

CRS Report for Congress

Received through the CRS Web

Navy Ship Propulsion Technologies: Options for Reducing Oil Use — Background for Congress

Updated July 26, 2006

Ronald O'Rourke
Specialist in National Defense
Foreign Affairs, Defense, and Trade Division

Navy Ship Propulsion Technologies: Options for Reducing Oil Use — Background for Congress

Summary

General strategies for reducing the Navy's dependence on oil for its ships include reducing energy use on Navy ships; shifting to alternative hydrocarbon fuels; shifting to more reliance on nuclear propulsion; and using sail and solar power.

Reducing energy use on Navy ships. A 2001 study concluded that fitting a Navy cruiser with **more energy-efficient electrical equipment** could reduce the ship's fuel use by 10% to 25%. The Navy has installed fuel-saving **bulbous bows** and **stern flaps** on many of its ships. Ship fuel use could be reduced by shifting to advanced turbine designs such as an **intercooled recuperated (ICR) turbine**. Shifting to **integrated electric-drive propulsion** can reduce a ship's fuel use by 10% to 25%; some Navy ships are to use integrated electric drive. **Fuel cell** technology, if successfully developed, could reduce Navy ship fuel use substantially.

Alternative hydrocarbon fuels. Potential alternative hydrocarbon fuels for Navy ships include **biodiesel** and liquid hydrocarbon fuels made from coal using the **Fischer-Tropsch (FT) process**. A 2005 Naval Advisory Research (NRAC) study and a 2006 Air Force Scientific Advisory Board both discussed FT fuels.

Nuclear propulsion. Oil-fueled ship types that might be shifted to nuclear propulsion include **large-deck amphibious assault ships** and large surface combatants (i.e., **cruisers and destroyers**). A 2005 "quick look" analysis by the Naval Nuclear Propulsion Program concluded that total life-cycle costs for nuclear-powered versions of these ships would equal those of oil-fueled versions when oil reaches about \$70 and \$178 per barrel, respectively.

Sail and solar propulsion. Kite-assisted propulsion might be an option for reducing fuel use on Navy auxiliaries and DOD sealift ships. Two firms are now offering kite-assist systems to commercial ship operators. **Solar power** might offer some potential for augmenting other forms of shipboard power, perhaps particularly on Navy auxiliaries and DOD sealift ships.

Legislative activity. Section 128 of the FY2007 defense authorization bill (**H.R. 5122**) states that "it is the sense of Congress that the Navy should make greater use of alternative technologies, including nuclear power, as a means of vessel propulsion for its future fleet of surface combatants." The Senate report (S.Rept. 109-292 of July 25, 2006) on the FY2007 defense appropriations bill (**H.R. 5631**) encourages DOD to continue exploring FT fuels and requires a report on synthetic fuels. **Section 214** of the conference report (H.Rept. 109-413 of April 6, 2006) on the Coast Guard and Maritime Transportation Act of 2006 (**H.R. 889**) requires the Coast Guard to conduct a feasibility study on using biodiesel fuel in new and existing Coast Guard vehicles and vessels. **Section 130** of the conference report (H.Rept. 109-360 of December 18, 2006) on the **FY2006 defense authorization act (H.R. 1815, P.L. 109-163** of January 6, 2006) requires the Navy to submit a report by November 1, 2006, on alternative propulsion methods for surface combatants and amphibious warfare ships. This report will be updated as events warrant.

Contents

Introduction	1
Reducing Energy Use on Navy Ships	1
General	1
Hotel-Load Electrical Systems	3
Bulbous Bows	4
Stern Flaps	5
Higher-Efficiency Gas Turbines	6
Integrated Electric-Drive Propulsion	8
Fuel Cells	9
Alternative Hydrocarbon Fuels	10
Navy Ground Vehicles And Installations	10
National Park Service Boat	12
2005 NRAC Study	12
ONR Interest In Synthetic Fuels	13
2006 Air Force Scientific Advisory Board Study	14
Nuclear Propulsion	15
2005 Naval Reactors Quick Look Analysis	15
Past Nuclear Ships Other than Carriers and Submarines	16
Implications for Procurement Costs of Other Ships	17
Implications for Construction Shipyards	18
Implications for Ship Maintenance	18
Implications for Port Calls and Forward Homeporting	18
Sail and Solar Power	19
Sails and Wingsails	19
Kites	23
KiteShip	23
SkySails	25
Solar Power	27
Solar Sailor Ferry Boat	28
E/S Orcelle Concept Design	29
Legislative Activity	30
FY2007 Defense Authorization Bill (H.R. 5122/S. 2766)	30
FY2007 Defense Appropriations Bill (H.R. 5631)	30
Coast Guard and Maritime Transportation Act of 2006 (H.R. 889)	30
FY2006 Defense Authorization Act (H.R. 1815/P.L. 109-163)	31

List of Figures

Figure 1. Bulbous Bow Section for CVN-77	4
Figure 2. Bulbous Bow Design For DDG-51 (bulb above, existing sonar dome below)	5
Figure 3. Stern Flap on DDG-51 Class Destroyer	6

Figure 4. Electric Power Plants	9
Figure 5. Shin Aitoku Maru (left) and Usuki Pioneer (right)	20
Figure 6. Pleasure Craft Equipped with Walker Wingsails	20
Figure 7. Project Windship 50,000-ton DWT Product Carrier	21
Figure 8. KiteShip Concept Applied to Commercial Cargo Ship	24
Figure 9. SkySails Concept Applied to Commercial Cargo Ship	26
Figure 10. Potential Fuel Savings from SkySails System	27
Figure 11. Solar Sailor Hybrid-Powered Ferry Boat	28
Figure 12. E/S Orcelle Concept Design	29

List of Tables

Table 1. Navy Nuclear-Powered Cruisers (CGNs)	17
---	----

Navy Ship Propulsion Technologies: Options for Reducing Oil Use — Background for Congress

Introduction

This report provides background information on options for technologies that could reduce the Navy's dependence on oil for its ships. It is based on testimony prepared for a hearing on alternative Navy ship propulsion technologies held on April 6, 2006, before the Projection Forces Subcommittee of the House Armed Services Committee, which granted permission for the testimony to be converted into this report.

The report discusses four general strategies for reducing the Navy's dependence on oil for its ships:

- reducing energy use on Navy ships;
- alternative hydrocarbon fuels;
- nuclear propulsion; and
- sail and solar power.

Following this discussion is a section on legislative activity.

A July 2006 Government Accountability Office (GAO) report discusses the status of Navy studies on alternative ship propulsion methods and certain Navy efforts for developing new ship-propulsion technologies.¹

Reducing Energy Use on Navy Ships

One strategy for reducing the Navy's dependence on oil would be to reduce energy use on Navy ships.

General

According to a Naval Research Advisory Committee (NRAC) study briefed to Department of Defense (DOD) senior officials in October 2005, the U.S. government in FY2003 used about 330,000 barrels of oil per day (BPD), or about 2% of the total U.S. use of 16 million BPD. Of the U.S. government total, the Department of Defense (DOD) accounted for about 300,000 BPD, or about 91%. Within the DOD

¹ Government Accountability Office, *Propulsion Systems for Navy Ships and Submarines*, GAO-06-789R, July 6, 2006.

total, aircraft accounted for 73%, ground vehicles 15%, and installations 4%. Ships accounted for the remaining 8% — about 24,000 BPD, or 8,760,000 barrels per year.²

For fossil-fueled Navy ships, reducing energy use can reduce fuel costs and increase cruising range. Increasing cruising range can improve operational flexibility by increasing the time between refuelings and the distance that the ship can operate away from its next refueling point. It might also reduce the ship's infrared signature, and thus increase its survivability, by reducing emissions of hot exhaust gasses. If applied to a significant number of ships, an increase in cruising range might permit a reduction in Navy costs for fuel-related force structure (e.g., oilers) and infrastructure (e.g., storage facilities).

A 2001 report by a Defense Science Board (DSB) task force on improving the fuel efficiency of DOD weapon platforms stated:

The Navy has had a program since 1977 to improve weapon platform fuel efficiency, focused primarily on legacy systems. The Navy staff estimates it has reduced the fuel consumption of the ship and aircraft fleet by 15 and 6 percent respectively. Deployment of the technologies and products has been primarily through no- and low-cost routes, such as the normal overhaul process or procedural changes. However, fuel efficiency has not been given a high priority in future system design. Fuel consumption enters design tradeoffs as one of many components of operating cost, and in most cases is one of the least important components because its benefits are so undervalued for reasons presented [elsewhere in the report]. As a result of this undervaluation and split incentives, new fuel saving technologies that promise increased performance and positive return on investment do not compete well for funding if the initial investment is high and the savings do not appear for several years....

A portion of the Navy's Development, Test and Evaluation (DT&E) program (Categories 6.4 and 6.5) is specifically dedicated to improving the fuel efficiency of ships, primarily legacy ships. This program began in the late 1970s, with funding peaking at about \$35M in 1984. After fuel prices dropped in 1985 the program was funded at a more modest level, settling to around \$8M per year through the 1990s.³

The DSB report listed options for power-plant improvements that could improve fuel efficiency by 3% to 8%, options for hull-system hydrodynamic improvements that could improve fuel efficiency by another 3% to 8%, and options for improvements to hull coatings and cleaning, auxiliary systems, sensors, controls, and procedures, and "hotel loads" (functions such as lighting and fresh water production) that could lead to further improvements in fuel efficiency. Some of the options listed in the DSB report are discussed in greater detail below.

² NRAC presentation entitled "Future Fuels, [presented to] Flag Officers & Senior Executive Service, 4 October 2005, The Pentagon Auditorium," slide 9, available online at [http://www.onr.navy.mil/nrac/docs/2005_brief_future_fuels.pdf].

³ U.S. Department of Defense, *More Capable Warfighting Through Reduced Fuel Burden: [Report of] The Defense Science Board Task Force on Improving Fuel Efficiency of Weapons and Platforms*. Washington, 2001. (January 2001, Office of the Under Secretary of Defense For Acquisition, Technology, and Logistics) p. 50.

Hotel-Load Electrical Systems

Dr. Amory Lovins, the director of the Rocky Mountain Institute (RMI) and a member of the DSB task force, estimated in 2001 that as much as 30% of the Navy's non-aviation fuel appears to be used to generate power for hotel loads.⁴ A study conducted by RMI for the Navy in 2001 of energy use on the Aegis cruiser Princeton (CG-59) found that hotel loads on these ships could be substantially reduced. According to the DSB report, the RMI study "found retrofittable hotel-load electric savings potential on the order of 20 to 50 percent, with significant further opportunities still to be assessed. Many of the savings opportunities were purely operational, requiring little or no investment."⁵ In an online article about the RMI study, Dr. Lovins stated:

The Naval Sea Systems Command's [NAVSEA's] able engineers had estimated that 19 percent could be saved on ships of this class, of which Princeton was in the top one fourth for efficiency....

Our preliminary survey found gratifyingly large potential savings: perhaps, if found feasible, as much as several times NAVSEA's expectations.

