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**United States Government Accountability Office**
**Washington, DC 20548**

July 6, 2006

The Honorable Roscoe G. Bartlett
Chairman
Subcommittee on Projection Forces
Committee on Armed Services
House of Representatives

Subject: *Propulsion Systems for Navy Ships and Submarines*

Dear Mr. Chairman:

In recent years, the Navy has used nuclear propulsion systems for its submarines and most aircraft carriers and conventional propulsion systems that rely on fossil fuel for its surface combatants and amphibious warfare ships. As the Navy looks to design an affordable force that is capable of meeting future security challenges, some of the assumptions and factors that have guided past Navy decisions on propulsion systems may require reassessment. For example, technological advances have enabled greater efficiency in both nuclear and conventional propulsion systems. Moreover, the cost of fossil fuel has risen sharply in recent years.

You requested that we review the Navy's assessment of alternative propulsion methods for submarines and surface combatants. Our objectives were to determine (1) the status and scope of key Navy studies on alternative propulsion methods, (2) the major improvements to existing propulsion systems, (3) near-term and future ships' propulsion systems, and (4) the various ship propulsion related technologies the Navy is pursuing. In March 2006, we provided you with a briefing of our findings regarding propulsion systems for Navy ships and submarines. This report summarizes the results of that briefing as well as additional work we performed since that time, and transmits the briefing slides with the updated information. (See enc.) Because of command changes at both the Naval Sea Systems Command and the Office of the Chief of Naval Operations and other factors, the Navy has not completed two ongoing studies. As a result, we were not able to assess the results of these studies.

To determine the status and scope of the Navy studies on alternative propulsion methods, the major improvements to existing propulsion systems, and the various ship propulsion-related technologies the Navy is pursuing, we reviewed and analyzed Navy and outside research organizations' analyses and our prior report related to propulsion systems for Navy ships and submarines. We also discussed propulsion systems with officials from the Naval Sea Systems Command, the Office of Naval Research, the Office of Naval Reactors, the Office of the Chief of Naval Operations Surface Warfare

Directorate, and the Defense Advanced Research Projects Agency. We obtained and analyzed information on Navy propulsion technologies from officials from the Naval Sea Systems Command, the Office of Naval Reactors, the Office of Naval Research, and the Office of the Chief of Naval Operations Surface Warfare Directorate. We performed our work from December 2005 through April 2006 in accordance with generally accepted government auditing standards.

**Summary**

The Navy has completed one study, and is in the process of completing two other studies on alternative propulsion systems for surface combatants, amphibious warfare ships, and submarines. The completed study is a "quick look" analysis of comparative life cycle costs of nuclear and fossil-fueled surface combatants and amphibious warfare ships. Although the study attempted to examine the fiscal break-even point for nuclear and conventional propulsion systems, it had several limitations. Specifically, it did not consider the operational requirements or advantages of nuclear and conventionally powered propulsion systems, nor did it undergo a high-level, Navy-wide review. According to Navy officials, the second study, required by the 2005 Chief of Naval Operations guidance, will be similar, but will provide in-depth analysis covering costs and operational factors for surface combatants as well as submarines. The Navy anticipates that the third study, required by the National Defense Authorization Act for Fiscal Year 2006,[1] will build upon the Chief of Naval Operations study. Our limited review indicates that while the planned methodology for this study, as described by Navy officials, appears reasonable, its usefulness will depend on the extent to which the Navy uses accurate, reliable data and reasonable assumptions for its modeling and considers all relative costs.

Nuclear and conventional propulsion systems for Navy ships and submarines have been improved in recent years. According to Navy officials, nuclear power plants are now simpler and smaller with reduced maintenance and personnel requirements, and their life span has also been increased. These reported improvements have eliminated the need for refueling newer submarines, such as the Virginia class submarines. Improvements have also been reportedly made to conventional propulsion systems, such as the Integrated Power System, which produces electrical power for both the propulsion system and ship's support systems.

Ships being developed in the near term and long term will have a variety of newly designed propulsion systems depending on their size, mission, and ship characteristics. For example, the Littoral Combat Ship will have two diesel engines for low-speed operations, which will be augmented by two gas turbine engines for high-speed operations. The next-generation destroyer, DDG 1000,[2] will have an Integrated Power System consisting of four gas turbines and two advanced induction motors, which will supply electrical power for the propulsion and ship support systems. The first aircraft carrier to be built under the CVN 21 program will have a newly designed nuclear power

[1] Pub. L. No. 109-163, § 130 (2006).
[2] Previously referred to as DD(X).

plant, and the Navy's amphibious replacement ship, LHA 6, will utilize a combined gas turbine and electric propulsion system instead of the steam propulsion systems now used in many amphibious warfare ships.

The Navy spent over $212 million from fiscal years 2003 through 2005, and plans to invest an additional $264 million from fiscal years 2006 through 2011 to develop propulsion and ship support technologies designed to make future ships more fuel efficient and mission effective. These technologies, which are at various levels of maturity and not yet ready for implementation, focus on making electric motors smaller but more powerful, using high-speed generators without reduction gears, and using fuel cells. These technologies will still require fossil fuel as an energy source, but Navy officials stated they have the potential to reduce the amount of fossil fuel needed and improve ship operations.

**Navy Has Completed One Study on Alternative Propulsion Systems and Has Two Others in Progress**

The Navy has completed one study and is in the process of completing two other studies of alternative propulsion methods for surface combatants, amphibious warfare ships, and submarines. These studies are (1) the 2005 "quick look" analysis of comparative costs of nuclear and fossil-fueled surface ships, (2) the 2005 Chief of Naval Operations guidance-directed study on alternative propulsion methods for surface combatants and submarines, and (3) the National Defense Authorization Act for Fiscal Year 2006-directed study on alternative propulsion methods for surface combatants and amphibious warfare ships.

