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Initiative: Tongue River Railroad

Submission Text

Please see attached comments of Earthjustice, Montana Environmental Information Center, National Wildlife Federation, Natural Resources Defense Council, and Sierra Club. Due to their volume, a DVD containing exhibits to this letter are being sent to STB by Federal Express.



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September 23, 2015

Ken Blodgett

Attention: Environmental filing, Docket No. 30186

Surface Transportation Board

395 E Street SW

Washington, DC 20423-0001

By Federal Express and online at www.tonguerivereis.com

RE: Docket No. FD 30186, Tongue River Railroad Draft Environmental Impact Statement

Dear Mr. Blodgett:

Earthjustice, Montana Environmental Information Center, National Wildlife Federation, Natural Resources Defense Council, and Sierra Club submit these comments on the Surface Transportation Board (“STB”) Draft Environmental Impact Statement (“DEIS”) for the Tongue River Railroad. As detailed in this letter, the DEIS fails in significant respects to satisfy NEPA’s requirements for thorough analysis and full disclosure of the project’s environmental consequences. Further, the project’s impacts would be severe and weigh decisively against STB’s approval of the application by Tongue River Railroad Corporation (“TRRC”) (including Arch Coal, one of its principle owners) to construct the Tongue River Railroad.

Arch Coal’s proposed Tongue River Railroad and the related Otter Creek coal mine would significantly degrade Montana’s land, water, cultural resources, and climate. The railroad and the coal mining it would make possible would require at least a 42-mile right-of-way cutting through family farms and ranches, carve up more than 7,600 acres of the rural southeastern Montana landscape, destroy tribal cultural resources near the Northern Cheyenne reservation, displace sensitive wildlife, and lead to billions of tons of carbon pollution at a time when President Obama has called for urgent reductions in carbon dioxide emissions in order to have a hope of avoiding the most dire environmental and economic effects of climate disruption.

The proposed Tongue River Railroad and Otter Creek are undeniably joined at the hip—Otter Creek cannot be economically developed without the railroad, and Tongue River Railroad would serve no purpose if Otter Creek remained undeveloped. Under the National Environmental Policy Act (“NEPA”), 42 U.S.C. § 4321 *et seq.*, the STB cannot avoid analyzing consequences from the mine as it evaluates and discloses the likely effects of the railroad. In

addition to industrializing 7,600 acres in southeastern Montana, the proposed Otter Creek mine would have a massive impact on U.S. coal production. With 1.5 billion tons of Otter Creek coal already under lease and available to Arch, the addition of the railroad would allow the proposed new mine to essentially swamp the Montana coal industry, which currently produces approximately 42 million tons of coal each year.¹ Moreover, if built as proposed, Otter Creek would immediately become the largest coal mine in the state and fifth largest anywhere in the country. In 2013, EIA reported that the U.S. had more than 1,000 coal mines.² At Arch Coal's anticipated production volume of 20 million tons per year, Otter Creek would be the fifth largest mine in the country based on annual production – placing it among the top 0.5 percent of all U.S. coal mines.

The Tongue River Railroad would be an unwelcome neighbor in southeastern Montana. At a public meeting hosted by STB in Ashland, Montana, Northern Cheyenne member Kitte Coffin said, “We want the quiet, we want the peace, we want the clean air, we want the clean water ... And we’re not going to give it up without a fight.”³ As explained in a resolution by the Northern Cheyenne Tribal Council opposing the railroad, unanimously approved on September 21, 2015, “the Northern Cheyenne Tribe believes that the direct and long term cultural and environmental impacts of the proposed Tongue River Railroad Project will be devastating to the local communities on or near the Northern Cheyenne reservation[.]”⁴ Hundreds of people turned out to the public meetings in Ashland and Lame Deer, Montana to convey these messages of opposition to STB; not one person at those meetings in the areas most acutely impacted by the Tongue River Railroad and Otter Creek mine spoke in favor of the coal projects.

Earthjustice, Montana Environmental Information Center, National Wildlife Federation, Natural Resources Defense Council, and Sierra Club join the Northern Cheyenne Tribal Council, the Missoula City Council,⁵ and the more than 117,000 individuals that have already commented

¹ U.S. Energy Information Administration, Annual Coal Report, Table 1, (April 23, 2015), available at <http://www.eia.gov/coal/annual/pdf/table1.pdf> (last visited September 21, 2015).

² *Id.*

³ D. Brouwer, Tribal members, ranchers tell regulators to spike Tongue River railroad project, BILLINGS GAZETTE (June 9, 2015), available at http://billingsgazette.com/news/state-and-regional/montana/tribal-members-ranchers-tell-regulators-to-spike-tongue-river-railroad/article_4607debe-e525-51a1-bc80-0277fbcd2632.html (last visited Sept. 21, 2015).

⁴ Tribal Council of the Northern Cheyenne Tribe, Northern Cheyenne Indian Reservation, Lame Deer, Montana, Resolution No. _____ (Sept. 21, 2015), attached as Ex. 1; *see also* Northern Cheyenne Officials Reject Coal Railroad Plan, BILLINGS GAZETTE (Sept. 21, 2015), available at http://billingsgazette.com/news/northern-cheyenne-officials-reject-coal-railroad-plans/article_f935821e-ed80-5fb5-ae69-f3929f2018a4.html#ixzz3mPX3rBxK (last visited Sept. 21, 2015).

⁵ Martin Kidston, City of Missoula Joins Growing List Opposed to Tongue River Railroad, MISSOULIAN (Sept. 21, 2015), available at http://missoulian.com/news/local/city-of-missoula-joins-growing-list-opposed-to-tongue-river/article_e9a07c56-a2d5-53d2-ab1c-5f2fb05212e5.html (last visited Sept. 22, 2015).

on the project in urging the STB to reject the proposed Tongue River Railroad in favor of the “no action” alternative.

I. BACKGROUND

A. NEPA

NEPA “is our basic national charter for protection of the environment.” 40 C.F.R. § 1500.1(a). NEPA has two fundamental purposes: (1) to guarantee that agencies take a “hard look” at the consequences of their actions before the actions occur by ensuring that “the agency, in reaching its decision, will have available, and will carefully consider, detailed information concerning significant environmental impacts,” Robertson v. Methow Valley Citizens Council, 490 U.S. 332, 349 (1989); and (2) to ensure 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,” *id.* at 349. NEPA “emphasizes the importance of coherent and comprehensive up-front environmental analysis to ensure informed decision making to the end that ‘the agency will not act on incomplete information, only to regret its decision after it is too late to correct.’” Blue Mountains Biodiversity Project v. Blackwood, 161 F.3d 1208, 1216 (9th Cir. 1998) (internal citation omitted).

Pursuant to NEPA, “all agencies of the Federal Government shall ... include in every recommendation or report on ... major Federal actions significantly affecting the quality of the human environment, a detailed statement ... on the environmental impact of the proposed action, any adverse environmental effects which cannot be avoided should the proposal be implemented, alternatives to the proposed action” (including a “No Action” alternative), and other environmental implications of the action. 42 U.S.C. § 4332(2)(C). This Environmental Impact Statement (“EIS”) helps to ensure “that environmental concerns [will] be integrated into the very process of agency decision-making.” Andrus v. Sierra Club, 442 U.S. 347, 350 (1979).

Meaningful public participation is a vital component of NEPA. NEPA regulations direct that each agency “must insure that environmental information is available to public officials and citizens before decisions are made and before actions are taken. The information must be of high quality. Accurate scientific analysis, expert agency comments, and public scrutiny are essential to implementing NEPA.” 40 C.F.R. § 1500.1(b). At a minimum, “[t]o fulfill NEPA’s public disclosure requirements, the agency must provide to the public ‘the underlying environmental data’ from which the [agency] develops its opinions and arrives at its decisions.” WildEarth Guardians v. Montana Snowmobile Ass’n, 790 F.3d 920, 925 (9th Cir. 2015) (quoting Idaho Sporting Cong. v. Thomas, 137 F.3d 1146, 1150 (9th Cir. 1998), overruled on other grounds by Lands Council v. McNair, 537 F.3d 981 (9th Cir. 2008) (en banc)).

B. The Tongue River Railroad and Otter Creek Mine

TRRC first applied to the Interstate Commerce Commission—STB’s predecessor agency—to construct a rail road from the Ashland area to the BNSF line in Miles City, Montana in 1983. The railroad’s purpose was at that time, as it is now, to serve new coal mines proposed for the Otter Creek area. Subsequently, TRRC proposed two separate southern extensions of the

railroad. Having lost a legal challenge to STB's prior approvals and environmental review, N. Plains Res. Council v. Surface Transp. Bd., 668 F.3d 1067, 1084 (9th Cir. 2011), and having abandoned its proposals for the southern extensions of the railroad, TRRC applied to construct just the northern portion of the railroad, designed to bring coal from the proposed Otter Creek coal mine and other Tongue River area mines to BNSF's northern rail line. As STB acknowledges, the proposed rail line would provide the only rail service available to [Otter Creek] and to other considerable coal resources in the Ashland area." DEIS at 1-5. The projects are entirely interdependent: without the railroad, the proposed Otter Creek coal mine could not economically bring coal to markets and would not be developed;⁶ without the mine, the Tongue River Railroad would have no purpose.⁷ Therefore, construction of the Tongue River Railroad is a direct and indirect cause of impacts associated with the coal mine.

According to TRRC, "[t]he coal resources available for transportation from the Otter Creek area will be substantial, consisting of the [sic] about 1.5 billion tons, which makes Otter Creek one of [sic] largest undeveloped sources of low sulfur, sub-bituminous coal in the United States."⁸ At full production, TRRC estimates 20 million tons of coal will be transported annually from the Otter Creek mine in 26 round-trips per week, though peak production could be even greater.⁹

Renewed interest in the Tongue River Railroad after plans for its construction languished for years is best explained by potential demand for Powder River Basin coal overseas, particularly in Asia. See DEIS at C.1-8 ("The domestic and Pacific Basin markets have changed sufficiently in recent years to make Tongue River coal more economically competitive. Specifically, Pacific Basin coal prices are higher, Pacific Basin demand for coal is higher, and other Powder River Basin coal prices have higher shipping costs to markets."). An economic report commissioned by Arch Coal and its Montana subsidiary, Otter Creek Coal, LLC (and attached to TRRC's Supplemental Application to STB) "anticipate[s] that the dominant market for this coal will be Asia, with coal shipped by rail to the (new and existing) Pacific northwest coal ports."¹⁰ On December 17, 2012, TRRC submitted a supplemental application to STB, which identified as TRRC's preferred route the Colstrip alternative, which "would extend from

⁶ See P. Barkey and P. Polzin, *The Impact of Otter Creek Coal Development on the Montana Economy*, at 8 (2012), attached to TRRC, Supplemental Application for Construction and Operation Authority, Finance Dkt. 30186, Appendix D (Dec. 17, 2012) ("TRRC Supp. App.") ("the economic competitiveness of the mine depends critically on access to the rail transportation network").

⁷ TRRC Supp. App., Appendix A, at 5 (Dec. 17, 2012) ("In fact, there is no viable alternative means of transporting coal in the volumes that will be produced at the Otter Creek mine, other than rail and no rail line other than the TRRC line will be capable of transporting the coal produced in the Otter Creek and Ashland areas of the Northern Powder River Basin.").

⁸ TRRC Supp. App. at 6.

⁹ Id. at 17; see also DEIS at F-22 (projecting Otter Creek coal production in low, medium, and high production scenarios).

¹⁰ See P. Barkey and P. Polzin (2012) at 8.

the BNSF line, known as the Colstrip Subdivision, at Colstrip, southeast toward Ashland.” DEIS at 2-14. TRRC’s selection of the Colstrip alternative as the preferred alternative further suggests an export-oriented focus, as that route offers a reduction in total mileage (and thus fuel, operational, and maintenance costs) from origin to ultimate West Coast destination.¹¹ The Colstrip route increases mileage (and thus fuel, operational, and maintenance costs) for coal traveling eastbound, however.¹² It would make little sense from a business standpoint for TRRC to “prefer” this route if the company did not expect to export most Otter Creek coal out of West Coast ports.

As further evidence of Arch Coal’s plans to export Otter Creek coal, the company acquired a 38% interest in Millennium Bulk Terminals-Longview, LLC, owner of a bulk commodity terminal in Longview, Washington. In announcing the purchase, Arch Coal’s president and CEO stated:

This transaction gives us a direct stake in participating in the growth of U.S. coal exports off the West Coast. With our superior operating position in the Powder River Basin and Western Bituminous Region, we have the capability to service growing coal demand in Asia, the world’s largest and fastest-growing coal market. We believe this first project—along with others in the pipeline—will provide Arch with more exposure to the seaborne thermal market and will further unlock the value inherent in our western coal assets.¹³

Arch’s press release further noted that the Longview terminal is served by BNSF railroads, “which will provide Arch with the flexibility to export its southern Powder River Basin and Western Bituminous coals, and eventually coal from its recently-acquired Montana reserves,” i.e. Otter Creek coal.¹⁴

Several days after the Longview transaction, Arch entered into an agreement with Canadian Crown Corporation Ridley Terminals, Inc., another coal and bulk commodity marine

¹¹ TRRC Supp. App. at 26, 27; see also id., Appendix A, Verified Statement of Stevan B. Bobb, at 8 (“For Otter Creek/Ashland Coal traffic heading westbound, the Colstrip Alignment ... offers a reduction in the total mileage from origin to ultimate destination for the coal, eliminating approximately 50 miles”).

¹² TRRC Supp. App. at 26; see also id., Appendix A, Verified Statement of Bobb at 8 (“Eastbound coal traffic would ultimately travel about 38 miles farther under the Colstrip Alignment”).

¹³ Press Release: Arch Coal Acquires Equity Interest in West Coast Terminal (Jan. 12, 2011), available at http://news.archcoal.com/phoenix.zhtml?c=107109&p=irol-newsArticle_Print&ID=1515428 (last visited Sept. 18, 2015), attached as Ex. 2.

¹⁴ Id.

terminal located in British Columbia.¹⁵ Over 80% of this terminal's total volume consists of coal, and Asia is its primary destination.¹⁶ Again, Arch's president and CEO explained: "This transaction is another important step in accomplishing our strategic objective of expanding Powder River Basin coal sales into the Asia-Pacific Region. This throughput agreement gives us direct, immediate access to the growing seaborne thermal market. It ... complements our recently announced investment in the Millennium Bulk Terminal in Longview, Wash., and other continuing terminal negotiations."¹⁷ Echoing this enthusiasm, Ridley Terminal's President declared that "Arch Coal's guaranteed U.S. coal volumes will support our goal of doubling our capacity by 2015."¹⁸

The nexus is clear: the purpose and intended effect of the Tongue River Railroad would be to enable Arch Coal to export the large majority of its 1.5-billion ton Otter Creek coal assets overseas. The proposed action directly causes substantial impacts not just from the construction and operation of the railroad itself; it also directly and indirectly causes all of the life cycle impacts of mining, transporting, and burning the substantial coal reserves the railroad enables. As described below, the DEIS insufficiently analyzes these direct and indirect effects.

II. STB'S ANALYSIS OF THE TONGUE RIVER RAILROAD'S CLIMATE CHANGE IMPACTS IS ARBITRARY

Decisions we make today about mining and burning fossil fuels—particularly carbon-intensive coal—will affect the world for centuries to come. The billions of tons of CO₂ emissions stemming from the proposed Otter Creek Mine and other area mines would exacerbate the ongoing warming of the Earth's climate. In 2014, the Intergovernmental Panel on Climate Change (IPCC) released its Fifth Assessment Report, stating that "[w]arming of the climate system is unequivocal," and that "[h]uman influence on the climate system is clear."¹⁹ "[M]ore than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in [greenhouse gas ("GHG")] concentrations,"²⁰ and

¹⁵ Press Release: Arch Coal Announces Agreement with Canada's Ridley Terminal for Pacific Coast Exports (Jan. 18, 2011), available at <http://news.archcoal.com/phoenix.zhtml?c=107109&p=irol-newsArticle&ID=1517028> (last visited Sept. 18, 2015), attached as Ex. 3.

¹⁶ Id.

¹⁷ Id.

¹⁸ Id.

¹⁹ Intergovernmental Panel on Climate Change, Climate Change 2014: Synthesis Report 2, 4 (Nov. 2014) ("IPCC Report"), available at http://ar5-syr.ipcc.ch/ipcc/ipcc/resources/pdf/IPCC_SynthesisReport.pdf (last visited Sept. 20, 2015), excerpts attached as Ex. 4.

²⁰ Id. at 48.

between 1970 and 2010, “CO₂ emissions from fossil fuel combustion and industrial processes contributed about 78% to the total GHG emission increase.”²¹

The harms to the human environment caused by climate change are inescapable. According to the U.S. National Climate Assessment, climate change affects the Great Plains region, including eastern Montana, by causing “more frequent and more intense droughts, severe rainfall events, and heat waves.”²² As the DEIS acknowledges, already Montana has “experienced a warming trend in the past five decades, and annual average maximum temperatures have increased by 1.4°F.”²³ And this trend is expected to continue.

Across Montana, hot summer temperatures (those at the 90th percentile) could rise by 4.8 to 5.0°F in moderate and high GHG concentration scenarios from 2025 to 2050, relative to the 1950 to 2005 period. Cold winter temperatures (those at the 10th percentile) are projected to increase by 3.8 to 4.5°F in moderate and high GHG concentration scenarios over 2025 to 2050, relative to the 1950 to 2005 period.²⁴

In western Montana and the northwestern United States, “warmer and drier conditions have helped increase the number and extent of wildfires Higher temperatures and drought stress [] contribut[e] to outbreaks of mountain pine beetles that are increasing pine mortality.”²⁵ Global warming also could profoundly affect the health of western fisheries, by “increas[ing] disease and/or mortality in several iconic salmon species,”²⁶ and “lead[ing] to increasing fragmentation of remaining habitats and accelerated decline” of Montana’s native Bull trout.²⁷

Competition for water resources will increase within already-stressed human and ecological systems, [] affecting crops, energy production, and how well people, animals, and plants can thrive. The region’s ecosystems, economies, and communities will be further strained by increasing intensity and frequency of floods,

²¹ Id. at 4.

²² U.S. National Climate Assessment, Climate Change Impacts in the United States, at 442 (May 2014), available at http://s3.amazonaws.com/nca2014/high/NCA3_Climate_Change_Impacts_in_the_United%20States_HighRes.pdf?download=1 (last visited Sept. 23, 2015), excerpts attached as Ex. 5.

²³ DEIS at 5.3-5.

²⁴ Id. (citation omitted).

²⁵ U.S. National Climate Assessment, at 495.

²⁶ Id. at 491.

²⁷ Bruce E. Reiman et al., Anticipated Climate Warming Effects on Bull Trout Habitats and Populations Across the Interior Columbia River Basin, 136 TRANSACTIONS AM. FISHERIES SOC’Y 1552, 1552 (2007).

droughts, and heat waves that will penetrate into the lives and livelihoods of Great Plains residents.²⁸

Earlier this month, President Obama called climate change “a challenge that will define the contours of this century more dramatically than any other.” The President elaborated in unequivocal terms:

*The science is stark. It is sharpening. It proves that this once-distant threat is now very much in the present. ... But the point is that climate change is no longer some far-off problem. It is happening here. It is happening now. Climate change is already disrupting our agriculture and ecosystems, our water and food supplies, our energy, our infrastructure, human health, human safety – now. Today. And climate change is a trend that affects all trends – economic trends, security trends. Everything will be impacted. And it becomes more dramatic with each passing year.*²⁹

The decision whether to permit construction of the Tongue River Railroad is directly tied to these impacts, as the railroad would enable the mining and burning of 1.5 billion tons of Otter Creek Coal and similarly large coal depositions at other potential mines in the Ashland area.³⁰ As discussed below and in the attached report by Synapse Energy Economics, Exhibit 8, STB’s analysis in the DEIS of the railroad’s climate change impacts is fundamentally flawed. First, the DEIS fails to acknowledge that any decision to enable mining of currently unused coal reserves will cause global warming to exceed the critical 2 °C threshold above which catastrophic climate change impacts are almost certain to occur. Second, the DEIS arbitrarily concludes that Tongue River coal mined as a result of the railroad will simply displace other coal mining, yielding no net increase in overall coal mined and burned. Third, the DEIS fails to disclose the environmental consequences of the project’s climate change impacts. Fourth, the DEIS improperly dodges any discussion of meaningful mitigation measures for the decision to allow mining and burning of Tongue River coal. And fifth, the DEIS fails to analyze whether greenhouse gas emissions attributable to the railroad are consistent with President Obama’s carbon emissions reduction targets. Accordingly, the EIS fails to reflect the requisite “hard look” under NEPA at the Tongue River Railroad’s impacts on the human environment. 40 C.F.R. § 1508.8(b) (requiring agencies to disclose the “ecological[,] ... economic, [and] social” impacts of proposed actions).

²⁸ U.S. National Climate Assessment, at 451.

²⁹ President Obama, Remarks by the President at the Glacier Conference -- Anchorage, AK (Sept. 1, 2015), available at <https://www.whitehouse.gov/the-press-office/2015/09/01/remarks-president-glacier-conference-anchorage-ak> (last visited Sept. 16, 2015).

³⁰ As in the DEIS, references in this letter to “Tongue River coal” include coal from Otter Creek and other potential mines in the Ashland area that would be served by the Tongue River railroad.

A. The DEIS Fails to Acknowledge that Any Amount of Coal Mining Will Contribute to Catastrophic Climate Change Impacts

If constructed, the Tongue River Railroad would enable the development of at least 1.5 billion tons of coal in the Tongue River Valley, and potentially substantially more. The Otter Creek mine alone could produce for sale to power plants between 20 and 30 million tons of coal each year. See DEIS at F-22 (projecting Otter Creek coal production in low, medium, and high production scenarios). If mined and burned as planned, the massive quantity of coal contained within the Otter Creek tracts would constitute one of the nation's largest single sources of carbon dioxide ("CO₂"), contributing to climate change and its potentially disastrous impacts in Montana and globally. Nearly all of the Otter Creek coal is destined for combustion at coal-fired power plants and could result in emissions of approximately 2.76 billion tons of CO₂.³¹ When coal production from Otter Creek is at its peak, combustion of Otter Creek coal could result in up to 55.2 million tons of annual CO₂ emissions.

At a minimum, the STB must acknowledge that the proposed railroad would bring with it such a massive amount of carbon pollution. The Bureau of Land Management, Office of Surface Mining, and the Forest Service routinely quantify and disclose total combustion-related CO₂ emissions when approving proposed federal coal leases and mine plans using a coal-seam specific emissions factor that converts "tons of coal mined" to "tons of CO₂ emitted during combustion." There is no excuse for STB's failure to do so here. The STB may think 2.76 billion tons of CO₂ is a lot of carbon pollution; or, it may not. The point is that under NEPA, the STB must disclose the full project impacts (including both direct and indirect effects) to the public and to decision makers.

Notwithstanding this massive, direct impact of mining and burning Otter Creek coal, STB concluded that the project's net effect on global greenhouse gas emissions is nil. The agency reached this conclusion by finding that "under most scenarios most Tongue River coal would be distributed to the Upper Midwest, where it would displace coal from other U.S. mines. . . . Internationally, Tongue River coal is likely to displace Australian, Indonesian, and/or Chinese coal in key Asian markets, including Japan, China, and South Korea." *Id.* at 5.2-9. In other words, the DEIS posits that more than a billion tons of coal from Otter Creek and surrounding mines would simply be absorbed by the market, yielding virtually no net increase in domestic or international coal mining and consumption. Thus, while STB assumes that 100% of Tongue River coal will be burned, STB concludes "that direct GHG emissions from the proposed rail line

³¹ The DEIS fails to identify the greenhouse gas emissions attributable to combusting this volume of coal. See DEIS at F-35–36 (identifying annual change in GHG emissions for studied production scenarios, but not identifying GHG emissions specifically attributable to each proposed or potentially induced mine). However, it can be calculated. Montana sub-bituminous coal has an average carbon dioxide emissions factor of 213.4 pounds of carbon dioxide per million BTUs. Energy Info. Admin., U.S. Dep't of Energy, Carbon Dioxide Emission Factors for Coal, DOE/EIA-0121, Table FE4 (Aug. 1994), available at http://www.eia.gov/cneaf/coal/quarterly/co2_article/co2.html. Otter Creek coal heating values average 8,600 BTU/lb on an as-received basis. DEIS at C.3-6. Accordingly, one ton of Otter Creek coal will emit approximately 1.84 tons CO₂ when combusted.

would be negligible. [STB] concludes that impacts from the net annual life-cycle emissions would range from a negligible positive impact to a minor adverse impact.” DEIS at 5.2-2.³²

Even if STB’s “perfect substitution” theory had merit—which it does not, as discussed below in section II.B—STB’s analysis is flawed because it fails to acknowledge that any new development of global fossil fuel reserves may condemn the world to severe climate change impacts. There is scientific agreement that, to avoid the most catastrophic impacts of climate change, we must keep global temperature increase to less than 2 degrees Celsius above pre-industrial temperatures.³³ Meeting this imperative is no easy task. A January 2015 study published in the Journal Nature concluded that, to have a better-than-even chance of keeping warming below this critical threshold, almost all of the world’s fossil fuel reserves that are still in the ground must stay there.³⁴ This includes, most importantly, coal.

The study considered two scenarios: one assuming that carbon capture and sequestration (“CCS”) technology will be unavailable and one assuming widespread deployment of CCS after 2025. Without CCS, 88% of coal reserves globally—and **95% of coal reserves in the United States**—must remain unused before 2050 to meet the target of 2 °C.³⁵ Even when CCS is deployed, the study concluded that 82% of current coal reserves globally—and 92% of current U.S. coal reserves—must remain unburned.³⁶ As the authors explained, “[b]ecause of the expense of CCS, its relatively late date of introduction (2025), and the assumed maximum rate at which it can be built, CCS has a relatively modest effect on the overall levels of fossil fuel that can be produced before 2050 in a 2 °C scenario.”³⁷

The states and U.S. government already have leased and permitted substantial coal reserves that have not yet been exploited, meaning that the government retains control over only a fraction of the remaining decisions whether to use existing reserves. In every single case where it retains control, the United States must make decisions to leave coal in the ground.

³² In projecting a potential decrease in global greenhouse gas emissions, STB found under some scenarios the displacement by Tongue River coal of more carbon-intensive coal from other sources may yield lower levels of coal combustion. See DEIS at F-3. The reasons STB’s determinations in this regard are flawed are set forth in section II.B.

³³ See United Nations Framework Convention on Climate Change (UNFCCC), Report of the Conference of the Parties on its Fifteenth Session, held in Copenhagen from 7 to 19 December 2009. Part Two: Action taken by the Conference of the Parties at its Fifteenth Session, at 5. United Nations Climate Change Conf. Report 43 (UNFCCC, 2009), at <http://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf> (last visited Sept. 18, 2015).

³⁴ Christoph McGlade & Paul Ekins, *The geographical distribution of fossil fuels unused when limiting global warming to 2°C*, 517 NATURE at 187 (Jan. 9, 2015) (attached as Ex. 6). The article defines “reserves” to include fossil fuel resources that are “recoverable under current economic conditions and have a specific probability of being produced.” *Id.*

³⁵ *Id.* at 189, Table 1.

³⁶ *Id.*

³⁷ *Id.* at 190.

STB's theory that mining Otter Creek and neighboring areas will simply perpetuate status quo carbon emissions by displacing coal mined elsewhere does not alter this conclusion. Considering the remaining carbon budget to avoid the most devastating impacts from climate change, status quo carbon emissions are unacceptable. If unabated, "[b]urning all fossil fuels would produce a different, virtually uninhabitable, planet."³⁸ The government must make the right decision on the Tongue River Railroad and Otter Creek, and also make decisions throughout the country to prevent mining and burning of unused coal reserves.

Furthermore, contrary to STB's flawed conclusion in the DEIS, constructing new infrastructure to permit brand new mines in the Otter Creek area is not equivalent to operating existing mines in Powder River Basin or elsewhere in the U.S. While mining is becoming more expensive at those existing mines and the domestic coal market is shrinking, companies are decreasing production at existing mines. If Otter Creek is developed, the mine's owners will have an incentive to continue production as long as necessary over the life of the mine to service the extraordinary debt incurred to develop the new infrastructure. From this perspective, even if net annual coal production was static, new mines in the Otter Creek area have greater climate change impacts than aging mines elsewhere, because new mines will extend climate-altering carbon emissions from coal over a longer time-frame. STB must analyze these impacts over the life of the mine. See S. Fork Band Council Of W. Shoshone Of Nevada v. U.S. Dep't of Interior, 588 F.3d 718, 725-26 (9th Cir. 2009) (holding that agency cannot avoid analysis of impacts from transporting and processing ore from gold mine expansion "simply because no change in the rate of shipping and processing is forecast. That may be so, but the mine expansion will create ten additional years of such transportation, that is, ten years of environmental impacts that would not be present in the no-action scenario.").

The DEIS does not deny the significance of climate change impacts on the human environment. The Final EIS should acknowledge that a decision to proceed with the Tongue River Railroad is a decision to permit these impacts to occur.

B. The DEIS Analysis of Life-Cycle GHG Emissions Overlooks Key Aspects of the Problem

The DEIS climate change analysis is flawed for another reason: its conclusion that Tongue River coal will simply displace coal production elsewhere in the world is based exclusively on a computer model that excludes consideration of key aspects of the problem and underestimated net coal production if the Tongue River Railroad is constructed. Lands Council v. McNair, 537 F.3d 981, 987 (9th Cir. 2008) (en banc) (internal quotation marks and citations omitted), abrogated on other grounds by Winter v. Natural Res. Def. Council, Inc., 555 U.S. 7, 21 (2008) (agency action arbitrary if it "entirely failed to consider an important aspect of the problem"). Furthermore, STB failed to disclose key data and technical information underlying its modeling exercise, thus precluding a full critique of the analysis and undermining NEPA's public disclosure mandate.

³⁸ Hansen, et al., Climate Sensitivity, Sea Level and Atmospheric Carbon Dioxide, 371 Phil. Trans. R. Soc'y (2013).

1. The DEIS improperly concludes that Tongue River coal will perfectly substitute for other sources of coal

STB's paradoxical conclusion that mining and burning more than 1.5 billion tons of coal will yield a minimal increase, or even a decrease, in global greenhouse gas emissions ignores clear evidence of the market for Tongue River coal and contradicts basic economic principles.

As an initial matter, STB discounted the significant likelihood that, if Tongue River coal mines are developed, most if not all of the coal will be exported for consumption overseas. STB considered a range of production and market scenarios for Tongue River coal, each yielding a projection of the percentage of domestic versus international consumption. At one end of the scale, STB evaluated fourteen scenarios in which no Tongue River coal is exported to international markets. At the other end of the scale, STB evaluated a single scenario in which just 53% of Tongue River coal is exported. As reported in Appendix C, "[o]n average, from 2018 to 2037, 4% of Tongue River coal would be exported" under the scenarios considered. DEIS at C.1-14.

STB's market scenarios are entirely fictitious. As described in section I.B above, Arch Coal has every incentive and intention to market Otter Creek coal for export. With its ownership interest in a proposed new export terminal in Longview, Washington and contracted-for capacity at a British Columbia coal export terminal, Arch Coal's export plan is clear. STB conceded this dynamic, noting that "Arch Coal is the developer or co-developer of the Tongue River Railroad, the Otter Creek Mine, and one of the export terminals (Millennium Bulk Terminal). Hence, Arch Coal might choose to export rather than sell domestically when there are opportunities to maximize profits over the suite of assets that include mines, railroads, and export terminals." DEIS at C.1-14. Nonetheless, STB's coal production analysis omitted this consideration.

STB's analysis also ignores that Tongue River coal is uniquely unsuitable for domestic consumption, in contrast with consumption abroad. STB concedes that the high sodium content of Tongue River coal "can be problematic for some power plants because it causes ash to accumulate in the boilers, creating conditions known as slagging and fouling." DEIS at C.3-15. As the Norwest Corporation concluded in its 2009 appraisal of the Otter Creek coal reserves, the domestic market for high-sodium coal is limited "to a small number of mid-western electric generating plants and some industrial plants."³⁹ STB noted that "[s]odium content concerns apply in both the domestic and export markets; however, in the export market, the coal is often a small part of a large blend of many coals and is of less concern in terms of boiler impact." DEIS, App. C, Attach. A at A-1. Despite these facts, STB concludes that "that sodium content is not a factor that would prevent the coal from being sold," DEIS at C.3-15, or, apparently, influence where the coal may be sold. In reaching this conclusion, STB apparently did not evaluate or consider whether the handful of power plants capable of burning Tongue River coal already have long-term contracts with existing mines, are slated for retirement, or otherwise are not in the market for new high-sodium coal sources. For this reason, too, STB's determination that most or

³⁹ Norwest Corp., Montana Otter Creek State Coal Valuation, at 2-4, (Jan. 30, 2009), excerpts attached as Ex. 7.

all Tongue River coal will be consumed in domestic, rather than international, markets is arbitrary.⁴⁰

STB's failure to account for these key indicators that most or all Tongue River coal would be exported is significant, since even under STB's flawed analysis, scenarios involving higher export volumes are projected to have higher correspondingly greenhouse gas emissions.⁴¹ STB's underestimate of the likely export volume of Tongue River coal thus caused STB to underestimate the net increase in global greenhouse gas emissions caused by developing the railroad and mining the coal.

Not only does the DEIS fail to acknowledge that nearly all Tongue River coal would likely be exported, the analysis understates the greenhouse gas emissions associated with high export volume. In particular, STB's analysis omits consideration of whether the availability of relatively inexpensive Tongue River coal may drive down the international price of coal, and consequently increase demand. As Synapse explains this general economic principle in the attached report, "a new source of coal that has a less expensive delivered price than some other coals currently being purchased should 'shift the supply curve' for coal."⁴² STB acknowledges that Tongue River coal has a cost advantage (on a dollar per million British thermal unit ("MMBtu") basis) over other coal, including Southern Powder River Basin coal, as delivered to Pacific Rim countries. See DEIS at C.1-13, C.4-9.

STB nonetheless concludes without citation or explanation that, for both domestic and international coal markets, the cost advantage of Tongue River coal would make it the low-cost option in order to out-compete other coal mines, but "would not be significant enough to noticeably lower delivered coal prices (which includes transportation), and thus, would not increase total demand for coal." DEIS at C.1-13–14. The STB failed to disclose the data and assumptions underlying this assertion, and it is not supported by STB's modeling exercise.

Instead, STB makes two fatal assumptions that have no support in the record and significantly undercut the STB's conclusions. First, the STB assumes coal prices will have no "noticeable" response to a project that will flood the market with up to 1.5 billion tons of relatively inexpensive coal. Second, the STB further assumes that there will be no change in overall coal demand or coal burning, even though the STB admits its proposal will add 1.5 billion tons of lower-cost coal to the market.⁴³ In other words, STB did not model or otherwise attempt to quantify the demand response to the additions of a substantial volume of low cost

⁴⁰ STB stated that "[t]he amount of Tongue River coal exported would be low across most scenarios because other Powder River Basin coals with higher heat content would be more competitive for export." DEIS at C.1-14. However, this statement, too, is unsupported. Tongue River coal has a lower delivered cost to the Pacific Rim than Southern Powder River Basin coal on a \$/MMBtu basis. STB has offered no rationale for its claim that the market prefers coals with higher heat content despite their higher costs per MMBtu.

⁴¹ Synapse Report at 2, 15-17; see also DEIS at 5.2-23

⁴² Synapse Report at 3.

⁴³ See id. at 2, 9, 17-18.

Tongue River coal in the domestic or Pacific Rim markets. Instead, the STB simply assumed perfect substitution of one coal for another in the market, despite delivered cost differences and the massive scale of the newly accessible coal reserves. Using a model that predetermines the key outcome by assuming flat coal demand failing to account for expected fluctuations in coal price and coal use skews the STB's entire analysis and causes the agency to drastically underreport the climate impacts of the proposed rail line.

STB's informational failures are particularly stark for three reasons. First, the assumptions that the addition of 1.5 billion tons of coal will have no impact of the price of use of coal in this country (and internationally) are the dual assumptions that underpin STB's conclusion that the Tongue River Railroad will have minimal climate effect, if any.⁴⁴ Without this assumption, STB's conclusions on climate have no support. Second, the notion that the addition of such a massive supply of comparatively inexpensive coal will have zero effect on coal price or coal consumption defies basic economic principles and is not supported by any rational economic explanation provided by STB.⁴⁵ Third, nowhere in the STB's voluminous DEIS or the attached appendices does STB even document that it evaluated impacts to price and use. To be sure, the STB offered conclusions on this point, but not only has it failed to show its work, it has failed to show that it did the work. As explained by Synapse, "STB did not document whether or not it considered if the presence of Tongue River coal might: 1. Lead to variation in the delivered prices of coal; 2. Cause existing coal plants to increase their production of electricity, and thus lead to increased greenhouse gas emissions; and 3. Delay the expected retirements of certain existing coal plants."⁴⁶

When called on the failure to include any support for its conclusions and asked to provide the model inputs used, STB refused to allow the public to review the information. As summarized in the attached Synapse report, "[b]y presenting its conclusions in the DEIS document but refusing to give any of the necessary data or assumptions, STB is essentially providing an answer to an equation and asking us to trust that it is correct without showing any of its work."⁴⁷ After reviewing the DEIS, appendices, and the documents STB was willing to provide, Synapse concluded that "it cannot be verified that ICF performed this analysis either. The information needed to review the STB's methodology on this important factor is not in the DEIS, it is not in Appendix C, and it is not in any of the documents the STB provided after we asked for this specific information."⁴⁸

Although courts reviewing an agency's EIS generally will not delve into competing scientific methodologies, courts will nonetheless evaluate "whether the challenged method had a rational basis and took into consideration the relevant factors." Silverton Snowmobile Club v. U.S. Forest Serv., 433 F.3d 772, 782 (10th Cir. 2006) (quotation omitted). Here, the STB did not

⁴⁴ Id. at 1-3, 17-18.

⁴⁵ Id. at 2-3, 7-8, 17.

⁴⁶ Id. at 1.

⁴⁷ Id. at 7.

⁴⁸ Id. at 8.

adequately consider all relevant factors and failed to “insure the professional integrity . . . of the discussions and analyses.” 40 C.F.R. § 1502.24.

STB’s implausible assumption that coal demand is unaffected by availability and price has been rejected by the courts. The U.S. District Court for the District of Colorado recently addressed this same issue in a challenge to the Forest Service’s authorization of mining activities on public land. High Country Conservation Advocates v. United States Forest Serv., 52 F. Supp. 3d 1174, 1197-98 (D. Colo. 2014). The agency in that case had argued, in the court’s words, that “coal is a global commodity, and if the coal does not come out of the ground in the North Fork [Valley of Colorado,] consumers will simply pay to have the same amount of coal pulled out of the ground somewhere else—overall GHG emissions from combustion will be identical under either scenario.” Id. at 1197. The court rejected the Forest Service’s “perfect substitution” theory:

I cannot make sense of this argument, and I am persuaded by an opinion from the Court of Appeals for the Eighth Circuit that rejected a nearly identical agency justification for not analyzing the future effects of coal combustion. In Mid States Coalition for Progress v. Surface Transportation Board, the court held that an agency violated NEPA when it failed to disclose and analyze the future coal combustion impacts associated with the agency’s approval of a railroad line. 345 F.3d 520, 549 (8th Cir. 2003). In that case—like this one—the agency argued that emissions would occur regardless of whether the railroad line were approved because “the demand for coal will be unaffected by an increase in availability and a decrease in price.” Id. The court rejected this argument as “illogical at best” and noted that “increased availability of inexpensive coal will at the very least make coal a more attractive option to future entrants into the utilities market when compared with other potential fuel sources, such as nuclear power, solar power, or natural gas.”

High Country Conservation Advocates, 52 F. Supp. 3d at 1197-98. Relying on basic economic principles, the court concluded that, “[a]t some point this additional supply will impact the demand for coal relative to other fuel sources, and coal that otherwise would have been left in the ground will be burned.” Id. at 1198. The agency’s failure to analyze this “reasonably foreseeable effect” violated NEPA. Id.

Here, as in the High Country and Mid States Coalition for Progress cases, STB’s unsupported “perfect substitution” theory forms an inadequate basis for its coal production projections, and consequently its conclusions regarding the climate change impacts of constructing the Tongue River Railroad.

2. The DEIS fails to disclose information essential to STB's analysis

While flaws in STB's climate change analysis are evident based on available information in the DEIS and its appendices, the DEIS does not disclose significant data underlying the analysis. As a result, the DEIS fails to afford the public a meaningful opportunity to understand and critique the analysis, undermining NEPA's public disclosure mandate.

"To take the required 'hard look' at a proposed project's effects, an agency may not rely on incorrect assumptions or data in an EIS." Native Ecosystems Council v. U.S. Forest Serv., 418 F.3d 953, 964 (9th Cir.2005) (citing 40 C.F.R. § 1500.1(b)). It necessarily follows that the agency must disclose such assumptions and data to allow the public to verify the agency's analysis and conclusions. Otherwise, "the public [i]s severely limited in its ability to participate in the decision-making process." WildEarth Guardians v. Montana Snowmobile Ass'n, 790 F.3d 920, 926 (9th Cir. 2015) (Forest Service violated NEPA by failing to disclose data on the location of the big game winter range in EIS analysis of the impact of snowmobiles on big game wildlife and habitat). An agency violates NEPA's public disclosure requirements when it asks the public "to assume the adequacy and accuracy of partial data without providing any basis for doing so." Id. at 927; see also N. Plains Res. Council, Inc. v. Surface Transp. Bd., 668 F.3d 1067, 1083 (9th Cir. 2011) ("NEPA requires that the agency provide the data on which it bases its environmental analysis.") (citation omitted). Where, as here, analysis in an EIS is based on modeling, NEPA "requires up-front disclosures of relevant shortcomings in the data or models." Lands Council v. Powell, 395 F.3d 1019, 1032 (9th Cir. 2005) (citing 40 C.F.R. § 1502.22; Lands Council v. Vaught, 198 F.Supp.2d 1211, 1239 (E.D. Wash. 2002).

Here, STB chose to rely on the Integrated Planning Model—or "IPM"—to project the coal production and greenhouse gas emissions resulting from constructing the railroad and associated coal mines. The IPM is a model that is proprietary to ICF International and unavailable to members of the public. As Synapse Energy Economics explains, "[u]nless the model input and output files and user documentation is made available, it is impossible for anyone attempting to evaluate the IPM methodology and results to have a full understanding of the input assumptions, calculations, and output results used by third-parties in doing an analysis."⁴⁹ STB not only failed to provide the requisite data underlying its analysis in the DEIS, despite repeated requests by Synapse Energy Economics, STB failed to provide the input and output files and technical model documentation, which provide the basis for the agency's analysis and underlie its conclusions.⁵⁰ Without this data, Synapse was unable to evaluate "the extent to which the presence of Tongue River coal might: 1) lead to variation in the delivered prices of coal; 2) cause existing coal plants to increase their production of electricity, and thus lead to increased greenhouse gas emissions; and 3) delay the expected retirements of certain existing coal plants."⁵¹

⁴⁹ Synapse Report, at 5.

⁵⁰ Id. at 5-8.

⁵¹ Id. at 1, 8, 17.

Because STB has not made the essential data and assumptions that formed the basis for its climate change analysis available to the public, STB has “effectively stymied the ‘public’s ability to challenge agency action,’” in violation of NEPA. WildEarth Guardians, 790 F.3d at 927 (quoting Ecology Ctr. v. Castaneda, 574 F.3d 652, 667 (9th Cir. 2009)).

C. The DEIS Fails to Discuss the Environmental Consequences of the Project’s Greenhouse Gas Emissions

In addition to STB’s failure to accurately quantify the Tongue River Railroad’s direct and indirect greenhouse gas emissions, the DEIS improperly fails to disclose the environmental consequences of those emissions. While quantifying the level of warming attributable to any given project’s carbon emissions is difficult, the federal interagency social cost of carbon protocol allows agencies to address the incremental environmental and financial impacts of adding a specific quantity of carbon to the atmosphere.

Using the social cost of carbon to analyze the climate impacts of proposals under NEPA has several benefits both to the public and agency decision makers. First, simply disclosing the amount of carbon pollution that will result from a project does not tell the public anything about the impact those emissions will have on the environment. Using the social cost of carbon corrects that flaw by providing an estimate of the economic harms caused by each incremental ton of carbon dioxide emissions. Second, by using dollars instead of tons of CO₂e, the social cost of carbon puts the scope of climate impacts of a proposal in a context that decision makers and the public can easily understand. Third, and perhaps most critically, utilizing the social cost of carbon to analyze climate impacts ensures that federal agencies use the best tools available to them to analyze the impacts of the projects those agencies review. NEPA specifically requires federal agencies to analyze and disclose the environmental effects of their actions, including “ecological ... aesthetic, historic, cultural, economic [and] health” impacts. 40 C.F.R. § 1508.8. Where “information relevant to reasonably foreseeable significant adverse impacts cannot be obtained because the overall costs of obtaining it are exorbitant or the means to obtain it are not known,” NEPA regulations direct agencies to evaluate a project’s impacts “based upon theoretical approaches or research methods generally accepted in the scientific community.” 40 C.F.R. § 1502.22(b)(4). The social cost of carbon is based on generally accepted research methods and years of peer-reviewed scientific and economic studies. As such, it is the best tool now available for agencies to use in predicting and analyzing the climate impacts of proposed federal actions. STB’s failure to use the social cost of carbon thus violates the requirement that agencies use the generally accepted tools available to them in order to evaluate the impacts of their decisions.

The social cost of carbon protocol is a method for estimating the damages associated with a small increase in CO₂ emissions (conventionally one metric ton) in a given year and represents the value of damages avoided for a small emission reduction (i.e. the benefit of a CO₂

reduction).⁵² The tool is intended to include changes in net agricultural productivity, human health, property damages, and the value of ecosystem services, all of which climate change can degrade.⁵³ As such, the social cost of carbon includes not only socioeconomic harm but also harm to the environment. The protocol was developed by a working group consisting of a dozen federal agencies with the primary aim of implementing Executive Order 12866, which requires that the costs and benefits of proposed regulations be taken into account. The Interagency Working Group published the protocol first in 2010,⁵⁴ followed by revisions and updates in 2013⁵⁵ and July 2015.⁵⁶

The social cost of carbon protocol includes a range of values for the cost of each additional ton of carbon, based on varying discount rates. In this way, the protocol addresses uncertainty by providing a range of values to assess the cost of carbon.⁵⁷ Depending on the discount rate and the year during which the carbon emissions are produced, the Interagency Working Group estimates the cost of carbon emissions, and therefore the benefits of reducing carbon emissions, to range from \$10 to \$212 per metric ton of carbon dioxide, measured in 2007

⁵² U.S. Environmental Protection Agency (“EPA”), “Fact Sheet: Social Cost of Carbon” (Nov. 2013) at 1, attached as Ex. 9, available online at <http://www.epa.gov/climatechange/Downloads/EPAactivities/scc-fact-sheet.pdf> (last viewed Sept. 23, 2015).

⁵³ 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 as Ex. 10, available online at <https://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf> (last viewed Sept. 23, 2015); see also Cass R. Sunstein, *The Real World of Cost-Benefit Analysis: Thirty-Six Questions (and Almost as Many Answers)*, 114 Colum. L. Rev. 167, 171-73 (Jan. 2014) (describing origins of interagency agreement on the social cost of carbon).

⁵⁴ Interagency Working Group on Social Cost of Carbon (Feb. 2010) (Ex. 10) at 1.

⁵⁵ Interagency Working Group on Social Cost of Carbon, “Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866” (May 2013), attached as Ex. 11, available online at https://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf (last visited Sept. 19, 2015).

⁵⁶ The July 2015 update, which slightly modified the range of social cost of carbon figures based on refinement of the models that go into the social cost values, is available at <https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf> (last visited Sept. 22, 2015).

⁵⁷ Interagency Working Group (2010) (Ex. 10) at 1 (“The main objective of this process was to develop a range of SCC [social cost of carbon] 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”).

dollars. In July 2014, the U.S. Government Accountability Office (“GAO”) confirmed that the Interagency Working Group’s estimates were based on sound procedures and methodology.⁵⁸

The social cost of carbon is a simple tool that is easy for federal agencies to use and easy for the public to understand. Putting a dollar figure on each ton of CO₂ emitted as a result of a federal project places climate impacts in a context that both decision makers and the public can readily comprehend. It is backed by years of peer-reviewed scientific and economic research, it is designed to be updated to reflect the most up-to-date information, and it has already been used by federal agencies in both rulemaking decisions and project-level reviews under NEPA. For example, the EPA recommended that an EIS prepared by the U.S. Department of State for the proposed Keystone XL oil pipeline include “an estimate of the ‘social cost of carbon’ associated with potential increases of GHG emissions.”⁵⁹ In addition, BLM, the agency tasked with leasing federal coal, has also utilized the social cost of carbon protocol. In recent Environmental Assessments for oil and gas leasing in Montana, the agency estimated “the annual SCC [social cost of carbon] associated with potential development on lease sale parcels.”⁶⁰ In conducting its analysis, the BLM used a “3 percent average discount rate and year 2020 values,” presuming social costs of carbon to be \$46 per metric ton.⁶¹ Based on its estimate of greenhouse gas emissions, the agency estimated total carbon costs to be “\$38,499 (in 2011 dollars).”⁶² In Idaho, the BLM also utilized the social cost of carbon protocol to analyze and assess the costs of oil and gas leasing. Using a 3% average discount rate and year 2020 values, the agency estimated the cost of carbon to be \$51 per ton of annual CO₂e increase.⁶³ Based on this estimate, the agency estimated the total carbon cost of developing 25 wells on five lease parcels to be \$3.7 million annually.⁶⁴

⁵⁸ General Accounting Office, “Regulatory Impact Analysis, Development of Social Cost of Carbon Estimates,” GAO-14-663 (July 2014), attached as Ex. 12 .

⁵⁹ EPA, Comments on Supplemental Draft EIS for the Keystone XL Oil Pipeline (June 6, 2011) attached as Ex. 13.

⁶⁰ BLM, “Environmental Assessment for October 21, 2014 Oil and Gas lease Sale,” DOI-BLM-MT-0010-2014-0011-EA (May 19, 2014) at 76, excerpts attached as Ex. 14, available online at [http://www.blm.gov/style/medialib/blm/mt/blm_programs/energy/oil_and_gas/leasing/lease_sale/2014/oct__21_2014/july23posting.Par.25990.File.dat/MCFO%20EA%20October%202014%20Sale_Post%20with%20Sale%20\(1\).pdf](http://www.blm.gov/style/medialib/blm/mt/blm_programs/energy/oil_and_gas/leasing/lease_sale/2014/oct__21_2014/july23posting.Par.25990.File.dat/MCFO%20EA%20October%202014%20Sale_Post%20with%20Sale%20(1).pdf) (last visited Sept. 19, 2015).

⁶¹ Id.

⁶² Id.

⁶³ BLM, “Little Willow Creek Protective Oil and Gas Leasing,” EA No. DOI-BLM-ID-B010-2014-0036-EA (February 10, 2015) at 81, excerpts attached as Ex. 15 available online at https://www.blm.gov/epl-front-office/projects/nepa/39064/55133/59825/DOI-BLM-ID-B010-2014-0036-EA_UPDATED_02272015.pdf (last visited Sept. 23, 2015).

⁶⁴ Id. at 83.

It is important to note that the social cost of carbon protocol presents a conservative estimate of damages associated with the environmental impacts climate change. As the EPA has noted, the protocol “does not currently include all important [climate change] damages.”⁶⁵

The models used to develop [social cost of carbon] estimates do not currently include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature because of a lack of precise information on the nature of damages and because the science incorporated into these models naturally lags behind the most recent research.⁶⁶

Scientific reviews have similarly concluded that the interagency social cost of carbon estimates do not account for, or poorly quantifies, certain impacts, suggesting that the estimated values are conservative and should be viewed as a lower bound.⁶⁷ Recent studies have reported significantly higher carbon costs. For instance, a report published in January 2015 found that current estimates for the social cost of carbon should be increased six times for a mid-range value of \$220 per ton.⁶⁸ In spite of uncertainty and likely underestimation of carbon costs, nevertheless, “the SCC is a useful measure to assess the benefits of CO2 reductions,” and thus a useful measure to assess the costs of CO2 increases.⁶⁹

The fact that the impacts of climate change reflected as a social cost should be a significant consideration in agency decisionmaking is emphasized by a recent White House

⁶⁵ EPA, Fact Sheet: Social Cost of Carbon (Ex. 9) at 1.

⁶⁶ Id.

