Electric Ships Office
PMS 320
Directing the Future of Ships Power

Ships at Sea: The Original Microgrids?

Eighth Annual Carnegie Mellon Conference on the Electricity Industry

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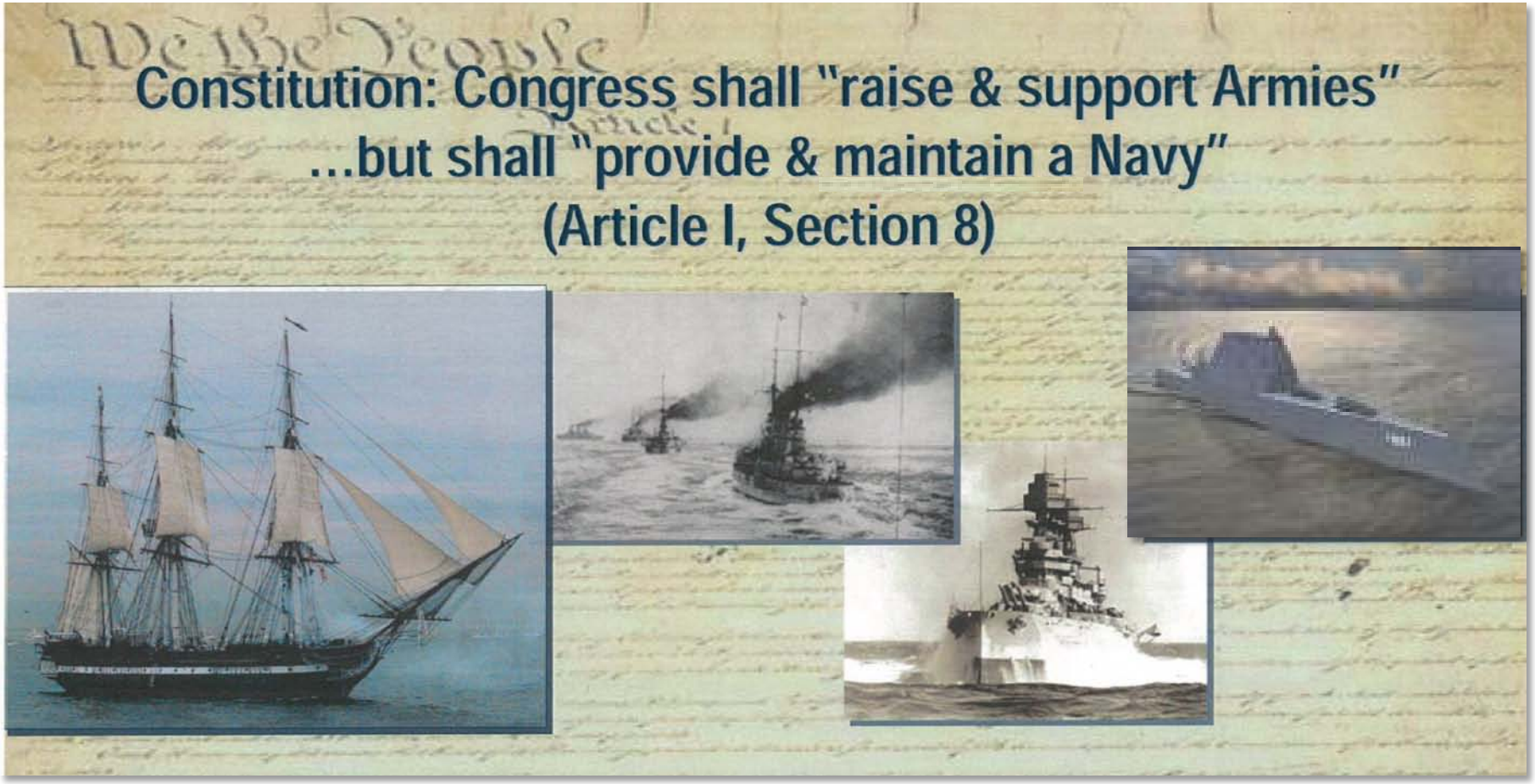
NAVSEA Naval Sea Systems Command
ONR Office of Naval Research
PEO SHIPS
PEO IWS
SEA 21

Outline

- Brief History of Electricity in the US Naval Fleet
- Today's Marine Power System Drivers
  - Naval Ships
  - Commercial Ships
- Shipboard Power Systems vs. Terrestrial Power Systems
- Ongoing Developments
- Summary

United States Navy



"Without a Navy the Nation's commerce will be at the mercy Of any who would choose to prey upon it" - Alexander Hamilton

US Navy Electric Ships History

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1877-1960

USS Trenton;
USS Langley;
USCGC Modoc;
USS New Mexico;
T-2 Tanker

1970s

- T-AG, T-ARC, T-AGOR, T-AGOS…
- IED alternatives for DDGX started
- Subscale superconducting ship applications analyses, including pod designs.

1980s

- 1988-1989 - Advanced and Integrated Electric Propulsion developed for NAVSEA
- 1988 – CNO ADM Trost designated IED for surface combatants
- 1984 - Integrated electric Propulsion evaluated for FFX—ship program cancelled

1990s

- Commercial IPS T-AKE
- 1995 – IPS Full Scale Advanced Development
- ASMP focus on AC ZEDS (DDG 51 Flight IIA) , ICR, and reduced scale PM Development

2000s

- 2000 – SECNAV determines DDG 1000 will be IPS
- Integrated Fight Through Power (IFTP) Development
- 2007 – Electric Ships Office (PMS 320) Established
- 2007 - Next Generation IPS Roadmap Published

2010

- Improved Fuel Efficiency and Increased Power Density
- 400hz Point of Use Power Conversion
- Whole Ship UPS Architecture
- EMALS / AAG
- Open Architecture Systems

2020

- Electric Weapons Support
- Advanced Sensors (AMDR)