In the first study, the Office of Naval Reactors, which is responsible for all aspects of the Navy's nuclear propulsion program and plants, conducted a "quick look" analysis of comparative costs of nuclear and fossil-fueled surface ships in 2005. The study attempted to determine the fossil fuel price point at which it becomes advantageous to use nuclear propulsion for amphibious warfare ships and surface combatants. This analysis was based on a review of historical and projected fossil fuel costs as well as the historical costs associated with nuclear aircraft carriers and cruisers. However, Navy officials cautioned that the study did not undergo a high-level Navy-wide review and contained several limitations and assumptions. For example, the study did not consider such factors as the operational advantages of nuclear and conventionally powered propulsion systems, the mission requirements under its Sea Power 21[3] concept of operations, and costs associated with lead ship design. The "quick-look" analysis indicated that the breakeven points for a notional large deck amphibious warfare ship (LHA/LHD) and a notional surface combatant are $80 and $205, per barrel respectively. However, since this analysis contained several limitations and assumptions, a more comprehensive analysis may yield different results.

[3] Sea Power 21 is the Navy's vision of how it will organize, integrate, and transform its forces to perform missions in the 21st century. Its pillars are (1) Sea Strike, which is projecting precise and persistent offensive power; (2) Sea Shield, which is projecting global defensive assurance; and (3) Sea Basing, which is projecting joint operational independence. Its ForceNet concept integrates the three pillars.

In addition to the "quick look" analysis, the 2005 Chief of Naval Operations guidance directed the Naval Sea Systems Command to conduct a study on alternative propulsion methods for submarines and surface combatants. The objective of the 2005 Chief of Naval Operations-directed study is to evaluate current propulsion systems, considering the operational needs of Sea Power 21 and the cost and availability of technology and energy sources. The 2005 Chief of Naval Operations guidance directed the Naval Sea Systems Command to complete this study by July 2005; however, at the time of our review, Naval Sea Systems Command officials stated that because of command changes at both the Naval Sea Systems Command and the Office of the Chief of Naval Operations, the study would not be completed until May 2006.[4] According to Navy officials, the Chief of Naval Operations-directed study will use a more comprehensive model to evaluate fuel source and propulsion plant alternatives for both submarines and surface combatants than did the "quick look" study. It will analyze ship design, using such factors as mission requirements; operational and support costs; manpower requirements; and fuel consumption, costs, and sources to determine at what price level the cost of diesel fuel (over the life of the ship) equals the additional life cycle cost of a similar ship powered by a nuclear propulsion plant.

The National Defense Authorization Act for Fiscal Year 2006 directed the Navy to conduct an analysis and report on alternative propulsion methods for amphibious warfare ships and surface combatants by November 1, 2006. Additionally, the conferees directed the Navy to brief the congressional defense committees on the organization and study plan for the preparation of the report by April 1, 2006.[5] On April 6, 2006, the Subcommittee on Projection Forces, House Committee on Armed Services, held a hearing at which the Navy testified on its plans to conduct the study in order to fulfill the requirement for a briefing. Navy officials stated that study guides will be developed for the National Defense Authorization Act study, and the study will build upon the methodology and results of the 2005 Chief of Naval Operations-directed study. Specifically, the study will analyze alternative propulsion systems in amphibious warfare ships, medium surface combatants, and small surface combatants; evaluate cost versus operational effectiveness; and compare nuclear plant with diesel fuel marine[6] plant alternatives. According to Navy officials, the study will analyze conceptual ship design to estimate acquisition costs and the life cycle costs of each variant. For each ship type, a break-even cost analysis will be performed to determine the cost of crude oil for which the life cycle cost of a nuclear propulsion variant of a ship concept will equal the life cycle cost of a diesel fuel marine concept. Navy officials said that the study will consider technologies such as nuclear power, gas turbines, diesels, fuel cells, mechanical drive, electrical drive, and various types of propellers, as well as other innovative concepts.

Based on our limited analysis, the Navy's plans to conduct the National Defense Authorization Act for Fiscal Year 2006-directed study, as outlined in the Navy's statement for the hearing before the Subcommittee on Projection Forces, House Committee on

[4] On June 14, 2006, the study had not been approved by senior Navy officials.
[5] H.R. Conf. Rep. 109-360 (2005).
[6] Diesel fuel marine is a type of military fuel that is a complex mixture of hydrocarbons produced by distillation of crude oil. The cost of diesel fuel marine is approximately 15 percent greater than that of crude oil.

Armed Services, appear reasonable for conducting a more thorough analysis on alternative propulsion systems for surface combatants and amphibious warfare ships. The methodology indicates that study guides will be developed to guide the study and major assumptions will be identified and documented. Additionally, the methodology will include consideration of nuclear and fossil fuel power plants that will meet mission requirements, and the use of modeling techniques to capture appropriate costs and evaluate mission effectiveness of various propulsion plant alternatives.

However, because the Navy had not completed its study guides for the analysis at the time of our review, we could not independently verify that they will be adequate to guide the study, nor could we determine if all relative costs will be considered and other pertinent factors addressed. For example, while the methodology indicated that manpower costs will be considered, it did not indicate whether these costs will include the additional training costs for nuclear-qualified personnel. Our prior work on the cost-effectiveness of conventionally and nuclear-powered carriers indicated that personnel training costs are substantially higher for nuclear-qualified personnel.[7] Our prior work also documented that the support activities required for nuclear-powered ships add significant costs. Additionally, it is highly important that accurate, reliable data are used for all of the models used to support the study. The consideration of all relative costs and use of accurate, reliable data will determine the extent to which the study results will be valid and useful.

**Improvements Have Been Made to Conventional and Nuclear Propulsion Systems**

The Navy has made improvements to both its nuclear and conventional propulsion systems. According to Navy officials, nuclear power plants are now simpler in design and smaller; have reduced maintenance requirements; and require half the manpower of older plants, as demonstrated by the design of the CVN 21 class aircraft carrier. Officials also stated that the life of nuclear reactor cores has been extended. For example, according to Navy officials, the extended life span of reactor cores eliminates the need for refueling newer submarines, which have a 33-year life span. This compares with the earlier Los Angeles class submarines, which are usually refueled at the 18- to 20-year point in their service life.