⁶⁷ See Peter Howard, et al., Environmental Defense Fund, Institute For Policy Integrity, Natural Resources Defense Council, OMITTED DAMAGES: WHAT’S MISSING FROM THE SOCIAL COST OF CARBON, (March 13, 2014) (providing, for example, that damages such as “increases in forced migration, social and political conflict, and violence; weather variability and extreme weather events; and declining growth rates” are either missing or poorly quantified in SCC models), attached as Ex. 16; Frank Ackerman & Elizabeth A. Stanton, CLIMATE RISKS AND CARBON PRICES: REVISING THE SOCIAL COST OF CARBON (2010), attached as Ex. 17 (concluding that the 2010 Interagency social cost of carbon “omits many of the biggest risks associated with climate change, and downplays the impact of current emissions on future generations,” and suggesting that the social cost of carbon should be almost \$900 per ton of carbon); Frances C. Moore and Delavane B. Diaz, Temperature impacts on economic growth warrant stringent mitigation policy, NATURE CLIMATE CHANGE (Jan. 12, 2015), attached as Ex. 18 (identifying a central value of \$220 for one ton of additional CO₂e).

⁶⁸ See Moore and Diaz (2015) (Ex. 18) at 2.

⁶⁹ EPA, Fact Sheet: Social Cost of Carbon (Ex. 9).

report, which warned that delaying carbon reductions would yield significant economic costs.⁷⁰ As the report states:

[D]elaying action to limit the effects of climate change is costly. Because CO₂ accumulates in the atmosphere, delaying action increases CO₂ concentrations. Thus, if a policy delay leads to higher ultimate CO₂ concentrations, that delay produces persistent economic damages that arise from higher temperatures and higher CO₂ concentrations. Alternatively, if a delayed policy still aims to hit a given climate target, such as limiting CO₂ concentration to given level, then that delay means that the policy, when implemented, must be more stringent and thus more costly in subsequent years. In either case, delay is costly.⁷¹

The requirement to analyze the social cost of carbon is supported by the general requirements of NEPA, specifically supported in federal case law, and by Executive Order 13514.

To this end, courts have ordered agencies to assess the social cost of carbon pollution, even before a federal protocol for such analysis was adopted. In 2008, the U.S. Court of Appeals for the Ninth Circuit ordered the National Highway Traffic Safety Administration to include a monetized benefit for carbon emissions reductions in an Environmental Assessment prepared under NEPA. Ctr. for Biological Diversity v. Nat'l Hwy. Traffic Safety Admin., 538 F.3d 1172, 1203 (9th Cir. 2008). The Highway Traffic Safety Administration had proposed a rule setting corporate average fuel economy standards for light trucks. A number of states and public interest groups challenged the rule for, among other things, failing to monetize the benefits that would accrue from a decision that led to lower carbon dioxide emissions. The Administration had monetized the employment and sales impacts of the proposed action. Id. at 1199. The agency argued, however, that valuing the costs of carbon emissions was too uncertain. Id. at 1200. The court found this argument to be arbitrary and capricious. Id. The court noted that while estimates of the value of carbon emissions reductions occupied a wide range of values, the correct value was certainly not zero. Id. It further noted that other benefits, while also uncertain, were monetized by the agency. Id. at 1202. Benefits and costs—including costs due to climate change—must be evaluated equally.

More recently, federal agencies' obligation to analyze the costs associated with GHG emissions through NEPA was directly affirmed by the court in High Country Conservation Advocates v. U.S. Forest Service, 52 F. Supp. 3d 1174 (D.Colo. 2014). In his decision, Judge Jackson identified the IWG's social cost of carbon protocol as a tool to "quantify a project's contribution to costs associated with global climate change." Id. at 1190. "The critical importance of [climate change] . . . tells me that a 'hard look' has to include a 'hard look' at whether this tool, however imprecise it might be, would contribute to a more informed

⁷⁰ Executive Office of the President of the United States, Council of Economic Advisers, "The Cost of Delaying Action to Stem Climate Change" (July 2014), attached as Ex. X, available at https://www.whitehouse.gov/sites/default/files/docs/the_cost_of_delaying_action_to_stem_climate_change.pdf (last visited Sept. 23, 2015).

⁷¹ Id. at 1.

assessment of the impacts than if it were simply ignored.” Id. at 1193.

For these reasons, STB must include the social cost of the Tongue River Railroad’s direct and indirect carbon emissions to meet its obligation to take a “hard look” at the scope and nature of the project’s climate pollution impacts on the human environment.

D. The DEIS Fails to Identify Appropriate Mitigation for the Full Scope of the Project’s Climate Change Impacts

While the signatories to this letter believe that STB should avoid the climate change impacts of the Tongue River Railroad altogether by selecting the “No Action” alternative, NEPA demands at a minimum that STB identify “appropriate mitigation measures” in the DEIS for the project’s direct and indirect climate change impacts. 40 C.F.R. § 1502.14(f). As the Council on Environmental Quality has affirmed:

The mitigation measures discussed in an EIS must cover the range of impacts of the proposal. ... Once the proposal itself is considered as a whole to have significant effects, all of its specific effects on the environment (whether or not “significant”) must be considered, and mitigation measures must be developed where it is feasible to do so.

Forty Most Asked Questions Concerning CEQ’s National Environmental Policy Act Regulations, Question 19a, 46 Fed. Reg. 18,026 (March 23, 1981). Such measures may lessen environmental impacts by avoiding them altogether, limiting the magnitude of the action, or compensating for adverse environmental effects. 40 C.F.R. § 1508.20.

STB’s discussion of mitigation measures to address the climate change impacts of the railroad is incomplete, at best. To mitigate the impacts of its decision to enable mining of Tongue River coal, STB proposes such paltry measures (relative to the project’s substantial impacts) as using fuels for onsite construction equipment “with a minimum biodiesel content of 5 percent (a B5 blend) as available” and “provid[ing] group transportation for construction personnel to and from the site.” DEIS at 5.2-34-35. Burning biodiesel and employee carpooling do not come close to compensating for the carbon emissions of burning more than 1.5 billion tons of coal.

STB candidly admits that it “is not recommending mitigation measures for indirect or cumulative life-cycle GHG emissions impacts from construction and operation of the proposed and potentially induced mines, or coal combustion.” DEIS at 5.2-35. As justification, STB explains that:

The Board’s consistent practice has been to mitigate only those impacts that result directly from the proposed project, and these life-cycle emissions would fall outside of the direct impacts of the proposed rail line. In addition, the Board has no jurisdiction or authority over the proposed and potentially induced mines or the

combustion of coal by power plants. As a result, the Board has no authority to impose any conditions on those activities.

Id. However, the omission of feasible mitigation measures in the DEIS based on STB's "consistent practice" or jurisdictional limits is without legal merit. NEPA does not distinguish between a project's direct and indirect effects for purposes of the requisite mitigation discussion. Instead, "all of [a project's] specific effects on the environment (whether or not "significant") must be considered, and mitigation measures must be developed where it is feasible to do so." CEQ Forty Questions, 19a (emphasis added). Such measures "must cover the range of impacts of the proposal." Id. Further, "[a]ll relevant, reasonable mitigation measures that could improve the project are to be identified, even if they are outside the jurisdiction of the lead agency or the cooperating agencies[.]" Id., 19b. The practical reason for these requirements is simple: "[b]ecause the EIS is the most comprehensive environmental document, it is an ideal vehicle in which to lay out not only the full range of environmental impacts but also the full spectrum of appropriate mitigation." Id. Accordingly, STB must expand its discussion of mitigation measures to encompass the full scope of the project's direct and indirect climate change impacts.

E. The DEIS Fails to Evaluate Whether Tongue River Railroad Is Consistent with the President's Carbon Emissions Reduction Targets

Additionally, the STB failed to analyze and disclose whether the proposed Tongue River Railroad, and the 1.5 billion tons of coal it would cause to be mined, would interfere with efforts to meet federal GHG emissions reduction targets recently established by President Obama. NEPA regulations require agencies, in evaluating the environmental consequences of an action, to specifically identify, "[p]ossible conflicts between the proposed action and the objectives of Federal, regional, State, and local (and in the case of a reservation, Indian tribe) land use plans, policies and controls for the area concerned." 40 C.F.R. § 1502.16(c); accord id. § 1506.2(d).

As explained by the Council on Environmental Quality ("CEQ") in its 2014 Draft Climate Guidance, these regulations already direct federal agencies evaluating the climate impacts of their decisions to "incorporate by reference applicable agency emissions targets such as applicable Federal, state, tribal, or local goals for GHG emission reductions to provide a frame of reference and make it clear whether the emissions being discussed are consistent with such goals." Council on Environmental Quality, "Revised Draft Guidance on the Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in NEPA Reviews," 79 Fed. Reg. 77,802-26 (Dec. 24, 2014) (citing 40 C.F.R. § 1502.16(c), 1506.2(d)). Although the CEQ Guidance is still in draft form, the Guidance itself makes clear that it does not set out any new legal obligations under NEPA, but rather identifies and clarifies those obligations that already exist under the statute and regulations. Id.

In particular, the STB must address whether the proposed rail line and the additional coal combustion it facilitates are in line with the goals of President Obama's Clean Power Plan. The Clean Power Plan, for example, calls for reducing power sector emissions to 30 percent below 2005 levels by 2030. The STB must address whether adding a new source of at least 20 million tons of coal each year through 2030 is consistent with significantly reducing power sector emissions within 15 years. Additionally, in November 2014 the President announced a joint U.S.-China agreement aimed at reducing climate pollution that calls for even more

aggressively cutting net greenhouse gas emissions to 26-28 percent below 2005 levels by 2025. White House Fact Sheet, U.S.-China Joint Announcement on Climate Change and Clean Energy Cooperation (November 11, 2014), available online at <https://www.whitehouse.gov/the-press-office/2014/11/11/us-china-joint-announcement-climate-change>, (last visited September 10, 2015). The STB must evaluate the impact of the proposed project on the feasibility of achieving these national climate targets established by the President and federal agencies.

III. STB'S ANALYSIS OF THE TONGUE RIVER RAILROAD'S IMPACTS TO CULTURAL RESOURCES IS ARBITRARY

In its DEIS, STB failed to adequately analyze and disclose the Tongue River Railroad's foreseeable impacts to cultural resources. The Board's analysis improperly postponed identification of cultural resource impacts to a later time and, for those impacts it evaluated, overlooked significant cultural resources that would be either destroyed or adversely affected by the proposed railroad. The result is that the DEIS significantly understates the cultural resource impacts of the proposed project and fails to give the public and decisionmakers an accurate and complete understanding of the true extent of the harm caused by the proposal.

A. STB Improperly Proposes to Delay Full Consideration of Cultural Resources Impacts

As a result of its desire to phase implementation of National Historic Preservation Act ("NHPA") section 106 consultation process, the Board declined to even attempt to evaluate all cultural resources impacts in the DEIS. As acknowledged in the DEIS, "[i]f the Board licenses a build alternative, OEA would complete its identification efforts and apply the National Register criteria to each cultural resource identified in the study area." DEIS at 11-17. Although phased implementation of the 106 process may be appropriate under the NHPA, under NEPA BLM may not defer disclosure of impacts simply because it may be more convenient to the agency to do so. Instead, NEPA requires agencies to "integrate the NEPA process with other planning at the earliest possible time to insure that planning and decisions reflect environmental values." 40 C.F.R. § 1501.2. Agencies must conduct their environmental analysis "early enough so that it can serve practically as an important contribution to the decisionmaking process and will not be used to rationalize or justify decisions already made." Andrus v. Sierra Club, 442 U.S. 347, 351-352 n.3 (quoting 43 Fed. Reg. 55,995 (1978) (codified in 40 CFR § 1502.5 (1979))); see also Conner v. Burford, 848 F.2d 1441, 1446 (9th Cir. 1988) ("The purpose of an EIS is to apprise decisionmakers of the disruptive environmental effects that may flow from their decisions at a time when they retain a maximum range of options.") (quotation and alteration omitted). Here, STB's decision to omit a complete cultural resources analysis in the DEIS undermines NEPA's aims of informed agency decisionmaking and informed public participation. To comply with NEPA, STB at a minimum must complete its cultural resources analysis and circulate that analysis in a revised DEIS for public review.

The Board attempts to justify its failure to analyze and disclose the full extent of the cultural resources that would be affected by the proposed railroad based on the existence of a Programmatic Agreement with the Advisory Council on Historic Preservation under section 106 of the National Historic Preservation Act ("NHPA"). DEIS at 11-17. This justification is

entirely unavailing. While Programmatic Agreements under the NHPA can be used to appropriately phase review in order to satisfy an agency's NHPA obligations (36 C.F.R. § 800.14(b)), nothing in NEPA, NEPA regulations, or the NHPA even remotely suggest that the reverse is true. NHPA regulations allow federal agencies to use the NEPA process to comply with the NHPA; the regulations unequivocally do not allow federal agencies to use the NHPA process to dodge the requirements of the EIS process, including the requirements that agencies give the public an opportunity to weigh in a project's likely environmental impacts. The very regulations that the Board relies on make this point abundantly clear, stating that federal agencies may use the NEPA process "to comply with section 106" (36 C.F.R. § 800.8(c)) and that "[c]ompliance with the procedures established by an approved programmatic agreement satisfies the agency's section 106 responsibilities." 36 C.F.R. § 800.14(b)(2)(iii) (emphasis added). The Board has not offered any valid justification for using the NHPA process to put off NEPA review until after the Board, in its words, "licenses a build alternative" and thus commits itself to a final decision. DEIS 11-17. As aptly summarized by the Ninth Circuit, "NEPA's effectiveness depends entirely on involving environmental considerations in the initial decisionmaking process." Metcalf v. Daley, 214 F.3d 1135, 1145 (9th Cir. 2006) (citing 40 C.F.R. §§ 1501.2, 1502.5).

B. STB Failed to Adequately Analyze and Disclose Impacts to Cultural Resources

Furthermore, TRRC's field investigation to inventory cultural resource impacts was woefully inadequate. As explained above, NEPA requires federal agencies to take a "hard look" at the environmental consequences of the projects they approve and ensures that those agencies "will carefully consider, detailed information concerning significant environmental impacts." Methow Valley Citizens Council, 490 U.S. at 349. This includes impacts to cultural resources. 40 C.F.R. § 1508.8. For example, NEPA requires agencies explain "[t]he degree to which the action may adversely affect districts, sites, highways, structures, or objects listed in or eligible for listing in the National Register of Historic Places or may cause loss or destruction of significant scientific, cultural, or historical resources." Id. § 1508.27(b)(8). As Congress stated in the Archaeological Resources Protection Act, "archaeological resources on public lands and Indian lands are an accessible and irreplaceable part of the Nation's heritage." 16 U.S.C. § 470aa. According to the U.S. Supreme Court, the mandatory disclosure of impacts is the "key requirement of NEPA" and agencies must "consider and disclose the actual environmental effects" of a proposed project in a way that "brings those effects to bear [an agency's] decisions." Baltimore Gas & Elec. Co. v. NRDC, 462 U.S. 87, 96 (1983).

In order to document and disclose cultural resource impacts, the Board relied heavily on field surveys conducted on some portion of the proposed rail line, which were managed by TRRC's contractor, ICF. Those surveys, as explained below, were fundamentally flawed excursions that failed to adhere to the required degree of professional diligence and documentation, misidentified several potential sites, and most significantly, missed a large number of tribal resources.

To help evaluate the cultural impacts of the proposed project, the Sierra Club retained an expert in archeology that is familiar with work in the region. That expert, Chris Finley, trained at

the University of Wyoming, spent many years in the Wyoming State Archeologist office, and worked with the National Park Service's cultural resources program for the Bighorn Canyon National Recreation Area. He also conducts field schools to help train American Indian tribal members in archaeology for Northwest College in Powell, Wyoming.

Mr. Finley both observed ICF's 2014 field survey for the Colstrip Alternative as it was underway and conducted an independent, eight-day site investigation of the survey area with his team of trained tribal members in April 2015. Finley Expert Report, p. 1 (attached as Exhibit _19). Mr. Finley and his team conducted their site investigation on seven of the areas surveyed by ICF in 2014. A total of 20 previously documented sites were examined in six of the survey areas, and a seventh area was selected in an area where the ICF crew leader informed the land owners that there were no cultural resources observed on the property. Id. at 3.

Mr. Finley's review found significant flaws both in the professional integrity of the work conducted and in its conclusions. After initially reviewing ICF's documentation of its work, Mr. Finley concluded that "it was apparent that the documentation did not follow the guidelines and standards provided in the MTSHPPO planning bulletin, and was incomplete, inaccurate, and misleading." Id. at 1. Moreover, "[w]hile examining these sites and one area where ICF said they found nothing, 36 undocumented sites were discovered," including 6 probable prehistoric burials and 2 historic human burials. Id. at 18. As explained below, STB's conclusions regarding cultural resources impacts based on ICF's flawed and incomplete evaluation violates NEPA.

1. Flaws in ICF's Documentation Process

As explained in greater detail in Mr. Finley's attached report, the documentation provided by ICF failed to live up to professional standards required by the state of Montana. Finley Report, at 1. The Montana State Historic Preservation Office contains specified forms designed to ensure that affected Tribes, landowners, decisionmakers, and the public have relevant information on cultural resource impacts. This information includes the following for identified sites:

- (A) Location
- (B) Environmental Information
- (C) Assessment, recording and management documentation
- (D) Prehistoric site description
- (E) Historic site description

Mr. Finley concluded that ICF failed to meet all five components of the review. ICF completely ignored "environmental information" (requirement B) and "assessment, recording and management documentation" (requirement C), and provided only minimal information on "location" (requirement A), "prehistoric site description" (requirement D), or "historic site description" (requirement E). Id. at 1. Additionally, ICF provided no assessment of eligibility, no site maps or illustrations of features, and the identification and description of artifacts and features were often incorrect. Id. As Mr. Finley summarized, "[o]verall, the quality of the survey documentation and maps was problematic with inaccurate and incomplete documentation

provided on most of the site forms, several of the . . . maps provided with the site forms, and even the project maps had sites plotted in the wrong place or omitted from the maps.” *Id.* at 18.

2. Flaws in ICF’s Field Survey Findings

Mr. Finley’s attached report also documents ICF’s failure to identify critical pieces of information on the seven sites studied by Mr. Finley and his team, raising serious questions about ICF’s review throughout each of the areas surveyed. **Perhaps most troubling is the fact that the field surveys conducted by ICF missed important cultural resources on each of the seven sites visited by Mr. Finley.**

Each of these sites and the corresponding findings are described in great detail in Mr. Finley’s expert report. In summary, Mr. Finley and his team identified 36 undocumented sites on land surveyed by ICF, including 5 cairns, 7 lithic scatters, 2 lithic procurement sites, 1 rock shelter, 2 historic rock art sites, 2 stone circle sites, 6 probable prehistoric burial sites, 2 historic burial sites, 1 TCP, 6 historic sites, and 4 isolates. *Id.* at 18. The presence of these sites is information critical to an adequate cultural resources analysis.

3. Underreporting of Cultural Resource Impacts

Based on ICF’s flawed documentation and incomplete and inaccurate identification of impacts, the Board significantly underrepresented the cultural resource impacts of the proposed railroad. As noted, ICF missed significant resources on each of the sites evaluated by the Mr. Finley and his team. Not only are these documented flaws significant, including the fact that ICF missed likely human burial sites, but they present significant problems for ICF’s attempt to extrapolate documented impacts onto unsurveyed areas.

As the Board explained, ICF was granted access for field surveys only on 51% of the archaeological and tribal resources area of potential effects. Of that 51%, ICF conducted field surveys only on approximately 72% of the accessible property. DEIS at 11-23. The Board then used its results from the field surveys – which were deeply flawed – and from record searches to extrapolate the sensitivity for archeological sites to more than half of the proposed project area. DEIS at 11-29.

The record searches cannot paper over the significant flaws in the field survey work because they yield no information on the vast majority of this area. As the Board noted, “less than 10 percent of the areas encompassed by the build alternatives had been previously surveyed for archaeological sites.” DEIS at 11-32.

Thus, when the Board used ICF’s filed survey information to predict impacts over the proposed alternatives, it very likely underreported the cultural and archeological resources that would be destroyed by the proposed Tongue River Railroad. For example, although the Board concluded that the applicant’s preferred Colstrip Alternative would “destroy or damage 58 cultural resources . . . where surveys were conducted in the right-of-way” DEIS at 11-59 to 11-60, that not only leaves out archeological and cultural sites on all unsurveyed areas, but it also fails to account for each of the sites identified by Mr. Finley and his team.

This underreporting, unfortunately, applies to each of the studied alternatives in the DEIS and must be corrected in order to give the public, Tribes, and decisionmakers a “full and fair” picture of the cultural resources that will be affected by the proposed rail line and the various alternatives, as required by NEPA. 40 C.F.R. § 1502.1

IV. STB’S ANALYSIS OF THE TONGUE RIVER RAILROAD’S DIRECT AND INDIRECT IMPACTS TO WILDLIFE IS ARBITRARY

The DEIS also fails to adequately examine the Tongue River Railroad’s impacts on the region’s treasured wildlife resources. Under NEPA, the agency must “provide full and fair discussion of significant environmental impacts and shall inform decision-makers and the public of the reasonable alternatives which would avoid or minimize adverse impacts or enhance the quality of the human environment.” 40 C.F.R. § 1502.1. This discussion must include an analysis of “direct effects,” which are “caused by the action and occur at the same time and place,” as well as “indirect effects which ... are later in time or farther removed in distance, but are still reasonably foreseeable.” *Id.* § 1508.8. An EIS must also consider the cumulative impacts of the proposed federal agency action together with past, present, and reasonably foreseeable future actions, including all federal and non-federal activities. *Id.* § 1508.7

The Supreme Court has held that impacts must be analyzed when there is “‘a reasonably close causal relationship’ between the environmental effect and the alleged cause.” *Dep’t of Transp. v. Public Citizen*, 541 U.S. 752, 767 (2004). When projects are linked, like the TRR and the Otter Creek mine, the impacts of both projects on wildlife must be examined. See *Sylvester v. U.S. Army Corps of Eng’rs*, 884 F.2d 394, 400 (9th Cir. 1989) (agency must consider secondary indirect and cumulative effects of an action other than the proposed action under NEPA if they are “two links of a single chain.”); *Thomas v. Peterson*, 753 F.2d 754, 761 (9th Cir. 1985) (agency’s EIS had to consider both a federal road and the federal timber sales that the road would facilitate); *Port of Astoria, Oregon v. Hodel*, 595 F.2d 467, 480 (9th Cir. 1979) (agency’s EIS had to consider the supply of federal power and the construction of a private magnesium plant that used the power); *In Border Power Plan Working Grp. v. Dep’t of Energy*, 260 F. Supp.2d 997, 1016 (S.D. Calif. 2003) (impacts of other projects must be examined where projects are “two links in the same chain” and “effects must be causally linked to the proposed federal action in order for NEPA to require consideration of those effects in an EA or EIS.”); *Colo. River Indian Tribes v. Marsh*, 605 F. Supp. 1425, 1433 (C.D.Cal. 1985) (agency had to prepare an EIS that considered both the federal action of stabilizing a river bank and the private housing built as a result).

Agencies must also analyze indirect adverse environmental effects that are “reasonably foreseeable” if it they sufficiently likely to occur. *Mid States Coal. for Progress v. Surface Transp. Bd.*, 2003, 345 F.3d 520 (8th Cir. 2003) (ruling that STB could not approve new and upgraded rail lines without examining impacts of resulting increase in coal consumption). Courts have routinely required agencies to consider “growth-inducing” indirect effects of an agency action, such as those that might occur at ports of export on the West Coast. See *City of Davis v. Coleman*, 521 F.2d 661, 676 (9th Cir. 1975) (requiring analysis of “growth-inducing” impacts of highway interchange); *Calif. v. U.S. Dept. of Transp.*, 260 F. Supp. 2d 969, 974 (N.D.

Cal. 2003) (EIS for airport failed to analyze impacts on region from hundreds of thousands of additional visitors).

For this proposed project, NEPA requires that the STB's DEIS assess all impacts of the TRR project on wildlife, including indirect and cumulative impacts. Specifically, this includes not only the direct impacts of the TRR operation and construction in the proposed right-of-ways, but also the indirect and cumulative impacts of the railroad. These include:

- Impacts to wildlife from the mining of the Otter Creek area that is dependent upon and will be enabled by the railroad.
- Impacts to wildlife caused by the ports – existing and proposed – that are likely to receive increased shipments of coal from the railroad, or are more likely to be constructed as a result of more coal being mined for export.
- Increased dust along the entire route of the railroad, as well as the route of connecting railroads that will experience more train traffic made up largely of coal trains.
- Increased air and water pollution resulting from increased shipments of and mining of coal resulting from activities from the mine site to the port.
- Increased GHG emissions from enabling the extraction and combustion of coal that will be produced as a result of the TRR.

The DEIS must also examine the impacts of the railroad in the context of climate change, which will exacerbate many of the stressors on wildlife that will be caused by the railroad. The DEIS does not look at the impacts of climate change on wildlife and fish. Climate change will have severe impacts on wildlife in the areas impacted by the railroad and generally. The TRR will contribute to climate change by allowing for a massive carbon deposit to be extracted and combusted at a time when policies are being put in place to avert the burning of fossil fuels – particularly coal – and associated emissions due to its negative impacts to wildlife and the environment.

A. The DEIS Fails to Adequately Analyze Direct, Indirect, and Cumulative Impacts to Wildlife

The DEIS does not properly examine the many direct, indirect, and cumulative impacts the project will have. Some impacts are simply not examined, such as habitat destruction and degradation from resulting mining; habitat destruction and degradation from increased railroad traffic beyond the right-of-way (“ROW”); collision fatalities from increased traffic beyond the ROW; habitat degradation and impacts from increased port activity and possible construction; and longer and more frequent trains that deprive wildlife of migration corridors and access to water and river corridors outside of the immediate ROW.⁷²

⁷² 40 C.F.R. §§ 1502.14, 1502.16.

1. Big Game Are Vulnerable to Development in the Area.

The DEIS generally concludes that “[a]ffected wildlife species are secure and not vulnerable to decline, and OEA concludes that adverse impacts would be minor.”⁷³ This conclusion is not supported by a recent study of population trends of big game and greater sage-grouse in Southeast Montana and Northeast Wyoming.⁷⁴ Studying trends starting in the 1980s and continuing through 2012 and 2013, a recent report demonstrates the vulnerability of mule deer, pronghorn antelope, and sage-grouse populations in the area to events like drought that will be exacerbated by climate change.⁷⁵ The report specifically cites “human development” as causing “additional impacts” on the species in this area.⁷⁶ The impacts the study examines include coal mining and habitat conversion.⁷⁷

The study finds that both mule deer and pronghorn antelope in the region have “shown declines in population size or productivity or both in the past 32 years.”⁷⁸ For example, of eight mule deer herds examined, only one was found to be in good condition, three in fair condition, and half in poor condition. The report concludes that “[mule deer] populations are especially vulnerable to additional habitat loss or degradation.”⁷⁹

Similarly, of twelve pronghorn herds examined, none received a good rating. The rest were either fair or poor and one could not be rated for lack of data.⁸⁰ At-risk herds were again determined to be “especially vulnerable to loss of habitat.”⁸¹

This report undermines a fundamental premise of the DEIS’s analysis—namely, that big game and other wildlife populations in the area are not vulnerable to the myriad direct impacts the railroad will have on them. The DEIS concludes that “Construction and operation would result in habitat loss, degradation of forage quality, increased mortality rates, and animal displacement for large ungulates. Mule deer, white-tailed deer, and antelope all have high-value winter range in the rights-of-way.”⁸² This type of habitat loss will likely create additional vulnerabilities for some existing populations of ungulates. These populations, particularly mule

⁷³ DEIS at 8.3-1.

⁷⁴ John Ellenberger and A. Eugene Byrne, Population Status and Trends of Big Game and Greater Sage-Grouse in Southeast Montana and Northeast Wyoming (Jan. 2015) at 3, attached hereto as Ex. 20.

⁷⁵ Id. at 3

⁷⁶ Id.

⁷⁷ Id.

⁷⁸ Id. at 4.

⁷⁹ Id.

⁸⁰ Id. at 6.

⁸¹ Id.

⁸² DEIS at 8.3-17.

deer and pronghorn, are under stress and vulnerable to habitat loss and degradation as well as impacts from climate change. This stress is not acknowledged by the DEIS.

The DEIS must examine the acknowledged impacts of the projects—in addition to impacts it fails to acknowledge like climate and related developments such as Otter Creek—in light of a more realistic and accurate assessment of the current vulnerabilities of wildlife populations that will be impacted.

2. STB Lacks Support for its Determination That the TRR Construction and Operation Will Have Only “Minor” Impacts on Wildlife.

The EIS generally concludes that “[a]ffected wildlife species are secure and not vulnerable to decline, and OEA concludes that adverse impacts would be minor.”⁸³ However, STB made only a cursory study in both geographical scope and time that does not provide enough information to conclude that the impacts will only be minor.

For instance, of the 881,732 acres in the 4-mile study area and the 485,150 acres of the ground survey study area, only a third of the area was briefly looked at on the ground. Additionally, the period of actual study took place in less than 9 months, not even a full year’s (or four seasons’) worth of data.⁸⁴

These surveys were also completed after the most devastating wildfires that southeastern Montana has ever experienced burned hundreds of thousands of acres in the study area including the Ash Creek and the Chalky (Lynch Coulee) Fires.⁸⁵ Those fires likely made many species of wildlife relocate since their habitat was destroyed and there was no winter feed in the burned areas – areas that the STB admits are high value winter range for mule deer.⁸⁶ Completing a limited survey after these fires does not give a complete or accurate picture of the wildlife resources in the region.

A lack of legitimate analysis on the part of the STB could mean that not all animals are accounted for. A comprehensive study that takes place over multiple years and over all four seasons is needed. The study must account for conditions that are representative of the area. Without such a study, conclusions about how the railroad would impact wildlife are not based on adequate and accurate information.

⁸³ DEIS at 8.3-1.

⁸⁴ Id. at 8.3-2–5.

⁸⁵ http://billingsgazette.com/news/state-and-regional/montana/fires-have-scorched-acres-in-southern-montana-fire-season-far/article_17cd14e8-b46b-52b7-b19b-574bc74f7bcc.html.

⁸⁶ DEIS at 8.3-6 – 8.

3. The DEIS Does Not Adequately Analyze the Impacts of Habitat Fragmentation.

The study area currently does not have extensive development or highly trafficked roads and, as a result, has a high level of landscape connectivity. This allows wildlife to move relatively freely through their habitats in order to meet their biological needs. This landscape connectivity is extremely important in southeastern Montana because the arid landscape means wildlife has to travel to access limited and widely distributed water sources. Many animals regularly move through the landscape to different habitats to meet their daily, seasonal, and basic biological needs.

Connectivity allows for areas to be recolonized, for dispersal, for maintaining regional metapopulations, and minimizing risks of inbreeding within populations. Reduced landscape connectivity and limited movements due to human structures like roads and railroads may result in higher wildlife mortality, lower reproduction rates, smaller populations, and overall lower population viability.⁸⁷

The DEIS dismisses concerns over habitat fragmentation because the land is “naturally patchy.”⁸⁸ However, naturally patchy or varied landscape does not create the same challenges that landscape fragmented by a rail line does. For instance, rail line and roads often provide sight lines for predators that a “patchy” landscape does not. Rail lines and roads present other dangers such as long rail trains (which can cut off access), fences (which can also cut off access), increased opportunities for human interactions that may harm wildlife, and noise. Given the need for migration of wildlife in the area, the DEIS needs to properly examine the fragmentation impacts associated with a railroad.

4. The DEIS Underestimates the Importance of Local Migration Corridors.

The DEIS states that there are no designated migration corridors in the study area and that “big game populations do not migrate in the study area. Herds do move between habitats in the region, but they do not move long distances in response to seasonal changes (Bureau of Land Management 2013a, Farmer 2012, Mackie et al. 1998, Martin 1980).”⁸⁹ However, many wildlife move up and down the valley to access the Tongue River. The level of genetic diversity among the large ungulate herds in southeastern Montana depends on landscape connectivity and the ability of herds to move and interbreed. The DEIS does not properly account for the value of connected habitat and its benefits in particular to ungulates.

⁸⁷ See <http://www.peopleswaywildlifecrossings.org/howdoroadsimpactwildlife.html>.

⁸⁸ DEIS at 8.3-16.

⁸⁹ Id. at 8.3-8.

5. The DEIS Does Not Have Dependable Information Regarding the Presence of Large Predators.

The DEIS claims that “project-related construction and operation would minimally affect large predators that are known to occur in the study area (Section 8.3.3.1, *Mammals*). These predators have large home ranges that are tied to prey abundance and availability. Impacts on a few individuals would be possible; however, because occurrence of large predators in the study area is low, impacts are not anticipated at the population level.”⁹⁰ But the DEIS contains no information, other than conversations with ranchers about their sightings, to support its conclusion that the occurrence of large predators in the area is low. This is extremely weak data for animals that are often furtive and elusive by nature. Moreover, even if STB’s conclusion is correct—that the number of predators is low—that means that impacts will likely have a more severe effect because a few losses can have overall larger impacts on the local population.

6. The DEIS Fails to Adequately Analyze the Project’s Impacts on Fish.

Similarly, for fish, the survey size and data sampling was too small and unrepresentative to conclude that the project will not have an impact on fish on the proposed alternative ROWs. Of the 150 public and privately owned properties abutting fish-bearing streams in the study area, OEA was granted access to 50 of these properties distributed throughout the study area with generally good access to the Tongue River and Moon Creek. It only surveyed 38 sites distributed across 25 properties.⁹¹ Additionally, most of these sites (30) were on the Tongue River. Five were on Moon Creek, only two on Otter Creek, and five affected streams (Beaver, Foster, Ash, Bull, and Rosebud Creeks) weren’t evaluated at all.⁹²

Despite this small sample area and the conclusion that multiple impacts to fish will result, the DEIS dismisses such impacts as “minor” and concludes that the “species addressed are secure and not vulnerable to decline.”⁹³ The acknowledged impacts to fish include mortality, blocked fish movement, fish stranding and injury, sedimentation and turbidity, alteration of instream and riparian habitats, degradation of water quality, alteration of stream hydraulics, and noise and vibration impacts (noise and vibration impacts applicable only to the Decker Alternatives).⁹⁴ These impacts are deemed unavoidable even with implementation of OEA’s recommended mitigation measures and TRR’s voluntary measures. The DEIS needs more data on fish presence, particularly in streams where no data was collected, before it can conclude impacts will be minor.

⁹⁰ Id. at 8.3-17.

⁹¹ Id. at 8.4-5.

⁹² Id.

⁹³ Id. at 8.4-1.

⁹⁴ See id. at 8.4-17 – 25.

7. The DEIS Must Look at the Impacts of Mining Otter Creek, the Entire Rail Line, and Ports in the West.

As described in TRRC's supplemental application, the principal purpose of the proposed rail line is to transport coal from the proposed mine in the Otter Creek area.⁹⁵ As such, the two projects are "links in a chain." However, the DEIS's Chapter 8 on Biological Resources improperly fails to consider the many impacts to wildlife that will occur due to the loss and degradation of a massive amount of habitat that mining Otter Creek will cause. But for the need to transport coal from the Otter Creek mine, there would be no reason to construct and operate the TRR. The DEIS must consider and analyze the direct, indirect, and cumulative impacts resulting from the development, extraction, transportation, and use of coal from the Otter Creek mine. It does not.

Likewise, as described above, the only likely market for Tongue River coal is Asia. To reach this market, coal must be transported over 1,000 miles by rail from the proposed Otter Creek mine to export port facilities (both existing and planned) in the Pacific Northwest. The DEIS must consider the cumulative and indirect impacts to wildlife of increased coal train traffic along the entire route as well as impacts in the Northwest on wildlife from exporting coal. The Pacific Northwest area that will be impacted has several species that could be harmed, including at-risk orca and several salmonid species.

The impacts along the route could be severe. Train traffic along the entire route—not just the proposed new rail line—will spark wildfires.⁹⁶ The West is experiencing extreme and long-term drought likely due, in part, to cumulative impacts of climate change, and the fire dangers to people, wildlife, and our agricultural system are becoming more severe.⁹⁷ The DEIS must analyze the impacts of these fires on wildlife and wildlife habitat, especially in light of climate change, which will exacerbate the damage from wildfires due to increased drought conditions, changes in snowmelt, stream flow, and precipitation. For instance, wildlife, like trout, living in headwater streams are far more vulnerable to the aftermath of forest fires when stream levels are low, temperatures are higher than usual, and shade cover is gone.⁹⁸

⁹⁵ TRRC Supp. App. at 3.

⁹⁶ See Wildfire Today (July 22, 2010), available at <http://wildfiretoday.com/2010/07/22/railroad-caused-fires-in-michigan-and-washington-two-different-approaches/> (last visited Sept. 21, 2015).

⁹⁷ For example, Seattle's King 5 News exposed the negligence of railroad companies in regards to starting hundreds of wildfires along tracks in Washington State. The news reporter found that during a 10-year period, trains caused 234 fires. One person was killed when he was overrun by one of the fires as he operated a combine. Several people have lost their homes. However the company has never been cited for causing any of the fires. King 5 News, Seattle Washington, available at <http://www.king5.com/news/investigators/K5-INVESTIGATORS--Railroad-PledgesMore-Fire-Safety-Following-Investigation-98938179.html>.

⁹⁸ National Wildlife Federation, Wildlife in Hot Water: America's Waterways and Climate, at 8 (2015), available at, http://www.nwf.org/~media/PDFs/Water/2015/NWF-Report_Wildlife-In-Hot-Water.pdf.

B. The DEIS Fails to Adequately Analyze Impacts to Wildlife in the Context of Climate Change

The DEIS also fails to take a hard look at how climate change will exacerbate the impacts on wildlife. It also fails to examine how the project will impact wildlife due to the climate change-inducing emissions it will cause. These omissions are fatal to the DEIS's analysis.

As described above, the Tongue River Railroad is designed to enable the massive mining of coal in the Otter Creek area. This coal will be extracted and combusted if the railroad is built, resulting in substantial greenhouse gas emissions that will exacerbate climate change and its devastating effects.

Climate change poses a direct threat to wildlife and communities.⁹⁹ If carbon pollution continues unabated, scientists predict that higher temperatures will lead to extinction of 50% of species around the globe.¹⁰⁰ With a warming world comes habitat shifts, and many wildlife species are finding themselves without a home. The latest National Climate Assessment report shows that wildlife and communities are already feeling the impacts of climate with rising seas, heavier precipitation, changes in growing seasons, fewer cold snaps, decreased snow pack, increased incidence of pests, devastating wildfires and droughts, and other significant impacts.¹⁰¹ Plant and animal species are shifting their entire ranges in search of colder locales, in many cases two-to-three-times faster than scientists anticipated.¹⁰² Due to irreversible changes, fish like trout are already disappearing from streams, big game populations such as moose are being pushed out of their historic range, and duck and wetland habitats are vanishing.¹⁰³

Direct impacts to wildlife from climate change are already being felt in Montana and Wyoming. Changes in snowpack, stream flow, and temperature are leading to midseason fishing closures in Montana and Wyoming and other areas in the West. Low flows and warmer temperatures likely linked to climate change are stressing trout and other fish populations. To reduce other stressors, fishing restrictions during periods of high water temperatures are being put in place for trout fisheries like the Bitterroot, Blackfoot, and Clark Fork Rivers due to warm

⁹⁹ The DEIS makes references to certain impacts that will be exacerbated by climate change. For instance, it notes that that “the incidence of large wildfires has increased in recent decades” associated with “increased spring and summer temperatures and earlier snowmelt.” DEIS at 8.2-8.

¹⁰⁰ International Panel on Climate Change, 4th assessment report: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

¹⁰¹ U.S. National Climate Assessment, Observed Change, at <http://nca2014.globalchange.gov/report/our-changing-climate/observed-change> (last visited Sept. 23, 2015)

¹⁰² NWF, *Wildlife in a Warming World*.

¹⁰³ <http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0098812>

water conditions. The average number of days each year that are thermally stressful for trout has nearly tripled in Montana's Madison River since the 1980s.¹⁰⁴ Closures of these popular fishing locations during summer vacations can have major economic implications. The fishing opportunities in Yellowstone National Park, where there have also been closures, are valued at between \$67.5 and \$385 million annually.¹⁰⁵

Additional climate-related stresses on wildlife are also becoming apparent in Montana and the West, and these stresses will worsen with increased emissions. For instance, the mule deer is under immense stress, and their populations all over the west are declining due to factors such as severe droughts that will be exacerbated by climate change.¹⁰⁶ Vulnerability of large ungulates in the area to events such as drought will increase as "human development causes additional impacts to wildlife habitat" and "these populations are forced to exist on less habitat or lower quality habitat [than] has existed in the past."¹⁰⁷

All of the "unavoidable consequences" of the TRR—"permanent loss of vegetation, constraints to plant germination and growth, the spread of noxious weeds, alternated plant growth from dust deposition and maintenance, increased risk of wildfires, and alteration of riparian vegetation"¹⁰⁸—will be worsened as a result of climate change. Yet, there is no analysis in the DEIS of how these impacts will be worsened and how that will impact wildlife.

C. STB's Analysis Does Not Comply with the Endangered Species Act

STB's analysis of wildlife impacts fails not only under NEPA; it also raises serious concerns under the Endangered Species Act ("ESA"). As is often the case, the STB's obligations under NEPA and the ESA Section 7 were considered together in a combined environmental and appended biological assessment (BA). The ESA requires that action agencies (here, STB) consult with the wildlife agencies to determine how the action agencies can use their authorities to further the conservation of listed species (section 7(a)(1)) and to avoid jeopardizing their existence (section 7(a)(2)).¹⁰⁹

Congress enacted the ESA in 1972 to provide a program for the conservation of threatened and endangered species and the ecosystems upon which those species depend.¹¹⁰ Section 2(c) of the ESA establishes that it is "the policy of Congress that all Federal departments

¹⁰⁴ NWF, *Wildlife in Hot Water*, at 8.

¹⁰⁵ Id.

¹⁰⁶ http://billingsgazette.com/lifestyles/recreation/studies-states-seek-to-halt-mule-deer-population-decline/article_e6a17e99-01dd-50ed-9edb-f39c976d9db3.html; Ellenberger and Byrne (2015) (Ex. 20) at 3.

¹⁰⁷ Ellenberger and Byrne (2015) (Ex. 20) at 3.

¹⁰⁸ DEIS at 8.2-26.

¹⁰⁹ 16 U.S.C. §§ 1536(a)(1)-(2).

¹¹⁰ Id. § 1531(b); Tenn. Valley Auth. v. Hill, 437 U.S. 153, 185 (1978).

and agencies shall seek to conserve endangered species and threatened species and shall utilize their authorities in furtherance of the purposes of this Act.”¹¹¹ The ESA defines “conservation” to mean “the use of all methods and procedures which are necessary to bring any endangered species or threatened species to the point at which the measures provided pursuant to this Act are no longer necessary.”¹¹² Similarly, section 7(a)(1) of the ESA directs the Secretary of the Interior to review “programs administered by him and utilize such programs in furtherance of the purposes of the Act,” and requires that “[a]ll other Federal agencies shall, in consultation with and with the assistance of the Secretary, utilize their authorities in furtherance of the purposes of this chapter by carrying out programs for the conservation of endangered species and threatened species.”¹¹³

To implement these purposes, Section 7 of the ESA requires that all federal agencies “in consultation with” the U.S. Fish & Wildlife Service (FWS) or the National Marine Fisheries Service (NMFS) “insure that any action authorized, funded, or carried out” by the agency “is not likely to jeopardize the continued existence” of any listed species.¹¹⁴ If an agency’s actions are likely to adversely affect a listed species, formal consultation is required.¹¹⁵ Consultation “shall be concluded within the 90-day period beginning on the date on which initiated,” unless extended by agreement between the Service and the action agency.¹¹⁶

Section 7(a)(2) thus imposes two obligations upon federal agencies. The first is procedural and requires that agencies consult with the FWS or NMFS to determine the effects of their actions on endangered or threatened species and their critical habitat.¹¹⁷ The second is substantive and requires that agencies ensure that their actions not jeopardize endangered or threatened species or their critical habitat.¹¹⁸

An agency must initiate consultation under Section 7 whenever it takes an action that “may affect” a listed species.¹¹⁹ The threshold for “may affect” is low. It is met if there is “[a]ny possible effect, whether beneficial, benign, adverse, or of an undetermined character. . . .”¹²⁰

¹¹¹ 16 U.S.C. § 1531(c)(1).

¹¹² Id. § 1532(3).

¹¹³ Id. § 1536(a)(1).

¹¹⁴ 16 U.S.C. § 1536(a)(2); see W. Watersheds Project v. Kraayenbrink, 632 F.3d 472, 495 (9th Cir. 2011) (describing Section 7(a)(2) as “the heart of the ESA” and explaining consultation).

¹¹⁵ 50 C.F.R. § 402.14(a).

¹¹⁶ 16 U.S.C. § 1536(b)(1).

¹¹⁷ Id. § 1536(b).

¹¹⁸ Id. § 1536(a)(2); Fla. Key Deer v. Paulison, 522 F.3d 1133, 1138 (11th Cir. 2008).

¹¹⁹ 50 C.F.R. § 402.14(a).

¹²⁰ 51 Fed. Reg. 19,926, 19,949 (June 3, 1986) (codified at 50 C.F.R. pt. 402). See Natural Res. Defense Council v. EPA, 2005 WL 1241904 5 (D. Md. 2005) (citing 50 C.F.R. 402).

Regulations implementing Section 7 broadly define what constitutes an “agency action” subject to consultation.¹²¹ Additionally, STB must consider “the effects of the action as a whole.”¹²²

After determining whether an action may affect a listed species, the action agency must decide whether to initiate formal or informal consultation with the Service. To make this determination, the agency typically prepares a BA evaluating how the action will affect listed species, using “the best scientific and commercial data available.”¹²³ If the action agency concludes the action is “likely to adversely affect” a listed species, the agency must formally consult with the consulting agency.¹²⁴ During formal consultation, the consulting agency prepares a biological opinion (BO) evaluating whether the proposed action is likely to jeopardize the continued existence of the species.¹²⁵ After consultation, the consulting agency produces a BO explaining how the proposed action will affect the listed species and determines “whether the action ... is likely to jeopardize the [species’] continued existence.”¹²⁶

Alternatively, if the action agency determines in its BA that the proposed action “may affect” but is “not likely to adversely affect” listed species, the agency may seek informal consultation with the Service. Informal consultation includes “discussions and correspondence” between the Service and the action agency, and if, but only if, the Service issues a “written concurrence” agreeing with the action agency’s not likely to adversely affect determination, consultation is complete, and Section 7 is satisfied.¹²⁷

If the consulting agency finds “jeopardy or adverse modification” to a listed species or its critical habitat, “the [consulting agency] shall suggest those reasonable and prudent alternatives which [it] believes would not violate subsection (a)(2).”¹²⁸ If the consulting agency makes a finding of “jeopardy or adverse modification,” the acting agency must either “terminate the

¹²¹ See 50 C.F.R. § 402.02 (defining “agency action” as “all activities or programs of any kind authorized, funded, or carried out, in whole or in part, by Federal agencies.... Examples include, but are not limited to: ... the granting of licenses, contracts, leases, easements, rights-of-way, permits or grants in aid). Courts have also construed “agency action” broadly. *E.g.*, Natural Res. Def. Council v. Houston, 146 F.3d 1118, 1125 (9th Cir. 1998), *cert. denied*, 526 U.S. 1111 (1999); Pacific Rivers Council v. Thomas, 30 F.3d 1050, 1054–55 (9th Cir. 1994), *cert. denied*, 514 U.S. 1082 (1995); Connor v. Burford, 848 F.2d 1441, 1453 (9th Cir. 1988), *cert. denied*, 489 U.S. 1012 (1989).

¹²² 50 C.F.R. § 402.14(c).

¹²³ *Id.* § 402.12(a), (k); 16 U.S.C. § 1536(a)(2).

¹²⁴ 50 C.F.R. § 402.14(a).

¹²⁵ *Id.* § 402.14(h)(3).

¹²⁶ *Id.* § 402.14(g)(3), (4).

¹²⁷ *Id.* § 402.13(a).

¹²⁸ 16 U.S.C. § 1536(b)(3)(A).

action, implement the proposed alternative, or seek an exemption from the Cabinet-level Endangered Species Committee pursuant to 16 U.S.C. § 1536(e).”¹²⁹

Thus, STB, in consultation with FWS and NMFS, must examine “the direct and indirect effects of [the TRR] on the species and critical habitat, together with the effects of other activities that are interrelated or interdependent with [the TRR], that will be added to the environmental baseline.”¹³⁰ The “environmental baseline” is “the past and present impacts of all Federal, State, or private actions and other human activities in the action area, the anticipated impacts of all proposed Federal projects in the action area that have already undergone formal or early section 7 consultation, and the impact of State or private actions which are contemporaneous with the consultation in process.” “Indirect effects” are “those that are caused by the proposed action and are later in time, but still are reasonably foreseeable.”¹³¹ “Interrelated actions” are “those that are part of a larger action and depend on the larger action for their justification.”¹³² “Interdependent actions” are “those that have no independent utility apart from the action under consideration.”¹³³ The “action area” that must be examined includes “*all areas* to be affected directly or indirectly by the Federal action and not merely the immediate area involved in the action.”¹³⁴

The BA concludes that the TRR may affect, but is not likely to adversely affect, the black-footed ferret, interior least tern, and whooping crane, and would have no effect on the pallid sturgeon.¹³⁵ The BA also concludes that the red knot, which is proposed to be listed as threatened, has not been documented in the action area and that the proposed TRR would not jeopardize the continued existence of this species. The BA reaches the same conclusion for the northern long-eared bat, currently proposed to be listed as endangered.¹³⁶ The STB’s OEA also examines two candidate species: the greater sage-grouse and Sprague’s pipit. For both of these species, the BA also concludes that the TRR “may affect” the species but is “not likely to adversely affect” them.¹³⁷

However, as detailed above, the DEIS fails to look at several important factors. Primarily, it fails to look at climate change impacts that will exacerbate other impacts of the TRR, including how increased risks of forest fires, droughts, floods, hotter days, and other impacts could jeopardize threatened and endangered species.

¹²⁹ Fla. Key Deer, 522 F.3d at 1139 (citing Nat’l Ass’n of Home Builders v. Defenders of Wildlife, 551 U.S. 644, 652 (2007)).

¹³⁰ 50 C.F.R. § 402.02.

¹³¹ Id.

¹³² Id.

¹³³ Id.

¹³⁴ 50 C.F.R. § 402.02 (emphasis added).

¹³⁵ Appx L, BA at S-1.

¹³⁶ Id.

¹³⁷ Id. at 7-3.

The BA fails because the action area examined is too limited. The BA limits the action area to “each build alternative’s ROW plus all areas surrounding the right-of-way plus all areas surrounding the right-of-way where construction or operation could potentially affect the environment, either directly, indirectly, or through interrelated or interdependent actions.”¹³⁸ The action area only extends one mile out from the ROW, except for the sage-grouse which extends two miles from the proposed ROWs plus four miles for known sage-grouse lek areas.¹³⁹ The BA also looks at an interdependent action – the proposed Otter Creek Mine (though the Otter Creek Mine is ignored completely in the analysis under Chapter 8 of the DEIS).¹⁴⁰ The BA defines the Otter Creek Mine action area as “all areas to be affected directly or indirectly by the proposed project and not merely the area immediately adjacent to the action. Therefore, the action area includes the mine disturbance area (4,723 acres) plus all areas surrounding the disturbance area where construction or operational activities could affect the environment.”¹⁴¹

Under the ESA, all areas to be affected directly or indirectly must be examined. This includes not only the proposed ROWs, but also the rail lines between the TRR and likely destinations and surrounding impacted areas, and existing and proposed coal export terminals in the Pacific Northwest where most of the coal would be headed. Increased coal traffic to the Pacific Northwest could adversely affect listed salmon and orca species and populations, as well as other listed species. These impacts include coal dust, noise, blockage of migration patterns, increased risk of forest fires, increased tanker traffic, and other impacts associated with the transportation and export of coal. Such impacts are never considered. They must be.

As with the impacts to wildlife generally, the baseline survey time to determine the impacts to ESA listed species was inadequate. They occurred over just a nine month period, all in the same year.¹⁴² By its own admission, STB did not assess 43% of the action area, which, again, was far too limited.¹⁴³

The BA also fails to examine the possible impact that climate change may have in exacerbating the impacts of the project on listed species. Indeed, the phrase “climate change” is not mentioned in the BA. As with impacts to wildlife in general, climate change will exacerbate forest fires, erosion (from more intense storms), drought (causing species to migrate farther for water sources, increasing collision likelihood), and other impacts such as increased spread of invasives. The effect climate change will have on these impacts and, in turn, on listed species must be considered.¹⁴⁴

¹³⁸ BA at 2-9.

¹³⁹ Id.

¹⁴⁰ BA Chap. 8.

¹⁴¹ BA 8-2.

