

Next Generation Power and Energy

EXPONAVAL 2010

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Valparaiso, Chile

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ONR Global)

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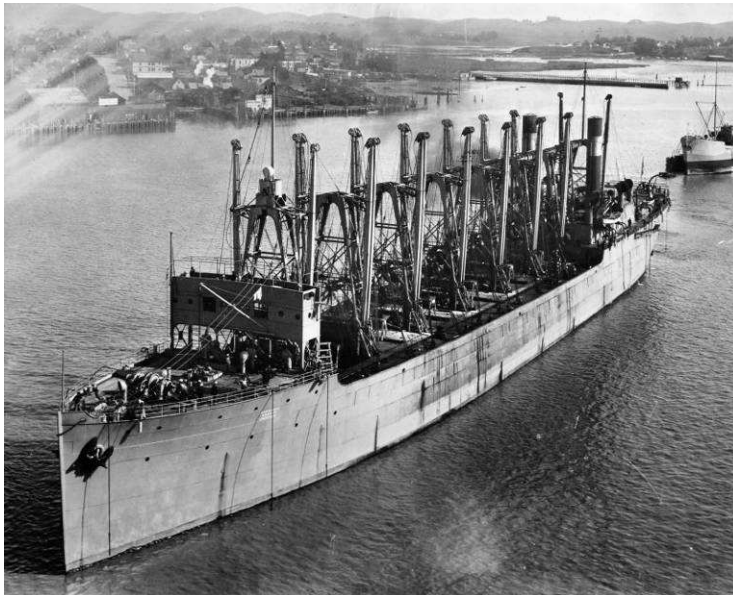
Outline

- 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)**



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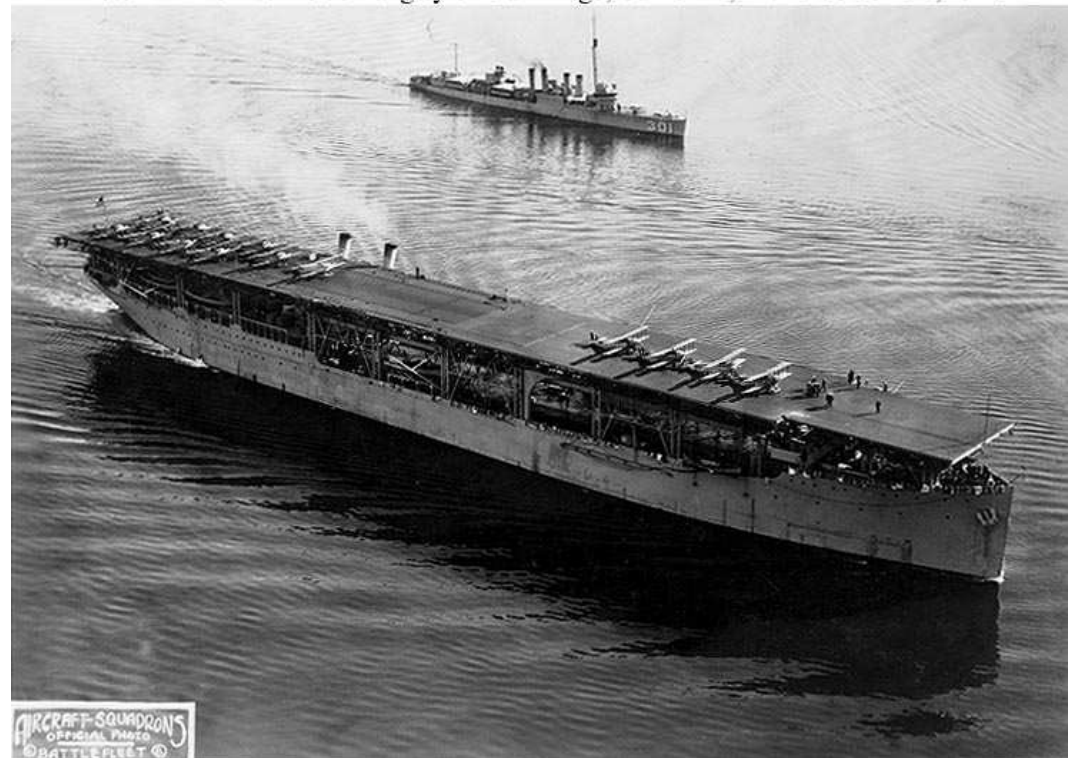
Electric Drive



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 <u>significant fuel savings compared with steam driven LHD</u>
	Combat Logistics Force (T-AKE) ◆ T-AKE is powered by a commercial integrated power system, providing <u>reduced acquisition and life cycle costs</u>
	Surface Combatant (DDG 1000) ◆ ZUMWALT's Integrated Power System (IPS) combines <u>78MW of installed power</u> 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



Netherlands (2 ships)

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



Germany

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



All diesel submarines are electric drive



France

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



France, Italy, Greece, Morocco

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



Australia (2 ships)

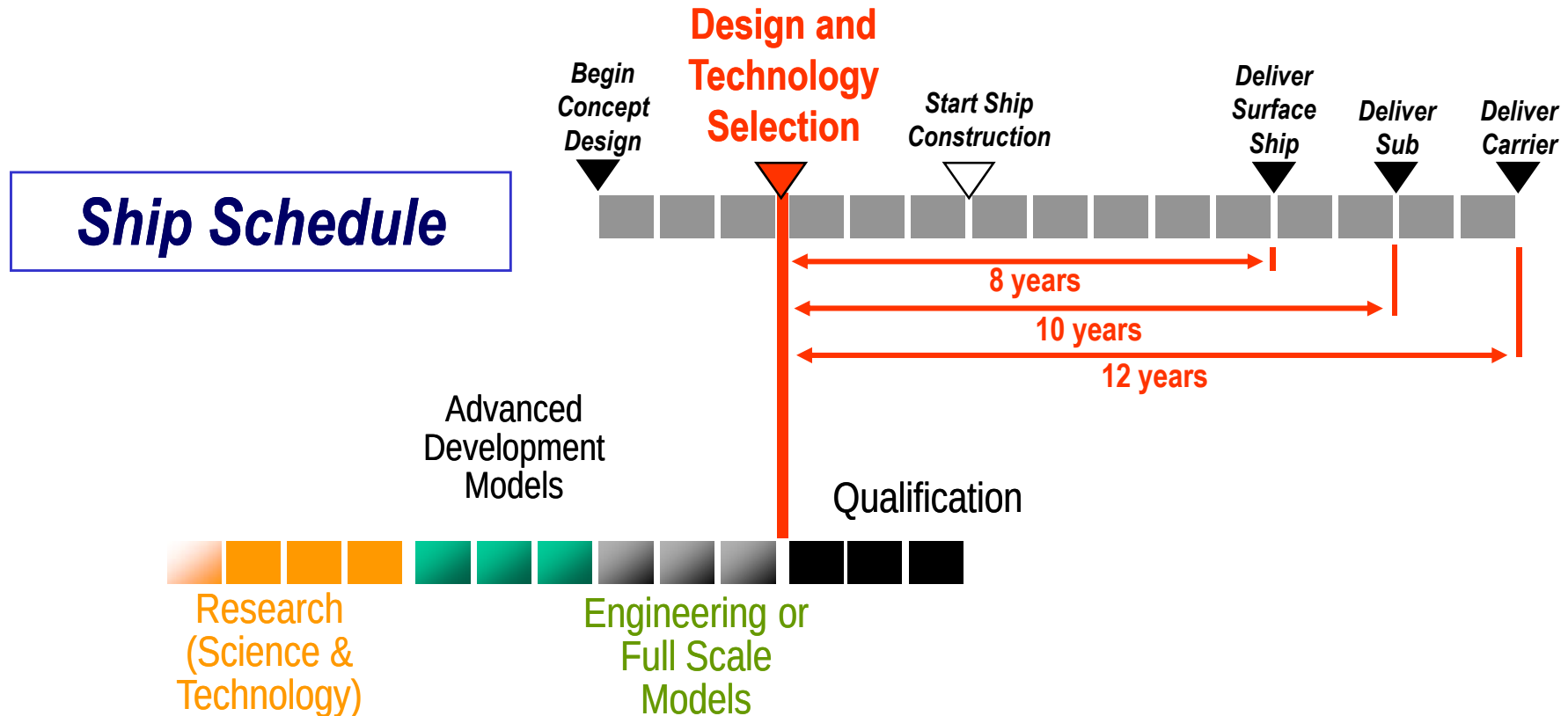
- ◆ Canberra Class LPD - Podded IPS
- ◆ Collins Class SSG - diesel-electric

