Electric Warship Technology Overview

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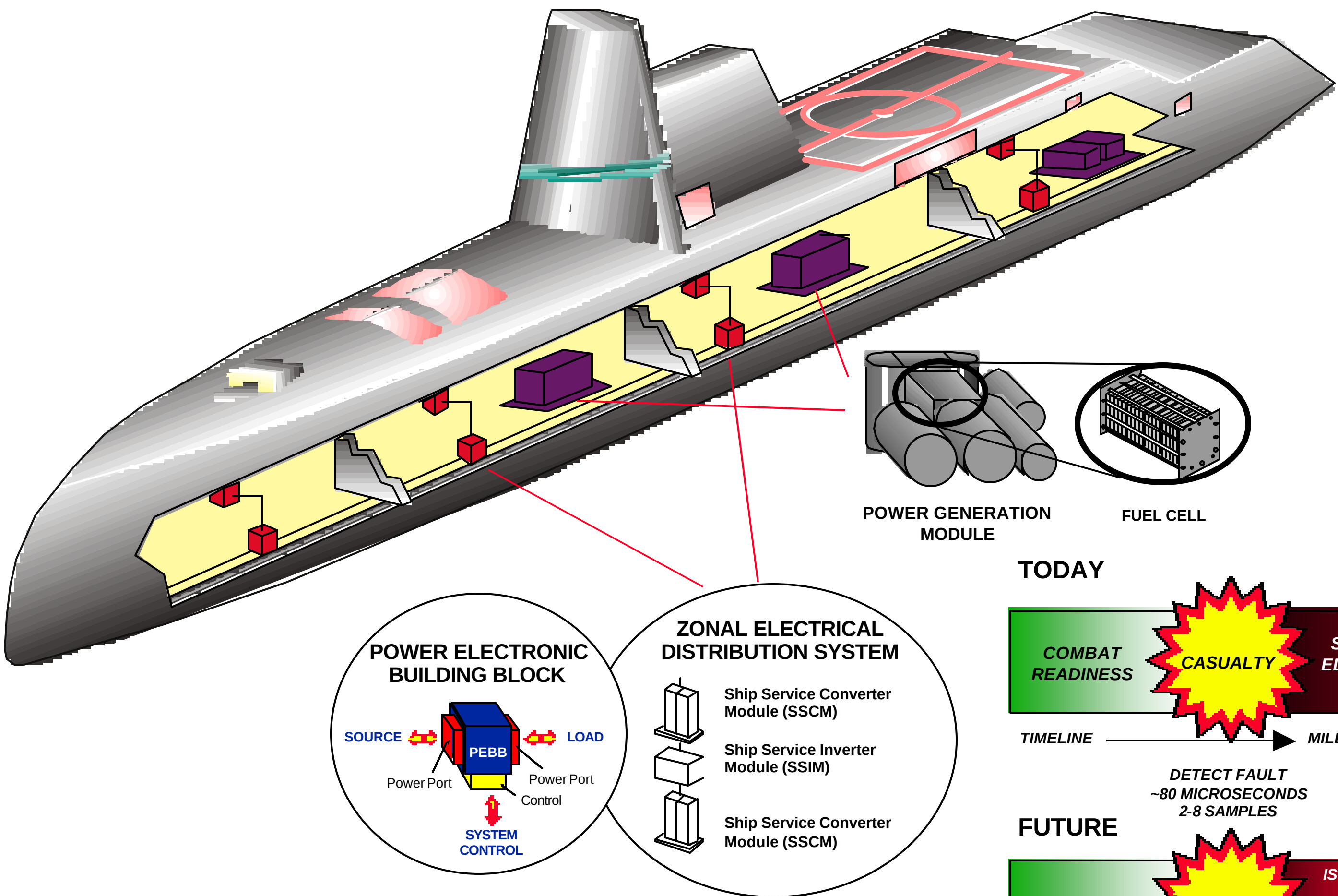
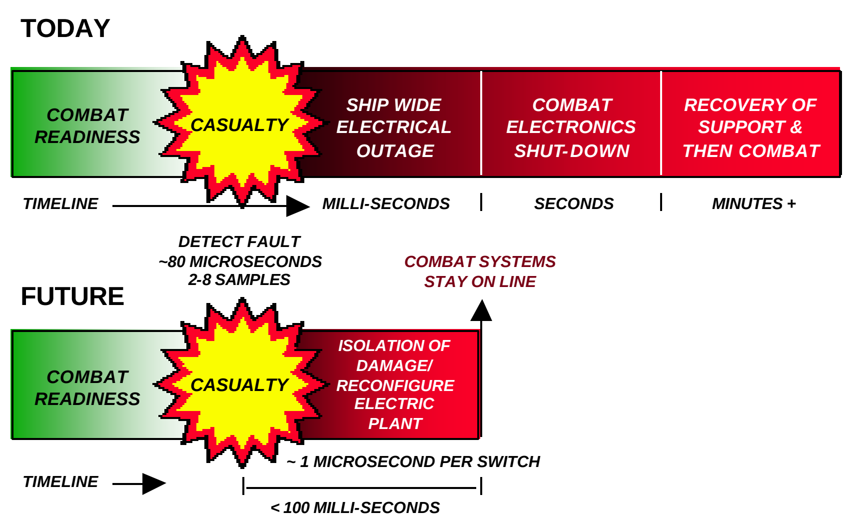
Reconfigurable, Survivable Power Systems