¹⁴² Id. at 3-6.

¹⁴³ Id.

¹⁴⁴ See NRDC v. Kempthorne, 506 F. Supp. 2d 322 (E.D. Cal. 2007).

The conclusion that the project will have no impact on the pallid sturgeon is seemingly contradicted by the BA itself, which concludes that “it is conceivable that a pallid sturgeon that is able to migrate through the historic side channel during a high flow event could migrate to the Tongue River.” Given that the sturgeon has made it past blockages considered not passable previously, it is possible sturgeon could make it up the Tongue River. For example, in 2014, five pallid sturgeon managed to pass upstream of Intake Dam on the Yellowstone River by using a natural side channel around the dam during high water flows. One of those five, a female, spawned upstream in the Powder River, a tributary to the Yellowstone, which is just east of the Tongue River. And there are currently significant efforts under consideration to improve fish passage on the Yellowstone River downstream of where the Tongue River joins the Yellowstone. Given the species’ dire condition, impacts on a potentially migrating sturgeon or sturgeons should be considered.

The pallid sturgeon, which was listed as endangered under the federal ESA in 1990,¹⁴⁵ require “large, turbid, free flowing riverine habitat with rocky or sandy substrate.”¹⁴⁶ Sturgeon habitat in the upper Missouri River basin has been drastically reduced, and what remains is highly fragmented.¹⁴⁷ “Destruction and alteration of habitats by human modification of the river system is believed to be the primary cause of decline in reproduction, growth, and survival of pallid sturgeon.”¹⁴⁸

Concerns also exist over the impacts at the Miles City Fish Hatchery. The BA concludes that “noise generated by rail construction and operation would be less than the ambient noise and vibration levels at the hatchery where pallid sturgeon are located.”¹⁴⁹ Yet, the BA does not appear to study the impacts of the TRR as additional noise and vibration to the current ambient noise and vibration.

The black-footed ferret was listed as endangered under the ESA in 1970. The black-footed ferret is endangered due to habitat modification and destruction in conjunction with the demise of the prairie dog.¹⁵⁰ Since European contact, about 97% of the suitable habitat available to the ferret historically has been lost, and much of the remaining occupied prairie dog habitat is highly fragmented, with only a few areas large enough to support the species remaining.¹⁵¹ Climate change is also affecting the recovery of the black-footed ferret through localized range

¹⁴⁵ See 55 Fed. Reg. 36,641 (Sep. 6, 1990)

¹⁴⁶ Office of Pesticide Programs, U.S. Env'tl. Protection Agency, Appendix C: Status and Life History of the Pallid Sturgeon (*Scaphirhynchus albus*) 5 (Aug. 31, 2007).

¹⁴⁷ *Id.* at 4, 5.

¹⁴⁸ See *id.* at 8

¹⁴⁹ BA 3-3.

¹⁵⁰ U.S. Fish & Wildlife Serv., Black-footed Ferret (*Mustela nigripes*) 5-Year Status Review: Summary and Evaluation 4 (Nov. 2008) at 13.

¹⁵¹ *Id.* at 28.

shifts and via the “strong relationship between plague outbreaks and climatic variables[.]”¹⁵² The BA concludes – without conducting any survey of black-footed ferrets – that the Otter Creek mine will have no effect on the ferret.¹⁵³ However, a sizable population of prairie dogs exist near the site. In fact, if there were slightly more prairie dogs in this area, a survey would be required to ensure black-footed ferrets are not present at the site.

In sum, the STB failed to satisfy the requirements both of NEPA and the ESA with respect to the Tongue River Railroad’s significant direct and indirect impacts to wildlife. STB’s flawed analyses cannot lawfully form the basis for its approval of the project

V. STB’S FAILURE TO ANALYZE THE TONGUE RIVER RAILROAD’S INDIRECT EFFECTS TO SURFACE WATER AND GROUNDWATER DUE TO COAL MINING VIOLATES NEPA

As with STB’s flawed investigation of wildlife impacts, the DEIS fails altogether to analyze the indirect effects due to operation of coal mines enabled by the Tongue River Railroad on surface and groundwater resources. It can hardly be disputed that impacts due to the operation of proposed and potentially induced coal mines are indirect effects of the Tongue River Railroad. “Indirect effects” are “caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable.” *Id.* § 1508.8(b). NEPA does not distinguish between the level of analysis required for direct and indirect effects. A federal agency must take a “hard look” at all of the environmental consequences of its decision. Methow Valley Citizens Council, 490 U.S. at 349.

In arid southeastern Montana, access to surface and groundwater resources of sufficient quality and quantity are essential to sustaining family ranches and life itself. While the Tongue River Railroad’s direct impacts to surface and groundwater resources are considerable, see DEIS at 9.2-25–26, 9.3-15 (describing unavoidable adverse impacts), they pale in comparison to the indirect water resources impacts due to planned and potentially induced coal strip mines. The Bureau of Land Management summarized these impacts in its Environmental Assessment for an expansion of the nearby Spring Creek Mine.¹⁵⁴ With respect to surface water, BLM stated:

General impacts to surface water resulting from surface coal mining include the following:

- Disruption of the surface drainage system (stream channels and their watershed areas) during mining, requiring replacement of these systems during reclamation.
- Changes in streamflow patterns during mining caused by the

¹⁵² *Id.* at 22, 24-25.

¹⁵³ BA 8-4 – 8-5.

¹⁵⁴ Environmental Assessment for Spring Creek Coal Lease by Application, MTM94378, EA# MT-020-2007-34 (Nov. 2006), excerpts attached as Ex. 21.

regulatory requirement to store runoff and settle out solids; by construction of flood control reservoirs or diversion systems needed to prevent unacceptable levels of runoff from entering the pit; and by discharges of pit inflows to streams or other sources of water in excess of the mine's water requirements.

- Possible changes in runoff rates due to changes in precipitation infiltration rates on restored land.
- Changes in surface water quality.¹⁵⁵

With respect to groundwater, BLM stated:

The general impacts to groundwater as a result of surface coal mining include the following:

- Removal of the coal aquifer and any overburden and alluvial aquifers within the areas that are mined, and replacement of these aquifers with backfilled overburden material. Should any overburden or alluvial aquifer be critical to the area's hydrologic balance, and restoration of the essential hydrologic functions can only be achieved by reestablishment of the aquifer, these materials may be selectively salvaged and replaced.
- A lowering of static water levels in the coal and overburden aquifers around the mine due to dewatering associated with removal of these aquifers within the mine boundaries. This reduction in static water levels would not be permanent, and recharge to the backfill and adjacent undisturbed aquifers would occur as mined areas are reclaimed.
- Other groundwater impacts, which may or may not occur, or which may occur only at specific locations, include changes in water quality (usually deteriorate on) outside the area that is mined and reclaimed as a result of communication between the reclaimed aquifer and the unmined aquifer, and changes in recharge-discharge conditions and/or groundwater flow patterns.¹⁵⁶

These same impacts to water resources are likely to occur due to development of the Otter Creek mine and other neighboring mines in response to construction of the Tongue River Railroad. These consequences are properly considered indirect effects because they are "caused by the [Tongue River Railroad] and are later in time or farther removed in distance, but are still reasonably foreseeable." Id. § 1508.8(b); see also Sierra Club v. United States, 255 F. Supp. 2d

¹⁵⁵ Id. at 83.

¹⁵⁶ Id. at 81.

1177, 1185 (D. Colo. 2002) (holding NEPA required Department of Energy to analyze the impacts of gravel mining as indirect and cumulative effects in connection with its decision to grant an easement for road to be used in proposed expansion of mining operation). Indeed, STB deemed other types of impacts due to the operation of Otter Creek and neighboring mines “indirect effects” appropriate for analysis. See, e.g., DEIS at 5.2-10 (describing greenhouse gas emissions from coal combustion as an “indirect impact[]” of the railroad). Nonetheless, STB’s effects analyses for surface water quality and groundwater quality and quantity examined only the direct construction and operation impacts of the railroad itself. See generally DEIS, Ch. 9; see also id. at 9.2-2–3 (describing methods for analyzing surface water impacts, omitting any consideration of impacts due to mining); id. at 9.3-3 (describing methods for analyzing groundwater impacts, omitting any consideration of impacts due to mining).

STB did offer a generic list impacts to water resources from coal mining in its analysis of cumulative effects. However, such impacts received little more than passing mention. Describing surface water impacts, the analysis states only that the Tongue River Railroad build alternatives “would contribute to cumulative impacts on surface water through physical alteration of surface water, degradation of water quality, and temporary surface water use” due to proposed and potentially induced coal mines. DEIS at 18-33. Without any further explication of the impacts—or any attempt to quantify them—STB simply stated that “[t]hese projects would have to comply with Montana DEQ and other state permits and approvals, any BLM-required mitigation measures, and Clean Water Act mitigation requirements”—apparently suggesting that compliance with separate regulatory obligations would adequately mitigate the mines’ impacts.

STB also mentioned impacts to groundwater from proposed and potentially induced mining in its cumulative impacts discussion. STB observed the railroad “would result in cumulative impacts on groundwater when combined with the proposed and potentially induced coal mines,” primarily “by altering infiltration and recharge characteristics, temporarily disrupting water balances, closing wells, and temporarily degrading water quality.” Id. at 18-34, 36. Without elaboration, STB again noted that “[t]hese projects would have to comply with Montana DEQ and other state permits and approvals, any BLM-required mitigation measures, and Clean Water Act mitigation requirements.” Id. at 18-36.

STB’s terse acknowledgment of water resources impacts due to coal mining does not fulfill STB’s NEPA obligation to conduct a meaningful analysis of indirect effects. Nor is STB excused from its obligation by virtue of the need for proposed and potentially induced coal mines to comply with separate permitting requirements. “A non-NEPA document—let alone one prepared and adopted by a state government—cannot satisfy a federal agency’s obligations under NEPA.” S. Fork Band Council Of W. Shoshone Of Nevada v. U.S. Dep’t of Interior, 588 F.3d 718, 726 (9th Cir. 2009) (citing Klamath–Siskiyou Wildlands Center v. BLM, 387 F.3d 989, 998 (9th Cir. 2004)) (rejecting argument that EIS for gold mining project need not address off-site impacts of an ore-processing facility because it operates pursuant to a state permit under the

Clean Air Act).¹⁵⁷ STB must fully analyze and disclose the water resources impacts due to coal mining in the EIS.

VI. STB'S ANALYSIS OF COAL DUST VOLUME AND IMPACTS IS ARBITRARY

STB's analysis also fails to disclose the full scope of impacts due to coal dust from trains on the Tongue River Railroad, including impacts to air quality and human health. The principal source of coal dust in areas affected by the Tongue River Railroad is coal "blown from the top of the rail cars by the air moving over the loaded, uncovered rail cars." DEIS at 4-14. As Ranajit Sahu, Ph.D., noted in his expert memorandum for the Northern Cheyenne tribe, BNSF estimates that coal loss from the tops of rail cars are 600 pounds per car over a 400 mile route. Sahu Mem. at 18.¹⁵⁸ For a single, 125-car train, this translates to 37.5 tons of coal and coal dust emitted to the air or deposited on the ground and in waterways in just the first 400 miles of the coal's route from Otter Creek to West Coast export terminals. As STB acknowledges, "[w]hen particulate matter is inhaled, larger particles are filtered in the nose or throat by cilia and mucus, but small particles can pass through into the lungs. The smallest particles can enter the circulatory system, where they harden and inflame the arteries. This increases the risk of heart attack and other cardiovascular problems." DEIS at 6-3.

STB underestimated fugitive coal dust emissions and their adverse impacts to air quality and human health. STB modeled dispersion of airborne particulate using EPA's AERMOD air dispersion and deposition model. DEIS at G-11. The model incorporates, most critically, assumptions based on estimated rail car coal dust emissions. *Id.* While have not undertaken a critique of STB's modeling, several of STB's underlying assumptions, as described in the DEIS, are inappropriate or unsupported.

First, STB improperly failed to consider coal dust emissions over the entire rail route. It appears that STB's conservative (i.e., high production) scenarios looked at coal loss from 6.32 trains per day for a daily total of 322.71 train miles—or just over 50 miles per train. DEIS at E-33. Yet fugitive dust from coal trains is known to occur well beyond the first 50 miles of its trip, and accordingly are "reasonably foreseeable" emissions that must be considered under NEPA.¹⁵⁹

¹⁵⁷ Arch Coal, through its subsidiary Otter Creek Coal LLC, has submitted to the Montana Department of Environmental Quality ("DEQ") both an application to mine and an application for a water discharge permit under the Montana Water Quality Act, which include information necessary to evaluate the water resources impacts of the Otter Creek mine. However, DEQ identified significant omissions and errors in both applications and STB may not rely solely on information provided by the applicant. See <http://www.deq.mt.gov/ottercreek/default.mcp> (DEQ project website with links to deficiency notices) (last visited Sept. 21, 2015). STB must undertake an independent analysis of the water resources impacts of mining.

¹⁵⁸ This letter incorporates by reference the coal dust arguments raised in the Northern Cheyenne Tribe's comments and expert report.

¹⁵⁹ See, e.g., Petition of Arkansas Electric Cooperative Corporation for a Declaratory Order, STB Finance Docket 35305, BNSF PowerPoint, at 3-10 (Nov. 17, 2010), excerpts attached as Ex. 22.

40 C.F.R. § 1508.8. In lieu of its truncated analysis in the DEIS, STB must analyze coal dust emissions over the entire route from mine to market.¹⁶⁰

Second, STB failed to disclose or justify its assumptions regarding particle size distribution from coal lost from trains, a significant factor in calculating overall fugitive dust emissions. While BNSF has provided estimates of coal loss from rail cars, those estimates appear to reference the total volume of coal lost. For purposes of evaluating coal dust emissions, STB considered only a fraction of this total volume, assuming that particles larger than 50 microns would be deposited immediately adjacent to the railway and not become airborne. In its analysis, STB estimated the total suspended particulate (“TSP”), defined as particles less than 50 microns, emitted from loaded rail cars for each build scenario. DEIS at E-45. TSP includes particles smaller than 50 microns and includes PM10 and PM2.5. *Id.* at 6-4. Based on examinations of other coal types, STB assumed a particle size distribution of 45% PM10 and 8.6% PM 2.5 relative to TSP. *Id.* at E-44. However, STB fails to disclose or justify its assumptions regarding the particle distribution of TSP relative to total coal lost from rail cars. STB’s analysis cannot be supported without such information.

Third, STB also failed to demonstrate the efficacy of coal dust mitigation measures. In particular, “much is unknown as far as the composition of almost all of the ‘approved’ [topper] agents.” Sahu Mem. at 21-22. As described in the separate comments of Northern Cheyenne Tribe, STB has refused to make available documents regarding the efficacy of coal dust mitigation measures, undermining the public’s ability to meaningfully evaluate STB’s assumptions and leaving STB without the requisite support for its claim that such measures will reduce fugitive coal dust emissions by 85%. Without such support, STB’s estimates of coal dust emissions that incorporate its mitigation assumptions are arbitrary.

Dr. Sahu’s independent analysis yielded far higher projections of coal dust emissions than those estimated by STB. Sahu Mem. at 18. Even applying STB’s assumed 85% reduction in emissions due to dust suppression measures, Dr. Sahu estimated 41 times higher emissions than the estimate provided by the STB. *Id.* at 18 n.36. Based on this analysis, we agree with Dr. Sahu’s conclusion that the STB’s estimates for coal dust emissions from the TRR are “grossly inaccurate.” *Id.* at 19.

STB’s flawed coal dust emissions calculations in turn corrupted the agency’s modeled air quality impacts from coal dust. STB’s modeling showed that airborne dust will not cause exceedances of air quality standards except for the 1-hour standard for nitrogen oxide (NOx) concentrations. DEIS at 4-17. However, because STB underestimated a fundamental input to its model—coal dust emissions—its modeling results are fatally flawed and form an illegitimate basis for STB’s conclusion that air quality impacts are not significant. See Silverton Snowmobile Club, 433 F.3d 782 (NEPA requires analysis to “ha[ve] a rational basis and t[ake] into consideration the relevant factors”).

¹⁶⁰ At a minimum, STB must consider coal dust emissions for the first 400 miles of train routes based on coal loss data that is readily available from BNSF.

Even with STB's unsupportably low emissions estimates, modeling demonstrated that NOx emissions will exceed the 1-hour standard in both medium- and high-production scenarios. DEIS at 4-17. In 2010, EPA promulgated the 1-hour standard for ambient NOx concentrations at the level it deemed necessary to protect human health after finding that even short-term exposures to high NOx levels can cause severe respiratory impacts.¹⁶¹ While this threshold is set at 188 µg/m³ for a 1-hour period, NOx emissions attributable to the Tongue River Railroad are modeled to reach 297 µg/m³. DEIS at 4-17. STB attempts to dismiss these modeled impacts. Citing a 2012 study by the American Petroleum Institute among others, STB claims that EPA's AERMOD model "has been documented in a number of studies to over-predict the highest 1-hour NO2 concentration from 1.7 to 2 times the observed concentration." *Id.* at 4-17-18. Accordingly, STB reduced predicted NOx concentrations to account for this "model bias." *Id.* at 4-18. While STB states that EPA is "aware" of the purported model bias, EPA has not conceded a bias of 1.7 to 2 times in its approved model, and has not sanctioned any post-modeling reductions in modeled values.¹⁶² Moreover, STB's analysis relied on a version of AERMOD (13350) that modified earlier versions to incorporate a "Tier 2 ambient ratio method for the 1-hour NO2 NAAQS" in order to partially address industry's critique of the models' treatment of NOx. *Id.*; see DEIS at E-135 (specifying use of AERMOD 13350). STB has failed to justify its post-modeling reduction of projected NOx impacts in the DEIS.

For all of these reasons, STB's analysis of air quality and human health impacts due to fugitive coal dust emissions is arbitrary and unsupported.

VII. CONCLUSION

As described in these comments, there are many ways in which STB's analysis of the environmental consequences of the Tongue River Railroad fails to satisfy NEPA. But these defects and omissions in the DEIS provide only part of the reason why the agency must re-evaluate this project. With the Tongue River Railroad, STB is faced with perhaps the most important decision in the agency's history—one that will impact every generation to come. In southeastern Montana, the Tongue River Railroad and the massive coal mines it would catalyze would devastate irreplaceable natural, cultural, and economic resources upon which the Northern Cheyenne, farmers and ranchers, and other local residents depend. On a global scale, constructing the Tongue River Railroad would result in carbon emissions from burning more than a billion tons of coal that could fundamentally tip the balance of our vulnerable climate into chaos. If humanity has any hope of avoiding catastrophic impacts from climate change, projects on the scale of the Otter Creek coal mine must be permanently off the table. Conceived in a bygone era, plans to build the Tongue River Railroad must stay there. We respectfully urge STB

¹⁶¹ Final Rule, Primary National Ambient Air Quality Standards for Nitrogen Dioxide, 75 Fed. Reg. 6,474, 6,483 (Feb. 9, 2010).

¹⁶² See Revision to the Guideline on Air Quality Models: Enhancements to the AERMOD Dispersion Modeling System and Incorporation of Approaches to Address Ozone and Fine Particulate Matter, 80 Fed. Reg. 45,340, 45,342-43 (July 29, 2015); see also R. Chris Owen and R. Brode, Clarification on the Use of AERMOD Dispersion Modeling for Demonstrating Compliance with the NO2 National Ambient Air Quality Standard (Sept. 30, 2014), attached as Ex. 23.

to select the “No Action” alternative and deny Arch Coal’s request to construct the Tongue River Railroad.

Sincerely,

A handwritten signature in blue ink, appearing to read "Jenny Harbine". The signature is fluid and cursive, with the first name "Jenny" being more prominent than the last name "Harbine".

Jenny Harbine
Earthjustice

Anne Hedges
Montana Environmental Information Center

Jim Murphy and Garrit Voggesser
National Wildlife Federation

Amanda Jahshan
Natural Resources Defense Council

Nathaniel Shoaff
Sierra Club

Exhibit 1

TRIBAL COUNCIL OF THE NORTHERN CHEYENNE TRIBE
NORTHERN CHEYENNE INDIAN RESERVATION
LAME DEER, MONTANA

9 yes
no

Resolution NO. _____

A Resolution of the Northern Cheyenne Tribal Council supporting the opposition to the Proposed Tongue River Railroad Project and its proposed alternatives to establish and create a railroad line from either Miles City, Montana to Ashland, Montana or from Colstrip, Montana to Ashland, Montana.

WHEREAS; the Northern Cheyenne Tribal Council is the governing body of the Northern Cheyenne Indian Reservation pursuant to the Amended Constitution and Bylaws as approved by the Secretary of the Interior on May 31, 1996; and

WHEREAS; the Northern Cheyenne Tribal Council possesses and exercises a broad array of governmental powers including the following powers: power to protect Tribal lands, interests in land, minerals, gas, oil, and other tribal assets; power to cultivate and preserve tribal culture and ceremonies; and

WHEREAS; THE Northern Cheyenne have a rich and colorful history in southeastern Montana and consider it as part of their ancestral lands; and

WHEREAS; a railroad line has been proposed called the Tongue River Railroad Project that with proposed routes either from Miles City Montana to Ashland Montana or from Colstrip Montana to Ashland Montana; and

WHEREAS; the Surface Transportation Board has the responsibility for determining a permit for this undertaking; and

WHEREAS; a Draft Environmental Impact Statement (EIS) has been completed and comments from the general public are currently being collected by Surface Transportation Board; and

WHEREAS; Surface Transportation Board has the responsibility to ensure that all adverse effects including cultural resources, environmental resources such as aquifers, plants, animals, air, water, human environment and others under federal laws are considered in the proposed federal undertaking; and

WHEREAS; the Northern Cheyenne tribe and other tribes, with ancestral ties to the area have consulted with the Surface Transportation Board in the last several years on cultural and environmental impacts in the area of potential effect; and

WHEREAS; the Surface Transportation Board has not consulted with the traditional leaders of the Northern Cheyenne therefore the ceremonial and cultural aspect of cultural resource issues are incomplete; and

WHEREAS; during the scoping sessions held on or near the Northern Cheyenne reservation there was overwhelming support to the opposition of the proposed Tongue River Railroad; and

WHEREAS; the Northern Cheyenne have cultural and environmental concerns regarding the proposed Tongue River railroad project including water resources; wetlands; groundwater; threatened and endangered Species; Aquifers; geology and soils, Terrestrial Vegetation; wildlife; Fisheries; Air quality and noise; land use; cultural resources and cumulative effects; and

WHEREAS; the Northern Cheyenne Tribe believes that the direct and long term cultural and environmental impacts of the proposed Tongue River Railroad Project will be devastating to the local communities on or near the Northern Cheyenne reservation; and

WHEREAS; the social economic welfare of the Northern Cheyenne reservation and surrounding area will be adversely impacted and undue burden and stress will be placed on local resources including law enforcement, housing, roads, public facilities, and other local resources; and

THEREFORE, BE IT RESOLVED, the Northern Cheyenne Tribe supports the opposition of the proposed Tongue River Railroad Project and that the proposed project and will do irreparable cumulative harm to the cultural, natural, social/economic, natural and environmental resources within the exterior boundaries of the Northern Cheyenne reservation and on ancestral lands within the proposed undertaking; and

BE IT FURTHER RESOLVED, that the Northern Cheyenne Tribe strongly believes that there is only one alternative and that is the "No Action" alternative and strongly recommends that the Surface Transportation board consider the "No Action" alternative

Exhibit 2



News Release

Arch Coal Acquires Equity Interest in West Coast Terminal

ST. LOUIS, Jan. 12, 2011 -- Arch Coal, Inc. (NYSE: ACI) today announced that it has acquired a 38 percent interest in Millennium Bulk Terminals-Longview, LLC ("MBT"), the owner of a bulk commodity terminal on the Columbia River near Longview, Wash., in exchange for \$25 million plus additional consideration upon the completion of certain project milestones.

"This transaction gives us a direct stake in participating in the growth of U.S. coal exports off the West Coast," said Steven F. Leer, Arch's chairman and chief executive officer. "With our superior operating position in the Powder River Basin and Western Bituminous Region, we have the capability to service growing coal demand in Asia, the world's largest and fastest-growing coal market. We believe this first project - along with others in the pipeline - will provide Arch with more exposure to the seaborne thermal market and will further unlock the value inherent in our western coal assets."

Under terms of the agreement, Arch will control 38 percent of the terminal's throughput and storage capacity to facilitate export shipments of coal off the west coast of the United States. The facility will be capable of handling panamax-sized vessels, which account for the vast majority of the seaborne thermal coal trade for the Asia-Pacific market. The terminal also is dual served by the Union Pacific and Burlington Northern Santa Fe railroads, which will provide Arch with the flexibility to export its southern Powder River Basin and Western Bituminous coals, and eventually coal from its recently-acquired Montana reserves.

The MBT terminal, a former aluminum smelter site, is currently operated as a bulk commodity facility. MBT continues to work on obtaining the required approvals and necessary permits to complete dredging and other upgrades to enable coal, alumina and cementitious material shipments through the brownfield terminal. Once completed, coal shipments could begin in 2012. As currently planned, the MBT facility will utilize existing infrastructure with some minor modifications to handle loading 5 million tons of coal per year in addition to other types of bulk commodities.

Encompassing more than 400 acres, the industrial site offers the potential for terminal expansion should market demand warrant. Should MBT elect to expand the facility, necessary regulatory approvals would be sought and additional infrastructure investment would be required.

MBT recently completed the purchase of the marine terminal from Chinook Ventures, Inc. Australia-based Ambre Energy owns the remaining 62 percent of the terminal. Ambre Energy is a progressive mining and technology company, acquiring coal and oil shale resources in Australia and the United States. "We are pleased to be partners with Ambre and value their experienced management team," said John W. Eaves, Arch's president and chief operating officer.

According to MBT estimates, the terminal development project should create 120 temporary jobs during the build-out of the facility, and ultimately would result in 70 permanent jobs from ongoing operations at the terminal. The construction of the export facility will generate \$2.7 million in sales tax revenue for state and county governments, while expected income tax revenue - once the facility is fully operational - will provide \$1.2 million annually for state and county governments.

St. Louis-based Arch Coal, Inc. is the second largest U.S. coal producer. Through its national network of mines, Arch supplies cleaner-burning, low-sulfur coal to fuel roughly 8 percent of the nation's electricity. The company also ships coal to domestic and international steel manufacturers as well as international power producers.

Forward-Looking Statements: This press release contains "forward-looking statements" - that is, statements related to future, not past, events. In this context, forward-looking statements often address our expected future business and financial performance, and often contain words such as "expects," "anticipates," "intends," "plans," "believes," "seeks," or "will." Forward-looking statements by their nature address matters that are, to different degrees, uncertain. For us, particular uncertainties arise from changes in the demand for our coal by the domestic electric generation industry; from legislation and regulations relating to the Clean Air Act and other environmental initiatives; from operational, geological, permit, labor and weather-related factors; from fluctuations in the amount of cash we generate from operations; from future integration of acquired businesses; and from numerous other matters of national, regional and global scale, including those of a political, economic, business, competitive or regulatory nature. These uncertainties may cause our actual future results to be materially different than those expressed in our forward-looking statements. We do not undertake to update our forward-looking statements, whether as a result of new information, future events or otherwise, except as may be required by law. For a description of some of the risks and uncertainties that may affect our future results, you should see the risk factors described from time to time in the reports we file with the Securities and Exchange Commission.

Exhibit 3

Arch Coal Announces Agreement With Canada's Ridley Terminal for Pacific Coast Exports

January 18, 2011 4:52 PM ET

ST. LOUIS, Jan. 18, 2011 -- Arch Coal, Inc. (NYSE: ACI) today announced an agreement with Canadian Crown Corporation Ridley Terminals Inc. ("RTI") - a coal and other bulk commodity marine terminal located near Prince Rupert, British Columbia - to facilitate coal exports to Pacific Rim markets. The five-year agreement will give Arch throughput capacity at the terminal of up to 2 million metric tons of coal for 2011 and up to 2.5 million metric tons of coal for 2012 through 2015.

"This transaction is another important step in accomplishing our strategic objective of expanding Powder River Basin coal sales into the Asia-Pacific region," said Steven F. Leer, Arch's chairman and chief executive officer. "This throughput agreement gives us direct, immediate access to the growing seaborne thermal market. It also complements our recently announced investment in the Millennium Bulk Terminal in Longview, Wash., and other continuing terminal negotiations."

RTI can load up to 12 million metric tons of coal annually, with expansion plans that could increase the facility's capacity to 24 million metric tons by 2015. Coal accounts for more than 80 percent of RTI's total volume, and Asia is the primary destination for the products shipped through the terminal. The terminal shipped 8.3 million metric tons of coal during 2010.

"RTI's vision is to provide value to its parent company and expand its role as a leading trade gateway between North American and world markets," said George Dorsey, president of Ridley Terminals. "This agreement is a very important contract for the terminal. Arch Coal's guaranteed U.S. coal volumes will support our goal of doubling our capacity by 2015."

Located on Ridley Island, RTI affords reduced sailing time to Asia - by more than one day compared to Vancouver, and nearly three days compared to Long Beach, Calif. RTI can handle panamax as well as capesize vessel loadings of up to 280,000 metric tons.

St. Louis-based Arch Coal, Inc. is the second largest U.S. coal producer. Through its national network of mines, Arch supplies cleaner-burning, low-sulfur coal to fuel roughly 8 percent of the nation's electricity. The company also ships coal to domestic and international steel manufacturers as well as international power producers.

Forward-Looking Statements: This press release contains "forward-looking statements" - that is, statements related to future, not past, events. In this context, forward-looking statements often address our expected future business and financial performance, and often contain words such as "expects," "anticipates," "intends," "plans," "believes," "seeks," or "will." Forward-looking statements by their nature address matters that are, to different degrees, uncertain. For us, particular uncertainties arise from changes in the demand for our coal by the domestic electric generation industry; from legislation and regulations relating to the Clean Air Act and other environmental initiatives; from operational, geological, permit, labor and weather-related factors; from fluctuations in the amount of cash we generate from operations; from future integration of acquired businesses; and from numerous other matters of national, regional and global scale, including those of a political, economic, business, competitive or regulatory nature. These uncertainties may cause our actual future results to be materially different than those expressed in our forward-looking statements. We do not undertake to update our forward-looking statements, whether as a result of new information, future events or otherwise, except as may be required by law. For a description of some of the risks and uncertainties that may affect our future results, you should see the risk factors described from time to time in the reports we file with the Securities and Exchange Commission.

Exhibit 4

Climate Change 2014

Synthesis Report

Edited by

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Photos:



I - Folgefonna glacier on the high plateaus of Sørkjorden, Norway (60°03' N - 6°20' E).

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II - Planting of mangrove seedlings in Funafala, Funafuti Atoll, Tuvalu. © David J. Wilson

III - China, Shanghai, aerial view. © Ocean/Corbis

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Climate Change 2014
Synthesis Report
Summary for Policymakers

Introduction

This Synthesis Report is based on the reports of the three Working Groups of the Intergovernmental Panel on Climate Change (IPCC), including relevant Special Reports. It provides an integrated view of climate change as the final part of the IPCC's Fifth Assessment Report (AR5).

This summary follows the structure of the longer report which addresses the following topics: Observed changes and their causes; Future climate change, risks and impacts; Future pathways for adaptation, mitigation and sustainable development; Adaptation and mitigation.

In the Synthesis Report, the certainty in key assessment findings is communicated as in the Working Group Reports and Special Reports. It is based on the author teams' evaluations of underlying scientific understanding and is expressed as a qualitative level of confidence (from *very low* to *very high*) and, when possible, probabilistically with a quantified likelihood (from *exceptionally unlikely* to *virtually certain*)¹. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers.

This report includes information relevant to Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC).

SPM 1. Observed Changes and their Causes

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems. {1}

SPM 1.1 Observed changes in the climate system

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen. {1.1}

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period from 1983 to 2012 was *likely* the warmest 30-year period of the last 1400 years in the Northern Hemisphere, where such assessment is possible (*medium confidence*). The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06] °C² over the period 1880 to 2012, when multiple independently produced datasets exist (Figure SPM.1a). {1.1.1, Figure 1.1}

In addition to robust multi-decadal warming, the globally averaged surface temperature exhibits substantial decadal and interannual variability (Figure SPM.1a). Due to this natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. As one example, the rate of warming over

¹ Each finding is grounded in an evaluation of underlying evidence and agreement. In many cases, a synthesis of evidence and agreement supports an assignment of confidence. The summary terms for evidence are: limited, medium or robust. For agreement, they are low, medium or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, e.g., *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: *virtually certain* 99–100% probability, *very likely* 90–100%, *likely* 66–100%, *about as likely as not* 33–66%, *unlikely* 0–33%, *very unlikely* 0–10%, *exceptionally unlikely* 0–1%. Additional terms (*extremely likely* 95–100%, *more likely than not* >50–100%, *more unlikely than likely* 0–<50%, *extremely unlikely* 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*. See for more details: Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L. Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.-K. Plattner, G.W. Yohe and F.W. Zwiers, 2010: Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties, Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland, 4 pp.

² Ranges in square brackets or following '±' are expected to have a 90% likelihood of including the value that is being estimated, unless otherwise stated.

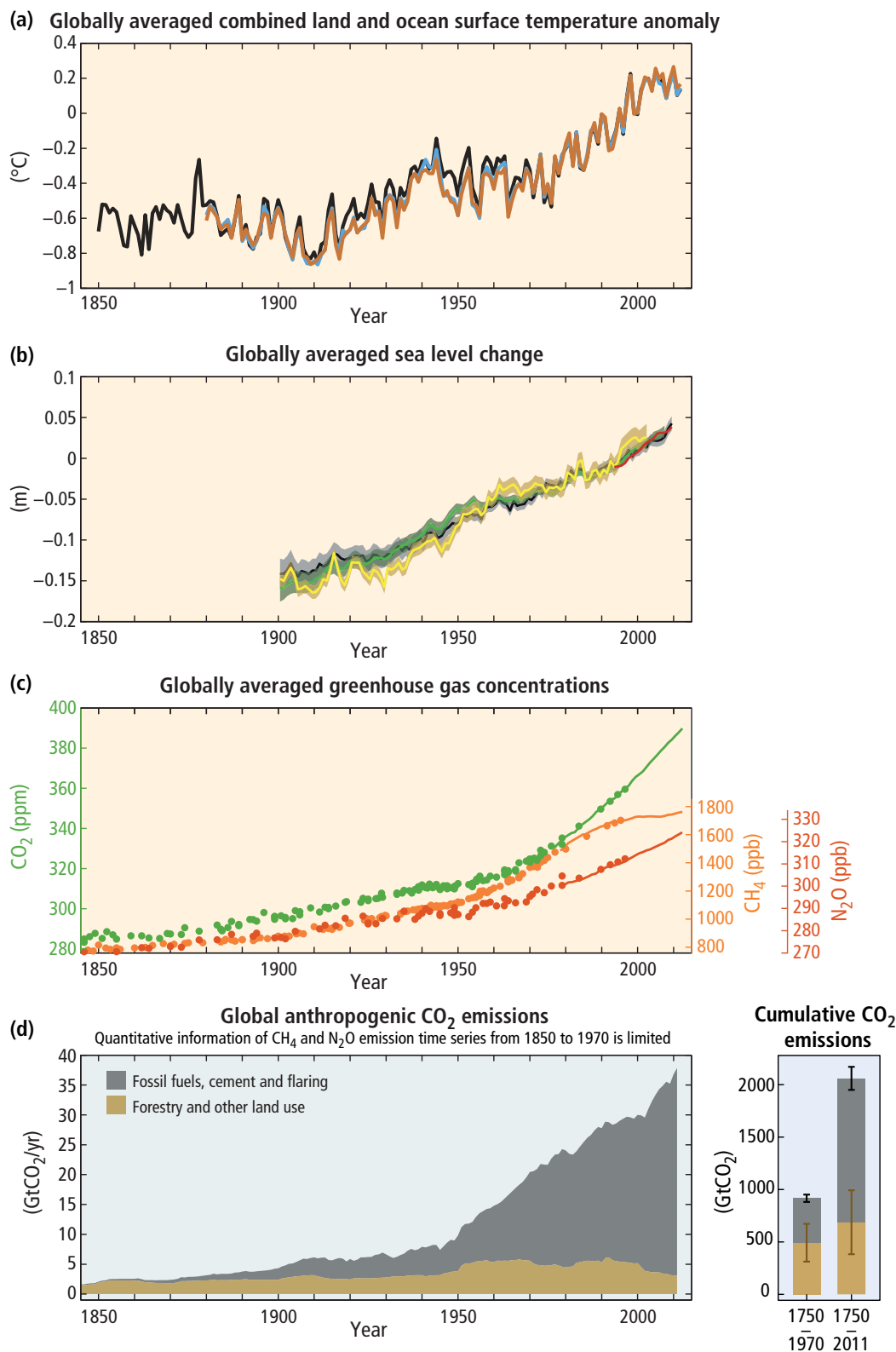


Figure SPM.1 | The complex relationship between the observations (panels a, b, c, yellow background) and the emissions (panel d, light blue background) is addressed in Section 1.2 and Topic 1. Observations and other indicators of a changing global climate system. Observations: **(a)** Annually and globally averaged combined land and ocean surface temperature anomalies relative to the average over the period 1886 to 2005. Colours indicate different data sets. **(b)** Annually and globally averaged sea level change relative to the average over the period 1886 to 2005 in the longest-running dataset. Colours indicate different data sets. All datasets are aligned to have the same value in 1993, the first year of satellite altimetry data (red). Where assessed, uncertainties are indicated by coloured shading. **(c)** Atmospheric concentrations of the greenhouse gases carbon dioxide (CO₂, green), methane (CH₄, orange) and nitrous oxide (N₂O, red) determined from ice core data (dots) and from direct atmospheric measurements (lines). Indicators: **(d)** Global anthropogenic CO₂ emissions from forestry and other land use as well as from burning of fossil fuel, cement production and flaring. Cumulative emissions of CO₂ from these sources and their uncertainties are shown as bars and whiskers, respectively, on the right hand side. The global effects of the accumulation of CH₄ and N₂O emissions are shown in panel c. Greenhouse gas emission data from 1970 to 2010 are shown in Figure SPM.2. {Figures 1.1, 1.3, 1.5}

the past 15 years (1998–2012; 0.05 [–0.05 to 0.15] °C per decade), which begins with a strong El Niño, is smaller than the rate calculated since 1951 (1951–2012; 0.12 [0.08 to 0.14] °C per decade). {1.1.1, Box 1.1}

Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*), with only about 1% stored in the atmosphere. On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 [0.09 to 0.13] °C per decade over the period 1971 to 2010. It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010, and it *likely* warmed between the 1870s and 1971. {1.1.2, Figure 1.2}

Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (*medium confidence* before and *high confidence* after 1951). For other latitudes, area-averaged long-term positive or negative trends have *low confidence*. Observations of changes in ocean surface salinity also provide indirect evidence for changes in the global water cycle over the ocean (*medium confidence*). It is *very likely* that regions of high salinity, where evaporation dominates, have become more saline, while regions of low salinity, where precipitation dominates, have become fresher since the 1950s. {1.1.1, 1.1.2}

Since the beginning of the industrial era, oceanic uptake of CO₂ has resulted in acidification of the ocean; the pH of ocean surface water has decreased by 0.1 (*high confidence*), corresponding to a 26% increase in acidity, measured as hydrogen ion concentration. {1.1.2}

Over the period 1992 to 2011, the Greenland and Antarctic ice sheets have been losing mass (*high confidence*), *likely* at a larger rate over 2002 to 2011. Glaciers have continued to shrink almost worldwide (*high confidence*). Northern Hemisphere spring snow cover has continued to decrease in extent (*high confidence*). There is *high confidence* that permafrost temperatures have increased in most regions since the early 1980s in response to increased surface temperature and changing snow cover. {1.1.3}

The annual mean Arctic sea-ice extent decreased over the period 1979 to 2012, with a rate that was *very likely* in the range 3.5 to 4.1% per decade. Arctic sea-ice extent has decreased in every season and in every successive decade since 1979, with the most rapid decrease in decadal mean extent in summer (*high confidence*). It is *very likely* that the annual mean Antarctic sea-ice extent increased in the range of 1.2 to 1.8% per decade between 1979 and 2012. However, there is *high confidence* that there are strong regional differences in Antarctica, with extent increasing in some regions and decreasing in others. {1.1.3, Figure 1.1}

Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m (Figure SPM.1b). The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*). {1.1.4, Figure 1.1}

SPM 1.2 Causes of climate change

Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are *extremely likely* to have been the dominant cause of the observed warming since the mid-20th century. {1.2, 1.3.1}

Anthropogenic greenhouse gas (GHG) emissions since the pre-industrial era have driven large increases in the atmospheric concentrations of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) (Figure SPM.1c). Between 1750 and 2011, cumulative anthropogenic CO₂ emissions to the atmosphere were 2040 ± 310 GtCO₂. About 40% of these emissions have remained in the atmosphere (880 ± 35 GtCO₂); the rest was removed from the atmosphere and stored on land (in plants and soils) and in the ocean. The ocean has absorbed about 30% of the emitted anthropogenic CO₂, causing ocean acidification. About half of the anthropogenic CO₂ emissions between 1750 and 2011 have occurred in the last 40 years (*high confidence*) (Figure SPM.1d). {1.2.1, 1.2.2}

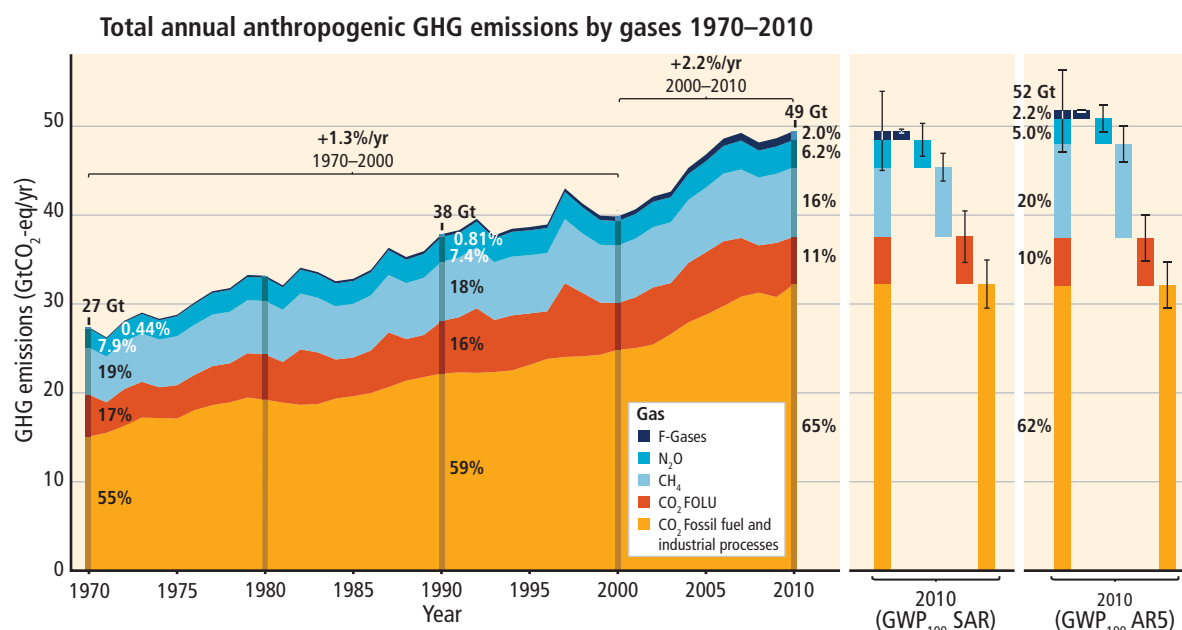


Figure SPM.2 | Total annual anthropogenic greenhouse gas (GHG) emissions (gigatonne of CO₂-equivalent per year, GtCO₂-eq/yr) for the period 1970 to 2010 by gases: CO₂ from fossil fuel combustion and industrial processes; CO₂ from Forestry and Other Land Use (FOLU); methane (CH₄); nitrous oxide (N₂O); fluorinated gases covered under the Kyoto Protocol (F-gases). Right hand side shows 2010 emissions, using alternatively CO₂-equivalent emission weightings based on IPCC Second Assessment Report (SAR) and AR5 values. Unless otherwise stated, CO₂-equivalent emissions in this report include the basket of Kyoto gases (CO₂, CH₄, N₂O as well as F-gases) calculated based on 100-year Global Warming Potential (GWP₁₀₀) values from the SAR (see Glossary). Using the most recent GWP₁₀₀ values from the AR5 (right-hand bars) would result in higher total annual GHG emissions (52 GtCO₂-eq/yr) from an increased contribution of methane, but does not change the long-term trend significantly. {Figure 1.6, Box 3.2}

Total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute increases between 2000 and 2010, despite a growing number of climate change mitigation policies. Anthropogenic GHG emissions in 2010 have reached 49 ± 4.5 GtCO₂-eq/yr³. Emissions of CO₂ from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emissions increase from 1970 to 2010, with a similar percentage contribution for the increase during the period 2000 to 2010 (*high confidence*) (Figure SPM.2). Globally, economic and population growth continued to be the most important drivers of increases in CO₂ emissions from fossil fuel combustion. The contribution of population growth between 2000 and 2010 remained roughly identical to the previous three decades, while the contribution of economic growth has risen sharply. Increased use of coal has reversed the long-standing trend of gradual decarbonization (i.e., reducing the carbon intensity of energy) of the world's energy supply (*high confidence*). {1.2.2}

The evidence for human influence on the climate system has grown since the IPCC Fourth Assessment Report (AR4). It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period (Figure SPM.3). Anthropogenic forcings have *likely* made a substantial contribution to surface temperature increases since the mid-20th century over every continental region except Antarctica⁴. Anthropogenic influences have *likely* affected the global water cycle since 1960 and contributed to the retreat of glaciers since the 1960s and to the increased surface melting of the Greenland ice sheet since 1993. Anthropogenic influences have *very likely* contributed to Arctic sea-ice loss since 1979 and have *very likely* made a substantial contribution to increases in global upper ocean heat content (0–700 m) and to global mean sea level rise observed since the 1970s. {1.3, Figure 1.10}

³ Greenhouse gas emissions are quantified as CO₂-equivalent (GtCO₂-eq) emissions using weightings based on the 100-year Global Warming Potentials, using IPCC Second Assessment Report values unless otherwise stated. {Box 3.2}

⁴ For Antarctica, large observational uncertainties result in *low confidence* that anthropogenic forcings have contributed to the observed warming averaged over available stations.

Contributions to observed surface temperature change over the period 1951–2010

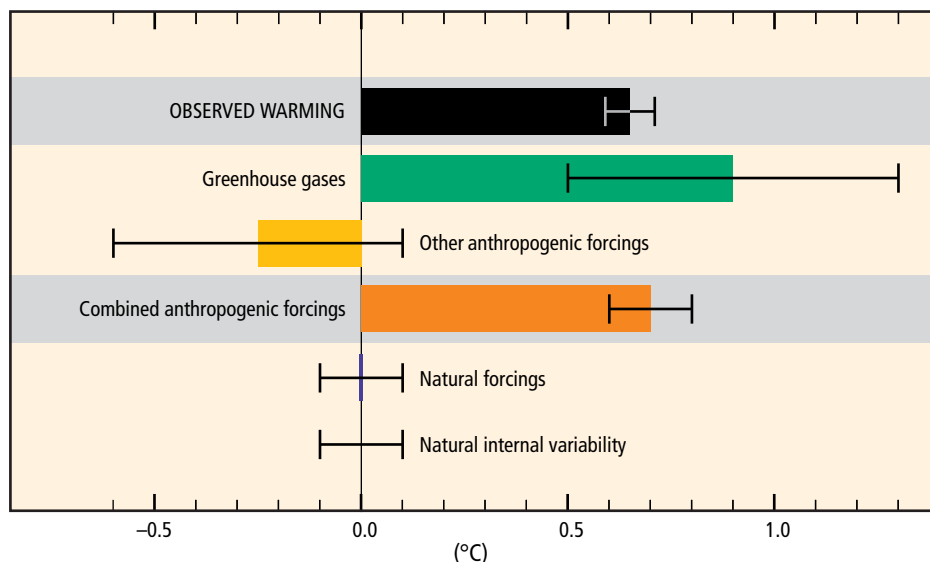


Figure SPM.3 | Assessed *likely* ranges (whiskers) and their mid-points (bars) for warming trends over the 1951–2010 period from well-mixed greenhouse gases, other anthropogenic forcings (including the cooling effect of aerosols and the effect of land use change), combined anthropogenic forcings, natural forcings and natural internal climate variability (which is the element of climate variability that arises spontaneously within the climate system even in the absence of forcings). The observed surface temperature change is shown in black, with the 5 to 95% uncertainty range due to observational uncertainty. The attributed warming ranges (colours) are based on observations combined with climate model simulations, in order to estimate the contribution of an individual external forcing to the observed warming. The contribution from the combined anthropogenic forcings can be estimated with less uncertainty than the contributions from greenhouse gases and from other anthropogenic forcings separately. This is because these two contributions partially compensate, resulting in a combined signal that is better constrained by observations. [Figure 1.9]

SPM 1.3 Impacts of climate change

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate.
{1.3.2}

Evidence of observed climate change impacts is strongest and most comprehensive for natural systems. In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality (*medium confidence*). Many terrestrial, freshwater and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances and species interactions in response to ongoing climate change (*high confidence*). Some impacts on human systems have also been attributed to climate change, with a major or minor contribution of climate change distinguishable from other influences (Figure SPM.4). Assessment of many studies covering a wide range of regions and crops shows that negative impacts of climate change on crop yields have been more common than positive impacts (*high confidence*). Some impacts of ocean acidification on marine organisms have been attributed to human influence (*medium confidence*). {1.3.2}

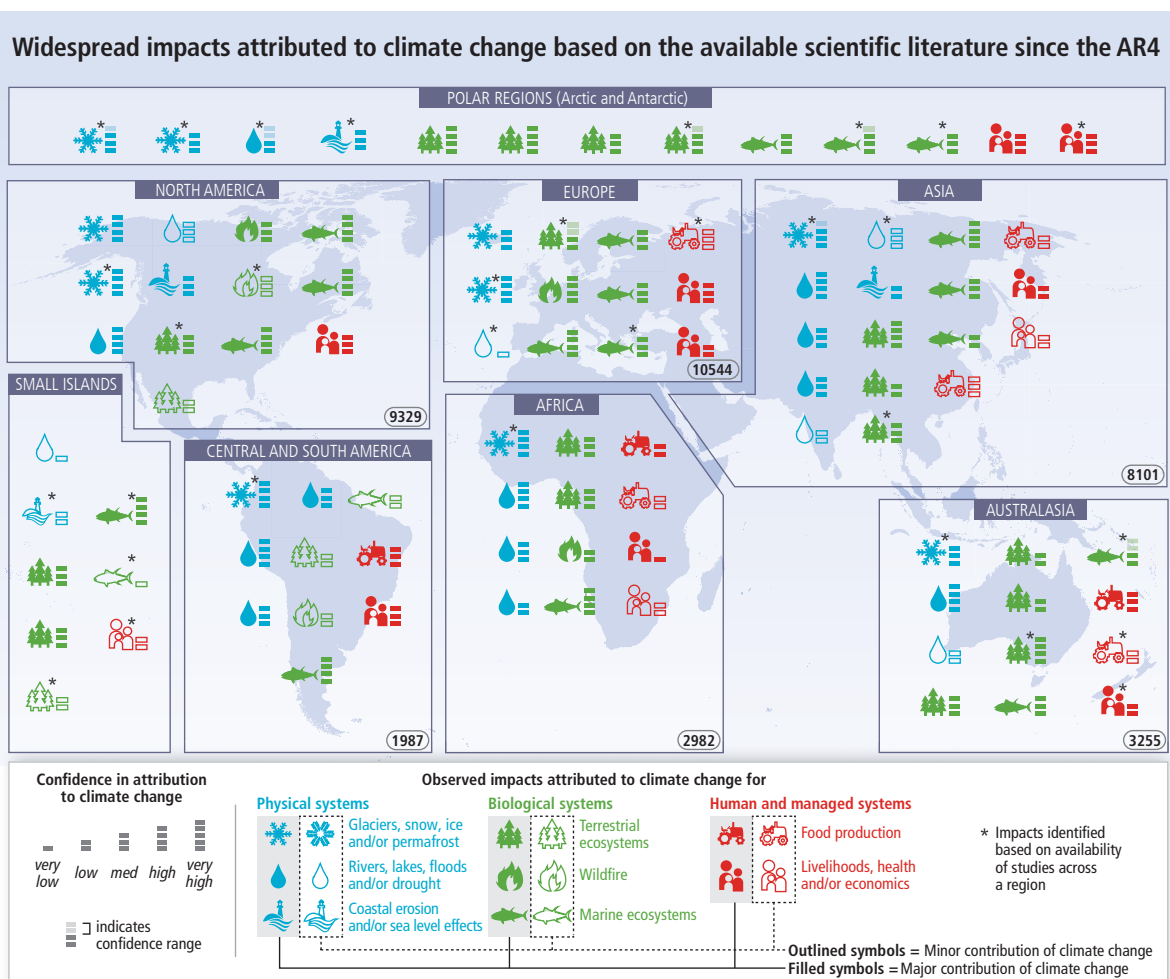


Figure SPM.4 | Based on the available scientific literature since the IPCC Fourth Assessment Report (AR4), there are substantially more impacts in recent decades now attributed to climate change. Attribution requires defined scientific evidence on the role of climate change. Absence from the map of additional impacts attributed to climate change does not imply that such impacts have not occurred. The publications supporting attributed impacts reflect a growing knowledge base, but publications are still limited for many regions, systems and processes, highlighting gaps in data and studies. Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact and confidence in attribution. Each symbol refers to one or more entries in WGII Table SPM.A1, grouping related regional-scale impacts. Numbers in ovals indicate regional totals of climate change publications from 2001 to 2010, based on the Scopus bibliographic database for publications in English with individual countries mentioned in title, abstract or key words (as of July 2011). These numbers provide an overall measure of the available scientific literature on climate change across regions; they do not indicate the number of publications supporting attribution of climate change impacts in each region. Studies for polar regions and small islands are grouped with neighbouring continental regions. The inclusion of publications for assessment of attribution followed IPCC scientific evidence criteria defined in WGII Chapter 18. Publications considered in the attribution analyses come from a broader range of literature assessed in the WGII AR5. See WGII Table SPM.A1 for descriptions of the attributed impacts. [Figure 1.11]

SPM 1.4 Extreme events

Changes in many extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events in a number of regions. {1.4}

It is *very likely* that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is *likely* that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. It is

very likely that human influence has contributed to the observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century. It is *likely* that human influence has more than doubled the probability of occurrence of heat waves in some locations. There is *medium confidence* that the observed warming has increased heat-related human mortality and decreased cold-related human mortality in some regions. {1.4}

There are *likely* more land regions where the number of heavy precipitation events has increased than where it has decreased. Recent detection of increasing trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at regional scale (*medium confidence*). It is *likely* that extreme sea levels (for example, as experienced in storm surges) have increased since 1970, being mainly a result of rising mean sea level. {1.4}

Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability (*very high confidence*). {1.4}

SPM 2. Future Climate Changes, Risks and Impacts

Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks. {2}

SPM 2.1 Key drivers of future climate

Cumulative emissions of CO₂ largely determine global mean surface warming by the late 21st century and beyond. Projections of greenhouse gas emissions vary over a wide range, depending on both socio-economic development and climate policy. {2.1}

Anthropogenic GHG emissions are mainly driven by population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy. The Representative Concentration Pathways (RCPs), which are used for making projections based on these factors, describe four different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). Scenarios without additional efforts to constrain emissions ('baseline scenarios') lead to pathways ranging between RCP6.0 and RCP8.5 (Figure SPM.5a). RCP2.6 is representative of a scenario that aims to keep global warming *likely* below 2°C above pre-industrial temperatures. The RCPs are consistent with the wide range of scenarios in the literature as assessed by WGIII⁵. {2.1, Box 2.2, 4.3}

Multiple lines of evidence indicate a strong, consistent, almost linear relationship between cumulative CO₂ emissions and projected global temperature change to the year 2100 in both the RCPs and the wider set of mitigation scenarios analysed in WGIII (Figure SPM.5b). Any given level of warming is associated with a range of cumulative CO₂ emissions⁶, and therefore, e.g., higher emissions in earlier decades imply lower emissions later. {2.2.5, Table 2.2}

⁵ Roughly 300 baseline scenarios and 900 mitigation scenarios are categorized by CO₂-equivalent concentration (CO₂-eq) by 2100. The CO₂-eq includes the forcing due to all GHGs (including halogenated gases and tropospheric ozone), aerosols and albedo change.