Princeton uses nearly \$6 million worth of diesel-like turbine fuel each year. Her gas turbines, akin to those on an older passenger jet aircraft, use about \$2-3 million worth of oil to make up to 2.5 megawatts of electricity, the rest for 80,000 horsepower of propulsion. The RMI team found that retrofitting motors, pumps, fans, chillers, lights, and potable water systems could save an estimated 20-50 percent of the ship's electricity. That could cut total fuel use by an estimated 10-25 percent....

Just as in civilian facilities ashore, the RMI team started by calculating what it's worth to save a kilowatt-hour. Since the electricity is being made inefficiently from fuel that's mainly delivered by "oiler" ships, the answer is an eye-popping 27 cents, six times a typical industrial tariff ashore. This high cost makes "megawatts" really juicy. For example, each percentage point of improved efficiency in a single 100-horsepower always-on motor is worth \$1,000 a year. Each chiller could be improved to save its own capital cost's worth of electricity (about \$120,000) every eight months. About \$400,000 a year could be saved if — under noncritical, low-threat conditions — certain backup systems were set to come on automatically when needed rather than running all the time. Half that saving could come just from two 125-horsepower firepumps that currently pump seawater continuously aboard, around the ship, and back overboard. In a critical civilian facility like a refinery, where one wanted to be equally certain the firefighting water was always ready, one would instead pressurize the pipes (usually with freshwater) with a 2-hp pump, and rig the main pumps to spring into action the instant the pressure dropped.

⁴ DSB report, p. 53.

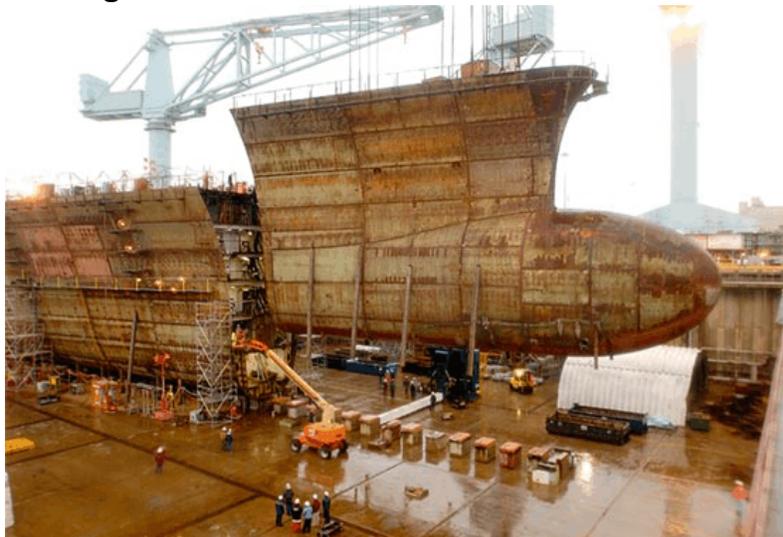
⁵ Ibid.

Princeton's total electricity-saving potential could probably cut her energy costs by nearly \$1 million a year, or about \$10 million in present value [over the ship's life cycle], while improving her warfighting capability.⁶

Bulbous Bows

A bulbous bow (**Figure 1**) can reduce a ship's wavemaking resistance and thereby increase its fuel efficiency. The Taylor Bow — an early form of the bulbous bow developed by U.S. naval architect and engineer David W. Taylor — was installed on the battleship Delaware (BB-28), which entered service in 1910, and subsequently on other large, higher-powered U.S.-built ships. The Inui Bow — a new form of the bulbous bow developed by Takao Inui of Japan in the late 1950s and early 1960s — is widely used on large commercial ships, where it typically reduces fuel consumption by about 5% at cruising speeds,⁷ and is now being applied to smaller commercial ships. Navy aircraft carriers, amphibious ships, and auxiliary ships and DOD sealift ships now feature bulbous bows, and the Navy has examined the idea of incorporating them into other ships, such as surface combatants.

Figure 1. Bulbous Bow Section for CVN-77



A study by the Navy's David Taylor Model Basin estimated that fitting a bow bulb onto an Arleigh Burke (DDG-51) class destroyer could reduce its fuel use by 3.9%, saving 2,400 barrels of fuel per year.⁸ An earlier (1994) study by the same

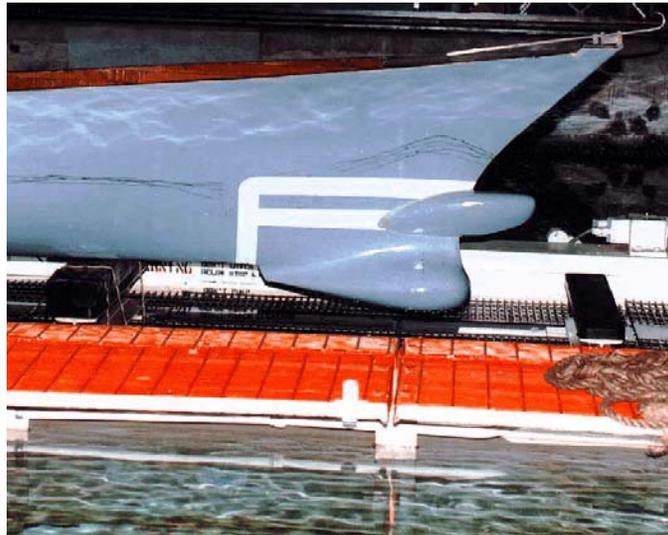
⁶ Amory B. Lovins, "All Energy Experts on Deck!" available online at [<http://www.rmi.org/sitepages/pid955.php>].

⁷ Thomas C. Gillmer and Bruce Johnson, *Introduction to Naval Architecture*, Annapolis (MD), U.S. Naval Institute, 1982; Patrick J. Bray, "The Bulbous Bow, What Is It, and Why?" available online at [http://www.dieselduck.ca/library/articles/bulbous_bows.htm] and "The Basics of Bulbous Bows," available online at [http://www.brayyachtdesign.bc.ca/article_bbows.html].

⁸ Dominic S. Cusanelli, "Stern Flaps and Bow Bulbs for Existing Vessels, Reducing Shipboard Fuel Consumption and Emissions," available online at [<http://www.unep.fr/>]
(continued...)

organization estimated that 79 existing Navy cruisers and destroyers could be fitted with bow bulbs for a total development and installation cost of less than \$30 million, and that the constant-dollar life-cycle fuel savings of the 79 ships would be \$250 million.⁹ DOD stated in 2000 that fitting bulbous bows onto 50 DDG-51s (a total of 62 DDG-51s have been procured) could save \$200 million in life-cycle fuel costs.¹⁰ The near-surface bow bulb designed for the DDG-51 (**Figure 2**) accommodates the ship's existing bow sonar dome. A developer of the bow bulb stated that "Due to funding cut backs, the [DDG-51] bow bulb has not yet been transitioned to sea."¹¹

Figure 2. Bulbous Bow Design For DDG-51
(bulb above, existing sonar dome below)



Stern Flaps

A stern flap (**Figure 3**) is a relatively small plate that extends behind a ship's transom, lengthening the bottom surface of the hull. A stern flap alters the water

⁸ (...continued)

ozonation/events/military/proceedings/Presentation%20Material/24%20-%20Cusanelli%20-%20SternFlaps.doc]. The study is undated but refers to a test that was "recently completed in Dec. 2000."

⁹ Dominic S. Cusanelli, "Development of a Bow for a Naval Surface Combatant which Combines a Hydrodynamic Bulb and a Sonar Dome," paper presented at the American Society of Naval Engineers Technical Innovation Symposium, September 1994, available online at [<http://www50.dt.navy.mil/reports/hydrobulb/>].

¹⁰ U.S. Department of Defense, *Climate Change, Energy Efficiency, and Ozone Protection, Protecting National Security and the Environment*. Washington, 2000. (Office of the Deputy Under Secretary of Defense (Environmental Security), November 2000) p. 5. Available online at [https://www.denix.osd.mil/denix/Public/Library/Air/Climate_Change/dodclimatechange.pdf].

¹¹ "Stern Flaps and Bow Bulbs for Existing Vessels, Reducing Shipboard Fuel Consumption and Emissions," op cit.

flow at the stern in ways that reduce the ship's resistance and increase fuel efficiency by a few or several percent. A stern flap for a Navy surface combatant in 2000 cost about \$170,000 to fabricate and install.¹² Preliminary tests of stern flaps on DDG-51s showed an annual fuel reduction of 3,800 to 4,700 barrels, or about 6.0% to 7.5%, per ship.¹³ As of November 2004, the Navy had installed stern flaps on 98 ships (primarily surface combatants) and planned to install them on an additional 85. The 98 ships equipped as of November 2004 had accumulated 403 ship-years of service and saved \$44 million in fuel costs.¹⁴ The Department of Energy stated in 2003 that by 2005, stern flap installations on Navy ships would save 446,000 barrels of fuel, or \$18 million, per year.¹⁵

Figure 3. Stern Flap on DDG-51 Class Destroyer



Higher-Efficiency Gas Turbines

Gas turbines with greater efficiencies than the simple-cycle gas turbines currently used in Navy ships could substantially reduce Navy ship fuel use. An example of such an engine is the WR-21 intercooled recuperated (ICR) gas turbine

¹² “Stern Flaps and Bow Bulbs for Existing Vessels, Reducing Shipboard Fuel Consumption and Emissions,” op cit, and *Climate Change, Energy Efficiency, and Ozone Protection, Protecting National Security and the Environment*, op cit.

¹³ “Stern Flaps and Bow Bulbs for Existing Vessels, Reducing Shipboard Fuel Consumption and Emissions,” op cit. See also William L. Cave, III and Dominic S. Cusanelli, “Effect of Stern Flaps on Powering Performance of the FFG-7 Class,” available on the Internet at [<http://www50.dt.navy.mil/reports/ffg7flap/>].

¹⁴ Carderock Division press release, November 17, 2004, “Navy Researcher Patents Ship Geometry,” available online at [<http://www.dt.navy.mil/pressreleases/archives/000129.html>]. An earlier (2003) Department of Energy publication stated that stern flaps had been installed on 61 ships, resulting in estimated savings of 203,000 barrels of fuel, and that when fully implemented in 2005, stern flap installations on Navy ships would save 446,000 barrels of fuel, or \$18 million, per year. U.S. Department of Energy, “Leading By Example to Improve Energy Security,” March 2003, available online at [http://www1.eere.energy.gov/office_eere/pdfs/federal_fs.pdf].

¹⁵ “Leading By Example to Improve Energy Security,” op cit.

engine, which was jointly developed between 1991 and 2000 by the U.S., UK, and French governments for potential use on future warships at a shared total cost of \$400 million. The industry team for the project included Northrop Grumman Marine Systems as the prime contractor, Rolls-Royce as the major subcontractor responsible for the design of the gas turbine, and other firms. Compared to the simple-cycle General Electric LM-2500 gas turbine used in Navy surface combatants, the WR-21 is bulkier and more expensive to procure, but could reduce fuel use on a mechanical-drive surface combatant by an estimated 25%-30%.¹⁶

The Navy in the late 1990s considered the WR-21 for the DD-21 program (now the DD(X) program). A 1998 article stated that with the WR-21:

Each DD-21 vessel, for example, would save about \$1.5 million a year in fuel and operating costs, [Northrop Grumman's ICR program manager] said. The savings provided by the new technology could pay back the premium on the original purchase of [the] WR-21 in two to six years.

