savings compared with steam driven LHD**
	**Combat Logistics Force (T-AKE)** ◆ T-AKE is powered by a commercial integrated power system, providing **reduced acquisition and life cycle costs**
	**Surface Combatant (DDG 1000)** ◆ ZUMWALT's Integrated Power System (IPS) combines **78MW of installed power** generation for propulsion and ship service into a single unified electrical system.

Meeting the Mission with Increased Power and Reduced Costs

Other Naval Trends…

UK (23 + IPS/hybrid ships)

- Type 23 Frigate, in-service – hybrid electric/mechanical drive
- Type 45 Destroyer, in-service – full Integrated Power System
- Albion Class LPD, in-service – full Integrated Power System
- Wave Class Oiler, in-service – full Integrated Power System
- CV(F) under contract – full Integrated Power System

France

- BPC (LPD) in-service, Podded Integrated Power System
- Future CV in design – full IPS, maybe Pods

Netherlands (2 ships)

- LPD “Rotterdam” Class, in-service – full Integrated Power System
- IPS declared for future surface combatants

France, Italy, Greece, Morrocco

- FREMM Frigate – Hybrid Drive (28 planned, 4 under construction)

Germany

- U-212 Submarines
  - Diesel Electric w/ PM Motors
  - AIP systems using fuel cells

All diesel submarines are electric drive

Australia (2 ships)

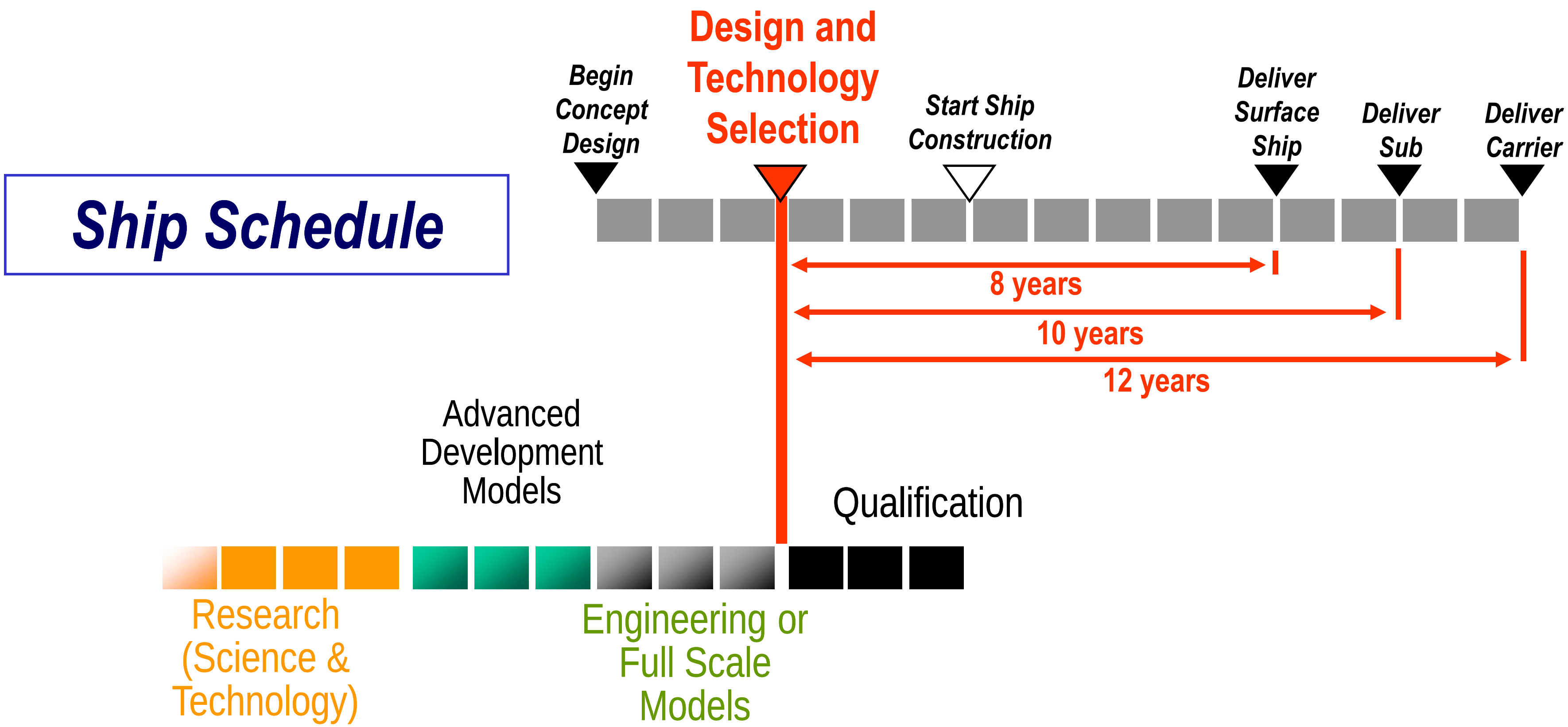
- Canberra Class LPD - Podded IPS
- Collins Class SSG - diesel-electric

…many other Navies interested

Our Challenges

- Reduce Fuel Dependency
- Greater Demands for Power
- Control Costs

… Also The Challenge of New Technology



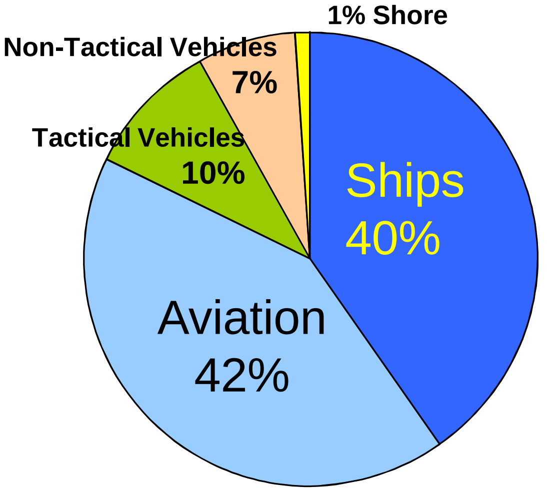
To Reduce Risk and Costs, Engineering Development Models Must Precede "Design and Technology Selection"

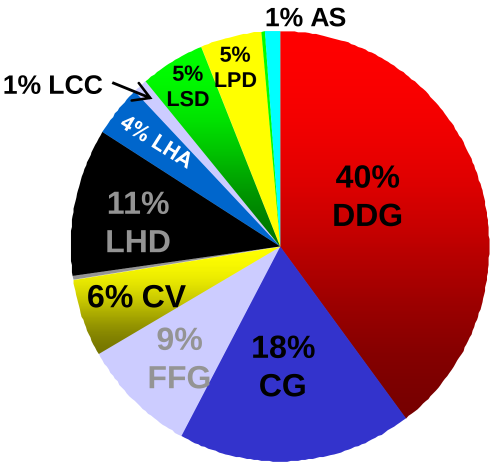
How Do We Meet Our Challenges

- Fleet-wide Analysis of Demand
- Early Investment in Technology
- Integrated System Demonstrations