Navy After Next

A History of Successful Development and Transition

History of U.S. Navy Electric Ships

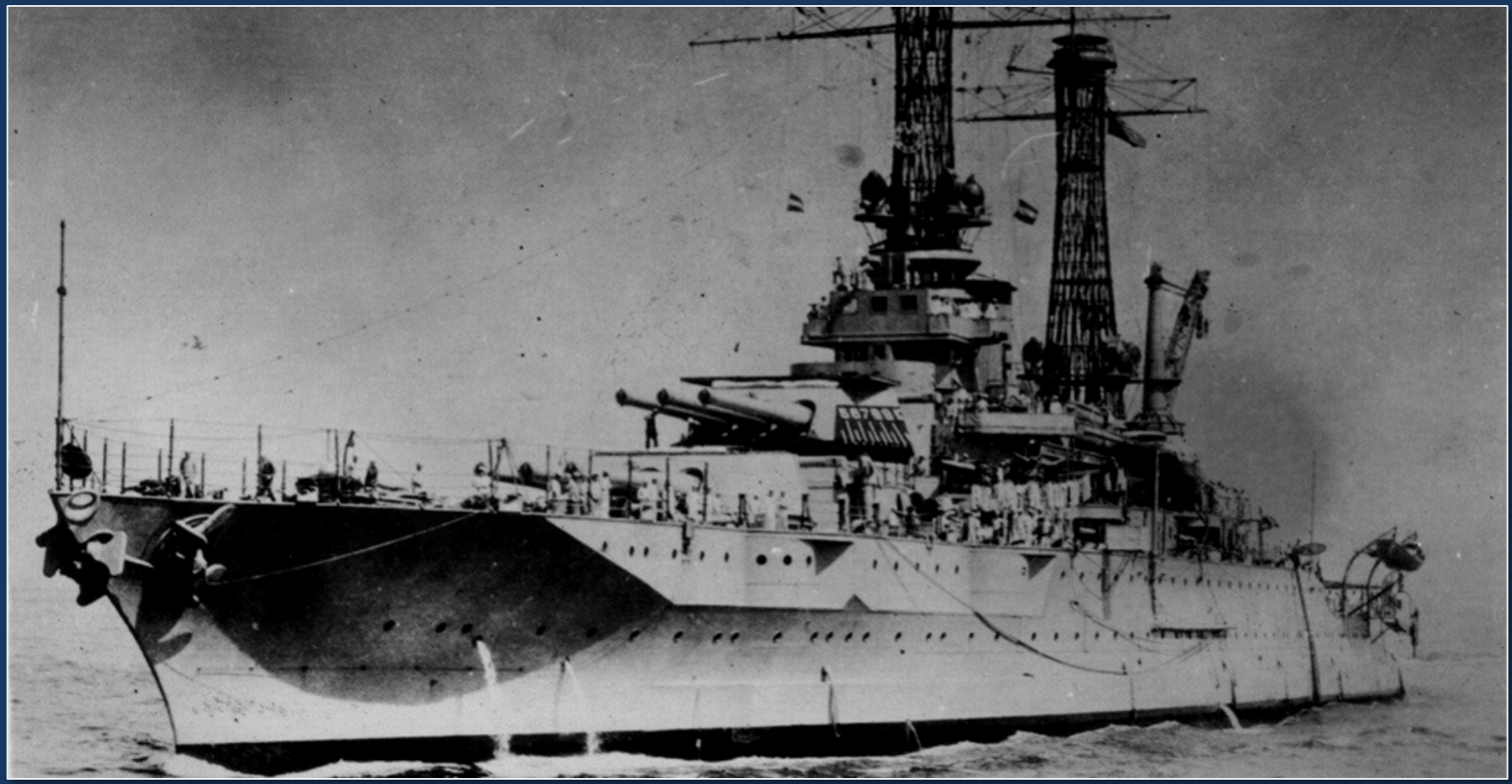
USS JUPITER (AC 3)
Commissioned 1913

Collier

USS LANGLEY (CV 1)
Recommissioned 1922

First U.S. Navy Aircraft Carrier

History of U.S. Navy Electric Ships



USS NEW MEXICO (BB 40) Commissioned 1918
U.S. Navy's First Electric Propulsion Combatant

Shipboard Power & Propulsion Systems

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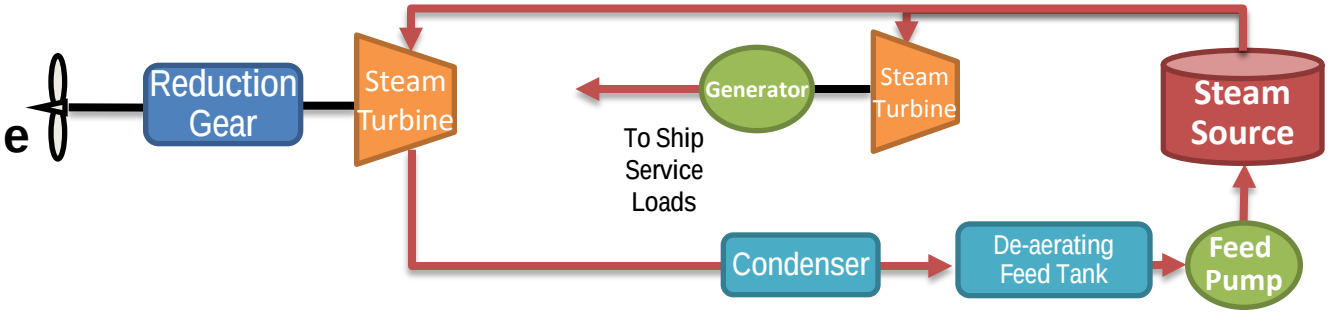
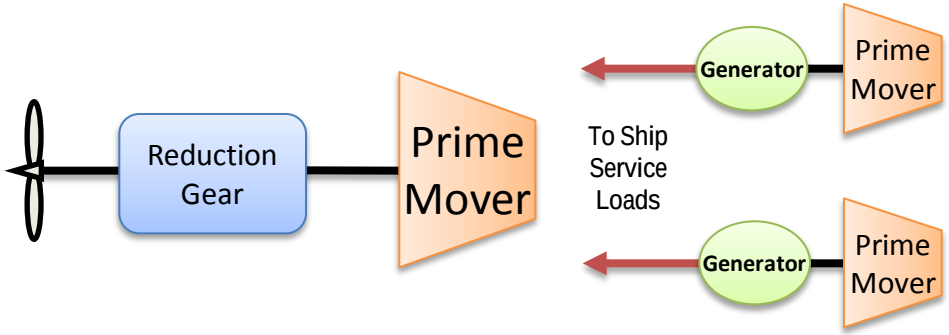
Steam ships are 'integrated' on the steam side