Improved fuel economy can translate into a range of enhanced mission capabilities as well. These benefits could include a 30-percent increase in weapons payload for the DD-21, a 27- to 30-percent reduction in fuel tankage, increased speed, additional days on station, or greater range.¹⁷

Supporters of the WR-21 also argued that the ICR engine would result in a lower exhaust temperature, which could reduce the ship's infrared signature.

The Navy ultimately selected a design for the DD(X) whose propulsion system employed the LM-2500. The UK in 2000 selected the WR-21 for its new 7,500-ton Type 45 destroyer, which, like the DD(X), will employ an integrated electric drive system (see discussion below).

Other advanced turbines with even higher efficiencies are viewed as technically possible.¹⁸

¹⁶ See, for example, Colin R. English, "The WR-21 Intercooled Recuperated Gas Turbine Engine — Integration Into Future Warships," Proceedings of the International Gas Turbine Congress 2003, Toko, November 2-7, 2003, available online at [http://nippon.zaidan.info/seikabutsu/2003/00916/pdf/igt2003tokyo_os203.pdf]; U.S. Department of Defense, *Developing Science and Technologies List, Section 13: Marine Systems Technology*, Defense Threat Reduction Agency, July 2002, pp. 13-11. See also pp. 13-11 to 13-15. Available online at [<http://www.dtic.mil/mct1/DSTL/Sec13.pdf>]; "WR-21 Propulsion Module," Rolls-Royce Fact Sheet, available online at [http://www.rolls-royce.com/marine/downloads/pdf/gasturbine/wr21_prop.pdf]; "Northrop Grumman Readies New Gas Turbine for Market," *MarineLink.com*, December 7, 1999, available online at [<http://www.marinelink.com/Story/ShowStory.aspx?StoryID=2141>]; and Joseph Lawton, presentation entitled "Gas Turbine Engine R&D for Shipboard Applications," undated but apparently 1999, available at [<http://www.netl.doe.gov/publications/proceedings/99/99ats/3-5.pdf>].

¹⁷ Steven Ashley, "Fuel-Saving Warship Drives," *Mechanical Engineering*, August 1998. Available at [<http://www.memagazine.org/backissues/aug98/features/fuelsav/fuelsav.html>].

¹⁸ See Alfonso (Al) Wei, "Technologies for Next Generation Turbine Systems," presentation (continued...)

Integrated Electric-Drive Propulsion

Compared to a traditional mechanical-drive propulsion system with two separate sets of turbines (one for propulsion, the other for generating electricity for shipboard use), an integrated electric-drive propulsion system can reduce a ship's fuel use by permitting the ship's single combined set of turbines to be run more often at their most fuel-efficient speeds. A 2000 CRS report that surveyed electric-drive propulsion technology stated:

Depending on the kind of ship in question and its operating profile (the amount of time that the ship spends traveling at various speeds), a Navy ship with an integrated electric-drive system may consume 10 percent to 25 percent less fuel than a similar ship with a mechanical-drive system. The Navy estimates a savings of 15 to 19 percent for a ship like a surface combatant.

In addition, electric drive makes possible the use of new propeller/stern configurations, such as a podded propulsor ... that can reduce ship fuel consumption further due to their improved hydrodynamic efficiency. Estimates of additional savings range from 4 percent to 15 percent, depending on the ship type and the exact propeller/stern configuration used.¹⁹

The Navy's TAKE-1 class cargo ships use an integrated electric-drive system derived from a commercially available system that has been installed on ships such as cruise ships. The Navy's lead DD(X) destroyers are to use an integrated electric-drive system with a more advanced motor type known as the advanced induction motor (AIM). The Navy submarine community has expressed an interest in shifting from mechanical-drive to electric-drive technology but requires a technology that is more torque-dense (i.e., more power-dense) than the AIM technology to be used on the lead DD(X)s. Candidates for a more torque-dense technology include a permanent magnet motor (PMM) and a high-temperature superconducting (HTS) synchronous motor.

¹⁸ (...continued)

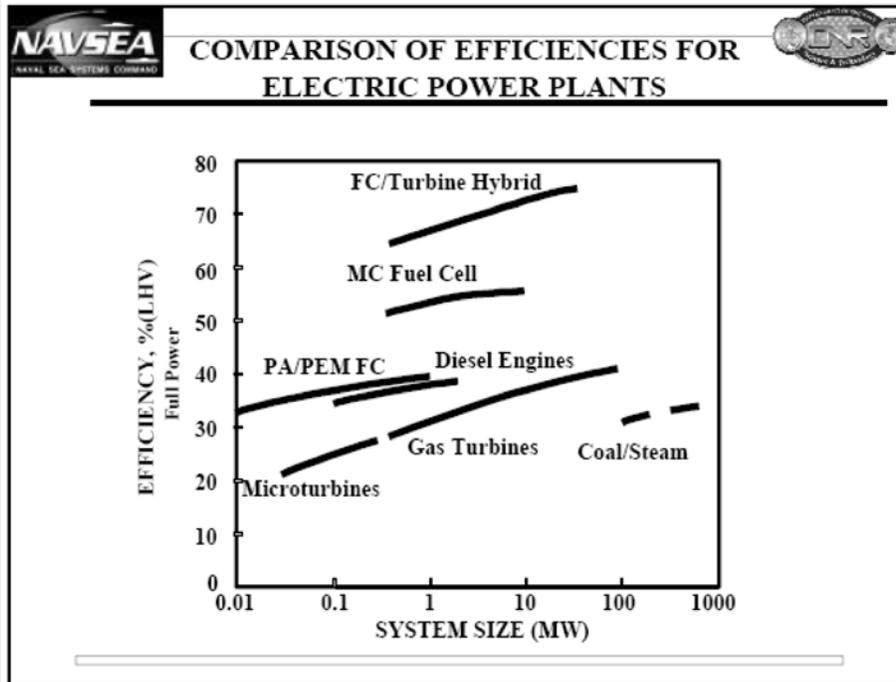
at Turbine Power Systems Conference and Condition Monitoring Workshop, February 25-27, 2002, Galveston, Texas, available online at [<http://www.netl.doe.gov/publications/proceedings/02/turbines/wei.pdf>], and Roger Anderson and Ronald Bischoff, "Mobile Propulsion and Fixed Power Production With Near-Zero Atmospheric Emissions," Tri-Service Power Expo 2003, Norfolk Waterside Marriott, 15-17 July 2003, available online at [<http://www.dtic.mil/ndia/2003triservice/bis1.pdf>].

¹⁹ CRS Report RL30622, *Electric-Drive Propulsion for U.S. Navy Ships: Background and Issues for Congress*, by Ronald O'Rourke. A 2002 DOD report similarly states that integrated electric drive propulsion can achieve "[g]reater than 15-19 percent savings over existing gas-turbine combatants when operating a minimum of two generator sets." *Developing Science and Technologies List, Section 13: Marine Systems Technology, op. cit.*, pp. 13-25.

Fuel Cells

Fuel cell technology,²⁰ if successfully developed for Navy shipboard application, could reduce Navy ship fuel use substantially by generating electricity much more efficiently than is possible through combustion. **Figure 4** is a Navy briefing slide comparing the relative efficiency of combustion and fuel cell electric power plants.²¹

Figure 4. Electric Power Plants



The Navy states that “the Navy’s shipboard gas turbine engines typically operate at 16 to 18 percent efficiency, because Navy ships usually sail at low to medium speeds that don’t require peak use of the power plant. The fuel cell system that ONR [the Office of Naval Research] is developing will be capable of between 37 to 52 percent efficiency.”²² As a result of these relative efficiencies, the Navy states that a DDG-51 gas turbine generator operating for 3,000 hours would consume 641,465 gallons of fuel while ship-service fuel cell plant with a built-in fuel processor (i.e., a fuel reformer) for forming hydrogen from Navy diesel fuel would, if operated for

²⁰ For basic information on fuel cell technology, see CRS Report RL32196, *A Hydrogen Economy and Fuel Cells: An Overview*, by Brent D. Yacobucci and Aimee E. Curtright. Additional information is available online at [<http://www.fuelcells.org>].

²¹ Source for Figure 4: “Marine Fuel Cells,” presentation at Marine Vessel and Air Quality Conference, 1-2 February 2001, Hyatt Regency Hotel, San Francisco, CA, available online at [<http://www.epa.gov/region9/air/marinevessel/pdfs/hoffman.pdf>]. This slide can also be found in the two other Navy briefings cited in the next footnote.

²² ONR program officer Anthony Nickens, as quoted in Ed Walsh, “Hybrids on the High Seas: Fuel Cells for Future Ships,” *Navy Newsstand*, March 8, 2004, available online at [http://www.news.navy.mil/search/display.asp?story_id=12221].

the same period, consume 214,315 gallons, or 33% as much.²³ The Navy has estimated, using past fuel prices, that shifting to fuel cell technology could save more than \$1 million per ship per year in ship-service fuel costs.²⁴ Other potential advantages of fuel cell technology include reduced maintenance costs, reduced emissions (and thus reduced infrared signature), reduced acoustic signature, reduced radar cross section (perhaps because of reduced-size exhaust stack structures), increased ship survivability due to distributed power reduction, and greater ship design flexibility.

There is strong interest in Europe, Japan, and the United States in developing shipboard fuel cell technology for both powering shipboard equipment and ship propulsion. In Europe, fuel cell technology has been incorporated into non-nuclear-powered submarines, such as the German Type 212 submarine, and is starting to be applied to civilian surface ships. ONR and the Naval Sea Systems Command (NAVSEA) have a shipboard fuel cell program for developing fuel cell power systems for Navy ships with an acquisition cost, weight, and volume comparable to other market options. A July 2006 GAO report states:

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.²⁵

Alternative Hydrocarbon Fuels

A second strategy for reducing the Navy's dependence on oil would be to shift to alternative hydrocarbon fuels.

Navy Ground Vehicles And Installations

The Department of the Navy (DON) in recent years has taken steps to increase its use of alternative hydrocarbon fuels, particularly biodiesel — an alternative diesel fuel produced from vegetable oils or animal fats — at installations and in non-tactical ground vehicles.

²³ Ibid. The same comparison can be found in "US Navy Shipboard Fuel Cell Program," briefing presentation for ShipTech 2003, January 2003, Biloxi, MS, available online at [<http://www.nsrp.org/st2003/presentations/hoffman.pdf>] and in "U.S. Navy Shipboard Fuel Cell Program," presentation for U.S. Maritime Administration Workshop on Maritime Energy and Clean Emissions, 29-30 January 2002, The St. Regis, Washington, DC, available online at [http://www.marad.dot.gov/nmrec/conferences_workshops/jan%2029-30%202002/house.pdf].

