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SUBMITTED VIA EMAIL to Olivia.h.romano@usace.army.mil

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Seattle Regulatory Brach
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Re: Northwest Environmental Defense Center Comments on the U.S. Army Corps of Engineers' Draft Environmental Impact Statement for BP Cherry Point North Wing Dock Expansion

Dear Ms. Romano:

The Northwest Environmental Defense Center ("NEDC") respectfully submits these comments to the United States Army Corps of Engineers ("Corps") and the United States Coast Guard ("Coast Guard") regarding the Draft Environmental Impact Statement ("DEIS") prepared for BP Cherry Point's previously authorized and constructed North Wing dock in the Strait of Georgia at Cherry Point, Washington. 79 Fed. Reg. 32924 (June 9, 2014) (Notice of Availability). The proposal to continue crude oil transloading operations at BP Cherry Point's North Wing dock is of significant interest to NEDC given our mission to protect and conserve the natural resources of the Pacific Northwest.

Background

In 1996 the Corps issued Department of the Army permit No. NWS-1992-00435, and declined to prepare an Environmental Impact Statement ("EIS") based on a finding of no significant impact under the National Environmental Policy Act ("NEPA"). Ocean Advocates, Fuel Safe Washington, North Cascades Audubon Society, and individuals challenged the Corps' decision in November of 2000, alleging violations of NEPA, 42 U.S.C. § 4332(2)(C), and the Magnuson Amendment, 33 U.S.C. § 476. The Ninth Circuit ultimately ruled in favor of Ocean Advocates on the NEPA claims, and remanded with instructions to the Corps to develop an EIS. More than ten years later, and almost eight years after completing scoping under NEPA, the Corps has produced a DEIS that was meant to inform its original decision.

NEPA is a procedural statute designed to ensure public participation and transparent decision making by federal agencies. *Robertson v. Methow Valley Citizens Council*, 490 U.S. 332, 350 (1989). Through the EIS requirement, NEPA mandates federal agencies to consider the environmental effects of proposed major actions and take a "hard look" at the potential environmental impacts of each major action. *Robertson*, 490 U.S. at 350. As set forth below, the analysis in the Corps' DEIS fails to conform with the letter and spirit of NEPA, the Council on Environmental Quality ("CEQ") guidelines implementing NEPA, and the Corps' own NEPA regulations.

I. Due to the inadequacy and lack of information in the Corps' DEIS, NEDC requests that the Corps extend the public comment period.

NEDC requests a 60-day extension of the public comment period. CEQ's guidelines give lead agencies the authority to extend prescribed periods in the EIS process, 40 C.F.R. § 1506.10, and the Corps' regulations implementing NEPA expressly adopt that portion of the guidelines. 33 C.F.R. Part 325, App. B(17). Given the inadequacy of the DEIS as set forth below in combination with the long history of events leading up to the DEIS, the dramatic increase in the transport of crude oil by rail and marine vessel[1] in recent years, the lack of information available to the public, and the misleading information contained in the DEIS, the current comment deadline does not give the public enough time to evaluate the Corps' compliance with NEPA.

The DEIS analyzes a highly complex facility with a long history. Understanding the materials included in the public notice and determining whether additional information is necessary requires more time. The Corps has already waited more than 10 years to prepare the DEIS, taking almost eight years to draft the analysis after the scoping period. The Corps afforded the public, however, forty working days to review and comment on the analysis. Plus, the DEIS fails to account for recent relevant information that shows a dramatically changing landscape of petroleum product transport in the United States. *See, e.g.*, Exhibit A. NEDC needs more time to identify and analyze this information as it pertains to BP's proposal to continue operating the North Wing dock and the Corps' analysis under NEPA. As set forth in the next section, the Corps' DEIS also lacks critical information and makes misleading statements. Sifting through these statements so that NEDC may adequately comment on the DEIS requires additional time.

Providing an additional 60 days to comment is within the Corps' authority under NEPA and its own regulations, is warranted, and is essential for NEDC to meaningfully evaluate the DEIS. NEDC requests that the Corps extend the public comment period an additional 60 days.

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[1] *See, e.g.,* Congressional Research Service R43653, *Shipping U.S. Crude Oil by Water: Vessel Flag Requirements and Safety Issues* (July 21, 2014) (attached hereto as Exhibit A), page 1 (noting that "waterborne transportation is playing an increasing role in moving crude oil within North America" and "[t]he quantity of oil moving by barge on the Mississippi River and its tributaries increased ten-fold from 2009 to 2013").

II. The DEIS contains insufficient and misleading information.

CEQ's guidelines under NEPA state that "public scrutiny is essential to implementing NEPA." 40 C.F.R. § 1500.1(b). The Ninth Circuit recently reaffirmed that "[i]nformed public participation in reviewing environmental impacts is essential to the proper functioning of NEPA." *League of Wilderness Defenders v. Connaughton*, 3:12-cv-02271-HZ (9th Cir. 2014). *See also Dep't of Transp. v. Pub. Citizen*, 541 U.S. 752, 768 (2004) (describing one of the purposes of NEPA as ensuring "that the relevant information will be made available to the larger audience that may also play a role in both the decisionmaking process and the implementation of that decision.") (quoting *Robertson v. Methow Valley Citizens Council*, 490 U.S. 332, 349 (1989)). The public cannot engage in an informed analysis of the proposed action and its alternatives because the Corps has failed to provide a full, honest and adequate disclosure of information in the DEIS.

As just one example, the DEIS improperly relies on vessel traffic data from 1998 through 2010 as "current operations." *See* U.S. Army Corps of Engineers, *BP Cherry Point Dock Draft Environmental Impact Statement* (May 2014) (hereafter "DEIS"), page ES-6 (explaining that "BP records of vessel calls from January 1998 through December 2010 show that an annual average of 321 vessel calls occurred at BP Cherry Point dock"); DEIS at ES-8 (referring to "the total material transfer at the BP Cherry Point dock" from "1998 through 2010"); DEIS Tables 2-1, 2-2, 2-3 (Monthly and Annual Vessel Calls at BP Cherry Point Dock (1998-2010), Total Annual Material Transfer at BP Cherry Point Dock (1998-2010), Annual Volume and Vessel Calls at BP Cherry Point Dock (1998-2010) Compared to 1998-2010 Average Values). There is no data provided for 2010 through 2014. Lack of sufficient information in the Corp's DEIS precludes meaningful public review.

The lack of data misrepresents the current situation. In December of 2013, BP installed a Rail Logistics Facility at the refinery that allows the facility to receive crude oil from domestic sources by rail. DEIS at ES-8. The Corps ignores any impact this construction and new operational capability might have on the operations of the South and North Wing docks. To the extent that the Corps' DEIS expects the Rail Logistics Facility to reduce the number of vessel calls at BP Cherry Point, that is likely wrong. *See* Exhibit A at 17 (explaining that "tankers should be significantly cheaper than rail for transport of crude oil, even when the water route is much longer"). The Corps also ignores that crude oil may be transloaded from rail to marine vessel at other facilities earlier in the supply chain, then transported to BP Cherry Point by barge or marine vessel. *See, e.g.*, Exhibit A at 2-3 (highlighting various intermodal routes for transporting crude oil that involve water transport, including rail to vessel terminals at Anacortes and Vancouver, Washington). The increased supply of crude oil from the Bakken region, Eagle Ford region, and Canada, may actually result in an increased demand for vessel calls to load the petroleum after being refined at BP's facility. Because the Corps' data in the DEIS only reflects operations through 2010, the agency has ignored information that is critical to its analysis.

CEQ regulations require an agency to "make clear that such information is lacking" when it is "evaluating reasonably foreseeable significant adverse effects on the human environment in an [EIS] and there is incomplete or unavailable information." 40 C.F.R. § 1502.22. *See also Native Village of Point Hope v. Jewell*, (9th Cir. 2014) ("an agency must either obtain information that is 'essential to a reasoned choice among alternatives' or explain why such information was too costly or difficult to obtain."). Yet there is no explanation for why BP could not provide throughput volumes of petroleum product and crude oil at the facility between 2010 and 2014. Nor is there an explanation as to why the numbers relied on by the Corps in the DEIS do not account for the facility's ability to receive an increased volume of crude oil based on the new Rail Logistics Facility.

Data from actual operations between 2010 and 2014 would more accurately reflect "current operations." Plus, this information should be readily available to BP given that any permit issued under the Clean Air Act would require the refinery to track volumes of product received and shipped. The volume of petroleum product and crude oil received, stored and shipped at BP's refinery is essential to understanding current operations that involve the South Wing and North Wing docks, and thus essential to any reasoned choice among alternatives. Without clear and accurate information, the Corps places itself and the public at risk of proceeding on mistaken assumptions, in violation of NEPA.

In addition, the Corps makes misleading statements that serve as the basis for comparing alternatives. As one example, the future traffic forecasts analyzing cumulative impacts on vessel traffic (DEIS at 5-59 – 5-62) fail to identify the Bakken reserves, Eagle Ford, or Canadian sources of crude oil that have become major drivers in the transport of petroleum products. *See* Exhibit A (explaining that "[n]ew sources of crude oil from North Dakota, Texas, and western Canada have induced new routes for shipping crude oil to U.S. and Canadian refineries"). There is no mention of these crude oil sources or the proposed projects in the Puget Sound that are likely to have a cumulative impact on traffic. The Corps does, however, recognize "the emergence of Bakken crude oil delivered by rail, construction of unloading facilities at the refinery by BP, and the market's desire to deliver crude from Alberta." DEIS at 5-58. But those references are not in the cumulative impacts section on traffic and actually downplay the impact these new sources might have on tanker traffic. DEIS at 5-58 (stating that despite these new sources of domestic crude oil, "the number of future tank ship and barge calls is more likely to continue in the mid-range or possibly low-range traffic projection" resulting in "no change or a reduction in risk" of an oil spill).

It is a "crucial cornerstone of NEPA" for federal agencies "to undertake a 'full and fair' analysis of the environmental impacts of their activities." *League of Wilderness Defenders v. Connaughton*, 3:12-cv-02271-HZ (9th Cir. 2014). The Corps' piecemeal approach of recognizing the burgeoning supply of domestic crude oil where it may be beneficial to the analysis but ignoring this fact when it is not beneficial is a far cry from the "full and fair" analysis that NEPA requires.

As another example of a misleading statement, the basis for determining the maximum capacity of the South Wing and projected future capacity of both wings lacks relevant information and is based on improper assumptions. *San Luis Obispo Mothers for Peace v. Nuclear Regulatory Comm'n*, 449 F.3d 1016, 1034 (9th Cir. 2006) (noting that one of the purposes of NEPA is "ensuring that the public can both contribute to that body of information, and can access the information that is made public"). The DEIS states that the actual greatest number of calls on South Wing, prior to operation of the North Wing in 2000, was 303. DEIS at 2-15. It then estimates the maximum capacity (number of vessel calls) of the South Wing to be 335 vessel calls per year. DEIS at 2-15. This estimate for *maximum capacity*, however, is based on numerous *averages* (i.e., average crude oil cargo size, average crude oil unloading rate, average crude oil loading time, average refined petroleum product cargo size, etc.). DEIS at 2-15. In fact, the same section later explains that maximum capacity based on the maximum number of monthly calls actually achieved in July of 1999 (33 calls) would be 396 calls per year, but would not allow for annual maintenance, weather outages, or other physical delays. DEIS at 2-15. Thus the previously stated "maximum capacity" of the South Wing should more accurately be titled the "estimated annual capacity, allowing for maintenance, weather, delays, and safe operation." Referring to the estimate of 335 vessel calls per year as the South Wing's "maximum capacity" throughout the DEIS is a misleading statement that prevents meaningful public review.

The faulty economic and projected growth assumptions identified in the DEIS lay the stage for a flawed comparison of alternatives in violation of the CEQ's regulations. Where an EIS includes an economic analysis, it cannot be misleading. *Hughes River Watershed Conservancy v. Glickman*, 81 F.3d 437, 446-48 (4th Cir. 1996) ("it is essential that the EIS not be based on misleading economic assumptions"). The Corps improperly uses the faulty data on maximum capacity of the South Wing and projected future operations to compare alternatives. *Johnston v. Davis*, 698 F.2d 1088, 1094-95 (10th Cir. 1983) (disapproving of misleading statements resulting in "an unreasonable comparison of alternatives" in an EIS). Specifically, the alternatives compared (1) the proposed action of continuing to operate the North and South Wings in the present configuration with a prohibition on use of the North Wing for loading or unloading crude oil, (2) a no action alternative prohibiting use of and requiring deconstruction of the North Wing dock, and (3) alternative A allowing continued use of both docks without a prohibition on loading or unloading crude oil at the North Wing.

In comparing these alternatives, the Corps relied heavily on two studies that looked at the incremental environmental risk of operating both wings (based on projected future traffic levels), compared with operating only the South Wing (based on "maximum capacity"). First of all, it is unclear why the Corps is comparing impacts of operating a single berth at maximum operating capacity with impacts of operating both berths at "a level of utilization projected for the years 2025 and 2030." DEIS at 6.11-1. As noted above, the actual maximum operating capacity, without reductions for delays or weather, should be quantifiable based on the size, process flow, and configuration of the facility. It should also be based on more recent data that accounts for increased supply of domestic and Canadian sources of crude oil.

Second, because the baseline information regarding maximum capacity and projected future traffic information are both based on misleading statements, as explained above, the Corps' alternatives analysis likewise is faulty. The Corps provided a skewed comparison of alternatives based on misleading statements, violating its own duties under NEPA and precluding meaningful public review.

III. The Corps defines the statement of purpose and need too narrowly.

The statement of purpose and need is central to a proper EIS because it will provide the guideposts for the analysis of actions, alternatives, and effects. 40 C.F.R. § 1502.13. As such, the EIS must include a concrete and accurate statement of purpose and need. The Corps' regulations require it to, "in all cases, exercise independent judgment in defining the purpose and need for the project from both the applicant's and public's perspective." 33 C.F.R. Part 325, App. B(9)(b)(4). It is fundamental that agencies do not avoid NEPA's requirements by unreasonably restricting the statement of purpose. *Simmons v. United States Army Corps of Eng'rs*, 120 F.3d 664, 666 (7th Cir. 1997) ("One obvious way for an agency to slip past the strictures of NEPA is to contrive a purpose so slender as to define competing 'reasonable alternatives' out of consideration (and even out of existence).") *See also Friends of Southeast's Future v. Morrison*, 153 F.3d 1059, 1066 (9th Cir. 1998) (stating that "[a]n agency may not define the objectives of its action in terms so unreasonably narrow that only one alternative from among the environmentally benign ones in the agency's power would accomplish the goals of the agency's action").

Here, it appears the Corps has blindly adopted BP's purpose and need, without considering the public perspective. The Corps states that the purpose of the North Wing was "to reduce tanker standby time in Puget Sound anchorage zones and to improve efficiency of the BP Cherry Point dock while loading and unloading petroleum transport vessels." DEIS at 1-5. The DEIS states that the need was to reduce demurrage costs due to vessels delayed because there was not enough space on the South Wing. There is no justification provided for that need in the DEIS. The Corps explains that there was no "project application" or "purpose and need for the project" for the agency to examine because the environmental review was not part of a permitting action for a newly proposed project. DEIS at 1-4. This explanation is insufficient to meet the agency's own regulations requiring it to "exercise independent judgment in defining the purpose and need for the project from both the applicant's and public's perspective." 33 C.F.R. Part 325, App. B(9)(b)(4). It also ignores the Ninth Circuit's opinion, in which the court noted that the 1996 permit stated the "Need and Purpose" of the project was to "expand a petroleum product loading/unloading facility." *See Ocean Advocates v. U.S. Army Corps of Engineers*, 402 F.3d 846, 870, (9th Cir. 2004).

Although BP's objectives may be relevant in determining the project's purpose and need, "[m]ore importantly, an agency should always consider the views of Congress, expressed, to the extent that the agency can determine them, in the agency's statutory authorization to act, as well as in other Congressional directives." *Citizens Against*

Burlington, Inc. v. Busey, 938 F.2d 190 (DC. Cir. 1991); *see also Westlands Water Dist. v. U.S. Dep't of Interior*, 376 F.3d 853, 866 (9th Cir. 2004) ("Where an action is taken pursuant to a specific statute, the statutory objectives of the project serve as a guide by which to determine the reasonableness of objectives outlined in an EIS."). Under the Rivers and Harbors Act, the Corps is tasked with reviewing then authorizing or rejecting proposals for structures that would obstruct navigation. 33 U.S.C. § 403. Combined with the Corps' independent mandate under NEPA to act as a steward for present and future generations, *see* 42 U.S.C. § 4331(b), and the prohibition against authorizing expanded capacity for crude oil in the Puget Sound under the Magnuson Amendment, 33 U.S.C. § 476, it is impossible for the Corps to equate its statutory objectives with BP's goal of continuing operations at the North Wing dock at Cherry Point. The Corps' narrowly defined purpose and need is unduly narrow in violation of NEPA.

IV. The Corps' environmental analysis violates NEPA by failing to consider a reasonable range of alternatives.

NEPA requires the Corps to evaluate a reasonable range of alternatives. The alternatives analysis is "the heart" of an EIS. 40 C.F.R. § 1502.14. An EIS must "rigorously explore and objectively evaluate all reasonable alternatives, and for alternatives which were eliminated from detailed study, briefly discuss the reasons for their having been eliminated." 40 C.F.R. § 1502.14(a); 42 U.S.C. 4332(2)(C)(iii). A "reasonable alternative" is one that is feasible, especially with regards to meeting the underlying purpose and need. 33 C.F.R. Part 325, App. B(9)(b)(5)(a). The alternatives analysis is meant to provide the federal agency and public with a "clear basis for choice among the options." 40 C.F.R. § 1502.14. Federal courts have routinely found that NEPA prevents federal agencies from effectively reducing the discussion of environmentally sound alternatives to a binary choice between granting and denying an application. *See, e.g.*, *Save Our Cumberland Mountains v. Kempthorne*, 453 F.3d 334, 345 (6th Cir. 2006). That is precisely what the Corps has done with the three alternatives set forth in the DEIS.

The DEIS fails to "[r]igorously explore and objectively evaluate all reasonable alternatives" as required by CEQ's regulations. 40 C.F.R. § 1502.14(a). The DEIS outlines just three alternatives: (1) the proposed action, (2) alternative "A" (which is a slight variation of the proposed action), and (3) a "no action" alternative. The Ninth Circuit has rejected this type of avoidance approach by agencies in the past. *See Muckleshoot Indian Tribe v. U.S. Forest Serv.*, 177 F.3d 800, 813 (9th Cir. 1999) (per curiam) (concluding that the EIS violated NEPA when the two action alternatives considered in detail were "virtually identical"). Indeed, "the evaluation of 'alternatives' mandated by NEPA is to be an evaluation of alternative means to accomplish the general goal of an action; it is not an evaluation of the alternative means by which a particular applicant can reach his goals." *Van Abbema v. Fornell*, 807 F.2d 633, 638 (7th Cir. 1986). By considering only the proposed action, a virtually identical alternative, and a no action alternative, the Corps essentially reduced the alternatives discussion to a binary choice between approving continued operations and denying continued operations. The Corps failed to consider a reasonable range of alternatives in violation of NEPA.

Here, the purpose and need of the action is to expand a petroleum product loading/unloading facility, and therefore increase the capacity for the movement of petroleum in the region. As a result the Corps must explore a range of alternatives that would meet this goal. To that end, the Corps must look at alternative locations that could be used to develop this type activity.

Specifically, the Corps must consider an alternative of not operating the North Wing while keeping the dock in place, and a separate alternative where the North Wing is deconstructed. The Corps explains that if it revokes the permit, "it may require that facilities constructed under the current permit remain in place or be removed." DEIS at 3-1. Yet in the list of alternatives, the Corps describes the "no action" option as revoking the permit and requiring removal of the North Wing, which in fact requires lots of action. The only justification the Corps provides for not considering a true "no action" alternative that would allow the North Wing to remain in place is that the North Wing will have no future use, eventually fall into disrepair and become an eyesore and public health hazard. DEIS 3-3. These impacts, however, are the types of impacts that should be discussed when considering this option as an alternative. It is not a reason for eliminating the alternative as unreasonable. This discussion also does not consider whether the North Wing could be used for some other purpose, such as refuge for wildlife. *See* 33 C.F.R. Part 325, App.B(9)(b)(5)(b) (explaining that when evaluating the "no-action" alternative, the Corps "should discuss, when appropriate, the consequences of other likely uses of a project site"). Discontinuing use of the North Wing without requiring removal is a reasonable alternative that the Corps should include, especially when combined with other options such as identifying an alternative site.

A confounding factor is that the Corps stacked the deck in favor of the proposed action by also improperly eliminating alternative sites as reasonable alternatives. The Corps' own regulations provide that "alternatives that are unavailable to the applicant, whether or not they require Federal action (permits), should normally be included in the analysis of the no-Federal-action (denial) alternative." 33 C.F.R. Part 325, App. B(9)(b)(5)(a). *See also* 33 C.F.R. Part 325, App. B(9)(b)(5)(c) ("The EIS should discuss geographic alternatives, e.g., changes in location and other site specific variables, and functional alternatives, e.g., project substitutes and design modifications."). As justification for not considering site alternatives, the Corps relied on the fact that the North Wing dock has been permitted and constructed, and thus flatly ruled out considering impacts of constructing a dock at other sites. DEIS at 3-2. The Corps' justification for not including alternative sites in its analysis is inconsistent with the agency's own regulations. The Corps should consider alternative sites. Also, the Corps need not consider a single location that could meet the goal, but must consider the expansion of capacity at several locations in concert, and the impacts resulting from this cumulative expansion alternative.

The Corps must consider alternative traffic management measures. CEQ's guidelines state that the alternatives analysis must "[i]nclude reasonable alternatives not within the jurisdiction of the lead agency" and "appropriate mitigation measures not already included in the proposed action or alternatives." 40 C.F.R. 1502.14(c), (f). In complete contrast to this express requirement, the Corps did not consider several traffic management alternative measures as potential minimization measures "because the USACE does not have jurisdiction to implement them." DEIS at 3-2. This justification is inconsistent with the CEQ guidelines. The Corps should consider the vessel traffic management measures as alternatives and minimization measures that would achieve the purpose and need. Moreover, the Corps must consider a reasonable range of operational alternatives at the site that will meet the goal of the project, but will reduce the impacts to the environment.

In sum, there are a myriad of onsite and offsite alternatives the Corps must consider and the Corps improperly eliminated or ignored identifying these reasonable alternatives to the proposed action. Instead, each of the alternatives in the Corps' analysis contemplates a lot of action with a lot of resulting impacts. By failing to comply with the essential requirement to set forth a reasonable range of alternatives, the Corps' DEIS violates NEPA.

V. The Corps improperly restricts the scope of analysis in the DEIS.

The scope of an EIS is "the range of action, alternatives, and impacts to be considered in an [EIS]." *Nw. Res. Info. Ctr., Inc. v. Nat'l Marine Fisheries Serv.*, 56 F.3d 1060 (9th Cir. 1995); 40 C.F.R. § 1508.25. By narrowly focusing on only specific impacts of the project, the Corps improperly restricted the scope of its analysis in the DEIS. The DEIS acknowledges that the Corps' own regulations and CEQ "guidelines for implementation of NEPA require that an EIS evaluate the effect of the proposed action on relevant environmental resources." ES-3. The Corps' DEIS, however, only evaluates (1) "the incremental environmental effects" when comparing operation of the South Wing at maximum operating capacity with operating both wings at forecasted future traffic levels; (2) "risk of potential accidents and oil spills" when carrying crude oil through the Puget Sound; (3) "effect of extended escorts"; and (4) "effect of discontinuing" the Huckleberry-Saddlebag route. DEIS at 1-7. It states that "[t]he EIS was prepared as required by a court-ordered review of a previous permitting action in order to address the incremental environmental risk of operating a portion of the BP Cherry Point dock." ES-1. Relying on this limited scope, the Corps explains that "operation of the refinery, tank farm, and interconnecting piping between these facilities are not part of the Project considered in the EIS." ES-3.

By restricting its analysis in the DEIS to only certain impacts of the project, the Corps has misconstrued the language of the Ninth Circuit's order and ignored NEPA's independent mandate. The Ninth Circuit remanded the case to the district court to remand to the Corps "with instructions to the Corps so it c[ould] (1) prepare a full EIS considering the impact of reasonably foreseeable increases in tanker traffic . . .." *Ocean Advocates*, 402 F.3d at 875. The court expressly ordered the Corps to prepare a *full* EIS, not simply an EIS that assesses the incremental environmental risk from vessel traffic related to operation of the North Wing dock. The court determined that a full EIS was necessary because the Corps had failed to consider the potential for increased tanker traffic when it granted the 1996 permit and subsequent permit extension.

Plus, NEPA's express terms require a full EIS to include, *inter alia*, the (1) environmental impact of the proposed action, (2) any adverse environmental effects that cannot be avoided, and (3) alternatives to the proposed action. 42 U.S.C. § 4332(2)(C). The Corps' own regulations explain:

> For those activities that require a DA permit for a major portion of a shoreside facility, the scope of analysis should extend to upland portions of the facility. For example, a shipping terminal normally requires dredging, wharves, bulkheads, berthing areas and disposal of dredged material in order to function. Permits for such activities are normally considered sufficient Federal control and responsibility to warrant extending the scope of analysis to include the upland portions of the facility.

33 C.F.R. Part 325, App. B(7)(b)(3). Operation of the North Wing dock has become part of the process flow of BP's facility at Cherry Point. Whether or not the North Wing dock is operational will, and does, have an impact on the operation of the refinery, including throughput volumes at the facility, use of the tank farm, use of the interconnecting piping between the facilities, and operations of the Rail Logistics Facility. By excluding the impacts that operation of the North Wing might have on BP's facility as a whole, the Corps has improperly ignored NEPA's requirement to consider the effects of the action.

VI. The Corps' DEIS fails to take the required "hard look" at the impacts.

NEPA requires agencies to disclose and evaluate all of the effects of a proposed action—direct, indirect, and cumulative. 40 C.F.R. § 1502.16. NEPA further defines impacts or effects to include "ecological[,] . . . economic, [and] social" impacts of a proposed action. 40 C.F.R. § 1508.8(b). Agencies must make "a reasonable, good faith, objective presentation of those impacts sufficient to foster public participation and informed decision making." *Colo. Envtl. Coal. V. Dombeck*, 185 F.3d 1162, 1177 (10th Cir. 1999). Once identified, NEPA requires federal agencies to take a "hard look" at those impacts. *Tillamook Cnty. v. U.S. Army Corps of Eng'rs*, 288 F.3d 1140, 1143 (9th Cir. 2002).

Water Quality and Land Use Impacts

The Corps' DEIS fails to identify and discuss the social, environmental and economic impacts of the proposed action and alternative A. For example, the DEIS fails to identify impacts to water quality or land use from the proposed action and alternative A. DEIS at 6.4-1 & 6.6-1. Under the land use section in particular, the DEIS notes, "[t]he Proposed Action would not cause direct effects on land use beyond those identified in the previously prepared environmental reports (ENSR 1992, 1997)." DEIS at 6.6-1. Since these reports were completed before the North Wing Dock was constructed, these reports cannot be relied on to accurately analyze impacts. Indeed, without any foundation or justification the Corps assumes that increased levels of tanker and barge traffic will not cause direct, indirect or cumulative impacts to water quality or land use.

North Wing Operations

The Corps fails to consider direct, indirect, and cumulative impacts of operating the North Wing on the operations at the facility as a whole. Foreseeable development resulting from an agency decision is an indirect impact that must be analyzed. 40 C.F.R. § 1508.25(c) (requiring the EIS to analyze direct, indirect and cumulative impacts from a federal action). *See also Davis*, 302 F.3d at 1122-23 (characterizing the growth-inducing effect of agency's approval of a highway project as an indirect impact requiring analysis). For example, of the seven future projects identified under cumulative impacts, only two of these are included in the models that analyze risk of accidents from increased vessel traffic. DEIS at 5-60.

Cherry Point Aquatic Reserve

The Corps' DEIS fails to disclose the impacts of the proposed action and alternative A in sufficient detail. For example, the Corps ignores direct, indirect and cumulative impacts to the Cherry Point Aquatic Reserve. DEIS at 6.12-4. Instead, the Corps states that the Cherry Point Aquatic Resource Management Plan was created after construction of the North Wing and at the time of construction the plan stated that existing industrial uses at Cherry Point "do not conflict with aquatic reserve status." *Id*. Yet, whether an industrial use is consistent with an aquatic reserve status is a very different question than whether an industrial use may impact the natural resources at the Cherry Point Aquatic Reserve. Additionally, the Corps may not rely on the Cherry Point Aquatic Resource Management Plan to satisfy its obligations under NEPA. *See, e.g., Klamath-Siskiyou Wildlands Center v. BLM*, 387 F.3d 989, 998 (9th Cir. 2004) (noting that "[a] non-NEPA document – let alone one prepared and adopted by a state government – cannot satisfy a federal agency's obligations under NEPA.").

On top of this, the Corps fails to identify or provide any detail as to the impactsthe proposed continued operations have on the Cherry Point Aquatic Reserve. DEIS at 6.12-4. This omission is particularly glaring given that the Corps had over 10 years to document such impacts. Simply turning a blind eye and deferring to the timing of the construction (which should have been preceded by an EIS) is insufficient to meet the Corps' requirements under NEPA. Also, the DEIS notes that ESA-listed salmon are located in the reserve and that the area is "a portion of treaty-protected U&As of local Native American Indians and [is] used by the Indians for commercial, ceremonial, and subsistence purposes." DEIS at 4.9-2. It is vital that the impacts of the proposed action and alternative A on this important resource are studied as required by NEPA.

Greenhouse Gases and Climate Change

The Corps' analysis on the impacts of increased vessel traffic on air quality and climate change is inadequate. Specifically, the Corps fails to take into account the social costs of increase green house gases as recommended by the EPA. *See* Sarah E. Light, *NEPA's Footprint: Information Disclosure as a Quasi-Carbon Tax on Agencies*, 87 Tul. L. Rev. 511, 545-46 & n.160 (Feb. 2013) (noting the EPA recommendation to the State Department to "explore . . . means to characterize the impact of the GHG emissions, including an estimate of the 'social cost of carbon' associated with potential increases of GHG emissions" in connection with the State Department's review of the Keystone XL pipeline). *See also* Interagency Working Group on Social Cost of Carbon, Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 (Feb. 2010) (attached hereto as Exhibit B). Instead, the potential impact of green house gas emissions are dismissed in the DEIS. The Corps merely notes that "[a]n increase of 85 vessels would contribute approximately 0.005 million metric tons per year CO2e, which would represent a very small fraction of all U.S. vessel traffic." DEIS at 6.8-1. To meet the "hard look" standard, the Corps must analyze the impacts of the proposed actions on air quality and climate change, as well as the social cost of carbon.

