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“The Ship as a Microgrid”

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Code 331

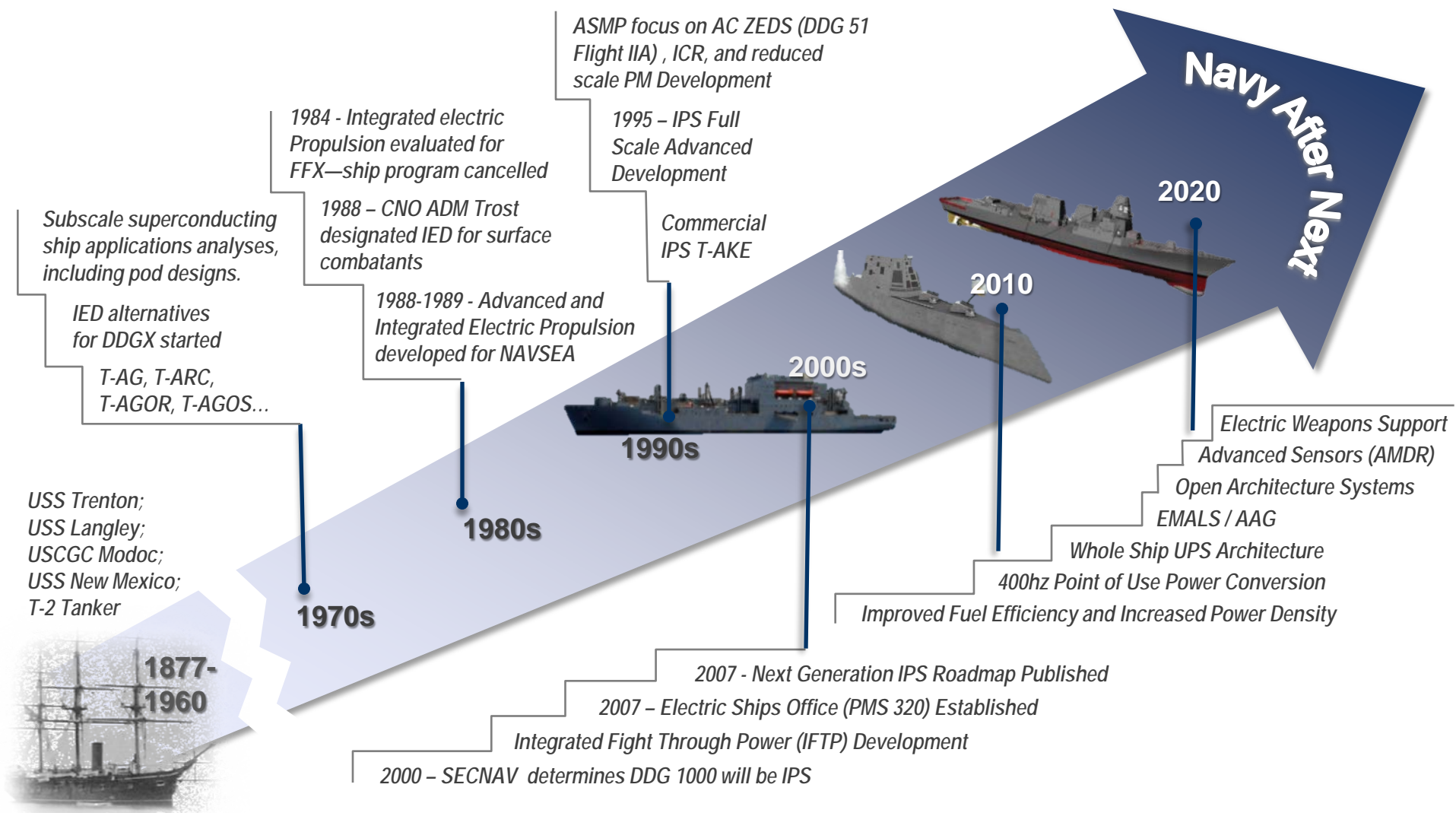
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Distribution Statement A: Distribution is unlimited.
Reference: Electric Machines Technology Symposium 2012

Outline

- Background
- Major Power System Design Drivers
 - Navy Systems
 - Marine Systems
 - Terrestrial Systems
- Microgrids and their Application to Navy Systems