²⁴ Presentation for U.S. Maritime Administration Workshop on Maritime Energy and Clean Emissions, op cit.

²⁵ Government Accountability Office, *Propulsion Systems for Navy Ships and Submarines*, GAO-06-789R, July 6, 2006, p. 7.

- In May 2000, the federal government opened its first alternative-fuel service station at the Navy Exchange at Arlington, VA, near the Pentagon. The station initially provided E85 fuel — a blend of 85% ethanol (i.e., grain alcohol) and 15% gasoline — and compressed natural gas.²⁶
- In 2001-2002, the services began using B20 fuel (a blend of 20% biodiesel and 80% petroleum diesel) to fuel non-tactical vehicles and other equipment at various bases and installations.
- In late 2003, the Navy started making its own biodiesel fuel in a demonstration project at the Naval Facilities Engineering Services Center, Port Hueneme, CA.²⁷
- In December 2004, the Navy added biodiesel to the list of fuels provided at the alternative-fuel service station at the Navy Exchange, Arlington, VA.²⁸
- On January 18, 2005, DON issued a memorandum requiring all Navy and Marine Corps non-tactical diesel vehicles to operate on B20 fuel by June 1, 2005, where B20 can be supplied by the Defense Energy Support Center, adequate fuel tanks are available, and the use of biodiesel is allowable and practical in light of local, state, and federal regulations. The requirement does not apply to tactical military equipment or deployable commercial equipment intended to support contingency operations.²⁹

²⁶ U.S. Department of Defense News Release, “Department of Defense Opens First Federal Multi-Alternative Fuel Service Station,” May 1, 2000, available online at [http://www.defenselink.mil/releases/2000/b05012000_bt218-00.html].

²⁷ “From Use Cooking Oil to Biodiesel,” *Fall West Bulletin*, Fall/Winter 2003, available online at [<http://www.zyn.com/flcfw/fwnews/fwarch/fw032a.htm>], Catherine Saillant, “Navy Vehicles Will Need an Order of Fries to Go,” *Los Angeles Times*, October 21, 2003, available online at [http://www.worldenergy.net/pdfs/newsstories/102103_russ_teal.pdf], and Presentation by Kurt Buehler, Naval Facilities Engineering Service Center, entitled “Production of Biodiesel from Used Vegetable Oil,” available online at [<http://www.federal sustainability.org/events/GGasperinoFNSDenver1.pdf>].

²⁸ Kristine M. Sturkie, “Navy Exchange Quarters Gas Station Offers Alternative Fuels,” *Navy Newsstand*, December 23, 2004, available online at [http://www.news.navy.mil/search/display.asp?story_id=16425].

²⁹ Memorandum from Department of the Navy Office of the Assistant Secretary (Installations and Environment), dated January 18, 2005, for Deputy Chief of Naval Operations for Readiness and Logistics (N4) [and] Deputy Commandant of the Marine Corps for Logistics (L), on Department of the Navy Environmental Policy Memorandum 05-01; Biodiesel Fuel Use In Diesel Engines, available online at [<http://www.federal sustainability.org/initiatives/biodiesel/NavyBiodieselPolicy.pdf>].

In June 2005, the National Biodiesel Board presented the Navy with an award for its leadership in the use of biodiesel.³⁰

National Park Service Boat

Since about 2001, the Channel Islands National Park has been using B100 (100% biodiesel fuel) to fuel its 56-foot boat *Pacific Ranger*.³¹

2005 NRAC Study

The 2005 NRAC study cited at the start of this report was sponsored by the Marine Corps Combat Development Command³² and was tasked to “Identify, review, and assess technologies for reducing fuel consumption and for militarily useful alternative fuels, with a focus on tactical ground mobility.... Two main focus areas to be considered in this effort are alternative fuels, and improving fuel efficiency (to include examination of alternative engine technologies).”³³ The study recommended making a long-term commitment to manufactured liquid hydrocarbon fuels made from domestically abundant feedstocks.³⁴ The briefing referenced “Hubbert’s Peak,” also known as the peak oil theory,³⁵ and included a discussion of the German-discovered Fischer-Tropsch (FT) process for converting coal into manufactured liquid hydrocarbon fuels.³⁶

The NRAC study concluded the following regarding manufactured fuels:

- “Liquid hydrocarbon fuel production using domestic energy sources is feasible

³⁰ National Biodiesel Board new release, “U.S. Navy Presented with Energy Security Award,” June 13, 2005, available online at [http://www.biodiesel.org/resources/pressreleases/fle/20050613_navyaward.pdf].

³¹ See “The Pacific Ranger,” available online at [<http://www.nps.gov/chis/pacranger.htm>], and “Alternative Fuel Vehicles,” available online at [<http://www.ofee.gov/wpr/altfuel.htm>].

³² Zachary M. Peterson, “NRAC Panel Offers Proposals For Breaking ‘The Tether of Fuel,’” *Inside the Navy*, October 17, 2005.

³³ Terms of Reference, Future Fuels, NRAC Summer Study 2005, available online at [http://www.onr.navy.mil/nrac/docs/2005_tor_future_fuels.pdf].

³⁴ “Future Fuels, [presented to] Flag Officers & Senior Executive Service, 4 October 2005, The Pentagon Auditorium,” op cit, slide 5.

³⁵ *Ibid.*, slide 28.

³⁶ *Ibid.*, slide 29. Descriptions of the FT process, which was discovered by Franz Fischer and Hans Tropsch in 1923, are available online at [<http://www.tntech.edu/chemistry/Inorganic/Chem4110/Student/01%20The%20Fischer-Tropsch%20Process.ppt#256,1>], [<http://www.answers.com/topic/fischer-tropsch-process>], [http://www.fischer-tropsch.org/primary_documents/presentations/presentationstoc.htm], [http://en.wikipedia.org/wiki/Fischer-Tropsch_process], and [<http://www.infoplease.com/ce6/sci/A0818760.html>]. See also the archive of Fischer-Tropsch documents available online at [<http://www.fischer-tropsch.org/>].

- “Commercial financing and infrastructure development will drive this process
- “DoD action needed to catalyze development & ensure US military takes advantage of manufactured fuels
- “Need to ensure military platforms can use manufactured fuels.”³⁷

As recommended actions for the longer term (defined in the study as 2015 and beyond), the NRAC study said that DOD should catalyze a manufactured liquid hydrocarbon fuels infrastructure, and characterize the compatibility of manufactured liquid hydrocarbon fuels with DON equipment.³⁸ Among the specific steps to be taken, the study recommended that the Assistant Secretary of the Navy for Research, Development and Acquisition (ASN [RDA]) should, with the Services, advocate the use of multiyear procurement [MYP] authority that was granted to the Secretary of Defense in the Energy Policy Act of 2005 (H.R. 6, P.L. 109-58 of August 8, 2005) to catalyze commercial financing of large-scale FT plants for producing transportation fuels.³⁹ The study also recommended that the Chief of Naval Research (CNR) monitor the status of the FT plant authorized by P.L. 109-58 and use fuel produced by the plant to conduct tests on current and future vehicles.⁴⁰

ONR Interest In Synthetic Fuels

In October 2005, an official from the Office of Naval Research (ONR) stated that ONR intends to explore methods for producing synthetic fuels, perhaps at sea. A press report stated:

ONR would like to explore how [Germany’s World War II fuel] processing technology could be miniaturized for land- and sea-based platforms, [George Solhan, ONR’s director of naval expeditionary maneuver warfare and combating terrorism science and technology] said Oct. 26 at the National Defense Industrial Association’s expeditionary warfare conference in Panama City, FL.

“We can’t predict energy availability in an operational sea base in a construct that’s far away from home,” he said. “This is something we’re investigating right now. We’re in the preliminary stages but this may well end up being one of the programs in our” Innovative Naval Prototype effort.

The idea originated from recommendations the Naval Research Advisory Committee made in a recent study, Solhan told Inside the Navy in a brief interview....

“We know that this can be done,” Solhan said of synthetic fuel production. “The Germans did it. They did it in a big physical plant. Can you miniaturize it?”

³⁷ Ibid., slide 30.

³⁸ Ibid., slide 32.

³⁹ Ibid., slide 33.

⁴⁰ Ibid., slide 34.

Can you do it in an environment where gravity doesn't always point straight down," where choppy waters could affect a ship-based processing system.

ONR would also investigate whether such a processing system could be scalable, so that several miniaturized systems could be linked for expanded production capacity, he added. A notional demonstration project could start with a land-based pilot project and eventually move to a sea-based system, perhaps on an offshore drilling platform or a ship, he speculated. But there is no program now, he pointed out.

"I wouldn't call it [being in] the planning phase," Solhan said. "I'd call it just the idea, brain-storm phase."

In the event petroleum supplies or refining capacity is disrupted, synthetic fuel could be produced from sources, such as methane and coal, he noted. And a worldwide infrastructure for coal mining and delivery already exists, he said. Ships carrying 500,000 metric tons of coal sail around the world on a regular basis.

"So diverting one of those haulers into the sea base and offloading the coal in bulk onto this plant would probably be doable," he said. "One thing that is readily available is coal. There is a huge global industry in coal."⁴¹

2006 Air Force Scientific Advisory Board Study

A January 2006 "quick look" study by the Air Force Scientific Advisory Board examined several potential alternative fuels for Air Force use.⁴² The one option it listed as available in the near term (defined as the next 0 to 5 years) was conversion of coal into synthetic fuel using the FT process. Other options — oil shale, liquified natural gas, ethanol blends, and biodiesel — were presented as mid-term options (defined in the study as the next 5 to 15 years). Two more options — biomass black liquor fuels⁴³ and hydrogen fuel for turbine engines — were presented as far-term options (defined as more than 15 years from now).

The study noted that FT fuels offered certain "significant benefits" in terms of their technical properties, and stated that the "Air Force has [the] ability to catalyze

⁴¹ Jason Ma, "ONR To Explore Synthetic Fuel Production For Seabasing Operations," *Inside the Navy*, November 7, 2005. Bracketed material as in the original.

⁴² Briefing by Air Force Scientific Advisory Board, entitled "Technology Options for Improved Air Vehicle Fuel Efficiency, A 'Quick Look' Study, January 26, 2006.

⁴³ Black liquor fuel is "a by-product of the papermaking process, is an important liquid fuel in the pulp and paper industry. It consists of the remaining substances after the digestive process where the cellulose fibres have been cooked out from the wood." Source: Magnus Marklund, "Black Liquor Recovery: How Does It Work?" available online at [http://etcpitea.se/blg/document/PBLG_or_RB.pdf]. See also the discussions available online at [http://eereweb.ee.doe.gov/biomass/fy04/fuel_chemistry_bed_performance.pdf], [http://eereweb.ee.doe.gov/industry/bestpractices/fall2001_black_liquor.html], [http://www.eng.utah.edu/~whitty/utah_blg/].

large-scale transition to alternative fuels.”⁴⁴ As one of its recommendations for the near term, the study said the Air Force should “Ramp up development and utilization of F-T fuels” and “take the lead in DOD’s transition to new fuels via blends.”⁴⁵ One of its recommendations for the mid- and far term was “Alternative fuels, e.g., ethanol, [and] alternative HC [hydrocarbon] fuel blends.”⁴⁶

Nuclear Propulsion

A third strategy for reducing the Navy’s dependence on oil would be to shift to a greater reliance on nuclear propulsion.