Impacts from Increased Crude Oil Trains and Oil Exports

The Corps incorrectly assumes that the "[u]se of the RLF [Rail Logistics Facility] to deliver crude oil to the refinery may displace crude oil deliveries by pipeline and/or ship." DEIS at 6.12-4. This statement fails to consider the possibility that the additional oil received by train will not then be transported through the North Wing to either domestic or international markets, thereby increasing vessel traffic.

Moreover, the White House recently loosened a decades old ban on exports of unrefined oil and may future expand this loophole as political pressure increases. *See* Christian Berthelsen and Lynn Cook, "U.S. Ruling Loosens Four-Decade Ban On Oil Exports," *The Wall Street Journal*, June 24, 2014, http://online.wsj.com/articles/u-s-ruling-would-allow-first-shipments-of-unrefined-oil-overseas-1403644494. This future change has the potential to increase vessel traffic at the South Wing and needs to be considered by the Corps.

Demurrage

The Corps equates, without any basis, time at anchor as an increase in risk exposure for vessels calling at the BP Cherry Point dock. *See* DEIS at 1-5. Figure 1-3, *see* DEIS at 1-6, supports the amount of demurrage between 1999 and 2003, but it does not support any conclusions regarding increased exposure for vessels. Because operation of the North Wing decreased demurrage time, the Corps concludes that operation of both wings reduces the risk of exposure for vessels. In addition to lacking any support for the assertion that demurrage time always means greater exposure, this analysis fails to consider that additional docking at the two berths increases the likelihood for human error because there would be a greater number of transfers for a greater number of vessels at the BP Cherry Point facility. Human error is the leading cause of marine accidents, not time at anchor. *See* Exhibit A, page 8. Each mooring, connecting, unmooring and disconnecting represents an opportunity for human error.

VII. Operation of the North Wing violates the Magnuson Amendment.

The Corps' analysis of the whether the addition of the North Wing violates the Magnuson Amendment is misleading because much of the discussion focuses on an increase in vessel traffic as opposed to the current volume of crude oil handled at the South Wing and whether the actual capacity of the South Wing will be increased because construction of the North Wing increased the facility's capacity for crude oil.

In fact, the DEIS notes in several locations that the purpose of the North Wing is to free up capacity for crude oil loading and unloading at the South Wing. The Corps states that "[t]he North Wing has reduced utilization of the South Wing for loading refined petroleum products (BP 2011)," DEIS Appendix H at 4, and that "[p]rior to the expansion, unloading and loading operations were performed at a single berth (the South Wing). The addition of the North Wing (second berth) allowed the South Wing to be dedicated to unloading crude oil and to load or unload refined petroleum product when needed (Figure 1-2)." DEIS at 1-2.

In addition, modifications to the North Wing to allow for increase capacity to load and unload crude oil likely will not trigger additional permitting. The Corps skirts this issue by focusing on the rate at which crude oil could be loaded and unloaded but not whether it is "*physically possible* to modify the new platform such that it could handle crude oil, without requiring additional permitting" as required by the 9th Circuit in *Ocean Advocates*. 402 F.3d at 874. All that would be required to accept crude oil would be for the North Wing to install "new crude oil unloading arms and a new connection to the existing Flush Line would be required to offload crude oil from a tank vessel." DEIS Appendix H. The Corps claims that a new Department of the Army (DA) Permit would be required to make these modifications as required by 33 CFR § 325.7. DEIS Appendix H at 4. But, the express language of the regulation does not require a permit for these types of modifications. Instead, the district engineer "*may* reevaluate the circumstances and conditions of any permit." 33 CFR § 325.7(a) (emphasis added). Thus it is unlikely that any future modifications to the North Wing allowing for the loading or unloading of crude oil will trigger additional permitting.

Conclusion

For all of the reasons set forth above, NEDC respectfully requests that the Corps grant a 60 extension to the public comment period and issue a corrected Supplemental DEIS for public comment.

Sincerely,

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Congressional Research Service
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Shipping U.S. Crude Oil by Water: Vessel Flag Requirements and Safety Issues

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Summary

New sources of crude oil from North Dakota, Texas, and western Canada have induced new routes for shipping crude oil to U.S. and Canadian refineries. While pipelines have traditionally been the preferred method of moving crude overland, they either are not available or have insufficient capacity to move all the crude from these locations. While rail has picked up some of this cargo, barges, and to a lesser extent tankers, also are moving increasing amounts of crude in domestic trade.

The rather sudden shift in transportation patterns raises concerns about the safety and efficiency of oil tankers and barges. The United States now imports less oil than five years ago by oceangoing tankers, while more oil is moving domestically by river and coastal barges. However, the Coast Guard still lacks a safety inspection regime for barges similar to that which has long existed for ships. The possibility of imposing an hours-of-service limit for barge crews as part of this regime is controversial. Congress called for a barge safety inspection regime a decade ago, but the related rulemaking is not complete. The Coast Guard's progress in revamping its Marine Safety Office is a related issue that Congress has examined in the past.

The majority of U.S. refineries are located near navigable waters to take advantage of economical waterborne transport for both import and export. However, for refineries switching from imported to domestic crude oil, the advantage diminishes considerably. This is because the Jones Act, a 1920 law that seeks to protect U.S. shipyards and U.S. merchant sailors in the interest of national defense, restricts domestic waterborne transport to U.S.-built and -crewed vessels. The purchase price of U.S.-built tankers is about four times the price of foreign-built tankers, and U.S. crewing costs are several times those of foreign-flag ships. The small number of U.S.-built tankers makes it difficult for shippers to charter tankers for a short period or even a single voyage, highly desirable in an oil market with shifting supply patterns. The unavailability of U.S.-built tankers may result in more oil moving by costlier, and possibly less safe, rail transport than otherwise would be the case. Some Texas oil is moving to refineries in eastern Canada, bypassing refineries in the northeastern United States, because shipping to Canada on foreign-flag vessels is much cheaper than shipping domestically on Jones Act-eligible ships.

Some of these issues may be addressed in the Coast Guard and Maritime Transportation Act of 2014 (H.R. 4005), which has passed the House, and the Coast Guard Authorization Act for Fiscal Years 2015 and 2016 (S. 2444), introduced in the Senate. The House bill requests federal agency studies and recommendations towards improving the competitiveness of the U.S.-flag industry while the Senate bill contains provisions related to oil spill response.

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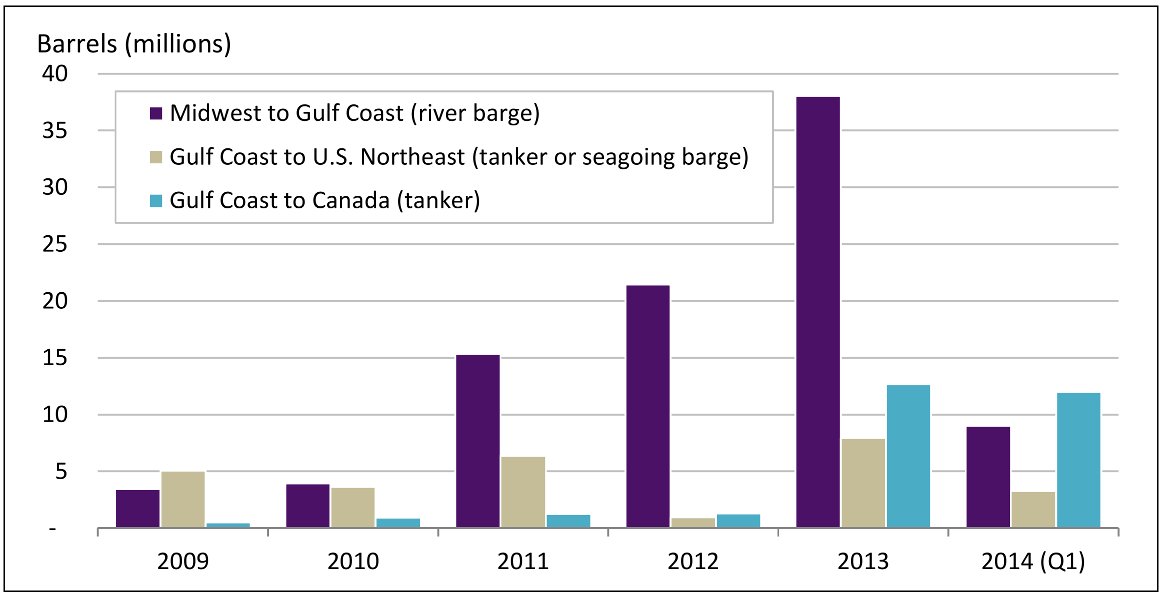
Introduction

New sources of crude oil from the Bakken region of North Dakota, the Eagle Ford and Permian basins in Texas, and western Canada have induced new routes for shipping crude oil to U.S. and Canadian refineries.[1] While pipelines have traditionally been the preferred method of moving crude overland, especially to or from landlocked locations, they either are not available or have insufficient capacity to move all the crude from these new sources of production.[2] Although much of this oil is now moving to refineries by rail,[3] waterborne transportation is playing an increasing role in moving crude oil within North America.[4] The quantity of oil moving by barge on the Mississippi River and its tributaries increased ten-fold from 2009 to 2013, and tanker shipments between the Gulf Coast and Atlantic Canada have grown at an even faster rate (**Figure 1**). There are no current data on the amount of domestic crude oil moving by barge or tanker to refineries along the Gulf Coast, but it is believed to have increased significantly since 2012.

Figure 1. Waterborne Crude Oil Movements between Selected Regions



Source: U.S. Energy Information Administration,

Two aspects of the oil industry critically influence shipping patterns: (1) not all crude oil is the same and (2) each refinery is currently equipped to refine a certain blend of crude oils. Refineries in the Northeast are predominantly configured to handle crudes from the Bakken, Eagle Ford, and

[1] For further information on "unconventional" crude oil, see CRS Report R43148, *An Overview of Unconventional Oil and Natural Gas: Resources and Federal Actions*, by Michael Ratner and Mary Tiemann, and CRS Report R42032, *The Bakken Formation: Leading Unconventional Oil Development*, by Michael Ratner et al.

[2] For further analysis on the role of pipelines in moving crude oil, see CRS Report R41668, *Keystone XL Pipeline Project: Key Issues*, by Paul W. Parfomak et al.

[3] See CRS Report R43390, *U.S. Rail Transportation of Crude Oil: Background and Issues for Congress*, by John Frittelli et al.

[4] In this report, barge refers to both a river and a seagoing barge; tanker refers to a deep-draft, self-propelled ocean-going ship; and "tank vessel" refers to both a barge and a tanker.

Permian regions, but cannot efficiently refine oil sands crude from western Canada. There is greater variety in the capabilities of refineries on the Gulf and West Coasts. Reconfiguring a refinery to handle a different type of crude is possible but may be costly. The feasibility of doing so depends on the relative costs of various types of crude, the projected availability of the various crude oils, and the price spread between crude oil and refined petroleum products such as gasoline and diesel fuel.[5]

The sudden shift toward domestic sourcing of crude oil raises issues regarding the safety and efficiency of the maritime component of this new supply chain. These fall into two main categories. One concerns the Coast Guard's role in preventing oil spills by regulating the safety of vessels and the training and working conditions of crews.[6] The other has to do with the impact of the Jones Act, a 1920 law that restricts domestic waterborne transport to vessels built in the United States and crewed by U.S. citizens, which may now be affecting U.S. producers' decisions about how to ship crude oil and whether to send it to refineries in the United States or in Canada.

New Shipping Routes

The vast majority of U.S. refineries are located along the coast (including the Great Lakes) or an inland waterway. Most coastal refineries traditionally have been supplied by imported crude, and some lack pipeline connections and may not be equipped or have the space to receive crude by rail. For this reason, large amounts of oil are being moved out of production areas by truck or rail, but are being transferred to barges or tanker ships for the last leg of the trip to a refinery.

Crude oil produced at Eagle Ford, TX, is conveniently located for waterborne transport due to its proximity to the coast. Some of it moves through the port of Corpus Christi, where outbound crude oil shipments nearly trebled from 2012 to 2013.[7] The nearby port of Victoria, TX, has also experienced a dramatic increase in crude oil barge traffic. It appears that most of the Texas crude moving by vessel goes to coastal refineries in Texas and Louisiana or to the Louisiana Offshore Oil Port (LOOP), an offshore ship-to-pipeline transfer facility. A comparatively small amount of Eagle Ford crude oil moves by water to refineries in proximity to New York Harbor and the Delaware River, but much larger quantities seem to be going to refiners in Canada's Atlantic provinces.

While much of the oil coming from the Bakken region moves to refineries by rail, there are now several well-established intermodal routes involving water transport. These include:[8]

- rail to barge at St. Louis and Hayti, MO, and Osceola, AR, on the Mississippi River, to Gulf refineries;
- rail to barge at Hennepin, IL, on the Illinois Waterway, to Gulf refineries;

[5] These factors are discussed in CRS Report R41478, *The U.S. Oil Refining Industry: Background in Changing Markets and Fuel Policies*, by Anthony Andrews et al.

[6] This report focuses on the Coast Guard's role in oil spill prevention. Regarding the agency's role in oil spill response, see CRS Report RL33705, *Oil Spills in U.S. Coastal Waters: Background and Governance*, by Jonathan L. Ramseur.

[7] http://www.portofcorpuschristi.com/index.php/general-information-155/statistics/monthly-reports.

[8] For further information on these and other routes, see BB&T Capital Markets, "Examining the Crude by Barge Opportunity," June 10, 2013.

- rail to vessel at Albany, NY, on the Hudson River, to East Coast refineries;
- rail to Yorktown, VA, for coastal transport to East Coast refineries;
- rail to vessel at Anacortes and Vancouver, WA, for coastal transport to West Coast refineries.

Pipeline to barge transfer is occurring at Cushing, OK, from where barges move the oil down the Arkansas and Mississippi Rivers to Gulf Coast refineries.

Vessel Types and Capacities

New waterborne services moving crude oil from the Bakken or Texas generally do so with smaller vessels than the trans-oceanic tankers used to carry Alaskan and imported oil. The fleet can be divided into two broad categories: "brownwater" vessels operating on inland and near-shore waters and "bluewater" vessels operating in the open ocean.

A river barge can hold 10,000 to 30,000 barrels of oil.[9] Two to three river barges are typically tied together in a single tow, and thus a river tow of tank barges could carry 20,000 to 90,000 barrels. In addition to inland rivers, this type of barge configuration is used on the intracoastal waterway (an inland canal) along the coasts of Texas and Louisiana. River barges have speeds of about 4 to 5 miles per hour (mph).

A coastal tank barge designed for open seas (an articulated tug-barge, or ATB)[10] can hold 50,000 to 185,000 barrels. However, newer ATBs can carry 240,000 to 340,000 barrels, a capacity comparable to that of coastal tankers. Seagoing barges have speeds of about 10 knots (12 mph).

In contrast to coastal tank barges, a river barge can be used in "drop and swap" operation—that is, the tugboat can drop a loaded barge at a facility where it can be used for storing product while the tugboat is free to make other barge movements—so that the relatively expensive self-propelled portion of the vessel is not tied up while unloading, as a tank ship would be. The tugs designed for ATBs sail poorly without the barge, so they seldom perform drop and swap operations.[11]

A coastal tank ship can hold 300,000 to 650,000 barrels. The coastal tankers that are being deployed to move Texas crude carry 330,000 barrels and are referred to as "handysize" or "medium range" tankers. Coastal tankers have speeds of about 12-15 knots.

For comparison, tankers moving Alaska oil to the West Coast carry between 800,000 and 1.3 million barrels of oil and fall into the "Aframax" or "Suezmax" size categories. Very large or ultra-large crude carriers (VLCCs and ULCCs) that carry imported oil from overseas hold 2 to 3 million barrels. A crude oil pipeline moves between 400,000 and 800,000 barrels per day, enough to service the largest U.S. refineries. The unit trains[12] that move Bakken and Texas crude oil can carry 70,000 to 80,000 barrels. **Table 1** summarizes conveyances for moving domestic crude oil.

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[9] A barrel of oil is equal to 42 gallons.

[10] The bow of the tug fits into a notch in the stern of the barge and the tug is hinged to the barge on both sides of its hull, allowing fore and aft (pitch) movement, such as over sea swells.

[11] George H. Reid, *Primer of Towing*, 3rd ed. (Centreville, MD: Cornell Maritime Press, 2004), p. 22.

[12] A unit train consists of only a single type of car, in this case crude oil tank cars, and is not broken up or reconfigured (continued...)

Table 1. U.S. Crude Oil Conveyances

Conveyance	Capacity (000 barrels)	Cruising Speed	Crew Size	Inventory	Operating Geography
River barge	20-90	4-5 mph	4-10	3,500-4,000*	inland rivers, intracoastal waterway
Seagoing barge (ATB)	50-300	10 knots (12 mph)	6-12	86*	coastal U.S.
Handysize product tanker	300	12-15 knots (14-18 mph)	21-28	31*	coastal U.S.
Aframax or Suezmax crude oil tanker	800-1,300	12-15 knots (14-18 mph)	21-28	11* 1,400 (foreign-flag)	Alaska to Puget Sound and California, U.S. Gulf Coast to Eastern Canada
100-car unit train	70-80	40-50 mph	2	45,000 crude oil tank cars/450 unit trains**	continental U.S., predominantly west-east
Crude oil pipeline	400-800	3-8 mph	1-2 (remote monitors)	57,500 miles	predominantly midcontinent, south-north, Alaska

Source: U.S. Department of Transportation; Army Corps of Engineers; Clarkson Research Services Ltd. *Tanker Register*.

Notes: *For domestic service, vessels must be U.S. built and U.S. flagged. **Tank car inventory increasing rapidly.

As **Table 1** indicates, the Jones Act-eligible fleet of crude oil tankers consists of 11 ships, all employed in moving Alaska crude oil to the U.S. West Coast or to a refinery in Alaska. Of the 86 seagoing barges, 42 can carry more than 130,000 barrels. While a tanker's capacity is better matched to the daily consumption rates of a single refinery than the capacity of a unit train or most barges, the limited fleet of Jones Act-eligible tankers has required some refineries with direct ocean access to ship domestic oil by barge or train or to continue to rely on foreign sources.

Jones Act-qualified ATBs and product tankers are also used to lighter ocean-going crude oil tankers.[13] Although it is technically feasible to do so, tank vessels do not readily alternate between carrying dirty oil (crude oil, residual fuel oil, asphalt) and refined (clean) petroleum products because the tanks would have to be extensively washed after carrying dirty product, a time-consuming and costly process. However, due to the recent increase in domestic crude oil production, particularly at Eagle Ford, some tonnage has shifted from the "clean" products trade to the crude oil trade.[14] Tankers that used to carry refined product from the Gulf Coast to Florida

(...continued)

between origin and destination.

[13] Lightering is the process of unloading a portion of an ocean-going tanker's load offshore, or at a harbor's entrance, to reduce the draft of the ship.

[14] Product tankers that carry chemicals are called parcel tankers, and since they have many more and smaller individual holding tanks than petroleum tankers, they would not be practicable for carrying petroleum.

(via the Port of Tampa) are now carrying crude oil because they can earn higher returns.[15] Barges are replacing them to move refined products to Florida, a development that has been blamed for higher gasoline prices in Florida.[16]

The decline of oil imports from overseas may free up some of the lightering fleet for the domestic crude trade. If West Coast refineries source more crude from the Bakken or Canada rather than Alaska, this could also free up Jones Act tankers. One such tanker is believed to have been redeployed to move crude oil from the Gulf of Mexico to the West Coast via the Panama Canal.[17] However, there is a limit to how many clean product tankers will switch to carrying crude oil. The crude oil boom has also led to a boom in U.S. refinery output, so there is also strong demand for clean product tankers.

Vessel Size Relates to Voyage Distance

The most economic tank vessel size to deploy depends largely on voyage distance. The longer the voyage, the more incentive there is to use a larger vessel because of economies of scale at sea. The first VLCCs were built when the Suez Canal was closed in the late 1960s and tankers headed from the Persian Gulf to Europe and North America had to sail longer routes around South Africa.

Larger tankers face diseconomies of scale in port: they take longer to load and unload than smaller ships, and some port charges are based on vessel size. Thus, smaller vessels are used for shorter voyages, on which a tanker will spend a greater portion of its total time in port. Aframax and Suezmax tankers, considered of medium size, are being used to ship Alaska oil from Valdez to Seattle, a distance of 1,200 nautical miles, and to Los Angeles, a distance of 2,000 nautical miles. Similar tankers carry Texas oil to eastern Canadian refineries with sailing distances ranging from 2,300 to 3,000 nautical miles.[18]

Evidence from these other trades suggests that Aframax or Suezmax tankers would be the preferred vessels for shipments from Texas ports to Delaware River and New York Harbor oil terminals, a distance of 1,900 to 2,000 nautical miles, if such tankers were available in the Jones Act-eligible fleet. The handysize tankers that are now used for this purpose may be smaller than the preferred size. Prior to carrying crude oil, these handysize tankers were moving refined product on much shorter *intra*coastal voyages, such as from Houston to Tampa. From 2001 to 2011 (before the Texas and Bakken oil boom began) the average haul of Jones Act handysize product tankers was roughly 1,000 nautical miles while the average haul for the larger Jones Act Aframax and Suezmax crude oil tankers was roughly 1,700 nautical miles.[19]

ATBs are used on much shorter coastal voyages. From 2001 to 2011, their average haul was about 420 nautical miles (the approximate sailing distance between Norfolk, VA, and Charleston, SC). Since they are somewhat slower than tankers, on longer voyages they could require an additional

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[15] "Shale Oil Has Revolutionized U.S. flagged Oil Tanker Fleet," *Petroleumworld.com*, July 1, 2013.

[16] The News Press, "Supply Shortage Fuels Gas Price Jump," November 21, 2013. According to the article, 97% of Florida's fuel is transported by vessel. The EIA also discusses the tight supply of vessels for transporting Florida's fuel; see, "The Spring Break Travel Rush and Changes in Florida's Gasoline Supply," *This Week in Petroleum*, March 26, 2014.

[17] Washington Analysis, LLC, *Energy Update: Alaska Oil Exports and Jones Act Tankers*, February 27, 2014.

[18] Tankers were identified with assistance from the U.S. Maritime Administration.

[19] U.S. Maritime Administration, *Coastal Tank Vessel Market Snapshot, 2011*, June 2012, p. 2.

day or two to reach destination. However, newer ATBs, which can be larger and faster, tend to be deployed on longer voyages. In 2010, coastal tank barges that were less than 10 years old accounted for 63% of overall coastal barge shipments less than 500 miles but 70% of the shipments 500 miles or more.[20]

Maritime Safety Issues

The large increase in domestic waterborne shipment of crude oil and refined products comes at a time when the Coast Guard is reevaluating its regulations and industry oversight. Several new regulations are pending.

New Barge Safety Regime

Barges are the workhorses in moving Bakken and Texas oil by water. However, the Coast Guard has just begun establishing a safety inspection regime for barges.

In the Coast Guard and Maritime Transportation Act of 2004 (P.L. 108-293, §415), Congress directed the Coast Guard to establish a barge safety inspection and certification regime similar to that which exists for ships. This includes establishing structural standards for vessels as well as standards for the crew. This new inspection regime will be more significant for tank barges used on rivers than for seagoing barges, because seagoing barges moving oil or other hazardous material are already inspected.[21] However, one pending rule would also apply to seagoing barges. Section 409 of the 2004 act authorized the Coast Guard to evaluate an hours-of-service limit for crews on towing vessels. This was in line with a 1999 National Transportation Safety Board (NTSB) recommendation that the Coast Guard establish scientifically based hours-of-service regulations for domestic vessel operators.[22]

On August 11, 2011, the Coast Guard issued a notice of proposed rulemaking on barge inspections and work hours.[23] In the notice, the Coast Guard states that on a schedule providing six hours of work followed by six hours of rest, as is typical on barges engaged in multi-day voyages, sleep debt accumulates and gradually increases crew members' fatigue levels.[24] ATB operators have filed comments opposed to addressing hours of service as part of this rulemaking, while maritime unions have filed comments in favor of a mandatory eight-hour rest period.[25] The NTSB filed comments reiterating its support of an eight-hour rest period. The Coast Guard has not issued final regulations.

[20] Ibid., p. 6.

[21] As per 46 U.S.C. subchapter I. River tows are subject to other regulations in Titles 33 and 46, C.F.R.

[22] NTSB, Recommendation M-99-1. The NTSB is an independent federal agency that investigates accidents in all modes of transportation and makes recommendations on how to improve safety.

[23] 76 *Federal Register* 49976-50050.

[24] See 76 *Federal Register* 49991-49997, August 11, 2011. Crews of towing vessels on the Great Lakes presently use a three-watch system as per 46 U.S.C. §8104(c).

[25] See http://www.regulations.gov, docket no. USCG-2006-24412.

Crewing Requirements of ATBs vs. Tankers

According to an original designer of the ATB, "The American coastwise shipping business has grown in a way that differs from many other nations. The high cost of manning and building ships has led over the years to a coastwise transportation network dominated by tugs and barges."[26] ATBs are sometimes referred to as "rule breakers" within the maritime industry because they operate with smaller crews.[27] The Coast Guard determines crewing requirements based on the registered tonnage of a vessel, which for barges includes only the tug, not the barges the tug may be pushing. As a result, the crew required aboard an ATB is one-third to one-half the number required aboard a tank ship; an ATB typically has a crew of 6 to 12, versus 21 to 28 for a tank ship. (The precise number for each vessel type depends on the amount of automation.)

The Coast Guard's pending decision on hours of service could force ATBs to carry larger crews, possibly negating their economic advantage compared to tankers. This occurred previously with a precursor to the ATB called the integrated tug barge: when the Coast Guard increased their manning requirements in 1981, integrated tug barges lost their economic advantage, and none have been built since.[28] The Coast Guard increased manning requirements because integrated tug barges operated essentially as ships since the tug and barge seldom separated. While ATBs are designed for easier separation of tug and barge, as noted earlier, they also seldom separate.

The distinction in crewing requirements between ships and ATBs has been criticized for distorting the domestic shipping market by encouraging the use of otherwise less efficient (and perhaps less militarily useful) barges instead of ships.[29] A counterargument is that the problem is not the small crew size on ATBs but the excessive manning requirements for coastal tankers.

Pace of Rulemaking an Issue for Congress

Congress has been concerned with the pace at which the Coast Guard is issuing barge safety regulations under the 2004 law. In the Coast Guard Authorization Act of 2010 (P.L. 111-281, §701), Congress requested that all rulemakings related to oil pollution prevention, including barge inspection, be finalized within 18 months of enactment (i.e., by April 15, 2012). The 2010 act (§702) also required the Coast Guard to promulgate additional regulations to reduce the risk of oil spills in operations involving the transfer of oil from or to a tank vessel. The Coast Guard has issued a request for public comments, but has not yet proposed regulations.[30]

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[26] Robert P. Hill, Ocean Tug & Barge Engineering, "The Articulated Tug/Barge – ATB: The History and State of the Art," http://www.oceantugbarge.com/PDF/history.pdf.

[27] See, Jeff Cowan, "The Articulated Tug Barge (ATB) Quandary," February 13, 2013; Robert P. Hill, "Responding to "The Articulated Tug Barge Quandary," April 5, 2013; and Tom Allegretti, "Safe Operation, Proven Results," April 17, 2013, all at http://www.MarineLink.com.

[28] Navigation Vessel Inspection Circular (NVIC)-2-81, February 25, 1981.

[29] IHS Global Insight, *An Evaluation of Maritime Policy in Meeting the Commercial and Security Needs of the United States*, January 7, 2009, p. 37.

[30] See 78 *Federal Register* 63235, October 23, 2013.

Performance of the Coast Guard's Marine Safety Office

The Coast Guard's ability to provide effective safety oversight of certain maritime operations has been a long-standing concern. In response to questions raised by Congress in 2007,[31] the Coast Guard acknowledged that its practice of regularly rotating staff geographically or by activity, as military organizations typically do, was hindering its ability to develop a cadre of staff with sufficient technical expertise in marine safety.[32] In response, the agency created additional civilian safety positions, converted military positions into civilian ones, and developed a long-term career path for civilian safety inspectors and investigators.[33] Despite these changes, at an October 2011 meeting to discuss inspection regulations towing operators complained about having to rehash the same issues with a "revolving door" of Coast Guard officials.[34] They also asserted that the Coast Guard was placing too much emphasis on a one-day-per-year inspection of vessels and equipment and not enough emphasis on human factors, the leading cause of marine accidents.

The number and quality of the Coast Guard's investigations and reports of marine accidents, as well as the lack of a "near-miss" reporting system, have been noted by the Department of Homeland Security Inspector General (IG) and other observers as missed opportunities to learn from past incidents. A May 2013 IG audit concluded:[35]

> The USCG does not have adequate processes to investigate, take corrective actions, and enforce Federal regulations related to the reporting of marine accidents. These conditions exist because the USCG has not developed and retained sufficient personnel, established a complete process with dedicated resources to address corrective actions, and provided adequate training to personnel on enforcement of marine accident reporting. As a result, the USCG may be delayed in identifying the causes of accidents; initiating corrective actions; and providing the findings and lessons learned to mariners, the public, and other government entities. These conditions may also delay the development of new standards, which could prevent future accidents.

The IG found that at the 11 sites it visited, two-thirds of accident inspectors and investigators did not meet the Coast Guard's own qualification standards. The IG noted that the shortage of qualified personnel would be further compounded by the new towing vessel safety regime, which would expand the inspections workload. In response to this audit, the Coast Guard stated it was developing a "Maritime Prevention Enhancement Plan" that it hoped to complete in FY2014. In the Coast Guard Authorization Act of 2010 (P.L. 111-281, §521), Congress requested an annual report from the Coast Guard assessing the adequacy of its marine safety workforce.[36]

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[31] House Committee on Transportation and Infrastructure, Subcommittee on Coast Guard and Maritime Transportation, Hearing on Challenges Facing the Coast Guard's Marine Safety Program, July 27, 2007.

[32] See the 2007 report on the Coast Guard's marine safety mission by a retired Coast Guard vice admiral at http://www.uscg.mil/hq/cg5/cg54/docs/VADM%20Card%20Report.pdf.

[33] U.S. Coast Guard, "Enhancing the Coast Guard's Marine Safety Program," September 25, 2007; http://www.uscg.mil/marinesafetyprogram/. See also *Coast Guard Proceedings*, Summer 2008, pp. 20-28, available at http://www.uscg.mil/proceedings.

[34] http://www.regulations.gov/#!documentDetail;D=USCG-2006-24412-0095.

[35] DHS, Office of Inspector General, "Marine Accident Reporting, Investigations, and Enforcement in the U.S. Coast Guard," OIG-13-92, May 2013; http://www.oig.dhs.gov/assets/Mgmt/2013/OIG_13-92_May13.pdf.

[36] This report has been delivered to Congress; http://www.uscg.mil/hq/cg8/cg82/.