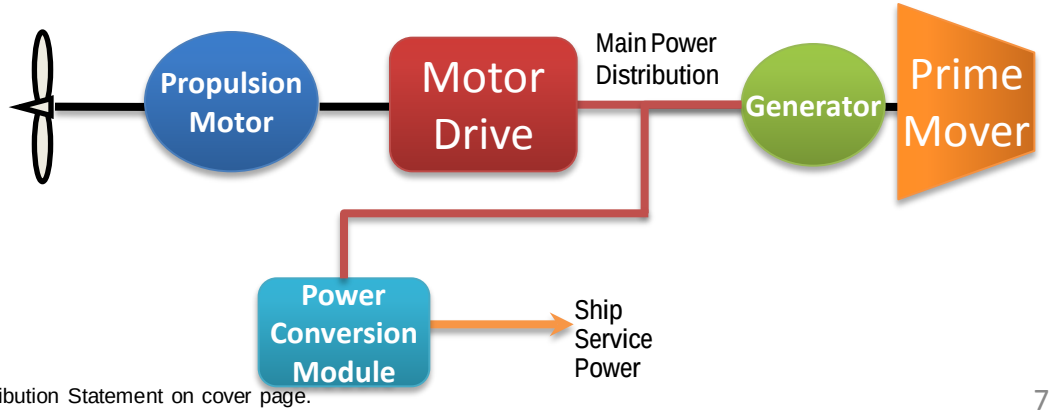


For Surface ships, 'Integration' was lost when we transitioned to internal combustion engines



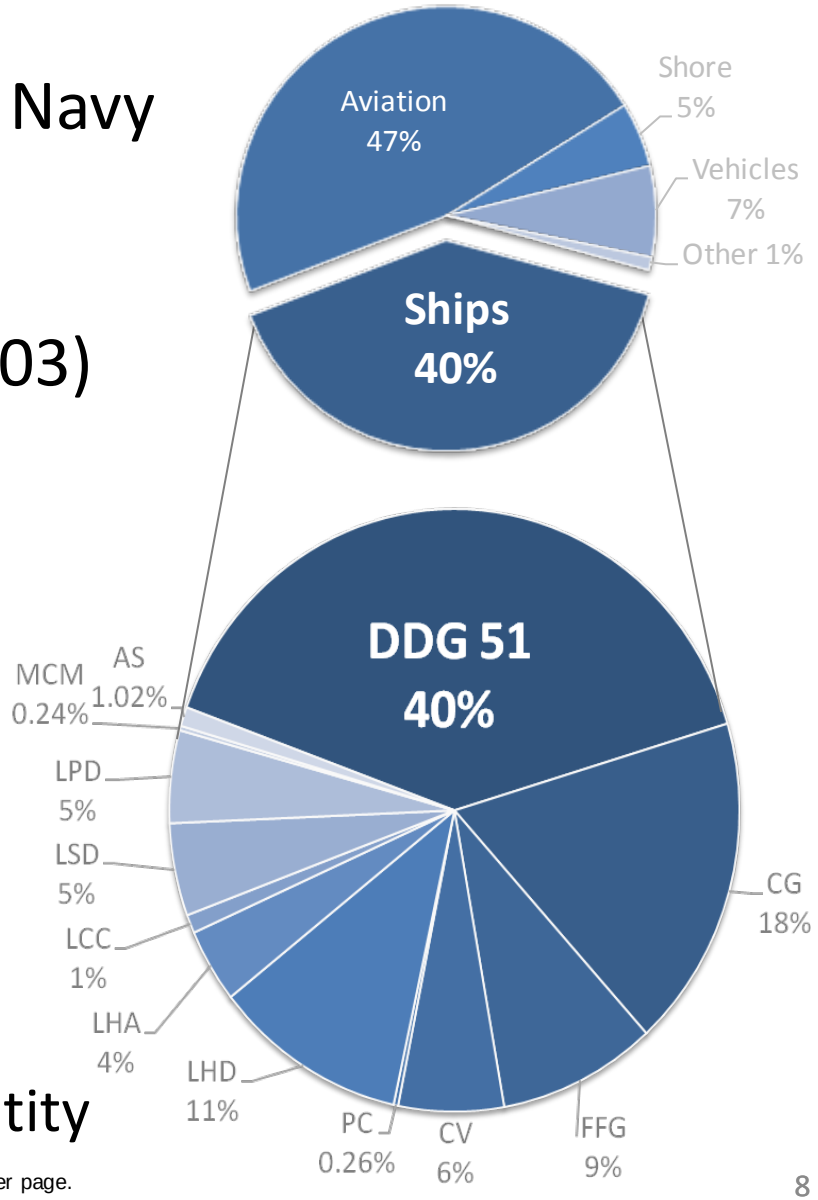
IPS brings back 'integration' on the electrical side, enabled by:

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



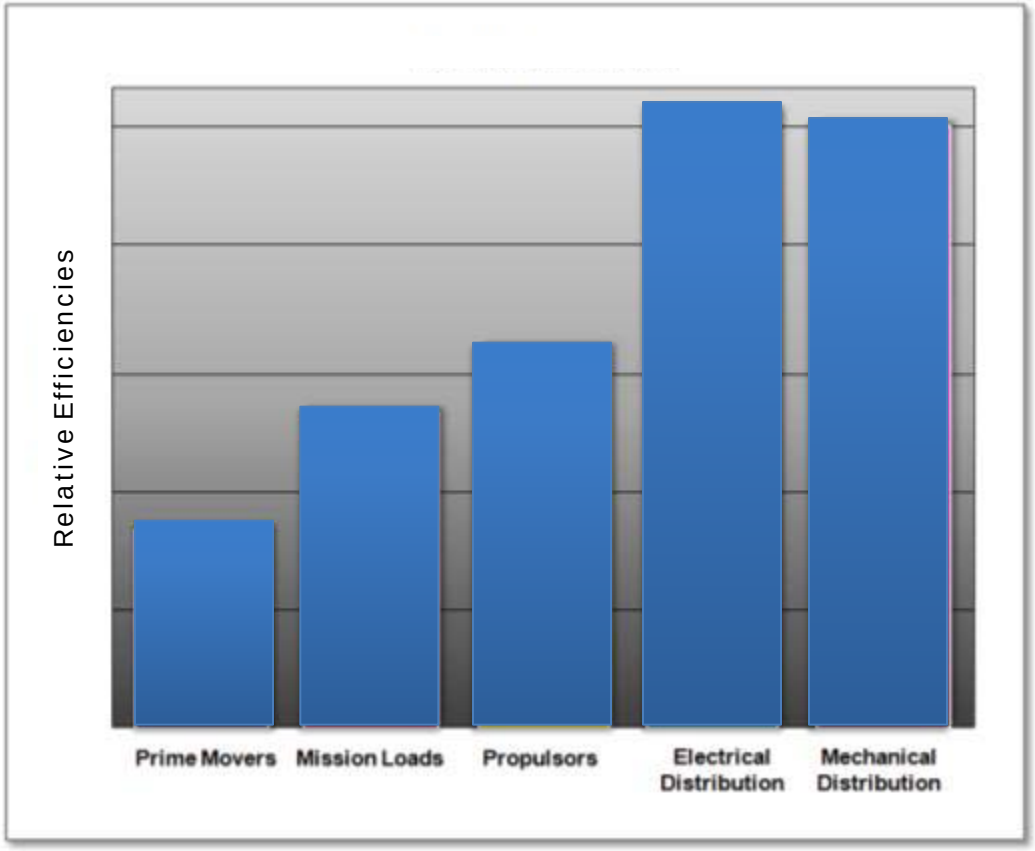
U.S. Navy Fuel Usage and Trends

- Surface ships account for 40% of Navy fuel consumption
- Fuel cost uncertainty (~400% per bbl increase since FY03)
- Energy (fuel) Demand Increasing
  - Combat / Weapons Power
  - Force Structure Changing: Higher Fuel Consumption
  - Operational Requirements
- Why focus on DDG 51 Class?
  - Provides best opportunity for long term payoff given platform age, production restart, and quantity