⁶ Quantification of this range of CO₂ emissions requires taking into account non-CO₂ drivers.

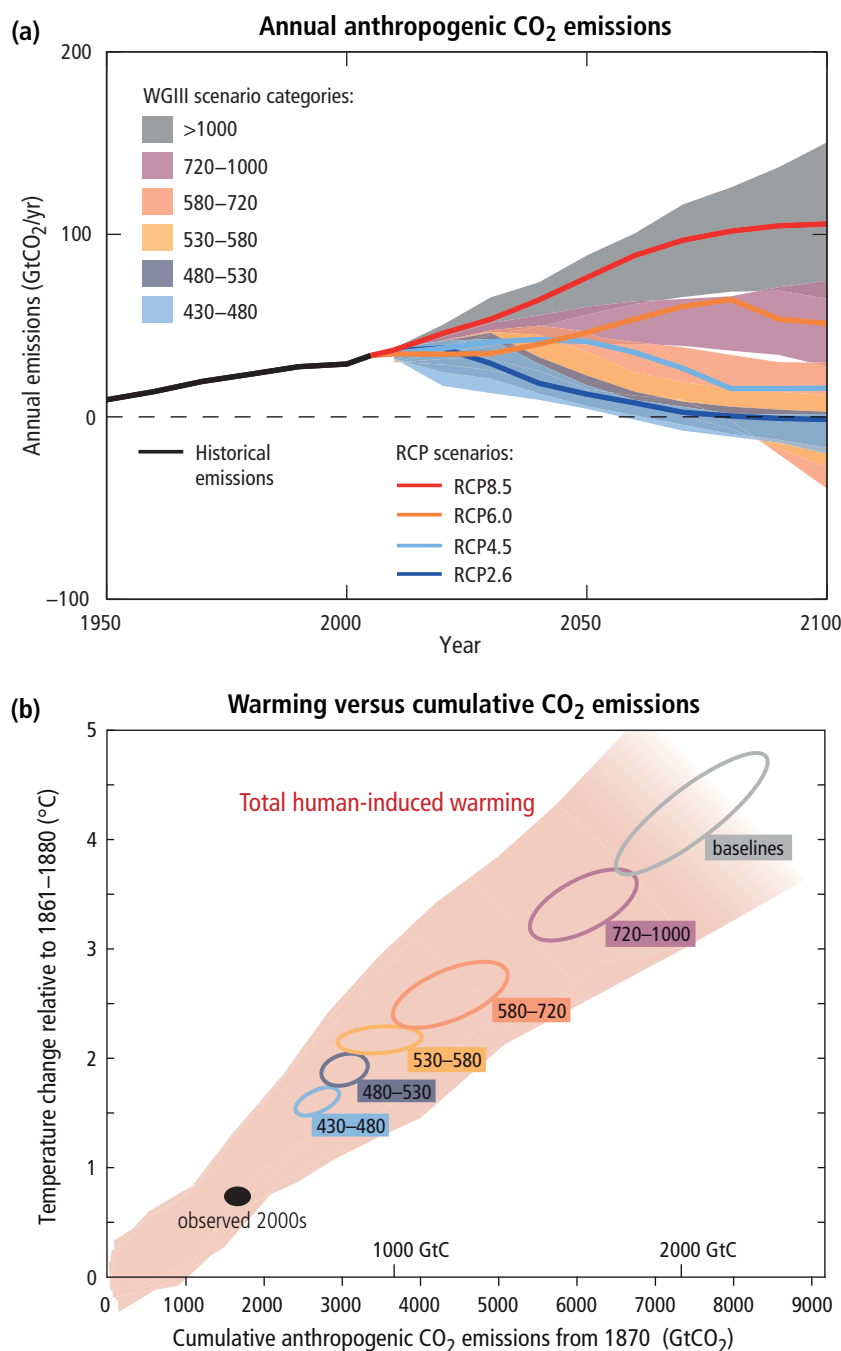


Figure SPM.5 | (a) Emissions of carbon dioxide (CO₂) alone in the Representative Concentration Pathways (RCPs) (lines) and the associated scenario categories used in WGIII (coloured areas show 5 to 95% range). The WGIII scenario categories summarize the wide range of emission scenarios published in the scientific literature and are defined on the basis of CO₂-eq concentration levels (in ppm) in 2100. The time series of other greenhouse gas emissions are shown in Box 2.2, Figure 1. **(b)** Global mean surface temperature increase at the time global CO₂ emissions reach a given net cumulative total, plotted as a function of that total, from various lines of evidence. Coloured plume shows the spread of past and future projections from a hierarchy of climate-carbon cycle models driven by historical emissions and the four RCPs over all times out to 2100, and fades with the decreasing number of available models. Ellipses show total anthropogenic warming in 2100 versus cumulative CO₂ emissions from 1870 to 2100 from a simple climate model (median climate response) under the scenario categories used in WGIII. The width of the ellipses in terms of temperature is caused by the impact of different scenarios for non-CO₂ climate drivers. The filled black ellipse shows observed emissions to 2005 and observed temperatures in the decade 2000–2009 with associated uncertainties. [Box 2.2, Figure 1; Figure 2.3]

Multi-model results show that limiting total human-induced warming to less than 2°C relative to the period 1861–1880 with a probability of >66%⁷ would require cumulative CO₂ emissions from all anthropogenic sources since 1870 to remain below about 2900 GtCO₂ (with a range of 2550 to 3150 GtCO₂ depending on non-CO₂ drivers). About 1900 GtCO₂⁸ had already been emitted by 2011. For additional context see Table 2.2. {2.2.5}

SPM 2.2 Projected changes in the climate system

Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is *very likely* that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise. {2.2}

The projected changes in Section SPM 2.2 are for 2081–2100 relative to 1986–2005, unless otherwise indicated.

Future climate will depend on committed warming caused by past anthropogenic emissions, as well as future anthropogenic emissions and natural climate variability. The global mean surface temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four RCPs and will *likely* be in the range 0.3°C to 0.7°C (*medium confidence*). This assumes that there will be no major volcanic eruptions or changes in some natural sources (e.g., CH₄ and N₂O), or unexpected changes in total solar irradiance. By mid-21st century, the magnitude of the projected climate change is substantially affected by the choice of emissions scenario. {2.2.1, Table 2.1}

Relative to 1850–1900, global surface temperature change for the end of the 21st century (2081–2100) is projected to *likely* exceed 1.5°C for RCP4.5, RCP6.0 and RCP8.5 (*high confidence*). Warming is *likely* to exceed 2°C for RCP6.0 and RCP8.5 (*high confidence*), *more likely than not* to exceed 2°C for RCP4.5 (*medium confidence*), but *unlikely* to exceed 2°C for RCP2.6 (*medium confidence*). {2.2.1}

The increase of global mean surface temperature by the end of the 21st century (2081–2100) relative to 1986–2005 is *likely* to be 0.3°C to 1.7°C under RCP2.6, 1.1°C to 2.6°C under RCP4.5, 1.4°C to 3.1°C under RCP6.0 and 2.6°C to 4.8°C under RCP8.5⁹. The Arctic region will continue to warm more rapidly than the global mean (Figure SPM.6a, Figure SPM.7a). {2.2.1, Figure 2.1, Figure 2.2, Table 2.1}

It is *virtually certain* that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases. It is *very likely* that heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur. {2.2.1}

⁷ Corresponding figures for limiting warming to 2°C with a probability of >50% and >33% are 3000 GtCO₂ (range of 2900 to 3200 GtCO₂) and 3300 GtCO₂ (range of 2950 to 3800 GtCO₂) respectively. Higher or lower temperature limits would imply larger or lower cumulative emissions respectively.

⁸ This corresponds to about two thirds of the 2900 GtCO₂ that would limit warming to less than 2°C with a probability of >66%; to about 63% of the total amount of 3000 GtCO₂ that would limit warming to less than 2°C with a probability of >50%; and to about 58% of the total amount of 3300 GtCO₂ that would limit warming to less than 2°C with a probability of >33%.

⁹ The period 1986–2005 is approximately 0.61 [0.55 to 0.67] °C warmer than 1850–1900. {2.2.1}

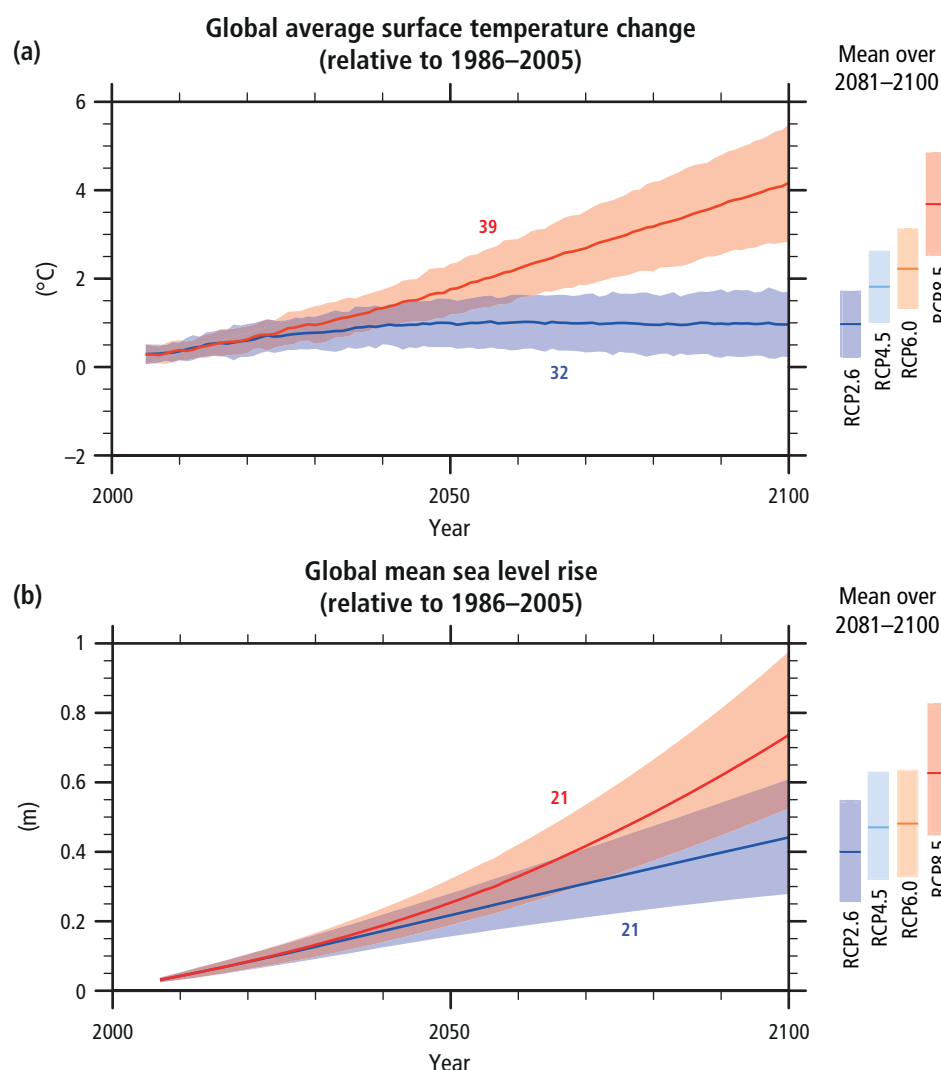


Figure SPM.6 | Global average surface temperature change **(a)** and global mean sea level rise¹⁰ **(b)** from 2006 to 2100 as determined by multi-model simulations. All changes are relative to 1986–2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). The mean and associated uncertainties averaged over 2081–2100 are given for all RCP scenarios as coloured vertical bars at the right hand side of each panel. The number of Coupled Model Intercomparison Project Phase 5 (CMIP5) models used to calculate the multi-model mean is indicated. {2.2, Figure 2.1}

Changes in precipitation will not be uniform. The high latitudes and the equatorial Pacific are *likely* to experience an increase in annual mean precipitation under the RCP8.5 scenario. In many mid-latitude and subtropical dry regions, mean precipitation will *likely* decrease, while in many mid-latitude wet regions, mean precipitation will *likely* increase under the RCP8.5 scenario (Figure SPM.7b). Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will *very likely* become more intense and more frequent. {2.2.2, Figure 2.2}

The global ocean will continue to warm during the 21st century, with the strongest warming projected for the surface in tropical and Northern Hemisphere subtropical regions (Figure SPM.7a). {2.2.3, Figure 2.2}

¹⁰ Based on current understanding (from observations, physical understanding and modelling), only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. There is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century.

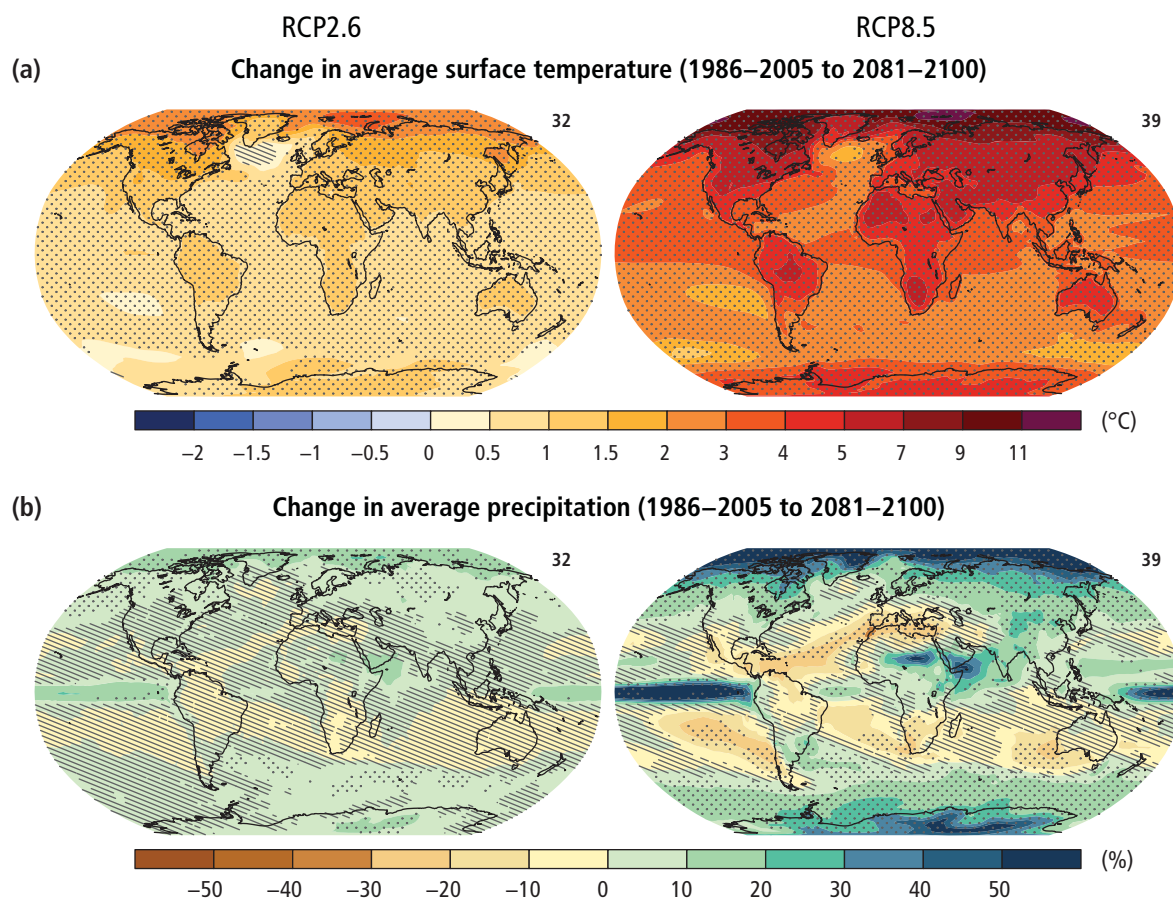


Figure SPM.7 | Change in average surface temperature **(a)** and change in average precipitation **(b)** based on multi-model mean projections for 2081–2100 relative to 1986–2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios. The number of models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Stippling (i.e., dots) shows regions where the projected change is large compared to natural internal variability and where at least 90% of models agree on the sign of change. Hatching (i.e., diagonal lines) shows regions where the projected change is less than one standard deviation of the natural internal variability. {2.2, Figure 2.2}

Earth System Models project a global increase in ocean acidification for all RCP scenarios by the end of the 21st century, with a slow recovery after mid-century under RCP2.6. The decrease in surface ocean pH is in the range of 0.06 to 0.07 (15 to 17% increase in acidity) for RCP2.6, 0.14 to 0.15 (38 to 41%) for RCP4.5, 0.20 to 0.21 (58 to 62%) for RCP6.0 and 0.30 to 0.32 (100 to 109%) for RCP8.5. {2.2.4, Figure 2.1}

Year-round reductions in Arctic sea ice are projected for all RCP scenarios. A nearly ice-free¹¹ Arctic Ocean in the summer sea-ice minimum in September before mid-century is *likely* for RCP8.5¹² (*medium confidence*). {2.2.3, Figure 2.1}

It is *virtually certain* that near-surface permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases, with the area of permafrost near the surface (upper 3.5 m) projected to decrease by 37% (RCP2.6) to 81% (RCP8.5) for the multi-model average (*medium confidence*). {2.2.3}

The global glacier volume, excluding glaciers on the periphery of Antarctica (and excluding the Greenland and Antarctic ice sheets), is projected to decrease by 15 to 55% for RCP2.6 and by 35 to 85% for RCP8.5 (*medium confidence*). {2.2.3}

¹¹ When sea-ice extent is less than one million km² for at least five consecutive years.

¹² Based on an assessment of the subset of models that most closely reproduce the climatological mean state and 1979–2012 trend of the Arctic sea-ice extent.

There has been significant improvement in understanding and projection of sea level change since the AR4. Global mean sea level rise will continue during the 21st century, *very likely* at a faster rate than observed from 1971 to 2010. For the period 2081–2100 relative to 1986–2005, the rise will *likely* be in the ranges of 0.26 to 0.55 m for RCP2.6, and of 0.45 to 0.82 m for RCP8.5 (*medium confidence*)¹⁰ (Figure SPM.6b). Sea level rise will not be uniform across regions. By the end of the 21st century, it is *very likely* that sea level will rise in more than about 95% of the ocean area. About 70% of the coastlines worldwide are projected to experience a sea level change within $\pm 20\%$ of the global mean. {2.2.3}

SPM 2.3 Future risks and impacts caused by a changing climate

Climate change will amplify existing risks and create new risks for natural and human systems. Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development. {2.3}

Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems, including their ability to adapt. Rising rates and magnitudes of warming and other changes in the climate system, accompanied by ocean acidification, increase the risk of severe, pervasive and in some cases irreversible detrimental impacts. Some risks are particularly relevant for individual regions (Figure SPM.8), while others are global. The overall risks of future climate change impacts can be reduced by limiting the rate and magnitude of climate change, including ocean acidification. The precise levels of climate change sufficient to trigger abrupt and irreversible change remain uncertain, but the risk associated with crossing such thresholds increases with rising temperature (*medium confidence*). For risk assessment, it is important to evaluate the widest possible range of impacts, including low-probability outcomes with large consequences. {1.5, 2.3, 2.4, 3.3, Box Introduction.1, Box 2.3, Box 2.4}

A large fraction of species faces increased extinction risk due to climate change during and beyond the 21st century, especially as climate change interacts with other stressors (*high confidence*). Most plant species cannot naturally shift their geographical ranges sufficiently fast to keep up with current and high projected rates of climate change in most landscapes; most small mammals and freshwater molluscs will not be able to keep up at the rates projected under RCP4.5 and above in flat landscapes in this century (*high confidence*). Future risk is indicated to be high by the observation that natural global climate change at rates lower than current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years. Marine organisms will face progressively lower oxygen levels and high rates and magnitudes of ocean acidification (*high confidence*), with associated risks exacerbated by rising ocean temperature extremes (*medium confidence*). Coral reefs and polar ecosystems are highly vulnerable. Coastal systems and low-lying areas are at risk from sea level rise, which will continue for centuries even if the global mean temperature is stabilized (*high confidence*). {2.3, 2.4, Figure 2.5}

Climate change is projected to undermine food security (Figure SPM.9). Due to projected climate change by the mid-21st century and beyond, global marine species redistribution and marine biodiversity reduction in sensitive regions will challenge the sustained provision of fisheries productivity and other ecosystem services (*high confidence*). For wheat, rice and maize in tropical and temperate regions, climate change without adaptation is projected to negatively impact production for local temperature increases of 2°C or more above late 20th century levels, although individual locations may benefit (*medium confidence*). Global temperature increases of ~4°C or more¹³ above late 20th century levels, combined with increasing food demand, would pose large risks to food security globally (*high confidence*). Climate change is projected to reduce renewable surface water and groundwater resources in most dry subtropical regions (*robust evidence, high agreement*), intensifying competition for water among sectors (*limited evidence, medium agreement*). {2.3.1, 2.3.2}

¹³ Projected warming averaged over land is larger than global average warming for all RCP scenarios for the period 2081–2100 relative to 1986–2005. For regional projections, see Figure SPM.7. {2.2}

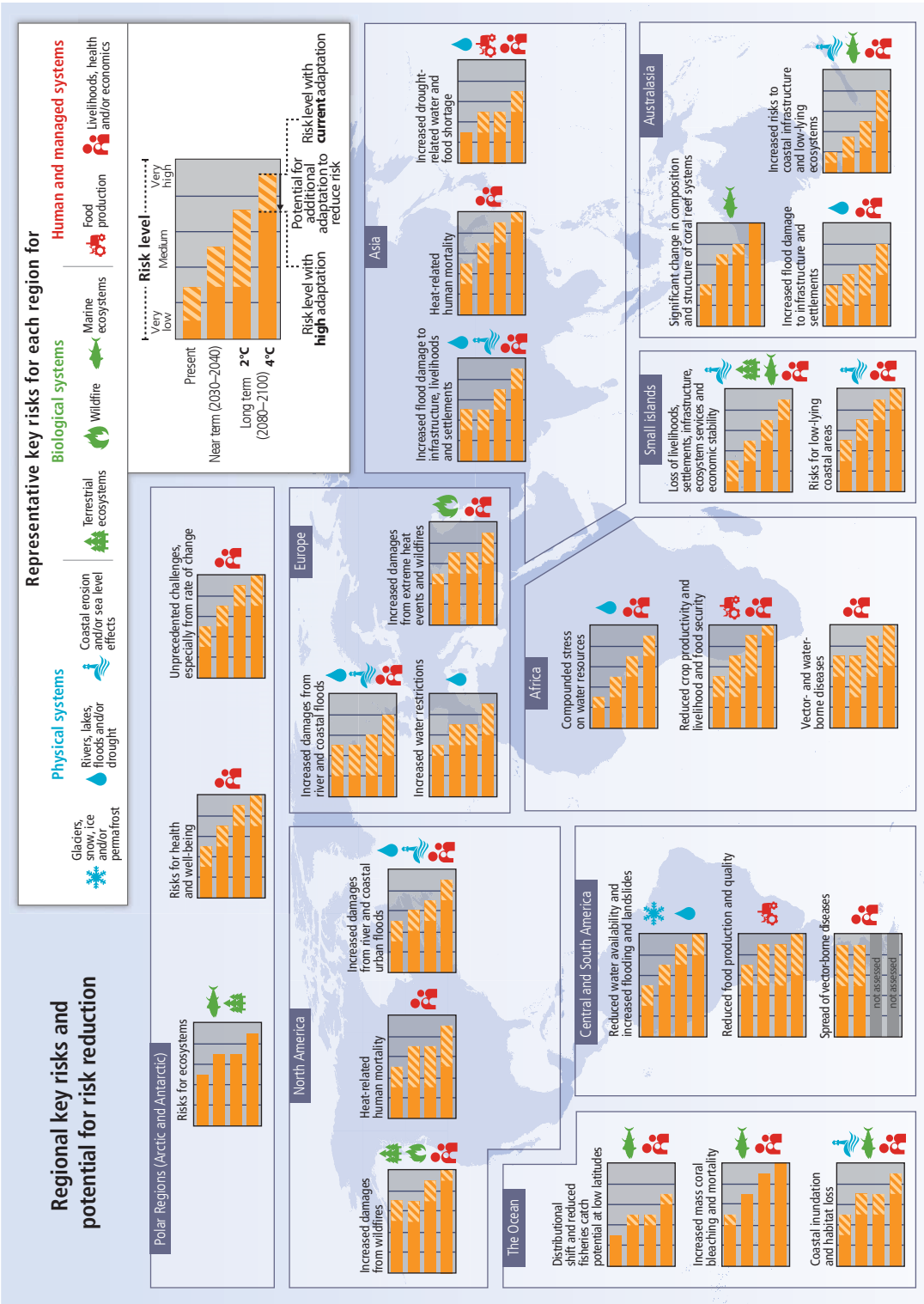


Figure SPM.8 | Representative key risks¹⁴ for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation. Each key risk is assessed as very low, low, medium, high or very high. Risk levels are presented for three time frames: present, near term (here, for 2030–2040) and long term (here, for 2080–2100). In the near term, projected levels of global mean temperature increase do not diverge substantially across different emission scenarios. For the long term, risk levels are presented for two possible futures (2°C and 4°C global mean temperature increase above pre-industrial levels). For each timeframe, risk levels are indicated for a continuation of current adaptation and assuming high levels of current or future adaptation. Risk levels are not necessarily comparable, especially across regions. (Figure 2.4)

¹⁴ Identification of key risks was based on expert judgment using the following specific criteria: large magnitude, high probability or irreversibility of impacts; timing of impacts; persistent vulnerability or exposure contributing to risks; or limited potential to reduce risks through adaptation or mitigation.

Climate change poses risks for food production

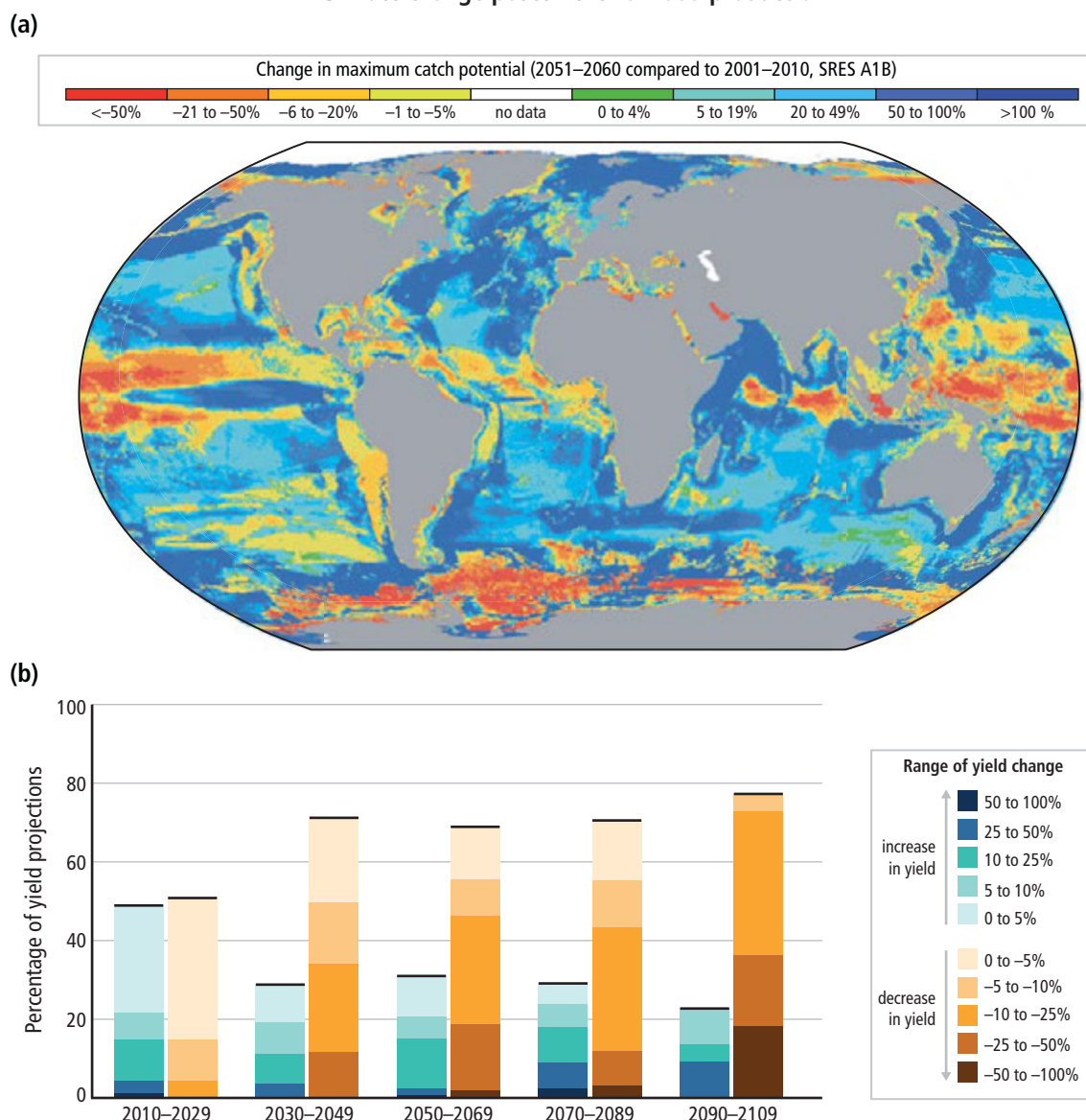


Figure SPM.9 | (a) Projected global redistribution of maximum catch potential of ~1000 exploited marine fish and invertebrate species. Projections compare the 10-year averages 2001–2010 and 2051–2060 using ocean conditions based on a single climate model under a moderate to high warming scenario, without analysis of potential impacts of overfishing or ocean acidification. **(b)** Summary of projected changes in crop yields (mostly wheat, maize, rice and soy), due to climate change over the 21st century. Data for each timeframe sum to 100%, indicating the percentage of projections showing yield increases versus decreases. The figure includes projections (based on 1090 data points) for different emission scenarios, for tropical and temperate regions and for adaptation and no-adaptation cases combined. Changes in crop yields are relative to late 20th century levels. {Figure 2.6a, Figure 2.7}

Until mid-century, projected climate change will impact human health mainly by exacerbating health problems that already exist (*very high confidence*). Throughout the 21st century, climate change is expected to lead to increases in ill-health in many regions and especially in developing countries with low income, as compared to a baseline without climate change (*high confidence*). By 2100 for RCP8.5, the combination of high temperature and humidity in some areas for parts of the year is expected to compromise common human activities, including growing food and working outdoors (*high confidence*). {2.3.2}

In urban areas climate change is projected to increase risks for people, assets, economies and ecosystems, including risks from heat stress, storms and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea level rise and storm surges (*very high confidence*). These risks are amplified for those lacking essential infrastructure and services or living in exposed areas. {2.3.2}

Rural areas are expected to experience major impacts on water availability and supply, food security, infrastructure and agricultural incomes, including shifts in the production areas of food and non-food crops around the world (*high confidence*). {2.3.2}

Aggregate economic losses accelerate with increasing temperature (*limited evidence, high agreement*), but global economic impacts from climate change are currently difficult to estimate. From a poverty perspective, climate change impacts are projected to slow down economic growth, make poverty reduction more difficult, further erode food security and prolong existing and create new poverty traps, the latter particularly in urban areas and emerging hotspots of hunger (*medium confidence*). International dimensions such as trade and relations among states are also important for understanding the risks of climate change at regional scales. {2.3.2}

Climate change is projected to increase displacement of people (*medium evidence, high agreement*). Populations that lack the resources for planned migration experience higher exposure to extreme weather events, particularly in developing countries with low income. Climate change can indirectly increase risks of violent conflicts by amplifying well-documented drivers of these conflicts such as poverty and economic shocks (*medium confidence*). {2.3.2}

SPM 2.4 Climate change beyond 2100, irreversibility and abrupt changes

Many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. The risks of abrupt or irreversible changes increase as the magnitude of the warming increases. {2.4}

Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO₂ emissions. A large fraction of anthropogenic climate change resulting from CO₂ emissions is irreversible on a multi-century to millennial timescale, except in the case of a large net removal of CO₂ from the atmosphere over a sustained period. {2.4, Figure 2.8}

Stabilization of global average surface temperature does not imply stabilization for all aspects of the climate system. Shifting biomes, soil carbon, ice sheets, ocean temperatures and associated sea level rise all have their own intrinsic long timescales which will result in changes lasting hundreds to thousands of years after global surface temperature is stabilized. {2.1, 2.4}

There is *high confidence* that ocean acidification will increase for centuries if CO₂ emissions continue, and will strongly affect marine ecosystems. {2.4}

It is *virtually certain* that global mean sea level rise will continue for many centuries beyond 2100, with the amount of rise dependent on future emissions. The threshold for the loss of the Greenland ice sheet over a millennium or more, and an associated sea level rise of up to 7 m, is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) of global warming with respect to pre-industrial temperatures. Abrupt and irreversible ice loss from the Antarctic ice sheet is possible, but current evidence and understanding is insufficient to make a quantitative assessment. {2.4}

Magnitudes and rates of climate change associated with medium- to high-emission scenarios pose an increased risk of abrupt and irreversible regional-scale change in the composition, structure and function of marine, terrestrial and freshwater ecosystems, including wetlands (*medium confidence*). A reduction in permafrost extent is *virtually certain* with continued rise in global temperatures. {2.4}

SPM 3. Future Pathways for Adaptation, Mitigation and Sustainable Development

Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to climate-resilient pathways for sustainable development. {3.2, 3.3, 3.4}

SPM 3.1 Foundations of decision-making about climate change

Effective decision-making to limit climate change and its effects can be informed by a wide range of analytical approaches for evaluating expected risks and benefits, recognizing the importance of governance, ethical dimensions, equity, value judgments, economic assessments and diverse perceptions and responses to risk and uncertainty. {3.1}

Sustainable development and equity provide a basis for assessing climate policies. Limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication. Countries' past and future contributions to the accumulation of GHGs in the atmosphere are different, and countries also face varying challenges and circumstances and have different capacities to address mitigation and adaptation. Mitigation and adaptation raise issues of equity, justice and fairness. Many of those most vulnerable to climate change have contributed and contribute little to GHG emissions. Delaying mitigation shifts burdens from the present to the future, and insufficient adaptation responses to emerging impacts are already eroding the basis for sustainable development. Comprehensive strategies in response to climate change that are consistent with sustainable development take into account the co-benefits, adverse side effects and risks that may arise from both adaptation and mitigation options. {3.1, 3.5, Box 3.4}

The design of climate policy is influenced by how individuals and organizations perceive risks and uncertainties and take them into account. Methods of valuation from economic, social and ethical analysis are available to assist decision-making. These methods can take account of a wide range of possible impacts, including low-probability outcomes with large consequences. But they cannot identify a single best balance between mitigation, adaptation and residual climate impacts. {3.1}

Climate change has the characteristics of a collective action problem at the global scale, because most GHGs accumulate over time and mix globally, and emissions by any agent (e.g., individual, community, company, country) affect other agents. Effective mitigation will not be achieved if individual agents advance their own interests independently. Cooperative responses, including international cooperation, are therefore required to effectively mitigate GHG emissions and address other climate change issues. The effectiveness of adaptation can be enhanced through complementary actions across levels, including international cooperation. The evidence suggests that outcomes seen as equitable can lead to more effective cooperation. {3.1}

SPM 3.2 Climate change risks reduced by mitigation and adaptation

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*). Mitigation involves some level of co-benefits and of risks due to adverse side effects, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change, increasing the benefits from near-term mitigation efforts. {3.2, 3.4}

Mitigation and adaptation are complementary approaches for reducing risks of climate change impacts over different time-scales (*high confidence*). Mitigation, in the near term and through the century, can substantially reduce climate change

impacts in the latter decades of the 21st century and beyond. Benefits from adaptation can already be realized in addressing current risks, and can be realized in the future for addressing emerging risks. {3.2, 4.5}

Five Reasons For Concern (RFCs) aggregate climate change risks and illustrate the implications of warming and of adaptation limits for people, economies and ecosystems across sectors and regions. The five RFCs are associated with: (1) Unique and threatened systems, (2) Extreme weather events, (3) Distribution of impacts, (4) Global aggregate impacts, and (5) Large-scale singular events. In this report, the RFCs provide information relevant to Article 2 of UNFCCC. {Box 2.4}

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*) (Figure SPM.10). In most scenarios without additional mitigation efforts (those with 2100 atmospheric concentrations

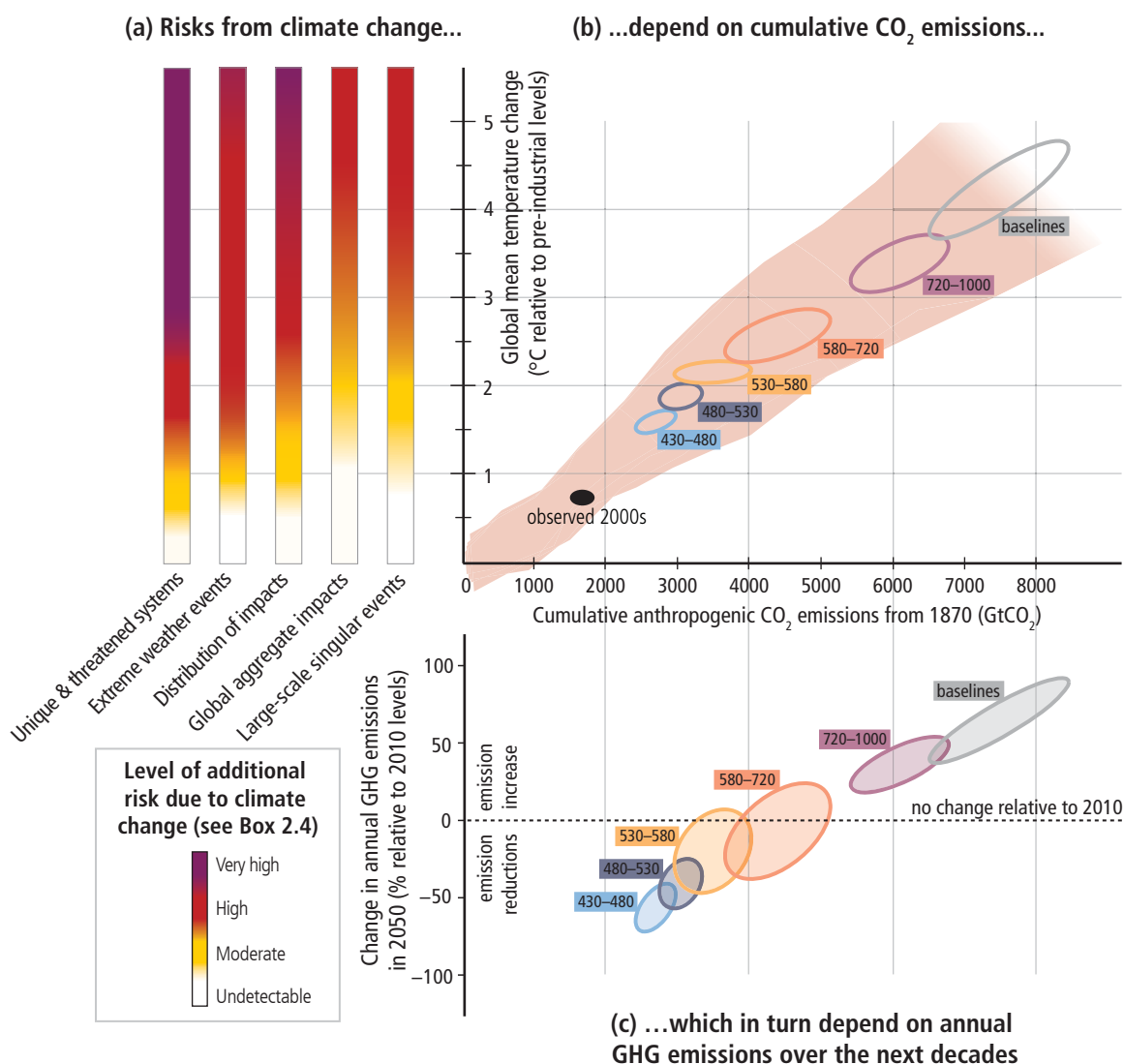


Figure SPM.10 | The relationship between risks from climate change, temperature change, cumulative carbon dioxide (CO₂) emissions and changes in annual greenhouse gas (GHG) emissions by 2050. Limiting risks across Reasons For Concern **(a)** would imply a limit for cumulative emissions of CO₂, **(b)** which would constrain annual GHG emissions over the next few decades **(c)**. **Panel a** reproduces the five Reasons For Concern {Box 2.4}. **Panel b** links temperature changes to cumulative CO₂ emissions (in GtCO₂) from 1870. They are based on Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations (pink plume) and on a simple climate model (median climate response in 2100), for the baselines and five mitigation scenario categories (six ellipses). Details are provided in Figure SPM.5. **Panel c** shows the relationship between the cumulative CO₂ emissions (in GtCO₂) of the scenario categories and their associated change in annual GHG emissions by 2050, expressed in percentage change (in percent GtCO₂-eq per year) relative to 2010. The ellipses correspond to the same scenario categories as in Panel b, and are built with a similar method (see details in Figure SPM.5). {Figure 3.1}

>1000 ppm CO₂-eq), warming is *more likely than not* to exceed 4°C above pre-industrial levels by 2100 (Table SPM.1). The risks associated with temperatures at or above 4°C include substantial species extinction, global and regional food insecurity, consequential constraints on common human activities and limited potential for adaptation in some cases (*high confidence*). Some risks of climate change, such as risks to unique and threatened systems and risks associated with extreme weather events, are moderate to high at temperatures 1°C to 2°C above pre-industrial levels. {2.3, Figure 2.5, 3.2, 3.4, Box 2.4, Table SPM.1}

Substantial cuts in GHG emissions over the next few decades can substantially reduce risks of climate change by limiting warming in the second half of the 21st century and beyond. Cumulative emissions of CO₂ largely determine global mean surface warming by the late 21st century and beyond. Limiting risks across RFCs would imply a limit for cumulative emissions of CO₂. Such a limit would require that global net emissions of CO₂ eventually decrease to zero and would constrain annual emissions over the next few decades (Figure SPM.10) (*high confidence*). But some risks from climate damages are unavoidable, even with mitigation and adaptation. {2.2.5, 3.2, 3.4}

Mitigation involves some level of co-benefits and risks, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change. Inertia in the economic and climate system and the possibility of irreversible impacts from climate change increase the benefits from near-term mitigation efforts (*high confidence*). Delays in additional mitigation or constraints on technological options increase the longer-term mitigation costs to hold climate change risks at a given level (Table SPM.2). {3.2, 3.4}

SPM 3.3 Characteristics of adaptation pathways

Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, especially with greater magnitudes and rates of climate change. Taking a longer-term perspective, in the context of sustainable development, increases the likelihood that more immediate adaptation actions will also enhance future options and preparedness. {3.3}

Adaptation can contribute to the well-being of populations, the security of assets and the maintenance of ecosystem goods, functions and services now and in the future. Adaptation is place- and context-specific (*high confidence*). A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability (*high confidence*). Integration of adaptation into planning, including policy design, and decision-making can promote synergies with development and disaster risk reduction. Building adaptive capacity is crucial for effective selection and implementation of adaptation options (*robust evidence, high agreement*). {3.3}

Adaptation planning and implementation can be enhanced through complementary actions across levels, from individuals to governments (*high confidence*). National governments can coordinate adaptation efforts of local and sub-national governments, for example by protecting vulnerable groups, by supporting economic diversification and by providing information, policy and legal frameworks and financial support (*robust evidence, high agreement*). Local government and the private sector are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing (*medium evidence, high agreement*). {3.3}

Adaptation planning and implementation at all levels of governance are contingent on societal values, objectives and risk perceptions (*high confidence*). Recognition of diverse interests, circumstances, social-cultural contexts and expectations can benefit decision-making processes. Indigenous, local and traditional knowledge systems and practices, including indigenous peoples' holistic view of community and environment, are a major resource for adapting to climate change, but these have not been used consistently in existing adaptation efforts. Integrating such forms of knowledge with existing practices increases the effectiveness of adaptation. {3.3}

Constraints can interact to impede adaptation planning and implementation (*high confidence*). Common constraints on implementation arise from the following: limited financial and human resources; limited integration or coordination of governance; uncertainties about projected impacts; different perceptions of risks; competing values; absence of key adaptation leaders and advocates; and limited tools to monitor adaptation effectiveness. Another constraint includes insufficient research, monitoring, and observation and the finance to maintain them. {3.3}

Greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*). Limits to adaptation emerge from the interaction among climate change and biophysical and/or socio-economic constraints. Further, poor planning or implementation, overemphasizing short-term outcomes or failing to sufficiently anticipate consequences can result in maladaptation, increasing the vulnerability or exposure of the target group in the future or the vulnerability of other people, places or sectors (*medium evidence, high agreement*). Underestimating the complexity of adaptation as a social process can create unrealistic expectations about achieving intended adaptation outcomes. {3.3}

Significant co-benefits, synergies and trade-offs exist between mitigation and adaptation and among different adaptation responses; interactions occur both within and across regions (*very high confidence*). Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, particularly at the intersections among water, energy, land use and biodiversity, but tools to understand and manage these interactions remain limited. Examples of actions with co-benefits include (i) improved energy efficiency and cleaner energy sources, leading to reduced emissions of health-damaging, climate-altering air pollutants; (ii) reduced energy and water consumption in urban areas through greening cities and recycling water; (iii) sustainable agriculture and forestry; and (iv) protection of ecosystems for carbon storage and other ecosystem services. {3.3}

Transformations in economic, social, technological and political decisions and actions can enhance adaptation and promote sustainable development (*high confidence*). At the national level, transformation is considered most effective when it reflects a country's own visions and approaches to achieving sustainable development in accordance with its national circumstances and priorities. Restricting adaptation responses to incremental changes to existing systems and structures, without considering transformational change, may increase costs and losses and miss opportunities. Planning and implementation of transformational adaptation could reflect strengthened, altered or aligned paradigms and may place new and increased demands on governance structures to reconcile different goals and visions for the future and to address possible equity and ethical implications. Adaptation pathways are enhanced by iterative learning, deliberative processes and innovation. {3.3}

SPM 3.4 Characteristics of mitigation pathways

There are multiple mitigation pathways that are *likely* to limit warming to below 2°C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of CO₂ and other long-lived greenhouse gases by the end of the century. Implementing such reductions poses substantial technological, economic, social and institutional challenges, which increase with delays in additional mitigation and if key technologies are not available. Limiting warming to lower or higher levels involves similar challenges but on different timescales. {3.4}

Without additional efforts to reduce GHG emissions beyond those in place today, global emissions growth is expected to persist, driven by growth in global population and economic activities. Global mean surface temperature increases in 2100 in baseline scenarios—those without additional mitigation—range from 3.7°C to 4.8°C above the average for 1850–1900 for a median climate response. They range from 2.5°C to 7.8°C when including climate uncertainty (5th to 95th percentile range) (*high confidence*). {3.4}

Emissions scenarios leading to CO₂-equivalent concentrations in 2100 of about 450 ppm or lower are *likely* to maintain warming below 2°C over the 21st century relative to pre-industrial levels¹⁵. These scenarios are characterized by 40 to 70% global anthropogenic GHG emissions reductions by 2050 compared to 2010¹⁶, and emissions levels near zero or below in 2100. Mitigation scenarios reaching concentration levels of about 500 ppm CO₂-eq by 2100 are *more likely than not* to limit temperature change to less than 2°C, unless they temporarily overshoot concentration levels of roughly 530 ppm CO₂-eq

¹⁵ For comparison, the CO₂-eq concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 to 520 ppm)

¹⁶ This range differs from the range provided for a similar concentration category in the AR4 (50 to 85% lower than 2000 for CO₂ only). Reasons for this difference include that this report has assessed a substantially larger number of scenarios than in the AR4 and looks at all GHGs. In addition, a large proportion of the new scenarios include Carbon Dioxide Removal (CDR) technologies (see below). Other factors include the use of 2100 concentration levels instead of stabilization levels and the shift in reference year from 2000 to 2010.

before 2100, in which case they are *about as likely as not* to achieve that goal. In these 500 ppm CO₂-eq scenarios, global 2050 emissions levels are 25 to 55% lower than in 2010. Scenarios with higher emissions in 2050 are characterized by a greater reliance on Carbon Dioxide Removal (CDR) technologies beyond mid-century (and vice versa). Trajectories that are *likely* to limit warming to 3°C relative to pre-industrial levels reduce emissions less rapidly than those limiting warming to 2°C. A limited number of studies provide scenarios that are *more likely than not* to limit warming to 1.5°C by 2100; these scenarios are characterized by concentrations below 430 ppm CO₂-eq by 2100 and 2050 emission reduction between 70% and 95% below 2010. For a comprehensive overview of the characteristics of emissions scenarios, their CO₂-equivalent concentrations and their likelihood to keep warming to below a range of temperature levels, see Figure SPM.11 and Table SPM.1. {3.4}

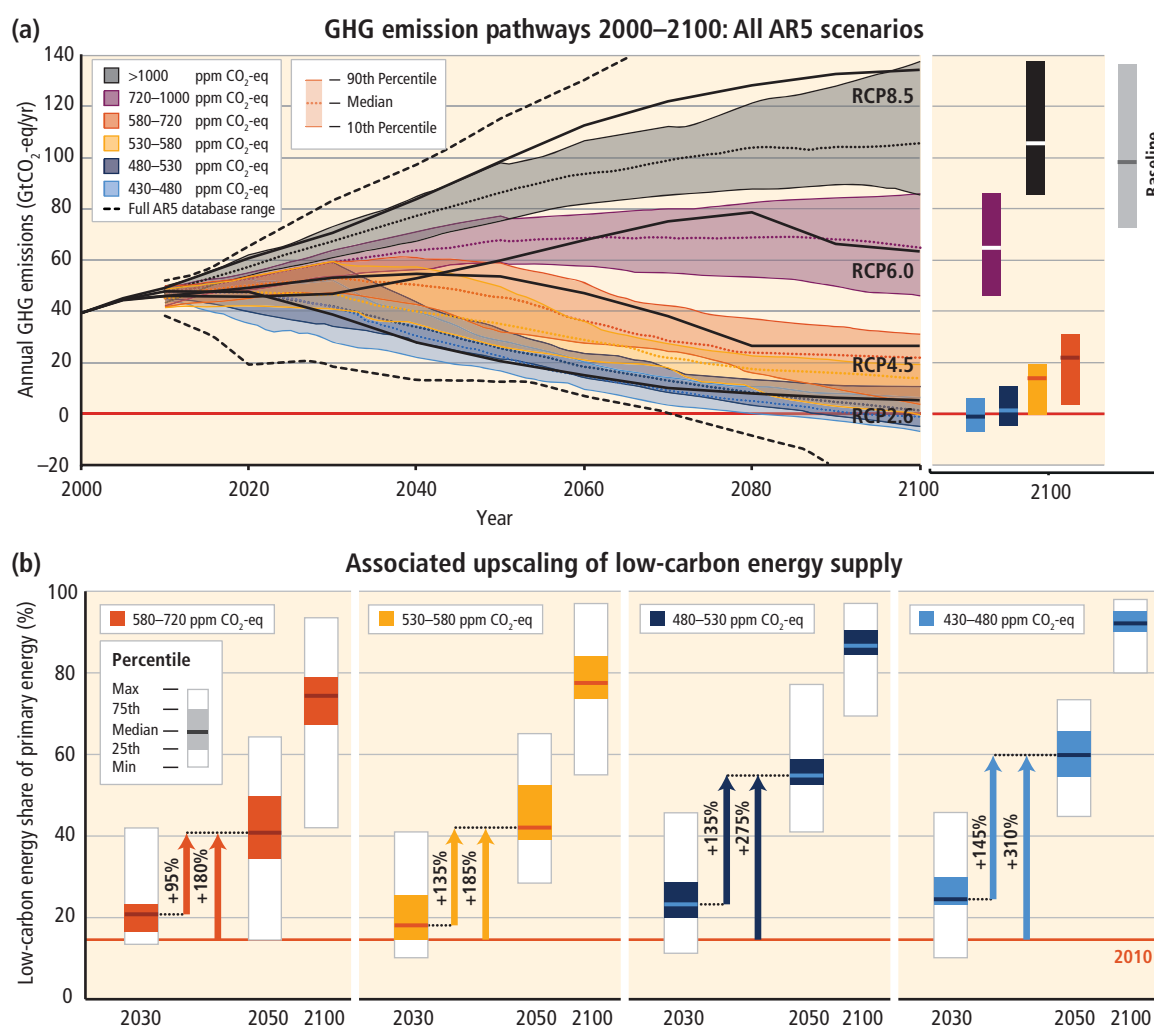


Figure SPM.11 | Global greenhouse gas emissions (gigatonne of CO₂-equivalent per year, GtCO₂-eq/yr) in baseline and mitigation scenarios for different long-term concentration levels (a) and associated upscaling requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100 compared to 2010 levels in mitigation scenarios (b). {Figure 3.2}

Table SPM.1 | Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters the 10th to 90th percentile of the scenarios is shown ^a. {Table 3.1}

CO ₂ -eq Con- centrations in 2100 (ppm CO ₂ -eq) ^f Category label (conc. range)	Subcategories	Relative position of the RCPs ^d	Change in CO ₂ -eq emissions compared to 2010 (in %) ^c		Likelihood of staying below a specific temperature level over the 21st cen- tury (relative to 1850–1900) ^{d, e}			
			2050	2100	1.5°C	2°C	3°C	4°C
<430	Only a limited number of individual model studies have explored levels below 430 ppm CO ₂ -eq ⁱ							
450 (430 to 480)	Total range ^{a, g}	RCP2.6	–72 to –41	–118 to –78	More unlikely than likely	Likely	Likely	Likely
500 (480 to 530)	No overshoot of 530 ppm CO ₂ -eq		–57 to –42	–107 to –73	Unlikely	More likely than not		
	Overshoot of 530 ppm CO ₂ -eq		–55 to –25	–114 to –90		About as likely as not		
550 (530 to 580)	No overshoot of 580 ppm CO ₂ -eq		–47 to –19	–81 to –59		More unlikely than likely ⁱ		
	Overshoot of 580 ppm CO ₂ -eq		–16 to 7	–183 to –86				
(580 to 650)	Total range	RCP4.5	–38 to 24	–134 to –50	Unlikely	Unlikely	More likely than not	
(650 to 720)	Total range		–11 to 17	–54 to –21			More unlikely than likely	
(720 to 1000) ^b	Total range	RCP6.0	18 to 54	–7 to 72	Unlikely ^h	Unlikely ^h	Unlikely	More unlikely than likely
>1000 ^b	Total range	RCP8.5	52 to 95	74 to 178			Unlikely	More unlikely than likely

Notes:

^a The 'total range' for the 430 to 480 ppm CO₂-eq concentrations scenarios corresponds to the range of the 10th to 90th percentile of the subcategory of these scenarios shown in Table 6.3 of the Working Group III Report.