The Jones Act

The Jones Act requires that vessels transporting cargo between two U.S. points be built in the United States, crewed by U.S. citizens, and at least 75% owned by U.S. citizens.[37] The law was enacted in 1920 (Merchant Marine Act of 1920, §27, P.L. 66-261).[38] One of the motivations for the U.S.-build requirement was to facilitate the disposal of cargo ships constructed during World War I by the U.S. Shipping Board, a government agency set up in 1916 to purchase, construct, and operate merchant ships during the war. The Jones Act authorized the sale of these vessels to the private sector.[39]

The Jones Act stated an explicit national policy of supporting a U.S. merchant marine and a U.S. shipbuilding industry in the interest of national defense. That policy remains in the law today:[40]

> It is necessary for the national defense and the development of the domestic and foreign commerce of the United States that the United States have a merchant marine (1) sufficient to carry the waterborne domestic commerce and a substantial part of the waterborne export and import foreign commerce of the United States and to provide shipping service essential for maintaining the flow of waterborne domestic and foreign commerce at all times; (2) capable of serving as a naval and military auxiliary in time of war or national emergency; (3) owned and operated as vessels of the United States by citizens of the United States; (4) composed of the best-equipped, safest, and most suitable types of vessels constructed in the United States and manned with a trained and efficient citizen personnel; and (5) supplemented by efficient facilities for building and repairing vessels.

Because of the restrictions on shipbuilding and crewing, Jones Act ships tend to be more costly to build and operate than vessels used by foreign-flag ocean carriers, which can order vessels from whichever shipyards offer the lowest bids and typically hire most of their crew members from countries where seafarers' wages are much lower than in the United States.

Jones Act Shipping Rates

According to oil shippers, the price for moving crude oil from the Gulf Coast to the U.S. Northeast on Jones Act tankers is $5 to $6 per barrel, while moving it to eastern Canada on foreign-flag tankers is $2.[41] For a Texas oil producer using a tanker with capacity of 300,000 barrels, this rate difference amounts to receiving $1 million less for a shipment of oil to a U.S. refinery than for a shipment to a more distant Canadian refinery. In consequence, from January

[37] The law is codified at Title 46 U.S.C. Chapter 121, Documentation of Vessels (46 U.S.C. §§12101-12152) and Title 46 U.S.C. Chapter 551, Coastwise Trade (46 U.S.C. §§55101-55121).

[38] The Act was named after Senator Wesley L. Jones, Washington State, Chairman of the Senate Interstate and Foreign Commerce Committee, who also included a provision to ensure that trade between Alaska and the lower 48 states not be shipped through Vancouver, Canada (to the benefit of Seattle).

[39] The ships were sold for about one-tenth the cost of construction. They had high-speed engines and other features that were useful for military operation, but that made them relatively costly to operate in commercial service.

[40] 46 U.S.C. §50101.

[41] *Bloomberg Businessweek*, "U.S. Law Restricting Foreign Ships Leads to Higher Gas Prices," December 12, 2013; *Platts Oilgram News*, "Regulation and Environment," September 9, 2013. See also Senate Committee on Energy and Natural Resources, Testimony of Faisel Khan, Managing Director, Integrated Oil and Gas Research, Citigroup. Hearing to Explore the Effects of Ongoing Changes in Domestic Oil Production, Refining and Distribution on U.S. Gasoline and Fuel Prices, July 16, 2013.

2013 through March 2014, more than twice as much Gulf Coast crude oil was shipped by water to Canada as was shipped to U.S. Northeast refineries.

Refineries in the U.S. Northeast consumed about 12 times as much crude oil from fields offshore of eastern Canada as oil shipped from the Gulf Coast in all of 2013. They also consumed imports from Nigeria, Saudi Arabia, and other countries. Shipping rates for these imports, regardless of country of origin, are much lower than domestic shipping rates for Gulf Coast oil (**Table 2**).[42] (Shipping oil from the Gulf Coast to eastern Canada costs more than shipping it from Africa to the U.S. Northeast because ice-class tankers must be used to serve Canadian refineries for a portion of the year.)

Table 2. Ocean Shipping Rates to U.S. Northeast Refineries

Dollars per barrel

Origin	**Estimated Rate**
U.S. Gulf Coast	$5.00-$6.00
Eastern Canada	$1.20
Nigeria	$1.45-$1.70
Saudi Arabia	$1.90

Source: *Platts Oilgram News*, "Regulation and Environment," September 9, 2013; *Platts OilGram Price Report*, McGraw Hill Financial, January-April, 2014.

Although there is currently no Bakken oil moving from Washington or Oregon ports to California refineries, the cost aboard a Jones Act tanker is estimated to be $4 to $5 per barrel; as the oil would have to move from the Bakken region to the ports by rail at a cost of about $9 per barrel, the total shipping cost would be $13 to $14 per barrel. The cost of shipping Eagle Ford oil through the Panama Canal to these refineries is estimated to be $10 per barrel.[43] By comparison, shipping oil from Ecuador to West Coast refineries costs around $3.25 per barrel, and Iraqi oil about $2.30 per barrel.[44]

Jones Act rates for shipping Alaska oil to West Coast refineries are not available, but Bakken oil shipped by rail to Pacific Northwest refineries is beginning to displace Alaskan oil. Alaska oil producers could look to resume exports to Asia to replace lost shipments to the U.S. West Coast. However, as specified by Congress when it lifted the export ban on Alaska North Slope oil in 1995 (P.L. 104-58), the oil must be exported on U.S.-crewed and -flagged tankers, although the tankers do not need to be U.S. built. After the Alaska export ban was lifted, roughly 5%-7% of Alaskan oil was exported, mostly to South Korea, Japan, and China, but exports ceased in 2000.[45]

In the case of crude oil, the price coastal refineries are willing to pay is based on the international price of oil, as a refinery has no way to raise the prices of gasoline and other refined products if

[42] *OilGram Price Report*, McGraw Hill Financial, January-April, 2014.

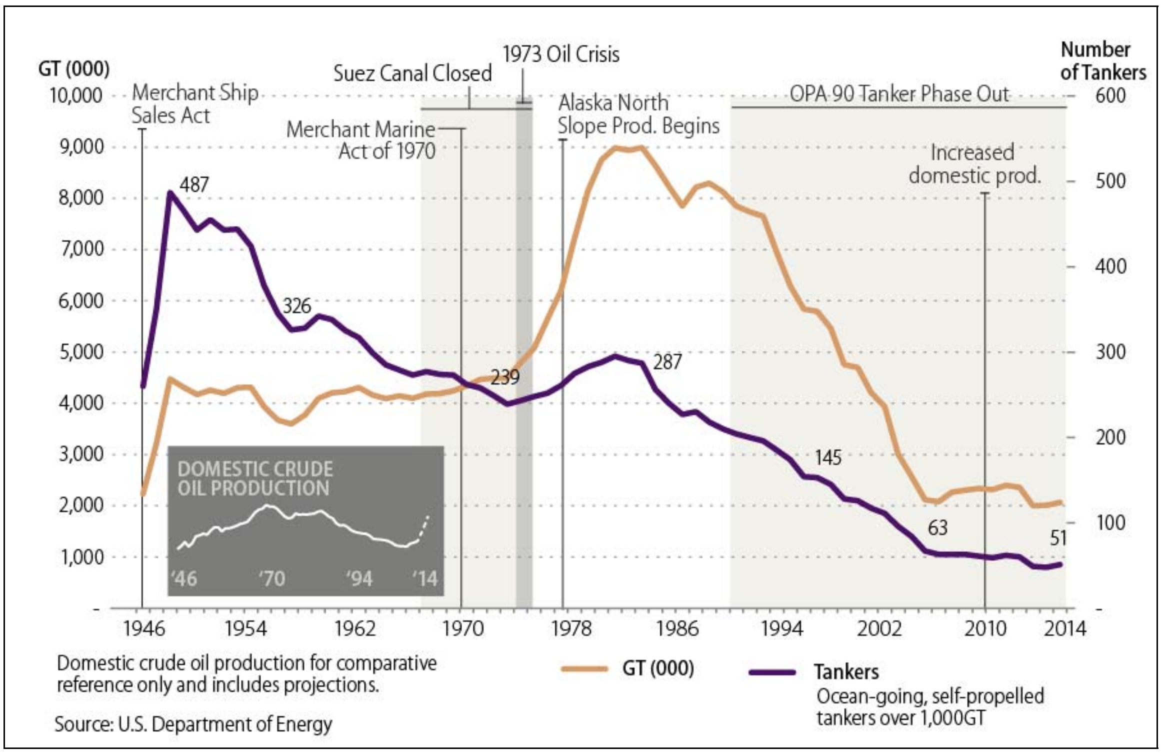
[43] En*Vantage, Inc., "The Surge in US Crude Oil Production," Presentation to PFAA 20th Annual Conference, October 24, 2013; http://www.pfaa-online.com/docs/2013/AC/8EnVantage-PFAA-Oil-Presentation-102413.pdf.; Bloomberg, "Texas Vies with Saudi Arabian Oil in California Shipments," January 29, 2014.

[44] *OilGram Price Report*, McGraw Hill Financial, January-April 2014 reports.

[45] U.S. Energy Information Administration, Petroleum and Other Liquids, Imports/Exports and Movements, http://www.eia.gov/petroleum/data.cfm#imports.

its transportation costs are higher than those of its competitors. In order to minimize transportation costs, U.S. oil shippers have favored barges over ships for coastwise transport, but this may have reduced the shipment distances over which domestic waterborne oil is price competitive. The long-term decline in the amount of petroleum carried domestically by tankers is reflected in the diminished capacity of the privately owned Jones Act-eligible tanker fleet (see **Figure 2**). Following World War II, the relatively small U.S.-flag tankers in international service were gradually replaced by much larger foreign-built tankers. Many of the Jones Act-eligible tankers in domestic service were replaced by tank barges following enactment of a double-hull requirement for tank vessels in the Oil Pollution Act of 1990. The decline of oil production in Alaska, which has fallen by about 46% over the last decade, also contributed to reduced demand for Jones Act-eligible crude oil tankers, causing some to be scrapped.

Figure 2. U.S.-Flag Privately-Owned Tanker Fleet



Source: CRS modification of figure from U.S. Maritime Administration.

Notes: GT= gross tonnage, an indication of the cargo capacity of a ship. Figures pertain to both Jones Act (domestic) and international tankers.

Domestic Tanker Construction Costs

According to data from the U.S. Maritime Administration (MARAD), an agency of the U.S. Department of Transportation, and from industry sources, the cost of domestically built tankers is approximately four times the cost of tankers of similar size built in foreign shipyards (**Table 3**). Almost all oceangoing tankers are built in Asia; in 2012, Korean shipyards received 60% of worldwide orders for new tankers, Chinese yards 30%, and Japanese yards 8% (measured by ship capacity). U.S. shipyards' prices are higher even though major ship components, like the engines, are built in foreign yards. The purchase price of new river tugs and barges in the United States is not considered to be as great a deterrent to river transport, perhaps because barges are simpler to build and are ordered in sufficient quantities that shipyards can achieve some economies of scale.[46]

As **Table 3** indicates, tank ships are more expensive to build than ATBs. They require more scantling (interior framing) and more freeboard (the height of the hull from the water to the deck) than barges. However, tank ships have significant advantages over barges. They can operate in more adverse weather conditions than ATBs, are faster, and have superior fuel economy. The U.S. Energy Information Administration estimated in 2012 that the cost of moving crude oil from the Gulf Coast to Northeast refineries by tanker would be about half the cost of moving it by barge—not counting the cost of construction.[47] This suggests that tankers could have a competitive advantage over barges on longer coastal voyages if domestic shipbuilding costs were lower or if foreign-built tankers could be employed.

Table 3. U.S. and World Prices for Tanker Vessels

(Cost of a newbuild, based on recent deliveries or construction contract announcements)

Vessel Type	Capacity	U.S. Price	World Price
Handysize product tanker (aka medium-range tanker)	40,000-50,000 dwt 330,000 bbl	$100-$135 million	$30-$35 million
Ocean-going ATB (smaller)	27,000 dwt 185,000 bbl	$60-$85 million	not available
Ocean-going ATB (larger)	45,000 dwt 250,000-300,000 bbl	$100-$130 million	not available
Aframax tanker	80,000-120,000 dwt 650,000-800,000 bbl	$200 million	$45-$55 million
Suezmax tanker	130,000-160,000 dwt 1 million bbl	No recent builds	$55-$65 million
Very Large Crude Carrier (VLCC)	200,000-320,000 dwt 2 million bbl	No recent builds	$90-$100 million

Source: U.S. Maritime Administration, Title XI Ship Financing Guarantees, Pending and Approved Loan Applications; American Petroleum Tankers S-1 SEC Filing; RBN Energy LLC; RS Platou Economic Research, annual and monthly reports; press releases from Kinder Morgan, Teekay Tankers, Scorpio Tankers, Euronav; Poten and Partners, *Weekly Tanker Opinion*.

The Tariff Act of 1930 (19 U.S.C. §1466), requires that U.S.-flag ships pay a 50% *ad valorem* duty on any non-emergency repairs conducted in foreign shipyards. A 2011 MARAD study[48] of

[46] U.S. shipyards have recently been able to export offshore supply vessels (servicing offshore oil platforms), indicating more competitiveness in this category of vessels as well.

[47] U.S. Energy Information Administration, "Additional Information on Jones Act Vessels' Potential Role in Northeast Refinery Closures," May 11, 2012.

[48] U.S. Maritime Administration, *Comparison of U.S. and Foreign-Flag Operating Costs*, September 2011.

ships operating in international trade found that ship repair costs for U.S.-flag ships are 1.3 times those of foreign-flag ships. The MARAD study found that many U.S. ships have repairs performed in foreign yards because, even with the 50% duty, the total cost is less than if the repairs were performed in a U.S. domestic shipyard.

U.S.-Flag Vessel Operating Costs

A 2011 MARAD study comparing U.S.-flag versus foreign-flag operating costs in international trade found that U.S.-flag vessels' operating costs were substantially higher—2.7 times higher. (This higher operating cost does not reflect higher domestic construction costs, because U.S.-flag ships engaging in international trade do not have to be built in the United States.) The study estimated the average daily operating cost of a foreign-flag ship to be under $6,000.[49] A separate MARAD study in June 2012 estimated the daily operating cost of a Jones Act tanker to be $22,000, which would be about 3.7 times the operating cost of a foreign-flag tanker. A major reason U.S.-flag vessels cost more to operate is that they are crewed by U.S. citizens. The crews on most foreign-flag ships are drawn mainly from poor countries and are paid significantly less than U.S. merchant seafarers.

According to MARAD, the daily operating cost of an ATB ($13,000) is almost half that of a U.S.-flag tanker ($22,000).[50] Since an ATB might travel two to three knots slower than a tanker, it might require additional sailing time. On a voyage from Texas to New York, an ATB would require two additional sailing days, reducing the ATB's cost savings over a tanker to about one-quarter, assuming that the vessels carry similar amounts of oil. However, only five ATBs in the Jones Act fleet match the capacity of a handysize tanker (330,000 barrels). Most ATBs now in use carry half as much oil as a tanker, thus requiring two voyages to match the capacity of a tanker; their operating cost per barrel of oil on this comparatively long voyage is likely to be higher than that of a tanker. A large tanker carrying oil from Nigeria to the U.S. East Coast, requiring two weeks sailing time, would be expected to have lower overall operating costs and lower operating costs per barrel than a U.S.-flag tanker ship or ATB making the much shorter domestic voyage.

The Missing Triangle Trade

One consequence of the relatively high cost of building and operating Jones Act tankers is that they cannot compete effectively for international cargo. This results in Jones Act tankers sailing empty much of the time, further raising shipowners' costs.

A key aspect to improving the economic competitiveness of freight carriers is reducing empty travel miles. If Jones Act product tankers were price competitive in the international market, they could triangulate their trade routes, perhaps moving diesel fuel from Gulf Coast refineries to Europe, then carrying European gasoline to the U.S. Atlantic Coast before sailing in ballast (carrying only ballast water for stability) to the Gulf Coast to repeat.[51] In this triangular route, two out of three voyages would generate revenue and the ballast sailing distance would amount to 18% of the total sailing distance. With their costs rendering them uncompetitive on international routes, however, Jones Act product tankers typically sail "piston" routes, carrying crude oil or

[49] U.S. Maritime Administration, *Comparison of U.S. and Foreign-Flag Operating Costs*, September 2011.

[50] U.S. Maritime Administration, *Coastal Tank Vessel Market Snapshot, 2011*, June 2012, p. 6.

[51] Michael D. Tusiani, *The Petroleum Shipping Industry* (Tulsa, OK: PennWell, 1996).

refined products from the Gulf Coast to the East Coast and then returning in ballast, thus earning revenue on only half the trip.

A peculiar triangular trade has developed to circumvent the Jones Act requirements. This involves Gulf Coast refineries shipping gasoline to the Bahamas, where additives are mixed in before the product is moved to the U.S. Northeast. So long as the product is processed in the Bahamas, both water movements can be made in foreign-flag tankers.[52] The savings from using foreign-flag shipping are apparently greater than the cost of an additional tanker unloading and loading operation.

Chartering and the Jones Act

Because of the Jones Act, U.S. oil shippers also cannot take advantage of the current surplus in the world tanker fleet, caused in part by the drop-off in crude oil shipments to the United States. If it were accessible, chartering could be done on a spot basis (for a single voyage) or on a time basis (for six months to two years). Given the rapid changes in the U.S. oil market, some shippers might prefer the flexibility of chartering to the long-term financial commitment required to build a pipeline or a rail terminal. However, the number of Jones Act-qualified tankers is small, and most appear to be tied up in charters lasting several years. Current Jones Act charter rates are $75,000 to $100,000 per day, up from about $50,000 per day in the 2010 through 2012 period.[53] In the world market, charter rates for tankers of similar size ("medium range") have fluctuated around $10,000 per day for spot charters and $15,000 per day for 12-month time charters.[54]

A spot market is also valuable because it lowers the overall cost of moving oil for everyone by adding fluidity to tanker supply. For instance, the sailing times of tankers cannot always be synchronized exactly with loading schedules. If an oil company's tanker is two weeks early for a shipment, rather than idling its tanker for that time, the company can re-let the tanker in the spot market for someone else's use. The oil company could then charter someone else's tanker for its intended shipment. In other words, by pooling the tanker supply in the spot market, the fleet is used more efficiently. By segregating the domestic shipping market from the international market, the Jones Act undermines a competitive advantage of tankers against pipelines, namely their status as mobile assets that can be redeployed in response to market changes.

Waterborne vs. Pipeline

Before the advent of oil produced from shale deposits and its movement by rail, tank vessels and pipelines were the primary options for moving oil. Both modes can move crude oil to refineries in lot sizes of hundreds of thousands of barrels, fitting a large refinery's daily intake needs. Economies of scale are important to both, but installing a larger pipe reduces the transportation cost per barrel more rapidly for pipelines than building a larger vessel does for ship lines. For this reason, oil companies typically share use of a large pipeline rather than building smaller individual pipelines. Pipelines face a disadvantage in that they must acquire, build, maintain, and pay property taxes on their rights of way, not only for the pipe but also for the pumping stations, whereas navigation infrastructure in harbors (shipping channels) and on inland waterways (locks

52 Reuters, "Customs About-face Could Make Bahamas Key Source For U.S. Gasoline," April 23, 2014.

53 RBN Energy LLC, "Rock The Boat – Don't Rock The Boat – The Jones Act Coastal Trade," January 12, 2014.

54 RS Platou Economic Research, Monthly Report – May 2014; http://www.platou.com/dnn_site/Default.aspx

and dams) is largely provided by the federal government. As indicated in **Table 1**, pipelines move product between 3 and 8 mph, so tankers have a speed advantage. This can be important when oil prices are volatile. On the other hand, pipelines are extremely dependable in delivering product on time, so little safety stock is needed.

Economies of Scale Diverge

Over recent decades, pipeline operators have managed to ship more oil with less pipe. Pipeline mileage leveled off in the 1980s. Since then, miles of trunk line have actually decreased but capacity has increased because the pipes are larger in diameter.[55] The amount of oil carried per mile of trunk line pipe is about 37% higher today than it was in the 1980s.

In contrast, Jones Act carriers are utilizing smaller, rather than larger, vessels to transport oil, a result of increasingly relying on barges rather than tankers in coastwise transport. In 1980, barges represented 39% of the total cargo capacity of the tank vessel fleet (barges and tankers).[56] In 2012, barges accounted for 82% of the total cargo capacity and carried about 65% of the coastwise refined product tonnage. The shift from tankers to barges is significant, because what should be the least-cost method for transporting crude oil and petroleum products is being utilized less than it might be in favor of a method that is cost-competitive due only to regulation.

The divergence in economies of scale between the pipeline and waterborne modes parallels a trend in their respective modal shares. In 1979, pipelines handled 58% of crude oil shipments (measured in ton-miles)[57] and waterborne carriers 41%. For refined products, 44% moved by pipeline and 48% by water. By 2009, pipelines were carrying 80% of crude oil shipments to 19% for ships and barges, and 63% of refined products movements went by pipeline as opposed to 26% by water.[58] Part of the reason for the change in modal share in refined product was a sharp decline in use of residual fuel oil for heat and power, which affected waterborne market share.[59] Today, tanker ships are used in domestic trade primarily where there is no pipeline service, as with crude oil shipments from Alaska to the lower 48 states and gasoline shipments from the Gulf Coast to Florida.

Pipelines appear to be preferred over river transport as well. Pipelines are used heavily to move Gulf Coast crude oil north to the Upper Midwest, carrying about 30 million barrels a month, whereas barges do not carry any crude oil upriver on the Mississippi waterway system. Barges have less than 10% of the market for refined products moving between the Gulf Coast and the Upper Midwest.

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[55] Pipeline statistics are available from *Oil and Gas Journal*.

[56] U.S. Army Corps of Engineers, Navigation Data Center; http://www.navigationdatacenter.us/.

[57] A ton-mile is one ton of freight moved one mile.

[58] Association of Oil Pipelines, *Shifts in Petroleum Transportation*, data reproduced by the Bureau of Transportation Statistics, *National Transportation Statistics,* Table 1-61; http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_61.html.

[59] Federal Trade Commission, Bureau of Economics, *The Petroleum Industry: Mergers, Structural Change, and Antitrust Enforcement,* August 2004, p. 210. A potential decline in the use of heating oil in New England, in favor of natural gas, similarly might affect waterborne and pipeline share in the future because much of the heating oil is carried by barge from New York Harbor.

Waterborne vs. Pipeline for Coastal Transport of Refined Products

Since production of refined products is more geographically dispersed than it is for crude oil, the competition between tanker and pipeline for moving refined products is more prevalent. A shift in relative costs between the two modes can change modal shares significantly, as happened in the early 1960s when the Colonial Pipeline was built.

By far the highest volume domestic route for shipping U.S. petroleum liquids is from the Gulf Coast to the Northeast. The U.S. government built two pipelines along the East Coast during World War II after German submarines sank 48 U.S. coastal tankers in four months. After the war, the pipelines were sold to private interests, and one was converted to natural gas. Despite the pipeline, the route continued to be the most important for U.S.-flag product tankers.

In the summer of 1961, U.S. seafarers staged an 18-day strike which idled 114 ships on the Gulf to East Coast run. It ended with a federal injunction, but with issues mostly unsettled. U.S. seafarers achieved higher wages but no success against using foreign-flag tankers to import oil. In 1962, nine oil companies announced plans to build a 22" to 36" pipeline from Houston to New York Harbor to move 600,000 barrels a day of refined product. The oil companies cited maritime strike disruptions and higher seafarer wages, along with new pipeline technology allowing for larger-diameter pipe, as reasons why the pipeline would be more economical than ships. The maritime industry estimated the pipeline would take one-third of its cargo and reduce fleet size by 50 tankers. The need for the pipeline depended upon continuation of federal restrictions on the amount of oil that could be imported. It was believed that if the import restrictions were lifted, the pipeline might not be built because the foreign-flag supertankers then coming into use could deliver foreign oil and refined products to the U.S. Northeast more cheaply than the pipeline could bring refined products from Texas. The Colonial Pipeline was completed in 1963. Automation was then increased aboard Jones Act tankers to reduce crew sizes and improve ships' competitiveness against the pipeline. At about the same time, three maritime strikes on the West Coast induced plans for a West Coast refined products pipeline. In 1965, a pipeline was completed from Puget Sound refineries to Portland, OR.

Today, the Gulf Coast ships approximately 75 million barrels per month of refined products to East Coast states by pipeline. About 15 million barrels per month move to East Coast states by tanker or barge, mostly to Florida, which receives no pipeline service. The East Coast imports about 30 million barrels per month of refined products, about a third from Canada and the rest from Europe, Nigeria, and Venezuela. Meanwhile, the Gulf Coast exports 75 million to 100 million barrels per month of refined products.

On the West Coast, Oregon receives 90% of its refined product from refineries in Puget Sound via pipeline and some from California by vessel. The Gulf Coast ships less than 5 million barrels per month of refined products to California by pipeline and nothing by vessel (via the Panama Canal). Although California is the third-largest state in terms of refining capacity, it also imports a substantial portion of its refined product needs, mostly from the Pacific Rim, Mexico, and Africa.

Waterborne vs. Railroad Options

For the many refineries located on the coasts, the cost of rail versus vessel transport is particularly relevant. Phillips 66 has chartered two Jones Act product tankers to move crude oil from Eagle Ford, TX, to its Bayway refinery in Linden, NJ (in proximity to New York harbor). The company also supplies that refinery with Bakken oil via railroad (or rail to barge via the Port of Albany), as well as with imported oil from West Africa.[60] The refinery has a capacity of 238,000 barrels per day.

Rail and coastal transport are competitors in supplying crude oil to the coastal refineries that process similar types of crude. Vessels, especially tankers, have superior economics in moving crude, which is why so many refineries are located on the water. A 330,000-barrel tank ship can move the equivalent of four to five unit trains of oil. A larger tanker, of the size used in the Alaska

[60] Phillips 66, Earnings Conference Call, October 30, 2013, Q&A.

trade, can move the equivalent of 15 unit trains. With the median capacity for U.S. refineries of about 160,000 barrels per day, even the smallest tankers can carry a two-day supply of oil. Rail loading and unloading terminals are being built to accommodate four to five trains per day to match a refinery's delivery needs; the challenge has been developing high-speed pumping equipment that can load/unload an entire train (100 to 120 tank cars) in sufficient time to avoid train backups at terminals (a unit train is over a mile long). On the other hand, coastal refineries already have docks and pumping facilities to receive vessels. Moreover, railroads must build and maintain track and pay property taxes on their rights of way, whereas the cost of building and maintaining navigation channels in harbors is largely born by the federal government. For these reasons, tanker should be significantly cheaper than rail for transport of crude oil, even when the water route is much longer.

A round-trip voyage from the Gulf to the Northeast might take two weeks. Thus, to sustain a supply chain for one refinery, a fleet of several tankers would be needed. As Jones Act-eligible tankers are in very short supply, however, refineries such as Bayway utilize waterborne transport as a supplement to the more expensive rail option from the Bakken. Phillips 66 has stated that if Jones Act eligible tankers were available, it would run 100,000 barrels a day of Gulf Coast oil to this refinery.[61] In 2013, an average of 22,000 barrels a day of Gulf Coast oil was shipped to all seven U.S. Northeast refineries.[62] By rail, Bayway alone receives 50,000 barrels per day and is completing a rail terminal with capacity to unload 75,000 barrels a day.

Eagle Ford crude oil is not currently shipped to California refineries, but such shipments are estimated to cost $14.50 per barrel.[63] The estimated cost of shipping Eagle Ford oil in Jones Act tankers to California through the Panama Canal is $10 per barrel. Again, the water route is cheaper than rail even though the railroad route is only one-fourth the length of the water route. The Panama Canal route would also be cheaper than moving Bakken oil to California refineries via rail to the Pacific Northwest followed by coastwise vessel transport to California, with a total cost of $13 to $14 per barrel.[64] When the Panama Canal's expansion project is completed in 2015, tankers with capacity of 600,000 barrels will be able to pass through, twice the size of the largest tankers using the canal today. This would further increase the cost advantage of ocean transport, if Jones Act-eligible vessels of that size are available.[65]

[61] Phillips 66 presentation at Bank of America Merrill Lynch Refining Conference, March 6, 2014.

[62] According to EIA, *Crude Oil Movements by Tanker and Barge between PADD Districts*; http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MCRMTP1P31&f=M.

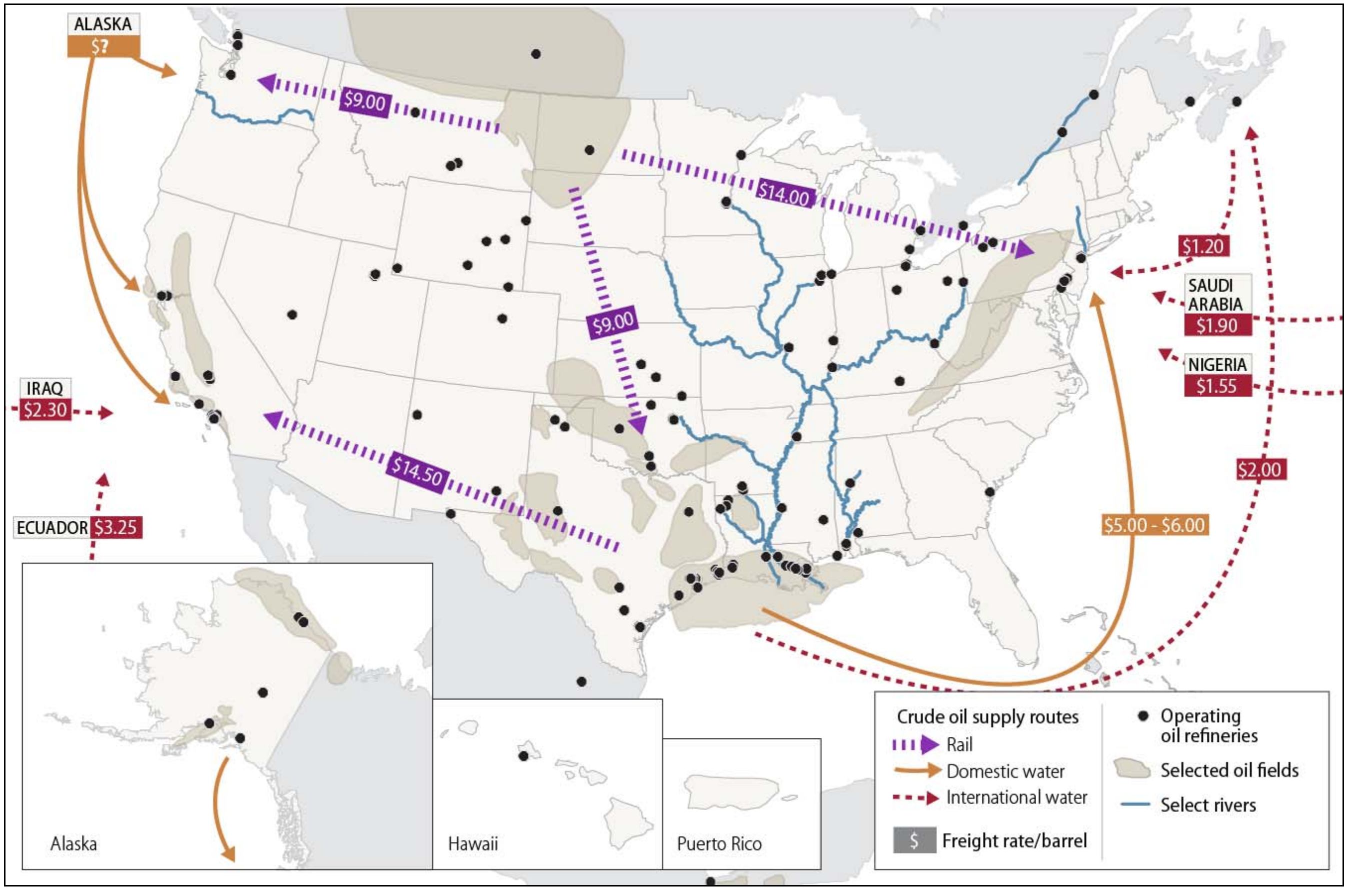
[63] En*Vantage, Inc., "The Surge in US Crude Oil Production," Presentation to PFAA 20th Annual Conference, October 24, 2013; http://www.pfaa-online.com/docs/2013/AC/8EnVantage-PFAA-Oil-Presentation-102413.pdf

[64] En*Vantage, Inc., "The Surge in US Crude Oil Production," Presentation to PFAA 20th Annual Conference, October 24, 2013; http://www.pfaa-online.com/docs/2013/AC/8EnVantage-PFAA-Oil-Presentation-102413.pdf.