Improvements have also been made to conventional propulsion systems. Currently, conventionally powered ships have separate systems dedicated to propulsion and ship support systems. An improvement upon this is the Integrated Power System. According to Navy officials, the Integrated Power System will enable conventional systems to produce electrical power for both the propulsion system and ship's support systems. Instead of the propeller drive shaft being connected to the engine through reduction gears, the Integrated Power System enables the propeller to be connected directly to an electric motor without the use of reduction gears. Officials further stated that the

[7] GAO, *Navy Aircraft Carriers: Cost-Effectiveness of Conventionally and Nuclear-Powered Carriers*, GAO/NSIAD-98-1 (Washington, D.C.: Aug. 27, 1998).

Integrated Power System will provide the electrical power for transformational weapons systems on future ships, improve survivability by allowing rapid reconfiguration of Power, and reduce acoustic signature or detection by sonar. The design of the Integrated Power System will require fewer components to the system, which, according to Navy officials, will result in reduced maintenance requirements and life cycle costs.

**Navy Ships in Development Will Have a Variety of Newly Designed Propulsion Systems**

Navy officials stated that ship requirement factors, which are developed during the early phases of ship design, drive the type of propulsion system that is selected for a ship. Some factors that influence the type of propulsion system selected are the maximum sustained speed required, operating profile (a characterization of how the ship will be used), acquisition cost constraints, industrial base capabilities, and the maturity of any new technology being considered.

The ships planned for both near-term and future ship construction will utilize a variety of newly designed propulsion systems. Navy officials said that a new underway replenishment vessel, the T-AKE, will utilize a diesel-electric propulsion system. Delivery of the first T-AKE ship is expected in June 2006. Another type of ship, the Littoral Combat Ship, is expected to have a hybrid propulsion system consisting of two gas turbines, for high-speed use, and two diesel engines, for low-speed use. According to Navy officials, the hybrid system of the Littoral Combat Ship will enable efficient low-speed cruising. Delivery of the first Littoral Combat Ship is expected in fiscal year 2007.

Additional future ship construction includes a next-generation destroyer, DDG 1000; an amphibious replacement ship, LHA 6; a new CVN 21 class aircraft carrier; and a next-generation cruiser, CG(X). According to Navy officials, DDG 1000 will have an Integrated Power System consisting of four gas turbines and two advanced induction motors. The amphibious replacement ship, LHA 6, will utilize a combined gas turbine and electric propulsion system instead of the steam propulsion systems used in many amphibious warfare ships. Delivery for both DDG 1000 and LHA 6 is expected in fiscal year 2012. According to Navy officials, the first aircraft carrier to be built under the CVN 21 program, CVN 78, will have a newly designed nuclear power plant, allowing for a reduction in both manning and reactor plant components. Delivery of CVN 78 is expected in fiscal year 2015. A propulsion decision has not yet been made for CG(X), although, according to Navy officials, CG(X) is likely to leverage the technology used in the DDG 1000 propulsion system, such as the Integrated Power System.

**Navy Is Spending Some Research and Development Funds to Develop New Propulsion Technologies**

In addition to analyzing alternative propulsion technologies for ships currently in development, the Navy is also spending research and development funds to develop new technologies to improve propulsion and support systems. For fiscal years 2003 through 2005, the Navy spent over $212 million and plans to spend an additional $264 million for fiscal years 2006 through 2011 to conduct research for various technologies, such as

superconducting motors, fuel cells, and high-speed generators. None of these technologies are immediately ready to be implemented in ship designs. However, the Office of Naval Research, which is responsible for managing advanced research, has categorized the maturity of each technology being funded by technology readiness levels 1 through 9. For example, a technology readiness level 1 indicates that the technology is still in a basic research phase, while a technology readiness level 9 indicates that a technology has been fully demonstrated. Some technologies being explored by the Navy, including fuel cell technology, high-speed generators, and superconducting motors, are at technology readiness levels 3 through 5. Level 5 indicates that the technologies have advanced to the point where stand-alone experiments can be conducted or the technology can be integrated with other systems in the target environment. These technologies will still require fossil fuel as an energy source, but Navy officials stated that when and if they are implemented, they will significantly reduce the amount of fuel required and improve ship operations.

According to Office of Naval Research officials, improvements to electrical components will generally improve fuel efficiency and overall mission effectiveness of future Navy surface ships. For example, superconducting motors, using special wiring to lower the resistance of electricity flow and employing cryogenics to reduce temperatures within the motor, will be more powerful and smaller, thereby reducing weight and saving onboard space for other purposes. High-speed generators, also projected to be smaller, will make it possible to couple high-speed gas turbine engines directly to the generators without the use of reduction gears, thereby reducing weight, saving space, and making the engines more fuel efficient. Eliminating these reduction gears will also help future ships to be quieter and consequently more difficult to be detected by enemy forces. The Office of Naval Research is also conducting research into fuel cell technology. Germany recently produced two submarines with fuel cell propulsion systems, but a Navy official said that nonnuclear submarines do not meet the mission requirements of the United States Navy. Additionally, these fuel cells use onboard hydrogen in its natural state, which is difficult and dangerous to store in large quantities. Conversely, the fuel cell technology the Office of Naval Research is pursuing involves extracting hydrogen from diesel fuel, which can be safely stored and transferred at sea, according to the official. The hydrogen is used to produce electrical power without the use of diesel or gas turbine engines. The use of fuel cells would also permit a ship's power system to be dispersed throughout the ship, increasing the ship's ability to survive if attacked, according to Navy officials. Office of Naval Research officials stated that fuel cell technology is promising for naval application and has already completed some prototype testing. However, officials stated that the technology is at least 3 to 5 years away from acquisition consideration.

**Agency Comments**

We received technical comments from DOD, which we incorporated as appropriate.

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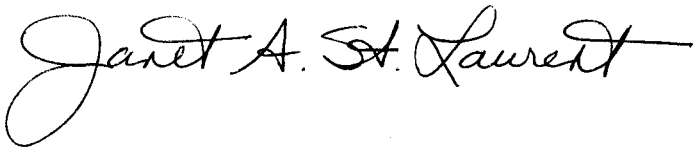
We are sending copies of this report to the Secretary of Defense and other interested parties. We will provide copies of this report to others upon request. In addition, the report is available at no charge on the GAO Web site at http://www.gao.gov.