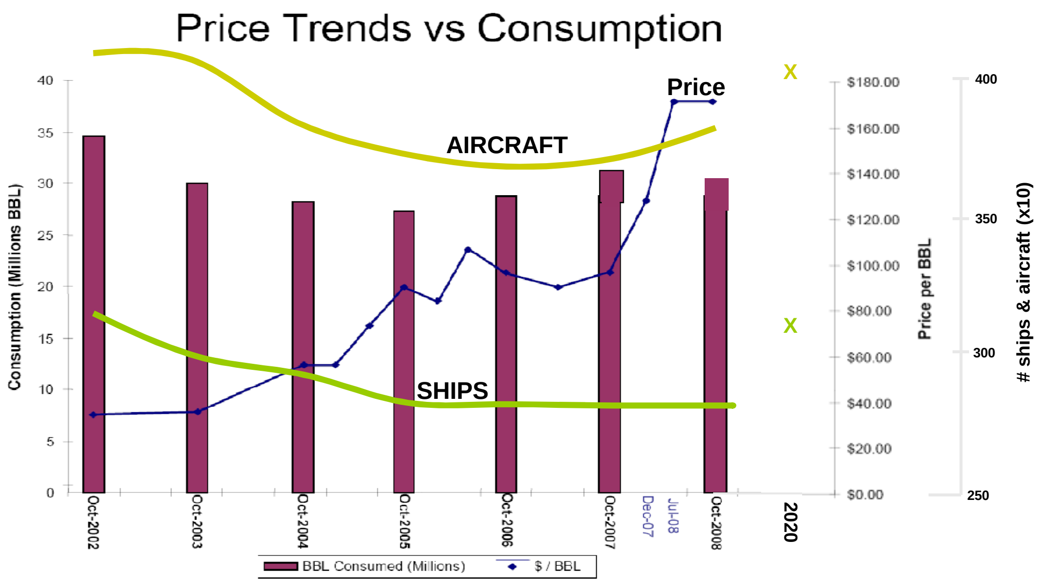
Navy Fuel Usage and Trends

FY07 DON Fuel Usage
(38.8 Million Barrels)





PRICE TRENDS VS NAVY SHIP / AIRCRAFT CONSUMPTION

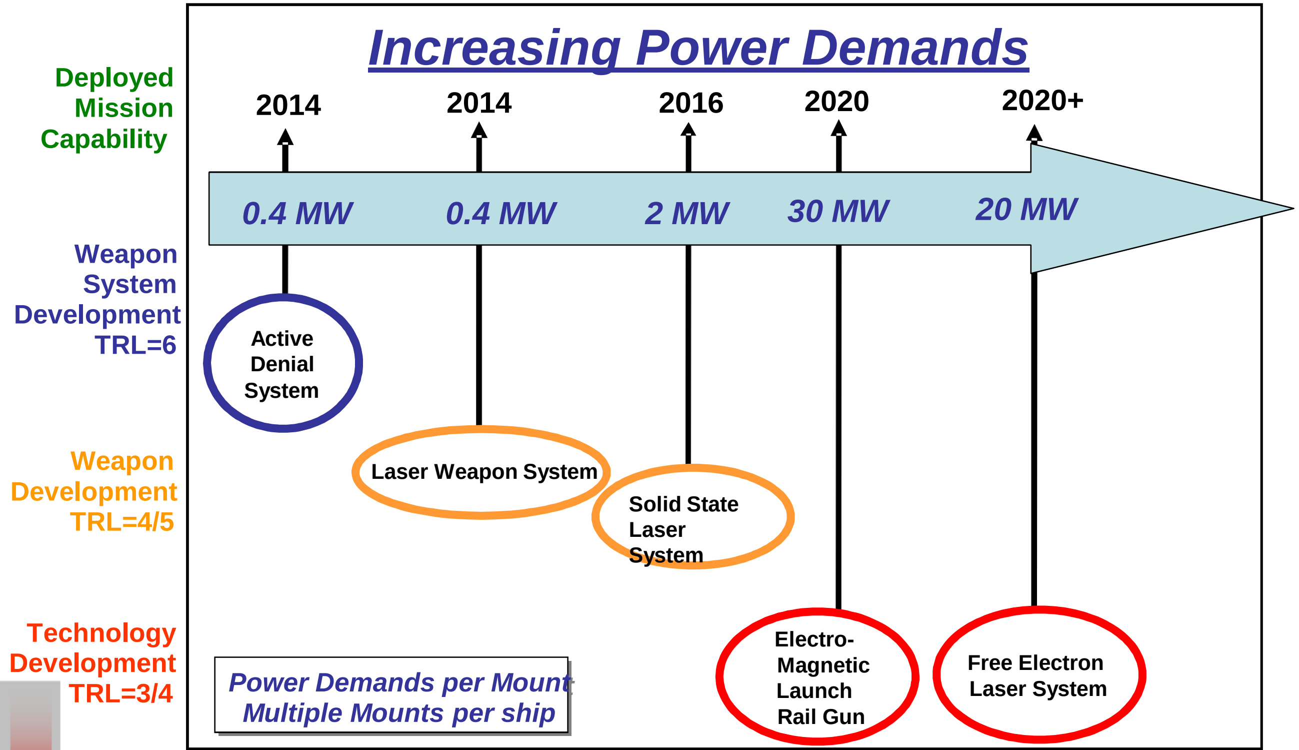


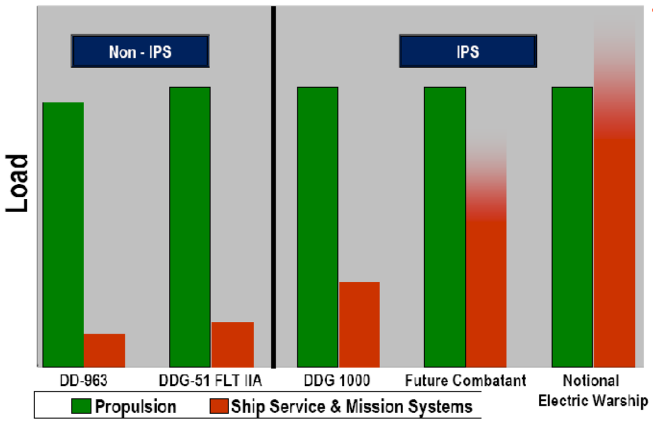
Expected FY09 fuel bill: $5.3B
Per bbl cost +400% since FY03

- **Energy (fuel) demand will increase**
  - **Combat / Weapons power**
  - **Force Structure changing – Higher fuel consumption**
  - **Operational requirements**
- **Fuel cost uncertainty – Probably**

Distribution A: Cleared for Public Release

Support High Power Mission Systems





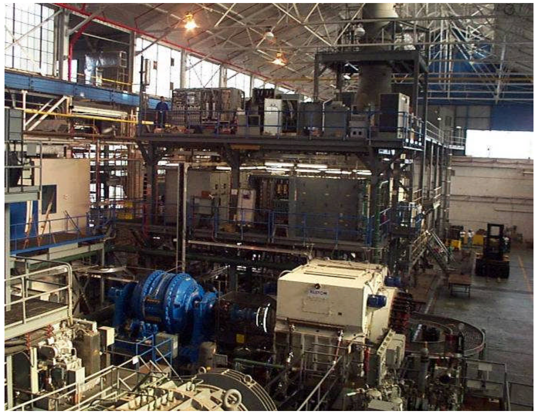
Sensor and Weapons Power Demands will Rival Propulsion Power Demands