POWER DISTRIBUTION MODULES

Challenges:

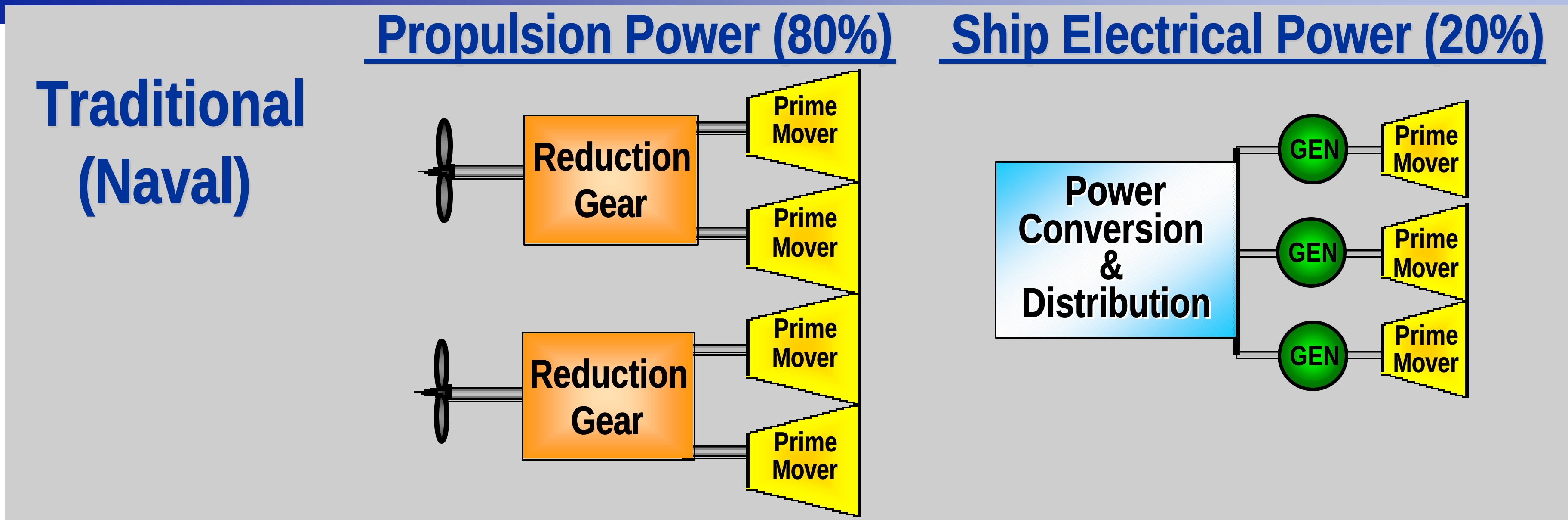
- ⇧ Power Density
- ⇧ Energy Density
- ⇧ System Efficiency
- ⇧ Resource Management and Control

