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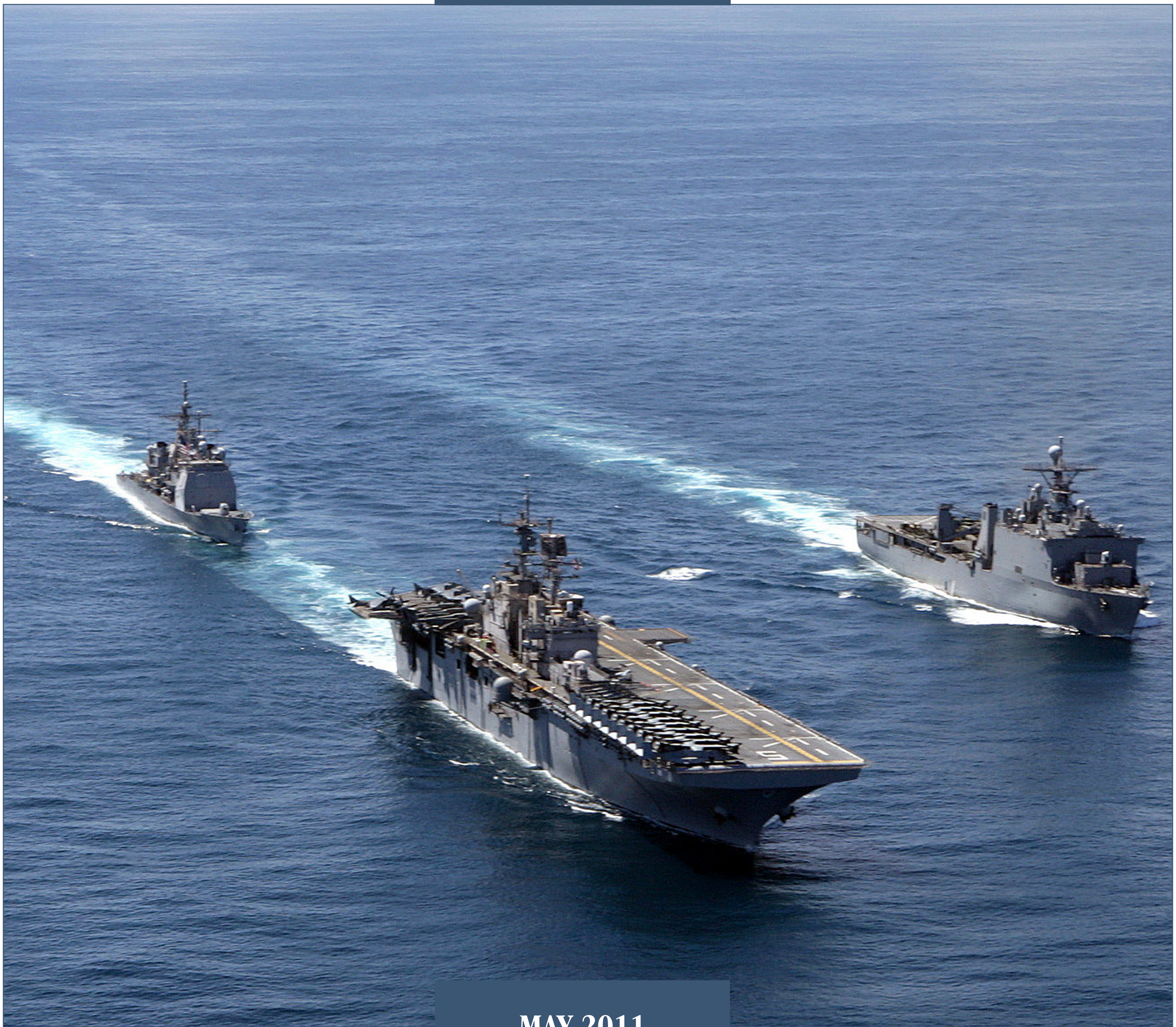
CBO

The Cost-Effectiveness of Nuclear Power for Navy Surface Ships



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The Cost-Effectiveness of Nuclear Power for Navy Surface Ships

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The Congress of the United States ■ Congressional Budget Office

Notes

All years referred to are federal fiscal years, which run from October 1 to September 30.

Numbers in the text and tables may not add up to totals because of rounding.

On the cover—A portion of the Bataan amphibious ready group, accompanied by a Ticonderoga class cruiser; photo by Corporal Theodore W. Tirchie, U.S. Marine Corps.

Preface

In recent years, the Congress has shown interest in powering some of the Navy's future destroyers and amphibious warfare ships with nuclear rather than conventional (petroleum-based) fuel. At the request of the former Chairman of the Subcommittee on Seapower and Projection Forces of the House Committee on Armed Services, the Congressional Budget Office (CBO) has estimated the difference in life-cycle costs (the total costs incurred for a ship, from acquisition through operations to disposal) between powering those new surface ships with nuclear reactors and equipping them with conventional engines.

R. Derek Trunkey and Matthew Goldberg of CBO's National Security Division wrote the study under the general supervision of J. Michael Gilmore (formerly of CBO) and David Mosher. Eric J. Labs, also of the National Security Division, provided projections of the Navy's future fleets. Raymond Hall of CBO's Budget Analysis Division prepared the estimates of acquisition costs under the general supervision of Sarah Jennings. Ron Gecan, Heidi Golding, Deborah Lucas, Damien Moore, Dawn Sauter Regan, and Jason Wheelock, all of CBO, contributed to the analysis, and Ron Gecan and Steven Weinberg developed CBO's forecasts of oil prices. Donald Birchler of the CNA Corporation reviewed the study. (The assistance of an external reviewer implies no responsibility for the final product, which rests solely with CBO.)

Leah Mazade edited the study, Christine Bogusz proofread it, and Jeanine Rees prepared it for publication. Maureen Costantino designed the cover. Monte Ruffin produced the initial print copies, Linda Schimmel coordinated the print distribution, and Simone Thomas prepared the electronic version for CBO's Web site (www.cbo.gov).

Douglas W. Elmendorf
Director

May 2011

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Summary and Introduction

The U.S. Navy plans to build a number of new surface ships in the coming decades, according to its most recent 30-year shipbuilding plan.[1] All of the Navy's aircraft carriers (and submarines) are powered by nuclear reactors; its other surface combatants are powered by engines that use conventional petroleum-based fuels. The Navy could save money on fuel in the future by purchasing additional nuclear-powered ships rather than conventionally powered ships. Those savings in fuel costs, however, would be offset by the additional up-front costs required for the procurement of nuclear-powered ships.

To assess the relative costs of using nuclear versus conventional propulsion for ships other than carriers and submarines, the Congressional Budget Office (CBO) developed a hypothetical future fleet, based on the Navy's shipbuilding plan, of new destroyers and amphibious warfare ships that are candidates for nuclear propulsion systems. Specifically, CBO chose for its analysis the Navy's planned new version of the DDG-51 destroyer and its replacement, the DDG(X); the LH(X) amphibious assault ship; and the LSD(X) amphibious dock landing ship. CBO then estimated the life-cycle costs for each ship in that fleet—that is, the costs over the ship's entire 40-year service life, beginning with its acquisition and progressing through the annual expenditures over 40 years for its fuel, personnel, and other operations and support and, finally, its disposal. CBO compared life-cycle costs under two alternative versions of the fleet: Each version comprised the same number of ships of each class but differed in whether the ships were powered by conventional systems that used petroleum-based fuels or by nuclear reactors.

Estimates of the relative costs of using nuclear power versus conventional fuels for ships depend in large part on the projected path of oil prices, which determine how much the Navy must pay for fuel in the future. The initial costs for building and fueling a nuclear-powered ship are greater than those for building a conventionally powered ship. However, once the Navy has acquired a nuclear ship, it incurs no further costs for fuel. If oil prices rose substantially in the future, the estimated savings in fuel costs from using nuclear power over a ship's lifetime could offset the higher initial costs to procure the ship. In recent years, oil prices have shown considerable volatility; for example, the average price of all crude oil delivered to U.S. refiners peaked at about $130 per barrel in June and July 2008, then declined substantially, and has risen significantly again, to more than $100 per barrel in March of this year.

CBO regularly projects oil prices for 10-year periods as part of the macroeconomic forecast that underlies the baseline budget projections that the agency publishes each year.[2] In its January 2011 macroeconomic projections, CBO estimated that oil prices would average $86 per barrel in 2011 and over the next decade would grow at an average rate of about 1 percentage point per year above the rate of general inflation, reaching $95 per

1. For details of that plan, see Department of the Navy, *Report to Congress on Annual Long-Range Plan for Construction of Naval Vessels for FY 2011* (February 2010); see also Congressional Budget Office, *An Analysis of the Navy's Fiscal Year 2011 Shipbuilding Plan* (May 2010).

2. For CBO's most recent economic projections, see Congressional Budget Office, *The Budget and Economic Outlook: Fiscal Years 2011 to 2021* (January 2011).

barrel (in 2011 dollars) by 2021.[3] After 2021, CBO assumes, the price will continue to grow at a rate of 1 percentage point above inflation, reaching $114 per barrel (in 2011 dollars) by 2040.[4]

If oil prices followed that trajectory, total life-cycle costs for a nuclear fleet would be 19 percent higher than those for a conventional fleet, in CBO's estimation. Specifically, total life-cycle costs would be 19 percent higher for a fleet of nuclear destroyers, 4 percent higher for a fleet of nuclear LH(X) amphibious assault ships, and 33 percent higher for a fleet of nuclear LSD(X) amphibious dock landing ships.

To determine how sensitive those findings are to the trajectory of oil prices, CBO also examined a case in which oil prices start from a value of $86 per barrel in 2011 and then rise at a rate higher than the real (inflation-adjusted) growth of 1 percent in CBO's baseline trajectory. That analysis suggested that a fleet of nuclear-powered destroyers would become cost-effective if the real annual rate of growth of oil prices exceeded 3.4 percent—which implies oil prices of $223 or more per barrel (in 2011 dollars) in 2040. Similarly, a fleet of nuclear LH(X) amphibious assault ships would become cost-effective if oil prices grew at a real annual rate of 1.7 percent, implying a price of $140 per barrel of oil in 2040—about the same price that was reached in 2008 but not sustained for any length of time. A fleet of nuclear LSD(X) amphibious dock landing ships would become cost-effective at real annual growth rate of 4.7 percent, or a price in 2040 of $323 per barrel.