...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”

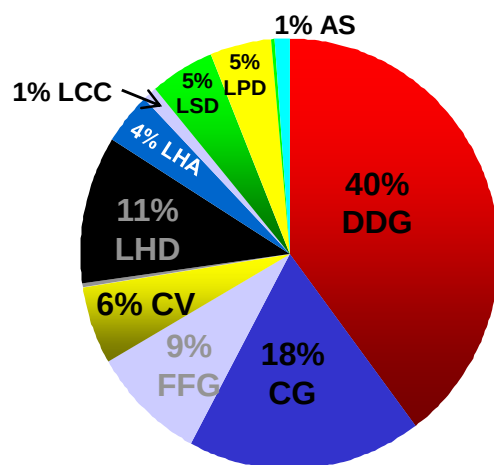
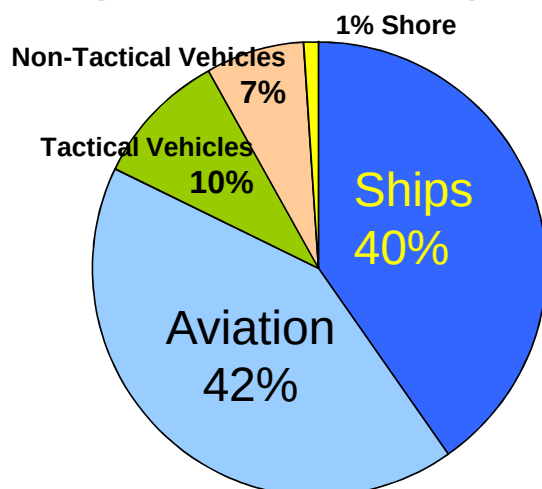
How Do We Meet Our Challenges



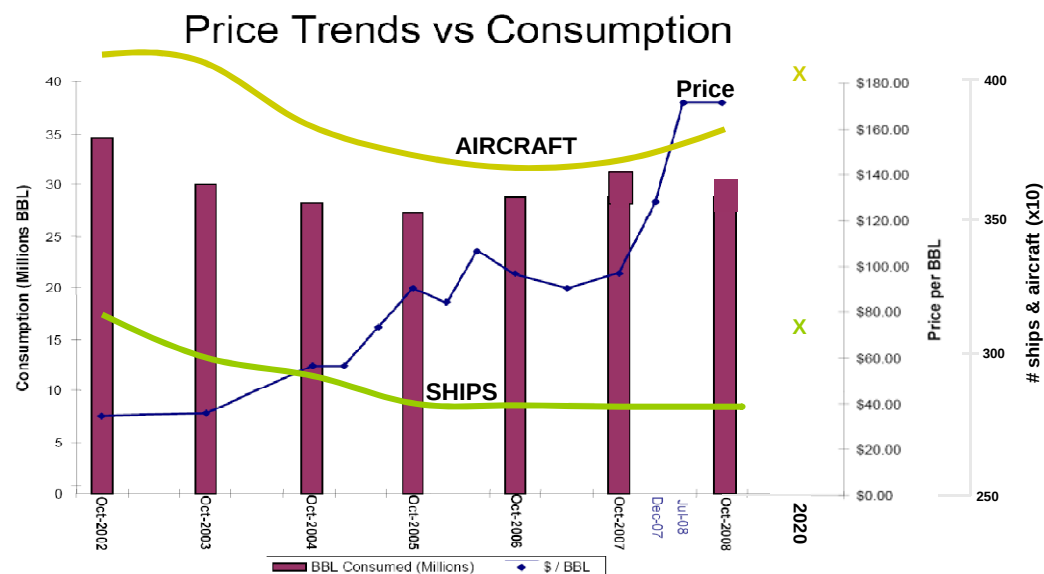
- ◆ Fleet-wide Analysis of Demand
- ◆ Early Investment in Technology
- ◆ Integrated System Demonstrations

Navy Fuel Usage and Trends

**FY07 DON Fuel Usage
(38.8 Million Barrels)**



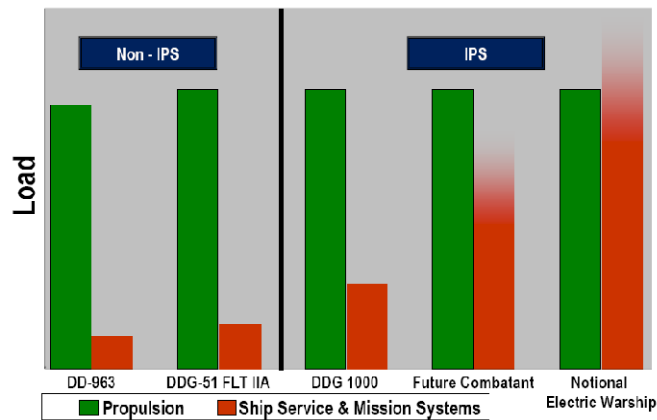
**PRICE TRENDS VS
NAVY SHIP / AIRCRAFT CONSUMPTION**