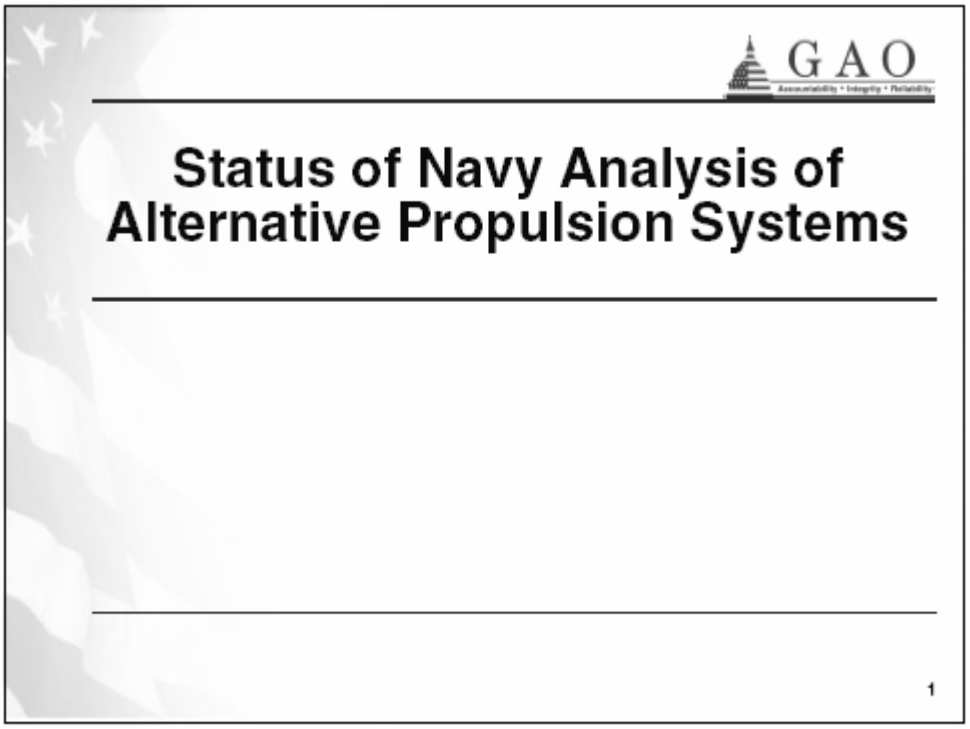
If you or your staff have any questions about this report, please contact me at (202) 512-4402 or stlaurentj@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Key contributors to this report were Patricia Lentini, Assistant Director, Willie Cheely, Elisha Matvay, and George Morse.

Sincerely yours,



Janet A. St. Laurent
Director, Defense Capabilities and Management

Enclosure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Status of Navy Analysis of Alternative Propulsion Systems
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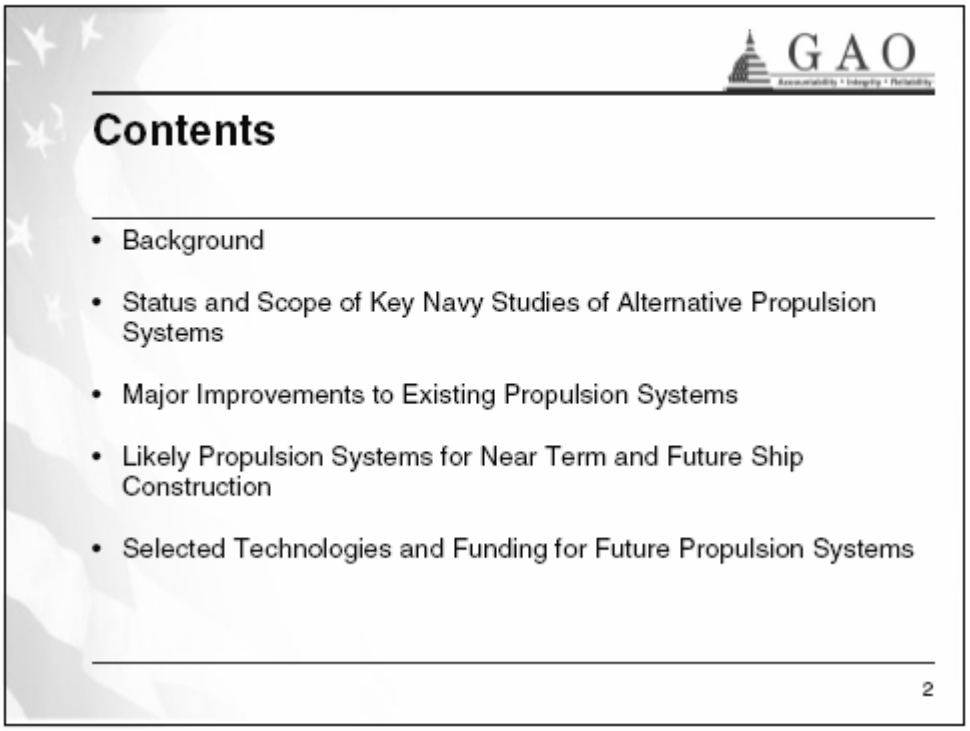
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• Background
• Status and Scope of Key Navy Studies of Alternative Propulsion Systems
• Major Improvements to Existing Propulsion Systems
• Likely Propulsion Systems for Near Term and Future Ship Construction
• Selected Technologies and Funding for Future Propulsion Systems
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## Background

- This briefing is in response to your request that GAO review the Navy's assessment of alternative propulsion methods for submarines and surface combatants.
- The committee expressed concerns about the assumptions and factors that have guided past Navy decisions on propulsion systems and the global demand and price of fossil fuel.
- The Navy currently has nuclear powered submarines and aircraft carriers, and conventionally powered surface combatants, amphibious warfare ships and aircraft carriers.

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## Status and Scope of Key Navy Studies of Alternative Propulsion Systems

- The Navy has completed a "quick look" analysis of alternative propulsion systems and has two other directed studies in process. These include:
  - The Naval Reactors "quick look" analysis presented to Congressman Bartlett on October 21, 2005.
  - Chief of Naval Operations (CNO) directed study estimated to be completed by May 2006, but had not been approved by Navy leaders as of June 14, 2006.
  - National Defense Authorization Act for Fiscal Year 2006 directed study to be completed by November 1, 2006.