In addition to the uncertain future path of oil prices, questions remain about the amount of energy that the new surface ships will use, which could be substantially higher or lower than projected. Energy usage is a particularly significant factor for ships such as destroyers that require large amounts of energy for purposes other than propulsion. Employing an approach similar to that used to assess sensitivity to oil prices, CBO estimated that providing destroyers with nuclear reactors would become cost-effective (given CBO's baseline trajectory for oil prices) only if energy use more than doubled for the entire fleet of destroyers.

The use of nuclear power has potential advantages besides savings on the cost of fuel. For example, the Navy would be less vulnerable to disruptions in the supply of oil: The alternative nuclear fleet would use about 5 million barrels of oil less per year, reducing the Navy's current annual consumption of petroleum-based fuels for aircraft and ships by about 15 percent.[5] The use of nuclear power also has some potential disadvantages, including the concerns about proliferating nuclear material that would arise if the Navy had more ships with highly enriched uranium deployed overseas. CBO, however, did not attempt to quantify those other advantages and disadvantages.

CBO's Analysis and Findings

Between 2016 and 2040, the Navy plans to build 39 DDG-51 Flight III destroyers (a "flight" is a variant) and their replacements, the DDG(X) class of ship;[6] 5 LH(X) amphibious assault ships; and 12 LSD(X) amphibious dock landing ships (see Figure 1 and Box 1). CBO's main analysis compared the costs for a fleet of those 56 ships under two alternative propulsion technologies: nuclear power and conventional fuel. CBO did not consider any other class of surface ship for its analysis. Aircraft carriers are already nuclear powered, and the littoral combat ship—a relatively small high-speed ship meant for close-to-shore operations and the only other major combat ship that the Navy is planning to procure in substantial numbers over the next 30 years—is too small to accommodate a nuclear reactor. Moreover, CBO assumed that only new classes of ships would be considered candidates for nuclear systems. Thus, in constructing its hypothetical fleet, CBO assumed that the specifications for classes of ships currently in production would not be changed, nor would existing ships be retrofitted with nuclear reactors.

3. Oil prices in the first four months of 2011 have averaged about $10 per barrel more than in CBO's January forecast for this year and could be higher or lower over the rest of the year. CBO expects to update its macroeconomic forecast in August.

4. CBO forecasts oil prices in part on the basis of futures markets in oil. For a discussion of that approach, see Congressional Budget Office, *The Budget and Economic Outlook: Fiscal Years 2006 to 2015* (January 2005).

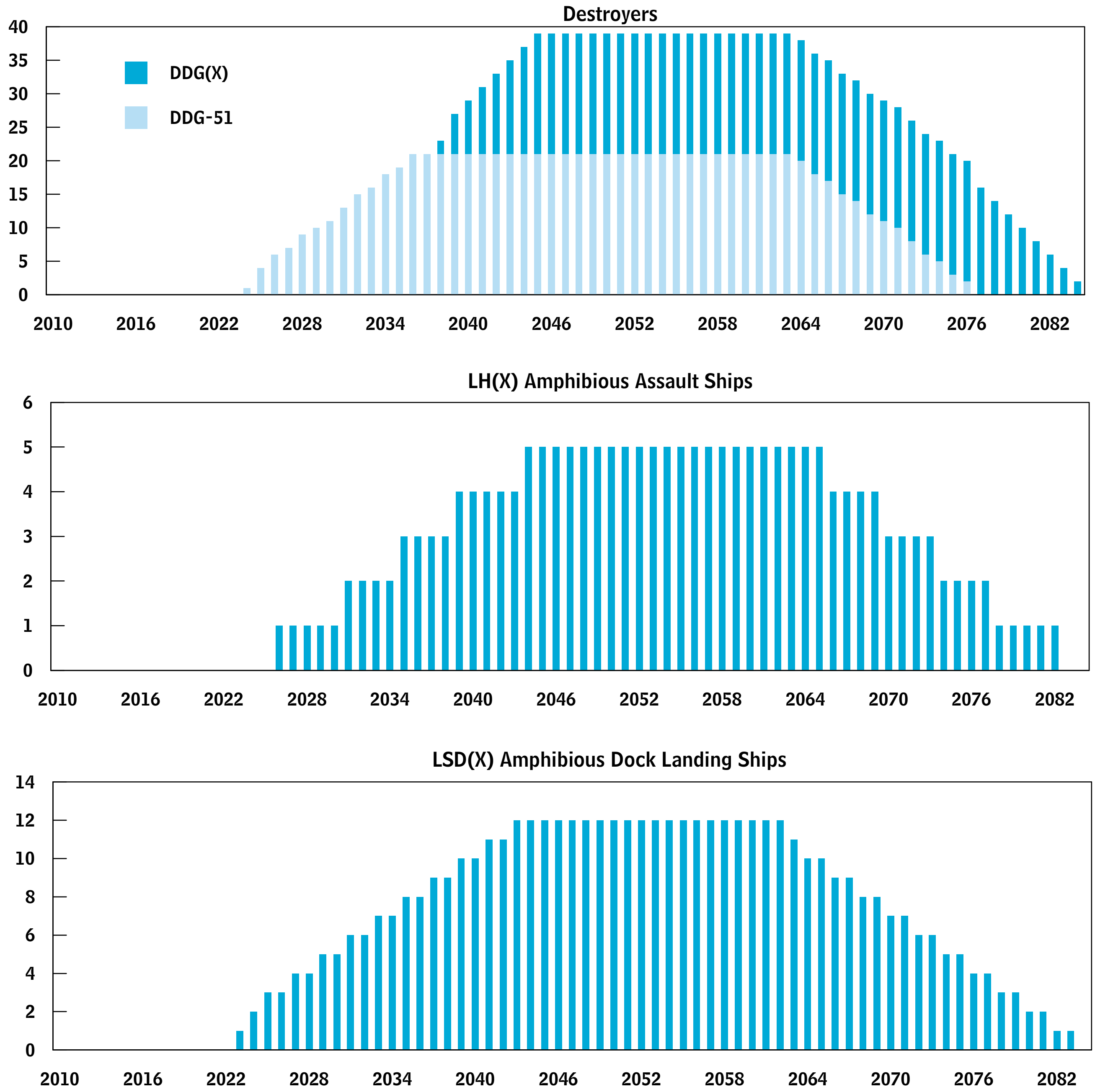
5. Those fuel-reduction findings are based on CBO's analysis and on data provided to CBO by the Defense Logistics Agency in April 2011. See also Ronald O'Rourke, *Navy Ship Propulsion Technologies: Options for Reducing Oil Use—Background for Congress*, Report for Congress RL33360 (Congressional Research Service, January 26, 2007).

6. The DDG-51 Flight III destroyer would, among other changes, incorporate the new Air and Missile Defense Radar that is now under development. The new radar is larger and more powerful than the radars on the earlier DDG-51s.

Figure 1.

Candidate Ships for Nuclear Propulsion Systems

(Number of ships in the fleet)



Source: Congressional Budget Office based on Department of the Navy, *Report to Congress on Annual Long-Range Plan for Construction of Naval Vessels for FY 2011* (February 2010).

Note: CBO modified the Navy's shipbuilding plan slightly to accommodate the possibility of nuclear reactors, applying the same changes to the plan in evaluating both conventional and nuclear fuel alternatives. Specifically, CBO's modified plan would delay the purchase of the first DDG-51 Flight III destroyer (a "flight" is a variant) from 2016 to 2018 to allow time for integrating a nuclear reactor into that hull. CBO's modification would also replace the LHA-6 amphibious assault ship that the Navy plans to purchase in 2021 with the first hull in the LH(X) class in order to make the latter ship a candidate for nuclear power.

Box 1.

Destroyers and Amphibious Ships in the Navy's Fleet

Arleigh Burke Class Destroyer (DDG-51)

The DDG-51 Arleigh Burke class destroyers (along with the CG-47 Ticonderoga class cruisers) serve a variety of roles in the Navy's fleet. They defend aircraft carriers and amphibious ships against threats posed by other surface ships, aircraft, and submarines. Increasingly, they will provide ballistic missile defense for the fleet as well as for major theaters of operations such as Europe and Northeast Asia. They also perform many day-to-day missions, such as patrolling sea lanes, providing overseas presence, and conducting exercises with allies. In addition, they are capable of striking land targets with Tomahawk missiles. The Navy considers the DDG-51 class so effective that it plans to modify the design into a configuration called Flight III (ships currently under construction are called Flight IIAs), beginning in the middle part of this decade. The upgraded DDG-51 design will have a more powerful radar along with increased shipboard power and cooling capabilities and will provide a ballistic missile defense capability greater than that provided by DDG-51 Flight IIAs. The existing DDG-51s displace about 9,500 tons, but the Flight III configuration is likely to weigh more than 10,000 tons.

Wasp Class Amphibious Assault Ship (LHD)

The Navy's two types of amphibious assault ships (also known as helicopter carriers)—the LHA-1 and LHD-1—are the second-largest types of ship in the fleet (behind aircraft carriers). The new LHA-6 America class is replacing the Tarawa class LHA-1s. The first LHA-6 is still under construction and will displace about 45,000 tons. A future class of this type of ship, currently designated the LH(X), will be designed and built in the 2020s to replace the Wasp class LHDs as they retire. Amphibious assault ships form the centerpiece of amphibious ready groups and can each carry about half the troops and equipment of a Marine expeditionary unit, which is typically composed of about 2,200 marines. The ships also can carry as many as 30 helicopters and 6 fixed-wing Harrier jump jets, or up to 20 Harriers.