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 

Support High Power Mission Systems



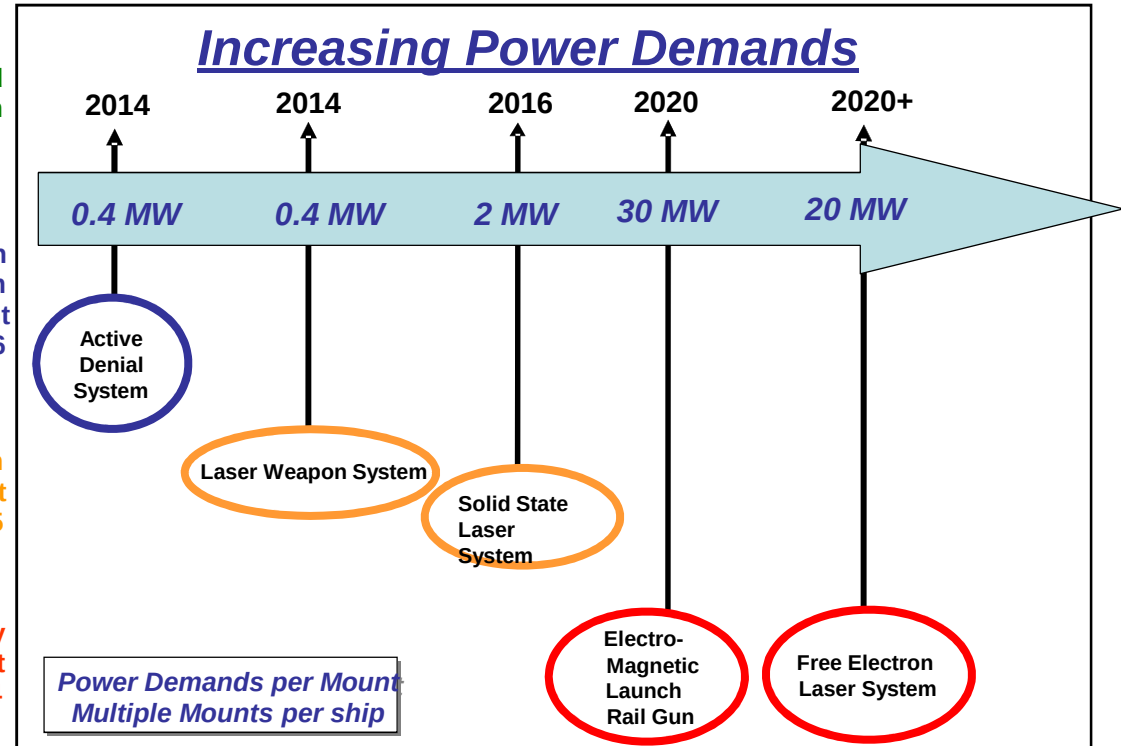
April 2009

Deployed Mission Capability

Weapon System Development TRL=6

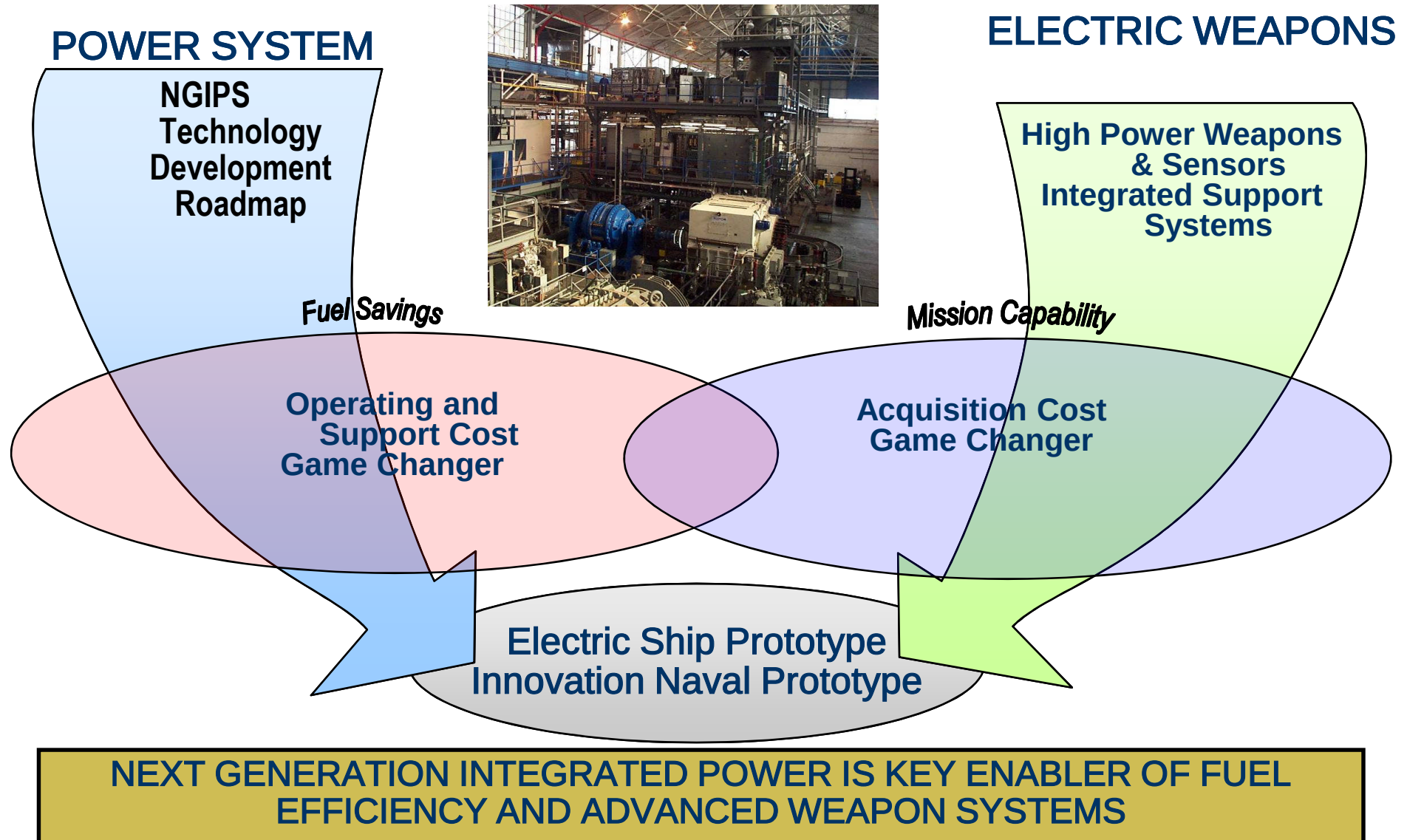
Weapon Development TRL=4/5

Technology Development TRL=3/4



Sensor and Weapons Power Demands will Rival Propulsion Power Demands

Integrated, Large Scale System Demonstrations: Electric Ship INP