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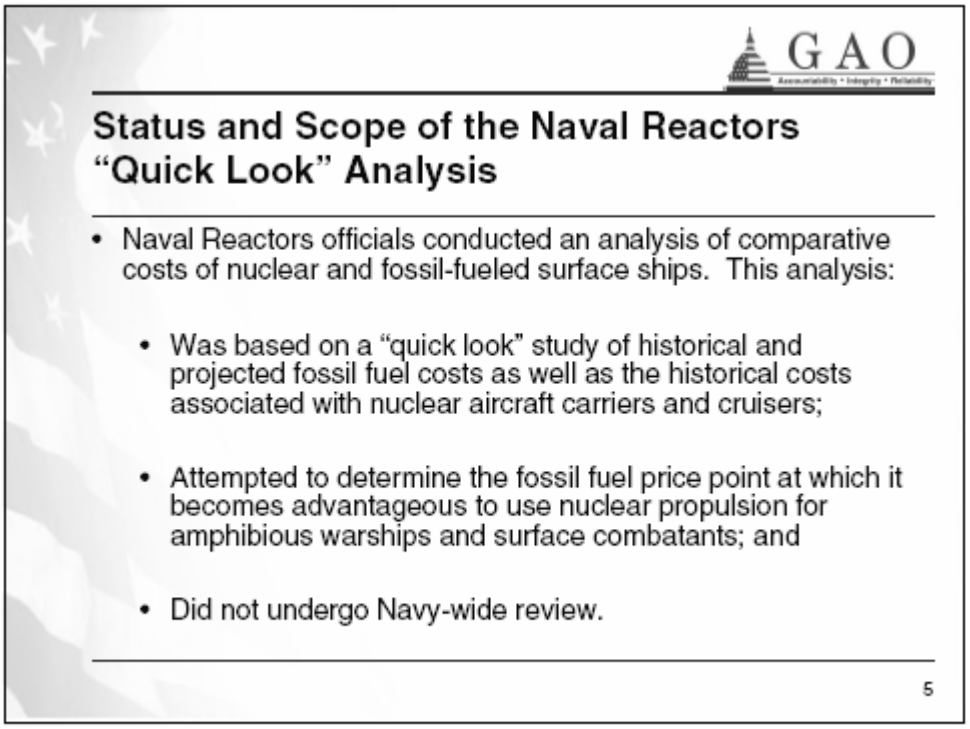
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Status and Scope of the Naval Reactors "Quick Look" Analysis
• Naval Reactors officials conducted an analysis of comparative costs of nuclear and fossil-fueled surface ships. This analysis:
• Was based on a "quick look" study of historical and projected fossil fuel costs as well as the historical costs associated with nuclear aircraft carriers and cruisers;
• Attempted to determine the fossil fuel price point at which it becomes advantageous to use nuclear propulsion for amphibious warships and surface combatants; and
• Did not undergo Navy-wide review.
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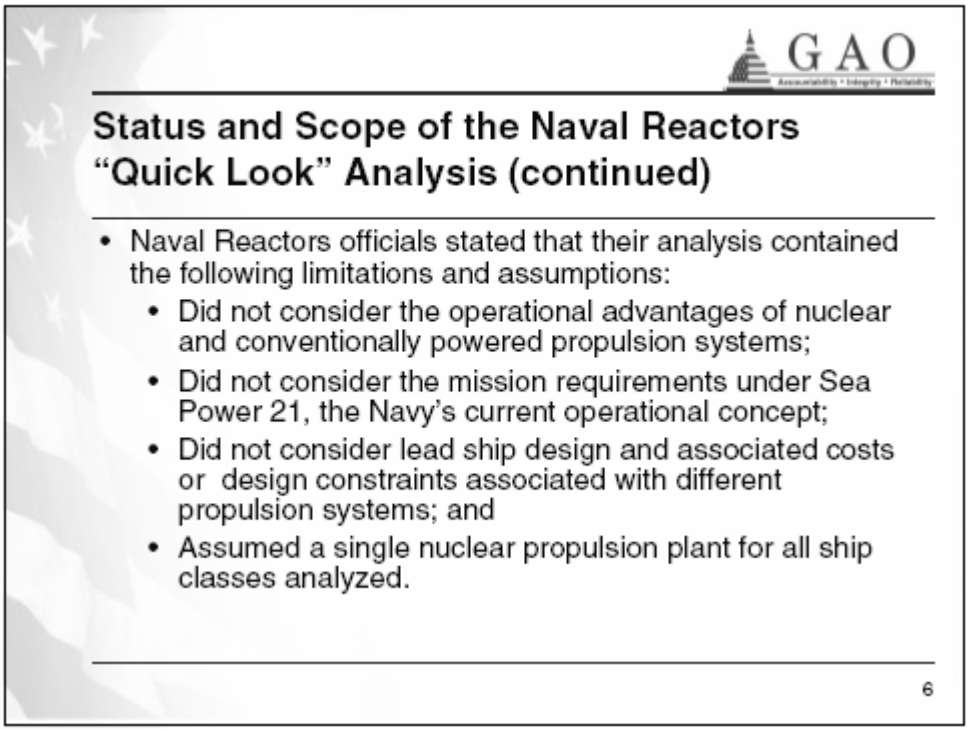
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Status and Scope of the Naval Reactors "Quick Look" Analysis (continued)
• Naval Reactors officials stated that their analysis contained the following limitations and assumptions:
• Did not consider the operational advantages of nuclear and conventionally powered propulsion systems;
• Did not consider the mission requirements under Sea Power 21, the Navy's current operational concept;
• Did not consider lead ship design and associated costs or design constraints associated with different propulsion systems; and
• Assumed a single nuclear propulsion plant for all ship classes analyzed.
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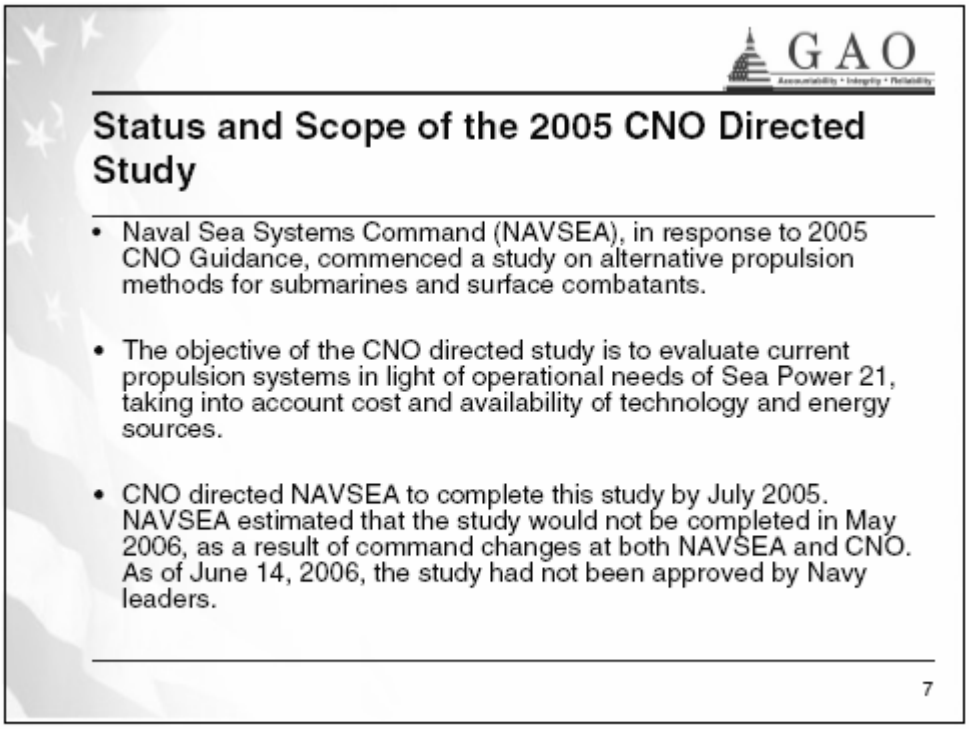
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Status and Scope of the 2005 CNO Directed Study
• Naval Sea Systems Command (NAVSEA), in response to 2005 CNO Guidance, commenced a study on alternative propulsion methods for submarines and surface combatants.
• The objective of the CNO directed study is to evaluate current propulsion systems in light of operational needs of Sea Power 21, taking into account cost and availability of technology and energy sources.
• CNO directed NAVSEA to complete this study by July 2005. NAVSEA estimated that the study would not be completed in May 2006, as a result of command changes at both NAVSEA and CNO. As of June 14, 2006, the study had not been approved by Navy leaders.