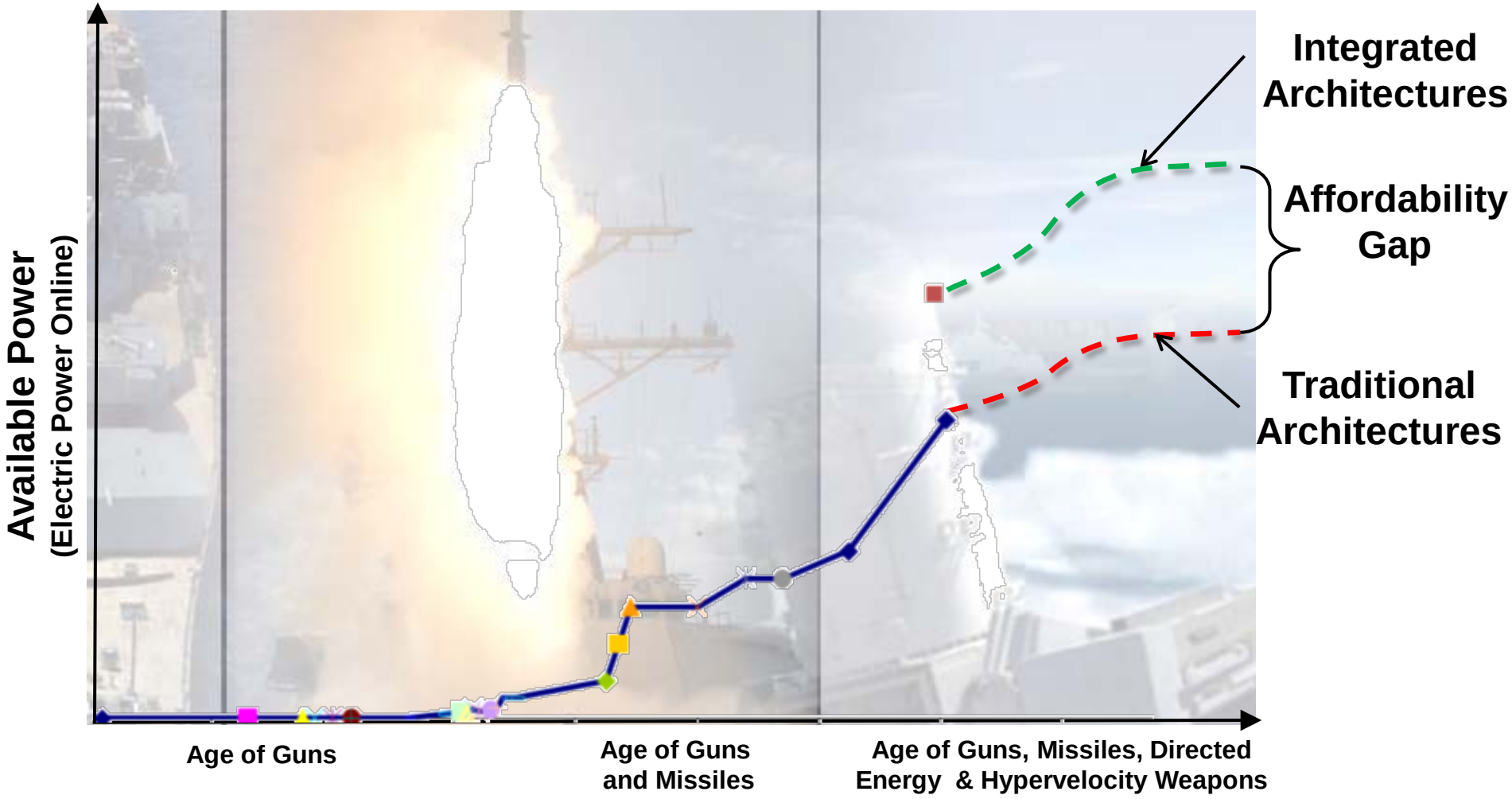
Opportunities for Energy Savings

- Prime Movers
  - Technical advances
  - Combined cycles
- Ship Propulsion
  - Propulsor efficiency
  - Hullform resistance
  - Energy Recovery
- Electrical Loads
  - Fans / Pumps
  - Mission Systems
  - Lighting
  - Variable Frequency Drives
- Operating Concepts
  - Alternate Architecture optimizes Fuel Consumption