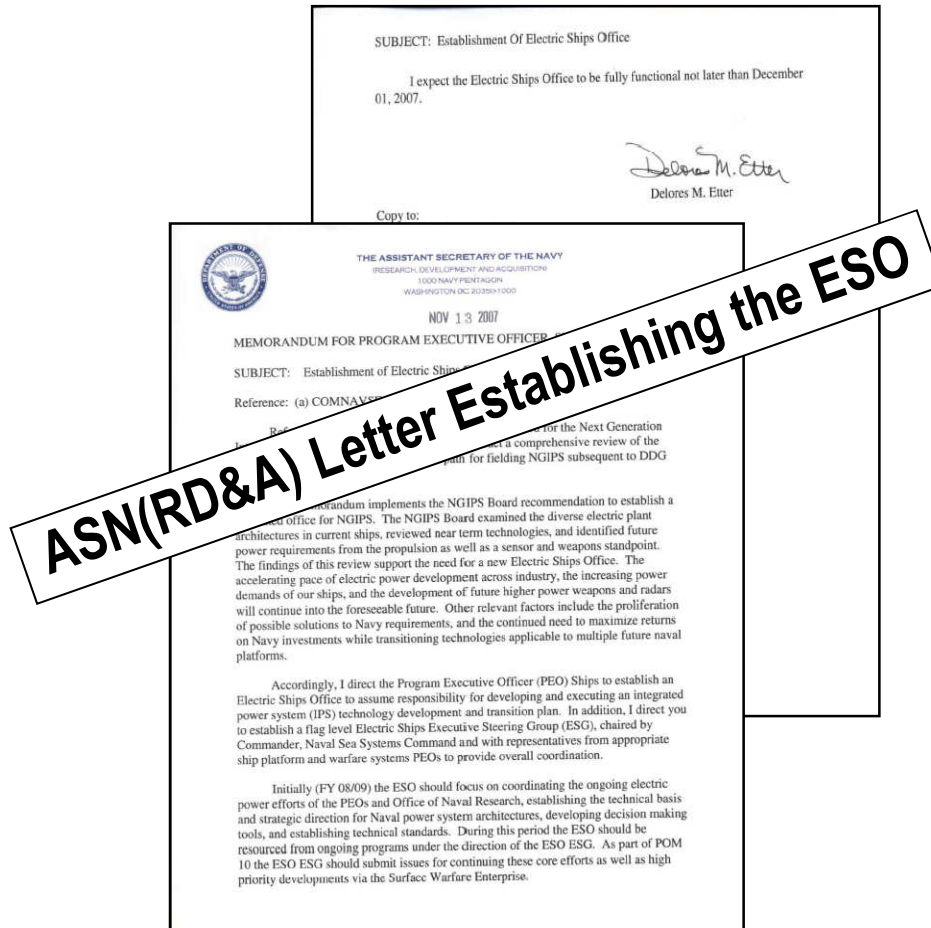


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ASN(RD&A) Letter Establishing the Electric Ships Office / 13 Nov 2007

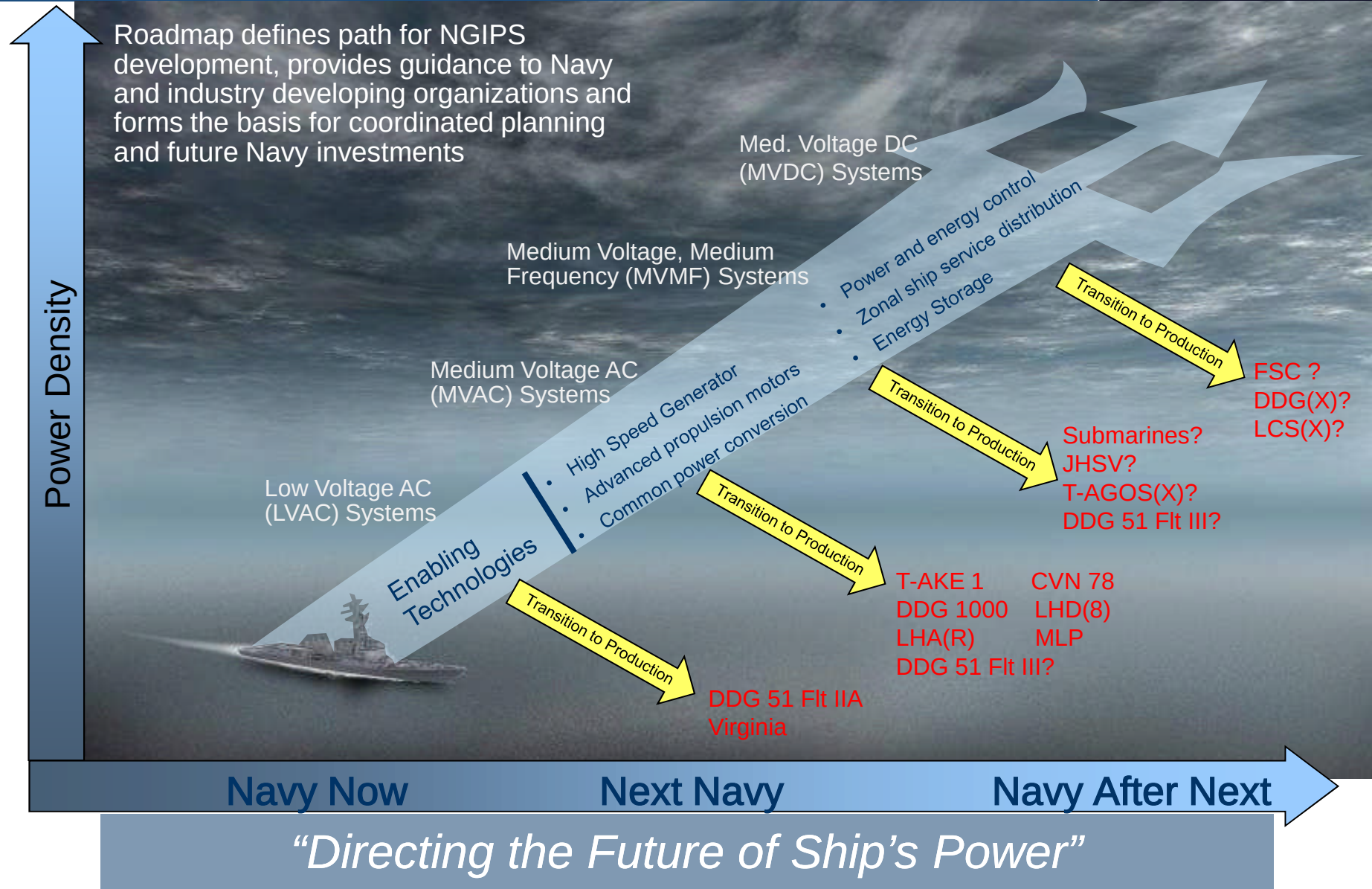


“I direct the Program Executive Officer (PEO) Ships to establish an Electric Ships Office to assume responsibility for developing and executing an integrated power system (IPS) technology development and transition plan.”