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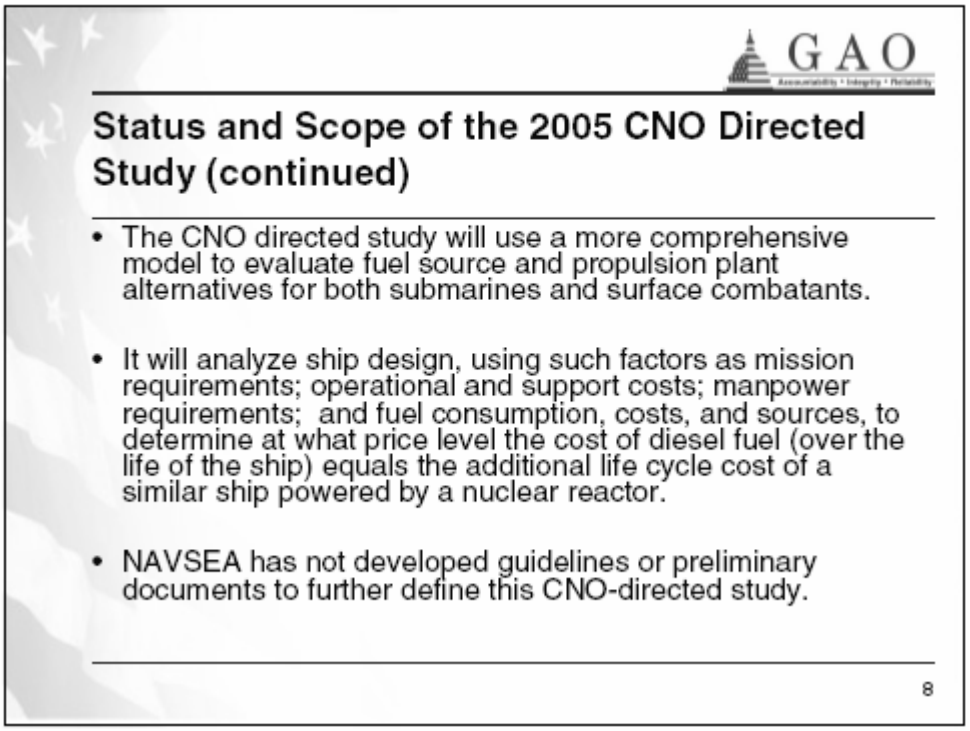
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Status and Scope of the 2005 CNO Directed Study (continued)
• The CNO directed study will use a more comprehensive model to evaluate fuel source and propulsion plant alternatives for both submarines and surface combatants.
• It will analyze ship design, using such factors as mission requirements; operational and support costs; manpower requirements; and fuel consumption, costs, and sources, to determine at what price level the cost of diesel fuel (over the life of the ship) equals the additional life cycle cost of a similar ship powered by a nuclear reactor.
• NAVSEA has not developed guidelines or preliminary documents to further define this CNO-directed study.
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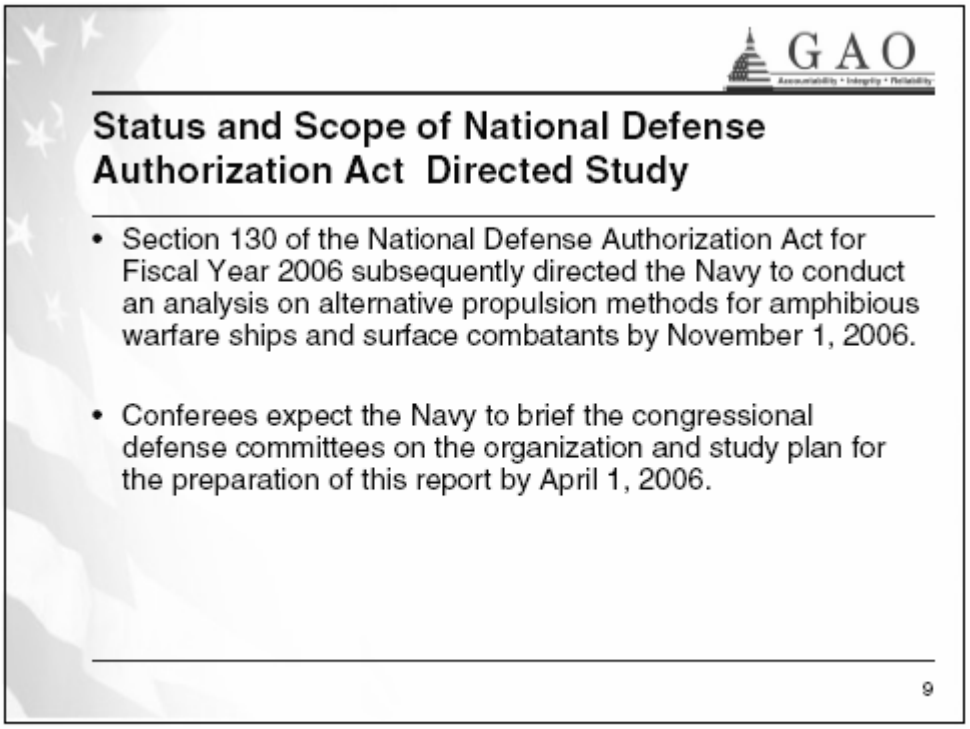
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Status and Scope of National Defense Authorization Act Directed Study
• Section 130 of the National Defense Authorization Act for Fiscal Year 2006 subsequently directed the Navy to conduct an analysis on alternative propulsion methods for amphibious warfare ships and surface combatants by November 1, 2006.
• Conferees expect the Navy to brief the congressional defense committees on the organization and study plan for the preparation of this report by April 1, 2006.
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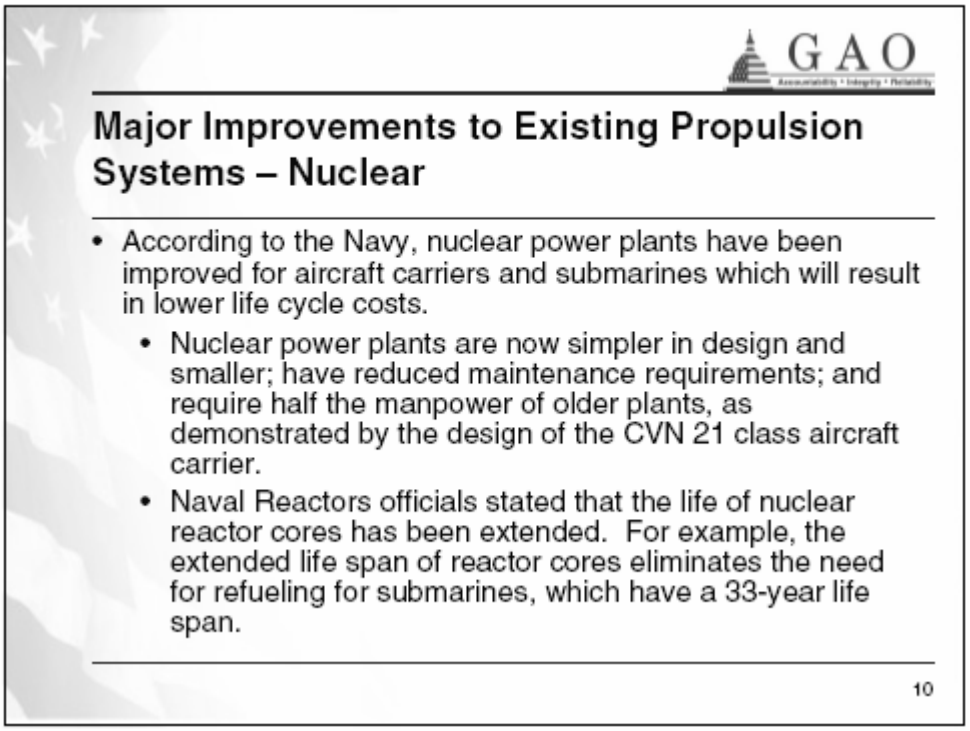
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Major Improvements to Existing Propulsion Systems – Nuclear
• According to the Navy, nuclear power plants have been improved for aircraft carriers and submarines which will result in lower life cycle costs.
• Nuclear power plants are now simpler in design and smaller; have reduced maintenance requirements; and require half the manpower of older plants, as demonstrated by the design of the CVN 21 class aircraft carrier.
• Naval Reactors officials stated that the life of nuclear reactor cores has been extended. For example, the extended life span of reactor cores eliminates the need for refueling for submarines, which have a 33-year life span.
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## Major Improvements to Existing Propulsion Systems – Conventional