Alternate Architectures Maximizes Energy Savings

Warfighting Needs Drive Power Systems



Increased demands for power will continue for the foreseeable future

Mission Systems:
Increasing Electrical Power Demands

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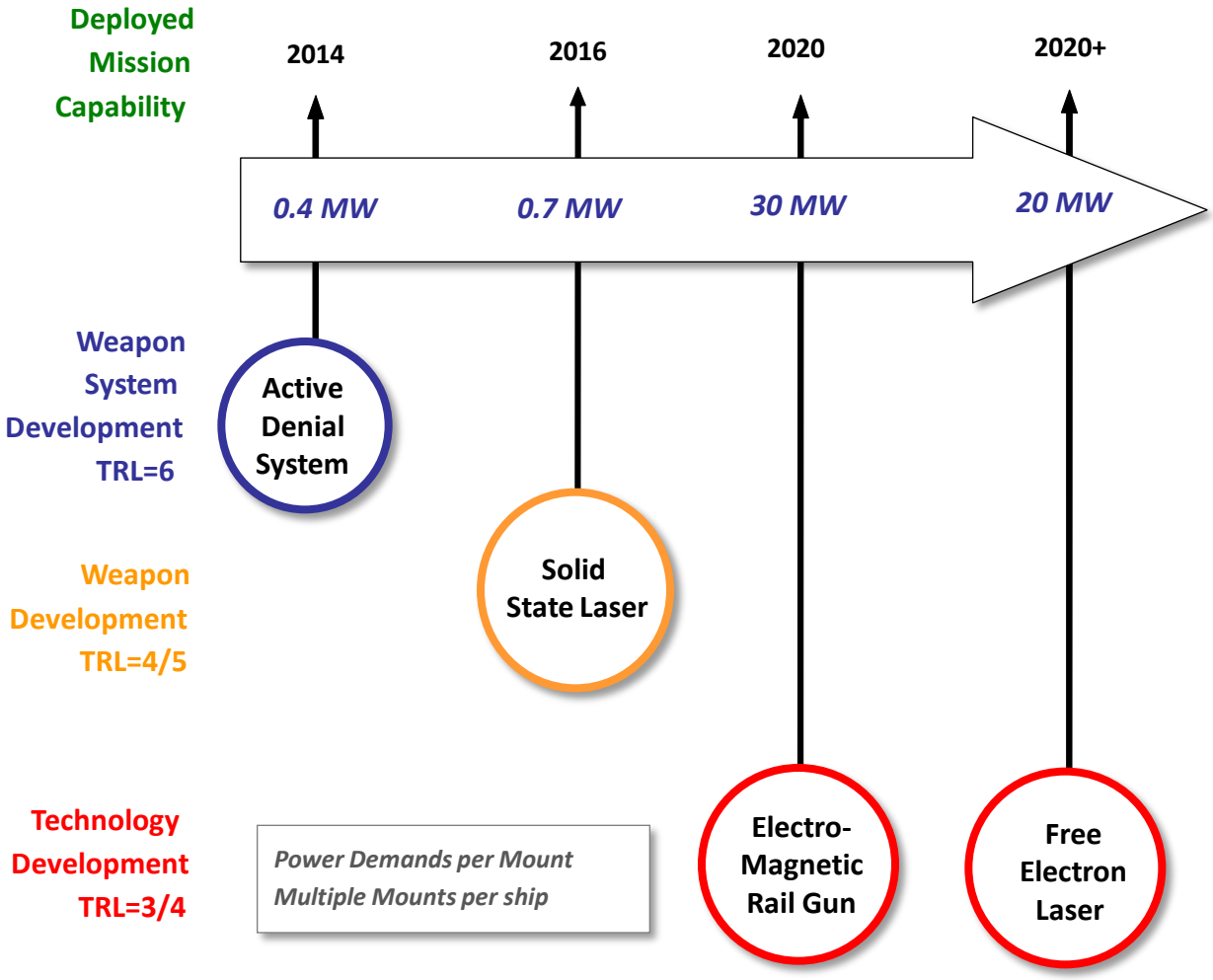
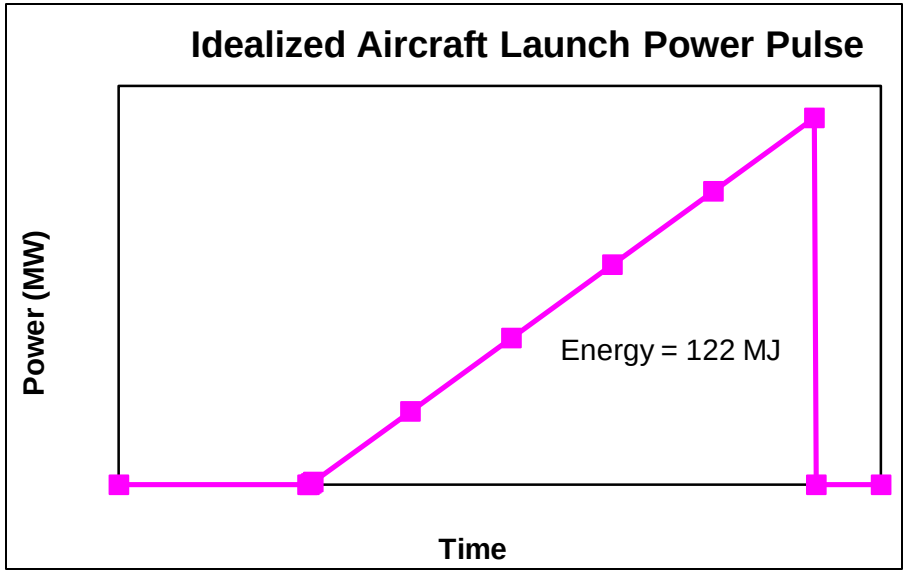
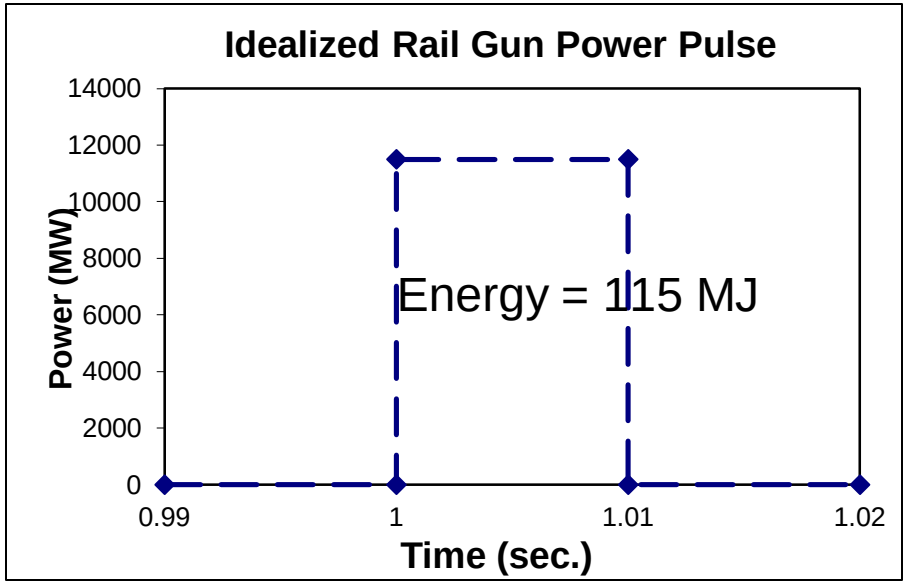