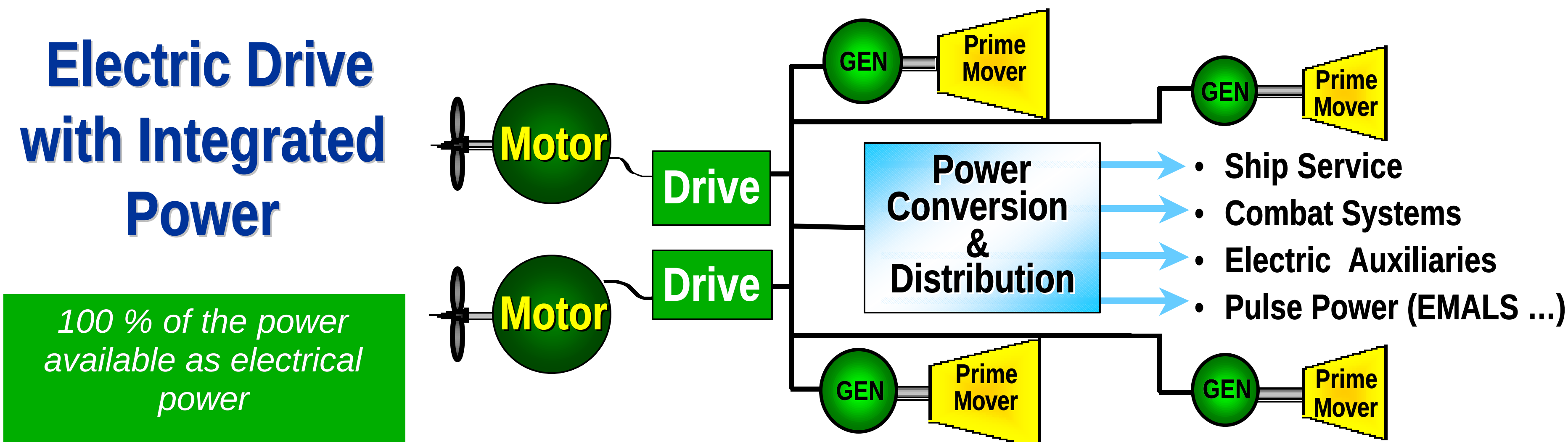


Compelling Advantages of Electric Warship

- **Reduced Life Cycle Costs**
  - More Efficient Propulsion and Electric Power Plant Reduces Operating and Maintenance Costs
  - Improved Reliability
  - Simplified Controls Supports Increased Automation and Reduced Manning
  - Design Flexibility Reduces Total Acquisition Costs
- **Improved Survivability**
  - Inherent Modularity Provides for Redundant, Distributed, Reconfigurable Power and Propulsion
  - Signature Reduction
- **Improved Flexibility for Upgrades Over Life (~50 Years)**
  - Advanced Weapon Systems
  - Propulsion System Upgrades

Electric Warship Configuration





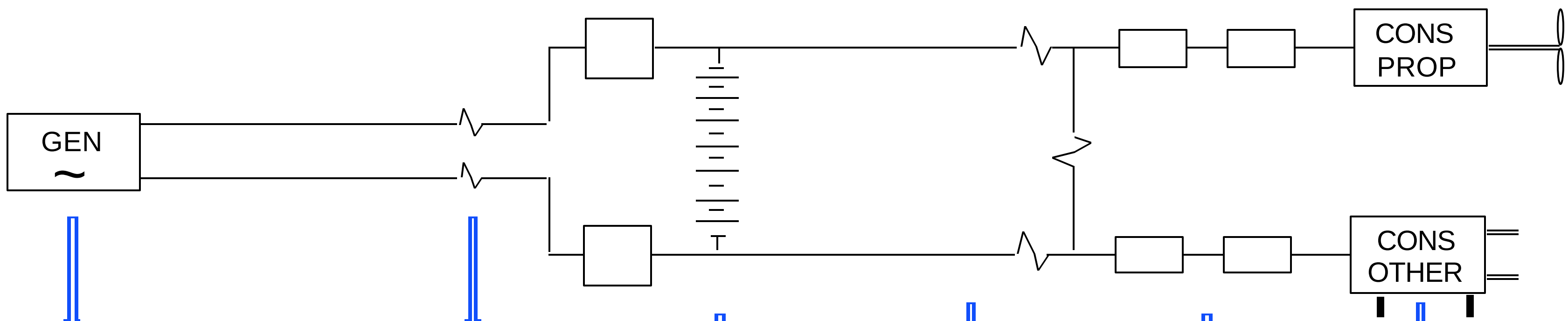
100 % of the power available as electrical power