^b Baseline scenarios fall into the >1000 and 720 to 1000 ppm CO₂-eq categories. The latter category also includes mitigation scenarios. The baseline scenarios in the latter category reach a temperature change of 2.5°C to 5.8°C above the average for 1850–1900 in 2100. Together with the baseline scenarios in the >1000 ppm CO₂-eq category, this leads to an overall 2100 temperature range of 2.5°C to 7.8°C (range based on median climate response: 3.7°C to 4.8°C) for baseline scenarios across both concentration categories.

^c The global 2010 emissions are 31% above the 1990 emissions (consistent with the historic greenhouse gas emission estimates presented in this report). CO₂-eq emissions include the basket of Kyoto gases (carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) as well as fluorinated gases).

^d The assessment here involves a large number of scenarios published in the scientific literature and is thus not limited to the Representative Concentration Pathways (RCPs). To evaluate the CO₂-eq concentration and climate implications of these scenarios, the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) was used in a probabilistic mode. For a comparison between MAGICC model results and the outcomes of the models used in WGI, see WGI 12.4.1.2, 12.4.8 and WGIII 6.3.2.6.

^e The assessment in this table is based on the probabilities calculated for the full ensemble of scenarios in WGIII AR5 using MAGICC and the assessment in WGI of the uncertainty of the temperature projections not covered by climate models. The statements are therefore consistent with the statements in WGI, which are based on the Coupled Model Intercomparison Project Phase 5 (CMIP5) runs of the RCPs and the assessed uncertainties. Hence, the likelihood statements reflect different lines of evidence from both WGs. This WGI method was also applied for scenarios with intermediate concentration levels where no CMIP5 runs are available. The likelihood statements are indicative only {WGIII 6.3} and follow broadly the terms used by the WGI SPM for temperature projections: likely 66–100%, more likely than not >50–100%, about as likely as not 33–66%, and unlikely 0–33%. In addition the term more unlikely than likely 0–<50% is used.

^f The CO₂-equivalent concentration (see Glossary) is calculated on the basis of the total forcing from a simple carbon cycle/climate model, MAGICC. The CO₂-equivalent concentration in 2111 is estimated to be 430 ppm (uncertainty range 340 to 520 ppm). This is based on the assessment of total anthropogenic radiative forcing for 2111 relative to 1750 in WGI, i.e., 2.3 W/m², uncertainty range 1.1 to 3.3 W/m².

^g The vast majority of scenarios in this category overshoot the category boundary of 480 ppm CO₂-eq concentration.

^h For scenarios in this category, no CMIP5 run or MAGICC realization stays below the respective temperature level. Still, an *unlikely* assignment is given to reflect uncertainties that may not be reflected by the current climate models.

ⁱ Scenarios in the 580 to 650 ppm CO₂-eq category include both overshoot scenarios and scenarios that do not exceed the concentration level at the high end of the category (e.g., RCP4.5). The latter type of scenarios, in general, have an assessed probability of *more unlikely than likely* to stay below the 2°C temperature level, while the former are mostly assessed to have an *unlikely* probability of staying below this level.

^j In these scenarios, global CO₂-eq emissions in 2050 are between 70 to 95% below 2010 emissions, and they are between 110 to 120% below 2010 emissions in 2100.

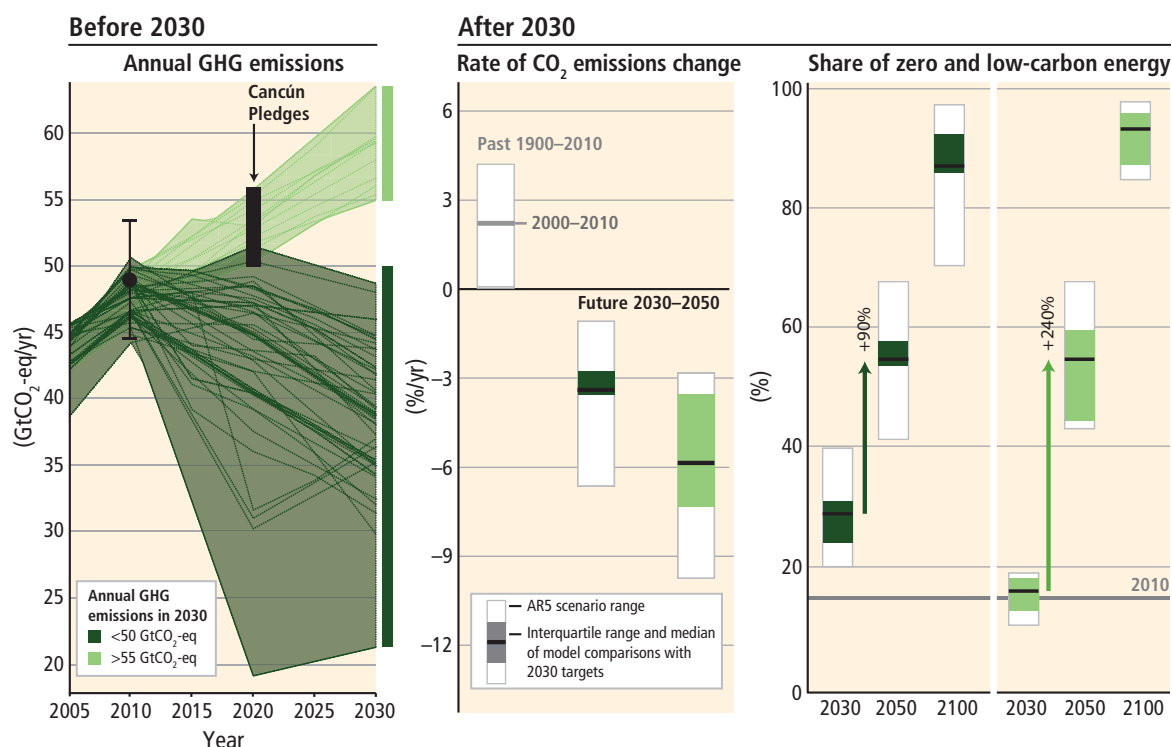


Figure SPM.12 | The implications of different 2030 greenhouse gas (GHG) emissions levels for the rate of carbon dioxide (CO₂) emissions reductions and low-carbon energy upscaling in mitigation scenarios that are at least *about as likely as not* to keep warming throughout the 21st century below 2°C relative to pre-industrial levels (2100 CO₂-equivalent concentrations of 430 to 530 ppm). The scenarios are grouped according to different emissions levels by 2030 (coloured in different shades of green). The left panel shows the pathways of GHG emissions (gigatonne of CO₂-equivalent per year, GtCO₂-eq/yr) leading to these 2030 levels. The black dot with whiskers gives historic GHG emission levels and associated uncertainties in 2010 as reported in Figure SPM.2. The black bar shows the estimated uncertainty range of GHG emissions implied by the Cancún Pledges. The middle panel denotes the average annual CO₂ emissions reduction rates for the period 2030–2050. It compares the median and interquartile range across scenarios from recent inter-model comparisons with explicit 2030 interim goals to the range of scenarios in the Scenario Database for WGIII AR5. Annual rates of historical emissions change (sustained over a period of 20 years) and the average annual CO₂ emission change between 2000 and 2010 are shown as well. The arrows in the right panel show the magnitude of zero and low-carbon energy supply upscaling from 2030 to 2050 subject to different 2030 GHG emissions levels. Zero- and low-carbon energy supply includes renewables, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS) or bioenergy with CCS (BECCS). [Note: Only scenarios that apply the full, unconstrained mitigation technology portfolio of the underlying models (default technology assumption) are shown. Scenarios with large net negative global emissions (>20 GtCO₂-eq/yr), scenarios with exogenous carbon price assumptions and scenarios with 2010 emissions significantly outside the historical range are excluded.] {Figure 3.3}

Mitigation scenarios reaching about 450 ppm CO₂-eq in 2100 (consistent with a *likely* chance to keep warming below 2°C relative to pre-industrial levels) typically involve temporary overshoot¹⁷ of atmospheric concentrations, as do many scenarios reaching about 500 ppm CO₂-eq to about 550 ppm CO₂-eq in 2100 (Table SPM.1). Depending on the level of overshoot, overshoot scenarios typically rely on the availability and widespread deployment of bioenergy with carbon dioxide capture and storage (BECCS) and afforestation in the second half of the century. The availability and scale of these and other CDR technologies and methods are uncertain and CDR technologies are, to varying degrees, associated with challenges and risks¹⁸. CDR is also prevalent in many scenarios without overshoot to compensate for residual emissions from sectors where mitigation is more expensive (*high confidence*). {3.4, Box 3.3}

Reducing emissions of non-CO₂ agents can be an important element of mitigation strategies. All current GHG emissions and other forcing agents affect the rate and magnitude of climate change over the next few decades, although long-term warming is mainly driven by CO₂ emissions. Emissions of non-CO₂ forcers are often expressed as ‘CO₂-equivalent emissions’, but the choice of metric to calculate these emissions, and the implications for the emphasis and timing of abatement of the various climate forcers, depends on application and policy context and contains value judgments. {3.4, Box 3.2}

¹⁷ In concentration ‘overshoot’ scenarios, concentrations peak during the century and then decline.

¹⁸ CDR methods have biogeochemical and technological limitations to their potential on the global scale. There is insufficient knowledge to quantify how much CO₂ emissions could be partially offset by CDR on a century timescale. CDR methods may carry side effects and long-term consequences on a global scale.

Global mitigation costs and consumption growth in baseline scenarios

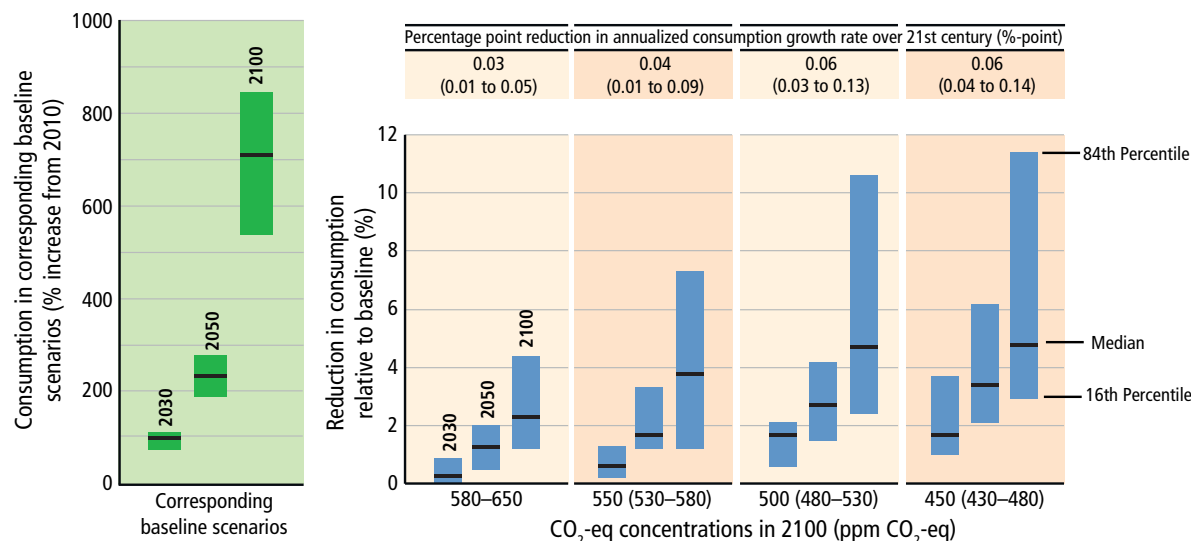


Figure SPM.13 | Global mitigation costs in cost-effective scenarios at different atmospheric concentrations levels in 2100. Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions. Consumption losses are shown relative to a baseline development without climate policy (left panel). The table at the top shows percentage points of annualized consumption growth reductions relative to consumption growth in the baseline of 1.6 to 3% per year (e.g., if the reduction is 0.06 percentage points per year due to mitigation, and baseline growth is 2.0% per year, then the growth rate with mitigation would be 1.94% per year). Cost estimates shown in this table do not consider the benefits of reduced climate change or co-benefits and adverse side effects of mitigation. Estimates at the high end of these cost ranges are from models that are relatively inflexible to achieve the deep emissions reductions required in the long run to meet these goals and/or include assumptions about market imperfections that would raise costs. *(Figure 3.4)*

Delaying additional mitigation to 2030 will substantially increase the challenges associated with limiting warming over the 21st century to below 2°C relative to pre-industrial levels. It will require substantially higher rates of emissions reductions from 2030 to 2050; a much more rapid scale-up of low-carbon energy over this period; a larger reliance on CDR in the long term; and higher transitional and long-term economic impacts. Estimated global emissions levels in 2020 based on the Cancún Pledges are not consistent with cost-effective mitigation trajectories that are at least *about as likely as not* to limit warming to below 2°C relative to pre-industrial levels, but they do not preclude the option to meet this goal (*high confidence*) (Figure SPM.12, Table SPM.2). {3.4}

Estimates of the aggregate economic costs of mitigation vary widely depending on methodologies and assumptions, but increase with the stringency of mitigation. Scenarios in which all countries of the world begin mitigation immediately, in which there is a single global carbon price, and in which all key technologies are available have been used as a cost-effective benchmark for estimating macro-economic mitigation costs (Figure SPM.13). Under these assumptions mitigation scenarios that are *likely* to limit warming to below 2°C through the 21st century relative to pre-industrial levels entail losses in global consumption—not including benefits of reduced climate change as well as co-benefits and adverse side effects of mitigation—of 1 to 4% (median: 1.7%) in 2030, 2 to 6% (median: 3.4%) in 2050 and 3 to 11% (median: 4.8%) in 2100 relative to consumption in baseline scenarios that grows anywhere from 300% to more than 900% over the century (Figure SPM.13). These numbers correspond to an annualized reduction of consumption growth by 0.04 to 0.14 (median: 0.06) percentage points over the century relative to annualized consumption growth in the baseline that is between 1.6 and 3% per year (*high confidence*). {3.4}

In the absence or under limited availability of mitigation technologies (such as bioenergy, CCS and their combination BECCS, nuclear, wind/solar), mitigation costs can increase substantially depending on the technology considered. Delaying additional mitigation increases mitigation costs in the medium to long term. Many models could not limit *likely* warming to below 2°C over the 21st century relative to pre-industrial levels if additional mitigation is considerably delayed. Many models could not limit *likely* warming to below 2°C if bioenergy, CCS and their combination (BECCS) are limited (*high confidence*) (Table SPM.2). {3.4}

Table SPM.2 | Increase in global mitigation costs due to either limited availability of specific technologies or delays in additional mitigation ^a relative to cost-effective scenarios ^b. The increase in costs is given for the median estimate and the 16th to 84th percentile range of the scenarios (in parentheses) ^c. In addition, the sample size of each scenario set is provided in the coloured symbols. The colours of the symbols indicate the fraction of models from systematic model comparison exercises that could successfully reach the targeted concentration level. {Table 3.2}

Mitigation cost increases in scenarios with limited availability of technologies ^d					Mitigation cost increases due to delayed additional mitigation until 2030	
[% increase in total discounted ^e mitigation costs (2015–2100) relative to default technology assumptions]					[% increase in mitigation costs relative to immediate mitigation]	
2100 concentrations (ppm CO ₂ -eq)	no CCS	nuclear phase out	limited solar/wind	limited bioenergy	medium term costs (2030–2050)	long term costs (2050–2100)
450 (430 to 480)	138% (29 to 297%) 	7% (4 to 18%) 	6% (2 to 29%) 	64% (44 to 78%) 	44% (2 to 78%) 	37% (16 to 82%) 
500 (480 to 530)	not available (n.a.)	n.a.	n.a.	n.a.		
550 (530 to 580)	39% (18 to 78%) 	13% (2 to 23%) 	8% (5 to 15%) 	18% (4 to 66%) 	15% (3 to 32%)	16% (5 to 24%)
580 to 650	n.a.	n.a.	n.a.	n.a.		
Symbol legend—fraction of models successful in producing scenarios (numbers indicate the number of successful models)						
 : all models successful			 : between 50 and 80% of models successful			
 : between 80 and 100% of models successful			 : less than 50% of models successful			

Notes:

^a Delayed mitigation scenarios are associated with greenhouse gas emission of more than 55 GtCO₂-eq in 2030, and the increase in mitigation costs is measured relative to cost-effective mitigation scenarios for the same long-term concentration level.

^b Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions.

^c The range is determined by the central scenarios encompassing the 16th to 84th percentile range of the scenario set. Only scenarios with a time horizon until 2100 are included. Some models that are included in the cost ranges for concentration levels above 530 ppm CO₂-eq in 2100 could not produce associated scenarios for concentration levels below 530 ppm CO₂-eq in 2100 with assumptions about limited availability of technologies and/or delayed additional mitigation.

^d No CCS: carbon dioxide capture and storage is not included in these scenarios. Nuclear phase out: no addition of nuclear power plants beyond those under construction, and operation of existing plants until the end of their lifetime. Limited Solar/Wind: a maximum of 20% global electricity generation from solar and wind power in any year of these scenarios. Limited Bioenergy: a maximum of 100 EJ/yr modern bioenergy supply globally (modern bioenergy used for heat, power, combinations and industry was around 18 EJ/yr in 2008). EJ = Exajoule = 10¹⁸ Joule.

^e Percentage increase of net present value of consumption losses in percent of baseline consumption (for scenarios from general equilibrium models) and abatement costs in percent of baseline gross domestic product (GDP, for scenarios from partial equilibrium models) for the period 2015–2100, discounted at 5% per year.

Mitigation scenarios reaching about 450 or 500 ppm CO₂-eq by 2100 show reduced costs for achieving air quality and energy security objectives, with significant co-benefits for human health, ecosystem impacts and sufficiency of resources and resilience of the energy system. {4.4.2.2}

Mitigation policy could devalue fossil fuel assets and reduce revenues for fossil fuel exporters, but differences between regions and fuels exist (*high confidence*). Most mitigation scenarios are associated with reduced revenues from coal and oil trade for major exporters (*high confidence*). The availability of CCS would reduce the adverse effects of mitigation on the value of fossil fuel assets (*medium confidence*). {4.4.2.2}

Solar Radiation Management (SRM) involves large-scale methods that seek to reduce the amount of absorbed solar energy in the climate system. SRM is untested and is not included in any of the mitigation scenarios. If it were deployed, SRM would

entail numerous uncertainties, side effects, risks and shortcomings and has particular governance and ethical implications. SRM would not reduce ocean acidification. If it were terminated, there is *high confidence* that surface temperatures would rise very rapidly impacting ecosystems susceptible to rapid rates of change. {Box 3.3}

SPM 4. Adaptation and Mitigation

Many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives. {4}

SPM 4.1 Common enabling factors and constraints for adaptation and mitigation responses

Adaptation and mitigation responses are underpinned by common enabling factors. These include effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods and behavioural and lifestyle choices. {4.1}

Inertia in many aspects of the socio-economic system constrains adaptation and mitigation options (*medium evidence, high agreement*). Innovation and investments in environmentally sound infrastructure and technologies can reduce GHG emissions and enhance resilience to climate change (*very high confidence*). {4.1}

Vulnerability to climate change, GHG emissions and the capacity for adaptation and mitigation are strongly influenced by livelihoods, lifestyles, behaviour and culture (*medium evidence, medium agreement*). Also, the social acceptability and/or effectiveness of climate policies are influenced by the extent to which they incentivize or depend on regionally appropriate changes in lifestyles or behaviours. {4.1}

For many regions and sectors, enhanced capacities to mitigate and adapt are part of the foundation essential for managing climate change risks (*high confidence*). Improving institutions as well as coordination and cooperation in governance can help overcome regional constraints associated with mitigation, adaptation and disaster risk reduction (*very high confidence*). {4.1}

SPM 4.2 Response options for adaptation

Adaptation options exist in all sectors, but their context for implementation and potential to reduce climate-related risks differs across sectors and regions. Some adaptation responses involve significant co-benefits, synergies and trade-offs. Increasing climate change will increase challenges for many adaptation options. {4.2}

Adaptation experience is accumulating across regions in the public and private sectors and within communities. There is increasing recognition of the value of social (including local and indigenous), institutional, and ecosystem-based measures and of the extent of constraints to adaptation. Adaptation is becoming embedded in some planning processes, with more limited implementation of responses (*high confidence*). {1.6, 4.2, 4.4.2.1}

The need for adaptation along with associated challenges is expected to increase with climate change (*very high confidence*). Adaptation options exist in all sectors and regions, with diverse potential and approaches depending on their context in vulnerability reduction, disaster risk management or proactive adaptation planning (Table SPM.3). Effective strategies and actions consider the potential for co-benefits and opportunities within wider strategic goals and development plans. {4.2}

Table SPM.3 | Approaches for managing the risks of climate change through adaptation. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Examples are presented in no specific order and can be relevant to more than one category. (Table 4.2)

Overlapping Approaches	Category	Examples
Vulnerability & Exposure Reduction through development, planning & practices including many low-regrets measures	Human development	Improved access to education, nutrition, health facilities, energy, safe housing & settlement structures, & social support structures; Reduced gender inequality & marginalization in other forms.
	Poverty alleviation	Improved access to & control of local resources; Land tenure; Disaster risk reduction; Social safety nets & social protection; Insurance schemes.
	Livelihood security	Income, asset & livelihood diversification; Improved infrastructure; Access to technology & decision-making fora; Increased decision-making power; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
	Disaster risk management	Early warning systems; Hazard & vulnerability mapping; Diversifying water resources; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements.
	Ecosystem management	Maintaining wetlands & urban green spaces; Coastal afforestation; Watershed & reservoir management; Reduction of other stressors on ecosystems & of habitat fragmentation; Maintenance of genetic diversity; Manipulation of disturbance regimes; Community-based natural resource management.
	Spatial or land-use planning	Provisioning of adequate housing, infrastructure & services; Managing development in flood prone & other high risk areas; Urban planning & upgrading programs; Land zoning laws; Easements; Protected areas.
	Structural/physical	Engineered & built-environment options: Sea walls & coastal protection structures; Flood levees; Water storage; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements; Floating houses; Power plant & electricity grid adjustments.
		Technological options: New crop & animal varieties; Indigenous, traditional & local knowledge, technologies & methods; Efficient irrigation; Water-saving technologies; Desalination; Conservation agriculture; Food storage & preservation facilities; Hazard & vulnerability mapping & monitoring; Early warning systems; Building insulation; Mechanical & passive cooling; Technology development, transfer & diffusion.
		Ecosystem-based options: Ecological restoration; Soil conservation; Afforestation & reforestation; Mangrove conservation & replanting; Green infrastructure (e.g., shade trees, green roofs); Controlling overfishing; Fisheries co-management; Assisted species migration & dispersal; Ecological corridors; Seed banks, gene banks & other <i>ex situ</i> conservation; Community-based natural resource management.
		Services: Social safety nets & social protection; Food banks & distribution of food surplus; Municipal services including water & sanitation; Vaccination programs; Essential public health services; Enhanced emergency medical services.
Adaptation including incremental & transformational adjustments	Institutional	Economic options: Financial incentives; Insurance; Catastrophe bonds; Payments for ecosystem services; Pricing water to encourage universal provision and careful use; Microfinance; Disaster contingency funds; Cash transfers; Public-private partnerships.
		Laws & regulations: Land zoning laws; Building standards & practices; Easements; Water regulations & agreements; Laws to support disaster risk reduction; Laws to encourage insurance purchasing; Defined property rights & land tenure security; Protected areas; Fishing quotas; Patent pools & technology transfer.
		National & government policies & programs: National & regional adaptation plans including mainstreaming; Sub-national & local adaptation plans; Economic diversification; Urban upgrading programs; Municipal water management programs; Disaster planning & preparedness; Integrated water resource management; Integrated coastal zone management; Ecosystem-based management; Community-based adaptation.
	Social	Educational options: Awareness raising & integrating into education; Gender equity in education; Extension services; Sharing indigenous, traditional & local knowledge; Participatory action research & social learning; Knowledge-sharing & learning platforms.
		Informational options: Hazard & vulnerability mapping; Early warning & response systems; Systematic monitoring & remote sensing; Climate services; Use of indigenous climate observations; Participatory scenario development; Integrated assessments.
		Behavioural options: Household preparation & evacuation planning; Migration; Soil & water conservation; Storm drain clearance; Livelihood diversification; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
	Spheres of change	Practical: Social & technical innovations, behavioural shifts, or institutional & managerial changes that produce substantial shifts in outcomes.
		Political: Political, social, cultural & ecological decisions & actions consistent with reducing vulnerability & risk & supporting adaptation, mitigation & sustainable development.
		Personal: Individual & collective assumptions, beliefs, values & worldviews influencing climate-change responses.
	Transformation	

SPM 4.3 Response options for mitigation

Mitigation options are available in every major sector. Mitigation can be more cost-effective if using an integrated approach that combines measures to reduce energy use and the greenhouse gas intensity of end-use sectors, decarbonize energy supply, reduce net emissions and enhance carbon sinks in land-based sectors. {4.3}

Well-designed systemic and cross-sectoral mitigation strategies are more cost-effective in cutting emissions than a focus on individual technologies and sectors, with efforts in one sector affecting the need for mitigation in others (*medium confidence*). Mitigation measures intersect with other societal goals, creating the possibility of co-benefits or adverse side effects. These intersections, if well-managed, can strengthen the basis for undertaking climate action. {4.3}

Emissions ranges for baseline scenarios and mitigation scenarios that limit CO₂-equivalent concentrations to low levels (about 450 ppm CO₂-eq, *likely* to limit warming to 2°C above pre-industrial levels) are shown for different sectors and gases in Figure SPM.14. Key measures to achieve such mitigation goals include decarbonizing (i.e., reducing the carbon intensity of) electricity generation (*medium evidence, high agreement*) as well as efficiency enhancements and behavioural changes, in order to reduce energy demand compared to baseline scenarios without compromising development (*robust evidence, high agreement*). In scenarios reaching 450 ppm CO₂-eq concentrations by 2100, global CO₂ emissions from the energy supply sector are projected to decline over the next decade and are characterized by reductions of 90% or more below 2010 levels between 2040 and 2070. In the majority of low-concentration stabilization scenarios (about 450 to about 500 ppm CO₂-eq, at least *about as likely as not* to limit warming to 2°C above pre-industrial levels), the share of low-carbon electricity supply (comprising renewable energy (RE), nuclear and carbon dioxide capture and storage (CCS) including bioenergy with carbon dioxide capture and storage (BECCS)) increases from the current share of approximately 30% to more than 80% by 2050, and fossil fuel power generation without CCS is phased out almost entirely by 2100. {4.3}

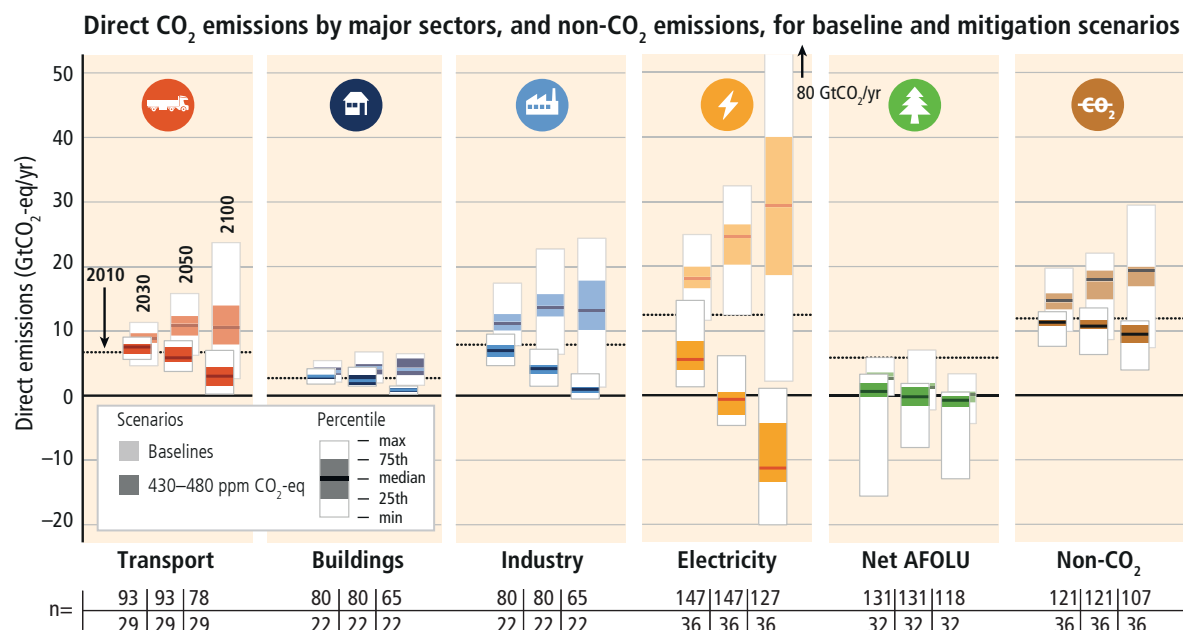


Figure SPM.14 | Carbon dioxide (CO₂) emissions by sector and total non-CO₂ greenhouse gases (Kyoto gases) across sectors in baseline (faded bars) and mitigation scenarios (solid colour bars) that reach about 450 (430 to 480) ppm CO₂-eq concentrations in 2100 (*likely* to limit warming to 2°C above pre-industrial levels). Mitigation in the end-use sectors leads also to indirect emissions reductions in the upstream energy supply sector. Direct emissions of the end-use sectors thus do not include the emission reduction potential at the supply-side due to, for example, reduced electricity demand. The numbers at the bottom of the graphs refer to the number of scenarios included in the range (upper row: baseline scenarios; lower row: mitigation scenarios), which differs across sectors and time due to different sectoral resolution and time horizon of models. Emissions ranges for mitigation scenarios include the full portfolio of mitigation options; many models cannot reach 450 ppm CO₂-eq concentration by 2100 in the absence of carbon dioxide capture and storage (CCS). Negative emissions in the electricity sector are due to the application of bioenergy with carbon dioxide capture and storage (BECCS). 'Net' agriculture, forestry and other land use (AFOLU) emissions consider afforestation, reforestation as well as deforestation activities. {4.3, Figure 4.1}

Near-term reductions in energy demand are an important element of cost-effective mitigation strategies, provide more flexibility for reducing carbon intensity in the energy supply sector, hedge against related supply-side risks, avoid lock-in to carbon-intensive infrastructures, and are associated with important co-benefits. The most cost-effective mitigation options in forestry are afforestation, sustainable forest management and reducing deforestation, with large differences in their relative importance across regions; and in agriculture, cropland management, grazing land management and restoration of organic soils (*medium evidence, high agreement*). {4.3, Figures 4.1, 4.2, Table 4.3}

Behaviour, lifestyle and culture have a considerable influence on energy use and associated emissions, with high mitigation potential in some sectors, in particular when complementing technological and structural change (*medium evidence, medium agreement*). Emissions can be substantially lowered through changes in consumption patterns, adoption of energy savings measures, dietary change and reduction in food wastes. {4.1, 4.3}

SPM 4.4 Policy approaches for adaptation and mitigation, technology and finance

Effective adaptation and mitigation responses will depend on policies and measures across multiple scales: international, regional, national and sub-national. Policies across all scales supporting technology development, diffusion and transfer, as well as finance for responses to climate change, can complement and enhance the effectiveness of policies that directly promote adaptation and mitigation. {4.4}

International cooperation is critical for effective mitigation, even though mitigation can also have local co-benefits. Adaptation focuses primarily on local to national scale outcomes, but its effectiveness can be enhanced through coordination across governance scales, including international cooperation: {3.1, 4.4.1}

- The United Nations Framework Convention on Climate Change (UNFCCC) is the main multilateral forum focused on addressing climate change, with nearly universal participation. Other institutions organized at different levels of governance have resulted in diversifying international climate change cooperation. {4.4.1}
- The Kyoto Protocol offers lessons towards achieving the ultimate objective of the UNFCCC, particularly with respect to participation, implementation, flexibility mechanisms and environmental effectiveness (*medium evidence, low agreement*). {4.4.1}
- Policy linkages among regional, national and sub-national climate policies offer potential climate change mitigation benefits (*medium evidence, medium agreement*). Potential advantages include lower mitigation costs, decreased emission leakage and increased market liquidity. {4.4.1}
- International cooperation for supporting adaptation planning and implementation has received less attention historically than mitigation but is increasing and has assisted in the creation of adaptation strategies, plans and actions at the national, sub-national and local level (*high confidence*). {4.4.1}

There has been a considerable increase in national and sub-national plans and strategies on both adaptation and mitigation since the AR4, with an increased focus on policies designed to integrate multiple objectives, increase co-benefits and reduce adverse side effects (*high confidence*): {4.4.2.1, 4.4.2.2}

- National governments play key roles in adaptation planning and implementation (*robust evidence, high agreement*) through coordinating actions and providing frameworks and support. While local government and the private sector have different functions, which vary regionally, they are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing (*medium evidence, high agreement*). {4.4.2.1}
- Institutional dimensions of adaptation governance, including the integration of adaptation into planning and decision-making, play a key role in promoting the transition from planning to implementation of adaptation (*robust evidence*,

high agreement). Examples of institutional approaches to adaptation involving multiple actors include economic options (e.g., insurance, public-private partnerships), laws and regulations (e.g., land-zoning laws) and national and government policies and programmes (e.g., economic diversification). {4.2, 4.4.2.1, Table SPM.3}

- In principle, mechanisms that set a carbon price, including cap and trade systems and carbon taxes, can achieve mitigation in a cost-effective way but have been implemented with diverse effects due in part to national circumstances as well as policy design. The short-run effects of cap and trade systems have been limited as a result of loose caps or caps that have not proved to be constraining (*limited evidence, medium agreement*). In some countries, tax-based policies specifically aimed at reducing GHG emissions—alongside technology and other policies—have helped to weaken the link between GHG emissions and GDP (*high confidence*). In addition, in a large group of countries, fuel taxes (although not necessarily designed for the purpose of mitigation) have had effects that are akin to sectoral carbon taxes. {4.4.2.2}
- Regulatory approaches and information measures are widely used and are often environmentally effective (*medium evidence, medium agreement*). Examples of regulatory approaches include energy efficiency standards; examples of information programmes include labelling programmes that can help consumers make better-informed decisions. {4.4.2.2}
- Sector-specific mitigation policies have been more widely used than economy-wide policies (*medium evidence, high agreement*). Sector-specific policies may be better suited to address sector-specific barriers or market failures and may be bundled in packages of complementary policies. Although theoretically more cost-effective, administrative and political barriers may make economy-wide policies harder to implement. Interactions between or among mitigation policies may be synergistic or may have no additive effect on reducing emissions. {4.4.2.2}
- Economic instruments in the form of subsidies may be applied across sectors, and include a variety of policy designs, such as tax rebates or exemptions, grants, loans and credit lines. An increasing number and variety of renewable energy (RE) policies including subsidies—motivated by many factors—have driven escalated growth of RE technologies in recent years. At the same time, reducing subsidies for GHG-related activities in various sectors can achieve emission reductions, depending on the social and economic context (*high confidence*). {4.4.2.2}

Co-benefits and adverse side effects of mitigation could affect achievement of other objectives such as those related to human health, food security, biodiversity, local environmental quality, energy access, livelihoods and equitable sustainable development. The potential for co-benefits for energy end-use measures outweighs the potential for adverse side effects whereas the evidence suggests this may not be the case for all energy supply and agriculture, forestry and other land use (AFOLU) measures. Some mitigation policies raise the prices for some energy services and could hamper the ability of societies to expand access to modern energy services to underserved populations (*low confidence*). These potential adverse side effects on energy access can be avoided with the adoption of complementary policies such as income tax rebates or other benefit transfer mechanisms (*medium confidence*). Whether or not side effects materialize, and to what extent side effects materialize, will be case- and site-specific, and depend on local circumstances and the scale, scope and pace of implementation. Many co-benefits and adverse side effects have not been well-quantified. {4.3, 4.4.2.2, Box 3.4}

Technology policy (development, diffusion and transfer) complements other mitigation policies across all scales, from international to sub-national; many adaptation efforts also critically rely on diffusion and transfer of technologies and management practices (*high confidence*). Policies exist to address market failures in R&D, but the effective use of technologies can also depend on capacities to adopt technologies appropriate to local circumstances. {4.4.3}

Substantial reductions in emissions would require large changes in investment patterns (*high confidence*). For mitigation scenarios that stabilize concentrations (without overshoot) in the range of 430 to 530 ppm CO₂-eq by 2100¹⁹, annual investments in low carbon electricity supply and energy efficiency in key sectors (transport, industry and buildings) are projected in the scenarios to rise by several hundred billion dollars per year before 2030. Within appropriate enabling environments, the private sector, along with the public sector, can play important roles in financing mitigation and adaptation (*medium evidence, high agreement*). {4.4.4}

¹⁹ This range comprises scenarios that reach 430 to 480 ppm CO₂-eq by 2100 (*likely* to limit warming to 2°C above pre-industrial levels) and scenarios that reach 480 to 530 ppm CO₂-eq by 2100 (without overshoot: *more likely than not* to limit warming to 2°C above pre-industrial levels).

Financial resources for adaptation have become available more slowly than for mitigation in both developed and developing countries. Limited evidence indicates that there is a gap between global adaptation needs and the funds available for adaptation (*medium confidence*). There is a need for better assessment of global adaptation costs, funding and investment. Potential synergies between international finance for disaster risk management and adaptation have not yet been fully realized (*high confidence*). {4.4.4}

SPM 4.5 Trade-offs, synergies and interactions with sustainable development

Climate change is a threat to sustainable development. Nonetheless, there are many opportunities to link mitigation, adaptation and the pursuit of other societal objectives through integrated responses (*high confidence*). Successful implementation relies on relevant tools, suitable governance structures and enhanced capacity to respond (*medium confidence*). {3.5, 4.5}

Climate change exacerbates other threats to social and natural systems, placing additional burdens particularly on the poor (*high confidence*). Aligning climate policy with sustainable development requires attention to both adaptation and mitigation (*high confidence*). Delaying global mitigation actions may reduce options for climate-resilient pathways and adaptation in the future. Opportunities to take advantage of positive synergies between adaptation and mitigation may decrease with time, particularly if limits to adaptation are exceeded. Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, encompassing connections among human health, water, energy, land use and biodiversity (*medium evidence, high agreement*). {3.1, 3.5, 4.5}

Strategies and actions can be pursued now which will move towards climate-resilient pathways for sustainable development, while at the same time helping to improve livelihoods, social and economic well-being and effective environmental management. In some cases, economic diversification can be an important element of such strategies. The effectiveness of integrated responses can be enhanced by relevant tools, suitable governance structures and adequate institutional and human capacity (*medium confidence*). Integrated responses are especially relevant to energy planning and implementation; interactions among water, food, energy and biological carbon sequestration; and urban planning, which provides substantial opportunities for enhanced resilience, reduced emissions and more sustainable development (*medium confidence*). {3.5, 4.4, 4.5}

or event with an assignment of statistical confidence²⁷. Attribution of climate change to causes quantifies the links between observed climate change and human activity, as well as other, natural, climate drivers. In contrast, attribution of observed impacts to climate change considers the links between observed changes in natural or human systems and observed climate change, regardless of its cause. Results from studies attributing climate change to causes provide estimates of the magnitude of warming in response to changes in radiative forcing and hence support projections of future climate change (Topic 2). Results from studies attributing impacts to climate change provide strong indications for the sensitivity of natural or human systems to future climate change. {WGI 10.8, WGII SPM A-1, WGI/III/IV/SYR Glossaries}

1.3.1 Attribution of climate changes to human and natural influences on the climate system

It is **extremely likely** that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcings together (Figure 1.9). The best estimate of the human induced contribution to warming is similar to the observed warming over this period. GHGs contributed a global mean surface warming **likely** to be in the range of 0.5°C to 1.3°C over the period 1951 to 2010, with further contributions from other anthropogenic forcings, including the cooling effect of aerosols, from natural forcings, and from natural internal variability (see Figure 1.9).

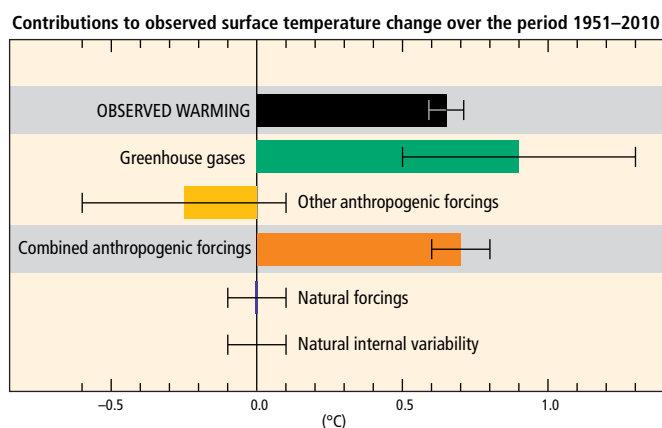


Figure 1.9 | Assessed *likely* ranges (whiskers) and their mid-points (bars) for warming trends over the 1951–2010 period from well-mixed greenhouse gases, other anthropogenic forcings (including the cooling effect of aerosols and the effect of land use change), combined anthropogenic forcings, natural forcings, and natural internal climate variability (which is the element of climate variability that arises spontaneously within the climate system, even in the absence of forcings). The observed surface temperature change is shown in black, with the 5 to 95% uncertainty range due to observational uncertainty. The attributed warming ranges (colours) are based on observations combined with climate model simulations, in order to estimate the contribution by an individual external forcing to the observed warming. The contribution from the combined anthropogenic forcings can be estimated with less uncertainty than the separate contributions from greenhouse gases and other anthropogenic forcings separately. This is because these two contributions partially compensate, resulting in a signal that is better constrained by observations. {Based on Figure WGI TS.10}

Together these assessed contributions are consistent with the observed warming of approximately 0.6°C to 0.7°C over this period. {WGI SPM D.3, 10.3.1}

It is **very likely** that anthropogenic influence, particularly GHGs and stratospheric ozone depletion, has led to a detectable observed pattern of tropospheric warming and a corresponding cooling in the lower stratosphere since 1961. {WGI SPM D.3, 2.4.4, 9.4.1, 10.3.1}

Over every continental region except Antarctica, anthropogenic forcings have *likely* made a substantial contribution to surface temperature increases since the mid-20th century (Figure 1.10). For Antarctica, large observational uncertainties result in *low confidence* that anthropogenic forcings have contributed to the observed warming averaged over available stations. In contrast, it is *likely* that there has been an anthropogenic contribution to the very substantial Arctic warming since the mid-20th century. Human influence has *likely* contributed to temperature increases in many sub-continental regions. {WGI SPM D.3, TS.4.8, 10.3.1}

Anthropogenic influences have *very likely* contributed to Arctic sea ice loss since 1979 (Figure 1.10). There is *low confidence* in the scientific understanding of the small observed increase in Antarctic sea ice extent due to the incomplete and competing scientific explanations for the causes of change and *low confidence* in estimates of natural internal variability in that region. {WGI SPM D.3, 10.5.1, Figure 10.16}

Anthropogenic influences *likely* contributed to the retreat of glaciers since the 1960s and to the increased surface melting of the Greenland ice sheet since 1993. Due to a low level of scientific understanding, however, there is *low confidence* in attributing the causes of the observed loss of mass from the Antarctic ice sheet over the past two decades. It is *likely* that there has been an anthropogenic contribution to observed reductions in Northern Hemisphere spring snow cover since 1970. {WGI 4.3.3, 10.5.2, 10.5.3}

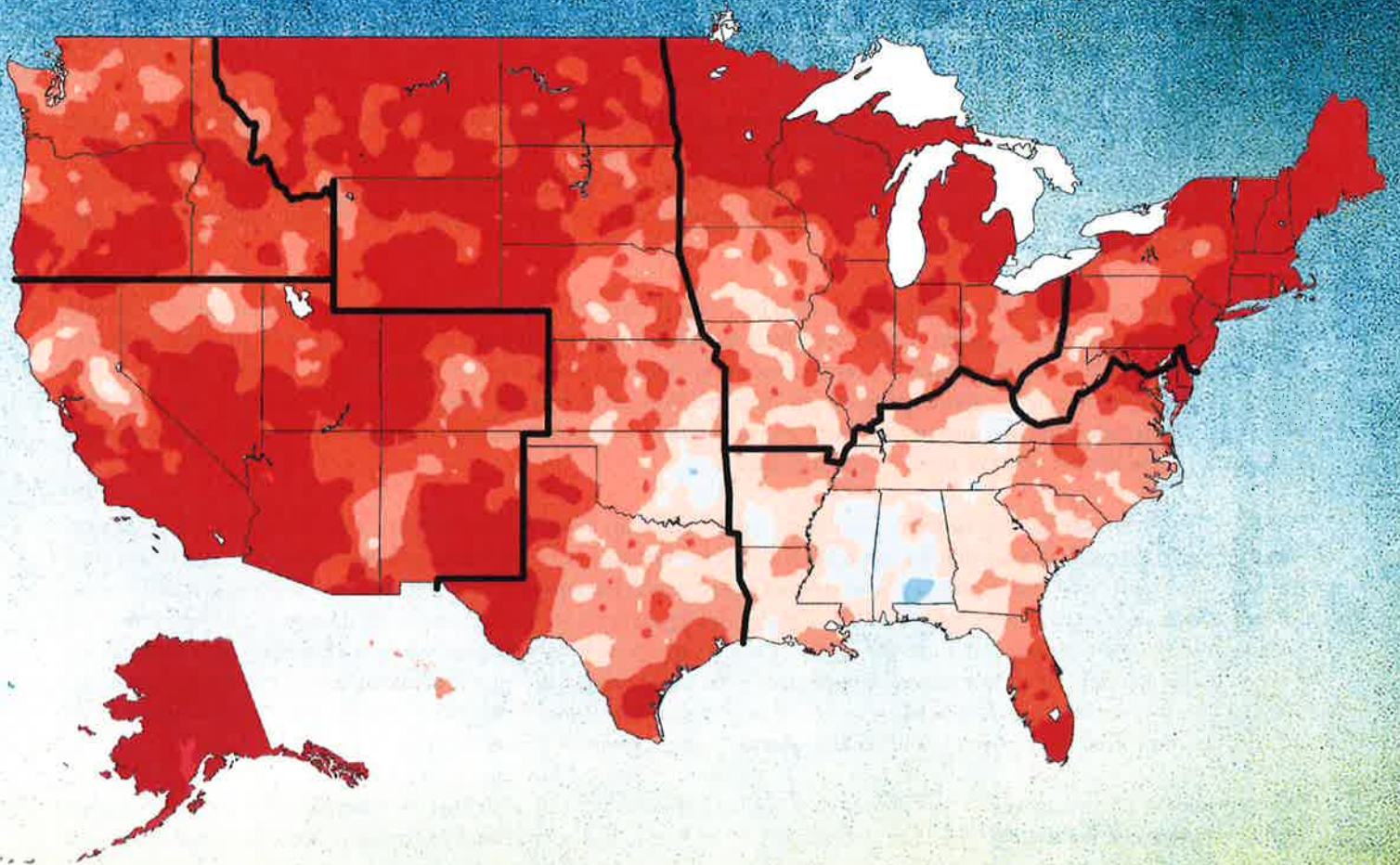
It is **likely** that anthropogenic influences have affected the global water cycle since 1960. Anthropogenic influences have contributed to observed increases in atmospheric moisture content (*medium confidence*), to global-scale changes in precipitation patterns over land (*medium confidence*), to intensification of heavy precipitation over land regions where data are sufficient (*medium confidence*) (see 1.4) and to changes in surface and subsurface ocean salinity (*very likely*). {WGI SPM D.3, 2.5.1, 2.6.2, 3.3.2, 3.3.3, 7.6.2, 10.3.2, 10.4.2, 10.6}

It is **very likely** that anthropogenic forcings have made a substantial contribution to increases in global upper ocean heat content (0–700 m) observed since the 1970s (Figure 1.10). There is evidence for human influence in some individual ocean basins. It is **very likely** that there is a substantial anthropogenic contribution to the global mean sea level rise since the 1970s. This is based on the *high confidence* in an anthropogenic influence on the two largest contributions to sea level rise: thermal expansion and glacier mass loss. Oceanic

²⁷ Definitions were taken from the Good Practice Guidance Paper on Detection and Attribution, the agreed product of the IPCC Expert Meeting on Detection and Attribution Related to Anthropogenic Climate Change; see Glossary.