Laser Weapon System

Sensor and Weapon System Power Demands will soon rival Propulsion Power Demands

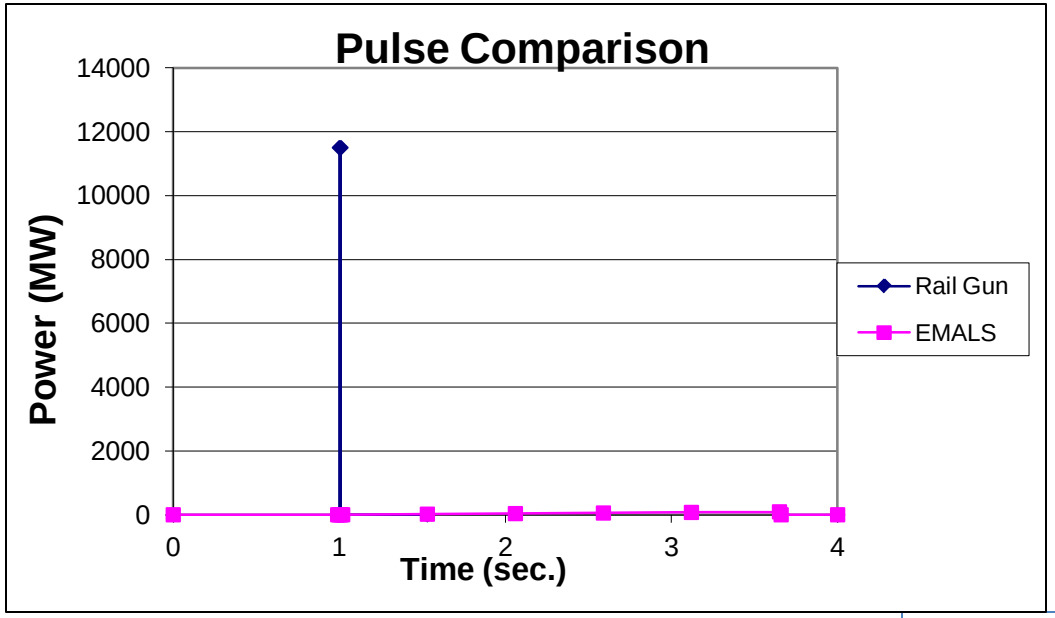
Example Ship Power System Loads

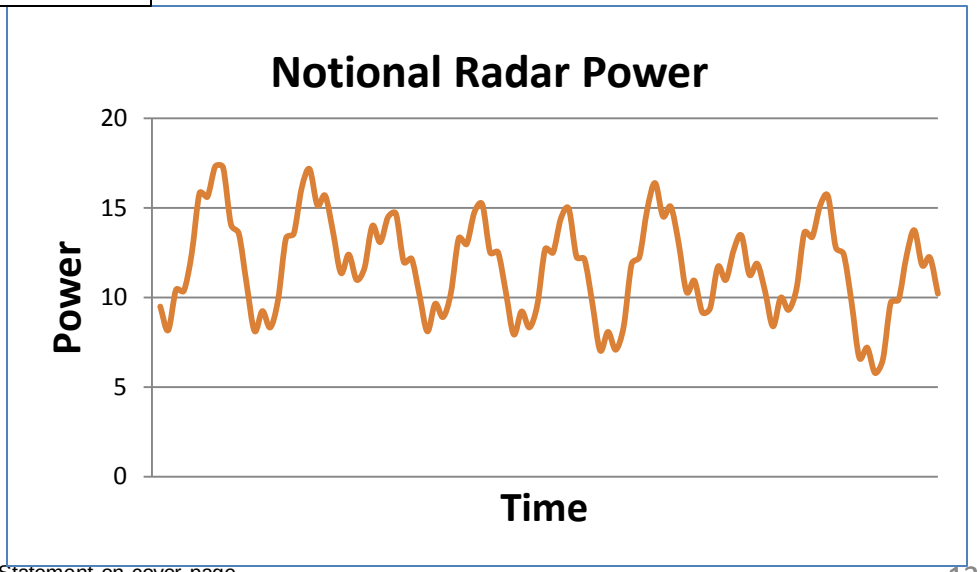




Placeholder for Videos

Loads Behaving Badly

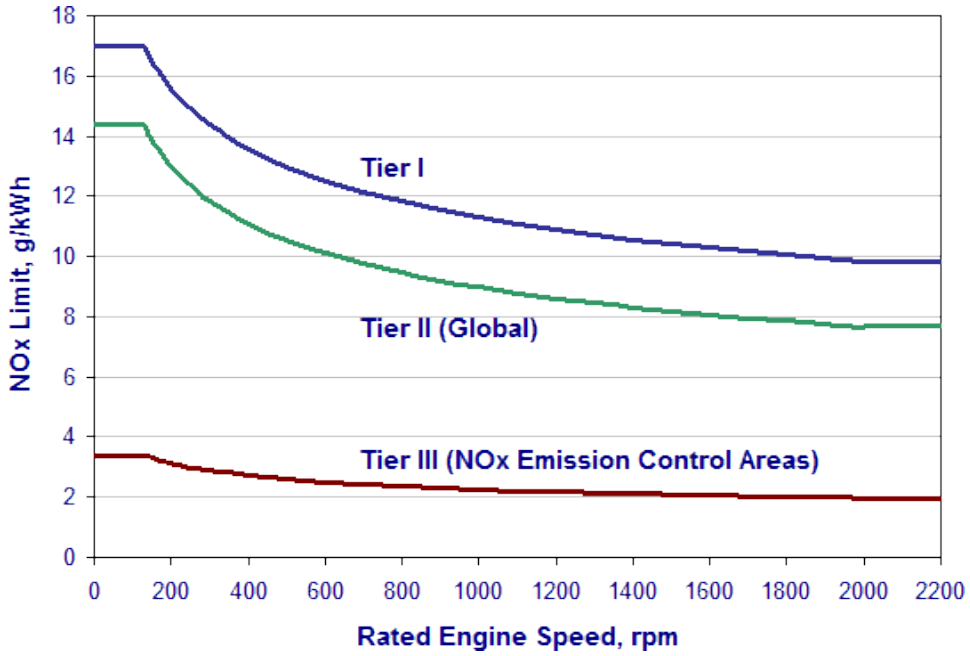




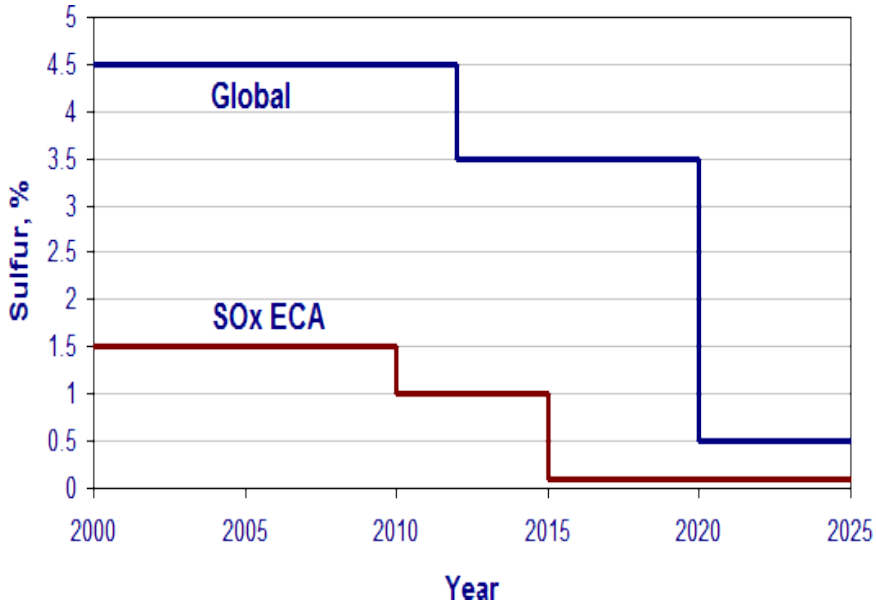
Commercial Marine Power Systems
Design Drivers

- **IMO MARPOL Annex VI Emissions Regulations**
  - **Limits NO_X Emissions**
  - **Limits Fuel Sulfur Content**
  - **Requires implemenation of:**
    - **Energy Efficiency Design Index (EEDI), for new ships**
    - **Ship Energy Efficiency Management Plan (SEEMP) for all ships.**