[65] When Alaskan oil began flowing in 1977, West Coast refineries could not handle all the oil. The excess was shipped from Valdez, AK, to Panama on supertankers and transferred there to smaller tankers that could fit through the canal's locks en route to Gulf and East Coast. The high cost of this shipping route ($4 to $5.25 per barrel) led to calls for allowing exports of Alaskan oil to Japan and Korea (with shipping costs of $0.60 per barrel). Later, a pipeline was built across Panama to replace the vessel transit through the Canal.

Figure 3. Selected Water and Rail Crude Oil Supply Routes

(Freight rates per barrel)



Source: Graphic created by CRS. Map boundaries and information generated using HSIP Gold 2013 – For Official Use Only (Platts); Esri Data & Maps (2013); U.S. Census (2013). Shipping rates approximated from those reported by Turner, Mason & Co. in Platts *Oilgram Price Report*, January-April 2014 issues, and as footnoted in text.

It is not inconceivable that tankers could also play a role in moving Bakken oil to East or West Coast refineries, although the route would be circuitous compared to rail. Significant amounts of Bakken oil are moved to Gulf Coast terminals by a combination of pipeline, railroad, and barge for refining within that region. From a Gulf Coast port, tankers could transport the oil either to East or West Coast refineries. Existing rail and pipeline connections serve Great Lakes ports, from which tankers could move Bakken oil to Northeast refineries. The experience of agricultural producers in the upper Midwest, however, suggests that these two routing options are not economically feasible because of the Jones Act.[66]

Notwithstanding the U.S.-flag requirement for Alaska oil exports, the situation is somewhat similar to that of Texas oil in that higher domestic shipping rates encourage sales to foreign buyers. This shipping pattern is not unique to oil. In the 1960s and 1970s, the U.S. lumber industry in Washington and Oregon asserted that the Jones Act hindered its ability to compete with western Canadian lumber that could be shipped at cheaper international freight rates to the U.S. east coast. Today, Oregon and Washington are still large waterborne shippers of forest products, but all their products shipped by water are exported while all the forest products the East Coast receives by vessel are imported.[67] Other bulk shippers have made similar assertions.[68]

Waterborne Transport and Concerns about Rail Safety

If Eagle Ford, and possibly Bakken oil producers were able to access foreign-flag tankers at international rates of around $2 or perhaps less per barrel, some of their domestic oil shipments would likely shift from rail to water.[69] That shift could be beneficial in terms of the safety of oil transport, although the allowance of foreign-flag tankers could potentially displace U.S. seafarer jobs.

Congress is greatly concerned about the safety of shipping crude oil by rail. Existing railroad tank cars are inadequately designed to prevent release of product during derailment, and the transportation of crude oil in unit trains, a new development, has meant that a single incident can involve a large quantity of flammable and explosive material. Incidents involving unit trains of crude oil have caused numerous fires and explosions, requiring evacuations and in one case resulting in 47 fatalities.[70] Railroads have increased track and equipment inspections on oil routes, and have reduced the speeds of unit trains of crude oil through populated areas. However, recent incidents have shown that a high proportion of derailed tank cars will puncture and release

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[66] Grain and feed producers in the upper Midwest contend that while they can move product economically by barge to New Orleans or by rail to a Great Lakes port, from there, because of the Jones Act, they have no economical access to dry bulk ships that could deliver the feed to eastern North Carolina hog and poultry farms. These farms import their feed from Canada and South America, See, for instance, "Can Soybeans Compete?" *Top Producer*, Spring 2005.

[67] U.S. Army Corps of Engineers, Navigation Data Center, http://www.navigationdatacenter.us/wcsc/wcsc.htm.

[68] These include grain and feed, scrap metal, and road salt producers. See U.S. Congress, House Committee on Transportation and Infrastructure, Subcommittee on Coast Guard and Maritime Transportation, *The Impact of U.S. Coastwise Trade Laws on the Transportation System in the United States*, 104th Cong., 2nd sess., 1996, 104-66.

[69] See, for example, the comments of the CEO of Phillips 66 during the company's earnings conference call, July 31, 2013.

[70] For details, see CRS Report R43390, *U.S. Rail Transportation of Crude Oil: Background and Issues for Congress*, by John Frittelli et al.

product even at much lower speeds. The capability and resources of local responders to crude-by-rail incidents are ongoing concerns.[71]

In contrast, tankers are not a new method for moving oil. Vessels have double hulls and vessel operators are required to have emergency response equipment and resources in place in case of a spill. The Coast Guard has a regulatory regime in place to safeguard tanker transits through harbors. Where allowed, states have imposed additional safeguards on tankers transiting their harbors. Environmental damage from an oil spill remains a grave concern, but tanker incidents generally do not require evacuations of towns and cities.

Impact on Other Rail Users

The heavy reliance on railroads to move crude oil has interfered with the smooth functioning of the rail system. This has had negative consequences for other rail users, including passengers as well as freight shippers.

From 2008 to 2013, annual rail car loadings of crude oil increased from 9,500 to over 400,000. In 2014, railroads are expected to move 650,000 tank cars of crude oil, the equivalent of 18 unit trains of 100 cars per day.[72] Many of these shipments move out of the Bakken region of North Dakota, and grain, sugar beet, potato, and coal shippers have complained of serious delays in rail service in the Upper Midwest.[73] Amtrak cancelled several trains across North Dakota because the freight railroad that owns the track could not accommodate them, and on other occasions it has had to substitute bus service between points in North Dakota for rail service.[74] Based on past experience, local rail backups can have ramifications for service nationwide.

Some railroads are installing new track to handle the growing demand to ship oil by rail. If tankers were available and their operating costs more competitive with rail costs, it is possible that increased use of waterborne transport could relieve some of the pressure on rail service.[75]

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[71] U.S. Congress, House Committee on Transportation and Infrastructure, Subcommittee on Railroads, Pipelines, and Hazardous Materials, Oversight of Passenger and Freight Rail Safety, 113th Cong., 2nd sess., February 26, 2014; U.S. Congress, Senate Committee on Commerce, Science, and Transportation, Subcommittee on Surface Transportation and Merchant Marine Infrastructure, Safety, and Security, Enhancing Our Rail Safety: Current Challenges for Passenger and Freight Rail, 113th Cong., 2nd sess., March 6, 2014; U.S. Congress, Senate Committee on Appropriations, Subcommittee on Transportation and Housing and Urban Development, and Related Agencies, Rail Safety, 113th Cong., 2nd sess., April 9, 2014.

[72] Platts, *OilGram Price Report*, March 26, 2014, p.1.

[73] "Surge in Rail Shipments of Oil Sidetracks Other Industries; Pileups at BNSF Railway Is Causing Delays for Shippers of Goods Ranging From Coal to Sugar," *The Wall Street Journal*, March 13, 2014.

[74] "Warning: Amtrak Trains Will Not Arrive on Schedule," *Great Falls Tribune,* February 16, 2014.

[75] See, for example, the comments of the CEO of Phillips 66 during the company's earnings conference call, July 31, 2013.

The U.S. Non-contiguous Oil and Gas Trade

The Jones Act is particularly consequential for Puerto Rico, Hawaii, and Alaska. Puerto Rico has no operating refineries. It imports all of its petroleum products. Island countries surrounding Puerto Rico have become major consumers of gasoline and other products refined on the U.S. Gulf Coast, as has the U.S. Virgin Islands, which is not subject to the Jones Act. However, Puerto Rico does not consume any petroleum products of U.S. origin.[76]

Two refineries located near Honolulu supply about 90% of Hawaii's demand for refined products. Most of the crude oil processed in these refineries comes from Indonesia or other Pacific Rim countries; none comes from other parts of the United States.[77] Any oil or refined products shipped from U.S. ports to Hawaii would have to move on Jones Act ships, putting U.S. production at a cost disadvantage against imports from more distant locations.

New drilling technology has also led to a boom in domestic natural gas production. The gas is cooled to minus 260 degrees Fahrenheit for shipment as liquefied natural gas (LNG) aboard special tankers with insulated tanks. There are no Jones Act-qualified LNG tankers available to carry U.S. natural gas to Hawaii and Puerto Rico; the United States has not built an LNG tanker since 1980. In 2011 (P.L. 112-61), Congress allowed three U.S.-built but foreign-flagged LNG tankers to enter the U.S. domestic trade under U.S. flag, but they have not done so; in any event, these vessels were built in the late 1970s and are over 35 years in age. In 1996 (P.L. 104-324), Congress also allowed any foreign-built or foreign-flagged LNG tankers then operating to re-flag under the United States if they would provide service between a U.S. state and Puerto Rico, but none has entered this service. (These vessels would now be at least 18 years old.) Several LNG export terminals are under development in the continental United States, and these could potentially also handle LNG for Puerto Rico and Hawaii. Puerto Rico has an LNG terminal that receives imported gas, mostly from Trinidad and Tobago, and the potential competitiveness of U.S. LNG shipped in Jones Act vessels is uncertain. Hawaii does not have an LNG terminal.

While Alaskan crude oil exports would be required to move in U.S.-flag tankers, the flag requirement does not apply to LNG. Alaska shipped LNG to Japan in foreign-flag tankers until 2012, and such shipments may resume in the future. Alaska gas could be shipped to the U.S. West Coast if Jones Act-qualified LNG tankers were available.[78]

The U.S. Virgin Islands is exempt from the Jones Act.[79] In the 1960s, Hess built what would become the largest refinery in North America (700,000 barrels per day) at St. Croix. The refinery shipped residual fuel oil to the U.S. East Coast (on foreign-flag tankers). It imported crude oil from foreign sources but also received Alaska oil that sailed around Cape Horn in foreign-flag tankers. In 1976, legislation (S. 2422) was introduced to repeal the Jones Act exemption for crude oil and petroleum products, but no action was taken.[80] The refinery closed in February 2012 and is now used as a storage facility while a buyer is being sought.

Jones Act Waivers

The executive branch has statutory authority to waive the Jones Act "in the interest of national defense."[81] During the summer of 2011, when President Obama released oil from the nation's Strategic Petroleum Reserve (SPR) due to unrest in Libya, the Administration waived the Jones Act and about 25 million barrels of SPR crude oil was moved on foreign-flag tankers to Gulf Coast, East Coast, West Coast, and Hawaii refineries. Each foreign-flag tanker carried 500,000

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[76] For further information on the Jones Act specific to Puerto Rico, see U.S. Government Accountability Office (GAO), *Puerto Rico: Characteristics of the Island's Maritime Trade and Potential Effects of Modifying the Jones Act*, GAO-13-260, March 2013.

[77] U.S. Energy Information Administration, Geography, U.S. States; http://www.eia.gov/state/?sid=HI.

[78] *Alaska Business Monthly*, "U.S. Cabotage Laws and Alaska's LNG Trade," February 2014.

[79] 46 U.S.C. §55101(b)(4).

[80] U.S. Congress, Senate Committee on Commerce, Subcommittee on Merchant Marine, *Amend the Merchant Marine Act of 1920*, S. 2422, 94th Cong., 2nd sess., February 25, 1976, Serial No. 94-75.

[81] 46 U.S.C. §501.

barrels or more in a total of 44 shipments. One delivery was made in a Jones Act vessel, a barge carrying 150,000 barrels.[82]

The Jones Act has also been waived temporarily after disruptions to normal oil supply routes, in the Gulf after Hurricanes Katrina and Rita in 2005, and in the Northeast after superstorm Sandy in 2012. During the 12-day waiver for superstorm Sandy, 12 foreign-flagged tankers transported more than 3 million barrels of refined product from the Gulf Coast to the Northeast.

Recent U.S. Shipbuilding Activity

Over the past decade, one tank ship and about 125 tank barges have been built in the United States each year, on average. Limited capacity exists in U.S. shipyards to build tankers. As of February 2014, there were 11 petroleum tankers on order for delivery before 2016 and three ATBs on order.[83] Two of these tankers are definitely being built for crude oil, and are planned to replace two Alaska tankers ready for scrapping. The intended use of the other nine ships has not been announced; they could carry either crude or refined products. If they are intended to carry refined products, the shipyard will install coatings on tank walls and more specialized pumping equipment than needed on crude oil tankers, so that the ship can carry a variety of refined products without cross-contamination.

The tanker ships are being built by the General Dynamics NASSCO Shipyard in San Diego and the Aker Philadelphia Shipyard. One industry analysis estimates that NASSCO has the capability of building four large vessels per year and that Aker has the capability of building three, and that these two yards are essentially booked through at least 2016.[84] Recent ATBs have been built by shipyards in Mississippi, Washington, Oregon, and Pennsylvania.

Foreign Components

NASSCO has partnered with Daewoo Shipbuilding and Aker with Hyundai Mipo Dockyards, both Korean shipbuilders, for ship design, engineering, and procurement support. In the past, shipyard unions have opposed such agreements with Korean shipbuilders because the engines, piping, crew quarters, and portions of the bow and stern were imported from overseas and only assembled in the United States. NASSCO has explained that since Korean yards "build a hundred times more ships, they learn at a rate a hundred times faster, so you learn from the best."[85] Shipyard unions refer to ships built in this manner as "kit ships."[86]

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[82] Staff memorandum to Members, House Committee on Transportation and Infrastructure, Subcommittee on Coast Guard and Maritime Transportation, regarding hearing, "Review of Vessels Used to Carry Strategic Petroleum Reserve Drawdowns," June 22, 2012.

[83] RBN Energy, LLC, "Rock the Boat Don't Rock the Boat – The Jones Act Articulated Barge Fleet," February 11, 2014.

[84] American Petroleum Tanker Partners LP, Form S-1 Registration Statement, October 22, 2013, p. 114.

[85] Tom Wetherald, General Dynamics NASSCO, panel discussion on U.S. shipbuilding at the Second National Maritime Strategy Symposium, hosted by the Maritime Administration, May 6, 2014; http://www.marad.dot.gov/mariners_landing_page/national_strategy_symposium/National_Maritime_Strategy_Symposium.htm.

[86] *Journal of Commerce*, "Unions Sue Over 'Kit' Ships," January 15, 2007; *PR Newswire*, "Metal Trades Department (AFL-CIO) Sues Coast Guard to Block Kit Ships," January 12, 2007.

Coast Guard regulations deem a vessel to be U.S. built if (1) all major components of its hull and superstructure are fabricated in the United States, and (2) the vessel is assembled in the United States.[87] The Coast Guard holds that propulsion machinery, other machinery, small engine room equipment modules, consoles, wiring, certain mechanical systems, and outfitting have no bearing on a U.S. build determination.[88]

Shipbuilding Loans, Grants, and Tax Deferrals

The federal government has long provided financial assistance to domestic shipyards. The so-called "Title XI" program (46 U.S.C. §53702) provides government-backed loan guarantees (with repayment over 25 years) for prospective buyers of U.S.-built vessels as well as to shipyards for modernization of their facilities. The loan guarantee covers 87.5% of the cost of a ship. In FY2014, Congress appropriated $38 million for the program, the first time it has provided funds to expand the loan portfolio in several years. For FY2015, the House passed bill (H.R. 4745) would rescind $29 million of this amount while the Senate reported bill (S. 2438) provides $7 million for the program. For each loan, a reserve amount must be held depending on the risk, but typically 5% to 10% of the loan amount. As of April 2014, MARAD had $73 million available for new guarantees, enough to cover approximately $735 million of loans and a current portfolio of outstanding loan guarantees totaling $1.7 billion covering about 250 vessels.[89]

The Title XI program has been controversial in Congress when large loan recipients have defaulted, like in October 2001, when American Classic Voyages defaulted on a loan for two cruise ships intended for the Hawaii trade. Other borrowers have defaulted since.[90] Foreign yards are subsidized also, although the form of assistance is often not transparent. An international agreement to reduce shipbuilding subsidies failed largely because the six largest U.S. shipyards objected to reducing the Title XI program.[91]

In the National Defense Authorization Act for FY2006 (P.L. 109-163, §3506), Congress created a grant program for small shipyards (currently defined as having no more than 1,200 employees). The grant can cover up to 75% of the cost of improving their facilities. Since then, about $10-$15 million a year has been made available for this program, except that the American Recovery and Reinvestment Act of 2009 provided $100 million and no funds were appropriated in FY2014.

[87] 49 C.F.R. §67.97.

[88] The Philadelphia Metal Trades Council sued the Coast Guard, but a U.S. District Court sided with the Coast Guard. See *Philadelphia Metal Trades Council v. Allen*, No. 07-145 (E.D. Pa. Jan. 12, 2007).

[89] MARAD, FY2015 Budget Request.

[90] Information on defaults is not available on MARAD's Title XI homepage. On July 14, 2010, the Maritime Administrator at the time testified that since 1993, there had been 13 defaults including two in FY2009 and two in FY2010. Testimony of David Matsuda, House Armed Services Committee on Seapower and Expeditionary Forces, Hearing on Activities of the Maritime Administration, July 14, 2010.

[91] After nearly a decade of receiving no shipbuilding subsidies in the 1980s, U.S. shipyards urged the government to negotiate an international agreement. In 1993, Congress resumed funding for Title XI. In 1994, after five years of negotiations, the United States, the European Union, Norway, Japan, and South Korea reached an agreement through the Organization for Economic Cooperation and Development to prohibit most shipbuilding subsidies. The United States would have been required to reduce Title XI guarantees to 80% of the loan amount and to limit them to 12 years. The so-called "big six" shipyards that do mostly Navy work, but some commercial work, objected to the agreement. The U.S. yards that do mostly commercial work supported it. The United States was the only participant that did not ratify the agreement.

MARAD also administers the Capital Construction Fund (CCF) program, which allows U.S.-flag operators to defer taxes on income placed in such a fund if used to purchase or reconstruct U.S. built ships.[92] The fund is established by the ship owner subject to MARAD regulations and reporting requirements.[93] The investment income in the CCF is also tax deferred. The tax deferral is essentially indefinite as long as the program remains active.

U.S.-flag Reservation for Export of Oil and Natural Gas?

Congress is debating whether to allow crude oil produced in the continental United States to be exported to other countries, in addition to Canada.[94] Domestic producers of natural gas are seeking federal export permits.[95] Current law would not require that such exports be carried in U.S.-flagged ships.[96] Many U.S.-based petroleum producers and refiners control foreign-flag tankers, some of which deliver imported crude oil to the United States or export refined petroleum products from U.S. refineries. U.S. merchant mariners are seeking additional U.S.-flag voyages because the government-impelled cargos (military and food-aid cargos) they rely on are in decline.

During markup of the Coast Guard and Maritime Transportation Act of 2014 (H.R. 4005) an amendment to require that LNG exports move in U.S.-crewed and eventually in U.S.-built tankers was withdrawn in favor of a Government Accountability Office study of maritime employment related to this requirement.[97] Also unsuccessful were two amendments to a House-passed energy bill (H.R. 6, passed on June 25, 2014) which sought to require that LNG exports be carried in U.S.-flag tankers and require that federal regulators give priority to export terminal projects that would use U.S.-flag vessels.[98] Amendments to the Energy and Water Appropriations Act of 2015 (H.R. 4923) would have tied federal approval of LNG export terminals to the use of U.S.-flag tankers, but they were defeated on points of order.[99]

Whether the nation's energy trade should be carried in U.S.-flag tankers is a long-standing debate in Congress. In 2006, when the United States was still expected to be an importer rather than an exporter of LNG, Congress specified that federal regulators give "top priority" to the processing of licenses for offshore LNG import terminals if they would be supplied by U.S.-flag tankers, so as to promote the security of the United States.[100] LNG shippers contended that tying U.S. trade

[92] 46 U.S.C. §53501.

[93] 46 C.F.R. Parts 390 and 391.

[94] CRS Report R43442, *U.S. Crude Oil Export Policy: Background and Considerations*, by Phillip Brown et al.

[95] CRS Report R42074, *U.S. Natural Gas Exports: New Opportunities, Uncertain Outcomes*, by Michael Ratner et al.

[96] U.S. law (The Cargo Preference Act) requires 50% of "U.S. government impelled" cargo, such as food-aid, to be shipped in U.S.-flag ships, but these do not have to be U.S. built. Most of these ships also receive operating subsidies because they are to be made available to the military as part of the Maritime Security Fleet program.

[97] H.Rept. 113-384, Howard Coble Coast Guard and Maritime Transportation Act of 2014, p. 27.

[98] *Congressional Record*, June 25, 2014, p. H5750.

[99] H.Amdt. 1029 and H.Amdt. 1031 to H.R. 4923.

[100] P.L. 109-241, §304.

routes to certain flag vessels would hinder the ability to supply LNG under short-term contracts, which was how LNG was increasingly traded as the global market matured.[101]

Security was the rationale put forth by proponents of requiring U.S. imported oil to be carried in U.S.-flag tankers in the 1970s. In 1974, The Energy Transportation Security Act (ETSA, H.R. 8193, 93rd Congress) would have required that 30% of imported oil be carried in U.S.-flag and U.S.-built tankers. The bill was pocket-vetoed by President Ford. In the 94th Congress (1975), Congress created the Strategic Petroleum Reserve in response to the supply crisis in imported oil (P.L. 94-163). Since the oil for the reserve is purchased by the federal government, half the oil shipped by vessel must be transported by U.S.-flag tankers pursuant to the Cargo Preference Act of 1954.[102] In the 95th Congress (1977), the ETSA was reintroduced (H.R. 1037, S. 61) with modifications. A version requiring that 9.5% of U.S. imported oil be carried in U.S.-flag tankers passed the House by voice vote, but was then defeated in a recorded vote of 257 to 165. In the House floor debate, supporters of the bill primarily cited national security and the importance of boosting the domestic shipbuilding base.[103] While opponents cited costs to consumers and potential retaliation from trading partners, much of their argument reflected a Common Cause report on political campaign contributions by the U.S.-flag industry, which had been released just days before.[104] That neither the Department of Defense nor Department of State had testified in support of a national security rationale for the bill was also noted in the floor debate. The Senate never took up the measure.

At a 2014 industry symposium organized by MARAD to solicit ideas for addressing the decline in U.S.-flag cargoes, several participants advocated requiring a certain amount of LNG exports be carried in U.S.-flag or U.S.-built ships.[105] Much of the discussion concerned additional statutory or regulatory requirements for staying the decline in cargoes. There was little or no discussion, given the inverse relationship between price and quantity demanded, of efficiencies that could lower the price of U.S.-flag shipping.[106] The one commercial shipper making a presentation at the symposium stated, "Today U.S. flag is seen as a group of carriers that we have to use. I think that going forward, to be successful, you have to be seen as a group of carriers that we want to use."[107]

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[101] See filings of Shell and the Center for LNG at http://www.regulations.gov under docket no. MARAD-2007-26841.

[102] At the time, the GAO estimated that U.S.-flag shipping costs would be 2.3 to 2.8 times that of foreign-flag rates and questioned whether there was an adequate supply of U.S.-flag tankers. GAO, *Transportation Planning For The Strategic Petroleum Reserve Should Be Improved,* LCD-78-211, October 18, 1978.

[103] *Congressional Record – House*, October 19, 1977, p. 34177 et seq.

[104] "The Maritime Payoff," *Wall Street Journal,* August 4, 1977; "The Great Ship Robbery," *New York Times,* August 6, 1977; "How To Buy A Bill," *The Washington Post,* September 1, 1977.

[105] For webcasts, transcripts and presentations at the symposium, see http://www.marad.dot.gov/mariners_landing_page/national_strategy_symposium/National_Maritime_Strategy_Symposium.htm.

[106] This focus is consistent with the observation of a former Maritime Administrator that the U.S. merchant marine has "become accustomed to thinking that the government could never do enough for them." Andrew Gibson and Arthur Donovan, *The Abandoned Ocean* (Columbia, SC: Univ. of South Carolina Press, 2000), p. 175.

[107] Scott Mogavero, Global Logistics and Planning Manager at GE Logistics, as quoted in *Journal of Commerce*, "Shippers Cite U.S.-Flag Challenges," January 15, 2014.

Current Legislation

Several bills now pending in Congress address matters related to waterborne transportation of oil, including many of the safety and commercial issues raised in this report:

The Coast Guard and Maritime Transportation Act of 2014 (H.R. 4005, passed by the House April 1, 2014) directs the U.S. Department of Transportation to submit a national maritime strategy that identifies federal regulations that reduce the competitiveness of U.S.-flag vessels in international trade, submit recommendations to make U.S.-flag vessels more competitive and enhance U.S. shipbuilding capability, and identify strategies to increase the use of U.S.-flag vessels to carry imports and exports and domestic commerce. The Coast Guard is directed to arrange with the National Academy of Sciences an assessment of laws that impact the ability of U.S.-flag vessels to compete in international trade, while GAO is directed to study how U.S. maritime employment would be affected by a requirement that LNG exports move in U.S.-flag vessels.

S. 2444, the Coast Guard Authorization Act for Fiscal Years 2015 and 2016, would require the Coast Guard to report marine casualties to state or tribal governments within 24 hours, publish on a publicly accessible website its incident action plans in response to an oil spill, and modify oil spill contingency plans to include advance planning for closing and reopening of fishing grounds.

H.R. 2838, sponsored by Resident Commissioner Pierluisi, would exempt liquefied natural gas and propane tankers serving Puerto Rico from the Jones Act. S. 1483, sponsored by Senator Cantwell, establishes a federal oil spill research committee and requires updates to vessel oil spill response plans.

The National Defense Authorization Act for FY2015 (H.R. 4435), as passed by the House on May 22, 2014, declares the sense of Congress (§3503) that "the United States coastwise trade laws [the Jones Act] promote a strong domestic trade maritime industry, which supports the national security and economic vitality of the United States and the efficient operation of the United States transportation system."

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Technical Support Document: -
Social Cost of Carbon for Regulatory Impact Analysis -
Under Executive Order 12866 -

Interagency Working Group on Social Cost of Carbon, United States Government

With participation by

Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of Transportation
Environmental Protection Agency
National Economic Council
Office of Energy and Climate Change
Office of Management and Budget
Office of Science and Technology Policy
Department of the Treasury

February 2010

Executive Summary

Under Executive Order 12866, agencies are required, to the extent permitted by law, “to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs.” The purpose of the “social cost of carbon” (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or “marginal,” impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

This document presents a summary of the interagency process that developed these SCC estimates. Technical experts from numerous agencies met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95^{th} percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

Discount Rate Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

I. Monetizing Carbon Dioxide Emissions

The "social cost of carbon" (SCC) is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. We report estimates of the social cost of carbon in dollars per metric ton of carbon dioxide throughout this document.[1]

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A recent report from the National Academies of Science (NRC 2009) points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to make it possible for agencies to incorporate the social benefits from reducing carbon dioxide emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. Most federal regulatory actions can be expected to have marginal impacts on global emissions.

For such policies, the benefits from reduced (or costs from increased) emissions in any future year can be estimated by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions. For policies that have a large (non-marginal) impact on global cumulative emissions, there is a separate question of whether the SCC is an appropriate tool for calculating the benefits of reduced emissions; we do not attempt to answer that question here.

An interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. Agencies that actively participated in the interagency process include the Environmental Protection

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[1] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).

Agency, and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are $5, $21, $35, and $65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to $24 per ton of CO_2 in 2015 and $26 per ton of CO_2 in 2020. See Appendix A for the full range of annual SCC estimates from 2010 to 2050.

It is important to emphasize that the interagency process is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, we have set a preliminary goal of revisiting the SCC values within two years or at such time as substantially updated models become available, and to continue to support research in this area. In the meantime, we will continue to explore the issues raised in this document and consider public comments as part of the ongoing interagency process.

II. Social Cost of Carbon Values Used in Past Regulatory Analyses

To date, economic analyses for Federal regulations have used a wide range of values to estimate the benefits associated with reducing carbon dioxide emissions. In the final model year 2011 CAFE rule, the Department of Transportation (DOT) used both a “domestic” SCC value of $2 per ton of CO_2 and a “global” SCC value of $33 per ton of CO_2 for 2007 emission reductions (in 2007 dollars), increasing both values at 2.4 percent per year. It also included a sensitivity analysis at $80 per ton of CO_2. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

A 2008 regulation proposed by DOT assumed a domestic SCC value of $7 per ton CO_2 (in 2006 dollars) for 2011 emission reductions (with a range of $0-$14 for sensitivity analysis), also increasing at 2.4 percent per year. A regulation finalized by DOE in October of 2008 used a domestic SCC range of $0 to $20 per ton CO_2 for 2007 emission reductions (in 2007 dollars). In addition, EPA’s 2008 Advance Notice of Proposed Rulemaking for Greenhouse Gases identified what it described as “very preliminary” SCC estimates subject to revision. EPA’s global mean values were $68 and $40 per ton CO_2 for discount rates of approximately 2 percent and 3 percent, respectively (in 2006 dollars for 2007 emissions).

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted.

The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of $55, $33, $19, $10, and $5 per ton of CO_2. The $33 and $5 values represented model-weighted means of the published estimates produced from the most recently available versions of three integrated assessment models—DICE, PAGE, and FUND—at approximately 3 and 5 percent discount rates. The $55 and $10 values were derived by adjusting the published estimates for uncertainty in the discount rate (using factors developed by Newell and Pizer (2003)) at 3 and 5 percent discount rates, respectively. The $19 value was chosen as a central value between the $5 and $33 per ton estimates. All of these values were assumed to increase at 3 percent annually to represent growth in incremental damages over time as the magnitude of climate change increases.

These interim values represent the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules and were offered for public comment in connection with proposed rules, including the joint EPA-DOT fuel economy and CO_2 tailpipe emission proposed rules.