April 2009

Integrated, Large Scale System Demonstrations: Electric Ship INP

Electric Ships Office
ESO
Directing the Future of Ships Power

PEO SHIPS



POWER SYSTEM

NGIPS Technology Development Roadmap

Fuel Savings

Operating and Support Cost Game Changer

ELECTRIC WEAPONS

High Power Weapons & Sensors Integrated Support Systems

Mission Capability

Acquisition Cost Game Changer

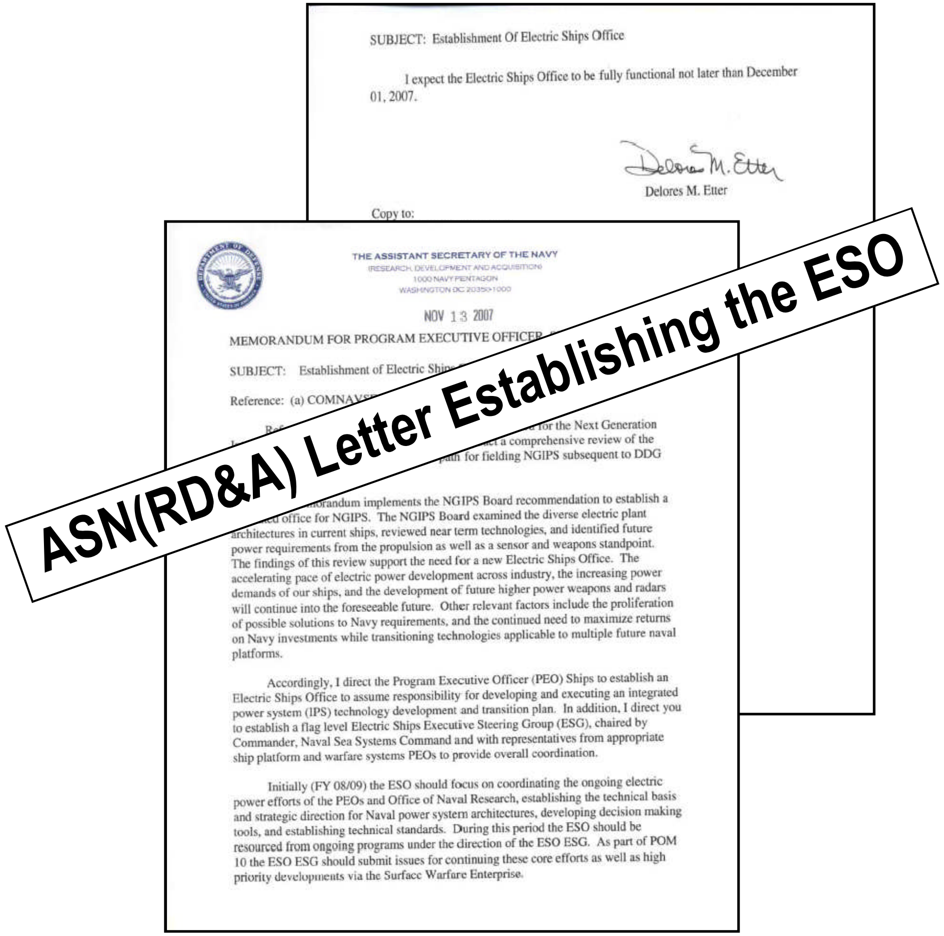
Electric Ship Prototype
Innovation Naval Prototype

NEXT GENERATION INTEGRATED POWER IS KEY ENABLER OF FUEL EFFICIENCY AND ADVANCED WEAPON SYSTEMS

Outline

- Brief History of Navy Electric Drive
- Challenges/Opportunities
- **Next Generation Integrated Power System**
- **Open Architecture Business Model**
- Intelligent Ship/Power Dense Technologies
- Hybrid Electric Drive (HED)

ASN(RD&A) Letter
Establishing the Electric Ships Office / 13 Nov 2007



SUBJECT: Establishment Of Electric Ships Office

I expect the Electric Ships Office to be fully functional not later than December 01, 2007.

Delores M. Etter

Copy to:

THE ASSISTANT SECRETARY OF THE NAVY
(RESEARCH, DEVELOPMENT AND ACQUISITION)
1000 NAVY PENTAGON
WASHINGTON DC 20350-1000

NOV 13 2007

MEMORANDUM FOR PROGRAM EXECUTIVE OFFICER

SUBJECT: Establishment of Electric Ships

Reference: (a) COMNAV

for the Next Generation ... a comprehensive review of the ... path for fielding NGIPS subsequent to DDG

...morandum implements the NGIPS Board recommendation to establish a ... office for NGIPS. The NGIPS Board examined the diverse electric plant architectures in current ships, reviewed near term technologies, and identified future power requirements from the propulsion as well as a sensor and weapons standpoint. The findings of this review support the need for a new Electric Ships Office. The accelerating pace of electric power development across industry, the increasing power demands of our ships, and the development of future higher power weapons and radars will continue into the foreseeable future. Other relevant factors include the proliferation of possible solutions to Navy requirements, and the continued need to maximize returns on Navy investments while transitioning technologies applicable to multiple future naval platforms.

Accordingly, I direct the Program Executive Officer (PEO) Ships to establish an Electric Ships Office to assume responsibility for developing and executing an integrated power system (IPS) technology development and transition plan. In addition, I direct you to establish a flag level Electric Ships Executive Steering Group (ESG), chaired by Commander, Naval Sea Systems Command and with representatives from appropriate ship platform and warfare systems PEOs to provide overall coordination.

Initially (FY 08/09) the ESO should focus on coordinating the ongoing electric power efforts of the PEOs and Office of Naval Research, establishing the technical basis and strategic direction for Naval power system architectures, developing decision making tools, and establishing technical standards. During this period the ESO should be resourced from ongoing programs under the direction of the ESO ESG. As part of POM 10 the ESO ESG should submit issues for continuing these core efforts as well as high priority developments via the Surface Warfare Enterprise.

"I direct the Program Executive Officer (PEO) Ships to establish an Electric Ships Office to assume responsibility for developing and executing an integrated power system (IPS) technology development and transition plan."