2005 Naval Reactors Quick Look Analysis

A 2005 “quick look analysis” conducted by the Naval Nuclear Propulsion Program, also known as Naval Reactors, concluded that total life-cycle costs (i.e., procurement plus life-cycle operating and support costs) for nuclear- and fossil-fueled versions of large-deck aircraft carriers would equalize when the price of diesel fuel marine (DFM) delivered to the Navy reached \$55. The break-even figures for LHA/LHD-type large-deck amphibious assault ships and large surface combatants (i.e., cruisers and destroyers) were \$80 and \$205 per barrel, respectively.⁴⁷ As of February 2006, the price of DFM delivered to the Navy was \$84 per barrel. Since the cost of DFM delivered to the Navy is roughly 15% greater than that of crude oil, these figures correspond to crude-oil costs of about \$48, \$70, and \$178 per barrel, respectively. The difference in the break-even points results in part from the different amounts of energy used by each type of ship over its life time.

The Naval Reactors study was based on a 40-year ship life, which is roughly consistent with the expected service life of an amphibious assault ship, but five years longer than the 35-year life the Navy now plans for its cruisers and destroyers. If the calculation were done on a 35-year basis for the surface combatants, the break-even figure for those ships might shift somewhat.

The results for the surface combatants are for a ship roughly equal in size to the Navy’s past nuclear-powered cruisers (CGNs). Since most of these CGNs were smaller than the 14,500-ton DD(X)/CG(X) design, the break-even point for a nuclear-powered version of the DD(X)/CG(X) design might be somewhat different, and perhaps somewhat lower.

The study did not attempt to quantify the mobility-related operational advantages of nuclear propulsion. These include the ability to transit long distances

⁴⁴ Ibid., slide 33.

⁴⁵ Ibid., slide 35.

⁴⁶ Ibid., slide 36.

⁴⁷ U.S. Naval Nuclear Propulsion Program, briefing entitled “Nuclear and Fossil Fuel Powered Surface Ships, Quick Look Analysis,” presented to CRS on March 22, 2006. The briefers explained that the study was originally conducted in 2005.

at high speeds (so as to respond quickly to distant contingencies) without having to slow down for refueling, the ability to commence combat operations immediately upon arrival in the theater of operations without having to first refuel, and the ability to maneuver at high speeds within the theater of operations without having to refuel. Nuclear-powered ships also lack the hot exhaust gasses that contribute to the infrared detectability of fossil-fueled ships.

Since this was a “quick look” study that excluded or made simplifying assumptions about certain factors, a more comprehensive analysis might be required to decide whether to shift from fossil-fueled large-deck amphibious assault ships or large surface combatants to nuclear-powered versions of these ships. The results of the quick look study, however, suggest that the option may be worth further exploration, at least for the large-deck amphibious assault ships. It may also be worth exploring the option for large surface combatants, particularly if oil prices are expected to rise from current levels, and if the operational advantages of nuclear propulsion are also taken into account.

Past Nuclear Ships Other than Carriers and Submarines

The Navy has not previously built nuclear-powered large-deck amphibious assault ships. One approach for doing so would be to take one-half of the twin reactor plant designed for the new CVN-21 class aircraft carriers and install it on an LHA/LHD-type hull. Another option would be to design a new plant specifically for this type of hull.⁴⁸

Table 1 shows the nine nuclear-powered cruisers (CGNs) previously built by the Navy. The ships include three one-of-a-kind designs followed by the two-ship California (CGN-36) class and the four-ship Virginia (CGN-38) class.

Procurement of nuclear-powered cruisers was halted after FY1975 due largely to a desire to constrain the procurement costs of future cruisers. In deciding in the late 1970s on the design for the new cruiser that would carry the Aegis defense system, two nuclear-powered Aegis-equipped options — a 17,200-ton nuclear-powered strike cruiser (CSGN) and a 12,100-ton derivative of the CGN-38 class design — were rejected in favor of the option of placing the Aegis system onto the smaller, conventionally powered hull developed for the Spruance (DD-963) class destroyer. The CSGN was estimated to have a procurement cost twice that of the DD-963 option, while the CGN-42 was estimated to have a procurement cost 30%-50% greater than that of the DD-963 option. The option based on the DD-963 hull became the 9,500-ton Ticonderoga (CG-47) class Aegis cruiser. The first Aegis cruiser was procured in FY1978.

Since one-half of the CVN-21 class twin reactor plant might be too large to install in the hull of a cruiser or destroyer, even one as large as the DD(X)/CG(X), a nuclear-powered cruiser or destroyer might be likely to incorporate a new-design

⁴⁸ A nuclear-powered version of an LHA(R) is discussed briefly in CRS Report RL32914, *Navy Ship Acquisition: Options for Lower-Cost Ship Designs — Issues for Congress*, by Ronald O'Rourke.

reactor plant. This plant could incorporate many of the cost-reducing features of the Virginia (SSN-774) and CVN-21 class reactor plants.

Table 1. Navy Nuclear-Powered Cruisers (CGNs)

Hull number	Name	Builder	Displacement (tons)	Procured	Entered service	Decommissioned
CGN-9	Long Beach	Bethlehem ^a	17,100	FY57	1961	1995
CGN-25	Bainbridge	Bethlehem ^a	8,580	FY59	1962	1996
CGN-35	Truxtun	New York ^b	8,800	FY62	1967	1995
CGN-36	California	NGNN ^c	10,530	FY67	1974	1999
CGN-37	South Carolina	NGNN ^c	10,530	FY68	1975	1999
CGN-38	Virginia	NGNN ^c	11,300	FY70	1976	1994
CGN-39	Texas	NGNN ^c	11,300	FY71	1977	1993
CGN-40	Mississippi	NGNN ^c	11,300	FY72	1978	1997
CGN-41	Arkansas	NGNN ^c	11,300	FY75	1980	1998

Source: Prepared by CRS based on Navy data and Norman Polmar, *The Ships and Aircraft of the U.S. Fleet*.

a. Bethlehem Steel, Quincy, MA.

b. New York Shipbuilding, Camden, NJ.

c. Newport News Shipbuilding, now known as Northrop Grumman Newport News (NGNN).

Implications for Procurement Costs of Other Ships

Naval Reactors estimates that building a nuclear-powered amphibious assault ship every three years or so could reduce the procurement cost of each nuclear-powered carrier (CVN) by about \$65 million and each nuclear-powered attack submarine (SSN) by about \$20 million due to increased economies of scale in the production of nuclear propulsion components. Naval Reactors further estimates that if nuclear-powered surface combatants were then added to this mix of nuclear-powered ships, it would reduce the cost of each CVN by an additional \$80 million or so, and each SSN by an additional \$25 million or so. Naval Reactors also states that the additional work in building nuclear-propulsion components could help stabilize the nuclear-propulsion component industrial base by providing extra work to certain component makers whose business situation is somewhat fragile.⁴⁹

If nuclear-powered amphibious assault ships or surface combatants are built partially or entirely by the two nuclear-construction yards — Northrop Grumman Newport News (NGNN) and General Dynamics' Electric Boat division (GD/EB); see discussion below — it might further reduce the cost of CVNs and SSNs built at those yards by spreading the fixed overhead costs at those yards over a wider workload and enabling more efficient rollover of workers from one ship to another. By the same token, it might increase the cost of other ships being built at Ingalls and GD/BIW by having the obverse effects in those yards.

⁴⁹ Telephone conversation with Naval Reactors, March 24, 2006.

Implications for Construction Shipyards

Large-deck amphibious assault ships are currently built by the Ingalls shipyard that forms part of Northrop Grumman Ship Systems (NGSS), and large surface combatants are currently built by Ingalls and General Dynamics' Bath Iron Works (GD/BIW). These yards, however, are not certified to build nuclear-powered ships. Shifting amphibious assault ships or large surface combatants from fossil-fuel propulsion to nuclear-propulsion might therefore shift at least some of the construction work for these ships away from these yards and toward one or both of the nuclear-construction yards.

If Ingalls or GD/BIW do not become certified to build nuclear-powered ships, then future nuclear-powered amphibious assault ships or nuclear-powered large surface combatants might be partially built by Ingalls or GD/BIW. Under this scenario, non-nuclear portions of the ships would be built by Ingalls or GD/BIW, while the reactor compartment would be built by NGNN or possibly GD/EB. Naval Reactors is currently uncertain whether final assembly would occur at NGNN or at the yard that built the non-nuclear portions of the ship.⁵⁰

Alternatively, if Ingalls (which built nuclear-powered submarines until the early 1970s at its East Bank facility) or GD/BIW became certified to build nuclear-powered ships, then future nuclear-powered amphibious assault ships or nuclear-powered large surface combatants could be built entirely at Ingalls or GD/BIW.⁵¹

Implications for Ship Maintenance

Shifting large-deck amphibious assault ships or large surface combatants from fossil-fuel propulsion to nuclear-propulsion would shift some portion of the maintenance work for these ships away from non-nuclear-certified yards and toward the nuclear-certified yards, which include NGNN, GD/EB, and the four government-operated naval shipyards.

Implications for Port Calls and Forward Homeporting

Shifting large-deck amphibious assault ships or large surface combatants from fossil-fuel propulsion to nuclear-propulsion might make them potentially less welcome in the ports of countries with strong anti-nuclear sentiments. The Navy works to minimize this issue in connection with its CVNs and SSNs, and these ships make calls at numerous foreign ports each year. Given their occasional need for

⁵⁰ Ibid.

⁵¹ At an April 6, 2006, hearing before the Projection Forces Subcommittee of the House Armed Services Committee, Representative Gene Taylor asked how long it might take for a shipyard to become certified to build a nuclear-powered ship. One witness — Dr. Norman Friedman — replied that he thought the process might take three or four years. Another witness — Ronald O'Rourke — noted that in addition to the regulatory steps involved, an additional potential issue for yards seeking to become nuclear-certified could be local political support for the idea. Dr. Friedman stated that, in the case of Ingalls, this likely would not be a significant issue.

access to nuclear-qualified maintenance facilities, shifting large-deck amphibious assault ships or large surface combatants from fossil-fuel propulsion to nuclear-propulsion might reduce the number of potentially suitable locations for forward-homeporting the ships, should the Navy decide that forward homeporting them would be desirable for purposes of shortening transit times to and from operating areas. The Navy plans to homeport the George Washington (CVN-73) at Yokosuka, Japan, the Navy's principal forward homeporting location, in 2008. In light of this decision, Yokosuka might be suitable as a potential forward homeporting location for nuclear-powered amphibious assault ships or surface combatants.