III. Approach and Key Assumptions

Since the release of the interim values, interagency group has reconvened on a regular basis to generate improved SCC estimates. Specifically, the group has considered public comments and further explored the technical literature in relevant fields. This section details the several choices and assumptions that underlie the resulting estimates of the SCC.

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Academy of Science (2009) points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. Throughout this document, we highlight a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC.

The U.S. Government will periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling. In this context, statements recognizing the limitations of the analysis and calling for further research take on exceptional significance. The interagency group offers the new SCC values with all due humility about the uncertainties embedded in them and with a sincere promise to continue work to improve them.

A. Integrated Assessment Models

We rely on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.[2] These models are frequently cited in the peer-reviewed literature and used in the IPCC assessment. Each model is given equal weight in the SCC values developed through this process, bearing in mind their different limitations (discussed below).

These models are useful because they combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single modeling framework. At the same time, they gain this advantage at the expense of a more detailed representation of the underlying climatic and economic systems. DICE, PAGE, and FUND all take stylized, reduced-form approaches (see NRC 2009 for a more detailed discussion; see Nordhaus 2008 on the possible advantages of this approach). Other IAMs may better reflect the complexity of the science in their modeling frameworks but do not link physical impacts to economic damages. There is currently a limited amount of research linking climate impacts to economic damages, which makes this exercise even more difficult. Underlying the three IAMs selected for this exercise are a number of simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize the available scientific and economic research characterizing these relationships.

The three IAMs translate emissions into changes in atmospheric greenhouse concentrations, atmospheric concentrations into changes in temperature, and changes in temperature into economic damages. The emissions projections used in the models are based on specified socio-economic (GDP and population) pathways. These emissions are translated into concentrations using the carbon cycle built into each model, and concentrations are translated into warming based on each model's simplified representation of the climate and a key parameter, climate sensitivity. Each model uses a different approach to translate warming into damages. Finally, transforming the stream of economic damages over time into a single value requires judgments about how to discount them.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. In PAGE, for example, the consumption-equivalent damages in each period are calculated as a fraction of GDP, depending on the temperature in that period relative to the pre-industrial average temperature in each region. In FUND, damages in each period also depend on the rate of temperature change from the prior period. In DICE, temperature affects both consumption and investment. We describe each model in greater detail here. In a later section, we discuss key gaps in how the models account for various scientific and economic processes (e.g. the probability of catastrophe, and the ability to adapt to climate change and the physical changes it causes).

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[2] The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, originally to study international capital transfers in climate policy. is now widely used to study climate impacts (e.g., Tol 2002a, Tol 2002b, Anthoff et al. 2009, Tol 2009).

The parameters and assumptions embedded in the three models vary widely. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: climate sensitivity, socio-economic and emissions trajectories, and discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socio-economic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments. In DICE, these parameters are handled deterministically and represented by fixed constants; in PAGE, most parameters are represented by probability distributions. FUND was also run in a mode in which parameters were treated probabilistically.

The sensitivity of the results to other aspects of the models (e.g. the carbon cycle or damage function) is also important to explore in the context of future revisions to the SCC but has not been incorporated into these estimates. Areas for future research are highlighted at the end of this document.

The DICE Model

The DICE model is an optimal growth model based on a global production function with an extra stock variable (atmospheric carbon dioxide concentrations). Emission reductions are treated as analogous to investment in "natural capital." By investing in natural capital today through reductions in emissions—implying reduced consumption—harmful effects of climate change can be avoided and future consumption thereby increased.

For purposes of estimating the SCC, carbon dioxide emissions are a function of global GDP and the carbon intensity of economic output, with the latter declining over time due to technological progress. The DICE damage function links global average temperature to the overall impact on the world economy. It varies quadratically with temperature change to capture the more rapid increase in damages expected to occur under more extreme climate change, and is calibrated to include the effects of warming on the production of market and nonmarket goods and services. It incorporates impacts on agriculture, coastal areas (due to sea level rise), "other vulnerable market sectors" (based primarily on changes in energy use), human health (based on climate-related diseases, such as malaria and dengue fever, and pollution), non-market amenities (based on outdoor recreation), and human settlements and ecosystems. The DICE damage function also includes the expected value of damages associated with low probability, high impact "catastrophic" climate change. This last component is calibrated based on a survey of experts (Nordhaus 1994). The expected value of these impacts is then added to the other market and non-market impacts mentioned above.

No structural components of the DICE model represent adaptation explicitly, though it is included implicitly through the choice of studies used to calibrate the aggregate damage function. For example, its agricultural impact estimates assume that farmers can adjust land use decisions in response to changing climate conditions, and its health impact estimates assume improvements in healthcare over time. In addition, the small impacts on forestry, water systems, construction, fisheries, and outdoor recreation imply optimistic and costless adaptation in these sectors (Nordhaus and Boyer, 2000; Warren et al., 2006). Costs of resettlement due to sea level rise are incorporated into damage estimates, but their magnitude is not clearly reported. Mastrandrea's (2009) review concludes that "in general, DICE assumes very effective adaptation, and largely ignores adaptation costs."

Note that the damage function in DICE has a somewhat different meaning from the damage functions in FUND and PAGE. Because GDP is endogenous in DICE and because damages in a given year reduce investment in that year, damages propagate forward in time and reduce GDP in future years. In contrast, GDP is exogenous in FUND and PAGE, so damages in any given year do not propagate forward.[3]

The PAGE Model

PAGE2002 (version 1.4epm) treats GDP growth as exogenous. It divides impacts into economic, non-economic, and catastrophic categories and calculates these impacts separately for eight geographic regions. Damages in each region are expressed as a fraction of output, where the fraction lost depends on the temperature change in each region. Damages are expressed as power functions of temperature change. The exponents of the damage function are the same in all regions but are treated as uncertain, with values ranging from 1 to 3 (instead of being fixed at 2 as in DICE).

PAGE2002 includes the consequences of catastrophic events in a separate damage sub-function. Unlike DICE, PAGE2002 models these events probabilistically. The probability of a "discontinuity" (i.e., a catastrophic event) is assumed to increase with temperature above a specified threshold. The threshold temperature, the rate at which the probability of experiencing a discontinuity increases above the threshold, and the magnitude of the resulting catastrophe are all modeled probabilistically.

Adaptation is explicitly included in PAGE. Impacts are assumed to occur for temperature increases above some tolerable level (2°C for developed countries and 0°C for developing countries for economic impacts, and 0°C for all regions for non-economic impacts), but adaptation is assumed to reduce these impacts. Default values in PAGE2002 assume that the developed countries can ultimately eliminate up to 90 percent of all economic impacts beyond the tolerable 2°C increase and that developing countries can eventually eliminate 50 percent of their economic impacts. All regions are assumed to be able to mitigate 25 percent of the non-economic impacts through adaptation (Hope 2006).

The FUND Model

Like PAGE, the FUND model treats GDP growth as exogenous. It includes separately calibrated damage functions for eight market and nonmarket sectors: agriculture, forestry, water, energy (based on heating and cooling demand), sea level rise (based on the value of land lost and the cost of protection),

[3] Using the default assumptions in DICE 2007, this effect generates an approximately 25 percent increase in the SCC relative to damages calculated by fixing GDP. In DICE2007, the time path of GDP is endogenous. Specifically, the path of GDP depends on the rate of saving and level of abatement in each period chosen by the optimizing representative agent in the model. We made two modifications to DICE to make it consistent with EMF GDP trajectories (see next section): we assumed a fixed rate of savings of 20%, and we re-calibrated the exogenous path of total factor productivity so that DICE would produce GDP projections in the absence of warming that exactly matched the EMF scenarios.

ecosystems, human health (diarrhea, vector-borne diseases, and cardiovascular and respiratory mortality), and extreme weather. Each impact sector has a different functional form, and is calculated separately for sixteen geographic regions. In some impact sectors, the fraction of output lost or gained due to climate change depends not only on the absolute temperature change but also on the rate of temperature change and level of regional income.[4] In the forestry and agricultural sectors, economic damages also depend on CO_2 concentrations.

Tol (2009) discusses impacts not included in FUND, noting that many are likely to have a relatively small effect on damage estimates (both positive and negative). However, he characterizes several omitted impacts as "big unknowns": for instance, extreme climate scenarios, biodiversity loss, and effects on economic development and political violence. With regard to potentially catastrophic events, he notes, "Exactly what would cause these sorts of changes or what effects they would have are not well-understood, although the chance of any one of them happening seems low. But they do have the potential to happen relatively quickly, and if they did, the costs could be substantial. Only a few studies of climate change have examined these issues."

Adaptation is included both implicitly and explicitly in FUND. Explicit adaptation is seen in the agriculture and sea level rise sectors. Implicit adaptation is included in sectors such as energy and human health, where wealthier populations are assumed to be less vulnerable to climate impacts. For example, the damages to agriculture are the sum of three effects: (1) those due to the rate of temperature change (damages are always positive); (2) those due to the level of temperature change (damages can be positive or negative depending on region and temperature); and (3) those from CO_2 fertilization (damages are generally negative but diminishing to zero).

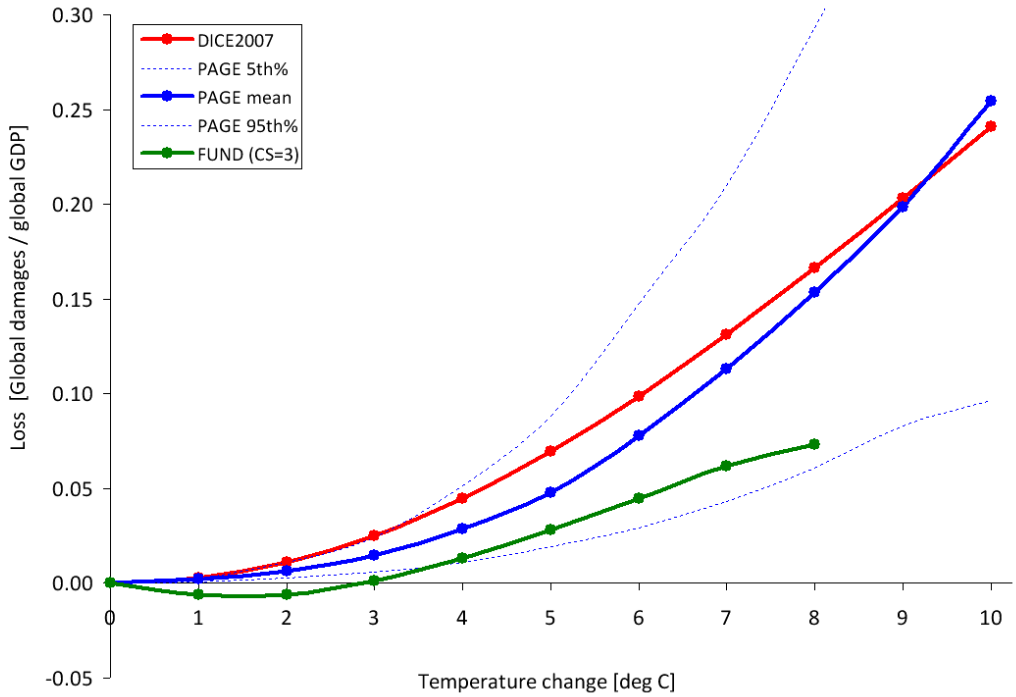
Adaptation is incorporated into FUND by allowing damages to be smaller if climate change happens more slowly. The combined effect of CO_2 fertilization in the agricultural sector, positive impacts to some regions from higher temperatures, and sufficiently slow increases in temperature across these sectors can result in negative economic damages from climate change.

Damage Functions

To generate revised SCC values, we rely on the IAM modelers' current best judgments of how to represent the effects of climate change (represented by the increase in global-average surface temperature) on the consumption-equivalent value of both market and non-market goods (represented as a fraction of global GDP). We recognize that these representations are incomplete and highly uncertain. But given the paucity of data linking the physical impacts to economic damages, we were not able to identify a better way to translate changes in climate into net economic damages, short of launching our own research program.

[4] In the deterministic version of FUND, the majority of damages are attributable to increased air conditioning demand, while reduced cold stress in Europe, North America, and Central and East Asia results in health benefits in those regions at low to moderate levels of warming (Warren et al., 2006).

Figure 1A: Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual - Global Temperature in the DICE, FUND, and PAGE models[5]



The damage functions for the three IAMs are presented in Figures 1A and 1B, using the modeler's default scenarios and mean input assumptions. There are significant differences between the three models both at lower (figure 1B) and higher (figure 1A) increases in global-average temperature.

The lack of agreement among the models at lower temperature increases is underscored by the fact that the damages from FUND are well below the 5th percentile estimated by PAGE, while the damages estimated by DICE are roughly equal to the 95th percentile estimated by PAGE. This is significant because at higher discount rates we expect that a greater proportion of the SCC value is due to damages in years with lower temperature increases. For example, when the discount rate is 2.5 percent, about 45 percent of the 2010 SCC value in DICE is due to damages that occur in years when the temperature is less than or equal to 3 °C. This increases to approximately 55 percent and 80 percent at discount rates of 3 and 5 percent, respectively.

These differences underscore the need for a thorough review of damage functions—in particular, how the models incorporate adaptation, technological change, and catastrophic damages. Gaps in the literature make modifying these aspects of the models challenging, which highlights the need for additional research. As knowledge improves, the Federal government is committed to exploring how these (and other) models can be modified to incorporate more accurate estimates of damages.

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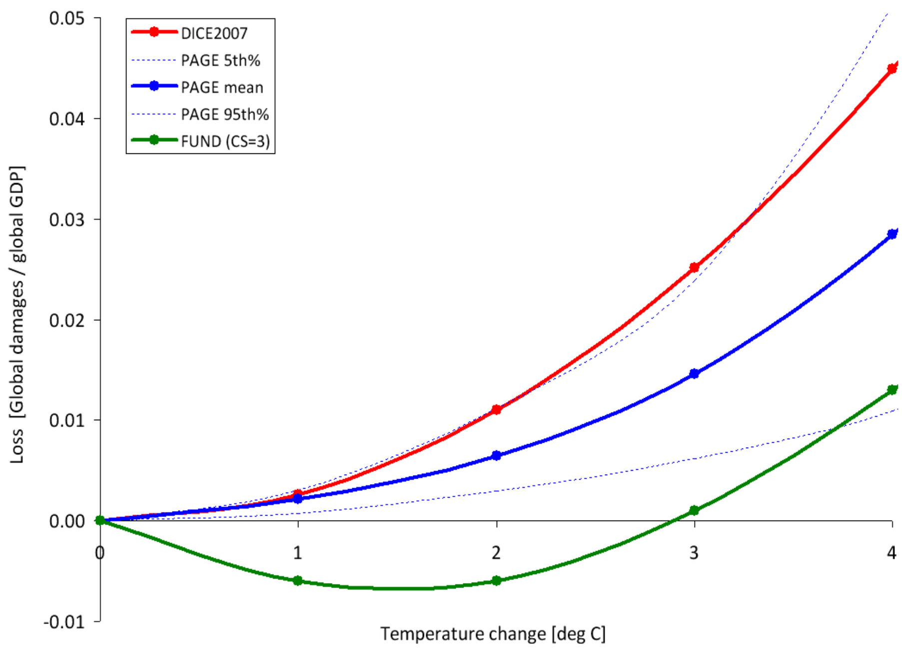
[5] The x-axis represents increases in annual, rather than equilibrium, temperature, while the y-axis represents the annual stream of benefits as a share of global GDP. Each specific combination of climate sensitivity, socio-economic, and emissions parameters will produce a different realization of damages for each IAM. The damage functions represented in Figures 1A and 1B are the outcome of default assumptions. For instance, under alternate assumptions, the damages from FUND may cross from negative to positive at less than or greater than 3 °C.

Figure 1B: Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE -



B. Global versus Domestic Measures of SCC

Because of the distinctive nature of the climate change problem, we center our current attention on a global measure of SCC. This approach is the same as that taken for the interim values, but it otherwise represents a departure from past practices, which tended to put greater emphasis on a domestic measure of SCC (limited to impacts of climate change experienced within U.S. borders). As a matter of law, consideration of both global and domestic values is generally permissible; the relevant statutory provisions are usually ambiguous and allow selection of either measure.[6]

Global SCC

Under current OMB guidance contained in Circular A-4, analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the climate change problem is highly unusual in at least two respects. First, it involves a global externality: emissions of most greenhouse gases contribute to damages around the world even when they are emitted in the United States. Consequently, to address the global nature of the problem, the SCC must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Even if the United States were to reduce its greenhouse gas emissions to zero, that step would be far from enough to avoid substantial climate change. Other countries would also need to take action to reduce emissions if

[6] It is true that federal statutes are presumed not to have extraterritorial effect, in part to ensure that the laws of the United States respect the interests of foreign sovereigns. But use of a global measure for the SCC does not give extraterritorial effect to federal law and hence does not intrude on such interests.

significant changes in the global climate are to be avoided. Emphasizing the need for a global solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions and in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. When these considerations are taken as a whole, the interagency group concluded that a global measure of the benefits from reducing U.S. emissions is preferable.

When quantifying the damages associated with a change in emissions, a number of analysts (e.g., Anthoff, et al. 2009a) employ “equity weighting” to aggregate changes in consumption across regions. This weighting takes into account the relative reductions in wealth in different regions of the world. A per-capita loss of $500 in GDP, for instance, is weighted more heavily in a country with a per-capita GDP of $2,000 than in one with a per-capita GDP of $40,000. The main argument for this approach is that a loss of $500 in a poor country causes a greater reduction in utility or welfare than does the same loss in a wealthy nation. Notwithstanding the theoretical claims on behalf of equity weighting, the interagency group concluded that this approach would not be appropriate for estimating a SCC value used in domestic regulatory analysis.[7] For this reason, the group concluded that using the global (rather than domestic) value, without equity weighting, is the appropriate approach.

Domestic SCC

As an empirical matter, the development of a domestic SCC is greatly complicated by the relatively few region- or country-specific estimates of the SCC in the literature. One potential source of estimates comes from the FUND model. The resulting estimates suggest that the ratio of domestic to global benefits of emission reductions varies with key parameter assumptions. For example, with a 2.5 or 3 percent discount rate, the U.S. benefit is about 7-10 percent of the global benefit, on average, across the scenarios analyzed. Alternatively, if the fraction of GDP lost due to climate change is assumed to be similar across countries, the domestic benefit would be proportional to the U.S. share of global GDP, which is currently about 23 percent.[8]

On the basis of this evidence, the interagency workgroup determined that a range of values from 7 to 23 percent should be used to adjust the global SCC to calculate domestic effects. Reported domestic values should use this range. It is recognized that these values are approximate, provisional, and highly speculative. There is no a priori reason why domestic benefits should be a constant fraction of net global damages over time. Further, FUND does not account for how damages in other regions could affect the United States (e.g., global migration, economic and political destabilization). If more accurate methods for calculating the domestic SCC become available, the Federal government will examine these to determine whether to update its approach.

[7] It is plausible that a loss of $X inflicts more serious harm on a poor nation than on a wealthy one, but development of the appropriate "equity weight" is challenging. Emissions reductions also impose costs, and hence a full account would have to consider that a given cost of emissions reductions imposes a greater utility or welfare loss on a poor nation than on a wealthy one. Even if equity weighting—for both the costs and benefits of emissions reductions—is appropriate when considering the utility or welfare effects of international action, the interagency group concluded that it should not be used in developing an SCC for use in regulatory policy at this time.

[8] Based on 2008 GDP (in current US dollars) from the *World Bank Development Indicators Report*.

C. Valuing Non-CO_2 Emissions

While CO_2 is the most prevalent greenhouse gas emitted into the atmosphere, the U.S. included five other greenhouse gases in its recent endangerment finding: methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The climate impact of these gases is commonly discussed in terms of their 100-year global warming potential (GWP). GWP measures the ability of different gases to trap heat in the atmosphere (i.e., radiative forcing per unit of mass) over a particular timeframe relative to CO_2. However, because these gases differ in both radiative forcing and atmospheric lifetimes, their relative damages are not constant over time. For example, because methane has a short lifetime, its impacts occur primarily in the near term and thus are not discounted as heavily as those caused by longer-lived gases. Impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Likewise, damages from methane emissions are not offset by the positive effect of CO_2 fertilization. Thus, transforming gases into CO_2-equivalents using GWP, and then multiplying the carbon-equivalents by the SCC, would not result in accurate estimates of the social costs of non-CO_2 gases.

In light of these limitations, and the significant contributions of non-CO_2 emissions to climate change, further research is required to link non-CO_2 emissions to economic impacts. Such work would feed into efforts to develop a monetized value of reductions in non-CO_2 greenhouse gas emissions. As part of ongoing work to further improve the SCC estimates, the interagency group hopes to develop methods to value these other greenhouse gases. The goal is to develop these estimates by the time we issue revised SCC estimates for carbon dioxide emissions.

D. Equilibrium Climate Sensitivity

Equilibrium climate sensitivity (ECS) is a key input parameter for the DICE, PAGE, and FUND models.[9] It is defined as the long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO_2 concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm)). Uncertainties in this important parameter have received substantial attention in the peer-reviewed literature.

The most authoritative statement about equilibrium climate sensitivity appears in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

> *Basing our assessment on a combination of several independent lines of evidence…including observed climate change and the strength of known feedbacks simulated in [global climate models], we conclude that the global mean equilibrium warming for doubling CO_2, or 'equilibrium climate*

[9] The equilibrium climate sensitivity includes the response of the climate system to increased greenhouse gas concentrations over the short to medium term (up to 100-200 years), but it does not include long-term feedback effects due to possible large-scale changes in ice sheets or the biosphere, which occur on a time scale of many hundreds to thousands of years (e.g. Hansen et al. 2007).

sensitivity', is likely to lie in the range 2 °C to 4.5 °C, with a most likely value of about 3 °C. Equilibrium climate sensitivity is very likely larger than 1.5 °C. [10]

For fundamental physical reasons as well as data limitations, values substantially higher than 4.5 °C still cannot be excluded, but agreement with observations and proxy data is generally worse for those high values than for values in the 2 °C to 4.5 °C range. (Meehl et al., 2007, p 799)

After consulting with several lead authors of this chapter of the IPCC report, the interagency workgroup selected four candidate probability distributions and calibrated them to be consistent with the above statement: Roe and Baker (2007), log-normal, gamma, and Weibull. Table 1 included below gives summary statistics for the four calibrated distributions.

Table 1: Summary Statistics for Four Calibrated Climate Sensitivity Distributions

	Roe & Baker	Log-normal	Gamma	Weibull
Pr(ECS < 1.5°C)	0.013	0.050	0.070	0.102
Pr(2°C < ECS < 4.5°C)	0.667	0.667	0.667	0.667
5th percentile	1.72	1.49	1.37	1.13
10th percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50th percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90th percentile	5.86	5.14	4.93	4.69
95th percentile	7.14	5.97	5.59	5.17

Each distribution was calibrated by applying three constraints from the IPCC:

(1) a median equal to 3°C, to reflect the judgment of "a most likely value of about 3 °C";[11]
(2) two-thirds probability that the equilibrium climate sensitivity lies between 2 and 4.5 °C; and
(3) zero probability that it is less than 0°C or greater than 10°C (see Hegerl et al. 2006, p. 721).

We selected the calibrated Roe and Baker distribution from the four candidates for two reasons. First, the Roe and Baker distribution is the only one of the four that is based on a theoretical understanding of the response of the climate system to increased greenhouse gas concentrations (Roe and Baker 2007,

[10] This is in accord with the judgment that it "is likely to lie in the range 2 °C to 4.5 °C" and the IPCC definition of "likely" as greater than 66 percent probability (Le Treut et al.2007). "Very likely" indicates a greater than 90 percent probability.

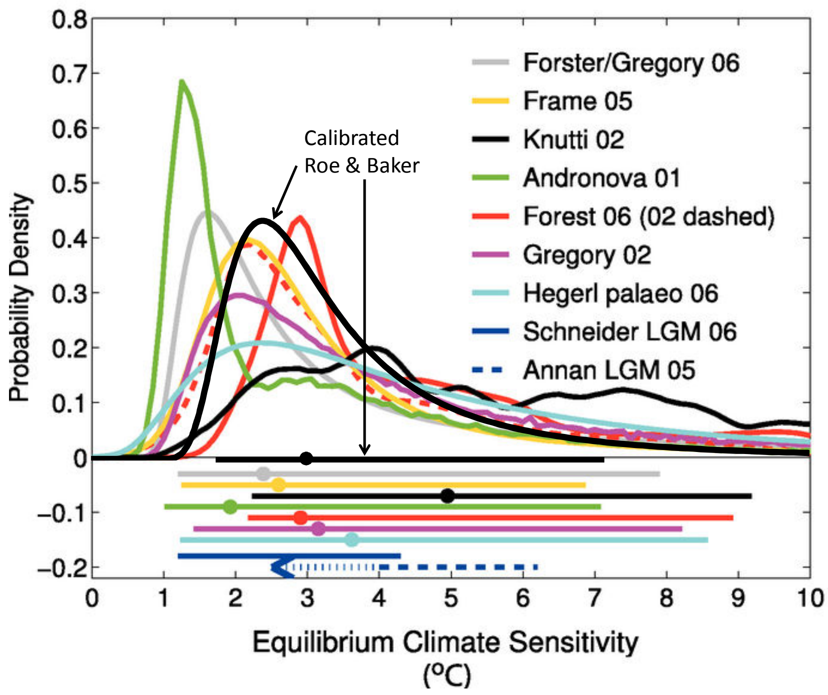
[11] Strictly speaking, "most likely" refers to the mode of a distribution rather than the median, but common usage would allow the mode, median, or mean to serve as candidates for the central or "most likely" value and the IPCC report is not specific on this point. For the distributions we considered, the median was between the mode and the mean. For the Roe and Baker distribution, setting the median equal to 3°C, rather than the mode or mean, gave a 95th percentile that is more consistent with IPCC judgments and the literature. For example, setting the mean and mode equal to 3°C produced 95th percentiles of 5.6 and 8.6 °C, respectively, which are in the lower and upper end of the range in the literature. Finally, the median is closer to 3°C than is the mode for the truncated distributions selected by the IPCC (Hegerl, et al., 2006); the average median is 3.1 °C and the average mode is 2.3 °C, which is most consistent with a Roe and Baker distribution with the median set equal to 3 °C.

Roe 2008). In contrast, the other three distributions are mathematical functions that are arbitrarily chosen based on simplicity, convenience, and general shape. The Roe and Baker distribution results from three assumptions about climate response: (1) absent feedback effects, the equilibrium climate sensitivity is equal to 1.2 °C; (2) feedback factors are proportional to the change in surface temperature; and (3) uncertainties in feedback factors are normally distributed. There is widespread agreement on the first point and the second and third points are common assumptions.

Second, the calibrated Roe and Baker distribution better reflects the IPCC judgment that "values substantially higher than 4.5°C still cannot be excluded." Although the IPCC made no quantitative judgment, the 95th percentile of the calibrated Roe & Baker distribution (7.1 °C) is much closer to the mean and the median (7.2 °C) of the 95th percentiles of 21 previous studies summarized by Newbold and Daigneault (2009). It is also closer to the mean (7.5 °C) and median (7.9 °C) of the nine truncated distributions examined by the IPCC (Hegerl, et al., 2006) than are the 95th percentiles of the three other calibrated distributions (5.2-6.0 °C).

Finally, we note the IPCC judgment that the equilibrium climate sensitivity "is very likely larger than 1.5°C." Although the calibrated Roe & Baker distribution, for which the probability of equilibrium climate sensitivity being greater than 1.5°C is almost 99 percent, is not inconsistent with the IPCC definition of "very likely" as "greater than 90 percent probability," it reflects a greater degree of certainty about very low values of ECS than was expressed by the IPCC.

Figure 2: Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)



To show how the calibrated Roe and Baker distribution compares to different estimates of the probability distribution function of equilibrium climate sensitivity in the empirical literature, Figure 2 (below) overlays it on Figure 9.20 from the IPCC Fourth Assessment Report. These functions are scaled to integrate to unity between 0 °C and 10 °C. The horizontal bars show the respective 5 percent to 95 percent ranges; dots indicate the median estimate.[12]

E. Socio-Economic and Emissions Trajectories

Another key issue considered by the interagency group is how to select the set of socio-economic and emissions parameters for use in PAGE, DICE, and FUND. Socio-economic pathways are closely tied to climate damages because, all else equal, more and wealthier people tend to emit more greenhouse gases and also have a higher (absolute) willingness to pay to avoid climate disruptions. For this reason, we consider how to model several input parameters in tandem: GDP, population, CO_2 emissions, and non-CO_2 radiative forcing. A wide variety of scenarios have been developed and used for climate change policy simulations (e.g., SRES 2000, CCSP 2007, EMF 2009). In determining which scenarios are appropriate for inclusion, we aimed to select scenarios that span most of the plausible ranges of outcomes for these variables.

To accomplish this task in a transparent way, we decided to rely on the recent Stanford Energy Modeling Forum exercise, EMF-22. EMF-22 uses ten well-recognized models to evaluate substantial, coordinated global action to meet specific stabilization targets. A key advantage of relying on these data is that GDP, population, and emission trajectories are internally consistent for each model and scenario evaluated. The EMF-22 modeling effort also is preferable to the IPCC SRES due to their age (SRES were developed in 1997) and the fact that 3 of 4 of the SRES scenarios are now extreme outliers in one or more variables. Although the EMF-22 scenarios have not undergone the same level of scrutiny as the SRES scenarios, they are recent, peer-reviewed, published, and publicly available.

To estimate the SCC for use in evaluating domestic policies that will have a small effect on global cumulative emissions, we use socio-economic and emission trajectories that span a range of plausible scenarios. Five trajectories were selected from EMF-22 (see Table 2 below). Four of these represent potential business-as-usual (BAU) growth in population, wealth, and emissions and are associated with CO_2 (only) concentrations ranging from 612 to 889 ppm in 2100. One represents an emissions pathway that achieves stabilization at 550 ppm CO_2e (i.e., CO_2-only concentrations of 425 – 484 ppm or a radiative forcing of 3.7 W/m^2) in 2100, a lower-than-BAU trajectory.[13] Out of the 10 models included in the EMF-22 exercise, we selected the trajectories used by MiniCAM, MESSAGE, IMAGE, and the optimistic scenario from MERGE. For the BAU pathways, we used the GDP, population, and emission trajectories from each of these four models. For the 550 ppm CO_2e scenario, we averaged the GDP, population, and emission trajectories implied by these same four models.

[12] The estimates based on instrumental data are from Andronova and Schlesinger (2001), Forest et al. (2002; dashed line, anthropogenic forcings only), Forest et al. (2006; solid line, anthropogenic and natural forcings), Gregory et al. (2002a), Knutti et al. (2002), Frame et al. (2005), and Forster and Gregory (2006). Hegerl et al. (2006) are based on multiple palaeoclimatic reconstructions of north hemisphere mean temperatures over the last 700 years. Also shown are the 5-95 percent approximate ranges for two estimates from the last glacial maximum (dashed, Annan et al. 2005; solid, Schneider von Deimling et al. 2006), which are based on models with different structural properties.