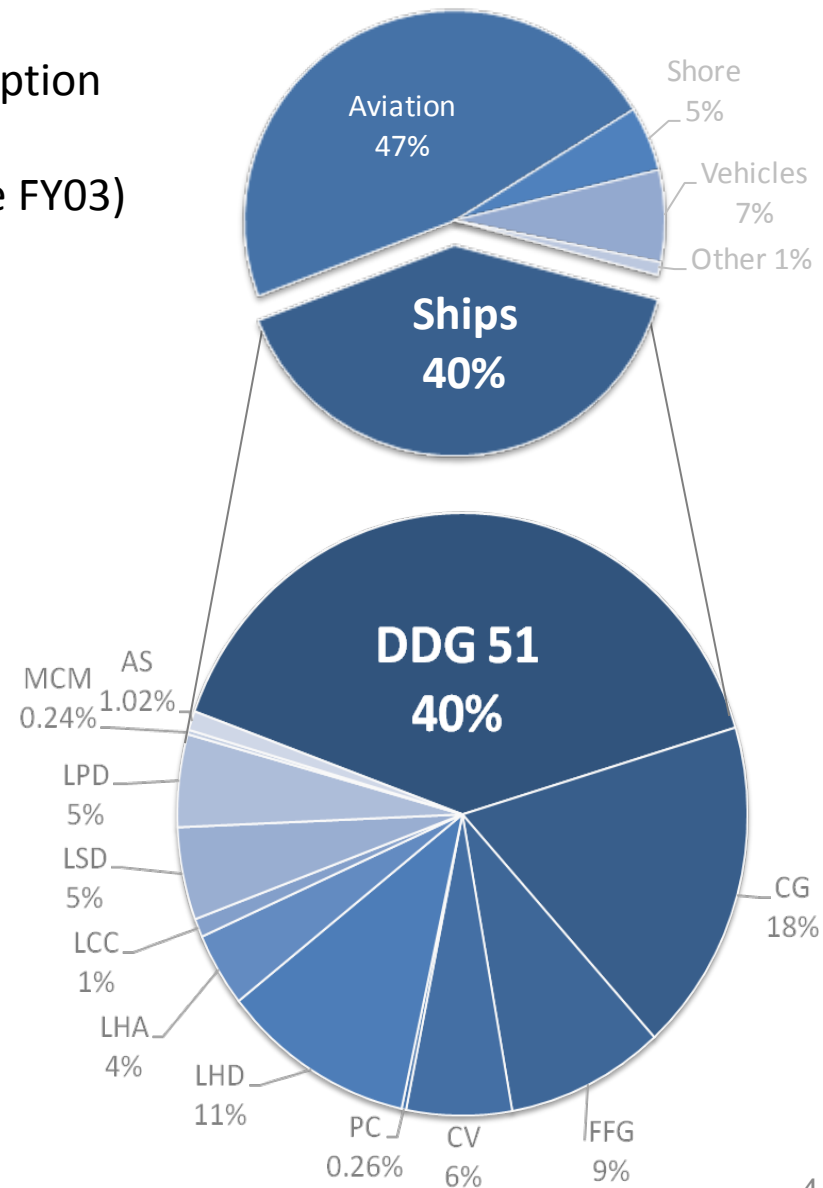
Background: US Navy Electric Ships History



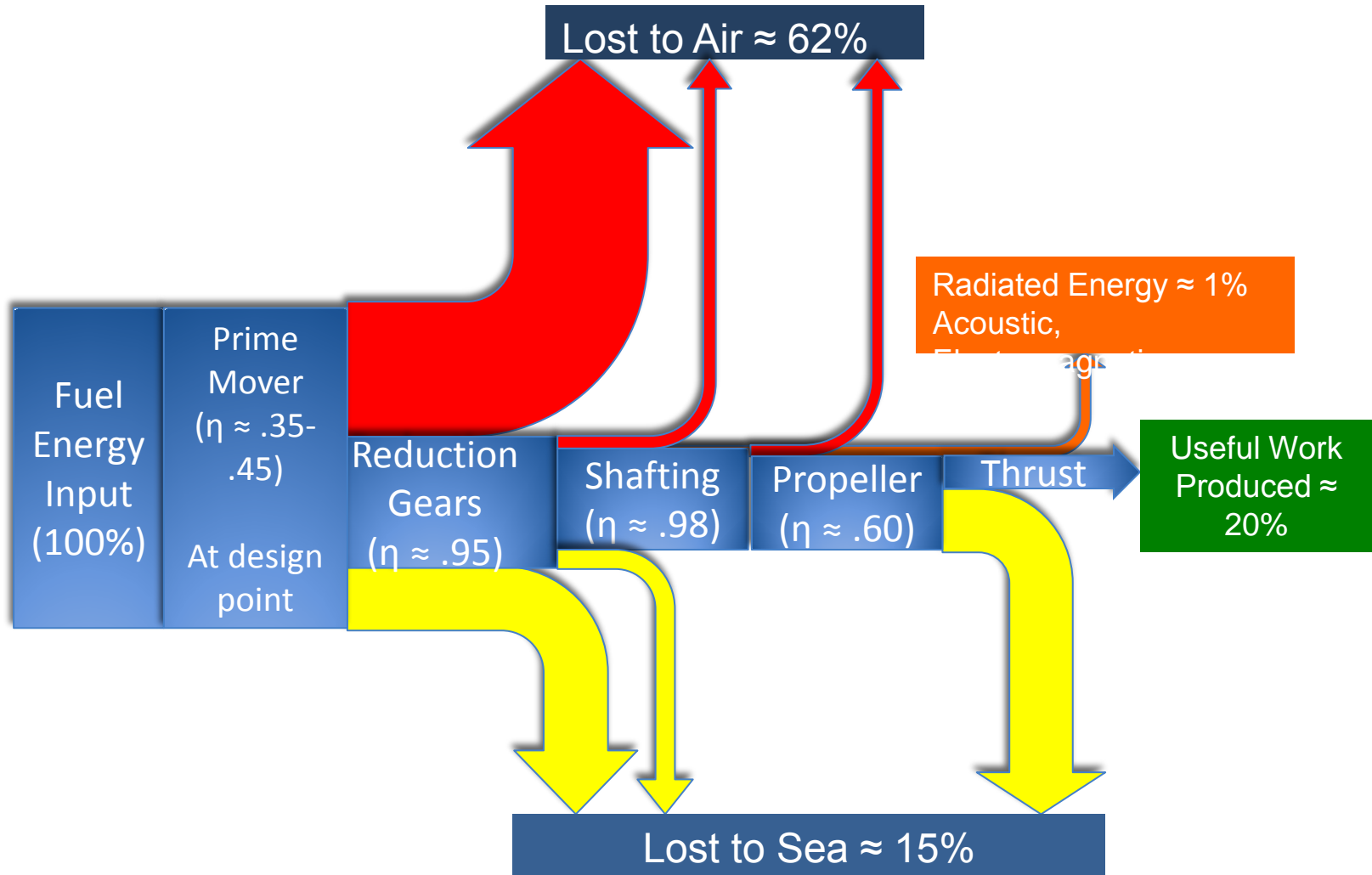
A History of Successful Development and Transition