Sail and Solar Power

A fourth strategy for reducing the Navy's dependence on oil would be to make use of sail and solar power, perhaps particularly on Navy auxiliaries and DOD sealift ships.

Sails and Wingsails

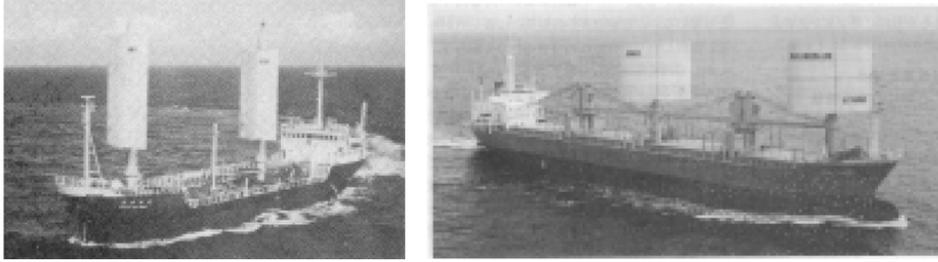
Sails on masts include both traditional sails and wingsails, which are airfoil-like structures that are similar to airplane wings that have been stood on end. A November 2004 magazine editorial notes that:

In the late 1970s and early 1980s, huge oil price hikes stimulated much interest in wind-assistance for merchant ships, and several interesting vessels were built from new or converted. These include a 1600dwt tanker *Shin Aitoku Maru* and a 26,000dwt bulk/log carrier *Usuki Pioneer* [Figure 5]. In Denmark, Knud E Hansen has designed a 50,000dwt-class bulk carrier, and today in Germany, more research is being handled by Sail Log into a 50,000dwt Panamax bulker with 20,000m² of sail. Traditional square rigs have been chosen by this company because they are known to work satisfactorily, but alternatives do exist, including the more revolutionary Walker Wingsail [Figure 6].

The long-haul bulk trades (traditionally not in need of express service) have been identified by the German team as most suitable for sail assistance, or even full sail, because the principal bulk trades run more or less in a north-south direction in parallel with the globe's principal wind systems. Sail Log is part of Schwab-Orga GmbH, which holds the patent to a modern square-rigged design with automated sails....

Sail Log claims that the running costs of an automated sail-assisted bulk carrier could be 22% lower than those of a fully diesel-powered vessel, although in general, it has to be said that figures appear to vary quite dramatically, depending on the source. Sail Log estimates that sails could normally be used for two-thirds of a voyage. A model has been built and has confirmed all propulsive predictions.⁵²

⁵² "Time to Seek Fossil-Free Propulsion?" *The Naval Architect*, November 2004, p. 3, available online at [<http://www.rina.org.uk/rfiles/navalarchitect/editorialnov04.pdf>].

Figure 5. Shin Aitoku Maru (left) and Usuki Pioneer (right)

Cooke Associates, an engineering consulting firm in Cambridge, England, that has worked with wingsail developers, states that in evaluations conducted between 1984 and 1993, the Usuki Pioneer and another sail-equipped ship called the Aqua City claimed a fuel reduction of 30%-40% in ideal wind conditions, but that the projects were terminated due to falling oil prices and high maintenance costs.⁵³

An 8-ton version of the Walker wingsail, Cooke states, was evaluated in 1986-1988 aboard the MV Ashington, a small commercial vessel. Due to low fuel costs at the time and limits on usable wind in the ship's trading routes, Cooke, states, the firm that operated the ship decided that wingsail did not meet the firm's payback criteria.⁵⁴ Cooke states that the "Collapse of world oil prices destroyed the economic case for use of wingsails in commercial shipping..."⁵⁵ Cooke also states that "Wingsails could in the future be used to drive large commercial ships."⁵⁶

Figure 6. Pleasure Craft Equipped with Walker Wingsails

⁵³ "Commercial History, Walker Wingsail and the MV Ashington," available online at [<http://www.cookeassociates.com/commercial.html>]. Cooke states that this information is from an article in the May 1996 issue of *Pacific Maritime* magazine.

⁵⁴ Ibid.

⁵⁵ "Wingsail History," available online at [<http://www.cookeassociates.com/history.html>].

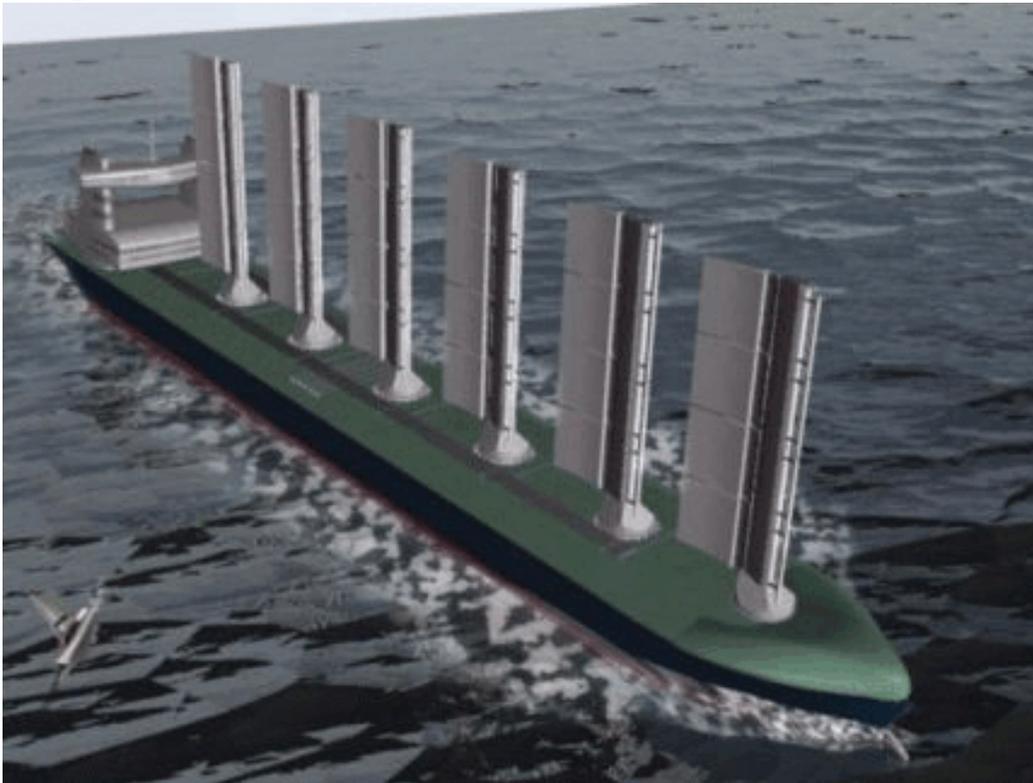
⁵⁶ Wingsails, Wingsail Technology, available online at [<http://www.cookeassociates.com/wingsails.html>].

A 1982 study examined the idea of converting a 245-foot Melville (AGOR-14) class oceanographic research ship into a wingsail-assisted ship. An abstract from the report states:

Operating statistics indicate that the AGOR-14 CLASS R/V KNORR spends 30% of her time in transit. Conventional research vessel cruise planning leads to wind statistics which are favorable to sail assist. A 3610 square foot wing sail retrofit to the KNORR would save 90 LT of fuel per year, and would not interfere with mission performance. Greater fuel savings would result for voyage scenarios with more time in transit. Potential benefits to oceanographic operations include increased fuel endurance, quiet propulsion, improved station keeping, motion reduction, and schedule reliability. Further consideration of sail-assist retrofit and/or new building is recommended.⁵⁷

In 1995, the Danish Ministry of Environment and Energy funded a study by Consulting Naval Architects and Marine Engineers Knud E. Hansen A/S to explore possibilities for sail-assisted commercial ships. In response, the firm between 1995 and 1999 developed a concept, called Modern Windship, for a 200-meter (656-foot), 50,000-ton, sail-assisted dwt product carrier. The design is shown in **Figure 7**.

Figure 7. Project Windship 50,000-ton DWT Product Carrier



⁵⁷ “Analysis of Sail-Assist for Navy Oceanographic Research Ships of the AGOR-14 Class,” abstract available online at [<http://www.stormingmedia.us/19/1963/A196311.html>].

The firm's report on the project stated:

A feasibility study was carried out. The impact of variations in fuel prices was stressed. The effect of varying the average speed was investigated. A product carrier was chosen as study example. The study pointed out some of the commercial limitations of WindShip-application at present time. It proved uneconomical to use WindShips on typical product carrier routes. A cost increase of approximately 10% was calculated when comparing the WindShip with an equal-sized conventional product carrier.

The results showed that by lowering the average speed of a conventional ship by 1 knot a reduction of approximately 25% in fuel consumption could be achieved. However, by adding the rig of the WindShip on average an additional three tons of fuel per 24 hrs could be saved in the more windy areas. This corresponded to 10-15% of the total fuel consumption....

On the economical side the results may be less inspiring at first sight. There is no doubt that the results were both reliable and realistic. However, the main conclusion that emerged was that a product carrier is not the preferred choice for a modern WindShip. There was no economical advantage in using a WindShip, instead it cost 10% more to sail with. Worse yet, the fuel savings were marginal, under certain assumptions and conditions a WindShip even consumed more fuel than a conventional ship.

However, on the route between Rotterdam, Holland and New York, USA an average HFO [heavy fuel oil] saving of 20.5 to 27% was shown, depending on average speed. It was only here that the average wind speed of 8 m/s initially estimated during phase 1 could be found. Decisions on sail area etc. were based on this estimate early on in phase 2 [1998-1999] of the project.

At the same time the feasibility study showed that the comparison had been made at a sub-optimal speed for a WindShip. Calculations using 11 knots instead of 13 lowered the required freight rate with up to 5%. Due to the special requirements of the product carrier trade the larger internal volume of a WindShip was not used to its advantage in the study.

Taking the above issues into account we see the potential of modern WindShips concept. If speed is reduced, but same productivity is maintained due to the larger volumes carried, money will be saved. It is in this market segment that the WindShip should operate. Careful routing, including effects of seasonal weather variations could then prove the WindShip both environmentally beneficial and economically favourable.⁵⁸

⁵⁸ Martin Rosander and Jens O.V. Bloch, *Modern Windships*, 2000 report, pp. 117-118, available at [http://www.mst.dk/default.asp?Sub=http://www.mst.dk/udgiv/publications/2000/87-7944-019-3/html/default_eng.htm]. For an earlier report on the project, see also Jens V. Bloch, et al, "Modern Windship," available at [http://www.eceee.org/library_links/proceedings/1997/pdf97/97p5-136.pdf]

As of 2003, there was continued interest, at least among maritime researchers in Japan, in developing oceangoing commercial ships with high-performance hybrid-sails similar to those on the Windship.⁵⁹

Kites

Sails on masts have certain potential disadvantages. One article states:

In unfavourable winds, large masts create a lot of drag. In gales, masts cause ships to heel, sometimes dangerously. Masts and their pivoting sails take up valuable container space on the deck. Loading and unloading is more expensive, since the cranes that lift containers must work around the masts. Engineers designed taller (and more expensive) masts, some exceeding 100 metres in height, to reduce their number and limit the loss of storage space. But the Panama Canal limits masts to 60 metres, and collapsable masts would be prohibitively expensive to build, operate and service....