Exhibit 5

Climate Change Impacts in the United States



U.S. National Climate Assessment
U.S. Global Change Research Program



May 2014

Members of Congress:

On behalf of the National Science and Technology Council and the U.S. Global Change Research Program, we are pleased to transmit the report of the Third National Climate Assessment: *Climate Change Impacts in the United States*. As required by the Global Change Research Act of 1990, this report has collected, evaluated, and integrated observations and research on climate change in the United States. It focuses both on changes that are happening now and further changes that we can expect to see throughout this century.

This report is the result of a three-year analytical effort by a team of over 300 experts, overseen by a broadly constituted Federal Advisory Committee of 60 members. It was developed from information and analyses gathered in over 70 workshops and listening sessions held across the country. It was subjected to extensive review by the public and by scientific experts in and out of government, including a special panel of the National Research Council of the National Academy of Sciences. This process of unprecedented rigor and transparency was undertaken so that the findings of the National Climate Assessment would rest on the firmest possible base of expert judgment.

We gratefully acknowledge the authors, reviewers, and staff who have helped prepare this Third National Climate Assessment. Their work in assessing the rapid advances in our knowledge of climate science over the past several years has been outstanding. Their findings and key messages not only describe the current state of that science but also the current and future impacts of climate change on major U.S. regions and key sectors of the U.S. economy. This information establishes a strong base that government at all levels of U.S. society can use in responding to the twin challenges of changing our policies to mitigate further climate change and preparing for the consequences of the climate changes that can no longer be avoided. It is also an important scientific resource to empower communities, businesses, citizens, and decision makers with information they need to prepare for and build resilience to the impacts of climate change.

When President Obama launched his Climate Action Plan last year, he made clear that the essential information contained in this report would be used by the Executive Branch to underpin future policies and decisions to better understand and manage the risks of climate change. We strongly and respectfully urge others to do the same.

Sincerely,

Dr. John P. Holdren
Assistant to the President for Science and Technology
Director, Office of Science and Technology Policy
Executive Office of the President

Dr. Kathryn D. Sullivan
Under Secretary for Oceans and Atmosphere
NOAA Administrator
U.S. Department of Commerce

19 GREAT PLAINS

KEY MESSAGES

1. **Rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs.**
2. **Changes to crop growth cycles due to warming winters and alterations in the timing and magnitude of rainfall events have already been observed; as these trends continue, they will require new agriculture and livestock management practices.**
3. **Landscape fragmentation is increasing, for example, in the context of energy development activities in the northern Great Plains. A highly fragmented landscape will hinder adaptation of species when climate change alters habitat composition and timing of plant development cycles.**
4. **Communities that are already the most vulnerable to weather and climate extremes will be stressed even further by more frequent extreme events occurring within an already highly variable climate system.**
5. **The magnitude of expected changes will exceed those experienced in the last century. Existing adaptation and planning efforts are inadequate to respond to these projected impacts.**

The Great Plains is a diverse region where climate and water are woven into the fabric of life. Day-to-day, month-to-month, and year-to-year changes in the weather can be dramatic and challenging for communities and their commerce. The region experiences multiple climate and weather hazards, including floods, droughts, severe storms, tornadoes, hurricanes, and winter storms. In much of the Great Plains, too little precipitation falls to replace that needed by humans, plants, and animals. These variable conditions in the Great Plains already stress communities and cause billions of dollars in damage; climate change will add to both stress and costs.

The people of the Great Plains historically have adapted to this challenging climate. Although projections suggest more frequent and more intense droughts, severe rainfall events, and heat waves, communities and individuals can reduce vulnerabilities through the use of new technologies, community-driven policies, and the judicious use of resources. Adaptation (means of coping with changed conditions) and mitigation (reducing emissions of heat-trapping gases

to reduce the speed and amount of climate change) choices can be locally driven, cost effective, and beneficial for local economies and ecosystem services.



Temperature and Precipitation Distribution in the Great Plains

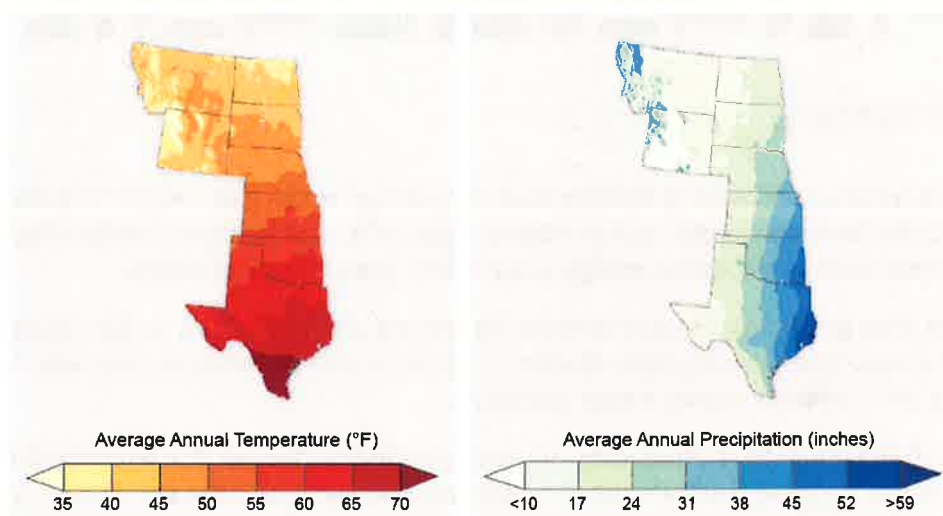


Figure 19.1. The region has a distinct north-south gradient in average temperature patterns (left), with a hotter south and colder north. For precipitation (right), the regional gradient runs west-east, with a wetter east and a much drier west. Averages shown here are for the period 1981-2010. (Figure source: adapted from Kunkel et al. 2013⁴).

Significant climate-related challenges are expected to involve 1) resolving increasing competition among land, water, and energy resources; 2) developing and maintaining sustainable agricultural systems; 3) conserving vibrant and diverse ecological systems; and 4) enhancing the resilience of the region's people to the impacts of climate extremes. These growing challenges will unfold against a changing backdrop that includes a growing urban population and declining rural population, new economic factors that drive incentives for crop and energy production, advances in technology, and shifting policies such as those related to farm and energy subsidies.

The Great Plains region features relatively flat plains that increase in elevation from sea level to more than 5,000 feet at the base of mountain ranges along the Continental Divide. Forested mountains cover western Montana and Wyoming, extensive rangelands spread throughout the Plains, marshes extend along Texas' Gulf Coast, and desert landscapes distinguish far west Texas.¹ A highly diverse climate results from the region's large north-south extent and change of elevation. This regional diversity also means that climate change impacts will vary across the region.

Great Plains residents already must contend with weather challenges from winter storms, extreme heat and cold, severe thunderstorms, drought, and flood-producing rainfall. Texas'

Gulf Coast averages about three tropical storms or hurricanes every four years,² generating coastal storm surge and sometimes bringing heavy rainfall and damaging winds hundreds of miles inland. The expected rise in sea level will result in the potential for greater damage from storm surge along the Gulf Coast of Texas (see Ch. 25: Coasts).

Annual average temperatures range from less than 40°F in the mountains of Wyoming and Montana to more than 70°F in South Texas, with extremes ranging from -70°F in Montana to 121°F in North Dakota and Kansas.³ Summers are long and hot in the south; winters are long and often severe in the north. North Dakota's increase in annual temperature over the past 130 years is the fastest in the contiguous U.S. and is mainly driven by warming winters.⁴

The region has a distinct north-south gradient in average temperature patterns, with a hotter south and colder north (Figure 19.1). Average annual precipitation greater than 50 inches supports lush vegetation in eastern Texas and Oklahoma. For most places, however, average rainfall is less than 30 inches, with some of Montana, Wyoming, and far west Texas receiving less than 15 inches a year. Across much of the region, annual water loss from transpiration by plants and from evaporation is higher than annual precipitation, making these areas particularly susceptible to droughts.

Projected climate change

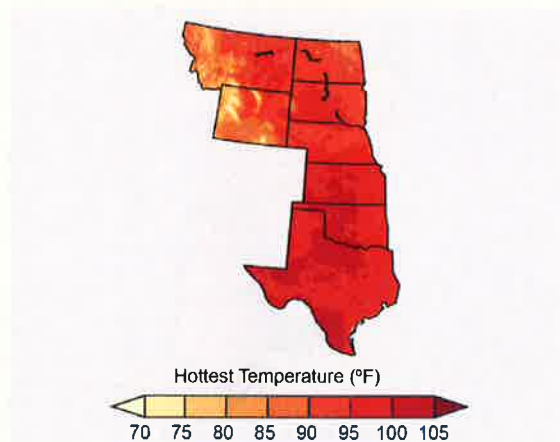
For an average of seven days per year, maximum temperatures reach more than 100°F in the Southern Plains and about 95°F

in the Northern Plains (Figure 19.2). These high temperatures are projected to occur much more frequently, even under a

scenario of substantial reductions in heat-trapping gas (also called greenhouse gas) emissions (B1), with days over 100°F projected to double in number in the north and quadruple in the south by mid-century (Ch. 2: Our Changing Climate, Key Message 7).⁴ Similar increases are expected in the number of nights with minimum temperatures higher than 80°F in the south and 60°F in the north (cooler in mountain regions; see Figure 19.3). These increases in extreme heat will have many

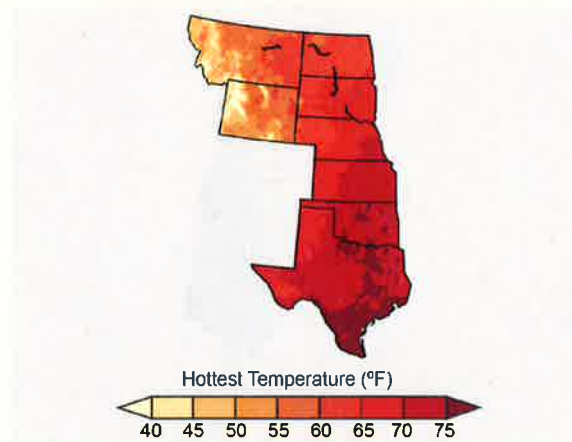
negative consequences, including increases in surface water losses, heat stress, and demand for air conditioning.⁵ These negative consequences will more than offset the benefits of warmer winters, such as lower winter heating demand, less cold stress on humans and animals, and a longer growing season, which will be extended by mid-century an average of 24 days relative to the 1971-2000 average.^{4,5} More overwintering insect populations are also expected.⁵

Historical Temperature on the
7 Hottest Days of the Year



The historical (1971-2000) distribution of temperature for the hottest 2% of days (about seven days a year) echoes the distinct north-south gradient in average temperatures.

Historical Temperature on the
7 Warmest Nights of the Year



The historical (1971-2000) distribution of temperature for the warmest 2% of nights (about seven days a year) echoes the distinct north-south gradient in average temperatures.

Projected Change in Number of Hot Days

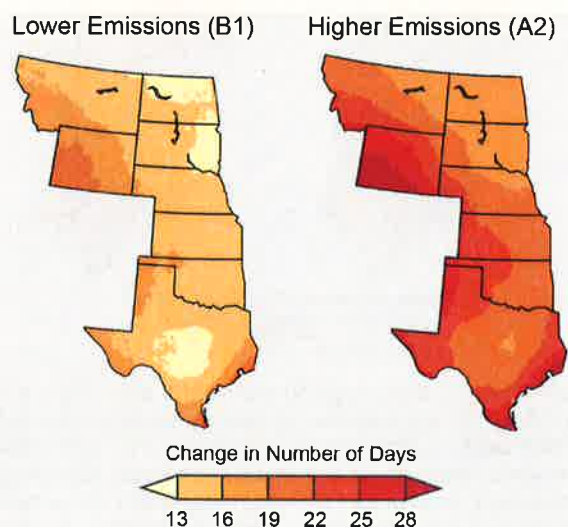


Figure 19.2. The number of days with the hottest temperatures is projected to increase dramatically. By mid-century (2041-2070), the projected change in the number of days exceeding those hottest temperatures is greatest in the western areas and Gulf Coast for both the lower emissions scenario (B1) and for the higher emissions scenario (A2). (Figure source: NOAA NCDC / CICS-NC).

Projected Change in Number of Warm Nights

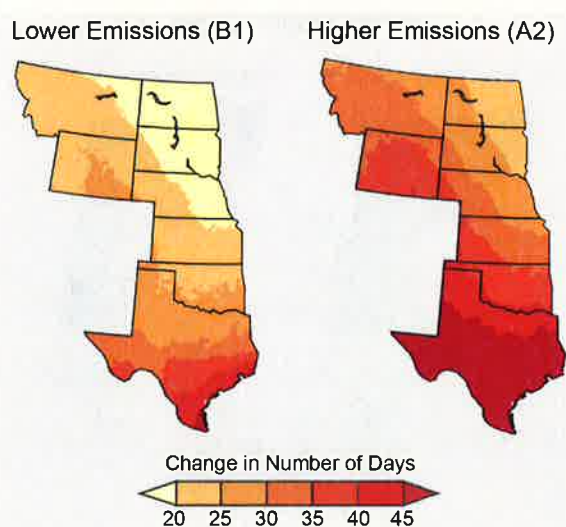
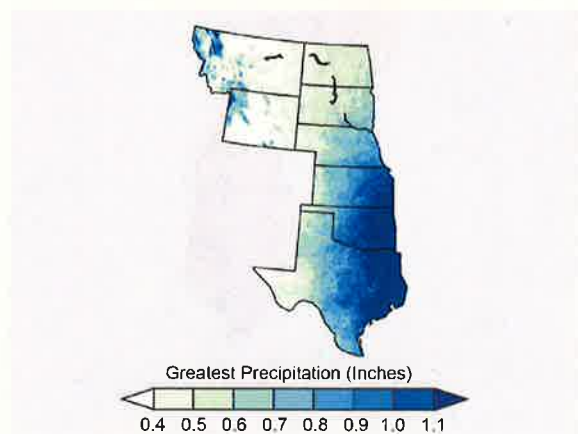


Figure 19.3. The number of nights with the warmest temperatures is projected to increase dramatically. By mid-century (2041-2070), the projected change in number of nights exceeding those warmest temperatures is greatest in the south for both the lower emissions scenario (B1) and for the higher emissions scenario (A2). (Figure source: NOAA NCDC / CICS-NC).

Winter and spring precipitation is projected to increase in the northern states of the Great Plains region under the A2 scenario, relative to the 1971-2000 average. In central areas, changes are projected to be small relative to natural variations (Ch. 2: Our Changing Climate, Key Message 5).⁴ Projected changes in summer and fall precipitation are small except for summer drying in the central Great Plains, although the exact locations

of this drying are uncertain. The number of days with heavy precipitation is expected to increase by mid-century, especially in the north (Ch. 2: Our Changing Climate, Key Message 6). Large parts of Texas and Oklahoma are projected to see longer dry spells (up to 5 more days on average by mid-century). By contrast, changes are projected to be minimal in the north (Ch. 2: Our Changing Climate, Key Message 7).⁴

Historical Amount of Precipitation on the 7 Wettest Days of the Year



The historical (1971-2000) distribution of the greatest 2% of daily precipitation (about seven days a year) echoes the regional west-east gradient in average precipitation.

Projected Change in Number of Heavy Precipitation Days

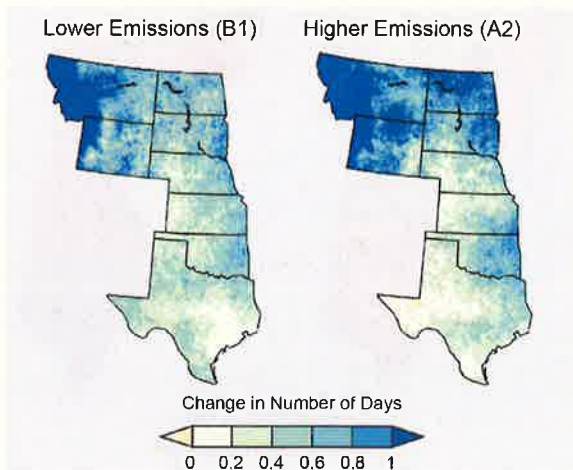


Figure 19.4. The number of days with the heaviest precipitation is not projected to change dramatically. By mid-century (2041-2070), the projected change in days exceeding those precipitation amounts remains greatest in the northern area for both the lower emissions scenario (B1) and for the higher emissions scenario (A2). (Figure source: NOAA NCDC / CICS-NC).

Projected Change in Number of Consecutive Dry Days

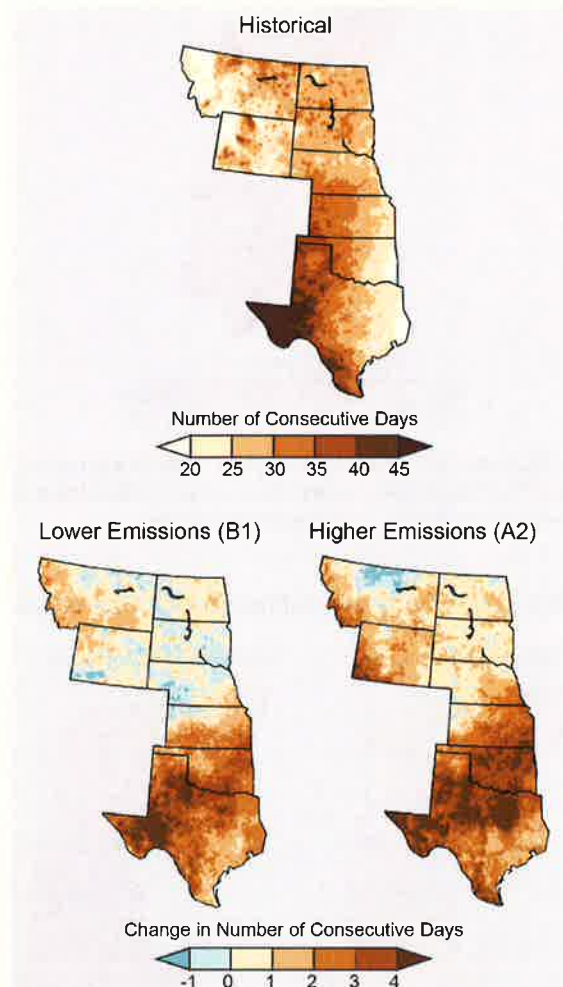


Figure 19.5. Current regional trends of a drier south and a wetter north are projected to become more pronounced by mid-century (2041-2070 as compared to 1971-2000 averages). Maps show the maximum annual number of consecutive days in which limited (less than 0.01 inches) precipitation was recorded on average from 1971 to 2000 (top), projected changes in the number of consecutive dry days assuming substantial reductions in emissions (B1), and projected changes if emissions continue to rise (A2). The southeastern Great Plains, which is the wettest portion of the region, is projected to experience large increases in the number of consecutive dry days. (Figure source: NOAA NCDC / CICS-NC).

Key Message 1: Energy, Water and Land Use

Rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs.

Energy, water, and land use are inherently interconnected,⁶ and climate change is creating a new set of challenges for these critical sectors (Ch. 2: Our Changing Climate; Ch. 10: Energy, Water, and Land).^{7,8,9} The Great Plains is rich with energy resources, primarily from coal, oil, and natural gas, with growing wind and biofuel industries.¹⁰ Texas produces 16% of U.S. energy (mostly from crude oil and natural gas), and Wyoming provides an additional 14% (mostly from coal). North Dakota is the second largest producer of oil in the Great Plains, behind Texas. Nebraska and South Dakota rank third and fifth in biofuel production, and five of the eight Great Plains states have more than 1,000 megawatts of installed wind generation capacity, with Texas topping the list.¹¹ More than 80% of the region's land area is used for agriculture, primarily cropland, pastures, and rangeland. Other land uses include forests, urban and rural development, transportation, conservation, and industry.

Significant amounts of water are used to produce energy^{7,12} and to cool power plants.¹³ Electricity is consumed to collect, purify, and pump water. Although hydraulic fracturing to release oil and natural gas is a small component of total water use,¹⁴ it can be a significant proportion of water use in local and rural groundwater systems. Energy facilities, transmission lines, and wind turbines can fragment both natural habitats and agriculture lands (Ch. 10: Energy, Water, and Land).⁵

The trend toward more dry days and higher temperatures across the south will increase evaporation, decrease water supplies, reduce electricity transmission capacity, and increase cooling demands. These changes will add stress to limited water resources and affect management choices related to irrigation, municipal use, and energy generation.¹⁵ In the Northern Plains, warmer winters may lead to reduced heating demand while hotter summers will increase demand for air conditioning, with the summer increase in demand outweighing the winter decrease (Ch. 4: Energy, Key Message 2).¹⁵

Changing extremes in precipitation are projected across all seasons, including higher likelihoods of both increasing heavy rain and snow events⁴ and more

intense droughts (Ch. 2: Our Changing Climate, Key Messages 5 and 6).¹⁶ Winter and spring precipitation and very heavy precipitation events are both projected to increase in the northern portions of the area, leading to increased runoff and flooding that will reduce water quality and erode soils. Increased snowfall, rapid spring warming, and intense rainfall can combine to produce devastating floods, as is already common along the Red River of the North. More intense rains will also contribute to urban flooding.

Increased drought frequency and intensity can turn marginal lands into deserts. Reduced per capita water storage will continue to increase vulnerability to water shortages.¹⁷ Federal and state legal requirements mandating water allocations for ecosystems and endangered species add further competition for water resources.

Diminishing water supplies and rapid population growth are critical issues in Texas. Because reservoirs are limited and have high evaporation rates, San Antonio has turned to the Edwards Aquifer as a major source of groundwater storage. Nineteen water districts joined to form a Regional Water Alliance for sustainable water development through 2060. The alliance creates a competitive market for buying and selling water rights and simplifies transfer of water rights.



Key Message 2: Sustaining Agriculture

Changes to crop growth cycles due to warming winters and alterations in the timing and magnitude of rainfall events have already been observed; as these trends continue, they will require new agriculture and livestock management practices

The important agricultural sector in the Great Plains, with a total market value of about \$92 billion (the most important being crops at 43% and livestock at 46%),¹⁸ already contends with significant climate variability (Ch. 6: Agriculture). Projected changes in climate, and human responses to it, will affect aspects of the region's agriculture, from the many crops that rely solely on rainfall, to the water and land required for increased energy production from plants, such as fuels made from corn or switchgrass (see Ch. 10: Energy, Water, and Land).

Water is central to the region's productivity. The High Plains Aquifer, including the Ogallala, is a primary source for irrigation.¹⁹ In the Northern Plains, rain recharges this aquifer quickly, but little recharge occurs in the Southern Plains.^{20,21}

Projected changes in precipitation and temperature have both positive and negative consequences to agricultural productivity in the Northern Plains. Projected increases in winter and spring precipitation in the Northern Plains will benefit agricultural productivity by increasing water availability through soil moisture reserves during the early growing season, but this can be offset by fields too wet to plant. Rising temperatures will lengthen the growing season, possibly allowing a second annual crop in some places and some years. Warmer winters pose challenges.^{22,23,24}

For example, some pests and invasive weeds will be able to survive the warmer winters.²⁵ Winter crops that leave dormancy earlier are susceptible to spring freezes.²⁶ Rainfall events already have become more intense,²⁷ increasing erosion and nutrient runoff, and projections are that the frequency and severity of these heavy rainfall events will increase.^{4,28} The Northern Plains will remain vulnerable to periodic drought because much of the projected increase in precipitation is expected to occur in the cooler months while increasing temperatures will result in additional evapotranspiration.

In the Central and Southern Plains, projected declines in precipitation in the south and greater evaporation everywhere due to higher temperatures will increase irrigation demand and exacerbate current stresses on

agricultural productivity. Increased water withdrawals from the Ogallala Aquifer and High Plains Aquifer would accelerate ongoing depletion in the southern parts of the aquifers and limit the ability to irrigate.^{21,29} Holding other aspects of production constant, the climate impacts of shifting from irrigated to dryland agriculture would reduce crop yields by about a factor of two.³⁰ Under these climate-induced changes, adaptation of agricultural practices will be needed, however, there may be constraints on social-ecological adaptive capacity to make these adjustments (see also Ch. 28: Adaptation).

Increases in Irrigated Farmland in the Great Plains

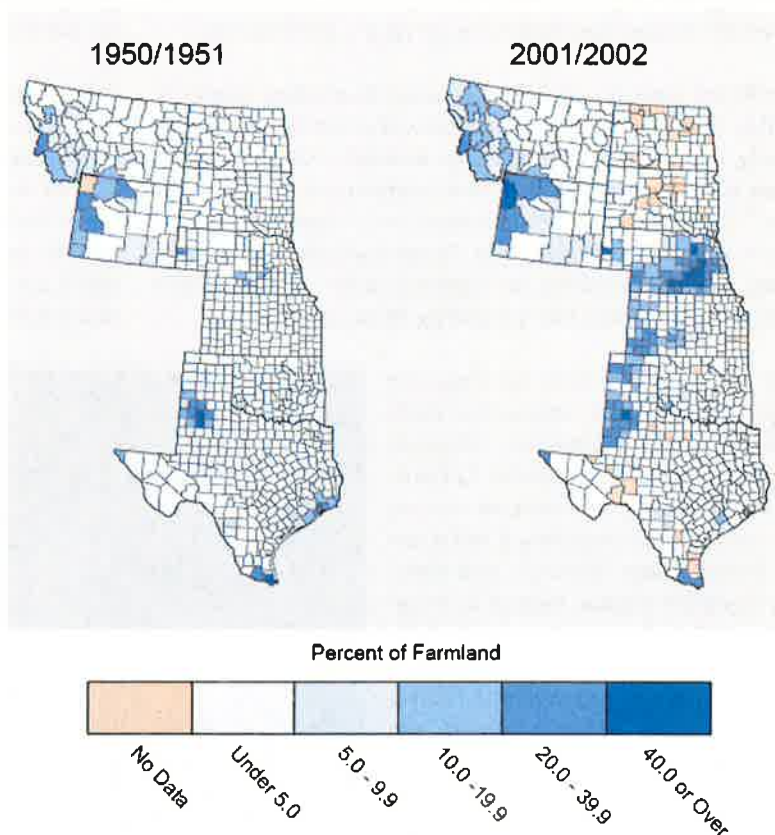


Figure 19.6. Irrigation in western Kansas, Oklahoma, and Texas supports crop development in semiarid areas. Declining aquifer levels threaten the ability to maintain production. Some aquifer-dependent regions, like southeastern Nebraska, have seen steep rises in irrigated farmland, from around 5% to more than 40%, during the period shown. (Figure source: reproduced from *Atlas of the Great Plains* by Stephen J. Lavin, Clark J. Archer, and Fred M. Shelley by permission of the University of Nebraska. Copyright 2011 by the Board of Regents of the University of Nebraska³³).

The projected increase in high temperature extremes and heat waves will negatively affect livestock and concentrated animal feeding operations.³¹ Shortened dormancy periods for winter wheat will lessen an important source of feed for the livestock industry. Climate change may thus result in a northward shift of crop and livestock production in the region. In areas projected to be hotter and drier in the future, maintaining agriculture on marginal lands may become too costly.

Adding to climate change related stresses, growing water demands from large urban areas are also placing stresses on limited water supplies. Options considered in some areas include

groundwater development and purchasing water rights from agricultural areas for transfer to cities.³²

During the droughts of 2011 and 2012, ranchers liquidated large herds due to lack of food and water. Many cattle were sold to slaughterhouses; others were relocated to other pastures through sale or lease. As herds are being rebuilt, there is an opportunity to improve genetic stock, as those least adapted to the drought conditions were the first to be sold or relocated. Some ranchers also used the drought as an opportunity to diversify their portfolio, managing herds in both Texas and Montana.

Key Message 3: Conservation and Adaptation

Landscape fragmentation is increasing, for example, in the context of energy development activities in the northern Great Plains. A highly fragmented landscape will hinder adaptation of species when climate change alters habitat composition and timing of plant development cycles.

Land development for energy production, land transformations on the fringes of urban areas, and economic pressures to remove lands from conservation easements pose threats to natural systems in the Great Plains.³⁴ Habitat fragmentation is already a serious issue that inhibits the ability of species to migrate as climate variability and change alter local habitats.³⁵ Lands that remain out of production are susceptible to invasion from non-native plant species.

Many plant and animal species are responding to rising temperatures by adjusting their ranges at increasingly greater rates.³⁶ These adjustments may also require movement of species that have evolved to live in very specific habitats, which may prove increasingly difficult for these species. The historic bison herds migrated to adapt to climate, disturbance, and associated habitat variability,³⁷ but modern land-use patterns, roads, agriculture, and structures inhibit similar large-scale migration.³⁸ In the playa regions of the southern Great Plains, agricultural practices have modified more than 70% of seasonal lakes larger than 10 acres, and these lakes will be further altered under warming conditions.^{39,40} These changes in seasonal lakes will further affect bird populations⁴¹ and fish populations⁴² in the region.

Observed climate-induced changes have been linked to changing timing of flowering, increases in wildfire activity and pest outbreaks, shifts in species distributions, declines in the abundance of native species, and the spread of invasive species (Ch. 8: Ecosystems). From Texas to Montana, altered flowering patterns due to more frost-free days have increased the length of pollen season for ragweed by as many as 16 days over the period from 1995 to 2009.⁴³ Earlier snowmelt in Wyoming from

1961 to 2002 has been related to the American pipit songbird laying eggs about 5 days earlier.⁴⁴ During the past 70 years, observations indicate that winter wheat is flowering 6 to 10 days earlier as spring temperatures have risen.²³ Some species may be less sensitive to changes in temperature and precipitation, causing first flowering dates to change for some species but not for others.²² Even small shifts in timing, however, can disrupt the integrated balance of ecosystem functions like predator-prey relationships, mating behavior, or food availability for migrating birds.

In addition to climate changes, the increase in atmospheric CO₂ concentrations may offset the drying effects from warming by considerable improvements in plant water-use efficiency, which occur as CO₂ concentrations increase.⁴⁵ However, nutrient content of the grassland communities may be decreased under enriched CO₂ environments, affecting nutritional quality of the grasses and leaves eaten by animals.

The interaction of climate and land-use changes across the Great Plains promises to be challenging and contentious. Opportunities for conservation of native grasslands, including species and processes, depend primarily and most immediately on managing a fragmented network of untillied prairie. Restoration of natural processes, conservation of remnant species and habitats, and consolidation/connection of fragmented areas will facilitate conservation of species and ecosystem services across the Great Plains. However, climate change will complicate current conservation efforts as land fragmentation continues to reduce habitat connectivity. The implementation of adaptive management approaches provides robust options for multiple solutions.

SAGE GROUSE AND CLIMATE CHANGE

Habitat fragmentation inhibits the ability of species such as the Greater Sage Grouse, a candidate for Endangered Species Act protections, to migrate in response to climate change. Its current habitat is threatened by energy development, agricultural practices, and urban development. Rapid expansion of oil and gas fields in North Dakota, Wyoming, and Montana and development of wind farms from North Dakota through Texas are opening new lands to development and contributing to habitat fragmentation of important core Sage Grouse habitat.⁴⁶ The health of Sage Grouse habitat is associated with other species' health as well.⁴⁷ Climate change projections also suggest a shift in preferred habitat locations and increased susceptibility to West Nile Virus.⁴⁸

Historical and Current Range of Sage Grouse Habitat

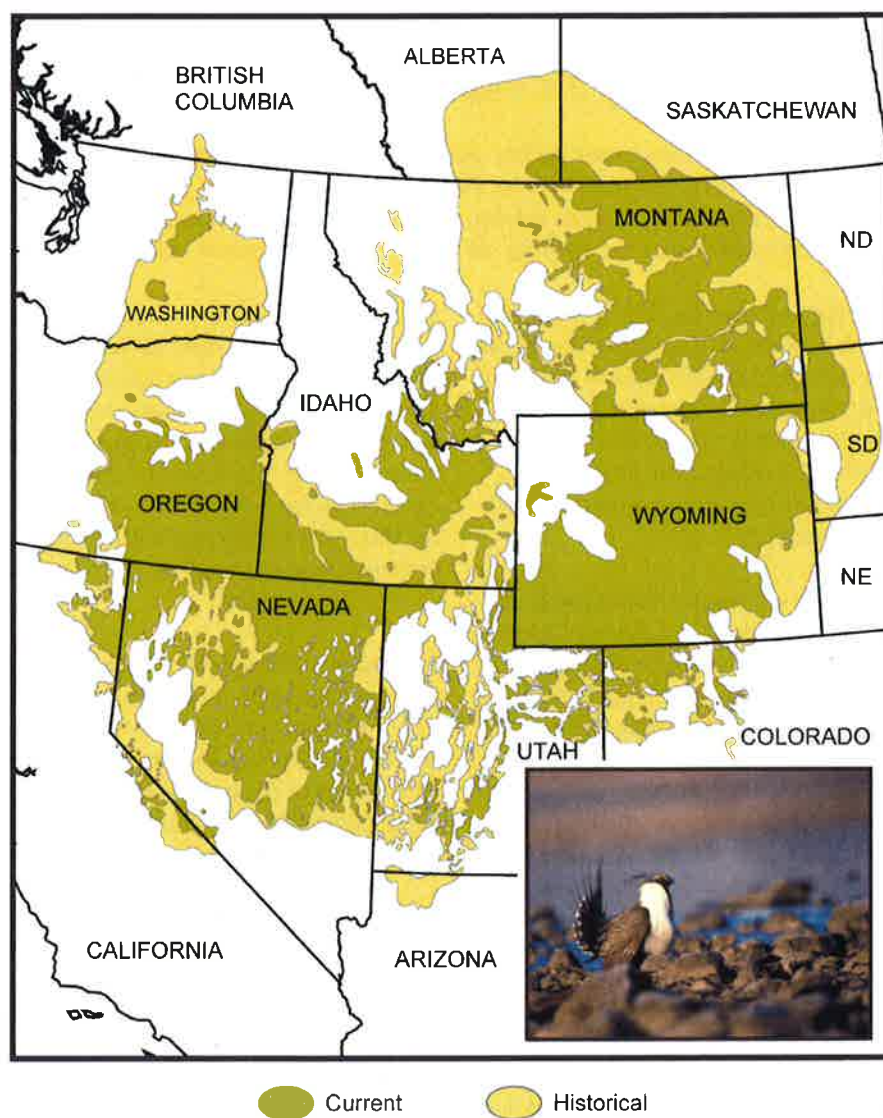


Figure 19.7. Comparing estimates of Greater Sage Grouse distribution from before settlement of the area (light green: prior to about 1800) with the current range (dark green: 2000) shows fragmentation of the sagebrush habitat required by this species. Over the last century, the sagebrush ecosystem has been altered by fire, invasion by new plant species, and conversion of land to agriculture, causing a decline in Sage Grouse populations. (Figure source: adapted from Aldridge et al. 2008.⁴⁹ Photo credit: U.S. Fish and Wildlife Service, Wyoming Ecological Services).

Key Message 4: Vulnerable Communities

Communities that are already the most vulnerable to weather and climate extremes will be stressed even further by more frequent extreme events occurring within an already highly variable climate system.

The Great Plains is home to a geographically, economically, and culturally diverse population. For rural and tribal communities, their remote locations, sparse development, limited local services, and language barriers present greater challenges in responding to climate extremes. Working-age people are moving to urban areas, leaving a growing percentage of elderly people in rural communities (see also Ch. 14: Rural Communities).

Overall population throughout the region is stable or declining, with the exception of substantial increases in urban Texas, tribal communities, and western North Dakota, related in large part to rapid expansion of energy development.⁵⁰ Growing urban areas require more water, expand into forests and crop-

land, fragment habitat, and are at a greater risk of wildfire – all factors that interplay with climate.

Populations such as the elderly, low-income, and non-native English speakers face heightened climate vulnerability. Public health resources, basic infrastructure, adequate housing, and effective communication systems are often lacking in com-

Population Change in the Great Plains

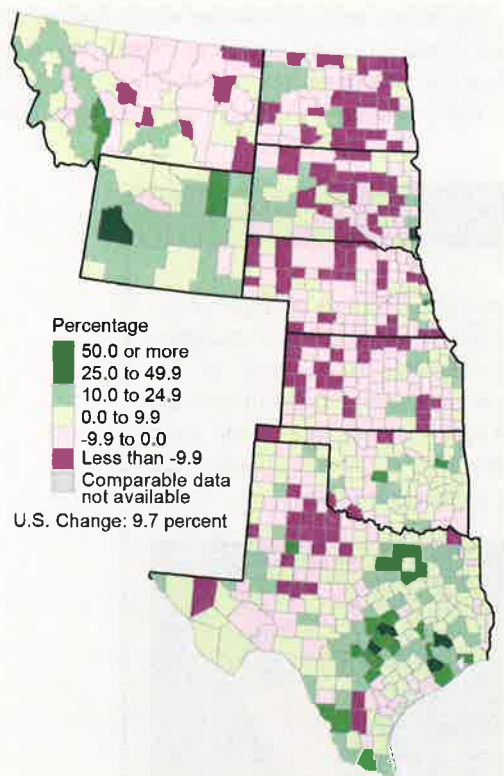


Figure 19.8. Demographic shifts continue to reshape communities in the Great Plains, with many central Great Plains communities losing residents. Rural and tribal communities will face additional challenges in dealing with climate change impacts due to demographic changes in the region (Ch. 14: Rural Communities; Ch. 12: Indigenous Peoples). Figure shows population change from 2000 to 2010. (Figure source: U.S. Census Bureau 2010⁵⁷).

Tribal Populations in the Great Plains

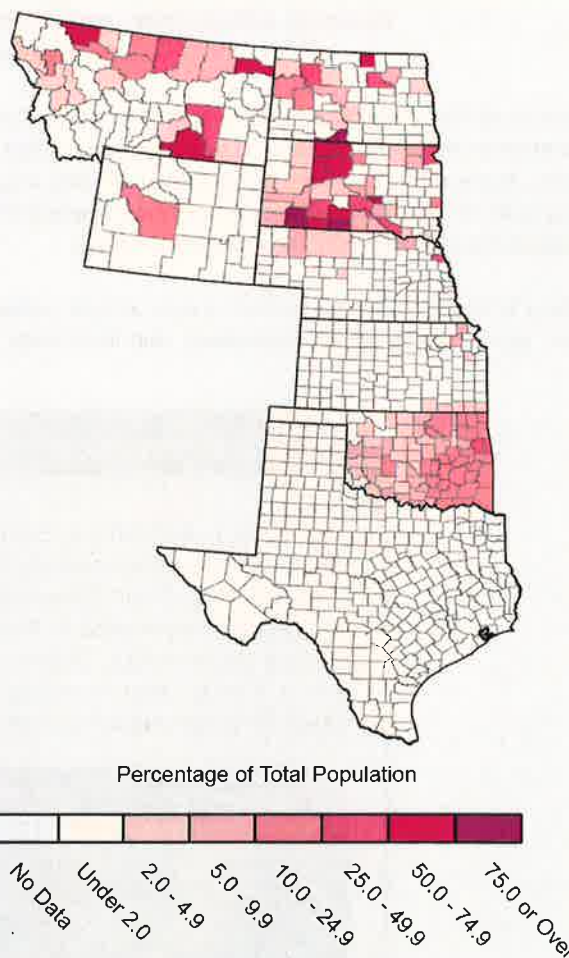


Figure 19.9. Tribal populations in the Great Plains are concentrated near large reservations, like various Sioux tribes in South Dakota and Blackfeet and Crow reservations in Montana; and in Cherokee, Chickasaw, Choctaw, and other tribal lands in Oklahoma (Figure source: reproduced from *Atlas of the Great Plains* by Stephen J. Lavin, Clark J. Archer, and Fred M. Shelley by permission of the University of Nebraska. Copyright 2011 by the Board of Regents of the University of Nebraska³³).

munities that are geographically, politically, and economically isolated.⁵¹ Elderly people are more vulnerable to extreme heat, especially in warmer cities and communities with minimal air conditioning or sub-standard housing.⁵² Language barriers for Hispanics may impede their ability to plan for, adapt to, and respond to climate-related risks.⁵³

The 70 federally recognized tribes in the Great Plains are diverse in their land use, with some located on lands reserved from their traditional homelands, and others residing within

territories designated for their relocation, as in Oklahoma (see also Ch. 12: Indigenous Peoples). While tribal communities have adapted to climate change for centuries, they are now constrained by physical and political boundaries.⁵⁴ Traditional ecosystems and native resources no longer provide the support they used to.⁵⁵ Tribal members have reported the decline or disappearance of culturally important animal species, changes in the timing of cultural ceremonies due to earlier onset of spring, and the inability to locate certain types of ceremonial wild plants.⁵⁶

Key Message 5: Opportunities to Build Resilience

The magnitude of expected changes will exceed those experienced in the last century. Existing adaptation and planning efforts are inadequate to respond to these projected impacts.

The Great Plains is an integrated system. Changes in one part, whether driven by climate or by human decisions, affect other parts. Some of these changes are already underway, and many pieces of independent evidence project that ongoing climate-related changes will ripple throughout the region.

Many of these challenges will cut across sectors: water, land use, agriculture, energy, conservation, and livelihoods. Com-

petition for water resources will increase within already-stressed human and ecological systems, particularly in the Southern Plains, affecting crops, energy production, and how well people, animals, and plants can thrive. The region's ecosystems, economies, and communities will be further strained by increasing intensity and frequency of floods, droughts, and heat waves that will penetrate into the lives and livelihoods of Great Plains residents. Although some communities and

OGLALA LAKOTA RESPOND TO CLIMATE CHANGE

The Oglala Lakota tribe in South Dakota is incorporating climate change adaptation and mitigation planning as they consider long-term sustainable development planning. Their *Oyate Omniciye* plan is a partnership built around six livability principles related to transportation, housing, economic competitiveness, existing communities, federal investments, and local values. Interwoven with this is a vision that incorporates plans to reduce future climate change and adapt to future climate change, while protecting cultural resources.⁵⁸



states have made efforts to plan for these projected changes, the magnitude of the adaptation and planning efforts do not match the magnitude of the expected changes.

Successful adaptation of human and natural systems to climate change would benefit from:

- recognition of and commitment to addressing these challenges;
- regional-scale planning and local-to-regional implementation;⁵⁹
- mainstreaming climate planning into existing natural resource, public health, and emergency management processes;⁶⁰
- renewed emphasis on restoration of ecological systems and processes;⁶¹
- recognition of the value of natural systems to sustaining life;^{62,63}
- sharing information among decision-makers; and
- enhanced alignment of social and ecological goals.⁶⁴

Communities already face tradeoffs in efforts to make efficient and sustainable use of their resources. Jobs, infrastructure, and tax dollars that come with fossil fuel extraction or renewable energy production are important, especially for rural communities. There is also economic value in the conversion of native grasslands to agriculture. Yet the tradeoffs among this development, the increased pressure on water resources, and the effects on conservation need to be considered if the region is to develop climate-resilient communities.

Untilled prairies used for livestock grazing provide excellent targets for native grassland conservation. Partnerships among

many different tribal, federal, state, local, and private land-owners can decrease landscape fragmentation and help manage the connection between agriculture and native habitats. Soil and wetland restoration enhances soil stability and health, water conservation, aquifer recharge, and food sources for wildlife and cattle. Healthy species and ecosystem services support social and economic systems where local products, tourism, and culturally significant species accompany large-scale agriculture, industry, and international trade as fundamental components of society.

Although there is tremendous adaptive potential among the diverse communities of the Great Plains, many local government officials do not yet recognize climate change as a problem that requires proactive planning.^{60,65} Positive steps toward greater community resilience have been achieved through local and regional collaboration and increased two-way communication between scientists and local decision-makers (see Ch. 28: Adaptation). For example, the Institute for Sustainable Communities conducts Climate Leadership Academies that promote peer learning and provides direct technical assistance to communities in a five-state region in the Southwest as part of their support of the Western Adaptation Alliance.⁶⁶ Other regions have collaborated to share information, like the Southeast Florida Regional Compact 2012. Programs such as NOAA's Regional Integrated Sciences and Assessments (RISA) support scientists working directly with communities to help build capacity to prepare for and adapt to both climate variability and climate change.⁶⁷ Climate-related challenges can be addressed with creative local engagement and prudent use of community assets.⁶⁸ These assets include social networks, social capital, indigenous and local knowledge, and informal institutions.

THE SUMMER OF 2011

Future climate change projections include more precipitation in the Northern Great Plains and less in the Southern Great Plains. In 2011, such a pattern was strongly manifest, with exceptional drought and record-setting temperatures in Texas and Oklahoma and flooding in the Northern Great Plains.

Many locations in Texas and Oklahoma experienced more than 100 days over 100°F. Both states set new records for the hottest summer since record keeping began in 1895. Rates of water loss due in part to evaporation were double the long-term average. The heat and drought depleted water resources and contributed to more than \$10 billion in direct losses to agriculture alone. These severe water constraints strained the ability to meet electricity demands in Texas during 2011 and into 2012, a problem exacerbated by the fact that Texas is nearly isolated from the national electricity grid.

These recent temperature extremes were attributable in part to human-induced climate change (approximately 20% of the heat wave magnitude and a doubling of the chance that it would occur).⁶⁹ In the future, average temperatures in this region are expected to increase and will continue to contribute to the intensity of heat waves (Ch. 2: Our Changing Climate, Key Messages 3 and 7).

By contrast to the drought in the Southern Plains, the Northern Plains were exceptionally wet in 2011, with Montana and Wyoming recording all-time wettest springs and the Dakotas and Nebraska not far behind. Record rainfall and snowmelt combined to push the Missouri River and its tributaries beyond their banks and leave much of the Crow Reservation in Montana underwater. The Souris River near Minot, North Dakota, crested at four feet above its previous record, with a flow five times greater than any in the past 30 years. Losses from the flooding were estimated at \$2 billion.

Days Above 100°F in Summer 2011

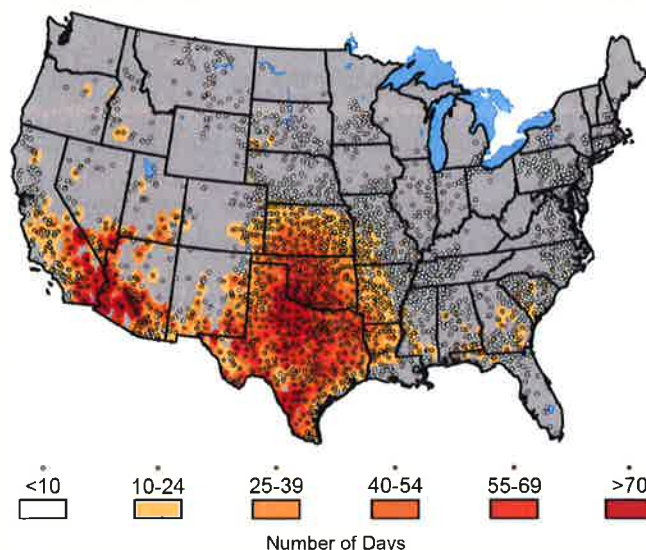


Figure 19.10. In 2011, cities including Houston, Dallas, Austin, Oklahoma City, and Wichita, among others, all set records for the highest number of days recording temperatures of 100°F or higher in those cities' recorded history. The black circles denote the location of observing stations recording 100°F days. (Figure source: NOAA NCDC 2012³).



A Texas State Park police officer walks across a cracked lakebed in August 2011. This lake once spanned more than 5,400 acres.



Increases in heavy downpours contribute to flooding.

21 NORTHWEST

KEY MESSAGES

- 1. Changes in the timing of streamflow related to changing snowmelt are already observed and will continue, reducing the supply of water for many competing demands and causing far-reaching ecological and socioeconomic consequences.**
- 2. In the coastal zone, the effects of sea level rise, erosion, inundation, threats to infrastructure and habitat, and increasing ocean acidity collectively pose a major threat to the region.**
- 3. The combined impacts of increasing wildfire, insect outbreaks, and tree diseases are already causing widespread tree die-off and are virtually certain to cause additional forest mortality by the 2040s and long-term transformation of forest landscapes. Under higher emissions scenarios, extensive conversion of subalpine forests to other forest types is projected by the 2080s.**
- 4. While the agriculture sector's technical ability to adapt to changing conditions can offset some adverse impacts of a changing climate, there remain critical concerns for agriculture with respect to costs of adaptation, development of more climate resilient technologies and management, and availability and timing of water.**

With craggy shorelines, volcanic mountains, and high sage deserts, the Northwest's complex and varied topography contributes to the region's rich climatic, geographic, social, and ecologic diversity. Abundant natural resources – timber, fisheries, productive soils, and plentiful water – remain important to the region's economy.

Snow accumulates in mountains, melting in spring to power both the region's rivers and economy, creating enough hydropower (40% of national total)¹ to export 2 to 6 million megawatt hours per month.² Snowmelt waters crops in the dry interior, helping the region produce tree fruit (number one in the world) and almost \$17 billion worth of agricultural commodities, including 55% of potato, 15% of wheat, and 11% of milk production in the United States.³

Seasonal water patterns shape the life cycles of the region's flora and fauna, including iconic salmon and steelhead, and forested ecosystems, which cover 47% of the landscape.⁴ Along more than 4,400 miles of coastline, regional economic centers are juxtaposed with diverse habitats and ecosystems that support thousands of species of fish and wildlife, including commercial fish and shellfish resources valued at \$480 million in 2011.⁵

Adding to the influence of climate, human activities have altered natural habitats, threatened species, and extracted so much water that there are already conflicts among multiple

users in dry years. More recently, efforts have multiplied to balance environmental restoration and economic growth while evaluating climate risks. As conflicts and tradeoffs increase, the region's population continues to grow, and the regional consequences of climate change continue to unfold. The need to seek solutions to these conflicts is becoming increasingly urgent.

The Northwest's economy, infrastructure, natural systems, public health, and vitally important agriculture sector all face important climate change related risks. Those risks – and possible adaptive responses – will vary significantly across the region.⁶ Impacts on infrastructure, natural systems, human health, and economic sectors, combined with issues of social and ecological vulnerability, will play out quite differently in largely natural areas, like the Cascade Range or Crater Lake National Park, than in urban areas like Seattle and Portland (Ch. 11: Urban),⁷ or among the region's many Native American tribes, like the Umatilla or the Quinault (Ch. 12: Indigenous Peoples).⁸

As climatic conditions diverge from those that determined patterns of development and resource use in the last century, and as demographic, economic, and technological changes also stress local systems, efforts to cope with climate change would benefit from an evolving, iterative risk management approach.⁹

Observed Climate Change

Temperatures increased across the region from 1895 to 2011, with a regionally averaged warming of about 1.3°F.¹⁰ While precipitation has generally increased, trends are small as compared to natural variability. Both increasing and decreasing trends are observed among various locations, seasons, and time periods of analysis (Ch. 2: Our Changing Climate, Figure 2.12). Studies of observed changes in extreme precipitation use different time periods and definitions of “extreme,” but

none find statistically significant changes in the Northwest.¹¹ These and other climate trends include contributions from both human influences (chiefly heat-trapping gas emissions) and natural climate variability, and consequently are not projected to be uniform or smooth across the country or over time (Ch. 2: Our Changing Climate, Key Message 3). They are also consistent with expected changes due to human activities (Ch. 2: Our Changing Climate, Key Message 1).