[13] Such an emissions path would be consistent with widespread action by countries to mitigate GHG emissions, though it could also result from technological advances. It was chosen because it represents the most stringent case analyzed by the EMF-22 where all the models converge: a 550 ppm, not to exceed, full participation scenario.

Table 2: Socioeconomic and Emissions Projections from Select EMF-22 Reference Scenarios -

Reference Fossil and Industrial CO_2 Emissions ($GtCO_2$/yr) -

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	26.6	31.9	36.9	40.0	45.3	60.1
MERGE Optimistic	24.6	31.5	37.6	45.1	66.5	117.9
MESSAGE	26.8	29.2	37.6	42.1	43.5	42.7
MiniCAM	26.5	31.8	38.0	45.1	57.8	80.5
550 ppm average	26.2	31.1	33.2	32.4	20.0	12.8

Reference GDP (using market exchange rates in trillion 2005$)[14]

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	38.6	53.0	73.5	97.2	156.3	396.6
MERGE Optimistic	36.3	45.9	59.7	76.8	122.7	268.0
MESSAGE	38.1	52.3	69.4	91.4	153.7	334.9
MiniCAM	36.1	47.4	60.8	78.9	125.7	369.5
550 ppm average	37.1	49.6	65.6	85.5	137.4	337.9

Global Population (billions)

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	6.1	6.9	7.6	8.2	9.0	9.1
MERGE Optimistic	6.0	6.8	7.5	8.2	9.0	9.7
MESSAGE	6.1	6.9	7.7	8.4	9.4	10.4
MiniCAM	6.0	6.8	7.5	8.1	8.8	8.7
550 ppm average	6.1	6.8	7.6	8.2	8.7	9.1

We explore how sensitive the SCC is to various assumptions about how the future will evolve without prejudging what is likely to occur. The interagency group considered formally assigning probability weights to different states of the world, but this proved challenging to do in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socio-economic pathways.

There are a number of caveats. First, EMF BAU scenarios represent the modelers' judgment of the most likely pathway absent mitigation policies to reduce greenhouse gas emissions, rather than the wider range of possible outcomes. Nevertheless, these views of the most likely outcome span a wide range,

[14] While the EMF-22 models used market exchange rates (MER) to calculate global GDP, it is also possible to use purchasing power parity (PPP). PPP takes into account the different price levels across countries, so it more accurately describes relative standards of living across countries. MERs tend to make low-income countries appear poorer than they actually are. Because many models assume convergence in per capita income over time, use of MER-adjusted GDP gives rise to projections of higher economic growth in low income countries. There is an ongoing debate about how much this will affect estimated climate impacts. Critics of the use of MER argue that it leads to overstated economic growth and hence a significant upward bias in projections of greenhouse gas emissions, and unrealistically high future temperatures (e.g., Castles and Henderson 2003). Others argue that convergence of the emissions-intensity gap across countries at least partially offset the overstated income gap so that differences in exchange rates have less of an effect on emissions (Holtsmark and Alfsen, 2005; Tol, 2006). Nordhaus (2007b) argues that the ideal approach is to use superlative PPP accounts (i.e., using cross-sectional PPP measures for relative incomes and outputs and national accounts price and quantity indexes for time-series extrapolations). However, he notes that it important to keep this debate in perspective; it is by no means clear that exchange-rate-conversion issues are as important as uncertainties about population, technological change, or the many geophysical uncertainties.

from the more optimistic (e.g. abundant low-cost, low-carbon energy) to more pessimistic (e.g. constraints on the availability of nuclear and renewables).[15] Second, the socio-economic trajectories associated with a 550 ppm CO_2e concentration scenario are not derived from an assessment of what policy is optimal from a benefit-cost standpoint. Rather, it is indicative of one possible future outcome. The emission trajectories underlying some BAU scenarios (e.g. MESSAGE's 612 ppm) also are consistent with some modest policy action to address climate change.[16] We chose not to include socio-economic trajectories that achieve even lower GHG concentrations at this time, given the difficulty many models had in converging to meet these targets.

For comparison purposes, the Energy Information Agency in its 2009 Annual Energy Outlook projected that global carbon dioxide emissions will grow to 30.8, 35.6, and 40.4 gigatons in 2010, 2020, and 2030, respectively, while world GDP is projected to be $51.8, $71.0 and $93.9 trillion (in 2005 dollars using market exchange rates) in 2010, 2020, and 2030, respectively. These projections are consistent with one or more EMF-22 scenarios. Likewise, the United Nations' 2008 Population Prospect projects population will grow from 6.1 billion people in 2000 to 9.1 billion people in 2050, which is close to the population trajectories for the IMAGE, MiniCAM, and MERGE models.

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane, nitrous oxide, fluorinated greenhouse gases, and net land use CO_2 emissions out to 2100. These assumptions also are used in the three models while retaining the default radiative forcings due to other factors (e.g. aerosols and other gases). See the Appendix for greater detail.

F. Discount Rate

The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law. Although it is well understood that the discount rate has a large influence on the current value of future damages, there is no consensus about what rates to use in this context. Because carbon dioxide emissions are long-lived, subsequent damages occur over many years. In calculating the SCC, we first estimate the future damages to agriculture, human health, and other market and non-market sectors from an additional unit of carbon dioxide emitted in a particular year in terms of reduced consumption (or consumption equivalents) due to the impacts of elevated temperatures, as represented in each of the three IAMs. Then we discount the stream of future damages to its present value in the year when the additional unit of emissions was released using the selected discount rate, which is intended to reflect society's marginal rate of substitution between consumption in different time periods.

For rules with both intra- and intergenerational effects, agencies traditionally employ constant discount rates of both 3 percent and 7 percent in accordance with OMB Circular A-4. As Circular A-4 acknowledges, however, the choice of discount rate for intergenerational problems raises distinctive

[15] For instance, in the MESSAGE model's reference case total primary energy production from nuclear, biomass, and non-biomass renewables is projected to increase from about 15 percent of total primary energy in 2000 to 54 percent in 2100. In comparison, the MiniCAM reference case shows 10 percent in 2000 and 21 percent in 2100.

[16] For example, MiniCAM projects if all non-US OECD countries reduce CO_2 emissions to 83 percent below 2005 levels by 2050 (per the G-8 agreement) but all other countries continue along a BAU path CO_2 concentrations in 2100 would drop from 794 ppmv in its reference case to 762 ppmv.

problems and presents considerable challenges. After reviewing those challenges, Circular A-4 states, “If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent.” For the specific purpose of developing the SCC, we adapt and revise that approach here.

Arrow et al. (1996) outlined two main approaches to determine the discount rate for climate change analysis, which they labeled “descriptive” and “prescriptive.” The descriptive approach reflects a positive (non-normative) perspective based on observations of people’s actual choices—e.g., savings versus consumption decisions over time, and allocations of savings among more and less risky investments. Advocates of this approach generally call for inferring the discount rate from market rates of return “because of a lack of justification for choosing a social welfare function that is any different than what decision makers [individuals] actually use” (Arrow et al. 1996).

One theoretical foundation for the cost-benefit analyses in which the social cost of carbon will be used—the Kaldor-Hicks potential-compensation test—also suggests that market rates should be used to discount future benefits and costs, because it is the market interest rate that would govern the returns potentially set aside today to compensate future individuals for climate damages that they bear (e.g., Just et al. 2004). As some have noted, the word “potentially” is an important qualification; there is no assurance that such returns will actually be set aside to provide compensation, and the very idea of compensation is difficult to define in the intergenerational context. On the other hand, societies provide compensation to future generations through investments in human capital and the resulting increase in knowledge, as well as infrastructure and other physical capital.

The prescriptive approach specifies a social welfare function that formalizes the normative judgments that the decision-maker wants explicitly to incorporate into the policy evaluation—e.g., how inter-personal comparisons of utility should be made, and how the welfare of future generations should be weighed against that of the present generation. Ramsey (1928), for example, has argued that it is “ethically indefensible” to apply a positive pure rate of time preference to discount values across generations, and many agree with this view.

Other concerns also motivate making adjustments to descriptive discount rates. In particular, it has been noted that the preferences of future generations with regard to consumption versus environmental amenities may not be the same as those today, making the current market rate on consumption an inappropriate metric by which to discount future climate-related damages. Others argue that the discount rate should be below market rates to correct for market distortions and uncertainties or inefficiencies in intergenerational transfers of wealth, which in the Kaldor-Hicks logic are presumed to compensate future generations for damage (a potentially controversial assumption, as noted above) (Arrow et al. 1996, Weitzman 1999).

Further, a legitimate concern about both descriptive and prescriptive approaches is that they tend to obscure important heterogeneity in the population. The utility function that underlies the prescriptive approach assumes a representative agent with perfect foresight and no credit constraints. This is an artificial rendering of the real world that misses many of the frictions that characterize individuals’ lives and indeed the available descriptive evidence supports this. For instance, many individuals smooth consumption by borrowing with credit cards that have relatively high rates. Some are unable to access traditional credit markets and rely on payday lending operations or other high cost forms of smoothing consumption. Whether one puts greater weight on the prescriptive or descriptive approach, the high interest rates that credit-constrained individuals accept suggest that some account should be given to the discount rates revealed by their behavior.

We draw on both approaches but rely primarily on the descriptive approach to inform the choice of discount rate. With recognition of its limitations, we find this approach to be the most defensible and transparent given its consistency with the standard contemporary theoretical foundations of benefit-cost analysis and with the approach required by OMB's existing guidance. The logic of this framework also suggests that market rates should be used for discounting future consumption-equivalent damages. Regardless of the theoretical approach used to derive the appropriate discount rate(s), we note the inherent conceptual and practical difficulties of adequately capturing consumption trade-offs over many decades or even centuries. While relying primarily on the descriptive approach in selecting specific discount rates, the interagency group has been keenly aware of the deeply normative dimensions of both the debate over discounting in the intergenerational context and the consequences of selecting one discount rate over another.

Historically Observed Interest Rates

In a market with no distortions, the return to savings would equal the private return on investment, and the market rate of interest would be the appropriate choice for the social discount rate. In the real world risk, taxes, and other market imperfections drive a wedge between the risk-free rate of return on capital and the consumption rate of interest. Thus, the literature recognizes two conceptual discount concepts—the consumption rate of interest and the opportunity cost of capital.

According to OMB's Circular A-4, it is appropriate to use the rate of return on capital when a regulation is expected to displace or alter the use of capital in the private sector. In this case, OMB recommends Agencies use a discount rate of 7 percent. When regulation is expected to primarily affect private consumption—for instance, via higher prices for goods and services—a lower discount rate of 3 percent is appropriate to reflect how private individuals trade-off current and future consumption.

The interagency group examined the economics literature and concluded that the consumption rate of interest is the correct concept to use in evaluating the benefits and costs of a marginal change in carbon emissions (see Lind 1990, Arrow et al 1996, and Arrow 2000). The consumption rate of interest also is appropriate when the impacts of a regulation are measured in consumption (-equivalent) units, as is done in the three integrated assessment models used for estimating the SCC.

Individuals use a variety of savings instruments that vary with risk level, time horizon, and tax characteristics. The standard analytic framework used to develop intuition about the discount rate typically assumes a representative agent with perfect foresight and no credit constraints. The risk-free rate is appropriate for discounting certain future benefits or costs, but the benefits calculated by IAMs are uncertain. To use the risk-free rate to discount uncertain benefits, these benefits first must be transformed into "certainty equivalents," that is the maximum certain amount that we would exchange for the uncertain amount. However, the calculation of the certainty-equivalent requires first estimating the correlation between the benefits of the policy and baseline consumption.

If the IAM projections of future impacts represent expected values (not certainty-equivalent values), then the appropriate discount rate generally does not equal the risk-free rate. If the benefits of the policy tend to be high in those states of the world in which consumption is low, then the certainty-equivalent benefits will be higher than the expected benefits (and vice versa). Since many (though not necessarily all) of the important impacts of climate change will flow through market sectors such as agriculture and energy, and since willingness to pay for environmental protections typically increases with income, we might expect a positive (though not necessarily perfect) correlation between the net benefits from climate policies and market returns. This line of reasoning suggests that the proper discount rate would exceed the riskless rate. Alternatively, a negative correlation between the returns to climate policies and market returns would imply that a discount rate below the riskless rate is appropriate.

This discussion suggests that both the post-tax riskless and risky rates can be used to capture individuals' consumption-equivalent interest rate. As a measure of the post-tax riskless rate, we calculate the average real return from Treasury notes over the longest time period available (those from Newell and Pizer 2003) and adjust for Federal taxes (the average marginal rate from tax years 2003 through 2006 is around 27 percent).[17] This calculation produces a real interest rate of about 2.7 percent, which is roughly consistent with Circular A-4's recommendation to use 3 percent to represent the consumption rate of interest.[18] A measure of the post-tax risky rate for investments whose returns are positively correlated with overall equity market returns can be obtained by adjusting pre-tax rates of household returns to risky investments (approximately 7 percent) for taxes yields a real rate of roughly 5 percent.[19]

The Ramsey Equation

Ramsey discounting also provides a useful framework to inform the choice of a discount rate. Under this approach, the analyst applies either positive or normative judgments in selecting values for the key parameters of the Ramsey equation: η (coefficient of relative risk aversion or elasticity of the marginal utility of consumption) and ρ (pure rate of time preference).[20] These are then combined with g (growth

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[17] The literature argues for a risk-free rate on government bonds as an appropriate measure of the consumption rate of interest. Arrow (2000) suggests that it is roughly 3-4 percent. OMB cites evidence of a 3.1 percent pre-tax rate for 10-year Treasury notes in the A-4 guidance. Newell and Pizer (2003) find real interest rates between 3.5 and 4 percent for 30-year Treasury securities.

[18] The positive approach reflects how individuals make allocation choices across time, but it is important to keep in mind that we wish to reflect preferences for society as a whole, which generally has a longer planning horizon.

[19] Cambell et al (2001) estimates that the annual real return from stocks for 1900-1995 was about 7 percent. The annual real rate of return for the S&P 500 from 1950 – 2008 was about 6.8 percent. In the absence of a better way to population-weight the tax rates, we use the middle of the 20 – 40 percent range to derive a post-tax interest rate (Kotlikoff and Rapson 2006).

[20] The parameter ρ measures the *pure rate of time preference*: people's behavior reveals a preference for an increase in utility today versus the future. Consequently, it is standard to place a lower weight on utility in the future. The parameter η captures *diminishing marginal utility*: consumption in the future is likely to be higher than consumption today, so diminishing marginal utility of consumption implies that the same monetary damage will

rate of per-capita consumption) to equal the interest rate at which future monetized damages are discounted: $\rho + \eta \cdot g$.[21] In the simplest version of the Ramsey model, with an optimizing representative agent with perfect foresight, what we are calling the "Ramsey discount rate," $\rho + \eta \cdot g$, will be equal to the rate of return to capital, i.e., the market interest rate.

A review of the literature provides some guidance on reasonable parameter values for the Ramsey discounting equation, based on both prescriptive and descriptive approaches.

- η. Most papers in the climate change literature adopt values for η in the range of 0.5 to 3 (Weitzman cites plausible values as those ranging from 1 to 4), although not all authors articulate whether their choice is based on prescriptive or descriptive reasoning.[22] Dasgupta (2008) argues that η should be greater than 1 and may be as high as 3, since η equal to 1 suggests savings rates that do not conform to observed behavior.

- ρ. With respect to the pure rate of time preference, most papers in the climate change literature adopt values for ρ in the range of 0 to 3 percent per year. The very low rates tend to follow from moral judgments involving intergenerational neutrality. Some have argued that to use any value other than $\rho = 0$ would unjustly discriminate against future generations (e.g., Arrow et al. 1996, Stern et al. 2006). However, even in an inter-generational setting, it may make sense to use a small positive pure rate of time preference because of the small probability of unforeseen cataclysmic events (Stern et al. 2006).

- g. A commonly accepted approximation is around 2 percent per year. For the socio-economic scenarios used for this exercise, the EMF models assume that g is about 1.5-2 percent to 2100.

Some economists and non-economists have argued for constant discount rates below 2 percent based on the prescriptive approach. When grounded in the Ramsey framework, proponents of this approach have argued that a ρ of zero avoids giving preferential treatment to one generation over another. The choice of η has also been posed as an ethical choice linked to the value of an additional dollar in poorer

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cause a smaller reduction of utility for wealthier individuals, either in the future or in current generations. If $\eta = 0$, then a one dollar increase in income is equally valuable regardless of level of income; if $\eta = 1$, then a one percent increase in income is equally valuable no matter the level of income; and if $\eta > 1$, then a one percent increase in income is less valuable to wealthier individuals.

[21] In this case, g could be taken from the selected EMF socioeconomic scenarios or alternative assumptions about the rate of consumption growth.

[22] Empirical estimates of η span a wide range of values. A benchmark value of 2 is near the middle of the range of values estimated or used by Szpiro (1986), Hall and Jones (2007), Arrow (2007), Dasgupta (2006, 2008), Weitzman (2007, 2009), and Nordhaus (2008). However, Chetty (2006) developed a method of estimating η using data on labor supply behavior. He shows that existing evidence of the effects of wage changes on labor supply imposes a tight upper bound on the curvature of utility over wealth (CRRA < 2) with the mean implied value of 0.71 and concludes that the standard expected utility model cannot generate high levels of risk aversion without contradicting established facts about labor supply. Recent work has jointly estimated the components of the Ramsey equation. Evans and Sezer (2005) estimate $\eta = 1.49$ for 22 OECD countries. They also estimate $\rho = 1.08$ percent per year using data on mortality rates. Anthoff, et al. (2009b) estimate $\eta = 1.18$, and $\rho = 1.4$ percent. When they multiply the bivariate probability distributions from their work and Evans and Sezer (2005) together, they find $\eta = 1.47$, and $\rho = 1.07$.

countries compared to wealthier ones. Stern et al. (2006) applies this perspective through his choice of ρ = 0.1 percent per year, η = 1 and g = 1.3 percent per year, which yields an annual discount rate of 1.4 percent. In the context of permanent income savings behavior, however, Stern's assumptions suggest that individuals would save 93 percent of their income.[23]

Recently, Stern (2008) revisited the values used in Stern et al. (2006), stating that there is a case to be made for raising η due to the amount of weight lower values place on damages far in the future (over 90 percent of expected damages occur after 2200 with η = 1). Using Stern's assumption that ρ = 0.1 percent, combined with a η of 1.5 to 2 and his original growth rate, yields a discount rate greater 2 percent.

We conclude that arguments made under the prescriptive approach can be used to justify discount rates between roughly 1.4 and 3.1 percent. In light of concerns about the most appropriate value for η, we find it difficult to justify rates at the lower end of this range under the Ramsey framework.

Accounting for Uncertainty in the Discount Rate

While the consumption rate of interest is an important driver of the benefits estimate, it is uncertain over time. Ideally, we would formally model this uncertainty, just as we do for climate sensitivity. Weitzman (1998, 2001) showed theoretically and Newell and Pizer (2003) and Groom et al. (2006) confirm empirically that discount rate uncertainty can have a large effect on net present values. A main result from these studies is that if there is a persistent element to the uncertainty in the discount rate (e.g., the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time. Consequently, lower discount rates tend to dominate over the very long term (see Weitzman 1998, 1999, 2001; Newell and Pizer 2003; Groom et al. 2006; Gollier 2008; Summers and Zeckhauser 2008; and Gollier and Weitzman 2009).

The proper way to model discount rate uncertainty remains an active area of research. Newell and Pizer (2003) employ a model of how long-term interest rates change over time to forecast future discount rates. Their model incorporates some of the basic features of how interest rates move over time, and its parameters are estimated based on historical observations of long-term rates. Subsequent work on this topic, most notably Groom et al. (2006), uses more general models of interest rate dynamics to allow for better forecasts. Specifically, the volatility of interest rates depends on whether rates are currently low or high and variation in the level of persistence over time.

While Newell and Pizer (2003) and Groom et al (2006) attempt formally to model uncertainty in the discount rate, others argue for a declining scale of discount rates applied over time (e.g., Weitzman 2001, and the UK's "Green Book" for regulatory analysis). This approach uses a higher discount rate

[23] Stern (2008) argues that building in a positive rate of exogenous technical change over time reduces the implied savings rate and that η at or above 2 are inconsistent with observed behavior with regard to equity. (At the same time, adding exogenous technical change—all else equal—would increase g as well.)

initially, but applies a graduated scale of lower discount rates further out in time.[24] A key question that has emerged with regard to both of these approaches is the trade-off between potential time inconsistency and giving greater weight to far future outcomes (see the EPA Science Advisory Board's recent comments on this topic as part of its review of their *Guidelines for Economic Analysis*).[25]

The Discount Rates Selected for Estimating SCC

In light of disagreement in the literature on the appropriate market interest rate to use in this context and uncertainty about how interest rates may change over time, we use three discount rates to span a plausible range of certainty-equivalent constant discount rates: 2.5, 3, and 5 percent per year. Based on the review in the previous sections, the interagency workgroup determined that these three rates reflect reasonable judgments under both descriptive and prescriptive approaches.

The central value, 3 percent, is consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest. As previously mentioned, the consumption rate of interest is the correct discounting concept to use when future damages from elevated temperatures are estimated in consumption-equivalent units. Further, 3 percent roughly corresponds to the after-tax riskless interest rate. The upper value of 5 percent is included to represent the possibility that climate damages are positively correlated with market returns. Additionally, this discount rate may be justified by the high interest rates that many consumers use to smooth consumption across periods.

The low value, 2.5 percent, is included to incorporate the concern that interest rates are highly uncertain over time. It represents the average certainty-equivalent rate using the mean-reverting and random walk approaches from Newell and Pizer (2003) starting at a discount rate of 3 percent. Using this approach, the certainty equivalent is about 2.2 percent using the random walk model and 2.8 percent using the mean reverting approach.[26] Without giving preference to a particular model, the average of the two rates is 2.5 percent. Further, a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return. Use of this lower value also responds to certain judgments using the prescriptive or normative approach and to ethical objections that have been raised about rates of 3 percent or higher.

[24] For instance, the UK applies a discount rate of 3.5 percent to the first 30 years; 3 percent for years 31 - 75; 2.5 percent for years 76 - 125; 2 percent for years 126 - 200; 1.5 percent for years 201 - 300; and 1 percent after 300 years. As a sensitivity, it recommends a discount rate of 3 percent for the first 30 years, also decreasing over time.

[25] Uncertainty in future damages is distinct from uncertainty in the discount rate. Weitzman (2008) argues that Stern's choice of a low discount rate was "right for the wrong reasons." He demonstrates how the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. Newbold and Daigneault, (2009) and Nordhaus (2009) find that Weitzman's result is sensitive to the functional forms chosen for climate sensitivity, utility, and consumption. Summers and Zeckhauser (2008) argue that uncertainty in future damages can also work in the other direction by increasing the benefits of waiting to learn the appropriate level of mitigation required.

[26] Calculations done by Pizer et al. using the original simulation program from Newell and Pizer (2003).

IV. Revised SCC Estimates

Our general approach to estimating SCC values is to run the three integrated assessment models (FUND, DICE, and PAGE) using the following inputs agreed upon by the interagency group:

- A Roe and Baker distribution for the climate sensitivity parameter bounded between 0 and 10 with a median of 3 °C and a cumulative probability between 2 and 4.5 °C of two-thirds.
- Five sets of GDP, population and carbon emissions trajectories based on EMF-22.
- Constant annual discount rates of 2.5, 3, and 5 percent.

Because the climate sensitivity parameter is modeled probabilistically, and because PAGE and FUND incorporate uncertainty in other model parameters, the final output from each model run is a distribution over the SCC in year *t*.

For each of the IAMS, the basic computational steps for calculating the SCC in a particular year *t* are:

1. Input the path of emissions, GDP, and population from the selected EMF-22 scenarios, and the extrapolations based on these scenarios for post-2100 years.

2. Calculate the temperature effects and (consumption-equivalent) damages in each year resulting from the baseline path of emissions.

   a. In PAGE, the consumption-equivalent damages in each period are calculated as a fraction of the EMF GDP forecast, depending on the temperature in that period relative to the pre-industrial average temperature in each region.
   b. In FUND, damages in each period depend on both the level and the rate of temperature change in that period.
   c. In DICE, temperature affects both consumption and investment, so we first adjust the EMF GDP paths as follows: Using the Cobb-Douglas production function with the DICE2007 parameters, we extract the path of exogenous technical change implied by the EMF GDP and population paths, then we recalculate the baseline GDP path taking into account climate damages resulting from the baseline emissions path.

3. Add an additional unit of carbon emissions in year *t.* (The exact unit varies by model.)

4. Recalculate the temperature effects and damages expected in all years beyond *t* resulting from this adjusted path of emissions, as in step 2.

5. Subtract the damages computed in step 2 from those in step 4 in each year. (DICE is run in 10 year time steps, FUND in annual time steps, while the time steps in PAGE vary.)

6. Discount the resulting path of marginal damages back to the year of emissions using the agreed upon fixed discount rates.

7. Calculate the SCC as the net present value of the discounted path of damages computed in step 6, divided by the unit of carbon emissions used to shock the models in step 3.

8. Multiply by 12/44 to convert from dollars per ton of carbon to dollars per ton of CO_2 (2007 dollars) in DICE and FUND. (All calculations are done in tons of CO_2 in PAGE).

The steps above were repeated in each model for multiple future years to cover the time horizons anticipated for upcoming rulemaking analysis. To maintain consistency across the three IAMs, climate damages are calculated as lost consumption in each future year.

It is important to note that each of the three models has a different default end year. The default time horizon is 2200 for PAGE, 2595 for DICE, and 3000 for the latest version of FUND. This is an issue for the multi-model approach because differences in SCC estimates may arise simply due to the model time horizon. Many consider 2200 too short a time horizon because it could miss a significant fraction of damages under certain assumptions about the growth of marginal damages and discounting, so each model is run here through 2300. This step required a small adjustment in the PAGE model only. This step also required assumptions about GDP, population, and greenhouse gas emission trajectories after 2100, the last year for which these data are available from the EMF-22 models. (A more detailed discussion of these assumptions is included in the Appendix.)

This exercise produces 45 separate distributions of the SCC for a given year, the product of 3 models, 3 discount rates, and 5 socioeconomic scenarios. This is clearly too many separate distributions for consideration in a regulatory impact analysis.

To produce a range of plausible estimates that still reflects the uncertainty in the estimation exercise, the distributions from each of the models and scenarios are equally weighed and combined to produce three separate probability distributions for SCC in a given year, one for each assumed discount rate. These distributions are then used to define a range of point estimates for the global SCC. In this way, no integrated assessment model or socioeconomic scenario is given greater weight than another. Because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context, we present SCCs based on the average values across models and socioeconomic scenarios for each discount rate.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC across models and socio-economic and emissions scenarios at the 2.5, 3, and 5 percent discount rates. The fourth value is included to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. (The full set of distributions by model and scenario combination is included in the Appendix.) As noted above, the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range.

As previously discussed, low probability, high impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high temperature outcomes, which in turn lead to higher projections of damages. Although FUND does not include catastrophic damages (in contrast to the other two models), its probabilistic treatment of the equilibrium climate sensitivity parameter will directly affect the non-catastrophic damages that are a function of the rate of temperature change.

In Table 3, we begin by presenting SCC estimates for 2010 by model, scenario, and discount rate to illustrate the variability in the SCC across each of these input parameters. As expected, higher discount rates consistently result in lower SCC values, while lower discount rates result in higher SCC values for each socioeconomic trajectory. It is also evident that there are differences in the SCC estimated across the three main models. For these estimates, FUND produces the lowest estimates, while PAGE generally produces the highest estimates.

Table 3: Disaggregated Social Cost of CO_2 Values by Model, Socio-Economic Trajectory, and Discount Rate for 2010 (in 2007 dollars)

	Discount rate:	**5%**	**3%**	**2.5%**	**3%**
Model	*Scenario*	Avg	Avg	Avg	95th
DICE	IMAGE	10.8	35.8	54.2	70.8
	MERGE	7.5	22.0	31.6	42.1
	Message	9.8	29.8	43.5	58.6
	MiniCAM	8.6	28.8	44.4	57.9
	550 Average	8.2	24.9	37.4	50.8
PAGE	IMAGE	8.3	39.5	65.5	142.4
	MERGE	5.2	22.3	34.6	82.4
	Message	7.2	30.3	49.2	115.6
	MiniCAM	6.4	31.8	54.7	115.4
	550 Average	5.5	25.4	42.9	104.7
FUND	IMAGE	-1.3	8.2	19.3	39.7
	MERGE	-0.3	8.0	14.8	41.3
	Message	-1.9	3.6	8.8	32.1
	MiniCAM	-0.6	10.2	22.2	42.6
	550 Average	-2.7	-0.2	3.0	19.4

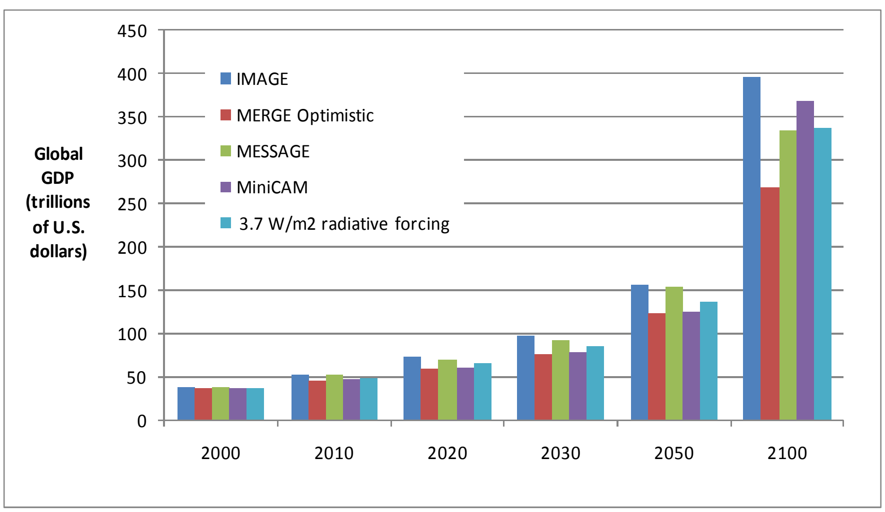
These results are not surprising when compared to the estimates in the literature for the latest versions of each model. For example, adjusting the values from the literature that were used to develop interim

SCC values to 2007 dollars for the year 2010 (assuming, as we did for the interim process, that SCC grows at 3 percent per year), FUND yields SCC estimates at or near zero for a 5 percent discount rate and around $9 per ton for a 3 percent discount rate. There are far fewer estimates using the latest versions of DICE and PAGE in the literature: Using similar adjustments to generate 2010 estimates, we calculate a SCC from DICE (based on Nordhaus 2008) of around $9 per ton for a 5 percent discount rate, and a SCC from PAGE (based on Hope 2006, 2008) close to $8 per ton for a 4 percent discount rate. Note that these comparisons are only approximate since the literature generally relies on Ramsey discounting, while we have assumed constant discount rates.[27]

The SCC estimates from FUND are sensitive to differences in emissions paths but relatively insensitive to differences in GDP paths across scenarios, while the reverse is true for DICE and PAGE. This likely occurs because of several structural differences among the models. Specifically in DICE and PAGE, the fraction of economic output lost due to climate damages increases with the level of temperature alone, whereas in FUND the fractional loss also increases with the rate of temperature change. Furthermore, in FUND increases in income over time decrease vulnerability to climate change (a form of adaptation), whereas this does not occur in DICE and PAGE. These structural differences among the models make FUND more sensitive to the path of emissions and less sensitive to GDP compared to DICE and PAGE.