- Currently, conventional ships have separate systems dedicated to propulsion and ships' support system.
- According to Office of Naval Research officials, the Integrated Power System (IPS) is an improvement that will enable conventional systems to produce electrical power for both the propulsion system and ship's support system. Specifically, it will:
  - Enable transformational weapons systems (future electromagnetic guns);
  - Improve survivability by allowing rapid reconfiguration of power;
  - Reduce acoustic signature or detection by sonar; and
  - Reduce life cycle costs, because fewer components and less maintenance will be required.

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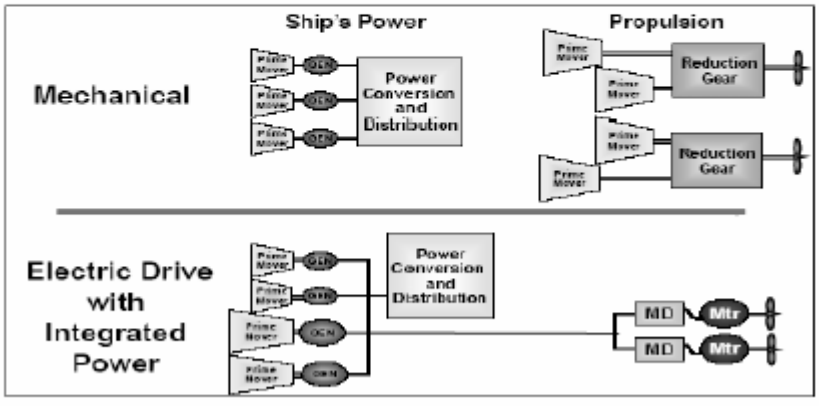
## Major Improvements to Existing Propulsion Systems – Conventional