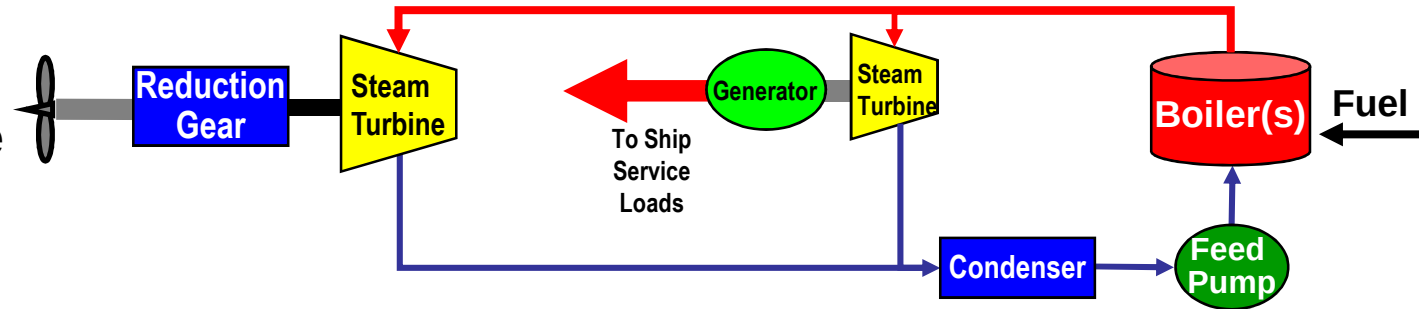
Message: Develop and Execute NGIPS Technology Development Roadmap

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

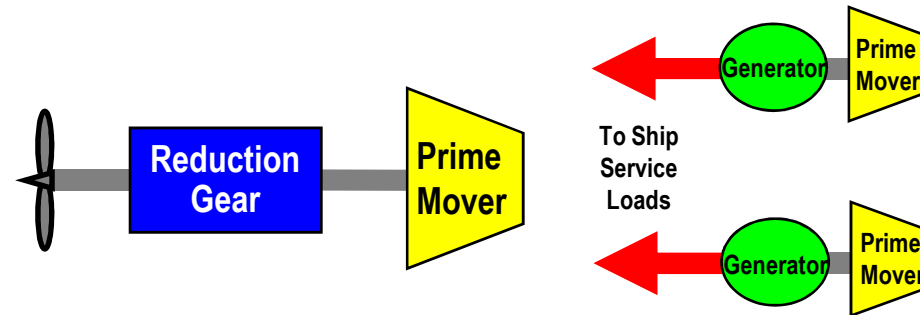


Shipboard Power & Propulsion Systems

Older ships were
'integrated' on the
steam side

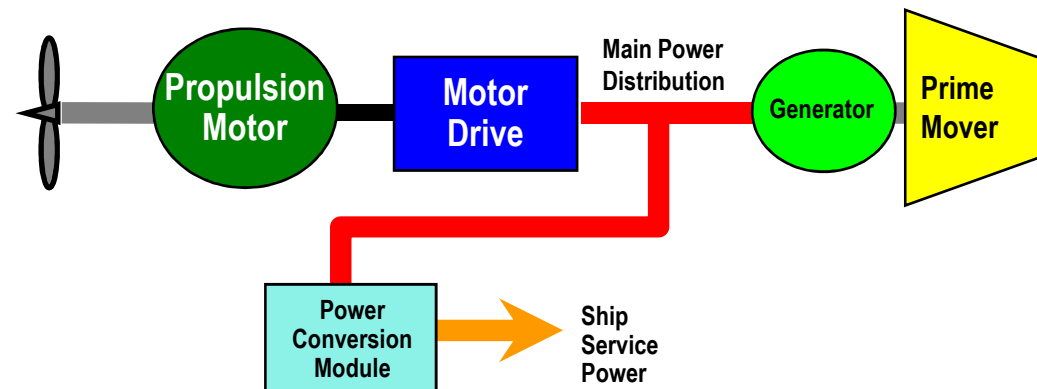


'Integration' was lost
when we transitioned to
internal combustion
engines



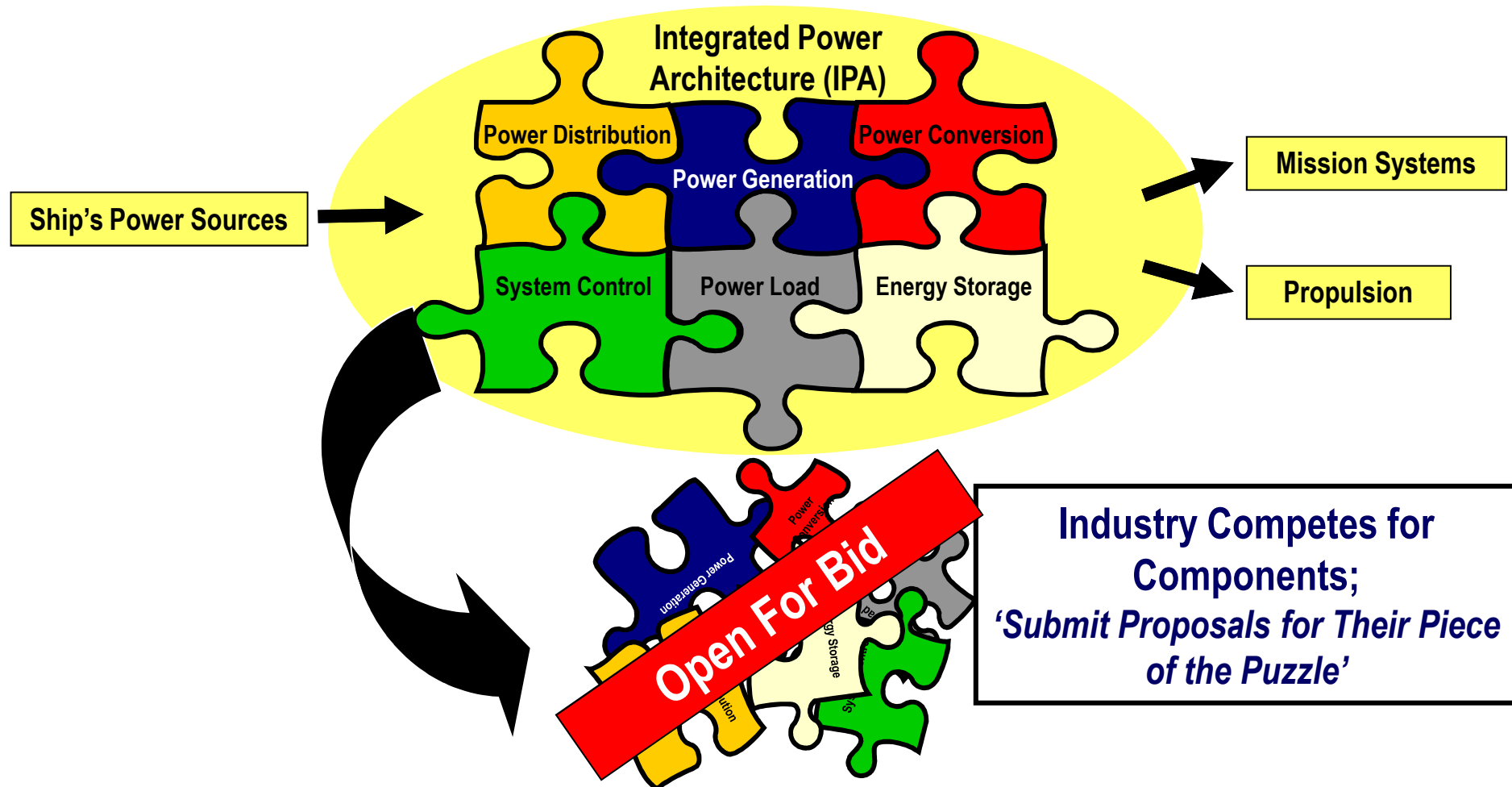
IPS brings back 'integration' on
the electrical side, enabled by:

- 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'**



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Technology Development Overview (ONR Advanced Naval Power)



Motors & Actuators

Motors
 Actuators
 Electro-Mechanical Devices

Heat Transfer, Thermal Mgmt

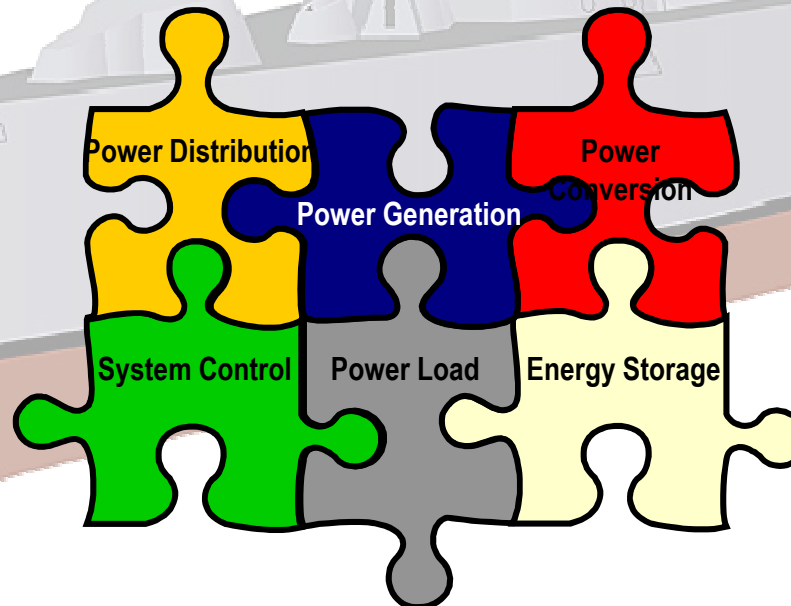
High Waste Heat Flux Removal
 Adv. Chiller Technologies / HVAC

Energy Storage

Batteries
 Capacitors
 Flywheels

Power Generation

Fuel Cells
 Advanced Generators
 Direct Conversion
 Photovoltaics
 Future Fuels



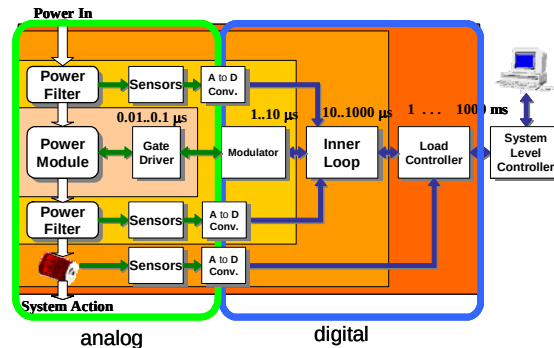
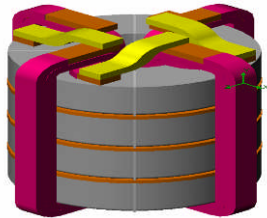
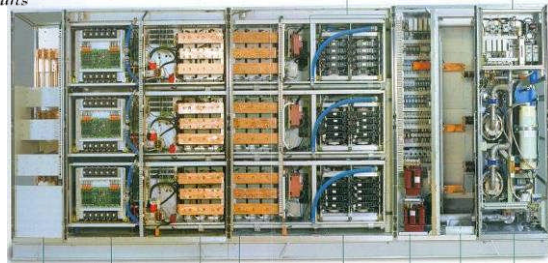
Distribution & Control

Architecture
 Switching & Conditioning

ONR Maintaining Robust S&T Investment



[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**.

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

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

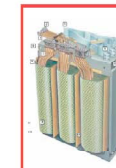
- Compact, light-weight replacement for 2.7 MVA, 13.8 kV/ 465 Vac, 60 Hz iron-core transformers
- ~3X improvement in weight
- Demonstrate high voltage, high frequency electronic power conversion (10 kV @ 20 kHz)

Status

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

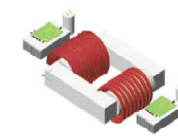


Phase III Program Goal



Low Frequency Conventional Transformer (analog)

- 2.7MVA
- 13.8kV/465V (Δ/Y) 60Hz
- 6 tons/each
- 10 m³/each
- fixed, single output



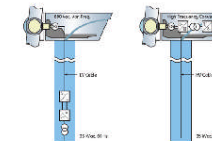
Estimated SiC-based Solid State Power Substation (digital)

- 2.7 MVA
- 13.8kV/465V (Δ/Y) 20 kHz
- 1.7 tons/each
- 2.7 m³/each
- multiple taps/outputs

HV-SiC: Potential Commercial Applications

Wind Turbines

Up-tower power conversion/step-up to reduce cable costs



Traction Transformers

HF transformers more compact, efficient than conventional transformers; catenary supply @ 16.7 Hz in Europe.