U.S. Navy Design Drivers

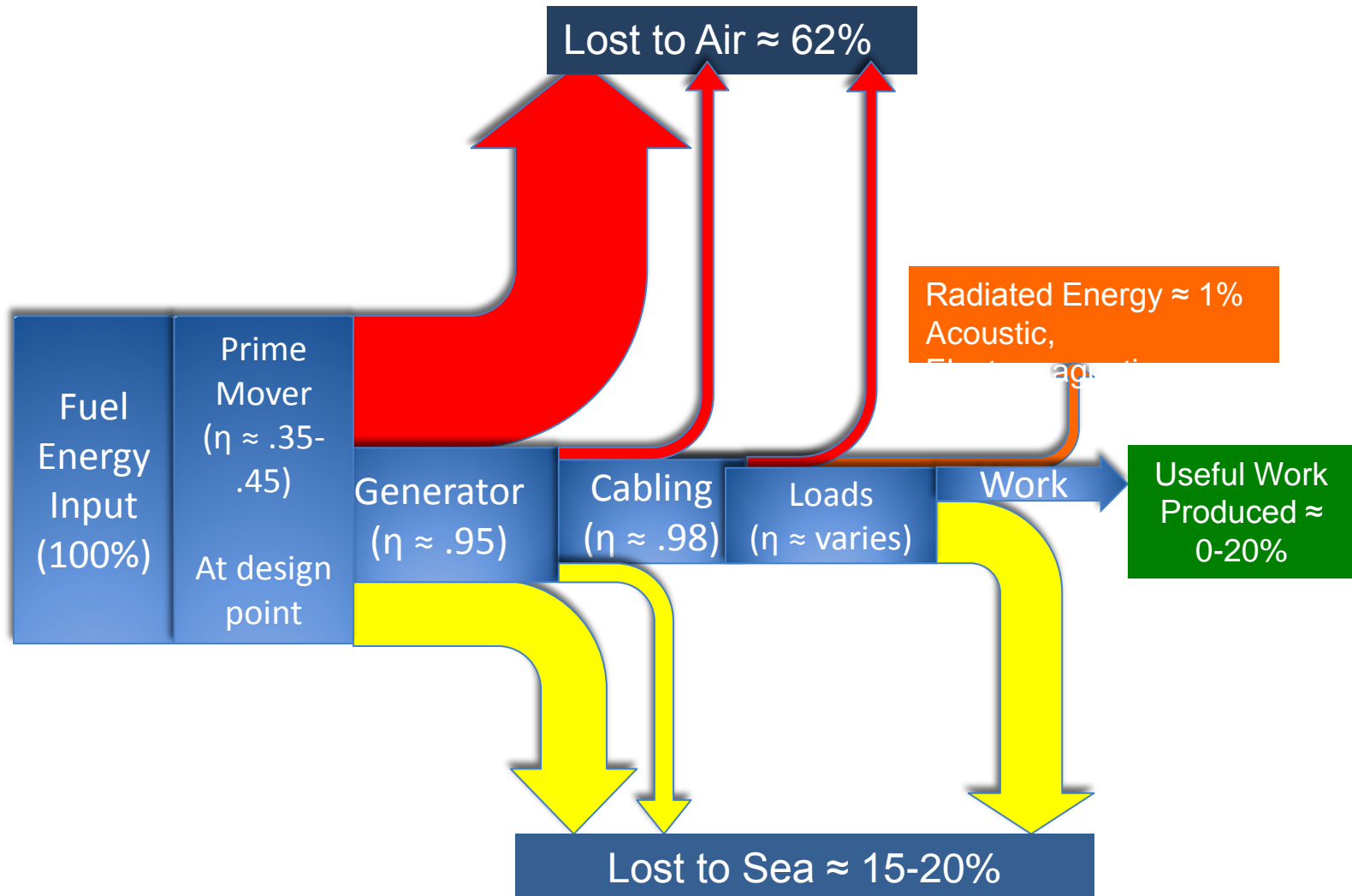
- Surface ships account for 40% of Navy fuel consumption
- Fuel cost uncertainty (~400% per bbl increase since FY03)
- Energy (fuel) Demand Increasing
 - Combat / Weapons Power
 - Force Structure Changing:
Higher Fuel Consumption
 - Operational Requirements
- Why focus on DDG 51 Class?
 - Provides best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