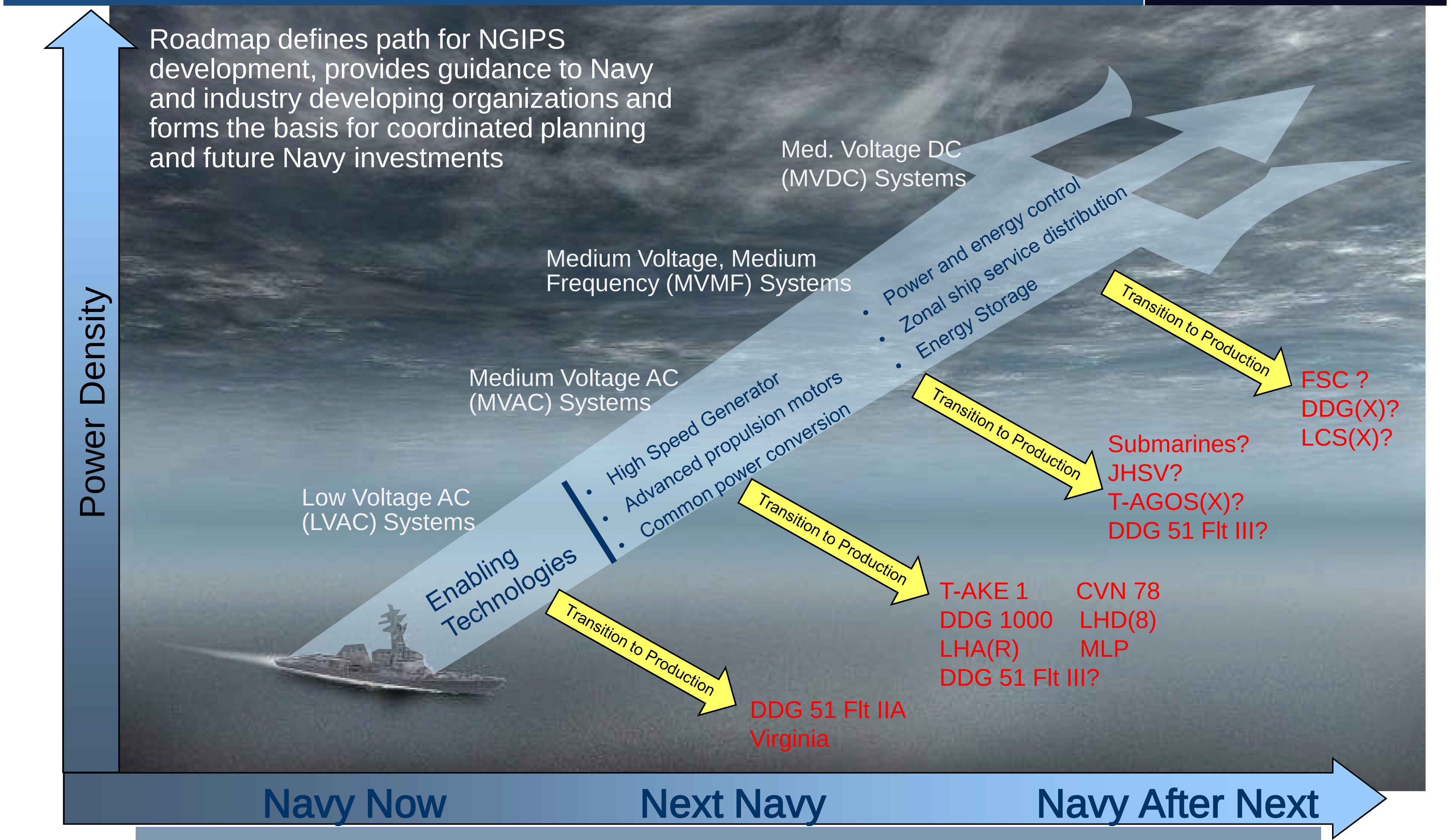
Message: Develop and Execute NGIPS Technology Development Roadmap

Next Generation Integrated Power System (NGIPS) Technology Development Roadmap (TDR)

Electric Ships Office

ESO

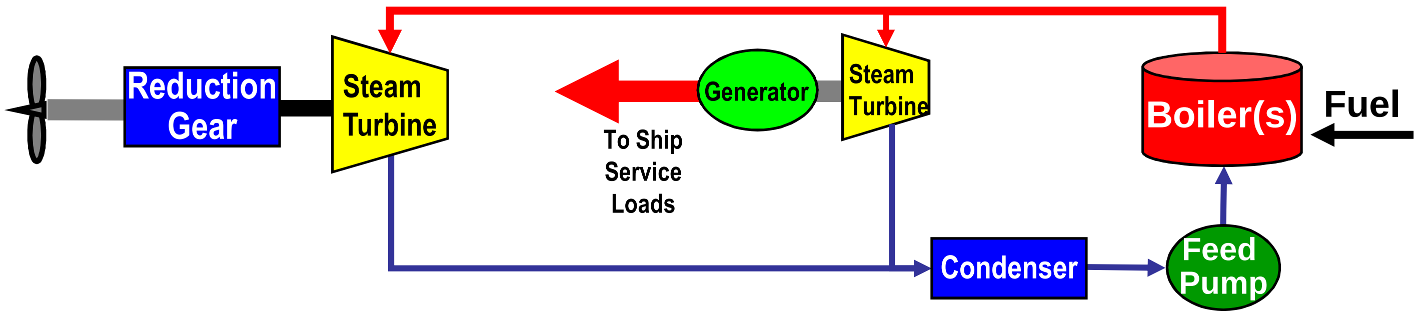
Directing the Future of Ships Power



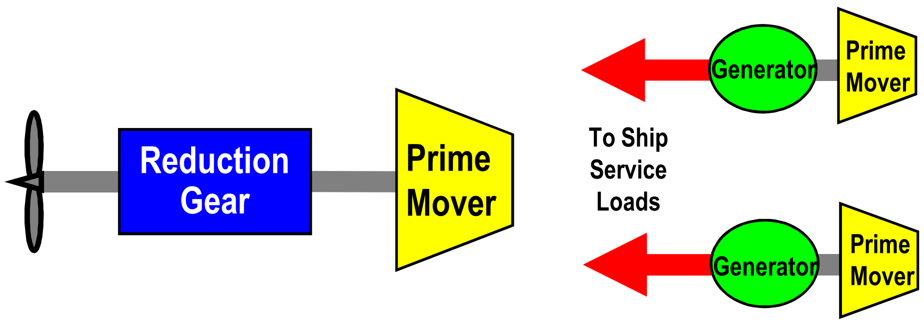
"Directing the Future of Ship's Power"

Shipboard Power & Propulsion Systems

Older ships were ‘integrated’ on the <u>steam side</u>

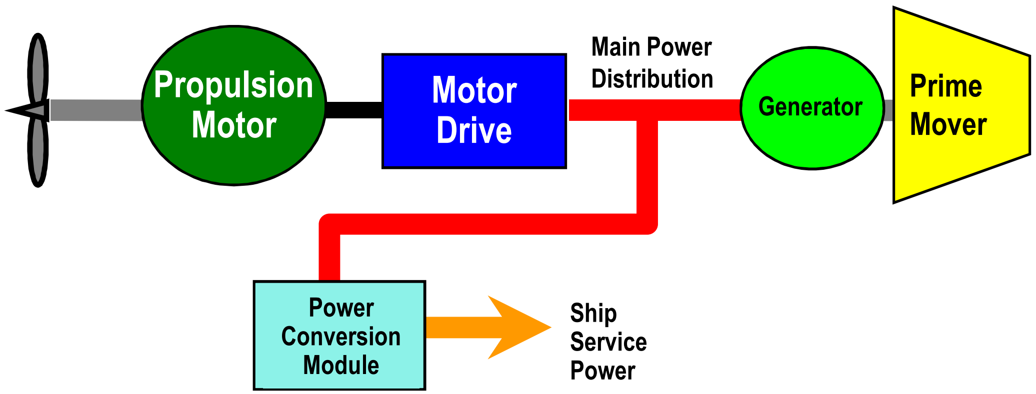


‘Integration’ was lost when we transitioned to internal combustion engines



IPS brings back ‘integration’ on the <u>electrical side</u>, enabled by:

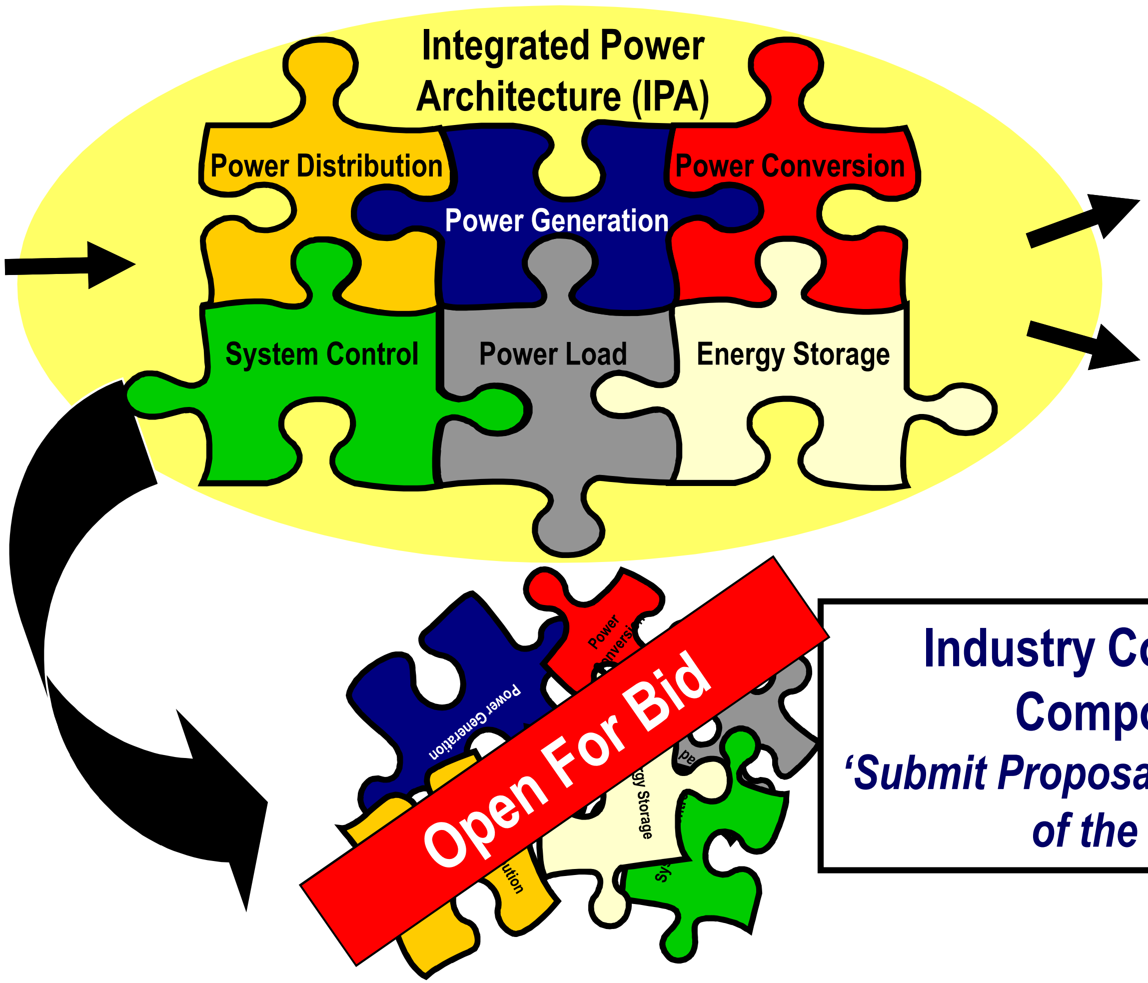
- Solid State Power Electronics
- Multi-Megawatt Motor Drives
- Automated Controls



Open Architecture Business Model

Navy Controls NGIPS Architecture and Interfaces;
'What Pieces Will Be Needed and How They Fit Together'

Ship's Power Sources



Mission Systems

Propulsion

Industry Competes for Components;
'Submit Proposals for Their Piece of the Puzzle'

Outline

- Brief History of Navy Electric Drive
- Challenges/Opportunities
- Next Generation Integrated Power System
- Open Architecture Business Model
- **Intelligent Ship/Power Dense Technologies**
- Hybrid Electric Drive (HED)

Distribution A: Cleared for Public Release

Electric Ships Office ESO Directing the Future of Ships Power

Technology Development Overview (ONR Advanced Naval Power)

PEO SHIPS

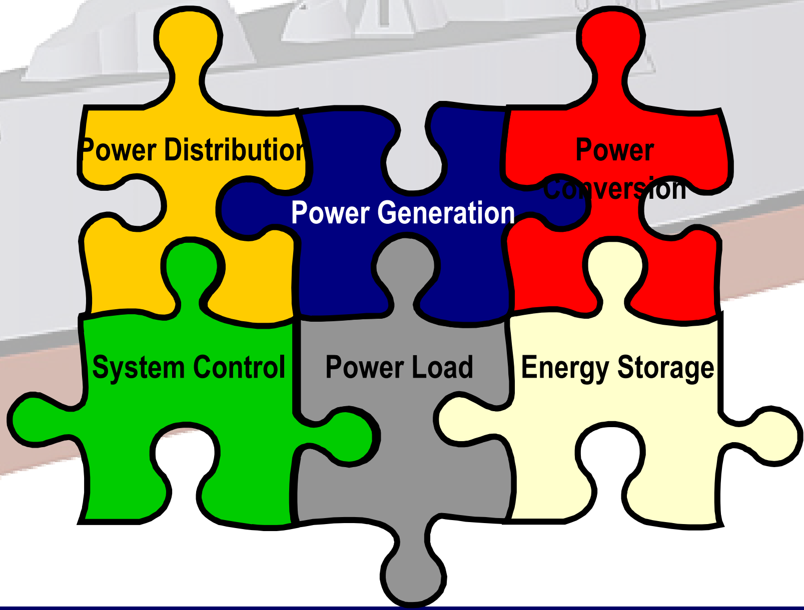
ONR Revolutionary Research . . . Relevant Results

Motors & Actuators
- Motors
- Actuators
- Electro-Mechanical Devices

Heat Transfer, Thermal Mgmt
- High Waste Heat Flux Removal
- Adv. Chiller Technologies / HVAC

Energy Storage
- Batteries
- Capacitors
- Flywheels

Power Generation
- Fuel Cells
- Advanced Generators
- Direct Conversion
- Photovoltaics
- Future Fuels



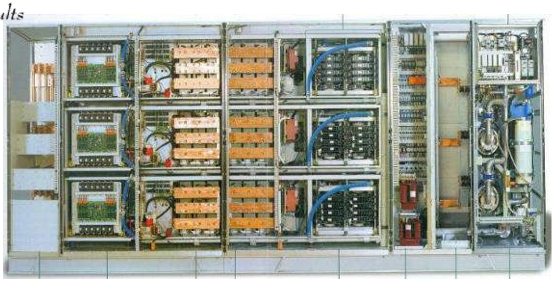
Distribution & Control
- Architecture
- Switching & Conditioning