Electric Grid Power Control

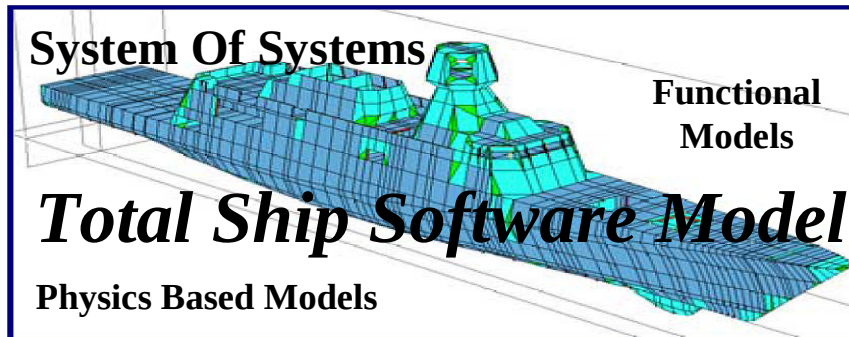
HV semiconductors will allow more efficient utility power flow management / 'smart grids'



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

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)



Enables

**Predictive and Adaptive
Machinery Monitoring and Control**

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

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

Technical Objectives:

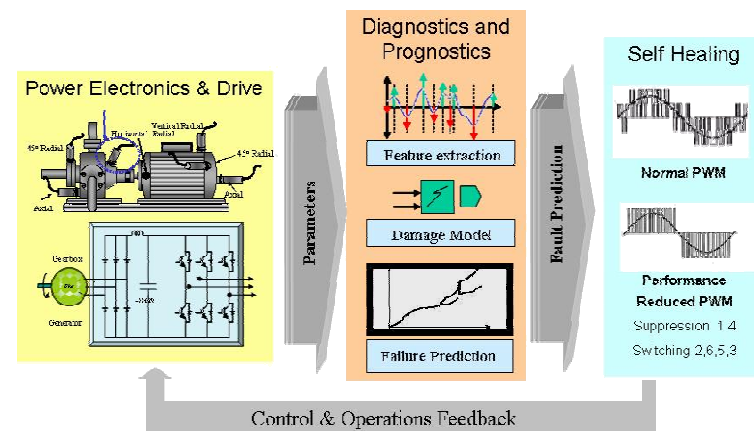
- ◆ Develop technologies to address incipient fault detection, fault accommodation and self-healing of electric drive systems
- ◆ Provide automated integration between the PHM technologies and fault accommodation / self healing approaches
- ◆ Demonstrate the developed technologies in a realistic hardware-in-the-loop 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

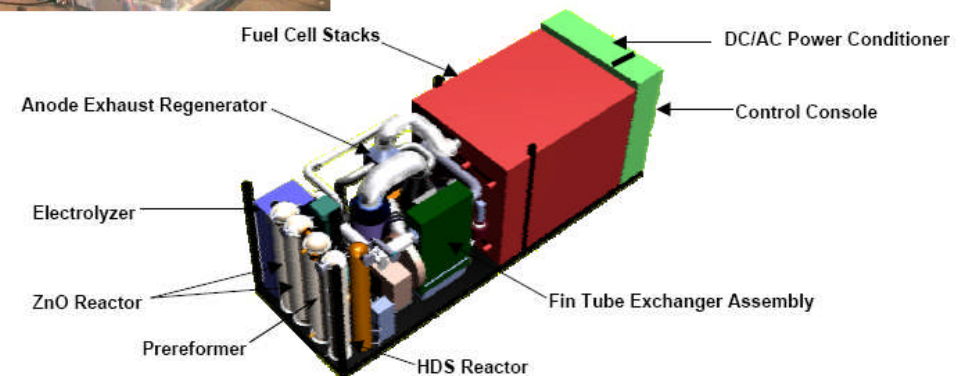
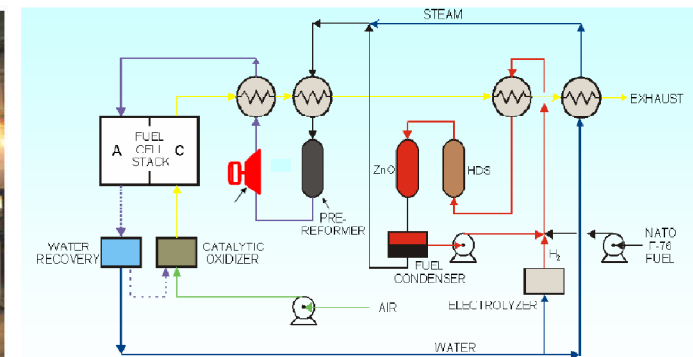
ID	Task Name	Q3 2006			Q4 2006			Q1 2007			Q2 2008		
		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Sep
1	Select Platform and Develop Test Strategy												
2	Conduct motor drive seeded fault testing												
3	Identify incipient fault indicators and develop signal processing												
4	Develop fault accommodation strategies												
5	Develop demonstration and draft transition plan												



- ◆ **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

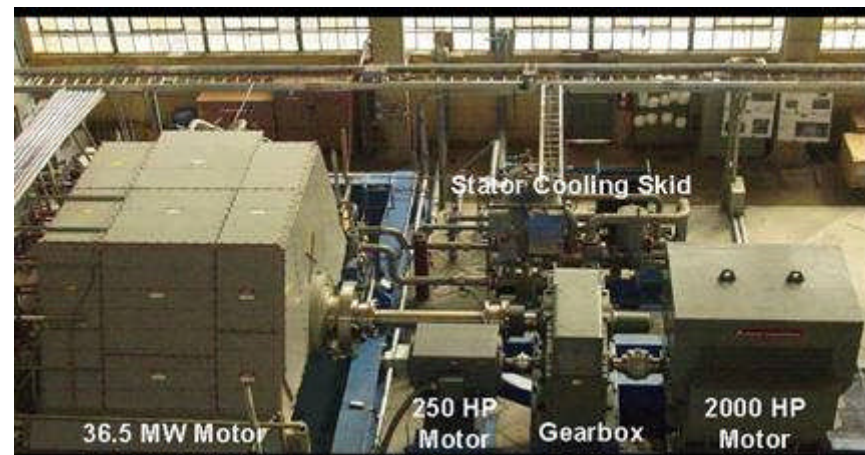


FuelCell Energy 625kW 450V, 3 ϕ , 60 HZ, MC SSFC Power System

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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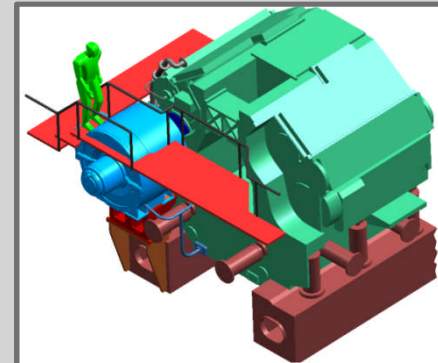


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Hybrid Electric Drive (HED) (for DDG-51 Flt IIA)Background



- ◆ 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.