Synopsis of ONR/DARPA Study (1997)

- **Electric Ship Offers New Paradigm for Future Ships**
  - Significantly Reduced Life Cycle Costs
  - Significant Operational Enhancements
  - Entirely New Design Flexibility
- **Electric Technology System Integration is Lacking**
  - Significant Opportunities to Increase Commonality Between Submarine and Surface Ship Applications
  - Integrated Power System Approach
    - DC Power is Preferred
  - U.S. Industrial and Technical Infrastructure
- **Technology Paradigm Shifters**
  - Fuel Cell Offers Possibility to Increase System efficiency
  - Technologies to Achieve the Component Power/Energy Densities Required for Most Naval Applications

Develop and Demonstrate Technology Enablers

Status of Electric Ship Technology



GENERATION

TECHNOLOGY	STATUS
Induction	Y
Synchronous	G
Permanent Magnet	R
Superconductivity	R
Fuel Cells	R

CONTROL

TECHNOLOGY	STATUS
System Management/Control	Y
Power System Modeling	R
Motor Drive Control	G
Reliability / Survivability	Y
EMI Signature	Y

DISTRIBUTION

TECHNOLOGY	STATUS
DC Architecture	G
DC Breakers	Y
AC Supercond. Trfm	Y
Supercond. Conductors	R
Insulation	G
Insulation High Power Density	Y

CONSUMPTION

TECHNOLOGY	STATUS
Acyclic (Homopolor) Motor	Y
Synchronous Motor	G
Induction Motor	R
PM Motor	R
Superconductivity Motor	R
EM Launch/Etc	R
Auxiliary Equipment	G

NOMENCLATURE

- R Further Technology Development Required
- Y Technology Generally Well Understood, but Affordability and Scaling to Ship Power Levels Requires Development and Demonstration
- G Technology Ready Near Term to Support Ship Design Development Studies

STORAGE

TECHNOLOGY	STATUS
Batteries	G
Flywheels	Y
Capacitors	Y
Superconducting Magnetic Energy Storage (SMES)	Y
Compressed Air	Y
Ship Fwd Motion	R

CONDITIONING

TECHNOLOGY	STATUS
Insulated Gate Bi- Polar Transistor (IGBT)	G
MOS Controlled Thyristor (MCT)	R
MOSFET Turn-Off Semiconductor (MTO)	R
PEBB	Y
Power Density	R
High Power Levels	R

Principal Findings

- **Global Findings**
  - Future Possibilities of Electric Technology
  - Steps Needed to Ensure Technological Availability
- **Break-Through Enablers**
  - Possibilities of Significantly Altering the Affordability and Performance of Naval Combatants
- **Process Development**
  - Development Needed to Facilitate the Introduction of Electric Technology to Naval Combatants

Global Findings

- Electric Technology Enables Improved Ship Performance
- Basic Electric Ship Technology is Available but the Power Density of Commercial Electrical Systems is Inadequate for All But the Largest Platforms
- Energy Density and Power Density Enhancements are Needed

Break-Through Enablers

- **Fuel Cells Provide a Major Paradigm Shift**
  - Technology Development is Required
- **A DC Ships Power Distribution Architecture is Preferred**
- **Density and Scaling of Power Conditioning Modules Needs More Development**

Process Development

- System-Level Engineering Requirements Must be Developed
- The Necessary Intellectual Base is Very Thin
- Modeling and Analytic Tools are Required
- Basic Understanding of the Physics is Required
- Advanced Techniques Required for Electric Power System Control
- EMI and EMC Must be Addressed