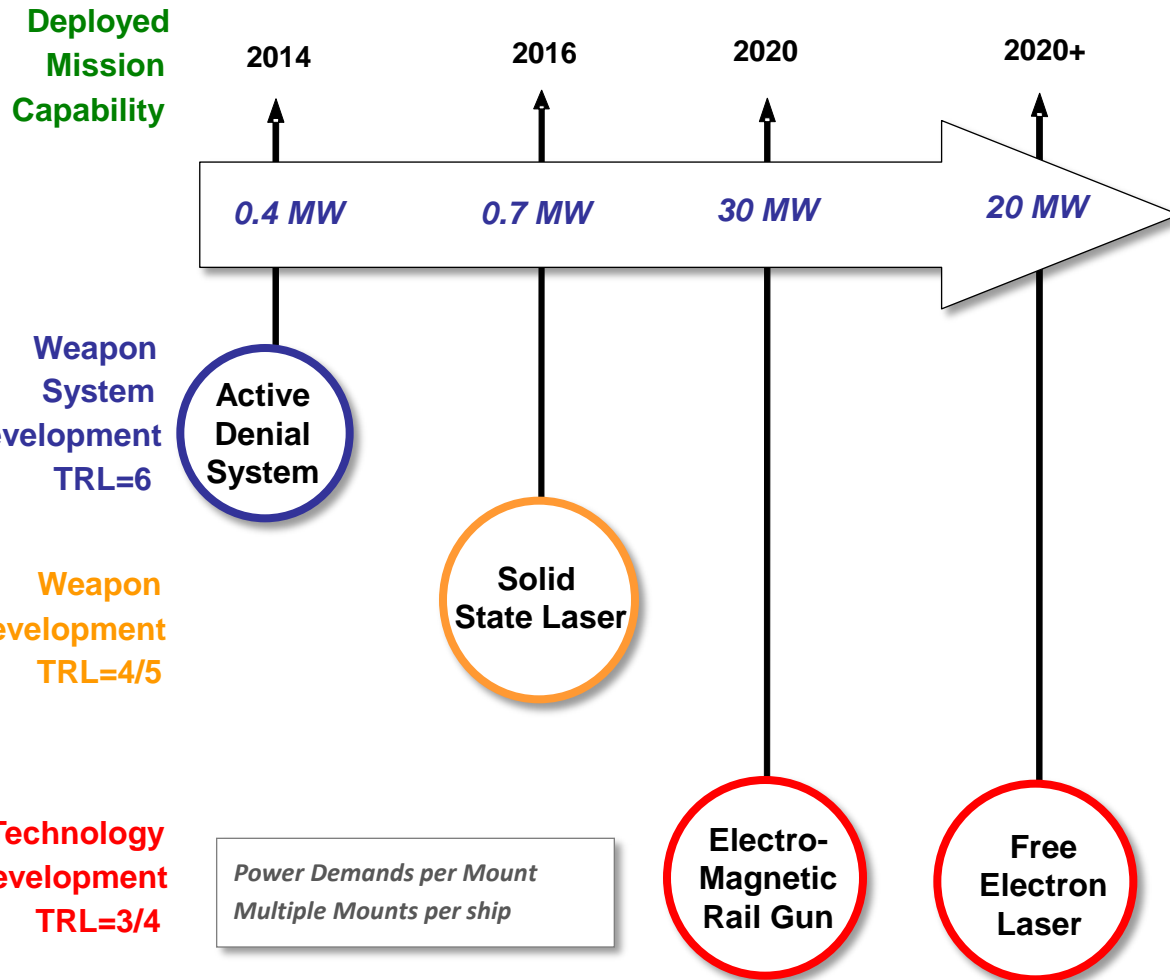
Typical Marine Propulsion System Efficiencies



Typical Marine Electric Power System Efficiencies



Mission Systems: Increasing Electrical Power Demands



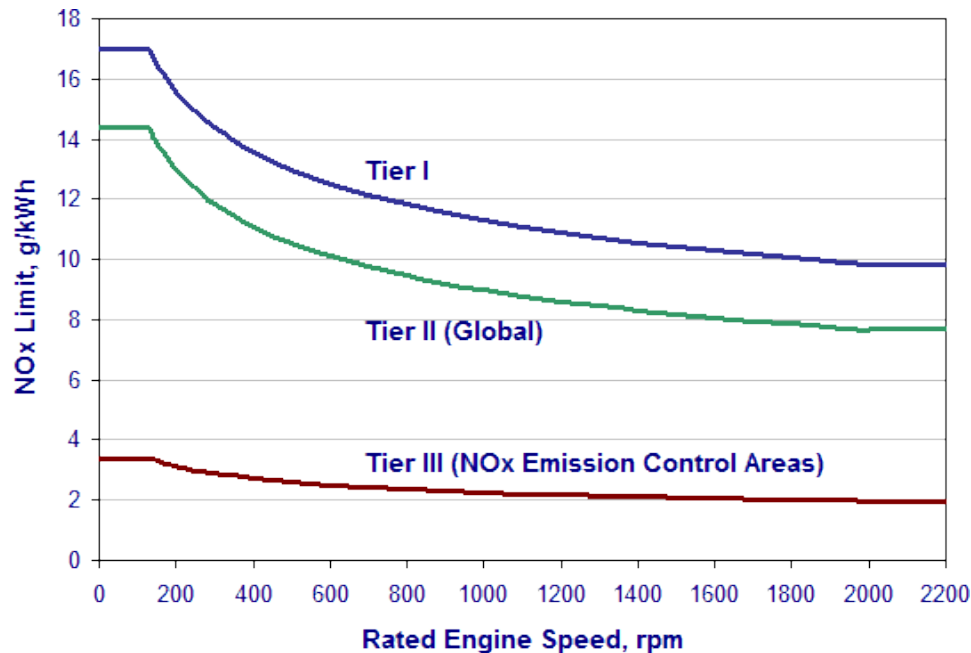
***Sensor and Weapon System Power Demands
will soon rival Propulsion Power Demands***