Whidbey Island Class Dock Landing Ship (LSD)

The Navy has four other classes of amphibious warfare ships, and such ships are divided into two types: amphibious transport docks (LPDs) and dock landing ships (LSDs). Two of those ships together provide the remaining transport capacity for a Marine expeditionary unit in an amphibious ready group. LPDs and LSDs are quite similar to each other; one major difference is that the LPDs have a hangar to embark helicopters whereas the LSDs do not, although they do have a helicopter landing area. The Navy's 12 LSDs are divided into two classes—the LSD-41 Whidbey Island and the LSD-49 Harpers Ferry—and displace 16,000 to 17,000 tons. The LSD-49 has a smaller docking well than the LSD-41 has in order to carry more troops and equipment; the LSD-41 has a larger docking well for conducting amphibious operations. The Navy plans to build one more LPD in 2012 but is not planning a direct successor to that class of ships. The service does plan to build a new class of LSDs, designated the LSD(X), beginning in 2017 to replace the existing LSDs as they retire. The design and capabilities of the new class are unknown at this time, although the Navy's 2011 shipbuilding plan implies that they will be similar to existing LSD class ships.

Source: Congressional Budget Office.

Note: Ship silhouettes are not to scale.

CBO's analysis was also based on several assumptions about the reactors the Navy would use if it chose the nuclear power alternative and the implications of the reactors for a ship's size. CBO assumed that the Navy would design a new reactor for use in the destroyers and LSD class ships because existing reactors would not be optimally sized for those ship types. CBO further assumed that in the LH(X) amphibious assault ships, the Navy would use one of the reactors that power its aircraft carriers.[7] Yet even if the Navy outfitted the destroyers and amphibious dock landing ships with a new, smaller reactor, the use of nuclear power would require an increase of about 2,000 tons in the DDG-51's displacement, or weight (an increase of 20 percent relative to the current size of that ship), and a similar increase in the LSD(X)'s displacement (an increase of 11 percent), by CBO's estimates.[8] The LH(X), in contrast, could accommodate a nuclear reactor without any substantial increase in the ship's displacement.

In comparing life-cycle costs for the fleet of ships under the alternative propulsion systems, CBO used a present-value approach that adjusted for market risk. CBO first calculated costs over a 40-year service life for each of the 56 ships chosen for the analysis and then summarized those costs as a present value—a single amount that expresses the stream of annual costs for the ships in terms of an equivalent lump sum spent at the start of the analysis period. To arrive at that present value, CBO discounted future costs for the fleet (converted them to current dollars) using a discount rate that takes into account that money in hand now is worth more than the same amount received in the future and that the cash flows face market risk (the risk of losses that cannot be avoided by diversifying investments and for which investors require compensation). Specifically, CBO used a discount rate for the fleet's future costs equal to the estimated return that a private investor would require on a project of similar risk and duration, discounting the life-cycle costs for all ships in each class under the nuclear-fleet alternative and comparing those totals with the corresponding discounted amounts under the conventional-fleet alternative.

The results of CBO's cost-effectiveness analysis depend heavily on what happens to oil prices over the next 70 years. CBO thus calculated costs for its hypothetical fleet under a trajectory for oil prices derived from its current macroeconomic projections and also under variations of that trajectory. (For details of CBO's approach, see "The Basis for CBO's Cost Estimates" on page 9.) It also noted certain noncost factors (for example, the ability of nuclear-powered ships to operate independently of logistics ships that supply oil) that might be important but that could not be fully accounted for. In addition, CBO compared its analysis and results with those from an earlier study conducted by the Navy to assess the advantages and disadvantages of extending nuclear power to a wider range of Navy ships.

Costs Under CBO's Projected Trajectory for Oil Prices

A nuclear-powered fleet comprising the three classes of ships considered in the analysis would cost the Navy more than a conventionally powered fleet under CBO's projected trajectory for oil prices (see Table 1). According to CBO's projections, the prices that U.S. refiners pay for oil will rise from $86 per barrel in 2011 to $95 per barrel (in 2011 dollars) in 2021, and then continue to escalate at a real annual rate of 1 percent thereafter. Under that projected price path, the present-value costs in 2011 for a nuclear-powered fleet would be higher than those for a conventionally powered fleet by about $14 billion (19 percent) for destroyers, $0.6 billion (4 percent) for LH(X) amphibious assault ships, and nearly $5 billion (33 percent) for LSD(X) amphibious dock landing ships.

7. Each of the Navy's current aircraft carriers (with the exception of U.S.S. *Enterprise*) uses two nuclear reactors of a design known as the A4W. The Navy's newest aircraft carrier, U.S.S. *Gerald R. Ford*, will also use two reactors of a new design, designated the A1B. An LH(X) amphibious ship, which is slightly less than half the size of a nuclear-powered aircraft carrier, could accommodate one of the A1B reactors to be used in the *Gerald R. Ford*. However, outfitting a destroyer or an LSD(X) amphibious ship with an A1B-sized reactor would require a significant increase in the size of those ships to accommodate the reactor and its cooling and other support systems. Nor could those ships be outfitted with the nuclear reactors that the Navy currently installs in its Virginia class submarines, because those reactors would be too small to adequately power a destroyer or an LSD(X). CBO assumed that the Navy would instead design a new reactor for its destroyers and LSD(X) ships.

8. Navy officials, in a personal communication in April 2011, provided CBO with an estimate of 3,000 tons for the increase in the displacement of the DDG-51 or the LSD that would be necessary to accommodate a nuclear reactor. However, CBO estimates, on the basis of other data provided by the Navy and various projected changes in design, that a new reactor would require an increase of only 2,000 tons in the ships' displacement. The use of existing reactors would require a greater increase in size, which in turn would boost the fleet's total costs more than would the design of a new reactor. In other words, if the Navy was going to put a nuclear reactor on its new destroyers and amphibious dock landing ships, designing a new reactor, by CBO's estimates, would be more cost-effective than using an existing reactor.

Table 1.

Estimated Life-Cycle Costs for a Nuclear Versus a Conventionally Powered Fleet, Calculated as Present Values Using Risk-Adjusted Discount Rates

(Billions of 2011 dollars)

	DDG-51 and DDG(X) Destroyers		LH(X) Amphibious Assault Ships		LSD(X) Amphibious Dock Landing Ships		All Ships	
	Conventional	Nuclear	Conventional	Nuclear	Conventional	Nuclear	Conventional	Nuclear
Acquisition								
Develop a new nuclear reactor[a]	n.a.	0.8	n.a.	0	n.a.	0.2	n.a.	1.0
Certify an additional nuclear shipyard[b]	n.a.	0.4	n.a.	*	n.a.	0.1	n.a.	0.5
Procure ships	36.6	55.0	6.2	8.2	6.3	11.3	49.2	74.5
Subtotal	36.6	56.2	6.2	8.2	6.3	11.6	49.2	76.0
Fuel	10.4	0	2.1	0	1.9	0	14.4	0
Personnel	19.6	24.1	4.2	4.9	4.8	6.1	28.6	35.1
Other Operations and Support	5.5	5.5	1.6	1.6	1.9	1.9	9.0	9.0
Disposal	*	0.4	*	0.1	*	0.2	*	0.7
Total	**72.1**	**86.1**	**14.2**	**14.8**	**14.8**	**19.8**	**101.1**	**120.7**
Memorandum:								
Number of Ships Built	39	39	5	5	12	12	56	56

Source: Congressional Budget Office.

Notes: Total costs for each type of ship consist of the sum of the discounted value of the life-cycle costs for each ship of that type considered in CBO's analysis—that is, for 39 destroyers, 5 amphibious assault ships, and 12 amphibious dock landing ships. (Life-cycle costs are costs over a ship's entire 40-year service life, beginning with its acquisition and progressing through the annual expenditures over 40 years for its fuel, personnel, and other operations and support and, finally, its disposal.) Details of CBO's present-value calculations and discounting methods are discussed in the text.

A conventionally powered DDG-51 Flight III destroyer (a "flight" is a variant) is expected to have a full-load displacement (weight) of 10,000 tons; CBO assumed that a nuclear-powered DDG-51 would displace 12,000 tons. CBO also assumed that the replacement class, the DDG(X), would displace 11,000 tons if conventionally powered and 13,000 tons if nuclear powered; that the LSD(X) amphibious dock landing ship would displace 18,000 tons if conventionally powered and 20,000 tons if nuclear powered; and that the LH(X) amphibious assault ship would displace 45,000 tons in either case (the ship would have adequate capacity to accommodate nuclear reactors with no increase in displacement).

n.a. = not applicable; * = between zero and $50 million.

a. CBO allocated the total $1 billion cost to develop a new nuclear reactor equally among the 51 destroyers and LSD(X)s under the nuclear-fleet alternative. No costs were allocated to the LH(X)s; CBO assumed those ships would be outfitted with one of the A1B reactors that the Navy plans to use in the new Gerald R. Ford class (CVN-78) of aircraft carriers.

b. CBO allocated the total $500 million cost to certify an additional nuclear shipyard equally among all 56 ships under the nuclear-fleet alternative.

The main reason is that the reduction in the Navy's costs for conventional fossil fuel that the use of nuclear power would lead to would not be large enough to compensate for the increase in the acquisition costs for nuclear-powered ships. Moreover, such ships require larger and more highly trained crews than their conventional counterparts do, so their personnel costs would be greater as well. Other differences in costs between the fleets do not make up a significant percentage of total costs. (The costs for designing a new reactor for the destroyers and the LSD(X) ships, certifying a third commercial shipyard for nuclear work—discussed later—and disposing of nuclear reactors at the end of the ships' service lives would each be less than 1 percent of the nuclear fleet's total discounted costs.)

Costs Under a Higher Projected Trajectory for Oil Prices

If oil prices followed the path that CBO has forecast, a nuclear fleet would be more expensive than a conventional fleet. The trajectory of oil prices, however, is highly uncertain. If the price of oil rose more rapidly over the service lives of those ships than CBO has projected, conventionally powered ships could become more expensive than nuclear-powered ships; that is, the higher cost of petroleum for conventional ships would begin to overtake the higher cost of acquisition for nuclear ships.