MARPOL Annex VI NO_X Limits[1]



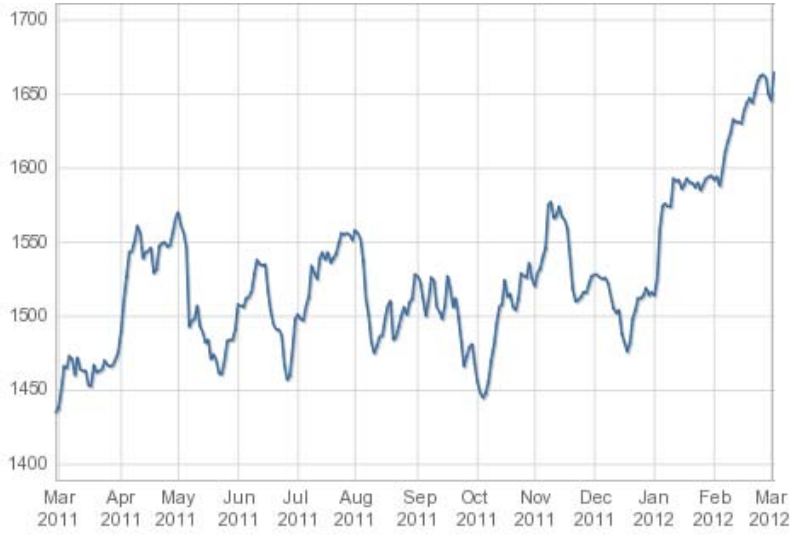
MARPOL Annex VI Sulfur Limits[1]



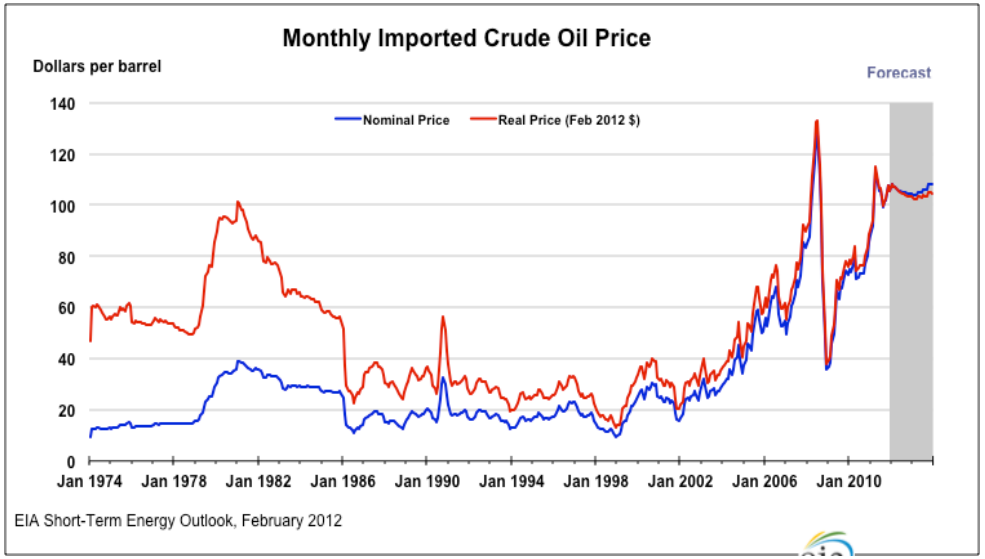
[1] www.dieselnet.com

- **Increasing Fuel Prices**

Bunker Fuel Price Index[1]



Crude Oil Price History[2]



[1] www.bunkerworld.com
[2] US Energy Information Administration

Terrestrial vs. Marine Power Systems

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Terrestrial Power Systems

- Structure – generally radial
- Large numbers of generators, busses, transmission lines, loads
- Constant frequency – linearized about an operating point
- Load flow analysis
- Market Implications

Marine Power Systems

- Structure – zonal / mesh
- Small number of generators, busses, negligible transmission lines
- Large transients, often not linearizeable
- Frequency domain analysis
- No market implications

Ongoing US Navy Power System Developments

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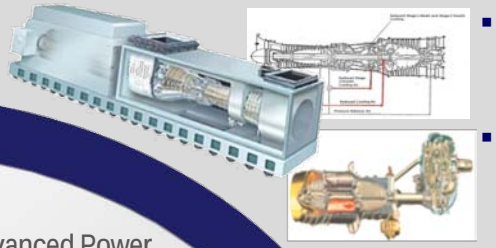
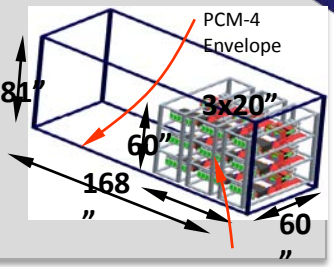
- Reduce DDG 51 Class in-service fuel consumption
- Provides propulsion at low ship speeds without the need for LM 2500 main engines
- Assure mobility, lighten the load, expand tactical reach, and green our footprint

- Provide fuel efficient and affordable power to meet power requirements for advanced sensors and future weapons



- Reduction in weight and lower life cycle costs
- Up to 17% reduction in fuel consumption over the DDG 51 FLT IIa GTG

- Power conversion from ship current to 1000 VDC for the AMDR
- Potential for faster switching frequencies and higher temp. operation
- Smaller footprint



- Ship Service electrical power from propulsion system through reduction gear

- De-risking Single Generator Operations
- High efficiency GTGs used with no electrical system degradation
- Support pulsed power requirements of advanced weapons

Summary

- **Shipboard Power Systems are evolving due to increases in load demands, environmental regulations and fuel prices**
- **Terrestrial Power Systems are evolving due to increases in load demands, environmental regulations, fuel prices and market deregulation**
- **Incorporation of distributed, renewable generation sources and smart grid technologies may make terrestrial systems behave more closely to shipboard systems**


Questions?