Projected Climate Change

An increase in average annual temperature of 3.3°F to 9.7°F is projected by 2070 to 2099 (compared to the period 1970 to 1999), depending largely on total global emissions of heat-trapping gases. The increases are projected to be largest in summer. This chapter examines a range of scenarios, including ones where emissions increase and then decline, leading to lower (B1 and RCP 4.5) and medium (A1B) total emissions, and scenarios where emissions continue to rise with higher totals (A2, A1FI, and RCP 8.5 scenarios). Change in annual average precipitation in the Northwest is projected to be within a range of an 11% decrease to a 12% increase for 2030 to 2059 and a 10% decrease to an 18% increase for 2070 to 2099¹² for the B1, A1B, and A2 scenarios (Ch. 2: Our Changing Climate). For every season, some models project decreases and some project increases (Ch. 2: Our Changing Climate, Key Message 5),^{10,12} yet one aspect of seasonal changes in precipitation is largely consistent across climate models: for scenarios of continued growth in global heat-trapping gas

emissions, summer precipitation is projected to decrease by as much as 30% by the end of the century (Ch. 2: Our Changing Climate).^{10,12} Northwest summers are already dry and although a 10% reduction (the average projected change for summer) is a small amount of precipitation, unusually dry summers have many noticeable consequences, including low streamflow west of the Cascades¹³ and greater extent of wildfires throughout the region.¹⁴ Note that while projected temperature increases are large relative to natural variability, the relatively small projected changes in precipitation are likely to be masked by natural variability for much of the century.¹⁵

Ongoing research on the implications of these and other changes largely confirms projections and analyses made over the last decade, while providing more information about how climate impacts are likely to vary from place to place within the region. In addition, new areas of concern, such as ocean acidification, have arisen.

Key Message 1: Water-related Challenges

Changes in the timing of streamflow related to changing snowmelt have been observed and will continue, reducing the supply of water for many competing demands and causing far-reaching ecological and socioeconomic consequences.

Description of Observed and Projected Changes

Observed regional warming has been linked to changes in the timing and amount of water availability in basins with significant snowmelt contributions to streamflow. Since around 1950, area-averaged snowpack on April 1 in the Cascade Mountains decreased about 20%,¹⁶ spring snowmelt occurred 0 to 30 days earlier depending on location,¹⁷ late winter/early spring streamflow increases ranged from 0% to greater than 20% as a fraction of annual flow,^{18,19} and summer flow decreased 0% to 15% as a fraction of annual flow,¹⁷ with exceptions in smaller areas and shorter time periods.²⁰

Hydrologic response to climate change will depend upon the dominant form of precipitation in a particular watershed, as well as other local characteristics including elevation, aspect, geology, vegetation, and changing land use.²² The largest responses are expected to occur in basins with significant snow accumulation, where warming increases winter flows and advances the timing of spring melt.^{18,23} By 2050, snowmelt is pro-



jected to shift three to four weeks earlier than the 20th century average, and summer flows are projected to be substantially lower, even for an emissions scenario that assumes substantial emissions reductions (B1).²⁴ In some North Cascade rivers, a significant fraction (10% to 30%) of late summer flow originates as glacier melt;²⁵ the consequences of eventual glacial disappearance are not well quantified. Basins with a significant groundwater component may be less responsive to climate change than indicated here.²⁶

Changes in river-related flood risk depends on many factors, but warming is projected to increase flood risk the most in mixed basins (those with both winter rainfall and late spring snowmelt-related runoff peaks) and remain largely unchanged in snow-dominant basins.²⁷ Regional climate models project increases of 0% to 20% in extreme daily precipitation, depending on location and definition of "extreme" (for example, annual wettest day).

Observed Shifts in Streamflow Timing

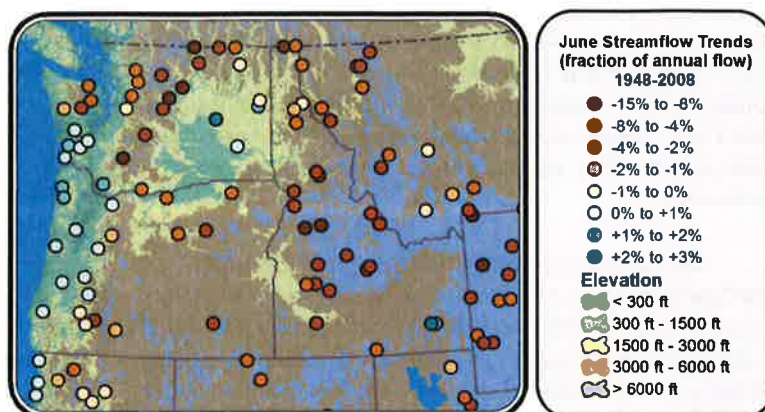
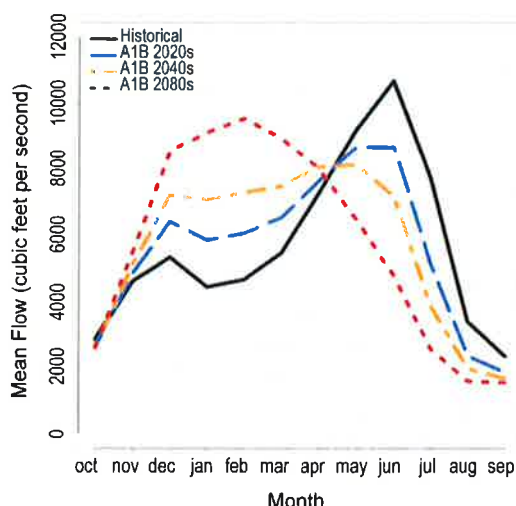


Figure 21.1. Reduced June flows in many Northwest snow-fed rivers is a signature of warming in basins that have a significant snowmelt contribution. The fraction of annual flow occurring in June increased slightly in rain-dominated coastal basins and decreased in mixed rain-snow basins and snowmelt-dominated basins over the period 1948 to 2008.²¹ The high flow period is in June for most Northwest river basins; decreases in summer flows can make it more difficult to meet a variety of competing human and natural demands for water. (Figure source: adapted from Fritze et al. 2011²¹).

Future Shift in Timing of Stream Flows



Reduced Summer Flows

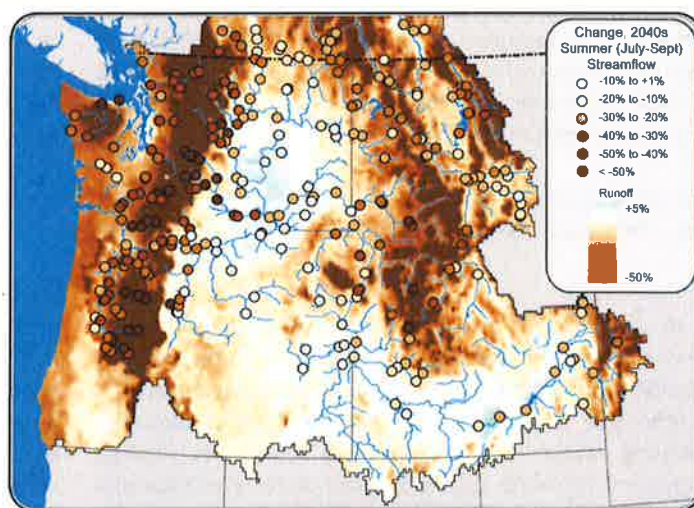


Figure 21.2. (Left) Projected increased winter flows and decreased summer flows in many Northwest rivers will cause widespread impacts. Mixed rain-snow watersheds, such as the Yakima River basin, an important agricultural area in eastern Washington, will see increased winter flows, earlier spring peak flows, and decreased summer flows in a warming climate. Changes in average monthly streamflow by the 2020s, 2040s, and 2080s (as compared to the period 1916 to 2006) indicate that the Yakima River basin could change from a snow-dominant to a rain-dominant basin by the 2080s under the A1B emissions scenario (with eventual reductions from current rising emissions trends). (Figure source: adapted from Elsner et al. 2010)²⁴.

(Right) Natural surface water availability during the already dry late summer period is projected to decrease across most of the Northwest. The map shows projected changes in local runoff (shading) and streamflow (colored circles) for the 2040s (compared to the period 1915 to 2006) under the same scenario as the left figure (A1B).²⁹ Streamflow reductions such as these would stress freshwater fish species (for instance, endangered salmon and bull trout) and necessitate increasing tradeoffs among conflicting uses of summer water. Watersheds with significant groundwater contributions to summer streamflow may be less responsive to climate change than indicated here.²⁶

Averaged over the region, the number of days with more than one inch of precipitation is projected to increase 13% in 2041 to 2070 compared with 1971 to 2000 under a scenario that assumes a continuation of current rising emissions trends (A2),¹⁰ though these projections are not consistent across models.²⁸ This increase in heavy downpours could increase flood risk in mixed rain-snow and rain-dominant basins, and could also increase stormwater management challenges in urban areas.

Consequences and Likelihoods of Changes

Reservoir systems have multiple objectives, including irrigation, municipal and industrial use, hydropower production, flood control, and preservation of habitat for aquatic species. Modeling studies indicate, with near 100% likelihood and for all emissions scenarios, that reductions in summer flow will occur by 2050 in basins with significant snowmelt (for example, Elsner et al. 2010²⁴). These reduced flows will require more tradeoffs among objectives of the whole system of reservoirs,³⁰ especially with the added challenges of summer increases in electric power demand for cooling³¹ and additional water consumption by crops and forests.^{10,32} For example, reductions in hydropower production of as much as 20% by the 2080s could be required to preserve in-stream flow targets for fish in the Columbia River basin.³³ Springtime irrigation diversions increased between 1970 and 2007 in the Snake River basin, as earlier snowmelt led to reduced spring soil moisture.³⁴ In the absence of human adaptation, annual hydropower production is much more likely to decrease than to increase in the Columbia River basin; economic impacts of hydropower changes could be hundreds of millions of dollars per year.³⁵

Region-wide summer temperature increases and, in certain basins, increased river flooding and winter flows and



decreased summer flows, will threaten many freshwater species, particularly salmon, steelhead, and trout.²⁷ Rising temperatures will increase disease and/or mortality in several iconic salmon species, especially for spring/summer Chinook and sockeye in the interior Columbia and Snake River basins.³⁶ Some Northwest streams³⁰ and lakes have already warmed over the past three decades, contributing to changes such as earlier Columbia River sockeye salmon migration³⁷ and earlier blooms of algae in Lake Washington.³⁸ Relative to the rest of the United States, Northwest streams dominated by snowmelt runoff appear to be less sensitive, in the short term, to warming due to the temperature buffering provided by snowmelt and groundwater contributions to those streams.³⁹ However, as snowpack declines, the future sensitivity to warming is likely to increase in these areas.⁴⁰ By the 2080s, suitable habitat for the four trout species of the interior western U.S. is projected to decline 47% on average, compared to the period 1978-1997.⁴¹ As species respond to climate change in diverse ways, there is potential for ecological mismatches to occur – such as in the timing of the emergence of predators and their prey.³⁸

Adaptive Capacity and Implications for Vulnerability

The ability to adapt to climate changes is strengthened by extensive water resources infrastructure, diversity of institutional arrangements,⁴² and management agencies that are responsive to scientific input. However, over-allocation of existing water supply, conflicting objectives, limited management flexibility caused by rigid water allocation and



operating rules, and other institutional barriers to changing operations continue to limit progress towards adaptation in many parts of the Columbia River basin.^{43,44} Vulnerability to projected changes in snowmelt timing is probably highest in basins with the largest hydrologic response to warming and lowest management flexibility – that is, fully allocated, mid-elevation, temperature-sensitive, mixed rain-snow watersheds with existing conflicts among users of summer water. Regional power planners have expressed concerns over the existing hydroelectric system's potential inability to provide adequate summer electricity given the combination of climate change, demand growth, and operating constraints.¹ Vulnerability is probably lowest where hydrologic change is likely to be smallest (in rain-dominant basins) and where institutional arrangements are simple and current natural and human demands rarely exceed current water availability.^{43,45,46}

The adaptive capacity of freshwater ecosystems also varies and, in managed basins, will depend on the degree to which

the need to maintain streamflows and water quality for fish and wildlife is balanced with human uses of water resources. In highly managed rivers, release of deeper, colder water from reservoirs could offer one of the few direct strategies to

lower water temperatures downstream.⁴⁷ Actions to improve stream habitat, including planting trees for shade, are being tested. Some species may be able to change behavior or take advantage of cold-water refuges.⁴⁸

Key Message 2: Coastal Vulnerabilities

In the coastal zone, the effects of sea level rise, erosion, inundation, threats to infrastructure and habitat, and increasing ocean acidity collectively pose a major threat to the region.

With diverse landforms (such as beaches, rocky shorelines, bluffs, and estuaries), coastal and marine ecosystems, and human uses (such as rural communities, dense urban areas, international ports, and transportation), the Northwest coast will experience a wide range of climate impacts.

Description of Observed and Projected Changes

Global sea levels have risen about 8 inches since 1880 and are projected to rise another 1 to 4 feet by 2100 (Ch. 2: Our Changing Climate, Key Message 10). Many local and regional factors can modify the global trend, including vertical land movement, oceanic winds and circulation, sediment compaction, subterranean fluid withdrawal (such as groundwater and natural gas), and other geophysical factors such as the gravitational effects of major ice sheets and glaciers on regional ocean levels.

Much of the Northwest coastline is rising due to a geophysical force known as “tectonic uplift,” which raises the land surface. Because of this, apparent sea level rise is less than the currently observed global average. However, a major earthquake along the Cascadia subduction zone, expected within the next few hundred years, would immediately reverse centuries of uplift and, based on historical evidence, increase relative sea level 40 inches or more.^{49,50} On the other hand, some Puget Sound



locations are currently experiencing subsidence (where land is sinking or settling) and could see the reverse effect, witnessing immediate uplift during a major earthquake and lowered relative sea levels.^{51,52}

Taking into account many of these factors and considering a wider range of emissions scenarios than are used in this assessment (Appendix 5: Scenarios and Models), a recent

Projected Relative Sea Level Rise for the Latitude of Newport, Oregon

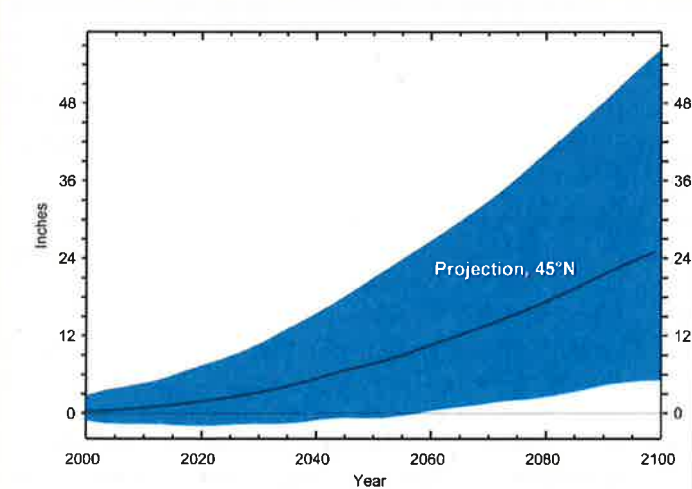


Figure 21.3. Projected relative sea level rise for the latitude of Newport, Oregon (relative to the year 2000) is based on a broader suite of emissions scenarios (ranging from B1 to A1FI) and a more detailed and regionally-focused calculation than those generally used in this assessment (see Ch. 2: Our Changing Climate).⁵⁰ The blue area shows the range of relative sea level rise, and the black line shows the projection, which incorporates global and regional effects of warming oceans, melting land ice, and vertical land movements.⁵⁰ Given the difficulty of assigning likelihood to any one possible trajectory of sea level rise at this time, a reasonable risk assessment would consider multiple scenarios within the full range of possible outcomes shown, in conjunction with long- and short-term compounding effects, such as El Niño-related variability and storm surge. (Data from NRC 2012⁶⁰).

evaluation calculated projected sea level rise and ranges for the years 2030, 2050, and 2100 (relative to 2000) based on latitude for Washington, Oregon, and California (see Figure 21.3).⁵⁰ In addition to long-term climate-driven changes in sea level projected for the Northwest, shorter-term El Niño conditions can increase regional sea level by about 4 to 12 inches for periods of many months.^{50,53}

Northwest coastal waters, some of the most productive on the West Coast,⁵⁴ have highly variable physical and ecological conditions as a result of seasonal and year-to-year changes in upwelling of deeper marine water that make longer-term changes difficult to detect. Coastal sea surface temperatures have increased⁵⁵ and summertime fog has declined between 1900 and the early 2000s, both of which could be consequences of weaker upwelling winds.⁵⁶ Projected changes include increasing but highly variable acidity,^{57,58,59} increasing surface water temperature (2.2°F from the period 1970 to 1999 to the period 2030 to 2059),⁶⁰ and possibly changing storminess.⁶¹ Climate models show inconsistent projections for the future of Northwest coastal upwelling.^{12,62}

Consequences and Likelihoods of Changes

In Washington and Oregon, more than 140,000 acres of coastal lands lie within 3.3 feet in elevation of high tide.⁶³ As sea levels continue to rise, these areas will be inundated more frequently. Many coastal wetlands, tidal flats, and beaches will probably decline in quality and extent as a result of sea level rise, particularly where habitats cannot shift inland because of topographical limitations or physical barriers resulting from human development. Species such as shorebirds and forage fish (small fish eaten by larger fish, birds, or mammals) would be harmed, and coastal infrastructure and communities would be at greater risk from coastal storms.⁶⁴

Ocean acidification threatens culturally and commercially significant marine species directly affected by changes in ocean chemistry (such as oysters) and those affected by changes in the marine food web (such as Pacific salmon⁶⁵). Northwest coastal waters are among the most acidified worldwide, especially in spring and summer with coastal upwelling^{58,59,66} combined with local factors in estuaries.^{57,58}

Increasing coastal water temperatures and changing ecological conditions may alter the ranges, types, and abundances of marine species.^{67,68} Recent warm periods in the coastal ocean, for example, saw the arrival of subtropical and offshore marine species from zooplankton to top predators such as striped marlin, tuna, and yellowtail more common to the Baja area.⁶⁹ Warmer water in regional estuaries (such as Puget Sound) may contribute to a higher incidence of harmful blooms of algae linked to paralytic shellfish poisoning,⁷⁰ and may result in adverse economic impacts from beach closures affecting recreational harvesting of shellfish such as razor clams.⁷¹ Toxicity of some harmful algae appears to be increased by acidification.⁷²

Rising Sea Levels and Changing Flood Risks in Seattle

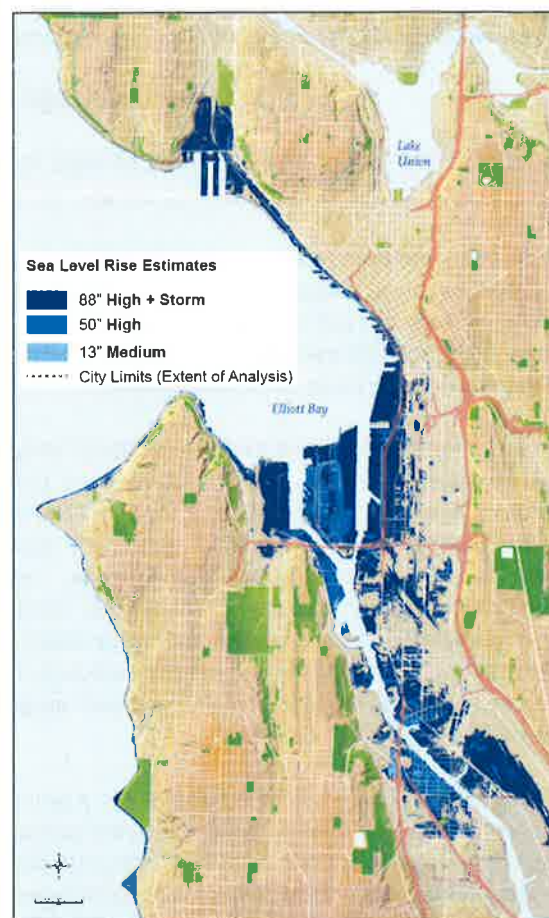


Figure 21.4. Areas of Seattle projected by Seattle Public Utilities to be below sea level during high tide (Mean Higher High Water) and therefore at risk of flooding or inundation are shaded in blue under three levels of sea level rise,⁷⁸ assuming no adaptation. (High [50 inches] and medium [13 inches] levels are within the range projected for the Northwest by 2100; the highest level [88 inches] includes the compounding effect of storm surge, derived from the highest observed historical tide in Seattle⁷⁹). Unconnected inland areas shown to be below sea level may not be inundated, but could experience problems due to areas of standing water caused by a rise in the water table and drainage pipes backed up with seawater. (Figure source: Seattle Public Utilities⁸⁰).

Many human uses of the coast – for living, working, and recreating – will also be negatively affected by the physical and ecological consequences of climate change. Erosion, inundation, and flooding will threaten public and private property along the coast; infrastructure, including wastewater treatment plants;^{7,73} stormwater outfalls;^{74,75} ferry terminals;⁷⁶ and coastal road and rail transportation, especially in Puget Sound.⁷⁷ Municipalities from Seattle⁷⁴ and Olympia,⁷⁵ Washington, to Neskowin, Oregon, have mapped risks from the combined effects of sea level rise and other factors.

Adaptive Capacity and Implications for Vulnerability

Human activities have increased the vulnerability of many coastal ecosystems, by degrading and eliminating habitat⁸¹ and by building structures that, along with natural bluffs, thwart inland movement of many remaining habitats. In Puget Sound, for example, seawalls, bulkheads, and other structures have modified an estimated one-third of the shoreline,⁸² though some restoration has occurred. Human responses to erosion and sea level rise, especially shoreline armoring, will largely

determine the viability of many shallow-water and estuarine ecosystems.^{68,82,83} In communities with few alternatives to existing coastal transportation networks, such as on parts of Highway 101 in Oregon, sea level rise and storm surges will pose an increasing threat to local commerce and livelihoods. Finally, there are few proven options for ameliorating projected ocean acidification.⁸⁴

Adapting the Nisqually River Delta to Sea Level Rise



Figure 21.5. In Washington's Nisqually River Delta, estuary restoration on a large scale to assist salmon and wildlife recovery provides an example of adaptation to climate change and sea level rise. After a century of isolation behind dikes (left), much of the Nisqually National Wildlife Refuge was reconnected with tidal flow in 2009 by removal of a major dike and restoration of 762 acres (right), with the assistance of Ducks Unlimited and the Nisqually Indian Tribe. This reconnected more than 21 miles of historical tidal channels and floodplains with Puget Sound.⁸⁶ A new exterior dike was constructed to protect freshwater wetland habitat for migratory birds from tidal inundation and future sea level rise. Combined with expansion of the authorized Refuge boundary, ongoing acquisition efforts to expand the Refuge will enhance the ability to provide diverse estuary and freshwater habitats despite rising sea level, increasing river floods, and loss of estuarine habitat elsewhere in Puget Sound. This project is considered a major step in increasing estuary habitat and recovering the greater Puget Sound estuary. (Photo credits: (left) Jesse Barham, U.S. Fish and Wildlife Service; (right) Jean Takekawa, U.S. Fish and Wildlife Service).

Key Message 3: Impacts on Forests

The combined impacts of increasing wildfire, insect outbreaks, and tree diseases are already causing widespread tree die-off and are virtually certain to cause additional forest mortality by the 2040s and long-term transformation of forest landscapes. Under higher emissions scenarios, extensive conversion of subalpine forests to other forest types is projected by the 2080s.

Evergreen coniferous forests are a prominent feature of Northwest landscapes, particularly in mountainous areas. Forests support diverse fish and wildlife species, promote

clean air and water, stabilize soils, and store carbon. They support local economies and traditional tribal uses and provide recreational opportunities.

Description of Observed and Projected Changes

Climate change will alter Northwest forests by increasing wildfire risk and insect and tree disease outbreaks, and by forcing longer-term shifts in forest types and species (see Ch 7: Forests). Many impacts will be driven by water deficits, which increase tree stress and mortality, tree vulnerability to insects, and fuel flammability. The cumulative effects of disturbance – and possibly interactions between insects and fires – will cause the greatest changes in Northwest forests.^{86,87} A similar outlook is expected for the Southwest region (see Ch. 20: Southwest, Key Message 3).

Although wildfires are a natural part of most Northwest forest ecosystems, warmer and drier conditions have helped increase the number and extent of wildfires in western U.S. forests since the 1970s.^{14,87,88,89} This trend is expected to continue under future climate conditions. By the 2080s, the median annual area burned in the Northwest would quadruple relative to the 1916 to 2007 period to 2 million acres (range of 0.2 to 9.8 million acres) under the A1B scenario. Averaged over the region, this would increase the probability that 2.2 million acres would burn in a year from 5% to nearly 50%.¹⁴ Within the region, this probability will vary substantially with sensitivity of fuels to climatic conditions and local variability in fuel type and amount, which are in turn a product of forest type, effectiveness of fire suppression, and land use. For example, in the Western Cascades, the year-to-year variability in area burned is difficult to attribute to climate conditions, while fire in the eastern Cascades and other specific vegetation zones is responsive to climate.¹⁴ How individual fires behave in the future and what impacts they have will depend on factors we cannot yet project, such as extreme daily weather and forest fuel conditions.

Higher temperatures and drought stress are contributing to outbreaks of mountain pine beetles that are increasing pine mortality in drier Northwest forests.^{90,91} This trend is projected to continue with ongoing warming.^{14,92,93,94} Between now and the end of this century, the elevation of suitable beetle habitat

Forest Mortality



Figure 21.6. Forest mortality due to fire and insect activity is already evident in the Northwest. Continued changes in climate in coming decades are expected to increase these effects. Trees killed by a fire (left side of watershed) and trees killed by mountain pine beetle and spruce beetle infestations (orange and gray patches, right side of watershed) in subalpine forest in the Pasayten Wilderness, Okanogan Wenatchee National Forest, Washington, illustrates how cumulative disturbances can affect forests. (Photo credit: Jeremy Littell, USGS).

is projected to increase as temperature increases, exposing higher-elevation forests to the pine beetle, but ultimately limiting available area as temperatures exceed the beetles' optimal temperatures.^{14,92,93} As a result, the proportion of Northwest pine forests where mountain pine beetles are most likely to survive is projected to first increase (27% higher in 2001 to 2030 compared to 1961 to 1990) and then decrease (about 49% to 58% lower by 2071 to 2100).⁹² For many tree species, the most climatically suited areas will shift from their current locations, increasing vulnerability to insects, disease, and fire in areas that become unsuitable. Eighty-five percent of the current range of three species that are host to pine beetles is projected to be climatically unsuitable for one or more of those species by the 2060s,^{14,95} while 21 to 38 currently existing plant species may no longer find climatically appropriate habitat in the Northwest by late this century.⁹⁶

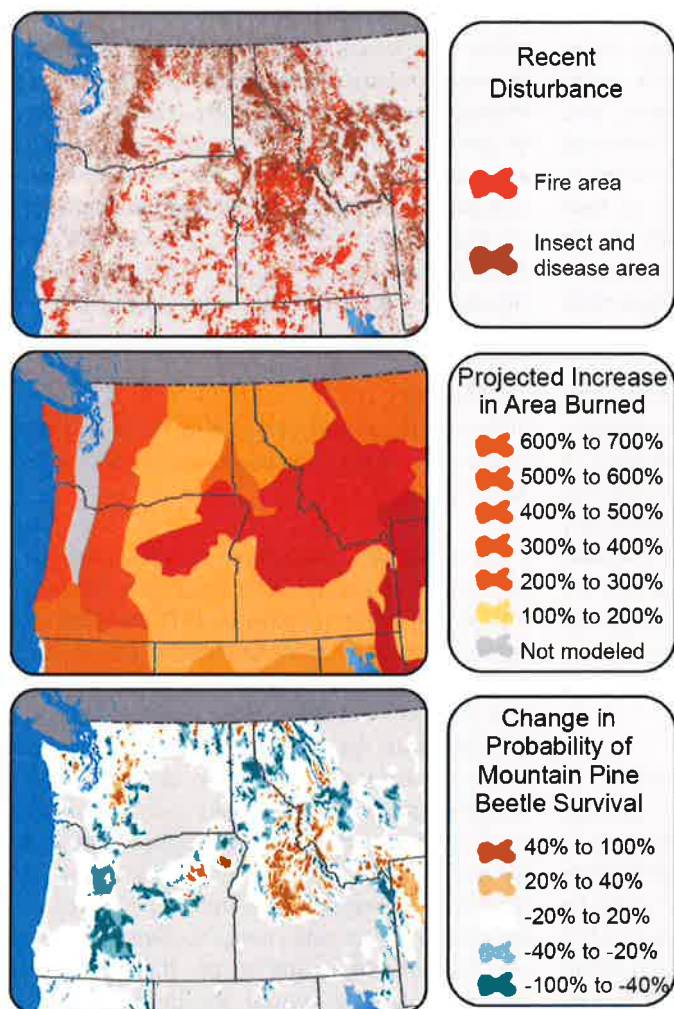
Consequences and Likelihoods of Changes

The likelihood of increased disturbance (fire, insects, diseases, and other sources of mortality) and altered forest distribution are very high in areas dominated by natural vegetation, and the resultant changes in habitat would affect native species and ecosystems. Subalpine forests and alpine ecosystems are especially at risk and may undergo almost complete conversion to other vegetation types by the 2080s (A2 and B1;¹⁰⁴ A2;¹⁰⁵ Ensemble A2, B1, B2;¹⁰⁶). While increased area burned can be statistically estimated from climate projections, changes in the risk of very large, high-intensity, stand-replacing fires

cannot yet be predicted, but such events could have enormous impacts for forest-dependent species.⁸⁸ Increased wildfire could exacerbate respiratory and cardiovascular illnesses in nearby populations due to smoke and particulate pollution (Ch. 9: Human Health).^{107,108}

These projected forest changes will have moderate economic impacts for the region as a whole, but could significantly affect local timber revenues and bioenergy markets.¹⁰⁹

Insects and Fire in Northwest Forests

**Figure 21.7.**

(Top) Insects and fire have cumulatively affected large areas of the Northwest and are projected to be the dominant drivers of forest change in the near future. Map shows areas recently burned (1984 to 2008)^{97,98} or affected by insects or disease (1997 to 2008).⁹⁹

(Middle) Map indicates the increases in area burned that would result from the regional temperature and precipitation changes associated with a 2.2°F global warming¹⁰⁰ across areas that share broad climatic and vegetation characteristics.¹⁰¹ Local impacts will vary greatly within these broad areas with sensitivity of fuels to climate.¹⁴

(Bottom) Projected changes in the probability of climatic suitability for mountain pine beetles for the period 2001 to 2030 (relative to 1961 to 1990), where brown indicates areas where pine beetles are projected to increase in the future and green indicates areas where pine beetles are expected to decrease in the future. Changes in probability of survival are based on climate-dependent factors important in beetle population success, including cold tolerance,¹⁰² spring precipitation,¹⁰³ and seasonal heat accumulation.^{91,92}

Adaptive Capacity and Implications for Vulnerability

Ability to prepare for these changes varies with land ownership and management priorities. Adaptation actions that decrease forest vulnerability exist, but none is appropriate across all of the Northwest's diverse climate threats, land-use histories, and management objectives.^{86,110} Surface and canopy thinning can reduce the occurrence and effects of high severity fire in

currently low severity fire systems, like drier eastern Cascades forests,¹¹¹ but may be ineffective in historically high-severity-fire forests, like the western Cascades, Olympics, and some subalpine forests. It is possible to use thinning to reduce tree mortality from insect outbreaks,^{86,112} but not on the scale of the current outbreaks in much of the West.

Key Message 4: Adapting Agriculture

While the agriculture sector's technical ability to adapt to changing conditions can offset some adverse impacts of a changing climate, there remain critical concerns for agriculture with respect to costs of adaptation, development of more climate resilient technologies and management, and availability and timing of water.

Agriculture provides the economic and cultural foundation for Northwest rural populations and contributes substantively to the overall economy. Agricultural commodities and food

production systems contributed 3% and 11% of the region's gross domestic product, respectively, in 2009.¹¹³ Although the overall consequences of climate change will probably be lower

in the Northwest than in certain other regions, sustainability of some Northwest agricultural sectors is threatened by soil

erosion¹¹⁴ and water supply uncertainty, both of which could be exacerbated by climate change.

Description of Observed and Projected Changes

Northwest agriculture's sensitivity to climate change stems from its dependence on irrigation water, a specific range of temperatures, precipitation, and growing seasons, and the sensitivity of crops to temperature extremes. Projected warming will reduce the availability of irrigation water in snowmelt-fed basins and increase the probability of heat stress to field crops and tree fruit. Some crops will benefit from a longer growing season¹¹⁵ and/or higher atmospheric carbon dioxide, at least for a few decades.^{115,116} Longer-term consequences are less certain. Changes in plant diseases,

pests, and weeds present additional potential risks. Higher average temperatures generally can exacerbate pest pressure through expanded geographic ranges, earlier emergence or arrival, and increased numbers of pest generations (for example, Ch. 6: Agriculture).¹¹⁷ Specifics differ among pathogen and pest species and depend upon multiple interactions (Ch. 6: Agriculture)¹¹⁸ preventing region-wide generalizations. Research is needed to project changes in vulnerabilities to pest, disease, and weed complexes for specific cropping systems in the Northwest.

Consequences of Changes

Because much of the Northwest has low annual precipitation, many crops require irrigation. Reduction in summer flows in snow-fed rivers (see Figure 21.2), coupled with warming that could increase agricultural and other demands, potentially produces irrigation water shortages.¹⁰⁸ The risk of a water-short year – when Yakima basin junior water rights holders are allowed only 75% of their water right amount – is projected to increase from 14% in the late 20th century to 32% by 2020 and 77% by 2080, assuming no adaptation and under the A1B scenario.⁴⁶

Assuming adequate nutrients and excluding effects of pests, weeds, and diseases, projected increases in average temperature and hot weather episodes and decreases in summer soil moisture would reduce yields of spring and winter wheat in rain-fed production zones of Washington State by the end of this century by as much as 25% relative to 1975 to 2005. However, carbon dioxide fertilization should offset these effects, producing net yield increases as great as 33% by 2080.¹¹⁵ Similarly, for irrigated potatoes in Washington State, carbon dioxide fertilization is projected to mostly offset direct climate change related yield losses, although yields are

still projected to decline by 2% to 3% under the A1B emissions scenario.¹¹⁵ Higher temperatures could also reduce potato tuber quality.¹¹⁹

Irrigated apple production is projected to increase in Washington State by 6% in the 2020s, 9% in the 2040s, and 16% in the 2080s (relative to 1975 to 2005) when offsetting effects of carbon dioxide fertilization are included.¹¹⁵ However, because tree fruit requires chilling to ensure uniform flowering and fruit set and wine grape varieties have specific chilling requirements for maturation,¹²⁰ warming could adversely affect currently grown varieties of these commodities. Most published projections of climate change impacts on Northwest agriculture are limited to Washington State and have focused on major commodities, although more than 300 crops are grown in the region. More studies are needed to identify the implications of climate change for additional cropping systems and locations within the region. The economic consequences for Northwest agriculture will be influenced by input and output prices driven by global economic conditions as well as by regional and local changes in productivity.

Adaptive Capacity and Implications for Vulnerability

Of the four areas of concern discussed here, agriculture is perhaps best positioned to adapt to climate trends without explicit planning and policy, because it already responds to annual climate variations and exploits a wide range of existing climates across the landscape.¹²¹ Some projected changes in climate, including warmer winters, longer annual frost-free periods, and relatively unchanged or increased winter precipitation, could be beneficial to some agriculture systems. Nonetheless, rapid climate change could present difficulties.

Adaptation could occur slowly if substantial investments or significant changes in farm operations and equipment are required. Shifts to new varieties of wine grapes and tree fruit, if indicated, and even if ultimately more profitable, are necessarily slow and expensive. Breeding for drought- and heat-resistance requires long-term effort. Irrigation water shortages that necessitate shifts away from more profitable commodities could exact economic penalties.¹⁰⁸

Exhibit 6

The geographical distribution of fossil fuels unused when limiting global warming to 2 °C

Christophe McGlade¹ & Paul Ekins¹

Policy makers have generally agreed that the average global temperature rise caused by greenhouse gas emissions should not exceed 2 °C above the average global temperature of pre-industrial times¹. It has been estimated that to have at least a 50 per cent chance of keeping warming below 2 °C throughout the twenty-first century, the cumulative carbon emissions between 2011 and 2050 need to be limited to around 1,100 gigatonnes of carbon dioxide (Gt CO₂)^{2,3}. However, the greenhouse gas emissions contained in present estimates of global fossil fuel reserves are around three times higher than this^{2,4}, and so the unabated use of all current fossil fuel reserves is incompatible with a warming limit of 2 °C. Here we use a single integrated assessment model that contains estimates of the quantities, locations and nature of the world's oil, gas and coal reserves and resources, and which is shown to be consistent with a wide variety of modelling approaches with different assumptions⁵, to explore the implications of this emissions limit for fossil fuel production in different regions. Our results suggest that, globally, a third of oil reserves, half of gas reserves and over 80 per cent of current coal reserves should remain unused from 2010 to 2050 in order to meet the target of 2 °C. We show that development of resources in the Arctic and any

increase in unconventional oil production are incommensurate with efforts to limit average global warming to 2 °C. Our results show that policy makers' instincts to exploit rapidly and completely their territorial fossil fuels are, in aggregate, inconsistent with their commitments to this temperature limit. Implementation of this policy commitment would also render unnecessary continued substantial expenditure on fossil fuel exploration, because any new discoveries could not lead to increased aggregate production.

Recent climate studies have demonstrated that average global temperature rises are closely related to cumulative emissions of greenhouse gases emitted over a given timeframe^{2,6,7}. This has resulted in the concept of the remaining global 'carbon budget' associated with the probability of successfully keeping the global temperature rise below a certain level^{4,8,9}. The Intergovernmental Panel on Climate Change (IPCC)³ recently suggested that to have a better-than-even chance of avoiding more than a 2 °C temperature rise, the carbon budget between 2011 and 2050 is around 870–1,240 Gt CO₂.

Such a carbon budget will have profound implications for the future utilization of oil, gas and coal. However, to understand the quantities that are required, and are not required, under different scenarios, we first

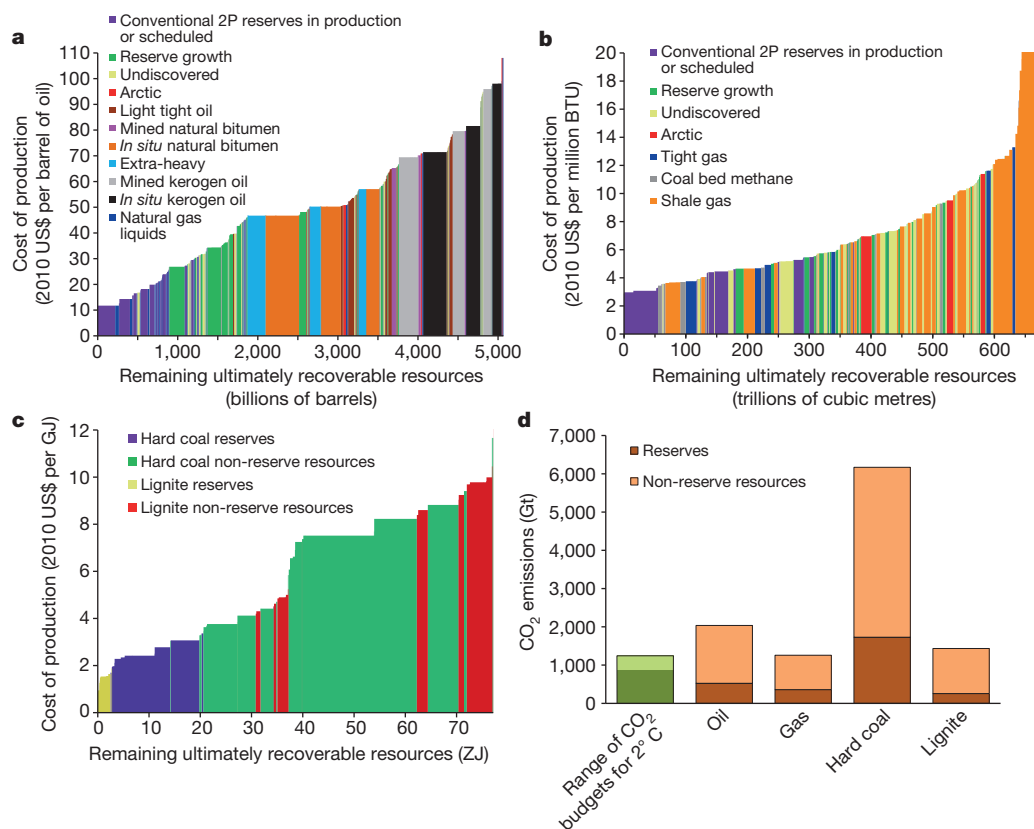


Figure 1 | Supply cost curves for oil, gas and coal and the combustion CO₂ emissions for these resources. a–c, Supply cost curves for oil (a), gas (b) and coal (c). d, The combustion CO₂ emissions for these resources. Within these resource estimates, 1,294 billion barrels of oil, 192 trillion cubic metres of gas, 728 Gt of hard coal, and 276 Gt of lignite are classified as reserves globally. These reserves would result in 2,900 Gt of CO₂ if combusted unabated. The range of carbon budgets between 2011 and 2050 that are approximately commensurate with limiting the temperature rise to 2 °C (870–1,240 Gt of CO₂) is also shown. 2P, 'proved plus probable' reserves; BTU, British thermal units (one BTU is equal to 1,055 J). One zettajoule (ZJ) is equal to one sextillion (10²¹) joules. Annual global primary energy production is approximately 0.5 ZJ.

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need to establish the quantities and location of those currently estimated to exist. A variety of metrics with disparate nomenclature are relied upon to report the availability of fossil fuels^{10,11}, but the two most common are 'resources' and 'reserves'. In this work 'resources' are taken to be the remaining ultimately recoverable resources (RURR)—the quantity of oil, gas or coal remaining that is recoverable over all time with both current and future technology, irrespective of current economic conditions. 'Reserves' are a subset of resources that are defined to be recoverable under current economic conditions and have a specific probability of being produced¹¹. Our best estimates of the reserves and resources are presented in Fig. 1 and, at the regional level, in Extended Data Table 1.

Figure 1 also compares the above carbon budget with the CO₂ emissions that would result from the combustion of our estimate of remaining fossil fuel resources (nearly 11,000 Gt CO₂). With the combustion emissions of the remaining reserves alone totalling nearly 2,900 Gt CO₂, the disparity between what resources and reserves exist and what can be emitted while avoiding a temperature rise greater than the agreed 2 °C limit is therefore stark.

Although previous research¹² has examined the implications that emissions mitigation might have on the rents collected by fossil fuel resource owners, more pertinent to policy and industry are the quantities of fossil fuel that are not used before 2050 in scenarios that limit the average global surface temperature rise to 2 °C. Such geographically disaggregated estimates of 'unburnable' reserves and resources are provided here using the linear optimization, integrated assessment model TIAM-UCL¹³.

To provide context to the issue of unburnable fossil fuels and our results, it is useful to examine scenarios provided by other models that quantify separately the volumes of oil, gas and coal produced globally under a range of future emissions trajectories⁵. Cumulative production between 2010 and 2050 from these are presented in Fig. 2. Since they have very different future greenhouse gas emissions profiles, we have converted them to approximate temperature rise trajectories. These have been calculated using the climate model MAGICC¹⁴, which generates a probability distribution over temperature rise trajectories for a given emissions profile. We use the 60th percentile temperature trajectory (to correspond with assumptions within TIAM-UCL) and then group the scenarios by the final temperature rise in 2100: below 2 °C, between 2 °C and 3 °C, or exceeding 3 °C.

In this work we have constructed three core scenarios that are constrained to limit the average surface temperature rise in all time periods to 2 °C, to 3 °C, and to 5 °C. Cumulative production of each fossil fuel between 2010 and 2050 in each of these scenarios can be identified within each of the three temperature groupings in Fig. 2.

The global reserves of oil, gas and coal included in Fig. 1 total approximately 7.4 ZJ, 7.1 ZJ and 20 ZJ, respectively. With narrow inter-quartile ranges, relative to the level of reserves available, Fig. 2 shows good agreement on the levels of fossil fuels produced within the temperature groups, despite the range of modelling methodologies and assumptions included.

Since assumptions in modelling the energy system are subject to wide bands of uncertainty¹⁵, we further constructed a number of sensitivity scenarios using TIAM-UCL that remain within a 2 °C temperature rise. These span a broad range of assumptions on production costs, the availability of bio-energy, oil and gas, demand projections, and technology availability (one with no negative emissions technologies, and one with no carbon capture and storage (CCS)) (Extended Data Table 2). The availability of CCS has the largest effect on cumulative production levels (Extended Data Fig. 1); however, there is little variability in the total production of fossil fuels if the world is to have a good chance of staying within the agreed 2 °C limit.

Global production of oil, gas and coal over time in our main 2 °C scenario is given in Fig. 3. This separates production by category, that is, by the individual kinds of oil and gas that make up the global resource base, and compares total production with the projections from the 2 °C scenarios in Fig. 2. The results generated using TIAM-UCL are a product

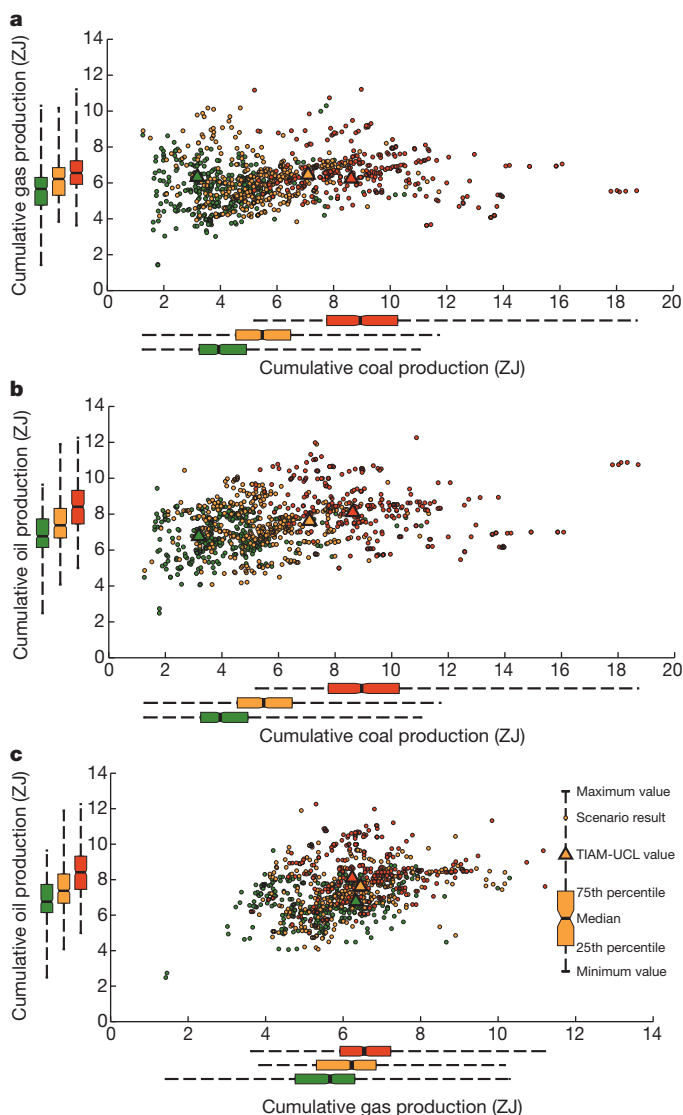


Figure 2 | Cumulative production between 2010 and 2050 from a range of long-term energy scenarios. Panels refer to coal and gas (a), coal and oil (b), and gas and oil (c). Scenarios⁵ are coloured according to their approximate resultant 2100 temperature rise above pre-industrial levels. 379 individual scenarios result in a temperature rise of less than 2 °C (green), 366 of between 2 °C and 3 °C (orange), and 284 of more than 3 °C (red). Triangles are the values from the 2 °C (with CCS), 3 °C and 5 °C TIAM-UCL scenarios. Ranges and symbols are as shown in the key in c.

of the economically-optimal solution, and other regional distributions of unburnable reserves are possible while still remaining within the 2 °C limit (even though these would have a lower social welfare). A future multi-model analysis could therefore usefully build on and extend the work that is presented here, but results at the aggregate level can be seen to lie within range of the ensemble of models and scenarios that also give no more than a 2 °C temperature rise.

In the TIAM-UCL scenarios, production of reserves and non-reserve resources occurs contemporaneously. It is therefore important to recognize that it would be inappropriate simply to compare the cumulative production figures in Fig. 2 with the reserve estimates from Fig. 1 and declare any reserves not used as 'unburnable'. Although there may be sufficient reserves to cover cumulative production between 2010 and 2050, it does not follow that only reserves should be developed and all other resources should remain unused. For oil and gas, resources that are not currently reserves may turn out to be cheaper to produce than some reserves, while new resources will also be developed to maintain

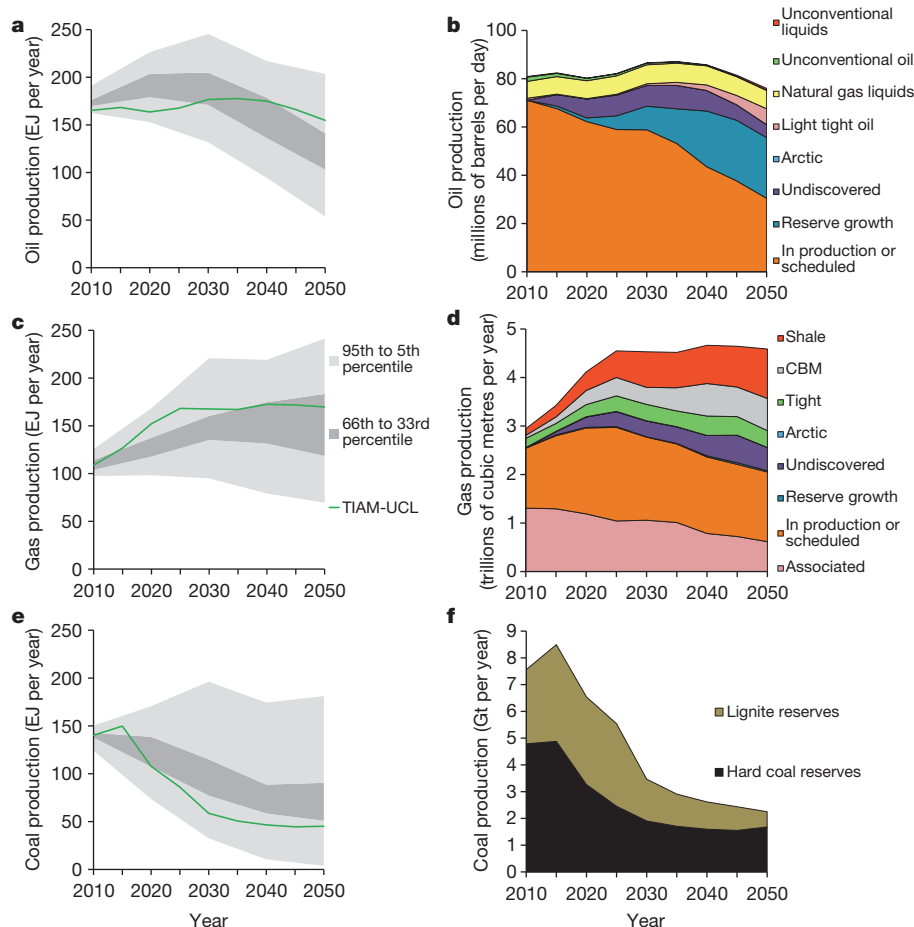


Figure 3 | Oil, gas and coal production in the TIAM-UCL 2 °C scenario (with CCS) and comparison with all other 2 °C scenarios in the Intergovernmental Panel on Climate Change Fifth Assessment Report (AR5) database⁵. a, c and e compare total production by oil, gas and coal with the AR5 database; b, d and f provide a disaggregated view of production for the TIAM-UCL 2 °C scenario separated by category. Associated gas is gas produced alongside crude oil from oil fields. One exajoule (EJ) is equal to one quintillion (10^{18}) joules.

the flow rates demanded by end-use sectors. However, if resources that are currently non-reserves are produced, a greater proportion of reserves must not be produced to stay within the carbon budget.

The reserves of oil, gas and coal that should be classified as unburnable within each region, and the percentage of current reserves that remain unused, are set out in Table 1. Since total production is most sensitive to assumptions on CCS, and since it has been suggested that the deployment of CCS will permit wider exploitation of the fossil fuel resource base¹⁶, Table 1 includes the unburnable reserves from two alternative 2 °C scenarios. One scenario permits the widespread deployment of CCS from 2025 onwards, and the other assumes that CCS is unavailable in any time period.