Technology Changes Since Report Issued

- **Motors**
  - Radial Field Permanent Magnet Technology has Matured
  - High Temp Superconducting Synchronous Motors Under Development
- **Podded Propulsion**
  - Wide Acceptance of Pods in Commercial Ships
  - PM Rim-Drive Pods Under Development
- **Power Electronics**
  - ABB, Rockwell to Announce Modular Power Electronic Building Block Technology
  - Costs Remain Barrier to Universal Application
- **Power Generation**
  - Reforming Diesel Fuel for Fuel Cell Demo of Aux Power
- **Modeling and Simulation**
  - Virtual Test Bed Provides Simulation of Architectures

Podded Propulsion

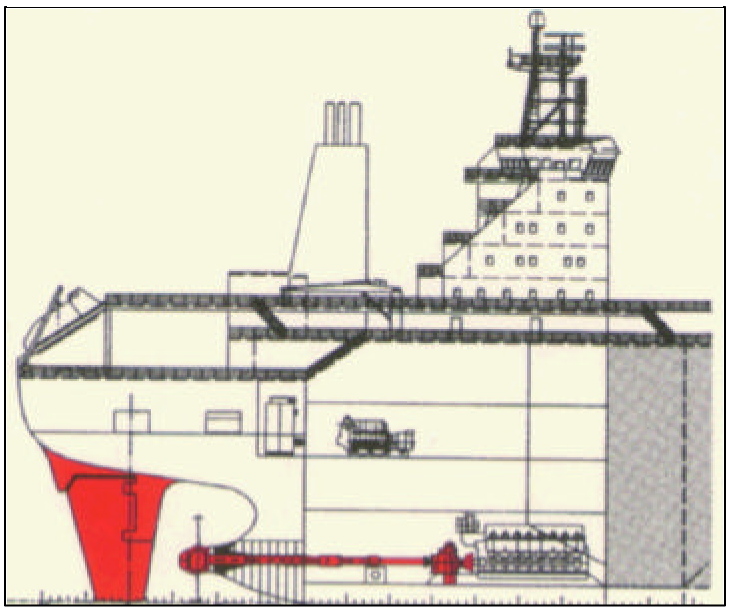
- **Gaining Wide Acceptance in Commercial Ship Industry**
  - Increased propulsive efficiency
  - Maneuverability
  - Increased cargo/passenger space
  - Installation late in shipbuilding process
- **Additional Warship Issues**
  - Signatures
  - Shock

Design Flexibility

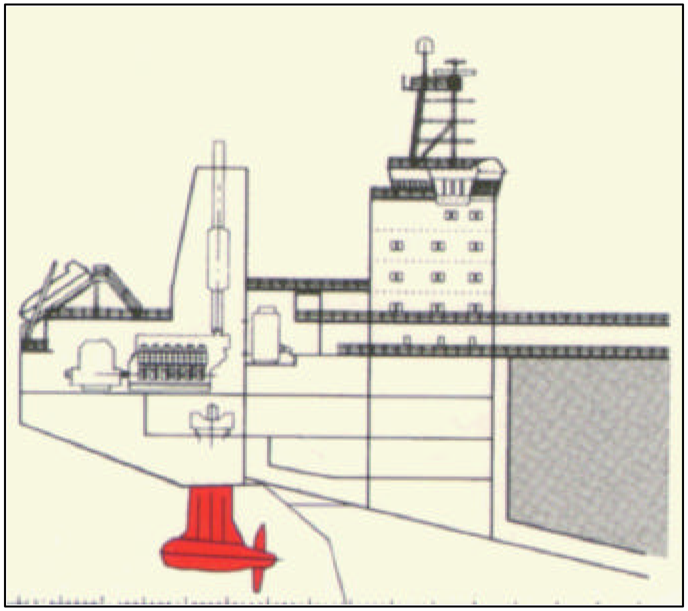
Alternative Propulsion Systems on 120,000 DWT Arctic Tanker

Diesel/Electric/Podded Propulsor
Allows Design Flexibility

Diesel/Mechanical Propulsion



Diesel/Electric Propulsion



with Podded Propulsor

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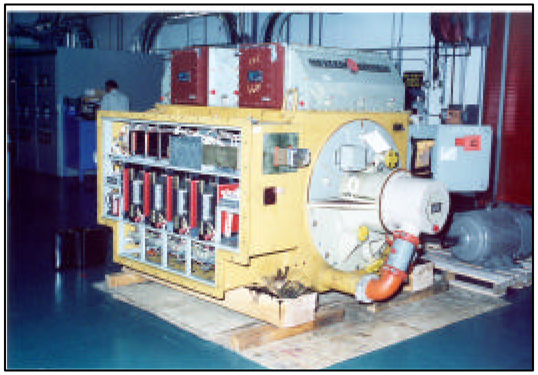
Advanced Electric Propulsion