CBO thus considered a case in which the price of oil grows at a rate higher than the 1 percent real growth in CBO's baseline, starting from the same value of $86 per barrel in 2011. A fleet of nuclear destroyers would become cost-effective only if the real rate of growth of oil prices exceeded 3.4 percent per year over the 2012–2084 period (see Figure 2); that projected rate would imply a price for oil (in 2011 dollars) of $223 per barrel or more in 2040 and higher prices in later years. Similarly, a fleet of nuclear LH(X) amphibious assault ships would become cost-effective at an annual real growth rate for oil prices of 1.7 percent, or a price of $140 per barrel in 2040, and a fleet of nuclear LSD(X) amphibious dock landing ships would become cost-effective at a real growth rate of 4.7 percent per year, or a price of $323 per barrel. Under an assumption that the prices of goods used to build and operate ships would not systematically vary with economic conditions (meaning that the appropriate discount rate would not need to take market risk into account), the rates of growth of oil prices at which nuclear propulsion would become cost-effective would be slightly higher (see the appendix for details).

Costs with Increased Energy Use by Destroyers

Another key factor about which there is considerable uncertainty is the amount of energy that new surface ships would use during their operations—particularly ships that, like destroyers, require large amounts of energy for purposes other than propulsion. Changes in those amounts could have a substantial effect on the relative costs of nuclear and conventional power. Power use could be lower on conventional ships if the Navy used a hybrid electric drive to reduce fuel consumption. Alternatively, and probably more likely, power use could be higher because of the new ships' larger radars, new weapon systems, other electronic systems, and a possible boost in the ships' steaming hours. However, those effects on the costs of the nuclear fleet would be relatively small. For example, if the DDG(X) were to consume 50 percent more energy than the current generation of destroyers, the percentage by which the cost of a fleet of nuclear destroyers would exceed the cost of a conventional fleet would decline from 19 percent to 16 percent.[9] Using an approach similar to the one it used to assess sensitivity to oil prices, CBO estimated that providing destroyers with nuclear reactors would become cost-effective (given CBO's baseline trajectory for oil prices) only if energy use more than doubled for the entire fleet of destroyers.

Other Considerations

Some observers argue that compared with conventionally powered ships, nuclear-powered ships are a better option for the Navy even if they cost more.[10] Nuclear ships may be able to steam faster and operate a larger, more powerful radar (which, like the propulsion system, would rely

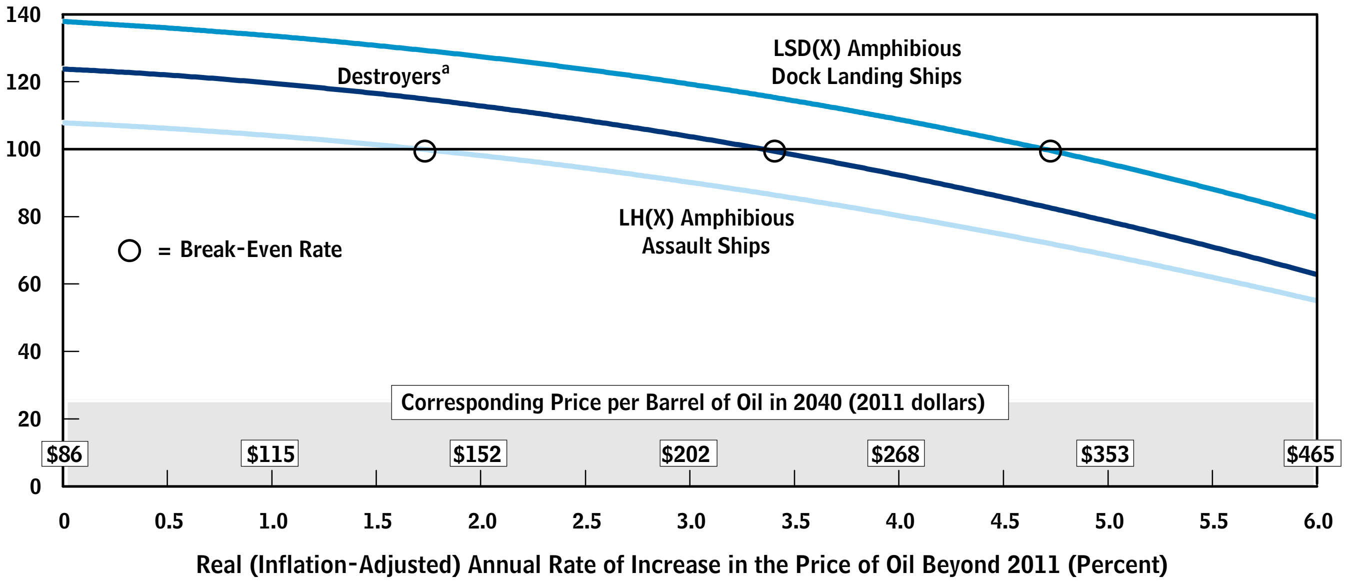
9. In April 2011, the Navy indicated to CBO that power use by the DDG(X) might be 50 percent greater, according to preliminary analyses, than would have been projected on the basis of historical antecedents, in part because of additional missile defense missions. If the use of power by the DDG-51 Flight III ships matched CBO's projections and power use for the follow-on DDG(X) class was 50 percent greater than that for the current DDG-51s, the effect on the discounted present value of costs would be small—because the DDG(X) would constitute only part of the destroyer fleet, because CBO's estimates already account for some growth in energy use, and because DDG(X) operations would occur further in the future and receive relatively less weight in the estimates.

10. For a summary of some of those arguments—though not an endorsement of them—see Hans M. Kristensen, William M. Arkin, and Joshua Handler, *Aircraft Carriers: The Limits of Nuclear Power,* Neptune Papers No. 7 (June 1994); and Government Accounting Office, *Nuclear or Conventional Power for Surface Combatant Ships?* PSAD 77-74 (March 21, 1977).

Figure 2.

Break-Even Rates for Oil Prices at Which Life-Cycle Costs, Discounted Using Risk-Adjusted Rates, Are Equal for a Nuclear and a Conventionally Powered Fleet

(Relative discounted cost, nuclear power to conventional power, as a percentage)



Source: Congressional Budget Office.

Notes: The break-even rate is the annual rate at which the price of oil must increase above general inflation, starting in 2011, so that life-cycle costs for ships equipped with nuclear propulsion systems equal 100 percent of the life-cycle costs for the same ships with conventional propulsion systems. CBO estimated break-even rates of 4.7 percent for LSD(X) amphibious dock landing ships, 3.4 percent for destroyers, and 1.7 percent for LH(X) amphibious assault ships.

Total costs for each type of ship consist of the sum of the discounted value of the life-cycle costs for each ship of that type considered in CBO's analysis—that is, for 12 amphibious dock landing ships, 39 destroyers, and 5 amphibious assault ships. (Life-cycle costs are costs over a ship's entire 40-year service life, beginning with its acquisition and progressing through the annual expenditures over 40 years for its fuel, personnel, and other operations and support and, finally, its disposal.) Details of CBO's discounting method and selection of rates are discussed in the text.

a. Includes DDG-51 Flight III (a "flight" is a variant) and DDG(X) destroyers.

on the reactor for energy); they may also be capable of operating for longer periods without restocking supplies or fuel. The extent of those potential advantages would depend on how the nuclear ships operated. On the one hand, such ships might need to restock perishable food or fuel for aircraft even if they did not require fuel for propulsion. Or nuclear ships might operate in battle groups with conventional ships and be tied to the conventional ships' operating schedules. On the other hand, nuclear-powered surface combatants might be more effective than conventional ships as escorts to nuclear carriers because the carriers would no longer be tied to the operating schedules of their escorts. CBO, however, was unable to quantify such considerations or account for them in its cost comparison.

Comparing CBO's Analysis with the Navy's Study of Nuclear Power for Future Surface Combatants

The Navy has also studied the possibility of using nuclear power in some of its future destroyers and amphibious warfare ships, the current versions of which are powered by conventional gas turbines.[11] The Navy found that for a likely range of oil prices, the costs for nuclear-powered ships would exceed the costs for equivalent ships with conventional power plants—the same conclusion that CBO reached. Unlike CBO's study, however, the Navy's

11. Section 130 of the Fiscal Year 2006 National Defense Authorization Act (Public Law 109-163) directed the Navy to examine the effectiveness of applying nuclear power to surface combatants (cruisers and destroyers) and amphibious warfare ships. For the Navy's response, see Naval Sea Systems Command, *Report to Congress on Alternative Propulsion Methods for Surface Combatants and Amphibious Warfare Ships* (January 2007).

analysis compared individual ships equipped with the two types of power plants without regard to the phased introduction of ships into the fleet. That is, the study did not account for the fact that even if oil prices were assumed to grow quite rapidly, the potential savings from moving to a nuclear-powered fleet would accrue largely in the future—because the new ships would require decades to be fully phased in to the fleet. Nor did the Navy's study account for the time value of money—the analysis did not compare costs calculated in terms of their present values. If it was, indeed, cost-effective to gradually shift a class of ships to nuclear power, the savings would increase as more nuclear ships were built over time. However, under CBO's present-value approach, the savings in fuel costs associated with the ships that entered the fleet in later years were heavily discounted because the savings accrued so far into the future.

The Basis for CBO's Cost Estimates

In calculating the overall costs of a fleet of new surface combatants under alternative propulsion systems, CBO used several different models to project costs over the ships' service lives. CBO began, however, with some general assumptions that were independent of how a ship was powered. First, CBO assumed that the ships chosen for its analysis would each take 5 years to build and have a service life of 40 years. Second, funds for procurement would be appropriated for the first of the new ships in 2016, although funding for research, development, testing, and evaluation would be provided sooner. Third, the first of the new ships would enter the fleet in 2023; the last of them would be procured in 2040, enter the fleet in 2045, and be retired in 2084.

CBO grouped its estimates of life-cycle costs for the new ships into the following categories:

- Acquisition and other onetime costs;
- Fuel;
- Personnel;
- Other operations and support (for example, maintenance); and
- Disposal.

In its calculations, CBO first considered costs incurred in earlier Navy shipbuilding programs that had produced ships similar to those in its hypothetical fleet. It then adjusted some of those cost elements for differences in the ships' displacement (weight). CBO used separate models to estimate acquisition costs and the different categories of operating costs (fuel, personnel, and maintenance); inputs for the models included historical operating costs and operating profiles (for example, quarterly averages of steaming hours under way and steaming hours not under way) from the Navy's Visibility and Management of Operating and Support Costs (VAMOSC) system.[12] So that expenditures made in different years and with different amounts of price risk (the risk associated with the amount of the cash outlays that the government will make in the future) could be appropriately compared, CBO expressed the total cost of the fleet under each alternative propulsion system as a present value in 2011.