Figure 3 shows that IMAGE has the highest GDP in 2100 while MERGE Optimistic has the lowest. The ordering of global GDP levels in 2100 directly corresponds to the rank ordering of SCC for PAGE and DICE. For FUND, the correspondence is less clear, a result that is to be expected given its less direct relationship between its damage function and GDP.

Figure 3: Level of Global GDP across EMF Scenarios



[27] Nordhaus (2008) runs DICE2007 with ρ = 1.5 and η = 2. The default approach in PAGE2002 (version 1.4epm) treats ρ and η as random parameters, specified using a triangular distribution such that the min, mode, and max = 0.1, 1, and 2 for ρ, and 0.5, 1, and 2 for η, respectively. The FUND default value for η is 1, and Tol generates SCC estimates for values of ρ = 0, 1, and 3 in many recent papers (e.g. Anthoff et al. 2009). The path of per-capita consumption growth, g, varies over time but is treated deterministically in two of the three models. In DICE, g is endogenous. Under Ramsey discounting, as economic growth slows in the future, the large damages from climate change that occur far out in the future are discounted at a lower rate than impacts that occur in the nearer term.

Table 4 shows the four selected SCC values in five year increments from 2010 to 2050. Values for 2010, 2020, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using a simple linear interpolation.

Table 4: Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

Discount Rate Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. Note that this approach allows us to estimate the growth rate of the SCC directly using DICE, PAGE, and FUND rather than assuming a constant annual growth rate as was done for the interim estimates (using 3 percent). This helps to ensure that the estimates are internally consistent with other modeling assumptions. Table 5 illustrates how the growth rate for these four SCC estimates varies over time. The full set of annual SCC estimates between 2010 and 2050 is reported in the Appendix.

Table 5: Changes in the Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Growth Rate (%)	**5%** Avg	**3%** Avg	**2.5%** Avg	**3.0%** 95th
2010-2020	3.6%	2.1%	1.7%	2.2%
2020-2030	3.7%	2.2%	1.8%	2.2%
2030-2040	2.7%	1.8%	1.6%	1.8%
2040-2050	2.1%	1.4%	1.1%	1.3%

While the SCC estimate grows over time, the future monetized value of emissions reductions in each year (the SCC in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. Damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency—i.e., future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate. For example, climate damages in the year 2020 that are calculated using a SCC based on a 5 percent discount rate also should be discounted back to the analysis year using a 5 percent discount rate.[28]

V. Limitations of the Analysis

As noted, any estimate of the SCC must be taken as provisional and subject to further refinement (and possibly significant change) in accordance with evolving scientific, economic, and ethical understandings. During the course of our modeling, it became apparent that there are several areas in particular need of additional exploration and research. These caveats, and additional observations in the following section, are necessary to consider when interpreting and applying the SCC estimates.

Incomplete treatment of non-catastrophic damages. The impacts of climate change are expected to be widespread, diverse, and heterogeneous. In addition, the exact magnitude of these impacts is uncertain because of the inherent complexity of climate processes, the economic behavior of current and future populations, and our inability to accurately forecast technological change and adaptation. Current IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature (some of which are discussed above) because of lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research. Our ability to quantify and monetize impacts will undoubtedly improve with time. But it is also likely that even in future applications, a number of potentially significant damage categories will remain non-monetized. (Ocean acidification is one example of a potentially large damage from CO_2 emissions not quantified by any of the three models. Species and wildlife loss is another example that is exceedingly difficult to monetize.)

Incomplete treatment of potential catastrophic damages. There has been considerable recent discussion of the risk of catastrophic impacts and how best to account for extreme scenarios, such as the collapse of the Atlantic Meridional Overturning Circulation or the West Antarctic Ice Sheet, or large releases of methane from melting permafrost and warming oceans. Weitzman (2009) suggests that catastrophic damages are extremely large—so large, in fact, that the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. However, Nordhaus (2009) concluded that the conditions under which Weitzman's results hold “are limited and do not apply to a wide range of potential uncertain scenarios."

Using a simplified IAM, Newbold and Daigneault (2009) confirmed the potential for large catastrophe risk premiums but also showed that the aggregate benefit estimates can be highly sensitive to the shapes of both the climate sensitivity distribution and the damage function at high temperature changes. Pindyck (2009) also used a simplified IAM to examine high-impact low-probability risks, using a right-skewed gamma distribution for climate sensitivity as well as an uncertain damage coefficient, but in most cases found only a modest risk premium. Given this difference in opinion, further research in this area is needed before its practical significance can be fully understood and a reasonable approach developed to account for such risks in regulatory analysis. (The next section discusses the scientific evidence on catastrophic impacts in greater detail.)

[28] However, it is possible that other benefits or costs of proposed regulations unrelated to CO_2 emissions will be discounted at rates that differ from those used to develop the SCC estimates.

Uncertainty in extrapolation of damages to high temperatures: The damage functions in these IAMs are typically calibrated by estimating damages at moderate temperature increases (e.g., DICE was calibrated at 2.5 °C) and extrapolated to far higher temperatures by assuming that damages increase as some power of the temperature change. Hence, estimated damages are far more uncertain under more extreme climate change scenarios.

Incomplete treatment of adaptation and technological change: Each of the three integrated assessment models used here assumes a certain degree of low- or no-cost adaptation. For instance, Tol assumes a great deal of adaptation in FUND, including widespread reliance on air conditioning ; so much so, that the largest single benefit category in FUND is the reduced electricity costs from not having to run air conditioning as intensively (NRC 2009).

Climate change also will increase returns on investment to develop technologies that allow individuals to cope with adverse climate conditions, and IAMs to do not adequately account for this directed technological change.[29] For example, scientists may develop crops that are better able to withstand higher and more variable temperatures. Although DICE and FUND have both calibrated their agricultural sectors under the assumption that farmers will change land use practices in response to climate change (Mastrandrea, 2009), they do not take into account technological changes that lower the cost of this adaptation over time. On the other hand, the calibrations do not account for increases in climate variability, pests, or diseases, which could make adaptation more difficult than assumed by the IAMs for a given temperature change. Hence, models do not adequately account for potential adaptation or technical change that might alter the emissions pathway and resulting damages. In this respect, it is difficult to determine whether the incomplete treatment of adaptation and technological change in these IAMs under or overstate the likely damages.

Risk aversion: A key question unanswered during this interagency process is what to assume about relative risk aversion with regard to high-impact outcomes. These calculations do not take into account the possibility that individuals may have a higher willingness to pay to reduce the likelihood of low-probability, high-impact damages than they do to reduce the likelihood of higher-probability but lower-impact damages with the same expected cost. (The inclusion of the 95th percentile estimate in the final set of SCC values was largely motivated by this concern.) If individuals do show such a higher willingness to pay, a further question is whether that fact should be taken into account for regulatory policy. Even if individuals are not risk-averse for such scenarios, it is possible that regulatory policy should include a degree of risk-aversion.

Assuming a risk-neutral representative agent is consistent with OMB's Circular A-4, which advises that the estimates of benefits and costs used in regulatory analysis are usually based on the average or the expected value and that "emphasis on these expected values is appropriate as long as society is 'risk neutral' with respect to the regulatory alternatives. While this may not always be the case, [analysts] should in general assume 'risk neutrality' in [their] analysis."

Nordhaus (2008) points to the need to explore the relationship between risk and income in the context of climate change across models and to explore the role of uncertainty regarding various parameters in

[29] However these research dollars will be diverted from whatever their next best use would have been in the absence of climate change (so productivity/GDP would have been still higher).

the results. Using FUND, Anthoff et al (2009) explored the sensitivity of the SCC to Ramsey equation parameter assumptions based on observed behavior. They conclude that “the assumed rate of risk aversion is at least as important as the assumed rate of time preference in determining the social cost of carbon.” Since Circular A-4 allows for a different assumption on risk preference in regulatory analysis if it is adequately justified, we plan to continue investigating this issue.

V. A Further Discussion of Catastrophic Impacts and Damage Functions

As noted above, the damage functions underlying the three IAMs used to estimate the SCC may not capture the economic effects of all possible adverse consequences of climate change and may therefore lead to underestimates of the SCC (Mastrandrea 2009). In particular, the models’ functional forms may not adequately capture: (1) potentially discontinuous “tipping point” behavior in Earth systems, (2) inter-sectoral and inter-regional interactions, including global security impacts of high-end warming, and (3) limited near-term substitutability between damage to natural systems and increased consumption.

It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling. In the meantime, we discuss some of the available evidence.

Extrapolation of climate damages to high levels of warming

The damage functions in the models are calibrated at moderate levels of warming and should therefore be viewed cautiously when extrapolated to the high temperatures found in the upper end of the distribution. Recent science suggests that there are a number of potential climatic “tipping points” at which the Earth system may exhibit discontinuous behavior with potentially severe social and economic consequences (e.g., Lenton et al, 2008, Kriegler et al., 2009). These tipping points include the disruption of the Indian Summer Monsoon, dieback of the Amazon Rainforest and boreal forests, collapse of the Greenland Ice Sheet and the West Antarctic Ice Sheet, reorganization of the Atlantic Meridional Overturning Circulation, strengthening of El Niño-Southern Oscillation, and the release of methane from melting permafrost. Many of these tipping points are estimated to have thresholds between about 3 °C and 5 °C (Lenton et al., 2008). Probabilities of several of these tipping points were assessed through expert elicitation in 2005–2006 by Kriegler et al. (2009); results from this study are highlighted in Table 6. Ranges of probability are averaged across core experts on each topic.

As previously mentioned, FUND does not include potentially catastrophic effects. DICE assumes a small probability of catastrophic damages that increases with increased warming, but the damages from these risks are incorporated as expected values (i.e., ignoring potential risk aversion). PAGE models catastrophic impacts in a probabilistic framework (see Figure 1), so the high-end output from PAGE potentially offers the best insight into the SCC if the world were to experience catastrophic climate change. For instance, at the 95th percentile and a 3 percent discount rate, the SCC estimated by PAGE across the five socio-economic and emission trajectories of \$113 per ton of CO_2 is almost double the value estimated by DICE, \$58 per ton in 2010. We cannot evaluate how well the three models account for catastrophic or non-catastrophic impacts, but this estimate highlights the sensitivity of SCC values in the tails of the distribution to the assumptions made about catastrophic impacts.

Table 6: Probabilities of Various Tipping Points from Expert Elicitation -

Possible Tipping Points	Duration before effect is fully realized (in years)	Additional Warming by 2100		
		0.5-1.5 C	1.5-3.0 C	3-5 C
Reorganization of Atlantic Meridional Overturning Circulation	about 100	0-18%	6-39%	18-67%
Greenland Ice Sheet collapse	at least 300	8-39%	33-73%	67-96%
West Antarctic Ice Sheet collapse	at least 300	5-41%	10-63%	33-88%
Dieback of Amazon rainforest	about 50	2-46%	14-84%	41-94%
Strengthening of El Niño-Southern Oscillation	about 100	1-13%	6-32%	19-49%
Dieback of boreal forests	about 50	13-43%	20-81%	34-91%
Shift in Indian Summer Monsoon	about 1	Not formally assessed		
Release of methane from melting permafrost	Less than 100	Not formally assessed.		

PAGE treats the possibility of a catastrophic event probabilistically, while DICE treats it deterministically (that is, by adding the expected value of the damage from a catastrophe to the aggregate damage function). In part, this results in different probabilities being assigned to a catastrophic event across the two models. For instance, PAGE places a probability near zero on a catastrophe at 2.5 °C warming, while DICE assumes a 4 percent probability of a catastrophe at 2.5 °C. By comparison, Kriegler et al. (2009) estimate a probability of at least 16-36 percent of crossing at least one of their primary climatic tipping points in a scenario with temperatures about 2-4 °C warmer than pre-Industrial levels in 2100.

It is important to note that crossing a climatic tipping point will not necessarily lead to an economic catastrophe in the sense used in the IAMs. A tipping point is a critical threshold across which some aspect of the Earth system starts to shifts into a qualitatively different state (for instance, one with dramatically reduced ice sheet volumes and higher sea levels). In the IAMs, a catastrophe is a low-probability environmental change with high economic impact.

Failure to incorporate inter-sectoral and inter-regional interactions

The damage functions do not fully incorporate either inter-sectoral or inter-regional interactions. For instance, while damages to the agricultural sector are incorporated, the effects of changes in food supply on human health are not fully captured and depend on the modeler's choice of studies used to calibrate the IAM. Likewise, the effects of climate damages in one region of the world on another region are not included in some of the models (FUND includes the effects of migration from sea level rise). These inter-regional interactions, though difficult to quantify, are the basis for climate-induced national and economic security concerns (e.g., Campbell et al., 2007; U.S. Department of Defense 2010) and are particularly worrisome at higher levels of warming. High-end warming scenarios, for instance, project water scarcity affecting 4.3-6.9 billion people by 2050, food scarcity affecting about 120 million additional people by 2080, and the creation of millions of climate refugees (Easterling et al., 2007; Campbell et al., 2007).

Imperfect substitutability of environmental amenities

Data from the geological record of past climate changes suggests that 6 °C of warming may have severe consequences for natural systems. For instance, during the Paleocene-Eocene Thermal Maximum about 55.5 million years ago, when the Earth experienced a geologically rapid release of carbon associated with an approximately 5 °C increase in global mean temperatures, the effects included shifts of about 400-900 miles in the range of plants (Wing et al., 2005), and dwarfing of both land mammals (Gingerich, 2006) and soil fauna (Smith et al., 2009).

The three IAMs used here assume that it is possible to compensate for the economic consequences of damages to natural systems through increased consumption of non-climate goods, a common assumption in many economic models. In the context of climate change, however, it is possible that the damages to natural systems could become so great that no increase in consumption of non-climate goods would provide complete compensation (Levy et al., 2005). For instance, as water supplies become scarcer or ecosystems become more fragile and less bio-diverse, the services they provide may become increasingly more costly to replace. Uncalibrated attempts to incorporate the imperfect substitutability of such amenities into IAMs (Sterner and Persson, 2008) indicate that the optimal degree of emissions abatement can be considerably greater than is commonly recognized.

VI. Conclusion

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are $5, $21, $35, and $65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to $24 per ton of CO_2 in 2015 and $26 per ton of CO_2 in 2020.

We noted a number of limitations to this analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes this modeling exercise even more difficult. It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling.

References

Andronova, N., and M. Schlesinger. 2001. "Objective estimation of the probability density function for climate sensitivity." *J. Geophys. Res.*, 106(D19), 22605–22611.

Annan, J., et al., 2005. "Efficiently constraining climate sensitivity with paleoclimate simulations." *Scientific Online Letters on the Atmosphere*, 1, 181–184.

Anthoff D, C. Hepburn, and R. Tol. 2009a. "Equity Weighting and the Marginal Damage Costs of Climate Change." *Ecological Economics* 68:836-849.

Anthoff, D., R. Tol, and G. Yohe. 2009b. "Risk aversion, time preference, and the social cost of carbon." *Environmental Research Letters* 4: 024002 (7pp).

Arrow, K. 2007. "Global climate change: a challenge to policy." *Economist's Voice* 4(3):Article 2.

Arrow, K. 2000. "A Comment on Cooper." *The World Bank Research Observer*. vol 15, no. 2.

Arrow, K., et al. 1996. *Benefit-Cost Analysis in Environmental, Health, and Safety Regulation: A Statement of Principles*. Washington, D.C., AEI Press. pp. 13-14.

Arrow, K.J., et al. 1996. "Intertemporal equity, discounting and economic efficiency," in Climate Change 1995: Economic and Social Dimensions of Climate Change, Contribution of Working Group III to the *Second Assessment Report of the Intergovernmental Panel on Climate Change*.

Campbell, J., P. Diamond, and J. Shoven. 2001. "Estimating the Real Rate of Return on Stocks Over the Long Term." Presented to the Social Security Advisory Board. August.

Campbell, K. et al. 2007. *The age of consequences: The foreign policy and national security implications of global climate change*. Center for Strategic & International Studies, 119 pp.

Castles, I. and D. Henderson. 2003. "The IPCC Emission Scenarios: An Economic-Statistical Critique." *Energy and Environment* 14(2-3): 159-185.

Chetty, R. 2006. "A New Method of Estimating Risk Aversion." *American Economic Review* 96(5): 1821–1834.

Dasgupta P. 2006. "Comments on the Stern Review's economics of climate change." University of Cambridge working paper.

Dasgupta P. 2008. "Discounting climate change." *Journal of Risk and Uncertainty* 37:141-169.

Easterling, W., et al. 2007. *Climate Change 2007: Impacts, Adaptation, and Vulnerability*. Intergovernmental Panel on Climate Change, 976 pp. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm, last accessed March 25, 2010.

Evans D., and H. Sezer. 2005. "Social discount rates for member countries of the European Union." *J. Econ. Stud*. 32 47–59.

Forest, C., et al. 2002. “Quantifying uncertainties in climate system properties with the use of recent observations.” *Science* 295, 113.

Forest, D., P. Stone, and A. Sokolov. 2006. “Estimated PDFs of climate system properties including natural and anthropogenic forcings.” *Geophys. Res. Lett*., 33, L01705.

Forster, P., and J. Gregory. 2006. “The climate sensitivity and its components diagnosed from Earth radiation budget data.” *J. Clim*., 19, 39–52.

Frame, D., et al. 2005. “Constraining climate forecasts: The role of prior assumptions.” *Geophys. Res. Lett*., 32, L09702.

Gingerich, P. 2006. “Environment and evolution through the Paleocene-Eocene thermal maximum.” *Trends Ecol. Evol.* 21: 246-253.

Gollier, C. 2008. “Discounting with fat-tailed economic growth.” *Journal of Risk and Uncertainty* 37:171-186.

Gollier, C. and M. Weitzman (2009). "How Should the Distant Future be Discounted When Discount Rates are Uncertain?" Harvard University, mimeo, Nov 2009.

Gregory, J., et al. 2002a. “An observationally based estimate of the climate sensitivity.” *J. Clim*., 15(22), 3117–3121.

Groom, B., Koundouri, P., Panipoulou, E., Pantelidis, T. 2006. “An econometric approach to estimating long-run discount rates.” *Journal of Applied Econometrics.*

Hall R, and C. Jones . 2007. “The value of life and the rise in health spending.” Quarterly *Journal of Economics* 122(1):39-72.

Hansen, J.,M. Sato, P. Kharecha, G. Russell, D. W. Lea and M. Siddall. 2007. “Climate change and trace gases.” *Phil. Trans. Roy. Soc. A* 365: 1925-1954.

Hegerl G, et al. 2007. “Understanding and attributing climate change.” in Solomon S, et al. (eds) *Climate Change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

Hegerl, G., T. Crowley, W. Hyde, and D. Frame. 2006. “Constraints on climate sensitivity from temperature reconstructions of the past seven centuries.” *Nature* 440.

Holtsmark, B., and K. Alfsen. 2005. “PPP Correction of the IPCC Emission Scenarios – Does it Matter?” *Climatic Change* 68(1-2): 11-19.

Hope C. 2006. “The marginal impact of CO2 from PAGE2002: an integrated assessment model incorporating the IPCC’s five reasons for concern.” *The Integrated Assessment Journal* 6(1):19-56.

Hope C. 2008. “Optimal carbon emissions and the social cost of carbon under uncertainty.” *The Integrated Assessment Journal* 8(1):107-122.

Intergovernmental Panel on Climate Change (2007). "Summary for Policymakers." In *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Just, R., D. Hueth, and A. Schmitz. 2004. *The Welfare Economics of Public Policy*. Glos UK: Edward Elgar Publishing Limited.

Knutti, R., T. Stocker, F. Joos, and G. Plattner. 2002. "Constraints on radiative forcing and future climate change from observations and climate model ensembles." *Nature*, 416, 719–723.

Kriegler, E. et al. 2009. "Imprecise probability assessment of tipping points in the climate system." *Proc. Natl. Acad. Sci.* 106: 5041-5046.

Kotlikoff, L. and D. Rapson. 2006. "Does It Pay, at the Margin, to Work and Save? – Measuring Effective Marginal Taxes on Americans' Labor Supply and Saving." National Bureau of Economic Research, Working Paper, No. 12533.

Le Treut H., et al. 2007. "Historical Overview of Climate Change." in Solomon et al., *Climate Change 2007*.

Lenton, T., et al. 2008. "Tipping elements in the Earth's climate system." *Proc. Natl. Acad. Sci.* 105: 1786-1793.

Levy, M., et al. 2005. "Ecosystem conditions and human well-being." In: *Ecosystems and Human Well-being: Current State and Trends, Volume 1.* [R. Hassan, R. Scholes, and N. Ash, eds.] Washington: Island Press. pp. 123-164.

Lind, R. 1990. "Reassessing the Government's Discount Rate Policy in Light of New Theory and Data in a World Economy with a High Degree of Capital Mobility." *Journal of Environmental Economics and Management* 18, S-8-S-28.

Mastrandre, M. 2009. "Calculating the benefits of climate policy: Examining the assumptions of Integrated Assessment Models." Pew Center on Global Climate Change Working Paper, 60 pp.

Meehl, G, et al. 2007. "Global Climate Projections." in Solomon et al., *Climate Change 2007*.

National Research Council (2009). *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*. National Academies Press.

Newbold S, Daigneault A. 2009. "Climate response uncertainty and the benefits of greenhouse gas emissions reductions." *Environmental and Resource Economics* 44:351-377.

Newell, R., and W. Pizer. 2003. Discounting the distant future: how much do uncertain rates increase valuations? *Journal of Environmental Economics and Management* 46: 52-71.

Nordhaus, W. 1994. "Expert Opinion on Climate Change." *American Scientist* 82: 45-51.

Nordhaus, W. 2007a. *Accompanying notes and documentation on development of DICE-2007 model: notes on DICE-2007.delta.v8 as of September 21, 2007.*

Nordhaus, W. 2007b. "Alternative measures of output in global economic-environmental models: Purchasing power parity or market exchange rates?" *Energy Economics* 29: 349-372.

Nordhaus W. 2008. *A Question of Balance: Weighing the Options on Global Warming Policies*. New Haven, CT: Yale University Press.

Nordhaus, W. 2009. "An Analysis of the Dismal Theorem. Cowles Foundation Discussion Paper. No. 1686. January.

Nordhaus W., and Boyer J. 2000. *Warming the World: Economic Models of Global Warming*. Cambridge, MA: MIT Press.

Pindyck, R. 2009. "Uncertain Outcomes and Climate Change Policy." NBER Working Paper, No. 15259. August.

Ramsey, F. 1928. "A Mathematical Theory of Saving." *The Economic Journal* 38(152): 543-559.

Roe, G. 2008. "Feedbacks, timescales, and seeing red." *Annual Review of Earth and Planetary Sciences* 37:5.1-5.23.

Roe, G., and M. Baker. 2007. "Why is climate sensitivity so unpredictable?" *Science* 318:629-632.

Schneider von Deimling, T., H. Held, A. Ganopolski, and S. Rahmstorf. 2006. "Climate sensitivity estimated from ensemble simulations of glacial climate." *Clim. Dyn*., 27, 149–163.

Smith, J. et al. 2009. "Transient dwarfism of soil fauna during the Paleocene-Eocene Thermal Maximum." *Proc. Natl. Acad. Sci.* 106: 17665-17660.

Stern, N., et al. (2006), *Stern Review: The Economics of Climate Change*, HM Treasury, London. See http://www.hm-treasury.gov.uk/stern_review_report.htm, last accessed March 25, 2010.

Stern N. 2008. "The economics of climate change." *American Economic Review* 98(2):1-37.

Sterner, T., and U. Persson. 2008. An even Sterner review: Introducing relative prices into the discounting debate. *Rev. Env. Econ. Pol.* 2: 61-76.

Summers, L., and R. Zeckhauser. 2008. "Policymaking for Posterity." Journal of Risk and Uncertainty 37: 115-140.

Szpiro, G. 1986. "Measuring Risk Aversion: An Alternative Approach." *The Review of Economics and Statistics* 68(1): 156-9.

Tol, R. 2002a. "Estimates of the damage costs of climate change. Part I: benchmark estimates." *Environmental and Resource Economics* 21:47-73.

Tol, R. 2002b. "Estimates of the damage costs of climate change. Part II: dynamic estimates." *Environmental and Resource Economics* 21:135-160.

Tol, R. 2006. "Exchange Rates and Climate Change: An Application of FUND." *Climatic Change* 75(1-2): 59-80.

Tol, R. 2009. "An analysis of mitigation as a response to climate change." Copenhagen Consensus on Climate. Discussion Paper.

U.S. Department of Defense. 2010. Quadrennial Defense Review Report. February.

Warren, R., et al. 2006. "Spotlight Impact Functions in Integrated Assessment." Tyndall Center for Climate Change Research, Working Paper 91.

Weitzman, M. 2009. "On modeling and interpreting the economics of catastrophic climate change." *Review of Economics and Statistics* 91:1-19.

Weitzman, M. 2007. "A review of The Stern Review of the Economics of Climate Change." *Journal of Economic Literature* 45:703-724.

Weitzman, M. 1999. In Portney P.R. and Weyant J.P. (eds.), *Discounting and Intergenerational Equity*, Resources for the Future, Washington, D.C.

Weitzman, M. 1998. "Why the Far-Distant Future Should Be Discounted at Its Lowest Possible Rate." *Journal of Environmental Economics and Management* 36 (3): 201-208.

Wing, S. et al. 2005. "Transient floral change and rapid global warming at the Paleocene-Eocene boundary." *Science* 310: 993-996.

Appendix

Table A1: Annual SCC Values: 2010–2050 (in 2007 dollars)

Discount Rate Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2011	4.9	21.9	35.7	66.5
2012	5.1	22.4	36.4	68.1
2013	5.3	22.8	37.0	69.6
2014	5.5	23.3	37.7	71.2
2015	5.7	23.8	38.4	72.8
2016	5.9	24.3	39.0	74.4
2017	6.1	24.8	39.7	76.0
2018	6.3	25.3	40.4	77.5
2019	6.5	25.8	41.0	79.1
2020	6.8	26.3	41.7	80.7
2021	7.1	27.0	42.5	82.6
2022	7.4	27.6	43.4	84.6
2023	7.7	28.3	44.2	86.5
2024	7.9	28.9	45.0	88.4
2025	8.2	29.6	45.9	90.4
2026	8.5	30.2	46.7	92.3
2027	8.8	30.9	47.5	94.2
2028	9.1	31.5	48.4	96.2
2029	9.4	32.1	49.2	98.1
2030	9.7	32.8	50.0	100.0
2031	10.0	33.4	50.9	102.0
2032	10.3	34.1	51.7	103.9
2033	10.6	34.7	52.5	105.8
2034	10.9	35.4	53.4	107.8
2035	11.2	36.0	54.2	109.7
2036	11.5	36.7	55.0	111.6
2037	11.8	37.3	55.9	113.6
2038	12.1	37.9	56.7	115.5
2039	12.4	38.6	57.5	117.4
2040	12.7	39.2	58.4	119.3
2041	13.0	39.8	59.0	121.0
2042	13.3	40.4	59.7	122.7
2043	13.6	40.9	60.4	124.4
2044	13.9	41.5	61.0	126.1
2045	14.2	42.1	61.7	127.8
2046	14.5	42.6	62.4	129.4
2047	14.8	43.2	63.0	131.1
2048	15.1	43.8	63.7	132.8
2049	15.4	44.4	64.4	134.5
2050	15.7	44.9	65.0	136.2

This Appendix also provides additional technical information about the non-CO_2 emission projections used in the modeling and the method for extrapolating emissions forecasts through 2300, and shows the full distribution of 2010 SCC estimates by model and scenario combination.

1. Other (non-CO_2) gases

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane (CH_4), nitrous oxide (N_2O), fluorinated gases, and net land use CO_2 emissions to 2100. These assumptions are used in all three IAMs while retaining each model's default radiative forcings (RF) due to other factors (e.g., aerosols and other gases). Specifically, to obtain the RF associated with the non-CO_2 EMF emissions only, we calculated the RF associated with the EMF atmospheric CO_2 concentrations and subtracted them from the EMF total RF.[30] This approach respects the EMF scenarios as much as possible and at the same time takes account of those components not included in the EMF projections. Since each model treats non-CO_2 gases differently (e.g., DICE lumps all other gases into one composite exogenous input), this approach was applied slightly differently in each of the models.

<u>FUND</u>: Rather than relying on RF for these gases, the actual emissions from each scenario were used in FUND. The model default trajectories for CH_4, N_20, SF_6, and the CO_2 emissions from land were replaced with the EMF values.

<u>PAGE</u>: PAGE models CO_2, CH_4, sulfur hexafluoride (SF_6), and aerosols and contains an "excess forcing" vector that includes the RF for everything else. To include the EMF values, we removed the default CH_4 and SF_6 factors[31], decomposed the excess forcing vector, and constructed a new excess forcing vector that includes the EMF RF for CH_4, N_20, and fluorinated gases, as well as the model default values for aerosols and other factors. Net land use CO_2 emissions were added to the fossil and industrial CO_2 emissions pathway.

<u>DICE</u>: DICE presents the greatest challenge because all forcing due to factors other than industrial CO_2 emissions is embedded in an exogenous non-CO_2 RF vector. To decompose this exogenous forcing path into EMF non-CO_2 gases and other gases, we relied on the references in DICE2007 to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) and the discussion of aerosol forecasts in the IPCC's Third Assessment Report (TAR) and in AR4, as explained below. In DICE2007, Nordhaus assumes that exogenous forcing from all non-CO_2 sources is -0.06 W/m^2 in 2005, as reported in AR4, and increases linearly to 0.3 W/m^2 in 2105, based on GISS projections, and then stays constant after that time.

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[30] Note EMF did not provide CO_2 concentrations for the IMAGE reference scenario. Thus, for this scenario, we fed the fossil, industrial and land CO_2 emissions into MAGICC (considered a "neutral arbiter" model, which is tuned to emulate the major global climate models) and the resulting CO_2 concentrations were used. Note also that MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

[31] Both the model default CH_4 emissions and the initial atmospheric CH_4 is set to zero to avoid double counting the effect of past CH_4 emissions.

According to AR4, the RF in 2005 from CH_4, N_20, and halocarbons (approximately similar to the F-gases in the EMF-22 scenarios) was 0.48 + 0.16 + 0.34 = 0.98 W/m^2 and RF from total aerosols was -1.2 W/m^2. Thus, the -.06 W/m^2 non-CO_2 forcing in DICE can be decomposed into: 0.98 W/m^2 due to the EMF non-CO_2 gases, -1.2 W/m^2 due to aerosols, and the remainder, 0.16 W/m^2, due to other residual forcing.