Commercial Marine Power Systems

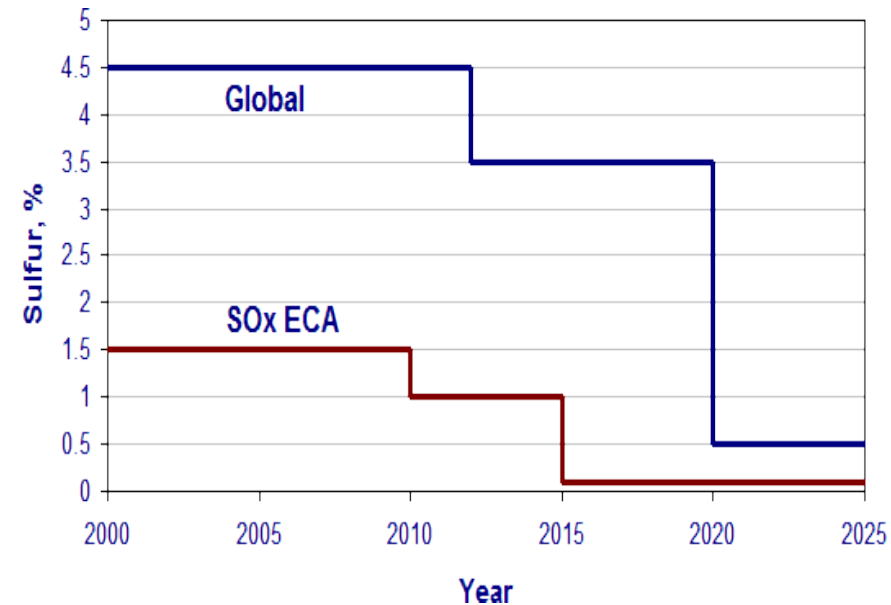
Design Drivers

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

MARPOL Annex VI NO_x Limits¹



MARPOL Annex VI Sulfur Limits¹

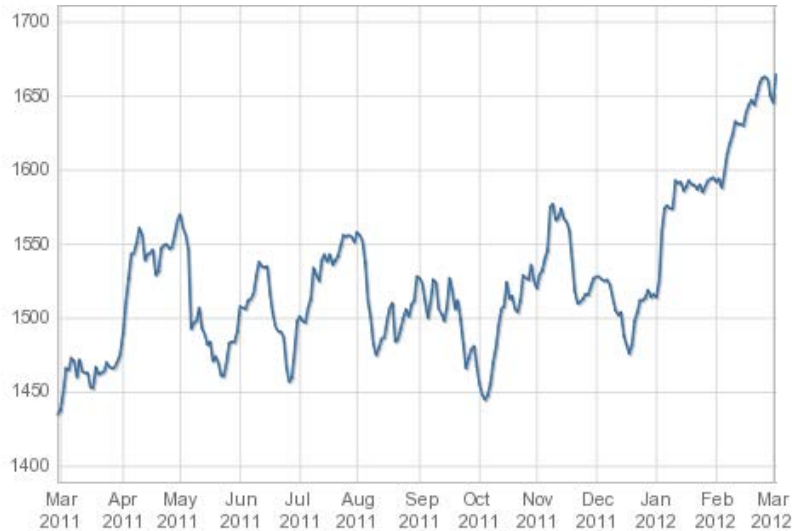


Commercial Marine Power Systems

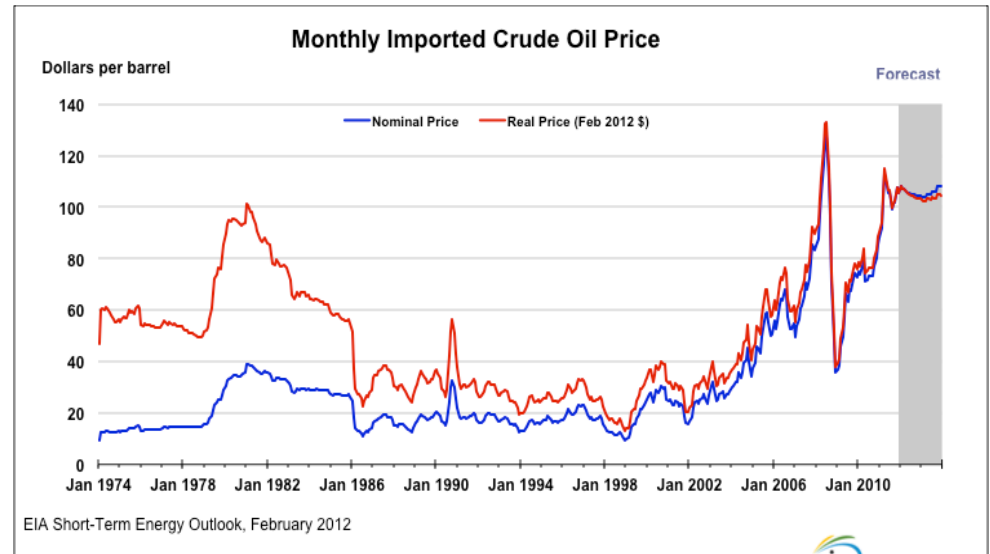
Design Drivers

- Increasing Fuel Prices

Bunker Fuel Price Index¹



Crude Oil Price History²



¹ www.bunkerworld.com

² US Energy Information Administration

Terrestrial vs Marine Power Systems

Terrestrial Power Systems

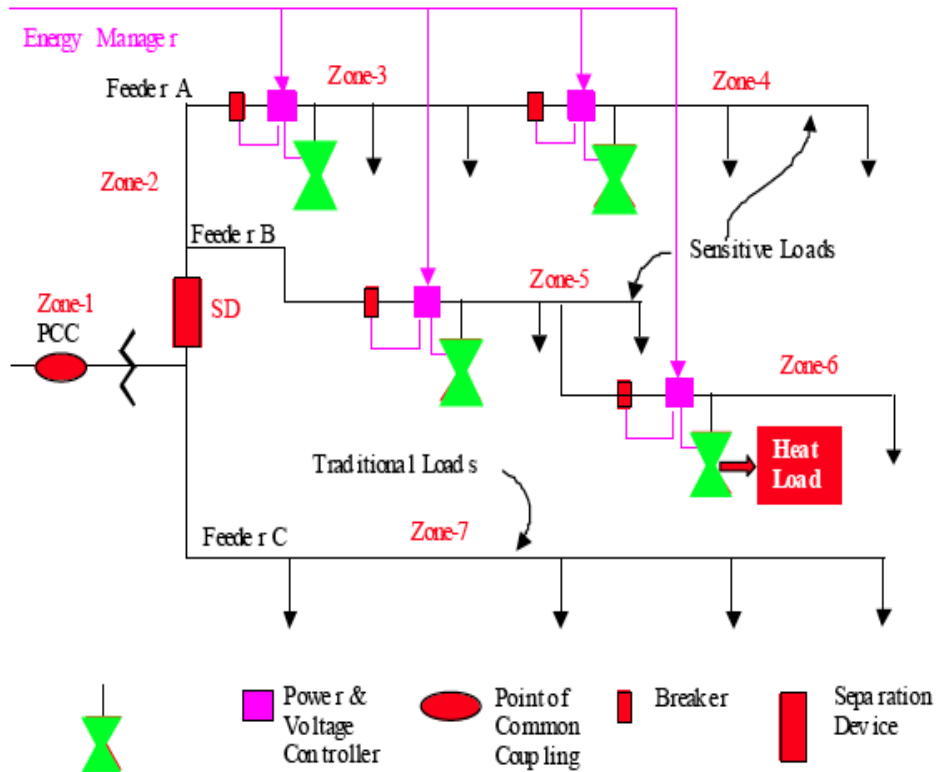
- Structure – generally radial
- Large numbers of generators, busses, transmission lines, loads
- Constant frequency – linearized about an operating point
- Load flow analysis
- Market Implications

Marine Power Systems

- Structure – zonal / mesh