Acquisition and Other Onetime Costs

CBO estimated acquisition costs for the new ships using a model that encompasses expenditures for research, design, and engineering as well as for actual construction. The model takes into account the effects of learning (unit costs—the costs of each ship constructed—decline as more ships of the same class are built in a continuous production run over a period of time) and production rates (unit costs are reduced when multiple ships of the same class are built concurrently in the same shipyard).

The model also reflects CBO's expectation that the costs of labor and materials in the naval shipbuilding industry will rise more rapidly than will general inflation during the first 35 years of the analysis—the period during which all of the ships that CBO considered would be authorized and funding would be provided by the Congress.[13] In particular, CBO projects that the composite growth of shipbuilding costs will outpace inflation (as measured by the gross domestic product price index) by an average of 1.9 percentage points per year between 2011 and 2017 and by about 1.5 percentage points per year from 2018 through 2045. (Although CBO's analysis considered operating and disposal costs for ships during a

12. The Navy's VAMOSC management information system (www.ncca.navy.mil/services/costtools.cfm#VAMOSC) collects and reports on historical operating and support costs and related information for the Navy's and the Marine Corps' weapon systems.

13. See Congressional Budget Office, *An Analysis of the Navy's Fiscal Year 2011 Shipbuilding Plan*, pp. 12–13.

period that extended to 2084, shipbuilding inflation is germane only through 2045—because all of the ships would be built by then.) Thus, in CBO's estimation, a ship costing $2.5 billion to build in 2011, for example, would cost $3.4 billion (in 2011 dollars) to build in 2030.[14]

Additional Acquisition Costs for Nuclear-Powered Ships. The Navy could apply different solutions to providing the three classes of new ships with nuclear propulsion systems, but for its analysis, CBO assumed the following:

- The Navy would use one of the twin A1B reactors that will power the new Ford class (CVN-78) of nuclear aircraft carriers to power the LH(X) amphibious assault ships, and

- The Navy would design a new reactor—smaller than the A1B reactor but larger than the reactor in the Virginia class submarines—for the destroyers and LSD(X) amphibious dock landing ships. That activity would entail a onetime cost of about $1 billion, by the Navy's estimates.[15]

In CBO's estimation, the acquisition-cost premium for a nuclear versus a conventional ship would average about $1 billion per hull, but it would vary by the class of ship. The initial fuel core for a modern reactor lasts for the life of the ship, and the U.S. government already owns enough nuclear material to supply all of the ships considered in this analysis. Moreover, unlike the case with aircraft carriers, which the Navy expects to serve in the fleet for 50 years, the ships that CBO considered would require no additional outlays for midlife refueling. Thus, CBO estimated that the acquisition-cost premium for a nuclear ship would be about $1.1 billion per destroyer, $0.8 billion per LSD(X), and $0.9 billion per LH(X); those amounts represent some additional expenditures for nuclear fuel together with the cost of the nuclear reactor and its cooling and other support systems, and the associated greater displacement of the destroyers and LSD(X) ships if they are nuclear powered.

The Navy has not built nuclear-powered surface ships for several decades but has substantial experience in procuring and operating other types of nuclear-powered ships. Therefore, the costs for nuclear ships should be no less certain than those for conventional ships. The engine technologies for both are "mature." The technology likely to be used for the new ships if conventional propulsion systems are chosen—the General Electric LM2500 gas turbine, a derivative of the General Electric TF39 aircraft engine—has been used on the Navy's Spruance class destroyers (first commissioned in September 1975) and Oliver Hazard Perry class frigates (first commissioned in December 1977). In addition, the Navy has over 50 years of experience in building a series of ever-evolving nuclear propulsion systems.[16]

Any difficulties associated with outfitting a new class of ships with nuclear propulsion would probably be limited to the lead ship of a class. The costs of a lead ship are notoriously difficult to predict because many of the problems that arise during production of a new class or flight (variant) of vessels are resolved during construction of that ship; in many cases, costs drop precipitously for the second ship of a class or flight and then generally follow a smooth, gradual downward curve for the duration of the production run. CBO did not attempt to quantify or account for the unpredictability of the cost of the lead ships. Rather, because nuclear fuel is already available in sufficient quantity, CBO treated the price of oil—a commodity that cannot be fully stockpiled in advance—as the only significant source of uncertainty in the cost of propulsion systems for the ships in this analysis. (However, CBO's analysis also incorporated uncertainty in the cost of building the nonpropulsion parts of the ships, as discussed below.)

14. CBO does not expect shipbuilding costs to continue forever to grow at a faster rate than the costs of goods and services in the economy as a whole; if that were to happen, the price of ships would eventually outstrip the Navy's ability to pay for them, even in very small numbers.

15. The Navy provided CBO with data on design costs in February 2009. CBO adjusted those data and divided the $1 billion cost equally among each of the destroyers and LSD(X)s in the hypothetical fleet. It allocated no additional design costs to the LH(X)s.

16. The Navy commissioned its first nuclear-powered submarine, U.S.S. *Nautilus* (SSN-571), in September 1954; that boat went to sea for the first time in January 1955. The Navy commissioned its first nuclear-powered surface ships, the cruiser U.S.S. *Long Beach* (CGN-9) and the aircraft carrier U.S.S. *Enterprise* (CVN-65), in September 1961 and November 1961, respectively. For additional details, see Ronald O'Rourke, *Navy Nuclear-Powered Surface Ships: Background, Issues, and Options for Congress*, Report for Congress RL33946 (Congressional Research Service, June 10, 2010).

Additional Onetime Costs for a Nuclear-Powered Fleet. Building nuclear-powered ships for CBO's hypothetical fleet might require an additional shipyard to be certified for nuclear construction. Two commercial shipyards are currently certified to build nuclear-powered ships: General Dynamics Electric Boat (which has traditionally built nuclear submarines but not surface ships) and Newport News Shipyard. The Navy plans to build the 56 ships considered in this analysis in any case. The question is whether the two shipyards could handle the workload involved in building 56 nuclear destroyers and amphibious warfare ships over the next 30 years in addition to the construction of carriers and submarines that the Navy is planning. Simple arithmetic implies that an average of about two new ships would begin construction each year, but each ship would remain under construction for about six years. During the peak shipbuilding years, as many as 18 of the 56 ships might be in one stage of construction or another.

The two shipyards that traditionally build conventional destroyers—General Dynamics Bath Iron Works and Ingalls Shipyard—have the capacity to build that many ships in a year. Just a few years ago, Bath Iron Works had 8 destroyers in various stages of construction, and Ingalls Shipyard had 10 ships (including 2 commercial vessels) in progress. The trend in the shipyards is toward building ships on land in so-called super- or megamodules, which require considerably less pier space (a rate-limiting factor) for much of the construction period.[17] Further, the shipyards have the capacity to handle even more ships than the statistics cited above; even if pier space or other aspects of the shipyards' physical plants had to be increased, the costs of doing so would be small relative to the procurement and operating costs that dominate this analysis. Another factor in such construction is the amount of labor required. To build more ships, the shipyards also might have to increase their workforces. CBO included the recurring costs of employing those workers in its estimates of procurement costs but not any onetime costs to recruit and train additional workers. Again, however, those costs would be small in the context of procurement and operating costs for the ships.

Although the two existing nuclear-certified shipyards may have sufficient capacity to build the 56 ships in CBO's hypothetical fleet, the Navy might choose instead to certify one of the other commercial shipyards, such as Bath Iron Works or the Ingalls Shipyard, for nuclear work. The shipyard not selected for certification could still build modules that would be integrated into ships at one of the certified shipyards. For example, if Bath Iron Works was certified for nuclear work, the Navy might contract with the Ingalls Shipyard to build one-third of a ship while Bath built the other two-thirds—not unlike the contract arrangement used for the DDG-1000 destroyer program today. Or the arrangement could be reversed, with Ingalls certified as the nuclear shipyard.[18] CBO assumed for its analysis that the Navy would certify one additional shipyard at an estimated cost of about $500 million.[19]

Costs for Other Supporting Infrastructure and Logistics. The Navy's existing shore infrastructure, including maintenance and repair facilities, currently supports nuclear-powered aircraft carriers and submarines. CBO assumed that it would be sufficient to accommodate the additional nuclear ships that would be built under the nuclear-fleet alternative and did not include any additional infrastructure costs for support of the 56 new ships.

CBO estimated that, on balance, the Navy's need for combat logistics ships—which resupply other ships with fuel for use by the ships themselves and by naval aircraft, and with ammunition, food, and other supplies—would be about the same whether or not the Navy switched to nuclear power for its new surface combatants. If the Navy made that shift, deliveries of petroleum-based fuel at sea would decline only slowly because the fleets of destroyers,

17. The Navy notes that, rather than saving pier space, the primary benefit of modular construction is efficiency.

18. The Ingalls Shipyard has some experience with nuclear-powered vessels, having built 12 nuclear submarines, the last one being the U.S.S. *Parche* (SSN-683), which was procured in 1968 and entered service in 1974. In addition, Ingalls has overhauled or refueled 11 nuclear-powered submarines. However, the Ingalls' nuclear-certified facility was decommissioned in 1980; its experience in nuclear work might or might not be a factor in the Navy's selection of another shipyard for nuclear certification—that is, if one was selected at all. See O'Rourke, *Navy Nuclear-Powered Surface Ships*.

19. The Navy provided data to CBO in February 2009 on the cost of certification. CBO adjusted those data and allocated the $500 million certification cost equally among the ships in its hypothetical nuclear fleet.

LH(X) ships, and LSD(X) ships would not become all-nuclear until the 2040s. In the meantime, the Navy plans to build 53 (conventionally powered) littoral combat ships in addition to the two that have already been completed, and all of those ships would continue to require fuel to be delivered at sea. CBO further assumed that, compared with what was required for conventional ships, nuclear ships would require the same degree of restocking of commodities, other than ships' fuel; nuclear ships might even require greater amounts of those stores, in view of the larger crews that CBO expects would be needed aboard the nuclear-powered ships (discussed below).