Current ONR Program is Demonstrating Three Motor Technologies with Podded Propulsion Application:

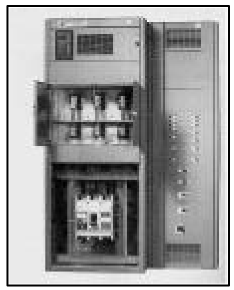
- **Rim-Driven Permanent Magnet Motor/Propulsor**
- **High Temperature Superconducting (HTS) AC Synchronous Motor**
- **DC Superconducting Homopolar Motor**

Rim Drive Podded Propulsor

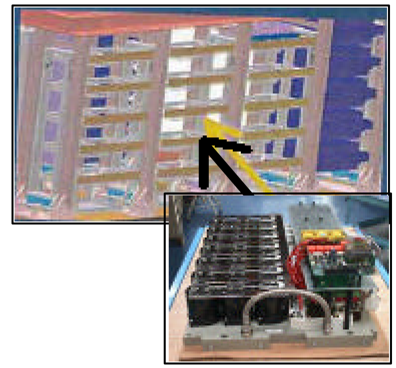
High Speed Gas Turbine Generator

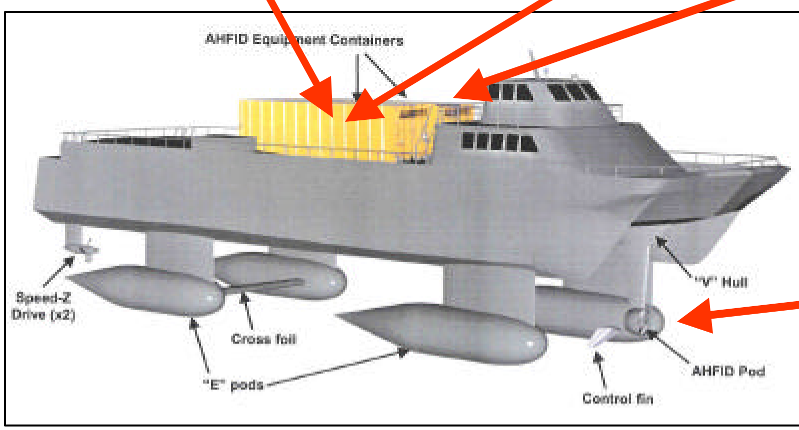


COTS Switchgear

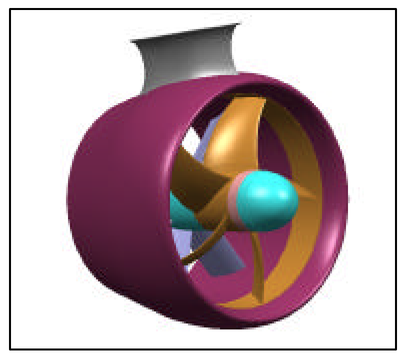


PWM Motor Drive





Converted SES 200B



Permanent Magnet Rim-Driven Propulsor

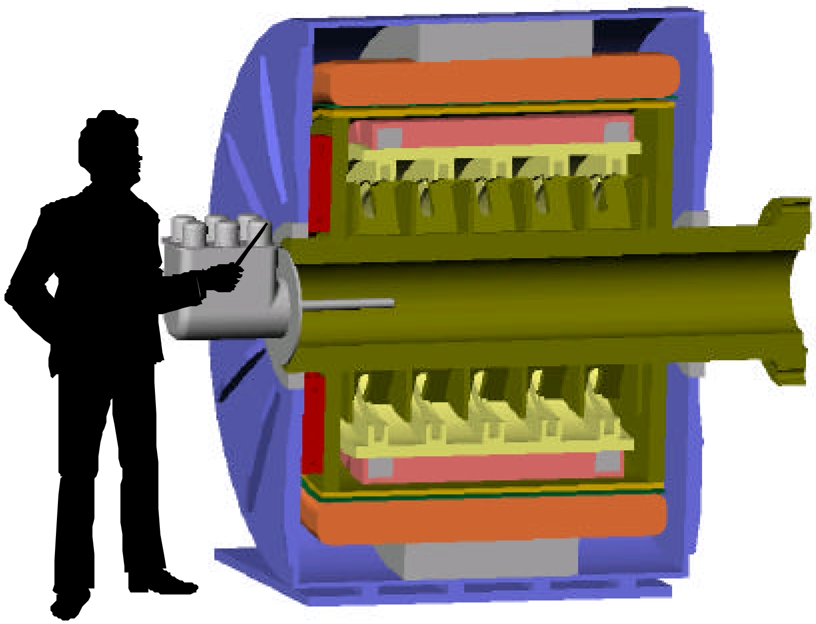
Embedded Sensor System

Composite Strut

General Dynamics BIW/EB

HTS AC Synchronous Motor

25 MW MOTOR CONCEPT



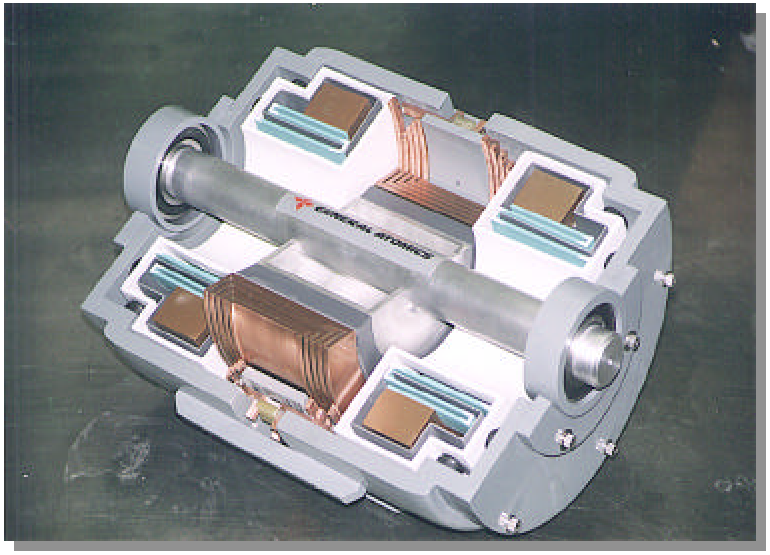
<u>Full-Scale (25MW) Concept Size</u>
Motor: OD = 2.65 m Length = 2.08 m
Cryo-Cooler: <1.0 m^3

- **HTS Motors for Naval Applications Offer the Following Potential Benefits:**
  - Smaller Size and Lighter Weight
  - Low Noise (No Cogging Torque)
  - Field De-Excitation During a Stator Fault
- **The ONR Demonstration Program**
  - 25MW Motor Conceptual Design
  - 5MW Sub-Scale Motor and Propulsion Pod
  - Risk Mitigating Technology Development

American Superconductor

DC Superconducting Homopolar Motor

MOTOR CONCEPT



<u>Full-Scale (25MW) Concept Size</u>
Motor: OD = 2.65m, Length = 3.05m
Cryo-Cooler: <1.4 m^3

- **DC Homopolar Motors for Naval Applications Offer the Following Potential Benefits:**
  - Small Size and Weight
  - Pure DC/Minimum Noise
  - Simple/small Motor Controller
- **Issues from Previous Navy Development Programs**
  - Brushes to Handle Very High Current
  - Cryo-Cooling for Low Temp SC
  - Integration of Low Voltage/High Current Motor into Integrated Power System Architectures
- **The ONR Demonstration Program**
  - Full Scale Motor Concept
  - 4MW Scale Motor Demonstration
    - Potential Pod application
  - Ship Integration Study

General Atomics

Summary

- System Power Density is a Significant Impediment to All-Electric Ship
- Power Electronics is a Key Enabling Technology but High Acquisition Cost Impedes Universal Application
- Podded Propulsion Offers a Wide Range of Potential Benefits But Technology Development is Needed to Address Warship-Unique Issues