The cost of retrofitting a cargo ship with a row of masts, and strengthening its hull and deck to dissipate the additional stress, was estimated at euro10m (\$12.5m). So the sails would have taken around 15 years to recoup their costs through fuel savings.⁶⁰

The aim of kite-assisted propulsion is to reduce or avoid these issues while taking advantage of the stronger winds that are available at heights greater than those attainable by sails on masts. At least two firms — the U.S.-based firm KiteShip and the German-based firm SkySails — have developed kite-assist systems for potential application to commercial cargo ships and thus, by extension, perhaps commercial-like Navy auxiliary and DOD sealift ships.

KiteShip.⁶¹ **Figure 8** depicts a commercial ship equipped with KiteShip's system. Kiteship states:

When fuel costs become sufficiently high and/or governmental air and water quality regulations became sufficiently heinous, the commercial shipping industry will look to sail power as an assist to petroleum powered vessels. The industry has done this before, and will do so again. These worldwide economic and political conditions are upon us today. This time, there is strong evidence that recent fuel cost increases aren't going to be temporary, and environmental restrictions will become increasingly draconian.

⁵⁹ See Toshifumi Fujiwara, et al., "On Aerodynamic Characteristics of a Hybrid-Sail with Square Soft Sail," Proceedings of The Thirteenth (2003) International Offshore and Polar Engineering Conference, Honolulu, Hawaii, May 25-30, 2003, available online at [http://www.nmri.go.jp/trans/Staff/fujiwara/ISOPE03_fujiwara.pdf], and Toshifumi Fujiwara et al., "On Development Of High Performance Sails for an Oceangoing Commercial Ship," available online at [<http://nippon.zaidan.info/seikabutsu/2003/00574/contents/0405.htm>].

⁶⁰ "Sailing Ships with a New Twist," *The Economist*, September 15, 2005, as posted online at [http://www.skysails.info/fileadmin/user_upload/Upload_Pressespiegel/2005/05-09_Economist.pdf].

⁶¹ KiteShip's online site is at [<http://www.kiteship.com/>].

Conventional masted sail solutions have inherent limitations which will continue to delay their application long past the point where wind-assist can become cost effective. The ability to design massive sail power without need for ballast, without fixed masts interfering with loading and unloading procedures, without adding hundreds of tons and tens of millions of dollars to build costs is critical. The ability to retrofit existing vessels cheaply and efficiently is paramount. The ability to build, repair and maintain systems remote from shipboard, eliminating downtime is an important asset; KiteShip has understood these advantages for decades. We have been readying appropriate technology for commercial tethered flight sailing since 1978.⁶²

Figure 8. KiteShip Concept Applied to Commercial Cargo Ship



One of the principals of Kiteship, Dave Culp, stated in a 2003 interview:

In studying attempts to bring back commercial sailing ships in the 1980's, it struck me that they were doomed to fail for the same reasons commercial sail failed in the 19th century. The cost of the equipment, expressed as a rate of amortization, was far higher than powered vessels, even including their fuel. Second, the fundamental inability to schedule wind power plays havoc with effectively utilizing expensive ships. Motor sailing was and is possible to fix this, but requires parallel systems on the boat — wind plus diesel — at even higher total cost.

Kites, on the other hand, can be added to existing ships. They take up no deck space, require minimal retro-fitting, need no ballast, fit under bridges and can be taken in out of the weather when not in use. They can be taken off the boat for maintenance and even used on a second boat when/if adverse or no wind is expected aboard the first. These factors dramatically decrease the capital cost of the sailing rig, thus the amortization rate. If added to existing vessels,

⁶² “Commercial Marine,” available online at [<http://www.kiteship.com/marine.php>].

especially if the vessels are partially depreciated already, it becomes very cost effective to fit a single ship with both power (which it has) and kites (which are cheap). It can then pure sail, motor sail or straight motor, as conditions dictate. I wrote a paper on the subject, [<http://www.dcss.org/kitetugs.html>] in which I suggested such an arrangement might become cost effective when diesel fuel hits about \$1/gal.⁶³

KiteShip has just signed a Letter of Intent with the cruise ship company Adventure Spa Cruises (www.adventurespacruise.com) to design and build an 8000 sq ft kite and to use it to pull a 200' commercial cruise ship. The intent is to showcase environmentally friendly fuel[-]saving technology, further develop kites and control systems for ever[-]larger applications, and to demonstrate to Adventure Spa Cruise customers a proactive stance regarding potential near-term fuel price spikes and shortages. We are excited about the prospects for this technology and look forward to a joint venture with Adventure Spa Cruises.⁶⁴

The kite for the cruise ship, measuring about 8,000 square feet, was to be installed on the 187-foot, 924-ton Adventurer II.⁶⁵

SkySails.⁶⁶ **Figure 9** depicts a commercial ship equipped with Skysails' system. Skysails states:

By using a SkySails system ship operation will become more profitable, safer and independent of declining oil reserves. On annual average fuel costs can be lowered between 10-35% depending on actual wind conditions and achievable operational period. Under optimal wind conditions, fuel consumptions [sic] can temporarily be reduced up to 50%.

From the second half of 2006 pilot systems for superyachts will be available. In 2007 the first SkySails-Systems for cargo vessels will be available. In 2007 series production of the SkySails-Systems for superyachts, in 2008 series production for cargo vessels will start....

Virtually all cargo ships can be retrofitted with the SkySails technology trouble-free.⁶⁷

⁶³ If the site listed in the article is not available, see also the papers at these online sites: [<http://www.dcss.org/speedsl/Whykites.html>], [<http://www.dcss.org/speedsl/KiteTugs.html>], and [http://www.dcss.org/speedsl/Trans_Sailcraft.html].

⁶⁴ "High As A Kite," interview with Dave Culp, available at [<http://www.sailinganarchy.com/innerview/2003/daveculp.htm>] and [<http://www.kiteship.com/press.php?pid=6>].

⁶⁵ "Largest Kite Ever Built to Power Cruise Ship," *Maritime Global Net*, April 6, 2003, posted online by Kiteship at [<http://www.kiteship.com/press.php?pid=5>].

⁶⁶ SkySail's English-language online site is at [<http://www.skysails.info/index.php?L=1>].

⁶⁷ Ibid.

Figure 9. SkySails Concept Applied to Commercial Cargo Ship



A March 2006 article states that for a commercial cargo ship, “The investment in a SkySails system will normally amortise within 3 to 5 years.”⁶⁸ A September 2005 article states that SkySails “says it can outfit a ship with a kite system for between [400,000 euros] and [2.5 million euros], depending on the vessel’s size. Stephen Wrage, the boss of SkySails, says the fuel savings will recoup these costs in just four or five years, assuming oil prices of \$50 a barrel.”⁶⁹ **Figure 10** shows SkySails’ calculation of potential fuel savings (or increased speed) from using a SkySails system on a 200-meter (656-foot) commercial ship.⁷⁰

In January 2006, it was announced that Beluga Shipping of Germany had purchased a SkySails kite system to be installed on the newly built 140-meter (459-foot) heavy cargo freighter MS Beluga SkySails, with the first demonstration cruises to take place in 2007. A managing partner of the Beluga Group stated:

The SkySails technology is ready for market entry exactly at the right time. The rising and continuously high price of oil is a matter that ship owners are already dealing with in order to be competitive in the present and future market. Furthermore, significantly tightened emission regulations, through which increasing costs will accrue, are being put into place.

Offshore wind energy is an unbeatable cost-effective propulsion source available in large quantities, and we expect to gain a considerable competitive

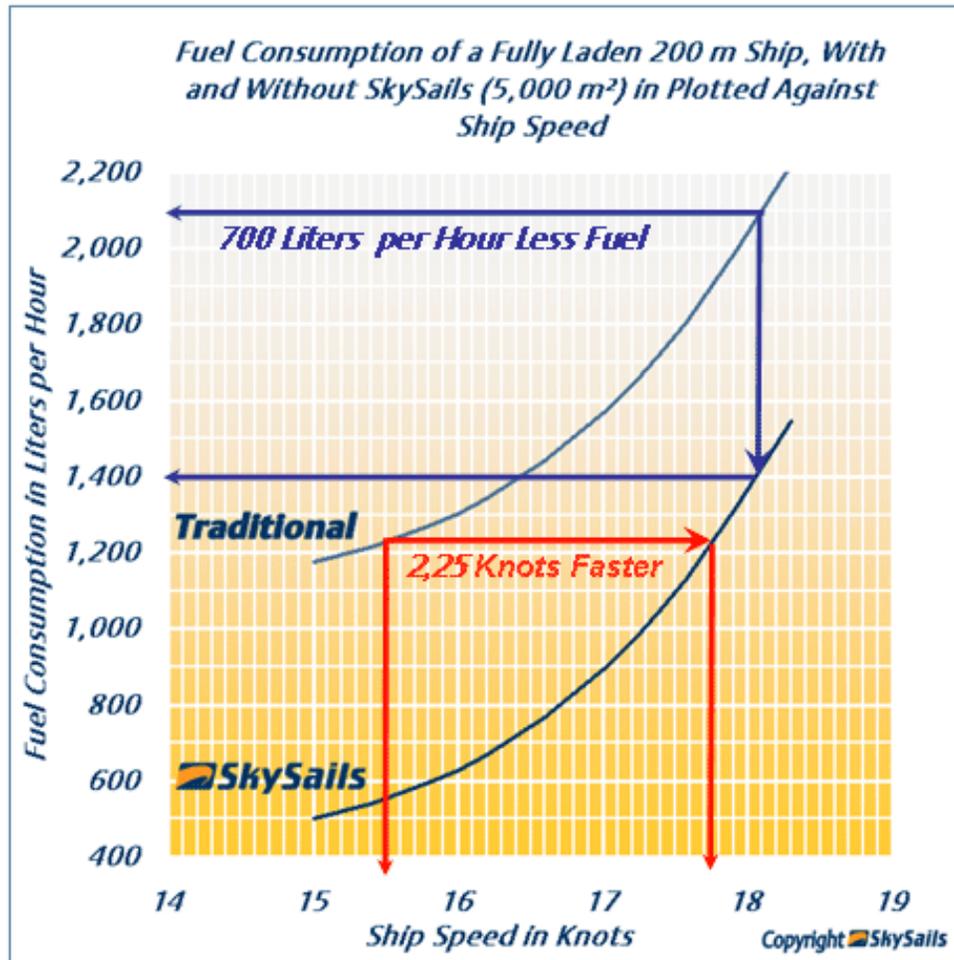
⁶⁸ “The Economic and Sustainable Utilisation in the Cargo Shipping Industry of Wind Power,” *HSB International*, March 2006, as posted on the SkySail site at [http://www.skysails.info/fileadmin/user_upload/Upload_Pressespiegel/2006/060301-HSB_international__The_economic...pdf].

⁶⁹ “Sailing Ships with a New Twist,” op. cit.