Fuel

CBO estimated rates of fuel consumption for conventionally powered ships in its hypothetical fleet by using historical data for selected Navy surface ships. Such ships consume fuel while they are under way and, to a lesser extent, while they are not under way. (For example, fuel may be converted to electricity to provide such services as lighting and climate control while a ship is in port.) Where necessary, CBO adjusted underway fuel consumption to reflect differences in displacement between the ships in the hypothetical new fleet and the ships selected as historical antecedents.

In general, a larger ship consumes more fuel than a smaller one and thus offers a greater opportunity to save money by replacing conventional engines with nuclear reactors. Yet how much fuel a ship consumes depends not only on the ship's size but also on the design of its hull and its mission (for example, the distances it is expected to travel during a typical deployment and the size of the radar and other electronics). For example, the DDG-51 Flight III destroyer is the smallest ship that CBO considered in this analysis—the destroyer displaces (weighs) 10,000 tons as opposed to the LSD(X), which displaces 18,000 tons, and the LH(X), which displaces 45,000 tons. But the destroyer consumes more fuel per ton per hour when under way than do the larger ships. Thus, replacing the destroyer's conventional power plant with a nuclear reactor would become cost-effective under a lower projected trajectory for oil prices than would be the case for the somewhat larger LSD(X).

Oil prices have been volatile over the past few decades and are difficult to predict (see Box 2). After peaking at almost $130 per barrel in June and July 2008, they had plummeted by December 2008 to about $36 per barrel; they then began to grow again and by March 2011 exceeded $100 per barrel.[20] CBO's macroeconomic projections as of January 2011 show oil prices rising to $95 per barrel (in 2011 dollars) by 2021.[21] Thereafter, CBO assumed, prices would escalate at a real annual rate of 1 percent. CBO also considered other trajectories for the price of oil to estimate the break-even rate of growth that would render the two types of propulsion systems equally costly.

The cost of the fuel delivered to Navy ships comprises many elements besides the price of crude oil. CBO thus used a method developed by the Navy for calculating a "fully burdened" cost of fuel—one that includes the price of crude oil refining, delivery of the fuel using the Navy's supply ships, necessary shore facilities, and administrative services through the Department of Defense's supply system. Extrapolating from the Navy's calculations, CBO projected the fully burdened cost of fuel (which comprises both a fixed- and a variable-cost component) on the basis of its historical relationship to the price of crude oil. For example, a price of $86 per barrel of crude oil would imply a fully burdened cost of $178 per barrel—or a burden rate of 107 percent.[22] If oil prices followed CBO's projected trajectory—increasing to $95 per barrel in 2021 and then continuing to escalate at a real rate of 1 percent per year—prices would reach $114 per barrel by 2040 (in 2011 dollars). By extension, the burdened price in 2040 would be $222, and the burden rate would be 95 percent.

Personnel

CBO also applied the notion of fully burdened costs to its estimates of expenditures on military personnel for the hypothetical fleet; in that case, its calculations

20. CBO used the average monthly price of imported oil delivered to U.S. refineries in its analysis.

21. Prices in the first four months of this year have averaged $10 per barrel more than CBO forecast in January, and they could be higher or lower during the rest of the year. CBO expects to update its macroeconomic projections in August.

22. The burden rate, reflecting the costs above the base cost of the fuel, is calculated in this instance as 178 divided by 86 minus 1.00.

encompassed basic military pay, withholding taxes paid by the federal government, housing benefits, current and future health benefits, retirement benefits, tax advantages, and veterans' benefits.[23] CBO estimated the costs in each category using data from 2010 and then projected the growth in each using rates consistent with its long-term economic projections (overall real growth of about 1 percent per year).[24] For nuclear-powered ships, CBO adjusted personnel costs in two ways: It increased basic military pay by 10 percent to reflect the mix of higher-level skills appropriate to a nuclear vessel, and it added 35 crew members to each ship's complement to support the operation of the reactor.

Other Operations and Support

CBO estimated average maintenance costs for the three kinds of ships by using historical data for similar ship classes and then adjusting those data for the differences in the ships' displacement. CBO's estimates allowed for overhauls and other periods when the ships might be unavailable because of maintenance—that is, periods when they would spend a minimal number of hours under way.

Disposal

CBO modeled disposal costs for conventional ships as a function of their displacement; for example, it would cost about $1 million to dispose of a conventional destroyer but about $9 million to dispose of the much larger LH(X) amphibious ship. For nuclear-powered ships, CBO estimated, on the basis of data provided by the Navy, that it would cost an additional $140 million to dispose of a single reactor from a nuclear-powered ship of any of the types considered in this analysis.[25]

Comparing the Costs of Alternative Propulsion Systems Using Present-Value Calculations

The total estimated costs for CBO's hypothetical fleet under both the conventional and nuclear power alternatives depend on the estimated future costs for building and operating the ships in the fleet and the discount rates used to convert those costs to present values—a standard method for valuing an extended stream of future cash flows. CBO thus estimated projected future costs in terms of 2011 dollars; it also used risk-adjusted discount rates that attach a market price to the risk associated with the amount of the cash outlays that the government will make in the future. That "fair-value" approach measures what a private entity in a competitive market would need to be paid to voluntarily assume the costs and risks that the government is assuming on behalf of taxpayers. Such an approach provides a more complete measure of the economic cost associated with the two alternatives than does a calculation that treats the government's capacity to bear market risk as having no cost. Although the government can borrow at rates that include no extra compensation for bearing market risk, its ability to do so depends on taxpayers—who back the debt and thus bear that risk.[26]

23. See Congressional Budget Office, *Evaluating Military Compensation* (June 2007). Veterans' benefits and some tax advantages for military personnel (certain allowances they receive are not subject to federal income tax) are not included in the defense budget but are instead reflected in higher outlays for other federal departments or in lower tax revenues. CBO has nonetheless included those elements in its estimates because they reflect actual costs to U.S. taxpayers.

24. See Congressional Budget Office, *The Long-Term Budget Outlook* (June 2010, revised August 2010).

25. The Navy provided CBO with data on disposal costs in February 2009. Other estimates are available but would not substantially change CBO's findings; see, for example, Ronald O'Rourke, *Navy Ship Acquisition: Options for Lower-Cost Ship Designs*, Report for Congress RL32914 (Congressional Research Service, December 11, 2006), p. 16. In 2005, the Navy provided O'Rourke with an estimate of $70 million (in 2011 dollars) for deactivating, dismantling, and disposing of a retired nuclear-powered submarine; according to the Navy, work related to the reactor compartment would constitute roughly half of that total, or $35 million. The Navy also provided O'Rourke with a projection of about $1.1 billion (in 2011 dollars) for deactivating the nuclear-powered carrier U.S.S. *Enterprise* (CVN-65) in 2013. Work related to the ship's eight nuclear reactors accounted for about $730 million of the total.

26. CBO has applied the fair-value approach in other contexts; see, for example, Congressional Budget Office, *Fannie Mae, Freddie Mac, and the Federal Role in the Secondary Mortgage Market* (December 2010); *The Budgetary Impact and Subsidy Costs of the Federal Reserve's Actions During the Financial Crisis* (May 2010); and *Costs and Policy Options for Federal Student Loan Programs* (March 2010).

Box 2.

Fluctuating Oil Prices

In comparisons of the cost-effectiveness of using conventional versus nuclear propulsion for the Navy's planned fleet of new surface combatants, an important consideration is the future price of oil. The Congressional Budget Office (CBO) regularly projects oil prices over a 10-year period as part of the macroeconomic forecast that underlies its baseline budget projections.[1] However, for its analysis of conventional versus nuclear propulsion, CBO had to consider the trajectory of oil prices over a much longer period—a total span of 75 years, with the Navy's new surface ships expected to be built over the next 35 years and then operated for 40 more years. Such a long forecasting horizon increases the uncertainty inherent in projections of oil prices.

Oil prices can be volatile even over short periods; in recent years, they have fluctuated widely. For example, the average price of all crude oil delivered to U.S. refiners generally declined throughout the 1990s (albeit with some variability) to about $12 per barrel (in 2011 dollars) in December 1998. It then rose to $38 in September 2001; fell again to $19 per barrel in December 2001; and subsequently, from that point to the middle of 2008, increased nearly sevenfold, peaking at almost $130 per barrel in June and July of that year (see the figure to the right).[2] The average price then fell to $36 per barrel in December 2008 and began to climb again, reaching a monthly average of more than $100 per barrel in March 2011.[3] Over longer periods, the real (inflation-adjusted) price of oil has generally increased: The real price was higher in the decade that began in 2001 than in the preceding decade.

1. For CBO's most recent economic projections, see Congressional Budget Office, *The Budget and Economic Outlook: Fiscal Years 2011 to 2021* (January 2011).

2. The average price of all oil imported and delivered to U.S. refiners is the measure of oil prices that is calculated by the Energy Information Administration, the Department of Energy's statistical agency (see www.eia.doe.gov/dnav/pet/pet_pri_rac2_dcu_nus_m.htm), and used by CBO in its macroeconomic forecast.

The primary reason for short-term fluctuations in oil prices is that the quantity of oil supplied and the quantity demanded are generally not very responsive to short-lived price pressures. That means that, in the face of an unexpected shortage or surplus of oil, prices may move sharply up or down in order to rebalance supply and demand in the world market. For example, the total supply of oil is strongly influenced by the nations that make up the Organization of Petroleum Exporting Countries, or OPEC.[4] OPEC controls essentially all of the spare oil production capacity in the world; if it decides to curtail its members' output, the nations outside of OPEC are seldom able to boost production in the short run to alleviate the shortage. Moreover, if prices rise rapidly, it takes time for industry and consumers to significantly lessen their demand. For example, the transportation sector accounts for about 75 percent of all petroleum consumed in the United States, and drivers (including commercial truckers) are reluctant or unable to quickly reduce the number of miles they drive.[5] In the longer run, the demand for oil in the transportation sector is more responsive to oil prices because businesses can change the way they transport their goods (for example, they can ship fewer goods by air), and consumers can choose more fuel-efficient vehicles or modify their commuting patterns.