- Small numbers of generators, busses, transmission lines, loads
- Large transients, often not “linearizeable”
- Frequency domain analysis
- No market Implications

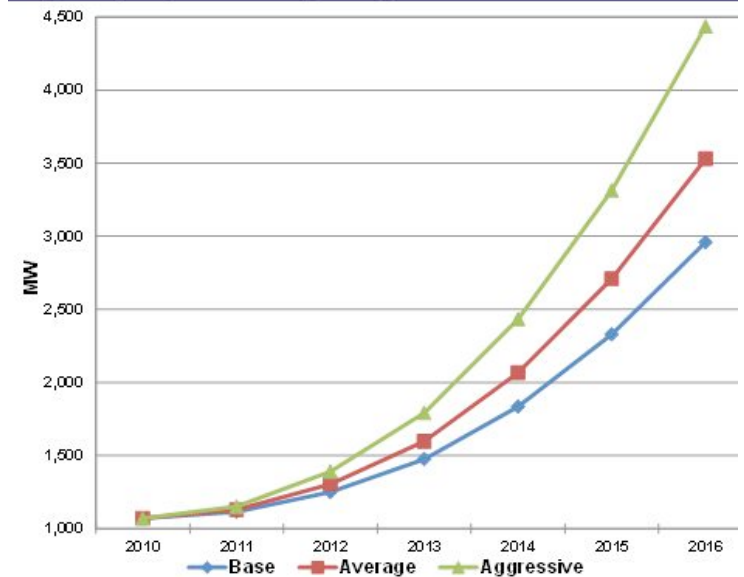
Microgrids - Overview

Microgrid Architecture²



² Integration of Distributed Energy Resources, the CERTS Microgrid Concept," Lawrence Berkeley National Lab, 2003

Microgrid Capacity, Base, Average & Aggressive Scenarios, World Markets:



(Source: Pike Research)

- **Definition of a Microgrid-** An integrated energy system consisting of distributed energy resources and multiple electrical loads operating as a single, autonomous grid either in parallel to or "islanded" from the existing utility power grid.¹

¹ "Distributed Energy Systems for Campus, Military, Remote, Community, and Commercial & Industrial Power Applications: Market Analysis and Forecasts," Pike Research, 2012.