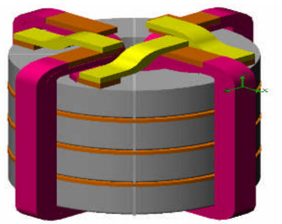
ONR Maintaining Robust S&T Investment

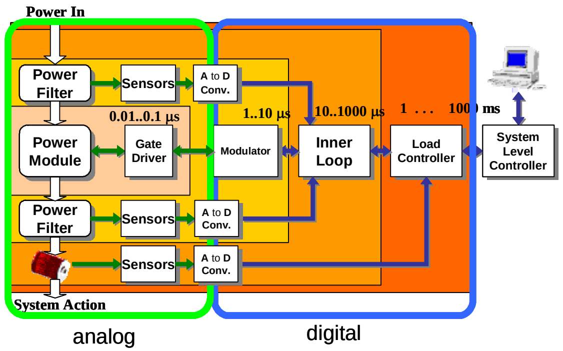
Intelligent Ship/Power Dense Technologies: Compact Power Conversion
Power Conversion Module/ Power Control Module

ONR
Revolutionary Research . . . Relevant Results

[EPE – 08-07]







S&T Products

- **Large scale demonstration of multifunction converter in FY 2011**
- **Large scale demonstration of bi-directional power converter in FY 2011**
- **Large scale demonstration of power management controller in FY 2012**

Objectives

- Develop motor drive topology and components that lead to a **2-3X increase** in power density (to 2-3 MVA/m3), a reduction in harmonic distortion **from ~9% to <1%,** and an increase in efficiency **from 94% to 98%,** i.e., a 2X reduction in thermal losses.
- Develop a high power density **bi-directional PCM** that interfaces to energy storage modules, enabling wider system usage of installed energy storage with an Integrated Power System.
- Develop a **power management controller** that will provide ~2x increase in whole system dynamic reaction time and power **partitioning from propulsion to ship service & weapons loads in <x ms.**

Electric Ships Office
ESO
Directing the Future of Ships Power

Intelligent Ship/Power Dense Technologies: Solid State Power Substation: Power Conversion Module

PEO SHIPS

Solid State Power Substation (SSPS) Program

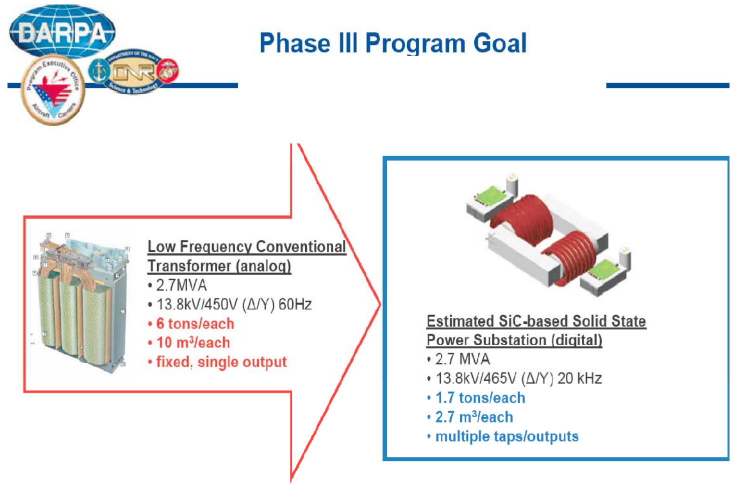
- DARPA, ONR, PEO-Carriers, ESO
- Phase III in progress (6/2007- 6/2010)
- Team: GE, Cree, Powerex, LANL, IAP, GD-EB

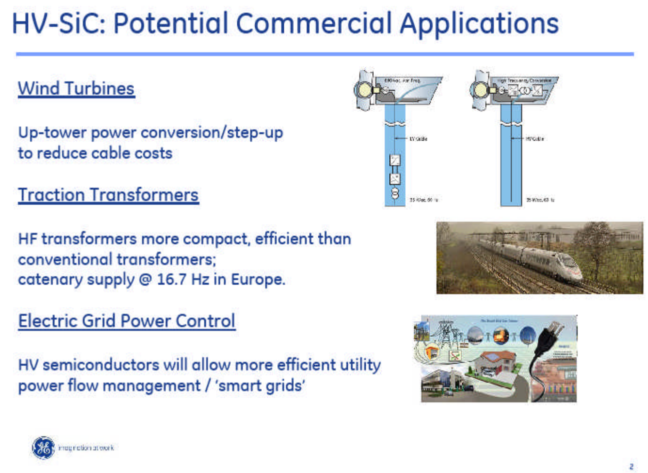
Goal

- Compact, light-weight replacement for 2.7 MVA, 13.8 kV/ 465 Vac, 60 Hz iron-core transformers
- ~3X improvement in weight
- Demonstrate high voltage, high frequency electronic power conversion (10 kV @ 20 kHz)

Status

- SSPS building block tested to full power at GE
- Navy testing completed at NSWC (Phila. LBES) from October 2010



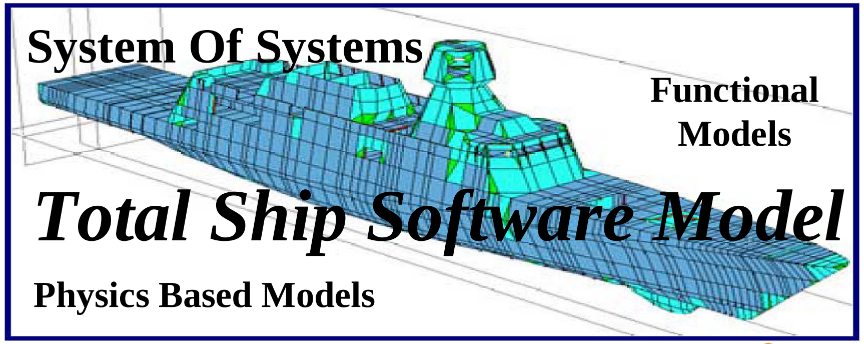


Enabling technology for other applications: radar power, MVDC circuit breakers
Reduction in SiC prices will open up large commercial markets!

Intelligent Ship/Power Dense Technologies: Adaptive Automation for Control

Requirement

- **Battlespace Situational Awareness**
- **Ship Capability Awareness**
- **Ship Systems Situational Awareness**
- **Resident Instantiated Modeling**
  - ***Shipboard to enable Real Time Analysis***
  - ***Predictive Performance based on Condition and Context (mission)***



Capability

- **Faster Time to Optimal Decision**
  - ***Cognitive Decision Aids***
  - ***Situational Awareness***
- **Faster Time to Optimal Action**
  - ***Autonomous/Reflexive Operations***
- **Increased Survivability**
  - ***Pre-Hit Reconfiguration***
- **Increased Recoverability**
  - ***Service Restoration***
  - ***Damage Mitigation***
- **Reduced Cost**
  - ***Reduced Watchstanding***
  - ***Reduced Maintenance***

Enables

Enables

Predictive* and *Adaptive

Machinery Monitoring and Control

Intelligent Ship/Power Dense Technologies: Diagnostics, Prognostics and Self Healing Control

Technical Objectives:

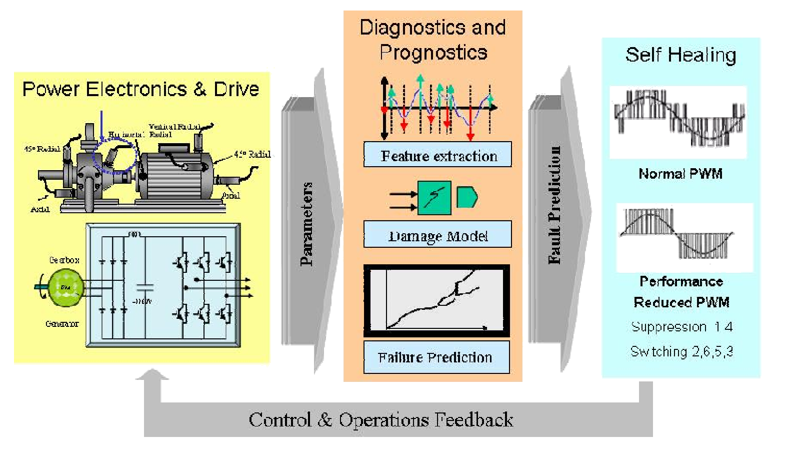
- Develop technologies to address incipient fault detection, fault accommodation and self-healing of electric drive systems
- Provide automated integration between the PHM technologies and fault accommodation / self healing approaches
- Demonstrate the developed technologies in a realistic hardware-in-the-loop test bed and with actual component faults/data
- Provide a logical path for technology transition in a ship systems application in Phase II and Phase III commercialization

S&T Challenges

- Identification of practical and cost effective failure precursor features and methods
- Determination of failure precursors directly linked to failure progression
- Development of dynamic fault accommodation strategies
- Development of physics-based failure progression modeling

Deliverables and Schedule

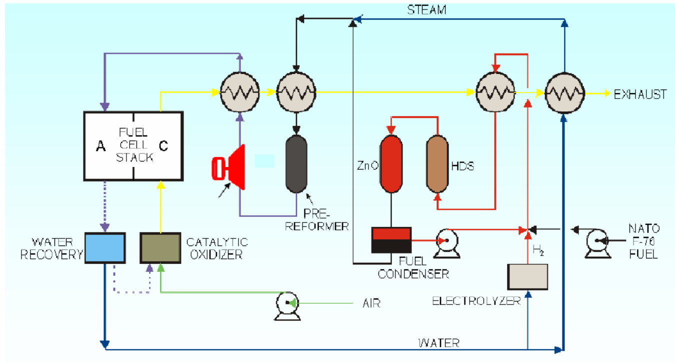
ID	Task Name	Milestone
1	Select Platform and Develop Test Strategy	Project Kick-off
2	Conduct motor drive seeded fault testing	Status Report 1
3	Identify incipient fault indicators and develop signal processing	Status Report 2
4	Develop fault accomodation strategies	Final Report Draft
5	Develop demonstration and draft transition plan	Demonstration and Debrief

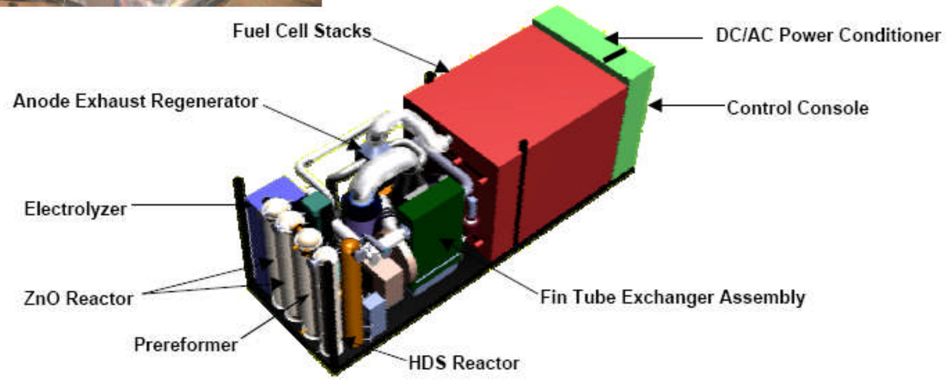


When is an IGBT Going to Fail?

Power Generation: Fuel Cells
(Power Generation Module)

- **Many Advantages**
  - **Highly Efficient (35-60%)**
  - **No Dedicated intakes-uptakes; use ventilation**
- **Challenges**
  - **Reforming Fuel into Hydrogen – Onboard Chemical Plant.**
  - **Eliminating Sulfur from fuels.**
  - **Slow Dynamic Response - Requires Energy storage to balance generation and load**
  - **Slow Startup – Best used for base-loads**



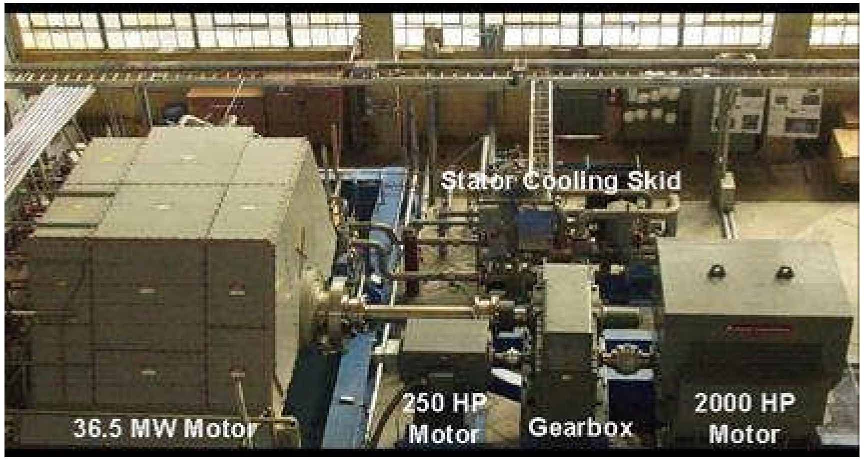


FuelCell Energy 625kW 450V, 3ϕ, 60 HZ, MC SSFC Power System

Motors and Actuators:
(Propulsion Motor Module)

- Permanent Magnetic Motor (PMM)
  - Load testing completed June 08
    - Full power on one stator ring (18MW)
  - No plans for additional testing

- High Temperature Superconducting Motor (HTS)
  - Full Power Testing Complete (December 08)
  - Motor Achieved Design Rated Torque @ Rated Speed for 36.5 MW!



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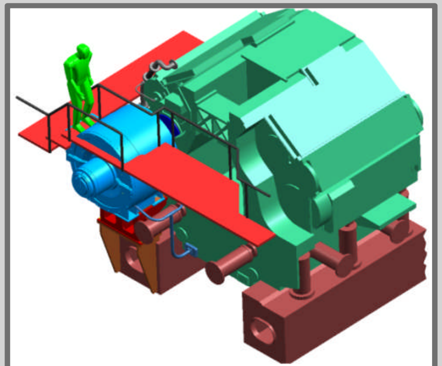
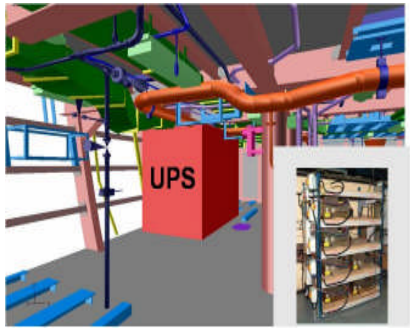
- **Hybrid Electric Drive (HED)**