Source: United States Navy

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## Likely Propulsion Systems for Near Term and Future Ship Construction

Near Term Ships--Propulsion Systems:

- T-AKE, a new underway replenishment vessel, utilizes a diesel-electric propulsion system. Delivery of the first ship is in June 2006.
- Littoral Combat Ship (LCS) is expected to have a hybrid propulsion system of two gas turbines and two diesel engines. Delivery is expected in FY 2007.

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## Likely Propulsion Systems for Near Term and Future Ship Construction (continued)

Future Ships--Propulsion Systems:

- DDG 1000, a next generation destroyer, will have an Integrated Power System consisting of four gas turbines and two advanced induction motors. Delivery is expected in FY 2012.
- LHA 6, an amphibious replacement ship, will utilize a combined gas turbine and electric propulsion system. Delivery is expected in 2012.
- CVN 78, the first aircraft carrier to be built under the CVN 21 program, will have a newly designed nuclear power plant, allowing for a reduction in both manning and reactor plant components. Delivery is expected in 2015.
- CG(X), a next generation cruiser, is likely to utilize an Integrated Power System similar to that of DDG 1000.

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## Selected Technologies for Future Propulsion Systems

- The Office of Naval Research has identified some developing technologies that will be applicable to future propulsion systems.
- Research is heavily concentrated on improving electric drive propulsion components for future ships.
- The technology readiness level (TRL) indicates the maturity of a technology. Levels range from TRL1, the lowest, to TRL9, the highest. A TRL of 6 indicates that a technology is ready for consideration in an acquisition program.

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## Selected Technologies for Future Propulsion Systems (continued)

| Technology | Improvement | Maturity Level |
|---|---|---|
| High speed, high frequency generators | More power per unit weight, eliminates reduction gear | TRL 5-Integrated with other systems in the target environment |
| Direct thermal to electric conversion | Uses a heat source to produce electric power, ultimate goal to eliminate steam and gas turbines. | TRL 3-Proof-of-concept experiments to prove scientific feasibility |
| Wide bandgap power electronics | Improved efficiency and reduced size and weight | TRL 3-Proof-of-concept experiments to prove scientific feasibility |
| Superconducting motors | With the use of magnets, produces more force or torque in a given size | TRL - 3 (see above) or TRL - 5 (see above) depending on type |
| Fuel cell technology | Fuel efficiency, modular nature which aids ship survivability | TRL 4-Standalone experiments in a laboratory environment or TRL 5 (see above) |

Source: GAO analysis of United States Navy data.

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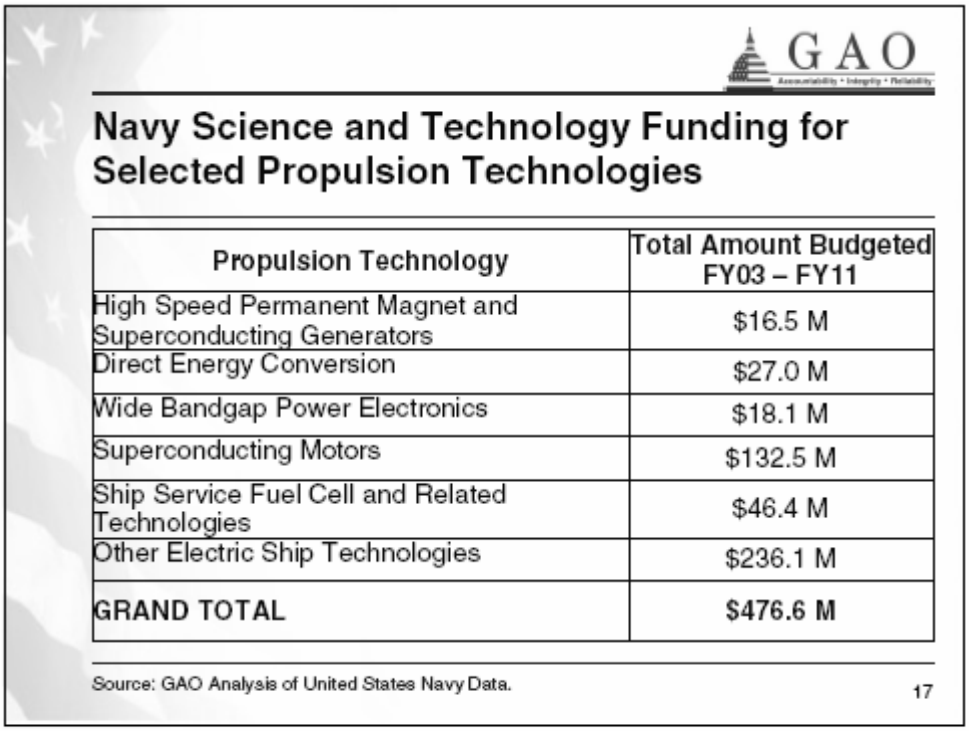

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## Navy Science and Technology Funding for Selected Propulsion Technologies

| Propulsion Technology | Total Amount Budgeted FY03 – FY11 |
|---|---|
| High Speed Permanent Magnet and Superconducting Generators | $16.5 M |
| Direct Energy Conversion | $27.0 M |
| Wide Bandgap Power Electronics | $18.1 M |
| Superconducting Motors | $132.5 M |
| Ship Service Fuel Cell and Related Technologies | $46.4 M |
| Other Electric Ship Technologies | $236.1 M |
| **GRAND TOTAL** | **$476.6 M** |

Source: GAO Analysis of United States Navy Data.

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## GAO's Mission

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