3. West Texas Intermediate crude oil, which is another benchmark for oil prices, peaked at a daily price of about $145 per barrel in July 2008 and, after declining from that high point, had by the end of April 2011 again risen to more than $110 per barrel. (West Texas Intermediate is a high-quality light sweet crude oil produced in North America.) See Department of Energy, Energy Information Administration, "Petroleum and Other Liquids" (May 2, 2011; www.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RWTC&f=D).

4. For additional information on the factors that influence oil prices, see Department of Energy, Energy Information Administration, *Oil Prices and Outlook* (updated December 17, 2010; www.eia.gov/energyexplained/index.cfm?page=oil_prices).

5. See Congressional Budget Office, *Effects of Gasoline Prices on Driving Behavior and Vehicle Markets* (January 2008).

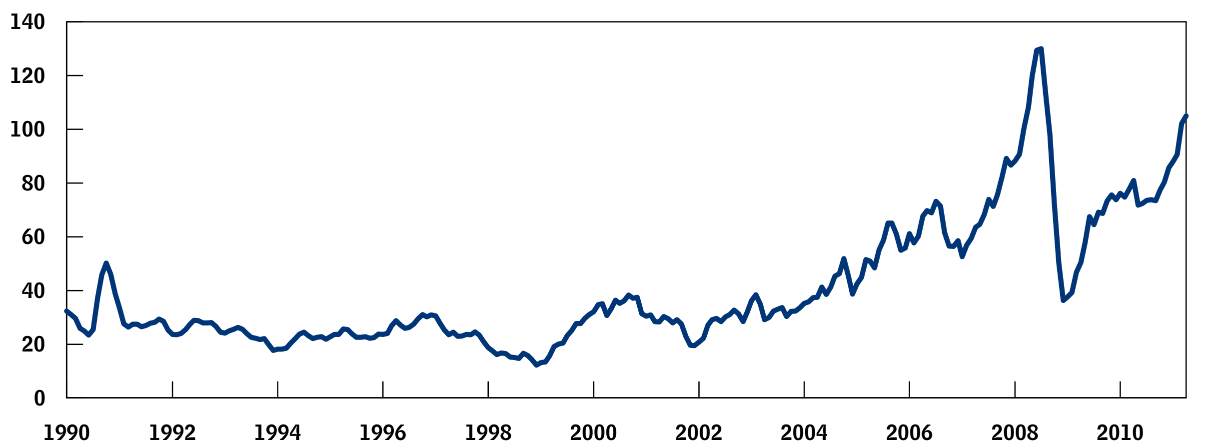
Continued

Box 2. **Continued**

Fluctuating Oil Prices

Monthly Average Price for All Oil Imported and Delivered to U.S. Refiners

(2011 dollars per barrel)



Source: Congressional Budget Office based on data from Department of Energy, Energy Information Administration, "Petroleum and Other Liquids" (www.eia.doe.gov/dnav/pet/pet_pri_rac2_dcu_nus_m.htm).

CBO bases its 10-year forecasts of oil prices partly on transactions in the futures market for oil (a market for commitments to deliver oil in the future), which reflects the developments that investors expect in the worldwide supply of and demand for oil.[6] In CBO's most recent forecast, oil prices after 2013 grow at a rate about 1 percentage point higher than that for inflation through 2021. CBO assumed for this study that the same trend would continue through 2084.[7]

That projection of long-term price growth is consistent with an outlook in which the world economy continues to expand and the increasing growth in the global demand for crude oil is satisfied by generally harder-to-access and higher-cost supplies. But oil market trends are uncertain. The rate of growth of oil prices that CBO has forecast—1 percentage point above inflation—might be lower if world demand grew more slowly than projected or if new oil reserves were discovered. Alternatively, real prices could rise faster if the growth in worldwide demand was greater than expected or if producers had more difficulty keeping pace with that growth. The policies and stability of OPEC will also influence future prices and are difficult to predict.

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6. For a specific discussion about projecting oil prices using data from futures markets, see Congressional Budget Office, *The Budget and Economic Outlook: Fiscal Years 2006 to 2015* (January 2005).

7. To reflect the uncertainty in that projected trajectory for oil prices, CBO conducted a sensitivity analysis to determine how much faster the price of oil would have to rise to overturn the conclusion of the main analysis that conventionally powered ships are more cost-effective than nuclear-powered ships. (See "Costs Under a Higher Projected Trajectory for Oil Prices" on page 7.) As a point of comparison, the Department of Energy's Energy Information Administration (EIA) publishes 25-year projections of oil prices. (For its most recent estimates, through 2035, see "Annual Energy Outlook—2011: Reference Case Tables," April 26, 2011; www.eia.gov/forecasts/aeo/tables_ref.cfm.) As of January 2011, CBO's and EIA's projections of long-term growth in prices were similar; however, EIA projected higher rates of growth than CBO did for years up to and including 2021, whereas for years after 2021, EIA projected lower rates of growth, relative to CBO's estimates.

Under the fair-value approach, CBO used discount rates for the federal government's estimated future costs that took into account that the prices of the inputs used to build and operate ships—such as steel, labor, and fuel—would vary with economic conditions. Like the stock market, the prices of those inputs tend to be procyclical: That is, they move with the business cycle and are higher when the economy is strong and lower when the economy is weak. The positive relationship between the prices of inputs for ships and the stock market means that those prices are more likely to be high when economic resources (for example, the revenues of private firms) are relatively plentiful and low when such resources are relatively scarce. If input prices tended to be higher when economic resources were scarce, then an adjustment for market risk would increase the discounted costs. However, because input prices tend to be lower when economic conditions are generally worse and savings on such inputs are particularly valuable, an adjustment for market risk lowers the discounted costs of building and operating ships. That is, risk-adjusted discount rates are higher than the rates on Treasury securities, so the present value of the costs is lower than if no adjustment for market risk had been made.

CBO used a real discount rate of 4 percent in computing the present value of construction and operating costs other than those for fuel under the two propulsion alternatives. The rate has two components: a short-term rate of 2 percent (CBO's estimate of the real rate on short-term Treasury securities) and a "risk premium" of 2 percent.[27] CBO's choice of rates was based in part on an analysis of the historical cost of capital for the U.S. maritime industry. The rate also reflects a slight downward adjustment to account for the weaker correlation with the business cycle of the Navy's purchases of ships and ship support services—weaker, that is, than the business cycle's correlation with the overall activity of the maritime industry.

Similarly, CBO based the discount rate that it applied to future purchases of oil on its estimate of the rate of return that private-sector investors would require for holding stocks in oil companies. Although the price of oil, like that of other inputs, tends to increase with the strength of the overall economy, the relationship historically has been significantly weaker than the ties between the economy's robustness and the costs associated with building and operating ships. CBO thus used a discount rate of 3 percent for future oil purchases; the rate combines a short-term real rate of 2 percent and a risk premium of 1 percent. In determining that risk premium, CBO used information on the prices of oil futures contracts and forecasts of future oil prices, and analyzed historical data on the correlation of oil prices with market risk.[28]

To determine whether the results of its analysis were sensitive to the choice of discount rates, CBO also compared the life-cycle costs for nuclear-powered and conventionally powered fleets using a real long-term discount rate of 3 percent for all cash flows (see the appendix). That rate corresponds to CBO's projection of the real rate of return on 30-year Treasury bonds. (Coincidentally, it is also identical to CBO's estimate of the required return on investments in oil.)[29] In that case, too, the costs for a fleet of conventionally powered ships would be significantly lower than the costs for a fleet of nuclear-powered ships.

27. CBO's methodology for estimating discount rates is based on the capital asset pricing model, which is commonly used by private-sector analysts to select discount rates for long-run investment projects. For a discussion of the model, see Stephen Ross, Randolph Westerfield, and Jeffrey Jaffe, *Corporate Finance* (New York: McGraw-Hill/Irwin, 2009).

28. Kenneth J. Singleton, in a March 2011 unpublished manuscript ("Investor Flows and the 2008 Boom/Bust in Oil Prices"; www.stanford.edu/~kenneths/OilPub.pdf), discusses estimating risk premiums on the basis of information about expected future oil prices and the forward price curve for oil prices.

29. The return on Treasury bonds is consistent with CBO's long-term macroeconomic forecast of interest rates. The required return on oil investment, though numerically the same, was calculated by using a different methodology (described above), which adds a risk premium to an estimate of short-term interest rates.

Appendix: Supplementary Calculations Using an Alternative Discount Rate

In its main analysis comparing the cost-effectiveness of using nuclear versus conventional power for the Navy's planned fleet of new surface ships, the Congressional Budget Office (CBO) calculated the costs for all the ships as a present value—a single amount that expressed the stream of the ships' annual costs in terms of an equivalent lump sum spent at the start of the analysis period. In those calculations, future costs were "discounted" (converted into current dollars) using a rate that took into account two factors: Money in hand is worth more than the same amount received in the future, and the cash flows face market risk. (Market risk is the risk of losses that investors cannot avoid by diversifying holdings and for which they require some compensation.) In particular, CBO used discount rates for future financial costs equal to the estimated return that a private investor would require on a project of similar risk and duration: a real (inflation-adjusted) discount rate of 3 percent in computing the present value of conventional fuel costs and a real discount rate of 4 percent in calculating construction and operating costs (for both nuclear and conventional ships) other than those for fuel.

In an alternative analysis, CBO recalculated the cost comparison using Treasury rates for discounting—specifically, using a real discount rate of 3 percent for all categories of costs. That rate is based on CBO's forecast of the rates of return on long-term (30-year) Treasury bonds; that it is identical to the discount rate CBO used to compute the present value of conventional fuel costs in the main analysis is coincidental. (CBO determined the discount rates for its main analysis by entirely different methods, as discussed in "Comparing the Costs of Alternative Propulsion Systems Using Present-Value Calculations" on page 13.) This alternative calculation does not take the cost of market risk into account; rather, it reflects the compensation that investors would require to make long-term investments that they believe entail no risk of loss from defaults. It also reflects the method of discounting (and, over the past decade, the approximate discount rate) used by executive branch agencies.[1]

Using the same rate (3 percent) to discount all costs—rather than applying a lower adjustment for risk (that is, a lower discount rate) to fuel costs than to other types of costs, as in the main analysis—leads to different estimates of the comparative cost-effectiveness of nuclear versus conventional power but the same net result: Nuclear ships would be more expensive unless oil prices sustained rapid growth through 2084. Under the alternative approach of discounting all costs at 3 percent, nuclear power would be even more expensive than conventional power relative to the findings from the main analysis, because the fuel savings would no longer be discounted at a rate lower than that used for other costs. As a corollary, the price of oil would have to grow more rapidly than in the trajectory presented in the main text before the costs for conventional fuel began to overtake the higher acquisition costs associated with nuclear-powered ships, thus making the use of nuclear propulsion cost-effective.