⁷⁰ See [http://www.greencarcongress.com/2006/01/beluga_shipping.html].

advantage by using the innovative SkySails system as a pioneer in this field. We are convinced that the SkySails system will revolutionize the cargo shipping industry.⁷¹

Figure 10. Potential Fuel Savings from SkySails System



Solar Power

Solar power might offer some potential for augmenting other forms of shipboard power, perhaps particularly in Navy auxiliaries and DOD sealift ships.

⁷¹ Niels Stolsberg, as quoted in “Beluga Shipping to Try ‘Wind Hybrid’ Kite Propulsion Assist for Cargo Vessel,” Green Car Congress, January 25, 2006, available online at [http://www.greencarcongress.com/2006/01/beluga_shipping.html]. See also Geoff Garfield, “Beluga Moves Closer to Sail-Assist Vessel,” TradeWinds, January 27, 2006: 8; posted on the SkySail site at [http://www.skysails.info/fileadmin/user_upload/Upload_Pressespiegel/2006/060127-Trade_Winds-Beluga_moves_closer_to_sailassist_vessel.pdf], and “Beluga Gets First Taste of SkySails Towing Kite,” *Lloyd’s List*, January 26, 2006: 2, posted on the SkySail site at [http://www.skysails.info/fileadmin/user_upload/Upload_Pressespiegel/2006/060126-Lloydslist.pdf].

Solar Sailor Ferry Boat. Figure 11 depicts the Solar Sailor, a small (69-foot, 100-person) catamaran ferry whose eight maneuverable “solar wing sails” can be used for both sail-assist propulsion and for generating electricity. The ferry was built in 1999-2000 as a demonstration project and can operate on wind power, solar power, stored battery power, diesel power, or any combination. The ship was developed and built by Solar Sailor Holdings Ltd. with assistance from the Australian government, and operates in Sydney Harbor.⁷² The firm also has a concept for a hybrid-powered 400-meter (1,312-foot) water-carrying tanker ship that it calls Aquatanker.⁷³

Figure 11. Solar Sailor Hybrid-Powered Ferry Boat



In June 2005, it was announced that UOV LLC, a Virginia-based partially-owned subsidiary of Solar Sailor Holdings, had

received a Phase 1 US Navy grant for the development of its patented unmanned ocean vehicles (UOV's). The automated and networked UOV's will be used for military and coast guard purposes, and have commercial and oceanographic applications including tsunami early warning systems. The US Navy is interested in the Unmanned Ocean Vehicles in order to meet their need for surveillance vessels to roam the world's oceans. The UOV's use of solar & wind

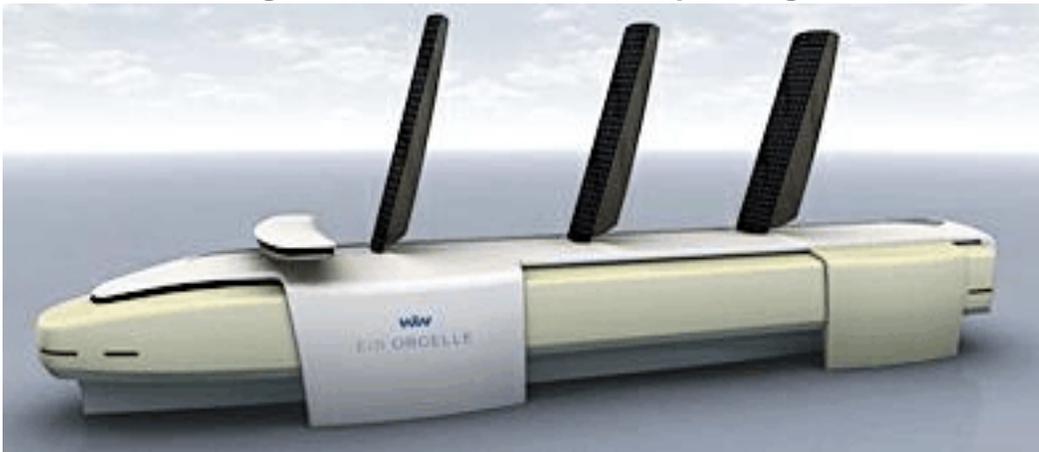
⁷² For more on the Solar Sailor, see the information available online at [<http://www.solarsailor.com.au/>], [<http://www.greenhouse.gov.au/renewable/recp/pv/fourteen.html>], and [http://www.solarnavigator.net/solar_sailor.htm].

⁷³ “Government Solutions,” available online at [http://www.solarsailor.com.au/solutions_gov.htm#aquatankers]. See also Andrea Mayes, “Supertanker Plan To Tackle Crisis,” *The Australian*, June 23, 2005, available online at [http://www.solarsailor.com.au/media_supertankers_230605.htm].

power enables it to act as an autonomous vehicle with almost unlimited range and endurance.⁷⁴

E/S Orcelle Concept Design. Figure 12 shows the E/S Orcelle, a concept design developed in 2005 by the Scandinavian shipping company Wallenius Wilhelmsen for an almost zero-emissions car carrier capable of transporting 10,000 cars (about 50% more than today's car carriers) that uses renewable energy to meet all propulsion and onboard power requirements. The pentamaran-hulled design employs fuel cells (which would generate about one-half of the ship's energy), wind power, solar power, and wave power, the last captured through 12 horizontal fins that would transform wave energy into hydrogen (for the fuel cells), electricity, or mechanical power. The fins would also act as propulsion units in combination with two podded propulsors. The developers believe a ship containing some of the Orcelle's features might be possible by 2010, and that a ship with all of its features might be possible by 2025.⁷⁵

Figure 12. E/S Orcelle Concept Design



⁷⁴ "Solar Sailor subsidiary wins US Navy grant for Unmanned Ocean Vehicles," available online at [http://www.solarsailor.com.au/media_uov_290605.htm]. See also the information available online at [<http://www.uovehicles.com/>].

⁷⁵ For more information on the E/S Orcelle, see "Sun, Wind, Fuel Cells Power Cargo Ship of the Future," *Environmental News Service*, April 6, 2005, available online at [<http://www.ens-newswire.com/ens/apr2005/2005-04-06-03.asp>], and "Pollution-Free Ship? Designers Try Their Hand," *MSNBC.com*, may 31, 2005, available online at [<http://www.msnbc.msn.com/id/8037087>].

Legislative Activity

FY2007 Defense Authorization Bill (H.R. 5122/S. 2766)

Section 128 of H.R. 5122 states:

SEC. 128. SENSE OF CONGRESS THAT THE NAVY MAKE GREATER USE OF NUCLEAR-POWERED PROPULSION SYSTEMS IN ITS FUTURE FLEET OF SURFACE COMBATANTS.

(a) Findings- Congress makes the following findings:

(1) Securing and maintaining access to affordable and plentiful sources of energy is a vital national security interest for the United States.

(2) The Nation's dependence upon foreign oil is a threat to national security due to the inherently volatile nature of the global oil market and the political instability of some of the world's largest oil producing states.

(3) Given the recent increase in the cost of crude oil, which cannot realistically be expected to improve over the long term, other energy sources must be seriously considered.

(b) Sense of Congress- In light of the findings in subsection (a), it is the sense of Congress that the Navy should make greater use of alternative technologies, including nuclear power, as a means of vessel propulsion for its future fleet of surface combatants.

FY2007 Defense Appropriations Bill (H.R. 5631)

The Senate Appropriations Committee, in its report (S.Rept. 109-292 of July 25, 2006) on H.R. 5631, states:

The Committee notes the recent developments relating to the conversion of coal to liquid fuels. Demonstration projects in the United States have produced high-quality, ultra clean synthetic diesel fuels that provide improved efficiency and improved emissions compared to traditionally produced diesel fuel. The Committee encourages the Department of Defense to continue to explore the use of Fischer-Tropsch fuels as alternative sources for DOD's fuel requirements. Further, the Committee requests that the Under Secretary for Acquisition, Technology, and Logistics prepare a report for the congressional defense committees on the Defense Department's assessment, use, and plans to continue to explore the potential of synthetic fuels, to include fuels produced through the Fischer-Tropsch process. (Page 157)

Coast Guard and Maritime Transportation Act of 2006 (H.R. 889)

The conference report (H.Rept. 109-413) on H.R. 889 was filed on April 6, 2006. Section 220 states:

SEC. 214. BIODIESEL FEASIBILITY STUDY.

(a) Study- The Secretary of the department in which the Coast Guard is operating shall conduct a study that examines the technical feasibility, costs, and potential cost savings of using biodiesel fuel in new and existing Coast Guard vehicles and vessels and that focuses on the use of biodiesel fuel in ports which

have a high density of vessel traffic, including ports for which vessel traffic systems have been established.

(b) Report- Not later than one year after the date of enactment of this Act, the Secretary shall submit a report containing the findings, conclusions, and recommendations (if any) from the study to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Transportation and Infrastructure of the House of Representatives.

FY2006 Defense Authorization Act (H.R. 1815/P.L. 109-163)

Section 130 of the conference report (H.Rept. 109-360 of December 18, 2006) on the FY2006 defense authorization act (H.R. 1815, P.L. 109-163 of January 6, 2006) requires the Navy to submit a report by November 1, 2006 on alternative propulsion methods for surface combatants and amphibious warfare ships. The section states:

SEC. 130. REPORT ON ALTERNATIVE PROPULSION METHODS FOR SURFACE COMBATANTS AND AMPHIBIOUS WARFARE SHIPS.

(a) ANALYSIS OF ALTERNATIVES. — The Secretary of the Navy shall conduct an analysis of alternative propulsion methods for surface combatant vessels and amphibious warfare ships of the Navy.

(b) REPORT. — The Secretary shall submit to the congressional defense committees a report on the analysis of alternative propulsion systems carried out under subsection (a). The report shall be submitted not later than November 1, 2006.

(c) MATTERS TO BE INCLUDED. — The report under subsection (b) shall include the following:

(1) The key assumptions used in carrying out the analysis under subsection (a).

(2) The methodology and techniques used in conducting the analysis.

(3) A description of current and future technology relating to propulsion that has been incorporated in recently-designed surface combatant vessels and amphibious warfare ships or that is expected to be available for those types of vessels within the next 10-to-20 years.

(4) A description of each propulsion alternative for surface combatant vessels and amphibious warfare ships that was considered under the study and an analysis and evaluation of each such alternative from an operational and cost-effectiveness standpoint.

(5) A comparison of the life-cycle costs of each propulsion alternative.

(6) For each nuclear propulsion alternative, an analysis of when that nuclear propulsion alternative becomes cost effective as the price of a barrel of crude oil increases for each type of ship.

(7) The conclusions and recommendations of the study, including those conclusions and recommendations that could impact the design of future ships or lead to modifications of existing ships.

(8) The Secretary's intended actions, if any, for implementation of the conclusions and recommendations of the study.

(d) LIFE-CYCLE COSTS. — For purposes of this section, the term "life-cycle costs" includes those elements of cost that would be considered for a life-cycle cost analysis for a major defense acquisition program