Hybrid Electric Drive (HED) (for DDG-51 Flt IIA)Background

- **NAVSEA 21 sponsored HED industry studies and Navy Trade Space Analysis for DDG 51 Class fuel economy**
- **NAVSEA Congressional Adds to design, build & test a HED *proof of concept* system to be demonstrated at Navy Land Based Engineering Site**
- **Leveraging ONR investments in shipboard energy storage and dynamic controls to be demonstrated at LBES (NSWC Philadelphia)**
- **Hybrid Electric Drive established as a top-priority for the Navy's energy task force to demonstrate the capability at the Navy's Land Based Engineering Site (Philadelphia, PA) in 2011 and at-sea in a DDG-51 Class ship in 2012.**

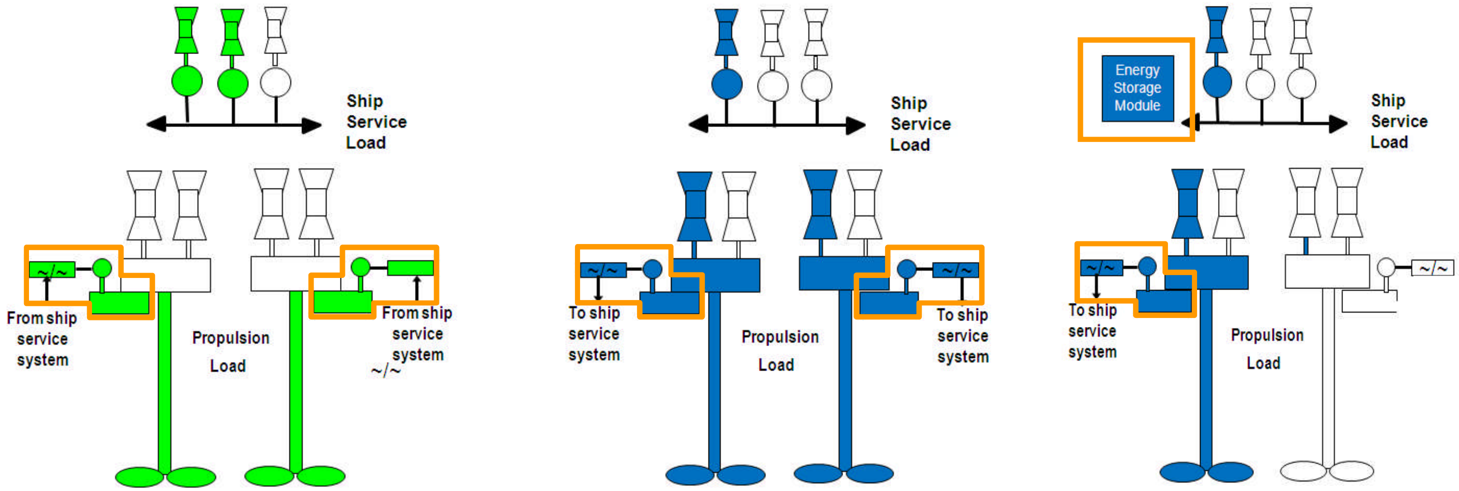


Hybrid Electric Drive (HED) ERM attached to Main Reduction Gear



Shipboard Energy Storage for Single Generator Operations

Fuel Efficiency Technology Enablers



Electric Propulsion System <12kts

Propulsion Derived Ship Service >12kts

Hybrid Electric Drive with Energy Storage

Increased Risk & Fuel Economy Payoff

Hybrid Electric Drive & Energy Storage improves energy efficiency of in service surface combatant power plants

ONR SWAMPWORKS: Enabler For Hybrid Electric Drive

- ONR investigated feasibility and conducted technical assessment of energy saving alternatives through BAA 07-029

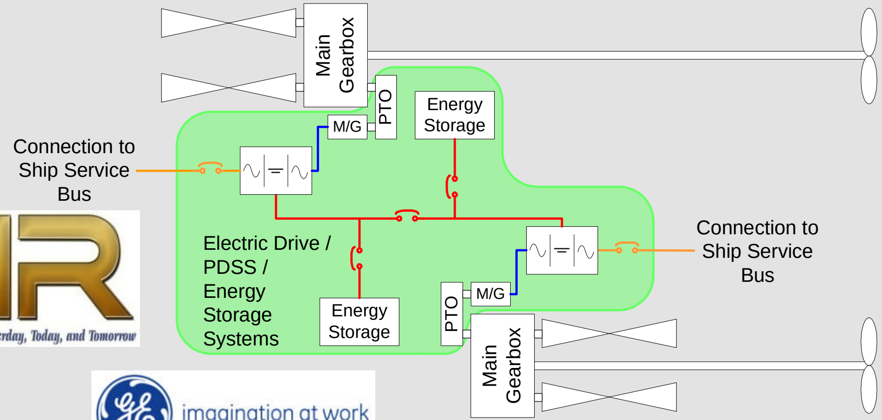
Shipboard Energy Storage

Satcon

ONR Relevant Research and Results . . . Yesterday, Today, and Tomorrow

- Energy storage enhances hybrid drive savings & enables single generator ops
- Eliminates "Dark Ship" condition
- De-Risks future Next Generation Integrated Power System Energy Storage Modules

Hybrid Drive Dynamic Controls



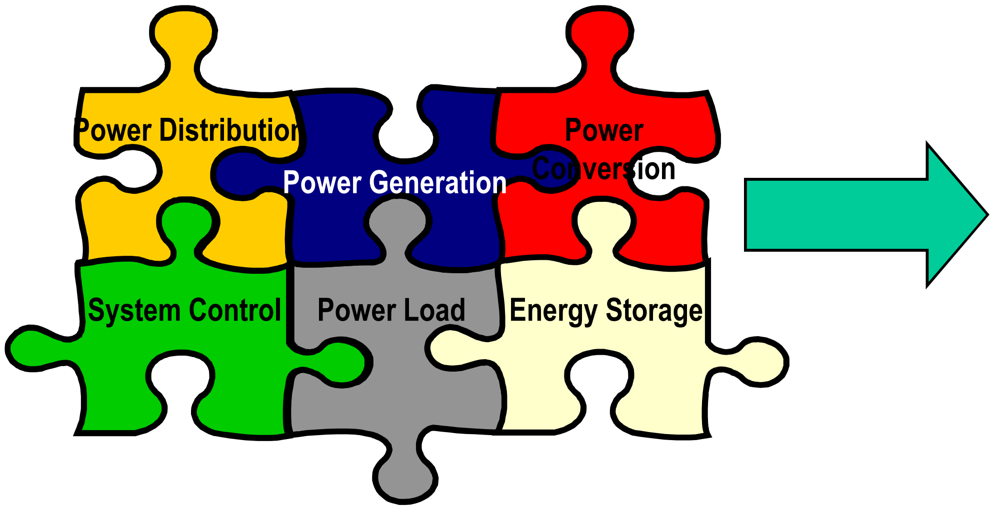
GE imagination at work

- Hybrid drive dynamic analysis ensures power quality capability and control
- Develop and de-risk control approaches to address DDG-51 Machinery Control System requirements

ENERGY STORAGE INTEGRATED INTO THE HYBRID ELECTRIC DRIVE SYSTEM PROVIDES THE GREATEST FUEL SAVINGS For NAVY SHIPS

Conclusion

"Valley of Death"



Questions?