Characteristics of Microgrids

Microgrids are Inherently:

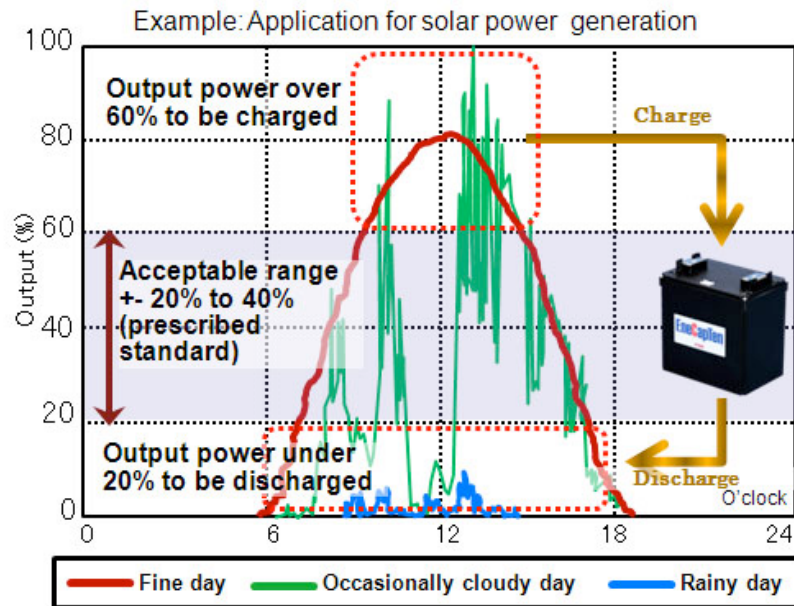
- Distributed
- Autonomous
- Reconfigurable
- Small
- Detachable from Macrogrid

Ships are the Original Microgrids!

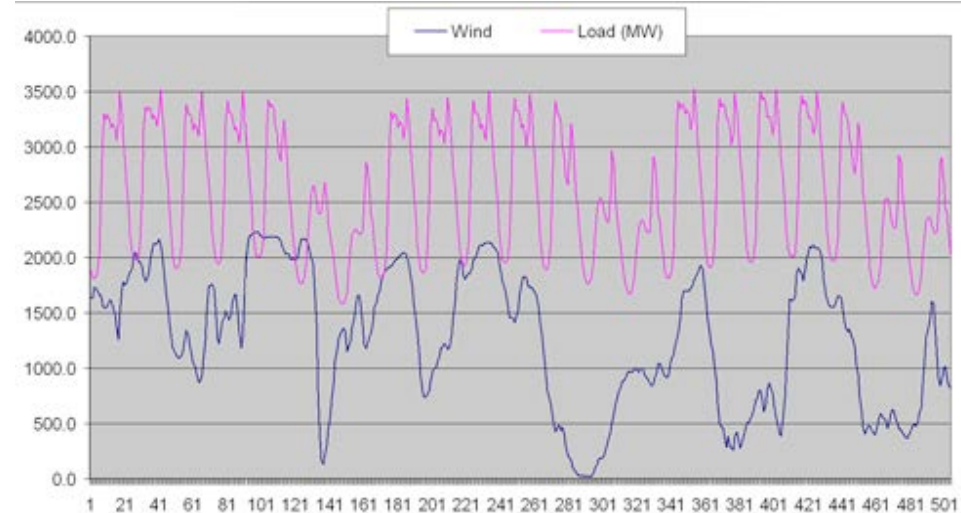
Terrestrial Microgrids: Renewables Integration

- Generators

“Sources Behaving Badly”



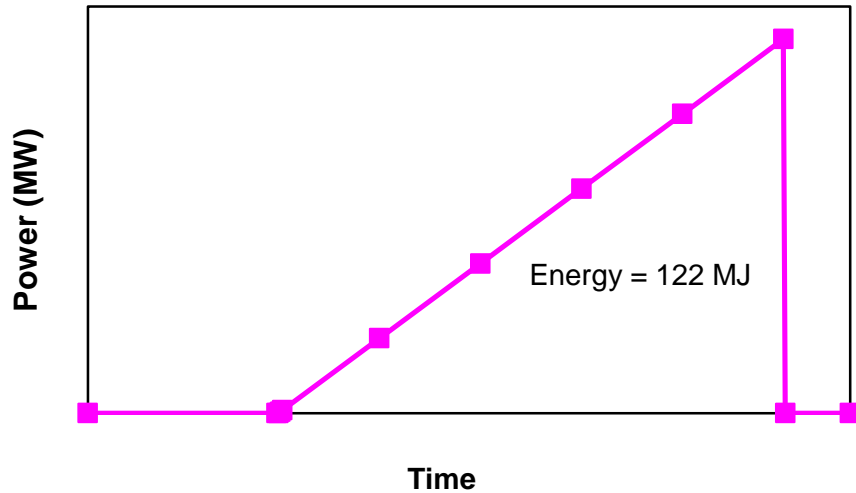
Source: Ashai Kasei Device Co.