For subsequent years, we calculated the DICE default RF from aerosols and other non-CO_2 gases based on the following two assumptions:

(1) RF from aerosols declines linearly from 2005 to 2100 at the rate projected by the TAR and then stays constant thereafter, and
(2) With respect to RF from non-CO_2 gases not included in the EMF-22 scenarios, the share of non-aerosol RF matches the share implicit in the AR4 summary statistics cited above and remains constant over time.

Assumption (1) means that the RF from aerosols in 2100 equals 66 percent of that in 2000, which is the fraction of the TAR projection of total RF from aerosols (including sulfates, black carbon, and organic carbon) in 2100 vs. 2000 under the A1B SRES emissions scenario. Since the SRES marker scenarios were not updated for the AR4, the TAR provides the most recent IPCC projection of aerosol forcing. We rely on the A1B projection from the TAR because it provides one of the lower aerosol forecasts among the SRES marker scenarios and is more consistent with the AR4 discussion of the post-SRES literature on aerosols:

Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulphur dioxide, black carbon and organic carbon, has improved in the post-SRES scenarios. Generally, these emissions are projected to be lower than reported in SRES. {WGIII 3.2, TS.3, SPM}.[32]

Assuming a simple linear decline in aerosols from 2000 to 2100 also is more consistent with the recent literature on these emissions. For example, Figure A1 shows that the sulfur dioxide emissions peak over the short-term of some SRES scenarios above the upper bound estimates of the more recent scenarios.[33] Recent scenarios project sulfur emissions to peak earlier and at lower levels compared to the SRES in part because of new information about present and planned sulfur legislation in some developing countries, such as India and China.[34] The lower bound projections of the recent literature have also shifted downward slightly compared to the SRES scenario (IPCC 2007).

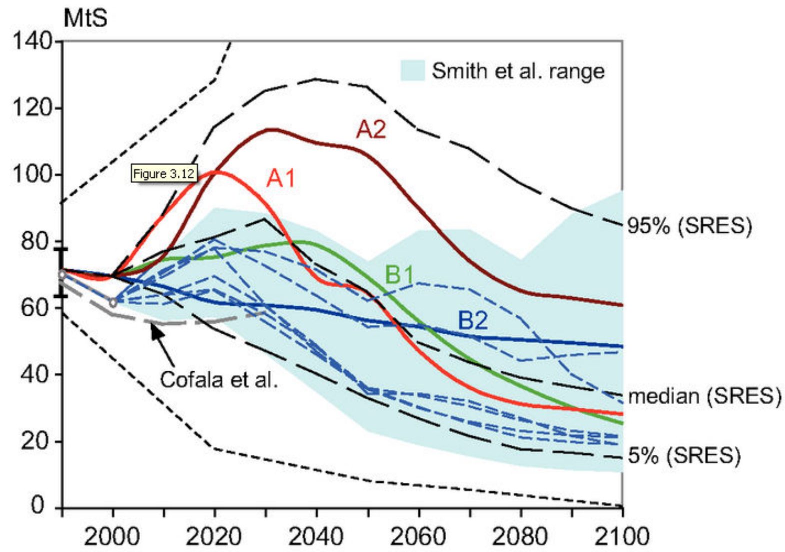
[32] AR4 Synthesis Report, p. 44, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[33] See Smith, S.J., R. Andres, E. Conception, and J. Lurz, 2004: Historical sulfur dioxide emissions, 1850-2000: methods and results. Joint Global Research Institute, College Park, 14 pp.

[34] See Carmichael, G., D. Streets, G. Calori, M. Amann, M. Jacobson, J. Hansen, and H. Ueda, 2002: Changing trends in sulphur emissions in Asia: implications for acid deposition, air pollution, and climate. Environmental Science and Technology, 36(22):4707- 4713; Streets, D., K. Jiang, X. Hu, J. Sinton, X.-Q. Zhang, D. Xu, M. Jacobson, and J. Hansen, 2001: Recent reductions in China's greenhouse gas emissions. Science, 294(5548): 1835-1837.

With these assumptions, the DICE aerosol forcing changes from -1.2 in 2005 to -0.792 in 2105 W/m^2; forcing due to other non-CO_2 gases not included in the EMF scenarios declines from 0.160 to 0.153 W/m^2.

Figure A1: Sulphur Dioxide Emission Scenarios -



Notes: Thick colored lines depict the four SRES marker scenarios and black dashed lines show the median, 5th and 95th percentile of the frequency distribution for the full ensemble of 40 SRES scenarios. The blue area (and the thin dashed lines in blue) illustrates individual scenarios and the range of Smith et al. (2004). Dotted lines indicate the minimum and maximum of SO_2 emissions scenarios developed pre-SRES.
Source: IPCC (2007), AR4 WGIII 3.2, http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch3-ens3-2-2-4.html.

Although other approaches to decomposing the DICE exogenous forcing vector are possible, initial sensitivity analysis suggests that the differences among reasonable alternative approaches are likely to be minor. For example, adjusting the TAR aerosol projection above to assume that aerosols will be maintained at 2000 levels through 2100 reduces average SCC values (for 2010) by approximately 3 percent (or less than $2); assuming all aerosols are phased out by 2100 increases average 2010 SCC values by 6-7 percent (or $0.50-$3)–depending on the discount rate. These differences increase slightly for SCC values in later years but are still well within 10 percent of each other as far out as 2050.

Finally, as in PAGE, the EMF net land use CO_2 emissions are added to the fossil and industrial CO_2 emissions pathway.

2. - Extrapolating Emissions Projections to 2300

To run each model through 2300 requires assumptions about GDP, population, greenhouse gas emissions, and radiative forcing trajectories after 2100, the last year for which these projections are available from the EMF-22 models. These inputs were extrapolated from 2100 to 2300 as follows:

1. Population growth rate declines linearly, reaching zero in the year 2200.
2. GDP/ per capita growth rate declines linearly, reaching zero in the year 2300.
3. The decline in the fossil and industrial carbon intensity (CO_2/GDP) growth rate over 2090-2100 is maintained from 2100 through 2300.
4. Net land use CO_2 emissions decline linearly, reaching zero in the year 2200.
5. Non-CO_2 radiative forcing remains constant after 2100.

Long run stabilization of GDP per capita was viewed as a more realistic simplifying assumption than a linear or exponential extrapolation of the pre-2100 economic growth rate of each EMF scenario. This is based on the idea that increasing scarcity of natural resources and the degradation of environmental sinks available for assimilating pollution from economic production activities may eventually overtake the rate of technological progress. Thus, the overall rate of economic growth may slow over the very long run. The interagency group also considered allowing an exponential decline in the growth rate of GDP per capita. However, since this would require an additional assumption about how close to zero the growth rate would get by 2300, the group opted for the simpler and more transparent linear extrapolation to zero by 2300.

The population growth rate is also assumed to decline linearly, reaching zero by 2200. This assumption is reasonably consistent with the United Nations long run population forecast, which estimates global population to be fairly stable after 2150 in the medium scenario (UN 2004).[35] The resulting range of EMF population trajectories (Figure A2) also encompass the UN medium scenario forecasts through 2300 – global population of 8.5 billion by 2200, and 9 billion by 2300.

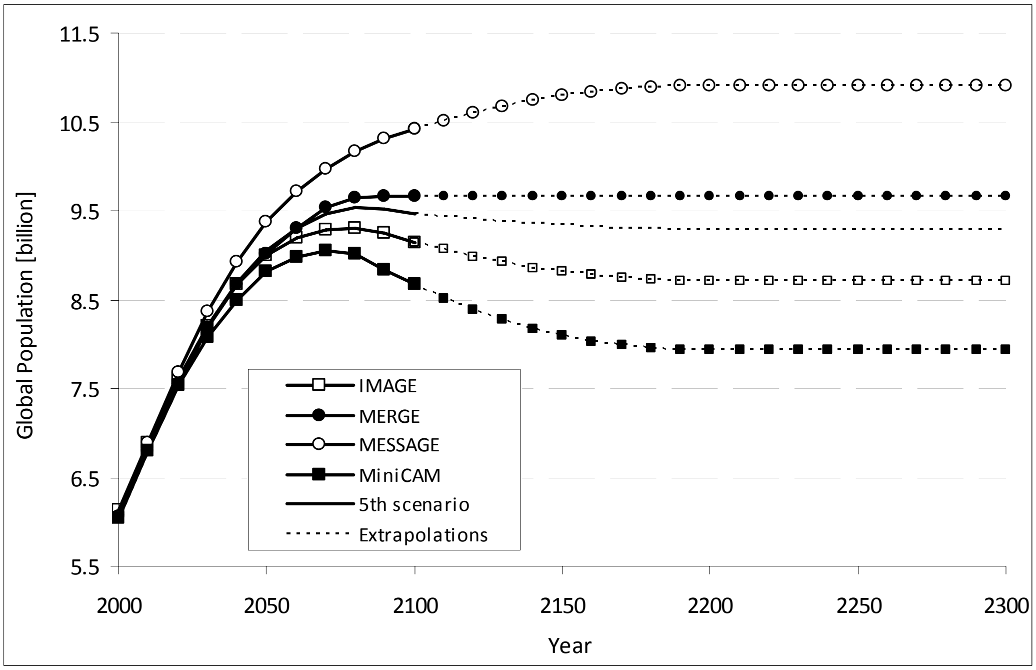
Maintaining the decline in the 2090-2100 carbon intensity growth rate (i.e., CO_2 per dollar of GDP) through 2300 assumes that technological improvements and innovations in the areas of energy efficiency and other carbon reducing technologies (possibly including currently unavailable methods) will continue to proceed at roughly the same pace that is projected to occur towards the end of the forecast period for each EMF scenario. This assumption implies that total cumulative emissions in 2300 will be between 5,000 and 12,000 GtC, which is within the range of the total potential global carbon stock estimated in the literature.

Net land use CO_2 emissions are expected to stabilize in the long run, so in the absence of any post 2100 projections, the group assumed a linear decline to zero by 2200. Given no a priori reasons for assuming a long run increase or decline in non-CO_2 radiative forcing, it is assumed to remain at the 2100 levels for each EMF scenario through 2300.

Figures A2-A7 show the paths of global population, GDP, fossil and industrial CO_2 emissions, net land CO_2 emissions, non-CO_2 radiative forcing, and CO_2 intensity (fossil and industrial CO_2 emissions/GDP) resulting from these assumptions.

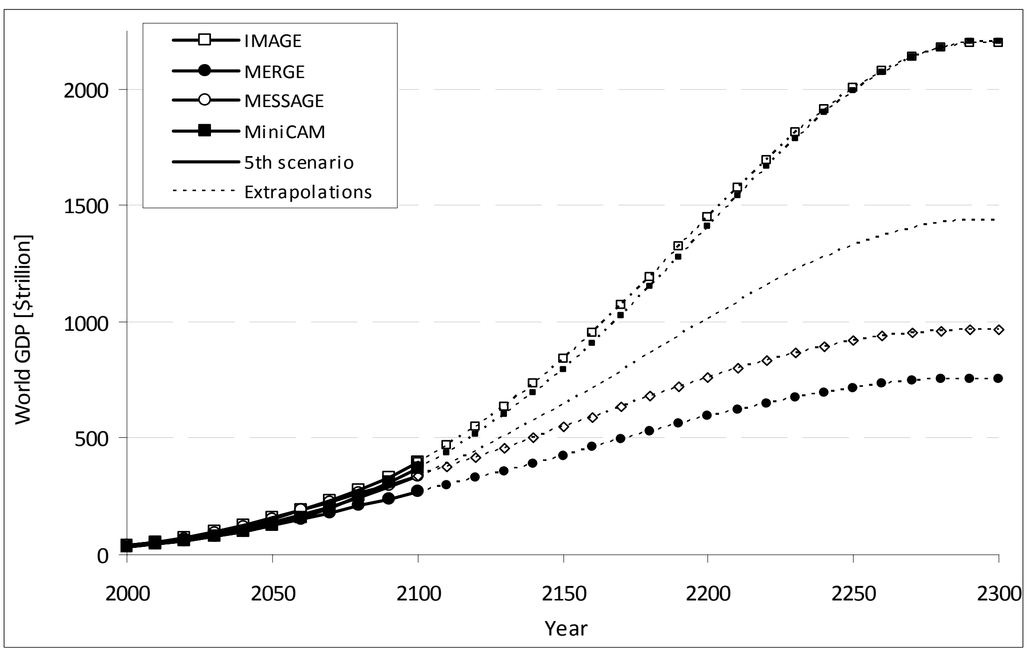
[35] United Nations. 2004. *World Population to 2300*. http://www.un.org/esa/population/publications/longrange2/worldpop2300final.pdf

Figure A2. Global Population, 2000-2300 (Post-2100 extrapolations assume the population growth - rate changes linearly to reach a zero growth rate by 2200.) -



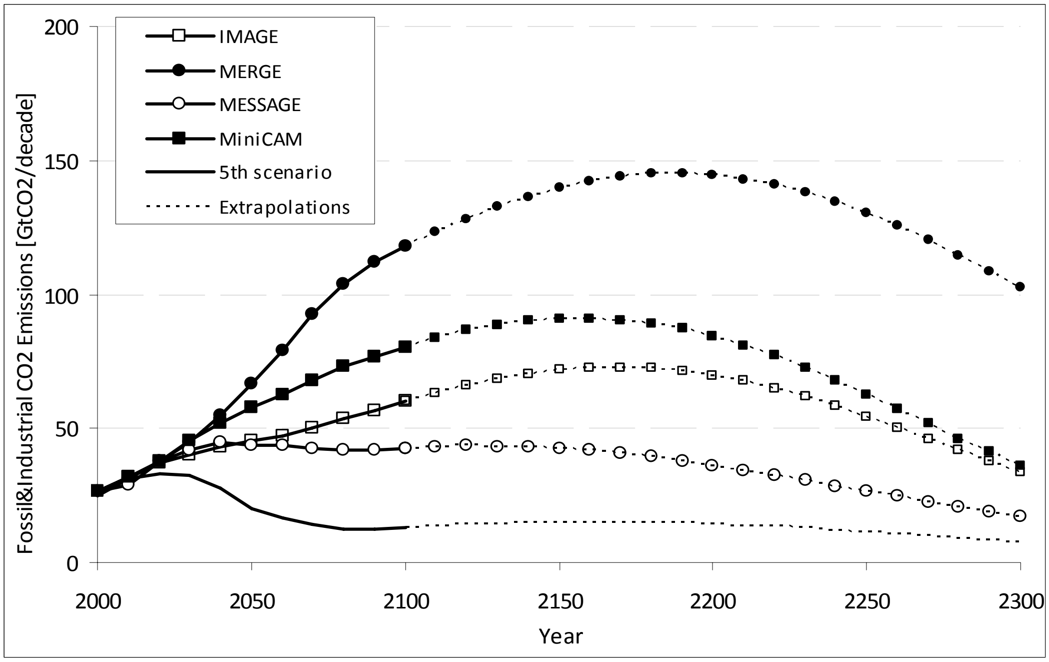
Note: In the fifth scenario, 2000-2100 population is equal to the average of the population under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Figure A3. World GDP, 2000-2300 (Post-2100 extrapolations assume GDP per capita growth declines linearly, reaching zero in the year 2300)



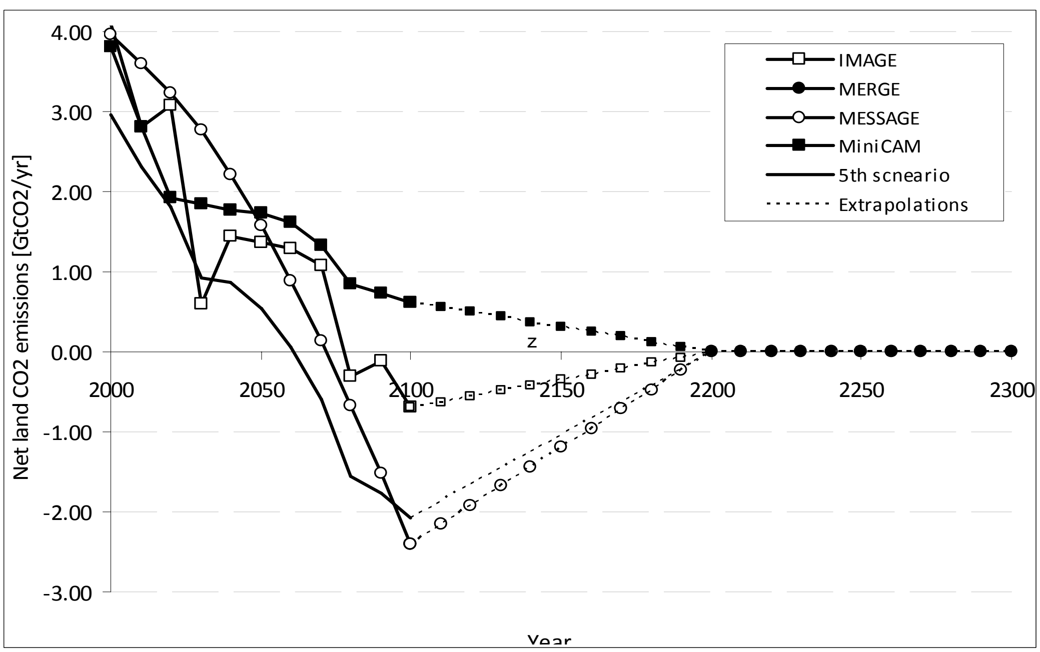
Note: In the fifth scenario, 2000-2100 GDP is equal to the average of the GDP under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Figure A4. Global Fossil and Industrial CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume growth rate of CO_2 intensity (CO_2/GDP) over 2090-2100 is maintained through 2300.)



Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO2e, full-participation, not-to-exceed scenarios considered by each of the four models.

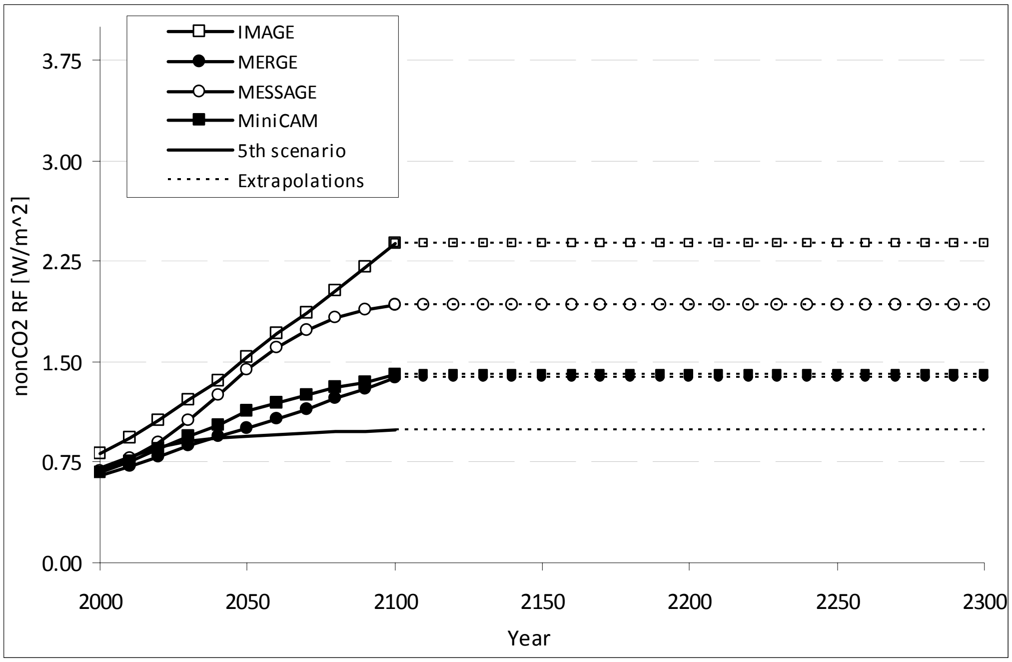
Figure A5. Global Net Land Use CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume emissions decline linearly, reaching zero in the year 2200)[36]



Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO2e, full-participation, not-to-exceed scenarios considered by each of the four models.

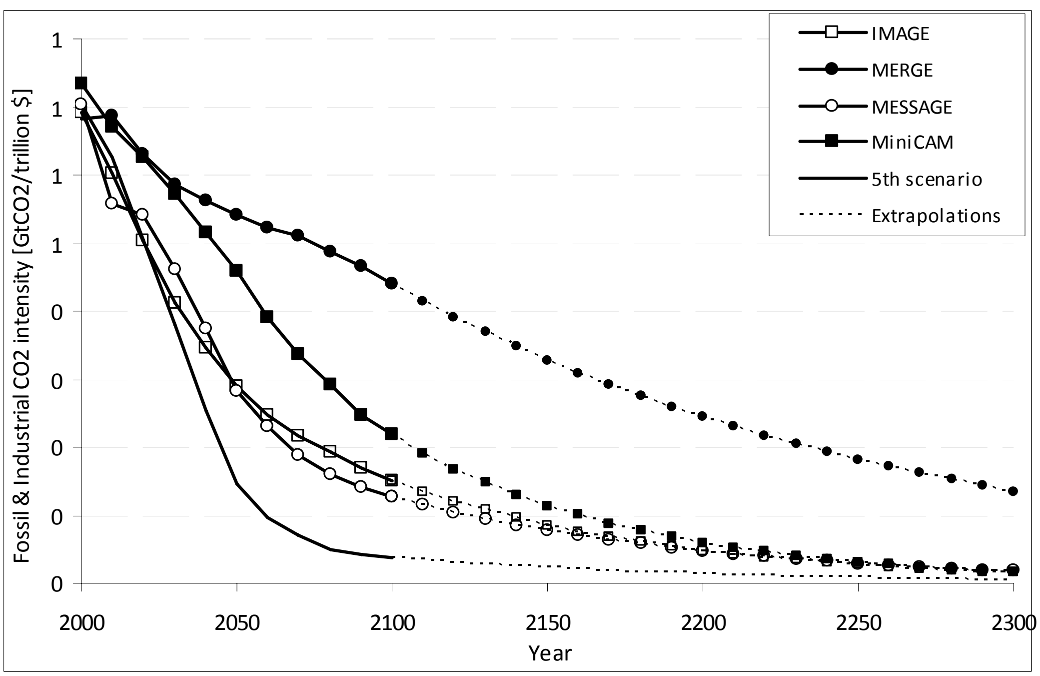
36 MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

Figure A6. Global Non-CO_2 Radiative Forcing, 2000-2300 (Post-2100 extrapolations assume constant non-CO_2 radiative forcing after 2100.)



Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Figure A7. Global CO_2 Intensity (fossil & industrial CO_2 emissions/GDP), 2000-2300 (Post-2100 extrapolations assume decline in CO_2/GDP growth rate over 2090-2100 is maintained through 2300.)



Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Table A2. 2010 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					**PAGE**					
IMAGE	3.3	5.9	8.1	13.9	28.8	65.5	68.2	147.9	239.6	563.8
MERGE optimistic	1.9	3.2	4.3	7.2	14.6	34.6	36.2	79.8	124.8	288.3
Message	2.4	4.3	5.8	9.8	20.3	49.2	50.7	114.9	181.7	428.4
MiniCAM base	2.7	4.6	6.4	11.2	22.8	54.7	55.7	120.5	195.3	482.3
5th scenario	2.0	3.5	4.7	8.1	16.3	42.9	41.5	103.9	176.3	371.9
Scenario					**DICE**					
IMAGE	16.4	21.4	25	33.3	46.8	54.2	69.7	96.3	111.1	130.0
MERGE optimistic	9.7	12.6	14.9	19.7	27.9	31.6	40.7	54.5	63.5	73.3
Message	13.5	17.2	20.1	27	38.5	43.5	55.1	75.8	87.9	103.0
MiniCAM base	13.1	16.7	19.8	26.7	38.6	44.4	56.8	79.5	92.8	109.3
5th scenario	10.8	14	16.7	22.2	32	37.4	47.7	67.8	80.2	96.8
Scenario					**FUND**					
IMAGE	-33.1	-18.9	-13.3	-5.5	4.1	19.3	18.7	43.5	67.1	150.7
MERGE optimistic	-33.1	-14.8	-10	-3	5.9	14.8	20.4	43.9	65.4	132.9
Message	-32.5	-19.8	-14.6	-7.2	1.5	8.8	13.8	33.7	52.3	119.2
MiniCAM base	-31.0	-15.9	-10.7	-3.4	6	22.2	21	46.4	70.4	152.9
5th scenario	-32.2	-21.6	-16.7	-9.7	-2.3	3	6.7	20.5	34.2	96.8

Table A3. 2010 Global SCC Estimates at 3 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					**PAGE**					
IMAGE	2.0	3.5	4.8	8.1	16.5	39.5	41.6	90.3	142.4	327.4
MERGE optimistic	1.2	2.1	2.8	4.6	9.3	22.3	22.8	51.3	82.4	190.0
Message	1.6	2.7	3.6	6.2	12.5	30.3	31	71.4	115.6	263.0
MiniCAM base	1.7	2.8	3.8	6.5	13.2	31.8	32.4	72.6	115.4	287.0
5th scenario	1.3	2.3	3.1	5	9.6	25.4	23.6	62.1	104.7	222.5
Scenario					**DICE**					
IMAGE	11.0	14.5	17.2	22.8	31.6	35.8	45.4	61.9	70.8	82.1
MERGE optimistic	7.1	9.2	10.8	14.3	19.9	22	27.9	36.9	42.1	48.8
Message	9.7	12.5	14.7	19	26.6	29.8	37.8	51.1	58.6	67.4
MiniCAM base	8.8	11.5	13.6	18	25.2	28.8	36.9	50.4	57.9	67.8
5th scenario	7.9	10.1	11.8	15.6	21.6	24.9	31.8	43.7	50.8	60.6
Scenario					**FUND**					
IMAGE	-25.2	-15.3	-11.2	-5.6	0.9	8.2	10.4	25.4	39.7	90.3
MERGE optimistic	-24.0	-12.4	-8.7	-3.6	2.6	8	12.2	27	41.3	85.3
Message	-25.3	-16.2	-12.2	-6.8	-0.5	3.6	7.7	20.1	32.1	72.5
MiniCAM base	-23.1	-12.9	-9.3	-4	2.4	10.2	12.2	27.7	42.6	93.0
5th scenario	-24.1	-16.6	-13.2	-8.3	-3	-0.2	2.9	11.2	19.4	53.6

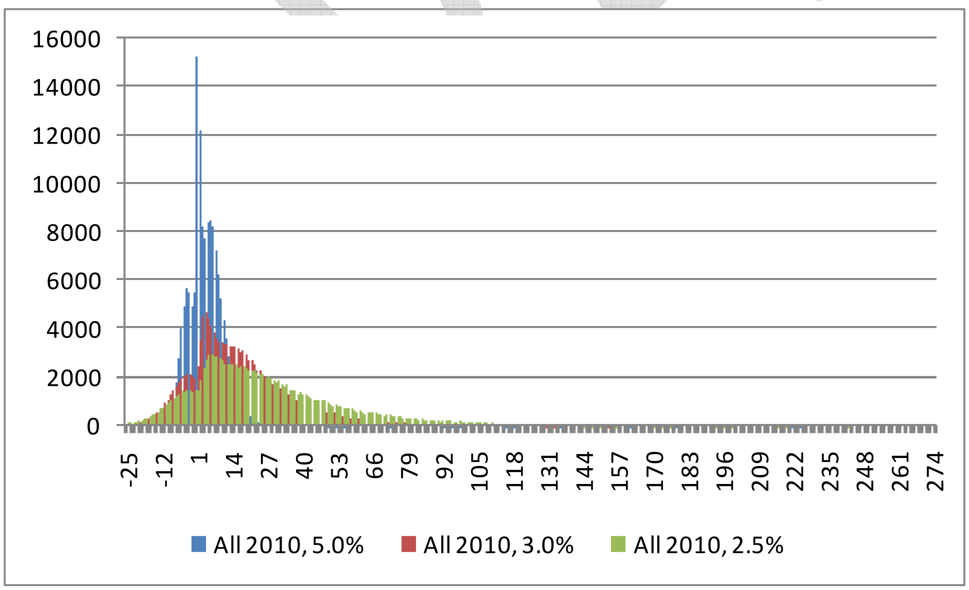
Table A4. 2010 Global SCC Estimates at 5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					PAGE					
IMAGE	0.5	0.8	1.1	1.8	3.5	8.3	8.5	19.5	31.4	67.2
MERGE optimistic	0.3	0.5	0.7	1.2	2.3	5.2	5.4	12.3	19.5	42.4
Message	0.4	0.7	0.9	1.6	3	7.2	7.2	17	28.2	60.8
MiniCAM base	0.3	0.6	0.8	1.4	2.7	6.4	6.6	15.9	24.9	52.6
5th scenario	0.3	0.6	0.8	1.3	2.3	5.5	5	12.9	22	48.7

Scenario					DICE					
IMAGE	4.2	5.4	6.2	7.6	10	10.8	13.4	16.8	18.7	21.1
MERGE optimistic	2.9	3.7	4.2	5.3	7	7.5	9.3	11.7	12.9	14.4
Message	3.9	4.9	5.5	7	9.2	9.8	12.2	15.4	17.1	18.8
MiniCAM base	3.4	4.2	4.7	6	7.9	8.6	10.7	13.5	15.1	16.9
5th scenario	3.2	4	4.6	5.7	7.6	8.2	10.2	12.8	14.3	16.0

Scenario					FUND					
IMAGE	-11.7	-8.4	-6.9	-4.6	-2.2	-1.3	0.7	4.1	7.4	17.4
MERGE optimistic	-10.6	-7.1	-5.6	-3.6	-1.3	-0.3	1.6	5.4	9.1	19.0
Message	-12.2	-8.9	-7.3	-4.9	-2.5	-1.9	0.3	3.5	6.5	15.6
MiniCAM base	-10.4	-7.2	-5.8	-3.8	-1.5	-0.6	1.3	4.8	8.2	18.0
5th scenario	-10.9	-8.3	-7	-5	-2.9	-2.7	-0.8	1.4	3.2	9.2

Figure A8. Histogram of Global SCC Estimates in 2010 (2007$/ton CO_2), by discount rate



* The distribution of SCC values ranges from -$5,192 to $66,116 but the X-axis has been truncated at approximately the 1st and 99th percentiles to better show the data.

Table A5. Additional Summary Statistics of 2010 Global SCC Estimates -

Discount rate:	5%				3%				2.5%			
Scenario	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis
DICE	9.0	13.1	0.8	0.2	28.3	209.8	1.1	0.9	42.2	534.9	1.2	1.1
PAGE	6.5	136.0	6.3	72.4	29.8	3,383.7	8.6	151.0	49.3	9,546.0	8.7	143.8
FUND	-1.3	70.1	28.2	1,479.0	6.0	16,382.5	128.0	18,976.5	13.6	150,732.6	149.0	23,558.3