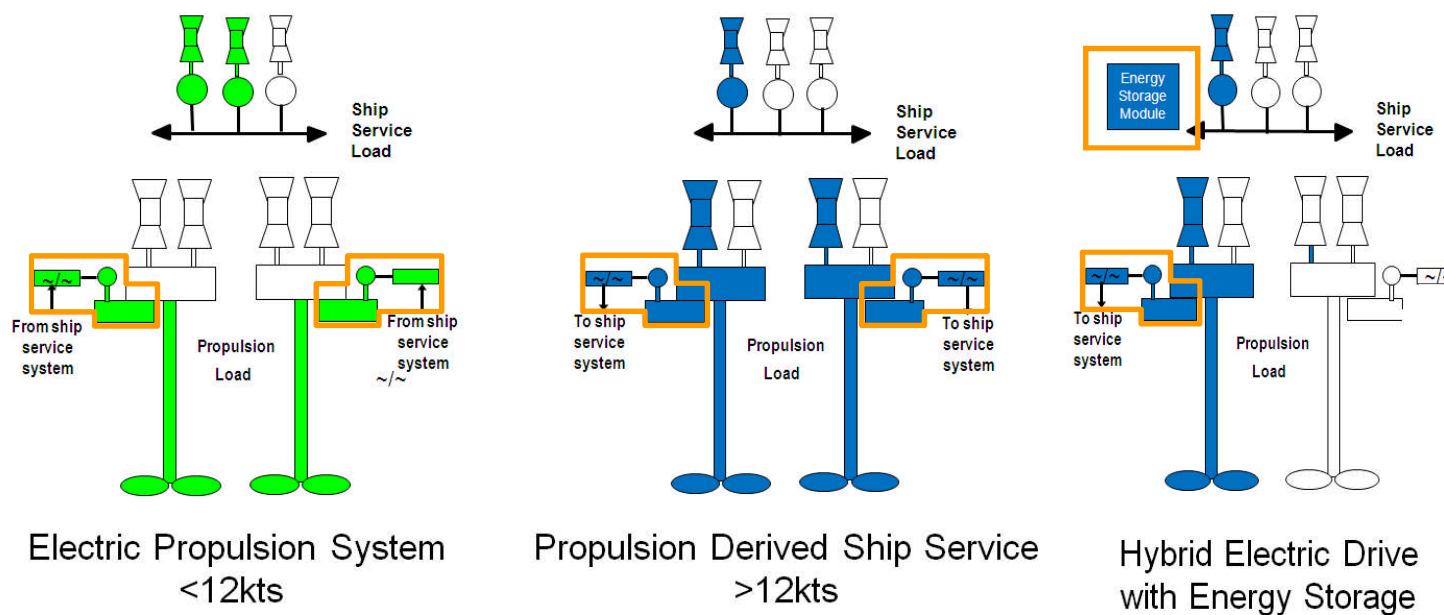


Hybrid Electric Drive (HED) ERM
attached to Main Reduction Gear



Shipboard Energy Storage
for Single Generator Operations

Fuel Efficiency Technology Enablers



Increased Risk & Fuel Economy Payoff

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

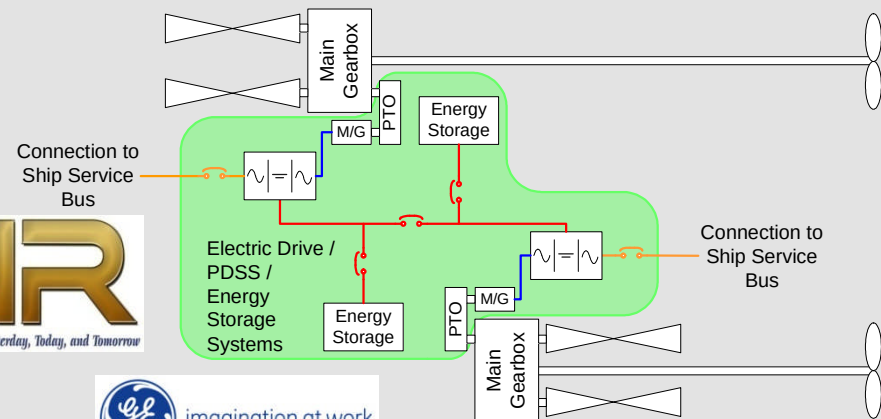
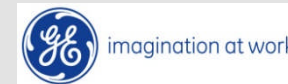
- ♦ ONR investigated feasibility and conducted technical assessment of energy saving alternatives through BAA 07-029

Shipboard Energy Storage



- 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



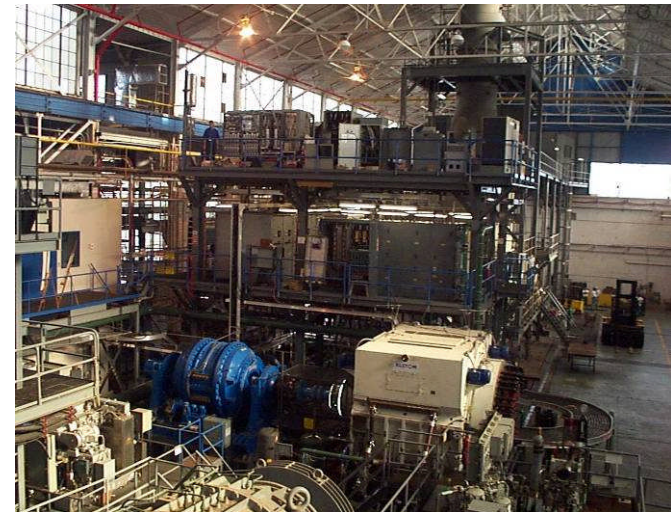
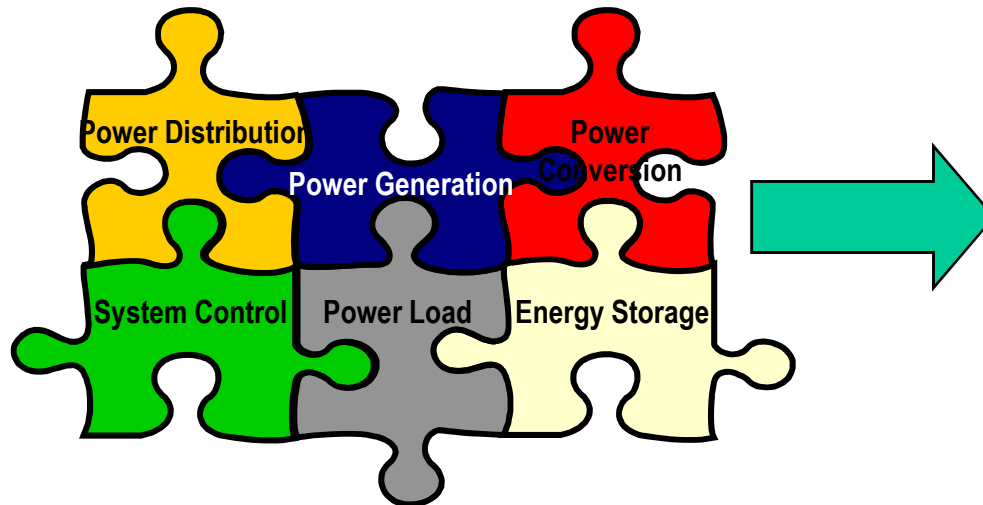
- Hybrid drive dynamic analysis ensures power quality capability and control
- Develop and de-risk control approaches to address DDG-51 Machinery Control System requirements

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

Conclusion



"Valley of Death"



Questions?