1. For general information, see Office of Management and Budget, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs,* Circular A-94 (October 29, 1992); for more specific information on past years' discount rates, see the table titled "Budget Assumptions: Nominal Treasury Interest Rates for Different Maturities (from the annual budget assumptions for the first year of the budget forecast)" in Appendix C of the circular (http://www.whitehouse.gov/sites/default/files/omb/assets/a94/dischist.pdf).

CBO assumed for this alternative analysis that the price of oil would follow the same projected trajectory that CBO used for the main analysis: Oil prices start at $86 per barrel in 2011 and grow at a rate about 1 percentage point per year above that of general inflation. In CBO's estimation, the present-value costs in 2011, if calculated using Treasury rates for discounting, for a nuclear-powered fleet relative to a conventionally powered one would be about $20 billion (22 percent) higher for destroyers, $1.4 billion (8 percent) higher for LH(X) amphibious assault ships, and $6.6 billion (35 percent) higher for LSD(X) amphibious dock landing ships (see Table A-1). For the sake of comparison, the findings from CBO's main analysis, which used risk-adjusted discount rates, were that costs would be higher for a nuclear-powered fleet by about $14 billion (or 19 percent) for destroyers, by $0.6 billion (4 percent) for LH(X) amphibious assault ships, and by nearly $5 billion (33 percent) for LSD(X) amphibious dock landing ships. The costs for conventional fuel that are avoided by the use of nuclear power—costs that are now, in this alternative analysis, discounted at the same rate as other costs and thus relatively smaller—would not be large enough to compensate for the increased acquisition costs of nuclear-powered ships.

In addition to the case just described, CBO also considered one in which the price of oil again starts from the value of $86 per barrel in 2011 but then increases over time at a fixed rate that exceeds the rate of general inflation by some amount greater than 1 percentage point. In CBO's estimation, a fleet of nuclear destroyers would become cost-effective under such a price path (and the alternative discount rate assumption) if the real annual rate of growth in oil prices exceeded 3.9 percent (see Figure A-1). Such a scenario implies a price for oil of $260 or more per barrel (in 2011 dollars) in 2040. Similarly, a fleet of nuclear-powered LH(X) amphibious assault ships would become cost-effective at a real annual growth rate for oil prices of 2.5 percent (for a price of $173 per barrel in 2040); and a fleet of nuclear-powered LSD(X) amphibious dock landing ships would become cost-effective if the price of oil grew at a real annual rate of 5.2 percent (for a price of $373 per barrel in 2040). The comparable findings from CBO's main analysis are a real annual rate of growth in oil prices of 3.4 percent and an implied price of $223 per barrel for destroyers, growth of 1.7 percent and an implied price of $140 per barrel for LH(X) amphibious assault ships, and growth of 4.7 percent and an implied price of $323 per barrel for amphibious dock landing ships.

Table A-1.

Estimated Life-Cycle Costs for a Nuclear Versus a Conventionally Powered Fleet, Calculated as Present Values Using Treasury Rates for Discounting

(Billions of 2011 dollars)

	DDG-51 and DDG(X) Destroyers		LH(X) Amphibious Assault Ships		LSD(X) Amphibious Dock Landing Ships		All Ships	
	Conventional	Nuclear	Conventional	Nuclear	Conventional	Nuclear	Conventional	Nuclear
Acquisition								
Develop a new nuclear reactor[a]	n.a.	0.8	n.a.	0	n.a.	0.2	n.a.	1.0
Certify an additional nuclear shipyard[b]	n.a.	0.4	n.a.	*	n.a.	0.1	n.a.	0.5
Procure ships	44.9	67.2	7.5	9.8	7.4	13.3	59.8	90.4
Subtotal	44.9	68.4	7.5	9.8	7.4	13.6	59.8	91.9
Fuel	10.4	0	2.1	0	1.9	0	14.4	0
Personnel	28.2	34.7	6.2	7.2	6.9	8.8	41.3	50.8
Other Operations and Support	7.9	7.9	2.4	2.4	2.7	2.7	13.0	13.0
Disposal	*	0.8	*	0.1	*	0.3	*	1.2
Total	**91.4**	**111.8**	**18.2**	**19.6**	**18.8**	**25.4**	**128.5**	**156.9**
Memorandum:								
Number of Ships Built	39	39	5	5	12	12	56	56

Source: Congressional Budget Office.

Notes: Total costs for each type of ship consist of the sum of the discounted value of the life-cycle costs for each ship of that type considered in CBO's analysis—that is, for 39 destroyers, 5 amphibious assault ships, and 12 amphibious dock landing ships. (Life-cycle costs are costs over a ship's entire 40-year service life, beginning with its acquisition and progressing through the annual expenditures over 40 years for its fuel, personnel, and other operations and support and, finally, its disposal.) Details of CBO's present-value calculations and discounting methods are discussed in the text.

A conventionally powered DDG-51 Flight III destroyer (a "flight" is a variant) is expected to have a full-load displacement (weight) of 10,000 tons; CBO assumed that a nuclear-powered DDG-51 would displace 12,000 tons. CBO also assumed that the replacement class, the DDG(X), would displace 11,000 tons if conventionally powered and 13,000 tons if nuclear powered; that the LSD(X) amphibious dock landing ship would displace 18,000 tons if conventionally powered and 20,000 tons if nuclear powered; and that the LH(X) amphibious assault ship would displace 45,000 tons in either case (the ship would have adequate capacity to accommodate nuclear reactors with no increase in displacement).

n.a. = not applicable; * = between zero and $50 million.

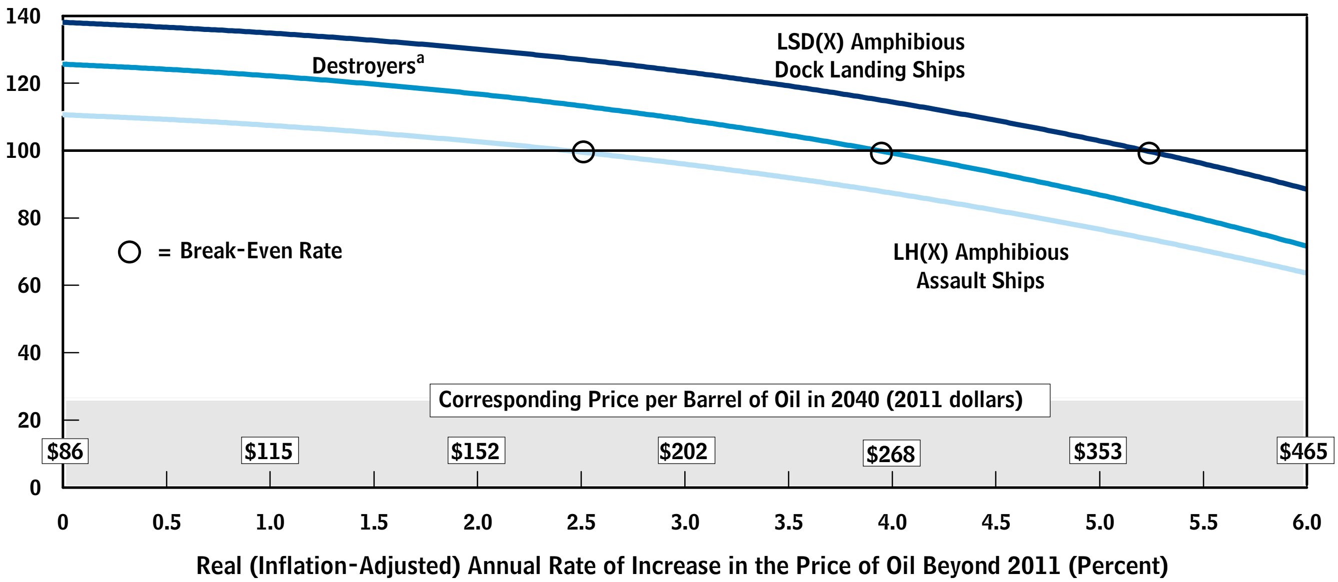
a. CBO allocated the total $1 billion cost to develop a new nuclear reactor equally among the 51 destroyers and LSD(X)s under the nuclear-fleet alternative. No costs were allocated to the LH(X)s; CBO assumed those ships would be outfitted with one of the A1B reactors that the Navy plans to use in the new Gerald R. Ford class (CVN-78) of aircraft carriers.

b. CBO allocated the total $500 million cost to certify an additional nuclear shipyard equally among all 56 ships under the nuclear-fleet alternative.

Figure A-1.

Break-Even Rates for Oil Prices at Which Life-Cycle Costs, Discounted Using Treasury Rates, Are Equal for a Nuclear and a Conventionally Powered Fleet

(Relative discounted cost, nuclear power to conventional power, as a percentage)



Source: Congressional Budget Office.

Notes: The break-even rate is the annual rate at which the price of oil must increase above general inflation, starting in 2011, so that life-cycle costs for ships equipped with nuclear propulsion systems equal 100 percent of the life-cycle costs for the same ships with conventional propulsion systems. CBO estimated break-even rates of 5.2 percent for LSD(X) amphibious dock landing ships, 3.9 percent for destroyers, and 2.5 percent for LH(X) amphibious assault ships.

Total costs for each type of ship consist of the sum of the discounted value of the life-cycle costs for each ship of that type considered in CBO's analysis—that is, for 12 amphibious dock landing ships, 39 destroyers, and 5 amphibious assault ships. (Life-cycle costs are costs over a ship's entire 40-year service life, beginning with its acquisition and progressing through the annual expenditures over 40 years for its fuel, personnel, and other operations and support and, finally, its disposal.) Details of CBO's discounting method and selection of rates are discussed in the text.

a. Includes DDG-51 Flight III (a "flight" is a variant) and DDG(X) destroyers.