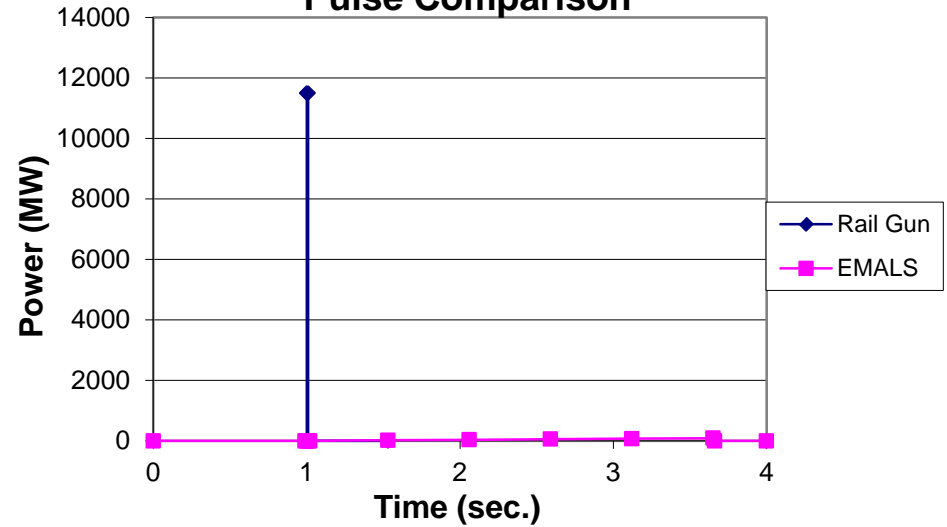
Source: www.energinet.dk

Electric Ship Microgrid: “Loads Behaving Badly”

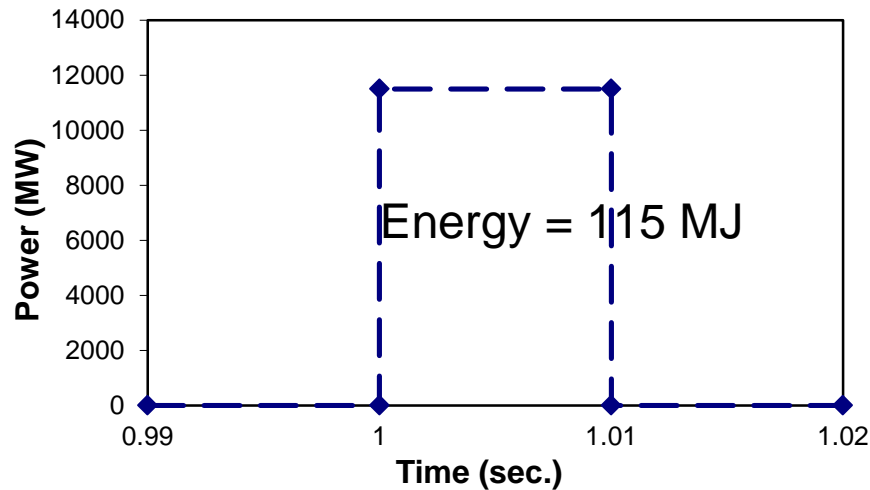
Idealized Aircraft Launch Power Pulse



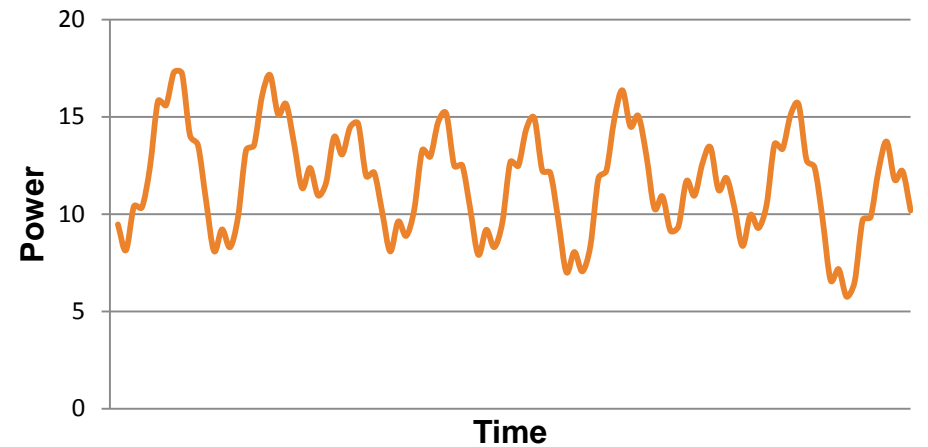
Pulse Comparison



Idealized Rail Gun Power Pulse



Notional Radar Power



Summary

- Austere Budgets and Evolving Mission requirements drive the need for innovation in Navy Ships
- Fuel Prices and Environmental Regulations drive the need for innovation in Commercial Ships
- Increasing Renewables penetration and Electric Vehicle integration drive the need for innovation in terrestrial power systems
- Microgrids and Distributed Generation are forcing terrestrial power systems to resemble shipboard power systems
- Terrestrial Microgrids Versus Electric Ship:
 - Sources tend to be Stochastic (Terrestrial Microgrid)
 - Loads tend to be Stochastic (Electric Ship)

Need to Look Outside Navy Lifelines



Questions?