Globally, when CCS is permitted, over 430 billion barrels of oil and 95 trillion cubic metres of gas currently classified as reserves should remain

unburned by 2050. The Middle East, although using over 60% of its oil reserves, carries over half of the unburnable oil globally, leaving over 260 billions of barrels in the ground. Canada has the lowest utilization of its oil reserves (25%), as its natural bitumen¹⁷ deposits remain largely undeveloped (see below) while the United States has the highest, given the proximity of supply and demand centres. The Middle East also holds half of unburnable global gas reserves, with Former Soviet Union countries accounting for another third, meaning that they can use only half their current reserves.

Coal reserves are by far the least-used fossil fuel, with a global total of 82% remaining unburned before 2050. The United States and the Former Soviet Union countries each use less than 10% of their current reserves, meaning that they should leave over 200 billion tonnes (Gt) coal (both hard and lignite) reserves unburned. Coal reserve utilization

Table 1 | Regional distribution of reserves unburnable before 2050 for the 2 °C scenarios with and without CCS

Country or region	2 °C with CCS						2 °C without CCS					
	Oil		Gas		Coal		Oil		Gas		Coal	
	Billions of barrels	%	Trillions of cubic metres	%	Gt	%	Billions of barrels	%	Trillions of cubic metres	%	Gt	%
Africa	23	21%	4.4	33%	28	85%	28	26%	4.4	34%	30	90%
Canada	39	74%	0.3	24%	5.0	75%	40	75%	0.3	24%	5.4	82%
China and India	9	25%	2.9	63%	180	66%	9	25%	2.5	53%	207	77%
FSU	27	18%	31	50%	203	94%	28	19%	36	59%	209	97%
CSA	58	39%	4.8	53%	8	51%	63	42%	5.0	56%	11	73%
Europe	5.0	20%	0.6	11%	65	78%	5.3	21%	0.3	6%	74	89%
Middle East	263	38%	46	61%	3.4	99%	264	38%	47	61%	3.4	99%
OECD Pacific	2.1	37%	2.2	56%	83	93%	2.7	46%	2.0	51%	85	95%
ODA	2.0	9%	2.2	24%	10	34%	2.8	12%	2.1	22%	17	60%
United States of America	2.8	6%	0.3	4%	235	92%	4.6	9%	0.5	6%	245	95%
Global	431	33%	95	49%	819	82%	449	35%	100	52%	887	88%

FSU, the former Soviet Union countries; CSA, Central and South America; ODA, Other developing Asian countries; OECD, the Organisation for Economic Co-operation and Development. A barrel of oil is 0.159 m³; %, Reserves unburnable before 2050 as a percentage of current reserves.

is twenty-five percentage points higher in China and India, but still they should also leave nearly 200 Gt of their current coal reserves unburned.

The utilization of current reserves is lower in nearly all regions for all of the fossil fuels when CCS is not available, although there is a slight increase in gas production in some regions to offset some of the larger drop in coal production. Nevertheless, Table 1 demonstrates that the reserves of coal that can be burned are only six percentage points higher when CCS is allowed, with the utilization of gas and oil increasing by an even smaller fraction (around two percentage points). Because of the expense of CCS, its relatively late date of introduction (2025), and the assumed maximum rate at which it can be built, CCS has a relatively modest effect on the overall levels of fossil fuel that can be produced before 2050 in a 2 °C scenario.

As shown in Fig. 3, there is substantial production of many of the non-reserve resource categories of oil and gas. Extended Data Table 3 sets out the regional unburnable resources of all coal, gas and oil in the scenario that allows CCS by comparing cumulative production of all fossil fuel resources with the resource estimates in Fig. 1.

The RURR of both types of coal and unconventional oil vastly exceed cumulative production between 2010 and 2050, with the overwhelming majority remaining unburned. Resources of conventional oil are used to the greatest extent, with just under 350 billion barrels of non-reserve resources produced over the model timeframe. The Middle East again holds the largest share of the unburnable resources of conventional oil, but there is a much wider geographical distribution of these unburnable resources than was the case for oil reserves.

Regarding the production of unconventional oil, open-pit mining of natural bitumen in Canada soon drops to negligible levels after 2020 in all scenarios because it is considerably less economic than other methods of production. Production by *in situ* technologies continues in the 2 °C scenario that allows CCS, but this is accompanied by a rapid and total decarbonization of the auxiliary energy inputs required (Extended Data Fig. 2). Although such a decarbonization would be extremely challenging in reality, cumulative production of Canadian bitumen between 2010 and 2050 is still only 7.5 billion barrels. 85% of its 48 billion of barrels of bitumen reserves thus remain unburnable if the 2 °C limit is not to be exceeded. When CCS is not available, all bitumen production ceases by 2040. In both cases, the RURR of Canadian bitumen dwarfs cumulative production, so that around 99% of our estimate of its resources (640 billion barrels), remains unburnable. Similar results are seen for extra-heavy oil in Venezuela. Cumulative production is 3 billion barrels, meaning that almost 95% of its extra-heavy reserves and 99% of the RURR are unburnable, even when CCS is available.

The utilization of unconventional gas resources is considerably higher than unconventional oil. Under the 2 °C scenario, gas plays an important part in displacing coal from the electrical and industrial sectors and so there is over 50 trillion cubic metres unconventional gas production globally, over half of which occurs in North America. Nevertheless, there is a low level of utilization of the large potential unconventional gas resources held by China and India, Africa and the Middle East, and so over 80% of unconventional gas resources (247 trillion cubic metres) are unburnable before 2050. Production of these unconventional gas resources is, however, only possible if the levels of coal reserves identified in Table 1 are not developed: that is, it is not possible for unconventional gas to be additional to current levels of coal production.

Finally, we estimate there to be 100 billion barrels of oil (including natural gas liquids) and 35 trillion cubic metres of gas in fields within the Arctic Circle that are not being produced as of 2010. However, none is produced in any region in either of the 2 °C scenarios before 2050.

These results indicate to us that all Arctic resources should be classified as unburnable.

To conclude, these results demonstrate that a stark transformation in our understanding of fossil fuel availability is necessary. Although there have previously been fears over the scarcity of fossil fuels¹⁸, in a climate-constrained world this is no longer a relevant concern: large portions of the reserve base and an even greater proportion of the resource base should not be produced if the temperature rise is to remain below 2 °C.

Online Content Methods, along with any additional Extended Data display items and Source Data, are available in the online version of the paper; references unique to these sections appear only in the online paper.

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METHODS

Fossil fuel definitions. A 'McKelvey' box¹⁹ is often used to provide an overview of the relationship between different resource and reserve estimates²⁰. The best estimates of current oil and gas reserves in Extended Data Table 1 were of the 'proved plus probable' or '2P' quantities. Since 2P reserve estimates are rare for coal and none are in the public domain, the best estimates shown for coal were of the 'proved' or '1P' reserves. Broadly speaking, 1P estimates are more conservative, often corresponding to an estimate with a 90% probability of being exceeded, while 2P estimates are the median estimate of the reserves for a given field or region¹¹.

Oil and gas can be further separated into 'conventional' and 'unconventional' reserves and resources. Again, there is no single definition of these terms, but here we define oil with density greater than water (often standardized as '10° API') to be unconventional and all other quantities as conventional. We therefore categorize the 'light tight oil' extracted from impermeable shale formations using hydraulic fracturing as conventional oil.

For gas, tight gas (gas trapped in relatively impermeable hard rock, limestone or sandstone), coal-bed methane (gas trapped in coal seams that is adsorbed in the solid matrix of the coal), and shale gas (gas trapped in fine-grained shale) are considered as the three 'unconventional gases'; all other quantities are considered to be conventional.

Coal is distinguished by its energy density following the definitions used by the Federal Institute for Geosciences and Natural Resources (BGR)²¹. Hard coal has an energy density greater than 16.5 MJ kg⁻¹; any quantities with energy density less than this are classified as lignite.

Derivation of reserve and resource estimates. The estimated oil and gas reserves and resources shown in Extended Data Table 1 were derived in the following manner²². We first identified the individual elements or categories of oil and gas that make up the global resource base. For oil these are: current conventional 2P reserves in fields that are in production or are scheduled to be developed, reserve growth, undiscovered oil, Arctic oil, light tight oil, natural gas liquids, natural bitumen, extra-heavy oil, and kerogen oil. The latter three of these are the unconventional oil categories.

Reserve growth is defined to be 'the commonly observed increase in recoverable resources in previously discovered fields through time'²³. Quantities in this category here include any contributions from reserves in fields that have been discovered but are not scheduled to be developed ('fallow fields'), the new implementation of advanced production technologies such as enhanced oil recovery, changes in geological understanding, and changes in regional definitions.

There are eight categories of conventional and unconventional gas: current conventional 2P reserves that are in fields in production or are scheduled to be developed, reserve growth, undiscovered gas, Arctic gas, associated gas, tight gas, coal-bed methane, and shale gas. As noted above, the latter three of these are collectively referred to as unconventional gas.

We then selected the most robust data sources that provide estimates of the resource potential of each individual category within each country; these sources are set out in Extended Data Table 4. Taken together, differences between these sources provide a spread of discrete quantitative resource estimates for each category within each country. We also differentiated between the quantities of conventional oil that are natural gas liquids, and the quantities of natural gas that are associated with oil fields; these distinctions are important for modelling purposes but are rarely made in the literature.

For unconventional oil, we first generated a range of estimates for the in-place resources of natural bitumen, extra-heavy oil, and kerogen oil, and a range of potential recovery factors for different extraction technologies. We separately characterized the natural bitumen and kerogen oil resources that are extractable using mining technologies and those resources that are extractable using *in situ* technologies because the resource potential, costs, and energy requirements of these technologies are very different.

Continuous distributions were next constructed across these data ranges. Since there is no empirical basis for the choice of a suitable shape or form for such distributions, we used both the triangular and the beta distributions, chosen because they can be skewed both positively and negatively, and because they allow identical distributions to be used across all of the ranges derived. With equal weighting for each distribution, we combined these into a single individual resource distribution for each category within each country.

We then estimated the production costs of each of the oil and gas resource categories. Taking account of the resource uncertainty, these were used to develop supply cost curves for each category of oil and gas within each country.

We finally used a Monte Carlo selection process to combine these country-level supply cost curves. Regional supply cost curves were thus formed from aggregated supply cost curves for individual countries, and similarly supply cost curves formed for multiple categories of oil or gas within one or more countries. Data in Fig. 1 are the median values from these aggregate distributions with Extended Data Table 4

giving high (95th percentile), median, and low (5th percentile) estimates for each category at the global level.

In most industry databases of oil and gas reserves (for example, the database produced by the consultancy IHS CERA^{24,25}), some of the quantities classified as reserves lie in fields that were discovered over ten years ago, yet these fields have not been developed and there are no plans at present to do so. These are sometimes referred to as 'fallow fields'. For gas these quantities can also be called 'stranded gas', and they can be quite substantial; for example ref. 24 suggests that 50% gas reserves outside of North America are in stranded fields. Strictly, oil and gas in such fields should not be classified as reserves (for example, ref. 11 states that reserve quantities must have a 'reasonable timetable for development'). However, in this work, to ensure that the reserve estimates provided in Table 1 are not substantially different from the global totals provided by these industry databases, we follow their convention of classifying these quantities as reserves.

There are fewer independent estimates of reserves for coal and so we simply relied upon the estimates provided by the BGR²¹ for the reserve figures in Extended Data Table 1. The RRR of coal are more problematic to characterize, however. The 'resource' estimates provided by the BGR are not estimates of the quantities that can actually be extracted but are the in-place quantities; large portions of these are unlikely ever to be technically recoverable.

We therefore used the proved, probable and possible reserve estimates for hard coal and lignite provided by the World Energy Council²⁶ for a selection of countries. The sum of these three figures gives an estimate of the 'tonnage within the estimated additional amount in place that geological and engineering information indicates with reasonable certainty might be recovered in the future' (the definition provided by the World Energy Council). Since the sum of these three figures takes account of technical recoverability, we consider that, while imperfect, they provide a better estimate of the ultimately recoverable resources of coal than either the (narrower) proved reserve or the (broader) in-place resource estimates.

There are a number of countries that are estimated by the BGR to hold large quantities of coal in place but for which no probable and possible reserve estimates are provided by the World Energy Council. The ratio of the World Energy Council resource estimate to the BGR in-place estimate in countries that have estimates provided by both sources can vary substantially, but the average ratio is 16% for hard coal and 31% for lignite. We therefore assumed this ratio to generate resource estimates for all countries for which only BGR in-place estimates are provided. The proved reserve estimates of coal are so large themselves that the resource estimates are less important than is the case for oil and gas resource estimates.

There are few other sources providing a comprehensive overview of fossil fuel availability. Further, these often do not provide their sources or the methods used to generate estimates, do not define fully what categories or elements are included or excluded, and do not indicate sufficient conversion factors that would allow a like-with-like comparison. Some exceptions, however, are the IEA^{27,28}, the IIASA Global Energy Assessment (GEA)²⁹, and the BGR²¹. Their estimates are shown together with our aggregated reserve and resource estimates in Extended Data Table 5.

A number of factors contribute to the large variation between these estimates. A key reason is that the definitions of 'reserves' and 'resources' differ among sources, and so it is problematic to seek to compare them directly. For example, as noted above, the BGR, whose estimates are followed closely by the other sources, gives the total coal in place rather than an estimate of the resources that can be recovered, as in our study. Other reasons for the differences seen include: (1) the exclusion or inclusion of certain categories of fossil fuels such as light tight oil, aquifer gas, and methane hydrates; (2) whether proved (1P) or proved plus probable (2P) reserves are reported, and the methods used to generate the 1P reserve estimates; (3) the potential inflation of reserve estimates for political reasons, and whether they should consequently be increased or reduced³⁰; (4) the inclusion of stranded gas volumes in gas reserve estimates; (5) differences in the functional form used to estimate volumes of reserve growth (if reserve growth is included at all); (6) the difficulty in estimating current recovery factors (the ratio of recoverable resources to total resources in place), and how these may increase in the future; (7) differences between the methods used to estimate undiscovered oil and gas volumes; (8) the scarcity of reports providing reliable estimates of the potential resources of Arctic oil and gas, light tight oil, tight gas and coal bed methane, and the frequent consequent reliance upon expert judgement; (9) variation in what unconventional oil production technologies, which vary considerably in their recovery factors, will be used in the future; and (10) the chosen cut-off 'yield' (the volume of synthetic oil produced from a given weight of shale rock) for kerogen oil.

The estimates considered in our model are the result of careful and explicit consideration of all these issues, with our choices justified in the light of available knowledge. It can be seen in Extended Data Table 5, however, that our median figures are generally lower than the estimates provided by the other sources shown there. Therefore, although we consider our median resource estimates to be more robust than the figures used by these other sources, in fact these other estimates were found

to be closer to being correct, then the unburnable resources given in Extended Data Table 3 would also be larger. For example, if total gas resources are actually at the GEA high estimate, then the percentage that should be classified as unburnable before 2050 under the 2 °C scenario would increase to 99% rather than our estimate of 75%.

The cut-off date after which quantities that have not been produced should be considered 'unburnable' is also an important assumption. While there are no specific timeframes attached to the definition of reserves, quantities are usually required to be developed within, for example, a 'reasonable timeframe'¹¹. It is doubtful whether any reserves not produced by 2050 would fulfil this criterion. We therefore take cumulative production of reserves between 2010 and 2050 as the reserve 'utilization', and classify any quantities not used within this time as those that should be 'unburnable' if a certain temperature rise is not to be exceeded. Similarly, if none, or only a minor proportion, of a certain non-reserve resource is produced before 2050, then any current interest in developing it would be questionable. We thus also rely on 2050 as the cut-off date for classifying resources that should be considered as unburnable.

Description and key assumptions in TIAM-UCL. The TIMES Integrated Assessment Model in University College London ('TIAM-UCL') is a technology-rich, bottom-up, whole-system model that maximizes social welfare under a number of imposed constraints. It models all primary energy sources (oil, gas, coal, nuclear, biomass, and renewables) from resource production through to their conversion, infrastructure requirements, and finally to sectoral end-use. An extended explanation of input assumptions, approaches and data sources can be found in ref. 13. The base year of TIAM-UCL is 2005, the model is run in full to 2100, and thereafter the climate module is run to 2200. Results are presented here only between 2010 and 2050 (and are reported in five-year increments). All scenarios in this paper are run with the assumption of perfect foresight.

Resources and costs of all primary energy production are specified separately within 16 regions covering the world, and separately within the regions that contain members of the Organisation of Petroleum Exporting Countries (OPEC); the names of these are presented in Extended Data Table 6. For clarity in the main text, we have aggregated some of these regions into ten more-encompassing groups.

The climate module of TIAM-UCL is calibrated to the MAGICC model¹⁴. This module can be used to project the effects of greenhouse gas emissions on: atmospheric concentrations of greenhouse gas, radiative forcing, and average global temperature rises. It can also be used to constrain the model to certain bounds on these variables. In this work, the climate module is used to restrict the temperature rise to certain levels (as explained below). For the calibration to MAGICC, values from the probability distributions of climate parameters in MAGICC were selected so that there is a 60% chance that the temperature rise will remain below any level reported. Any constraints imposed using the TIAM-UCL climate module thus also correspond to this probability.

The emissions profiles⁵ used in Fig. 2 were converted to temperature rises using MAGICC. To ensure consistency with TIAM-UCL, we use the 60th percentile temperature trajectory from MAGICC and then group by the final temperature rise in 2100; there is therefore also a 60% chance that the temperature rise will be below the level indicated.

For each of the scenarios run in this paper using TIAM-UCL, a 'base case' is first formed that incorporates no greenhouse gas abatement policies. This base case uses the standard version of the model that relies upon minimizing the discounted system cost. This is used to generate base prices for each commodity in the model. TIAM-UCL is then re-run using the elastic-demand version with the greenhouse gas abatement policies introduced. This version of the model maximizes social welfare (the sum of consumer and producer surplus) and allows the energy-service demands to respond to changes in the endogenously determined prices resulting from these new constraints.

Fossil fuel modelling in TIAM-UCL. Oil and gas are both modelled in a similar manner in TIAM-UCL. The nine categories of conventional and unconventional oil and eight categories of conventional and unconventional gas identified above are all modelled separately. Coal production in TIAM-UCL is modelled more collectively, with only two categories, reserves and resources, for hard coal and lignite.

Natural bitumen and kerogen oil resources can be produced using either mining or *in situ* means, the technologies for which have different costs, efficiencies, and energy inputs. Although natural gas is predominantly used at present for the energy inputs to these unconventional resources, the model is free to choose any source of heat, electricity and hydrogen to allow greater flexibility. The costs of the auxiliary energy inputs required to extract and upgrade the native unconventional oils are determined endogenously by the model.

Each of the coal, gas and oil categories are modelled separately within the regions listed in Extended Data Table 6, with each resource category within each region split into three cost steps. As discussed above, the supply cost curves given in Fig. 1 comprise the data input to TIAM-UCL.

After processing, oil is next refined into products (gasoline, diesel, naphtha and so on), whereas processed gas and coal can be used directly. Fuel switching to and from all of the fossil fuels is possible. Trade of hard coal, crude oil, refined products, natural gas, both in pipelines and as liquefied natural gas, is allowed. Lignite cannot be traded between the regions.

Refined oil products can also be produced directly using Fischer–Tropsch processes with possible feedstocks of coal, gas, or biomass; these technologies can also be employed either with or without carbon capture and storage. Regional coal, oil and gas prices are generated endogenously within the model. These incorporate the marginal cost of production, scarcity rents, rents arising from other imposed constraints, and transportation costs.

A new key aspect of TIAM-UCL is the imposition of asymmetric constraints on the rate of production of oil and gas given a certain resource availability; these are intended to represent 'depletion rate constraints'. In TIAM-UCL, these constraints are modelled through introducing maximum annual production growth and maximum 'decline rate' restrictions. These are imposed on each cost step of each category of both oil and gas in each region, and ensure that the production follows a more realistic profile over time.

Data for these constraints are available at the field level from the bottom-up economic and geological oil field production model ('BUEGO')³¹. BUEGO contains a data-rich representation of 7,000 producing 'undiscovered' and discovered but undeveloped oil fields. These data include each field's 2P reserves, potential production capacity increases, water depth, capital and operating costs, and natural decline rate (the rate at which production would decline in the absence of any additional capital investment).

We used production-weighted averages (as of 2010) of the individual fields within each region to give average regional natural decline rates, which were imposed as maximum decline constraints in TIAM-UCL in the form of equal maximum annual percentage reductions. Although data on gas natural decline rates are much more sparse, some are available at a regional level³², which can be compared with similar results for oil natural decline rates²⁵. This comparison suggests that gas natural decline rates are on average 1% per year greater than for oil, with similar distributions for location (onshore/offshore) and size. The constraints placed on the maximum annual reductions in natural gas production were thus assumed to be 1% higher than those derived for oil.

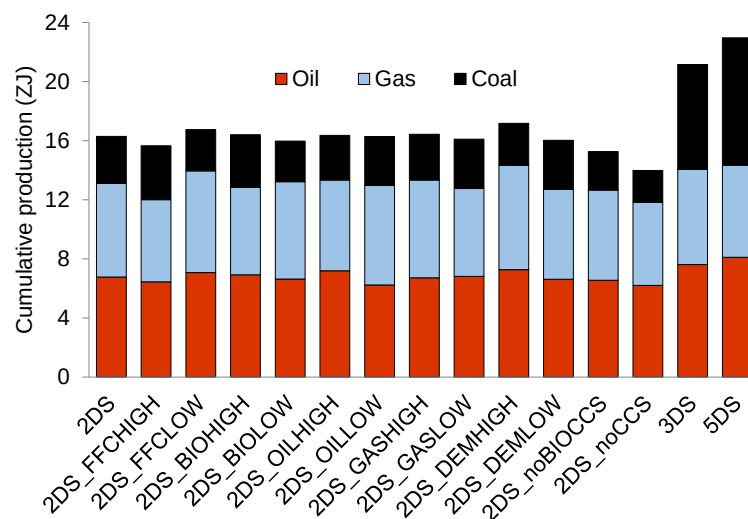
As identified in the main text, to understand the quantities of reserves of oil and gas that are unburnable, production of reserve sources only should be compared with reserve estimates, while cumulative production of all sources should be compared with the resource estimates. For coal, the reserves are so much greater than cumulative production under any scenario that this distinction is not as important.

The base year of TIAM-UCL is 2005, but the base year of this study is 2010. Since reserves have grown, and oil and gas have been discovered in the intervening five years, some quantities that were classified as reserve growth and undiscovered oil and gas in 2005 should be classified as reserves in 2010. Within each region, the cumulative production figures to which the reserve estimates in Extended Data Table 1 are compared therefore contain production from the conventional 2P reserves in the 'fields in production or scheduled to be developed' category, as well as some portions of production from the 'reserve growth' and 'undiscovered' categories. In addition, since, for example, reserves of natural bitumen are included in the reserves figures of Canada and unconventional gas reserves are included in the reserves figures of the United States, production of some of the unconventional categories are also included in these cumulative production figures. To ensure consistency within each region, the maximum production potentials over the modelling period from the categories included in the cumulative production figures are equal to the reserve estimates given in Extended Data Table 1.

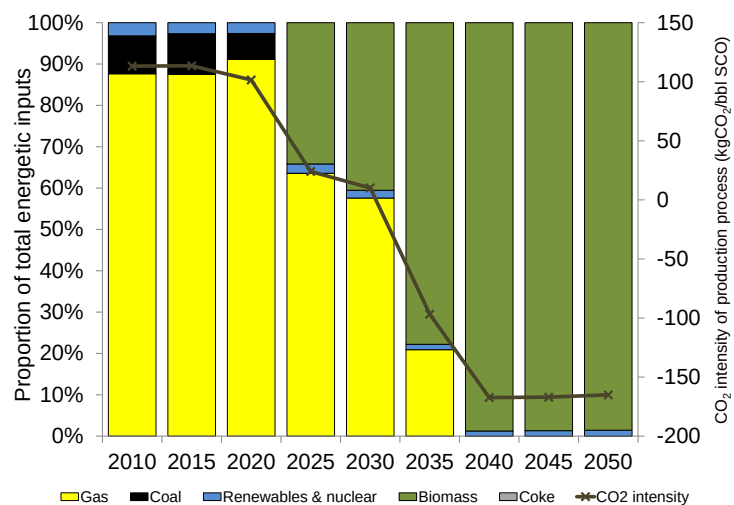
Overview of scenarios implemented. A brief overview of the main assumptions within the four scenarios run as part of this work is provided in Extended Data Table 7. For the emissions mitigation scenarios (those that limit the temperature rise to 3 °C and 2 °C), we assume that there are only relatively modest efforts to limit emissions in early periods as explained. The assumptions within the 2 °C sensitivity scenarios used to construct Extended Data Fig. 1 are provided in Extended Data Table 2.

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Extended Data Figure 1 | Cumulative fossil fuel production under a range of sensitivity scenarios run using TIAM-UCL. Scenario names and characteristics are given in Extended Data Table 2.



Extended Data Figure 2 | The auxiliary energy inputs for natural bitumen production in Canada by *in situ* technologies in the 2 °C scenario and the CO₂ intensity of these. bbl SCO, a barrel of synthetic crude oil, the oil that results after upgrading the natural bitumen.

Extended Data Table 1 | Best estimates of remaining reserves and remaining ultimately recoverable resources from 2010

Country or region	Oil (Gb)			Gas (Tcm)			Hard coal (Gt)		Lignite (Gt)	
	Res	Con RURR	Uncon RURR	Res	Con RURR	Uncon RURR	Res	RURR	Res	RURR
Africa	111	280	70	13	45	35	31	45	2	5
Canada	53	60	640	1	5	25	4	35	2	40
China and India	38	90	110	5	10	40	255	1,080	16	120
FSU	152	370	360	61	95	30	123	580	94	490
CSA	148	360	450	9	30	55	10	25	5	10
Europe	25	110	30	6	25	20	17	70	66	160
Middle East	689	1,050	10	76	105	20	2	10	2	5
OECD Pacific	6	30	130	4	10	20	45	120	44	200
ODA	23	75	5	9	25	15	15	40	14	155
United States	50	190	650	8	25	40	226	560	31	335
Global	1,294	2,615	2,455	192	375	300	728	2,565	276	1,520

'Con' and 'Uncon' stand for conventional and unconventional sources, respectively. Coal is specified in billions of tonnes (Gt), gas in trillions of cubic metres (Tcm) and oil in billions of barrels (Gb). Res, reserves.

Extended Data Table 2 | Labels and description of the sensitivity scenarios modelled in this project

Sensitivity Name	Description
2DS_FFCHIGH	Production costs of all fossil fuel technologies are 50% larger in 2015 and 100% larger in 2020 than in 2DS, with equal annual percentage changes between these dates and remaining at this level for the model horizon
2DS_FFCLow	Production costs of all fossil fuel technologies are 33% lower in 2015 and 50% lower in 2020 than in 2DS, with equal annual percentage changes between these dates and remaining at this level for the model horizon
2DS_BIOHIGH	The maximum annual production of solid biomass and bio-crops in 2050 is assumed to be 350 EJ. This is close to the highest level of production of bio-energy in any of the scenarios from the AR5 scenario database ⁵ and is around three times the equivalent figure in 2DS (119 EJ).
2DS_BIOLOW	The maximum annual production of solid biomass and bio-crop in 2050 is assumed to be 38 EJ. This is similar to the figure given in the central scenario from ³³ and is around a third of the equivalent figure in 2DS (119 EJ).
2DS_OILHIGH	Uses the high values of each category of oil in each region from the aggregate resource distributions described in the methods section (Extended Data Table 4)
2DS_OILOW	Uses the low values of each category of oil in each region (Extended Data Table 4)
2DS_GASHIGH	Uses the high values of each category of gas in each region (Extended Data Table 4)
2DS_GASLOW	Uses the low values of each category of gas in each region (Extended Data Table 4)
2DS_DEMHIGH	The major drivers of energy service demands in TIAM-UCL are growth in GDP, population, and GDP/capita. Future regional growth in GDP and population are therefore modified to the values given in Shared Socioeconomic Pathway (SSP) number 5 ³⁴ the SSP with the highest GDP and GDP/capita growth by 2050 (a 240% increase in the global average; cf. a 120% increase in 2DS). All other energy service demands (not relying on GDP or population) are also modified commensurately.
2DS_DEMLOW	Future regional growth in GDP and population are modified to the values given in Shared Socioeconomic Pathway (SSP) number 3: ³⁴ the SSP with the lowest GDP and GDP/capita growth by 2050 (a 50% increase in the global average).
2DS_NOBIOCCS	No negative emissions technologies are permitted i.e. carbon capture and storage (CCS) cannot be applied to any electrical or industrial process that uses biomass or bio-energy as feedstock in any period.
2DS_NOCCS	CCS is not permitted to be applied to any electrical or industrial process in any period.

Data for bio-energy sensitivities from refs 5 and 33, and for demand sensitivities from ref. 34.

Extended Data Table 3 | Regional distribution of resources unburnable before 2050 in absolute terms and as a percentage of current resources under the 2 °C scenario that allows CCS

Country or region	Conven oil		Unconven oil		Conven Gas		Unconven Gas		Hard Coal		Lignite	
	Gb	%	Gb	%	Tcm	%	Tcm	%	Gt	%	Gt	%
Africa	141	50%	70	100%	28	61%	35	100%	42	94%	2.8	56%
Canada	43	72%	633	99%	3.6	73%	18	71%	34	98%	39	97%
China and India	54	60%	110	100%	8.0	80%	35	88%	1,003	93%	106	88%
FSU	201	54%	360	100%	63	67%	27	89%	576	99%	480	98%
CSA	198	55%	447	99%	23	76%	51	92%	21	85%	6.3	63%
Europe	64	58%	30	100%	18	72%	16	78%	69	99%	142	89%
Middle East	554	53%	10	100%	72	68%	20	100%	10	100%	5.0	99%
OECD Pacific	23	77%	130	100%	9.0	90%	15	74%	116	97%	198	99%
ODA	38	51%	5.0	100%	14	55%	12	78%	34	84%	142	92%
United States	99	52%	650	100%	19	75%	20	50%	556	99%	317	95%
Global	1,417	54%	2,445	100%	257	69%	247	82%	2,462	96%	1,438	95%

*Conven' and 'Unconven' stand for conventional and unconventional resources, respectively.

Extended Data Table 4 | Principal data sources used to derive reserve and resource estimates and estimates at the global level for each category of production

Category	Data sources used to provide country-level estimates of resources	Aggregated high estimate	Aggregated median estimate	Aggregated low estimate
Oil		(in Gb)	(in Gb)	(in Gb)
Current conventional 2P reserves in fields in production or scheduled to be developed	21,31,35,36	950	820	620
Reserve growth	37,38	1,200	850	610
Undiscovered oil	Fact sheets since USGS World Petroleum Assessment ³⁹ and ^{35,40,41}	580	300	180
Arctic oil	42,43	80	65	40
Light tight oil	10	470	300	150
Natural gas liquids (NGL)	26			
	Ancillary data associated with ³⁹	380	280	170
Natural bitumen	Oil in place estimates ^{17,26}	Mined RURR 130	Mined RURR 100	Mined RURR 70
	Extraction technologies ^{44–46}	<i>In situ</i> RURR 1290	<i>In situ</i> RURR 840	<i>In situ</i> RURR 520
Extra-heavy oil	Oil in place estimates ^{47,48}	750	440	230
	Extraction technologies ⁴⁷ and refs for bitumen			
Kerogen oil	Oil in place estimates ^{49,50}	Mined RURR 740	Mined RURR 485	Mined RURR 270
	Extraction technologies ⁵¹	<i>In situ</i> RURR 1,080	<i>In situ</i> RURR 590	<i>In situ</i> RURR 190
Total		7,650	5,070	3,050
Gas		(in tcm)	(in tcm)	(in tcm)
Current conventional 2P reserves in fields in production or scheduled to be developed	35,52	140	130	110
Reserve growth	24,37,38	125	90	60
Undiscovered gas	Fact sheets since USGS World Petroleum Assessment ³⁹ and ^{35,41}	180	120	80
Arctic gas	42,43	40	35	25
Tight gas	20	60	60	60
Coal-bed methane	20	45	40	20
Shale gas	20	310	200	120
Associated gas	36,37,44	Included in the above		
Total		900	675	475

High and low values are the aggregated 95th and 5th percentile estimates, respectively. 'tcm', trillions of cubic metres. Data are from references 10, 17, 20, 21, 31, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50 and 51.

Extended Data Table 5 | Global aggregated oil, gas and coal reserve and resource estimates from a selection of data sources

Organisation	Oil (Gb)		Gas (Tcm)		Coal (Gt)	
	Reserves	Resources	Reserves	Resources	Reserves	Resources
BGR	1,600	4,750	195	825	1,000	23,500
IEA	1,700	5,950	190	810	1,000	21,000
GEA	1,500 - 2,300	4,200 - 6,000	670 - 2,000	2,000 - 12,500	850 - 1,000	14,000 - 20,000
This study's median figures	1,300	5,070	190	675	1,000	4,085

BGR, Federal Institute for Geosciences and Natural Resources²¹; IEA, International Energy Agency^{27,28}; GEA, Global Energy Assessment²⁹.

Extended Data Table 6 | Regions included in TIAM-UCL and their aggregation to the regions given in the main text

Region	Aggregated region in main text
Non-OPEC Africa	Africa
OPEC Africa	Africa
Australia	OECD Pacific
Canada	Canada
Non-OPEC Central and South America	Central and South America (CSA)
OPEC Central and South America	Central and South America (CSA)
China	China and India
Eastern Europe	Europe
Former Soviet Union	Former Soviet Union (FSU)
India	China and India
Japan	OECD Pacific
Non-OPEC Middle	Middle East
OPEC Middle East	Middle East
Mexico	Central and South America (CSA)
Other Developing Asia	Other Developing Asia (ODA)
South Korea	OECD Pacific
United Kingdom	Europe
United States	United States
Western Europe	Europe

Extended Data Table 7 | Labels and description of the four core scenarios modelled in this project

Scenario Name	Description
5DS	The model is constrained to keep the average global surface temperature rise to less than 5°C in all years to 2200. No other emissions constraints are imposed, and since allowed emissions under this scenario are so high (i.e. the constraint is very lax), no real emissions mitigation is required. These constraints result in 2050 GHG emissions of 71 Gt CO₂-eq (up from around 48 Gt CO₂-eq in 2010).
3DS	From 2005 to 2010, the model is fixed to the solution given in the 5°C temperature i.e. we assume that no emissions reductions are required. From 2010-2015, it is assumed that the model must be on track to achieve the emissions reduction pledges set out in the Copenhagen Accord¹, but no other emissions reductions are required. From 2015 onwards the model must meet the Copenhagen Accord emissions reductions in 2020, and emissions must be such as to keep the average global surface temperature rise below 3°C in all years to 2200. These constraints result in 2050 GHG emissions of 54 Gt CO₂-eq
2DS	The constraints between 2005 and 2015 in this scenario are identical to the 3DS. From 2015 onwards the model must meet the Copenhagen Accord emissions reductions in 2020, and emissions must be such as to keep the average global surface temperature rise below 2°C in all years to 2200. These constraints result in 2050 GHG emissions of 21 Gt CO₂-eq
2DS-noCCS	Emissions reduction requirements are identical to 2DS. Carbon capture and storage (CCS) is not permitted to be applied to any electricity or industrial process in any period.

GHG, greenhouse gas measured in tonnes of CO₂ equivalent (CO₂-eq). Data from ref. 1.

Exhibit 7

**MONTANA OTTER
CREEK STATE COAL
VALUATION**

ENERGY, MINING, AND ENVIRONMENTAL CONSULTANTS

NORWEST
CORPORATION

**MONTANA OTTER
CREEK STATE COAL
VALUATION**

Submitted to:

**MONTANA DEPARTMENT OF
NATURAL RESOURCES &
CONSERVATION**

TRUST LAND MANAGEMENT DIVISION
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JANUARY 30, 2009

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NORWEST
CORPORATION

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EXECUTIVE SUMMARY

Norwest Corporation (Norwest) completed a valuation of the Otter Creek Coal Tracts 1 through 3 located in the State of Montana. The purpose is to determine the fair market value that Montana should accept from a qualified bidder. This valuation was completed according to the methods specified in the Bureau of Land Management (BLM) Handbook H-3070-1, *Economic Evaluation of Coal Properties*. The handbook provides two separate methods for determining a coal property's value. These methods are the Comparable Lease Sales Approach and the Income Approach. Research for this valuation was completed in October, 2008 and all revenue and costs reflect economic conditions at that time. The actual valuation process went through multiple reviews by Norwest and by the State of Montana prior to completion and preparation of this report on January 30, 2009.

Comparable Lease Sales Approach

The Comparable Lease Sales Approach uses similar past lease sales to determine the bonus price per ton of the coal. It is generally assumed that this approach provides the best indication of value when reliable sales data are available. The Comparable Lease Sales Approach takes past lease sale transactions and compares them to the new coal property to determine its value. Adjustments to the reference properties are made to develop a more accurate estimate of the new property. Typically these adjustments include key economic parameters such as coal quality, stripping ratio, and transportation options among others. The final per ton value is calculated by taking an average of the similar lease sales or one that is the closest in coal quality and stripping ratio to the new property and applying any adjustments for differences in these parameters.

Income Approach

Using the Income Approach, an economic model of the coal property is created. This model should emulate the most economic mine plan for the coal property which creates the highest net present value (NPV). Under the Income Approach, a mine plan based on current and projected coal markets is created. Cost and revenue streams are estimated and combined to produce a cash flow over the projected mine life. The cash flow is then discounted to present day values using a discount rate of 10%. This rate is

justified on the basis that it is representative of the alternative cost of capital and has been successfully used for a number of years in coal land valuations. The calculated NPV is then divided by the number of recoverable tons for the lease to determine the bonus price per ton.

FINDINGS

The results of the two valuation methods are discussed in detail in the body of this report and are summarized in Table E.1 below.

Table E.1 Fair Market Value of Montana Unleased Coal

Method	Bonus (\$/ton)	Recoverable Tons (1,000,000s)	Total Bonus (\$1,000,000s)
Comparable Lease Sales Approach	\$0.0539	572.3	\$30.8
Income Approach	\$0.0652	572.3	\$37.3

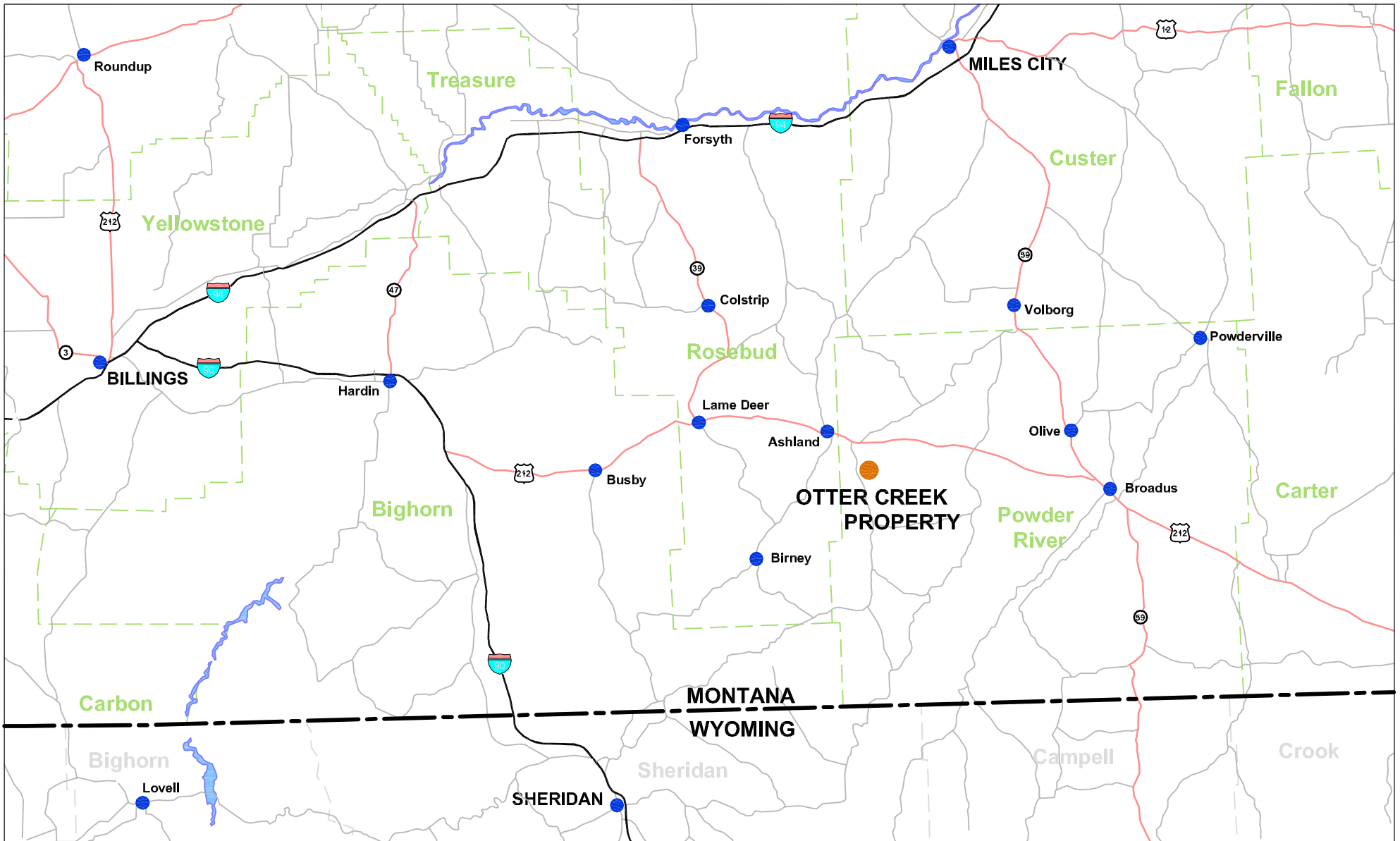
The Comparable Lease Sales Approach produced a value of \$30.8 million (M) or approximately \$0.05/ton for Montana's 572M recoverable tons of coal. This value is lower than similar federal lease sales of high sodium coal in Montana, reflecting the lack of existing rail service at Otter Creek.

The Income Approach produced a value of \$37.3M, or \$0.07/ton for 572M tons of coal. The economic model includes \$187M for an 85 mile rail line addition. There is an approved rail line proposed along this same route, owned by the Tongue River Railroad Company (TRRC), but construction has not begun, nor is Norwest aware of a set schedule for construction. Norwest has assumed that the developer of Otter Creek would pay for this railroad in the two years ahead of production and be reimbursed by TRRC over 15 years from the start of production. Because the developer would not own the railroad, the cost is not included as a capital expenditure, but rather is shown in the cash flow calculation along with recapture payments from TRRC at 4% interest. Had the railroad been in place at the time of this report, the resulting NPV would have been \$124.8M, or approximately \$0.10/ton.

In addition to the bonus bid, Montana will receive production royalties for coal mined on these leases as well as an annual fee of \$3 per acre. The typical royalty is 12.5% of the gross sales value. On a theoretical market price of \$20/ton FOB mine, the royalty would be \$2.50/ton.

In summary, Norwest concludes that a bonus bid between \$0.05 and \$0.07/ton of recoverable coal, as determined through the Comparable Lease Sales and Income approaches, represents the fair market value range for the Otter Creek Tracts 1 through 3.

Figure E.1 shows the general location of the Otter Creek Coal Tracts. Figure E.2 illustrates the remaining lease areas.



LEGEND

- Interstate
- Principal Highway
- Other Roads
- - - State Line
- - - County Line

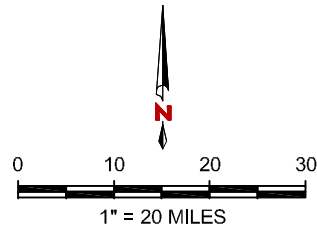
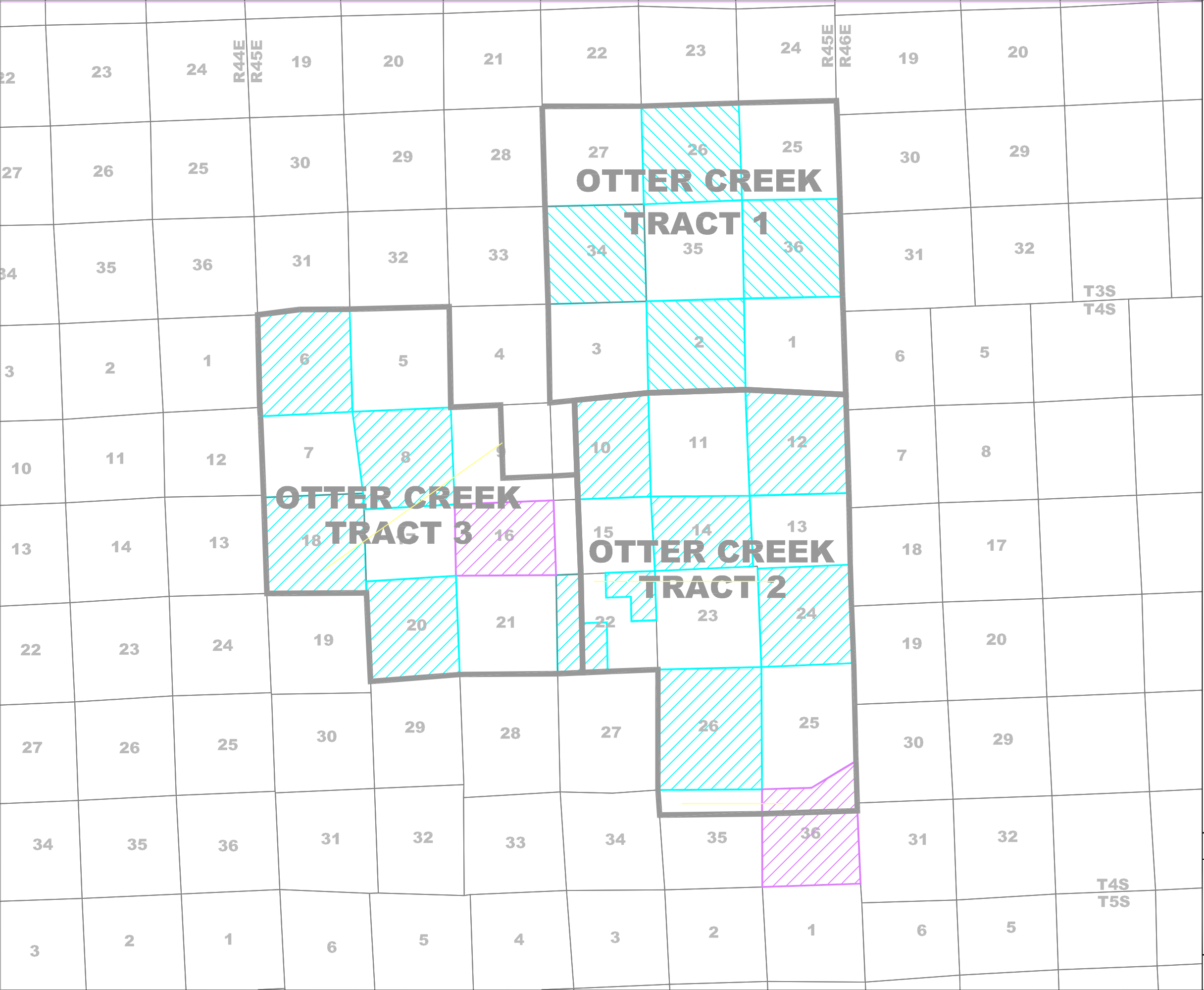


Figure E.1
Otter Creek
Location Map

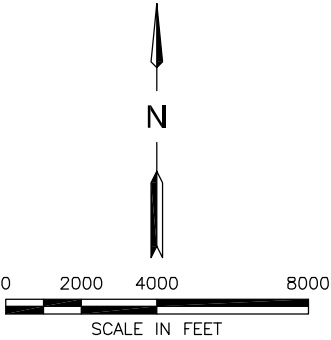
DATE: 10/31/2008
FILE: E.1Location

PROJECT:
3823
NORWEST
CORPORATION



LEGEND:

- MT UNLEASED COAL
- MT ALREADY LEASED COAL
- OTHER



INTRODUCTION

PROPERTY TO BE APPRAISED

The mineral property being appraised is the Otter Creek Coal Tracts 1 through 3 located in Powder River County, Montana approximately 10 miles southeast of Ashland, Montana near US Route 212. The coal tracts are bounded on three sides by the Custer National Forest. A portion of the coal property is owned by the State of Montana and is administered by the Trust Land Management Division of the Montana Department of Natural Resources & Conservation. The remainder of the coal property is owned by private parties of which Great Northern Properties Limited Partnership (GNP-LP) is the majority owner.

The tracts are located in the following townships of Powder River County:

Township 4 South, Range 45 East:

All of Section 2

All of Section 6

All of Section 8

E1/2W1/2 and the E1/2 of Section 10

All of Section 12

All of Section 14

All of Section 18

All of Section 20

W1/2W1/2; E1/2SW1/4; NW1/4NE1/4; E1/2NE1/4 of Section 22

All of Section 24

All of Section 26

Township 3 South, Range 45 East:

All of Section 26

All of Section 34

All of Section 36

PURPOSE OF APPRAISAL

The results of this appraisal will be used by the state of Montana to set a minimum bid price for Otter Creek Coal Lease Tracts 1, 2 and 3. This bid price is typically expressed in dollars per ton of recoverable coal contained in the lease area.

PREMISE OF VALUE

The premise of the valuation used by Norwest is that these coal lands will be acquired through a competitive lease sale and developed into an operating mine. This appraisal does not consider re-sale of the undeveloped leases which could result in a significantly lower value.

EFFECTIVE DATE

The effective date of this valuation is October 2008, as that is when the research was completed. Coal pricing as well as equipment prices, fuel, electricity and wages are based on information and quotations obtained at that time. This report was issued January 30, 2009 after considerable review and discussion within Norwest and between Norwest and the state of Montana.

**SIGNIFICANT
PROFESSIONAL
ASSISTANCE PROVIDED
BY OTHERS**

In the course of completing this appraisal assignment, significant professional assistance was provided by Mr. Kevin Gunesch, a Norwest associate, and Mr. Gary Stubblefield of Norwest Corporation. Mr. Gunesch, a Mining Engineer, developed the financial models used in the Income Approach. Gunesch also assisted in the reporting of the Comparable Lease Sales analyses.

LIMITING CONDITIONS

Norwest has made no attempt to determine current legal ownership of the coal lands that are set forth herein, nor have we investigated as to the existence of any liens or encumbrances on these lands.

All related facts, comments and data set forth herein have been obtained from sources believed to be knowledgeable, reliable and accurate. For purposes of this report those sources include a 2005 study by Norwest on Otter Creek; 2007 Mine & Mill Equipment Costs An Estimators Guide and the 2008 Mining Cost Service.

Coal tonnage and qualities within Tracts 1 through 3 used in this appraisal were determined through the use of a geologic model of the deposit compiled using public information combined with proprietary information from GNP-LP. The 3D model was compiled using geological modeling software¹ by Carlson Software, Inc. The site of Otter Creek Coal Tracts 1 through 3 were not physically visited or inspected during the preparation of this report. These coal lands are undeveloped and thus would reveal very little information in a site visit beyond the general topography and flora and fauna.

¹ "Carlson Mining 2008", by Carlson Software, Inc.

CERTIFICATION

This report was prepared by Norwest Corporation for the Montana Department of Natural Resources & Conservation, Trust Land Management Division located at 1625 11th Avenue, Helena, MT 59620-1601. The material herein reflects our best judgment in light of the information available to us at the time of preparation. Accordingly, Norwest accepts no responsibility for decisions made or actions taken based on this report.

We HEREBY CERTIFY to the best of our knowledge and belief the following are true and accurate:

- The facts and data reported by the appraiser and used in the appraisal process are true and correct.
- The analyses, opinions, and conclusions in this appraisal report are limited only by the assumptions and limiting conditions stated in this appraisal report and our personal, impartial, and unbiased professional analyses, opinions, and conclusions.
- That no deeper coal seams would be adversely affected by the mine plan used in this study. This is in conformance with Montana Statute 77-3-305, Sub. 2.
- That we have no present or prospective interest in the property that is the subject of this appraisal report and no personal interest with respect to the parties involved.
- That we have no bias with respect to the property that is the subject of this appraisal report or to the parties involved in this assignment.
- That our engagement in this assignment was not contingent upon developing or reporting predetermined results.
- That our compensation is not contingent on any action or event resulting from the analyses, opinions, or conclusions in this report or from its use.
- That the reported analyses, opinions, and conclusions were developed and this appraisal report was prepared, in conformity with the requirements of the Code of Professional Ethics & Standards of Professional Appraisal Practice of the Appraisal Institute, which include the Uniform Standards of Professional Appraisal Practice.
- That no one other than the undersigned prepared the analyses, conclusions and opinions concerning the coal lands that are set forth in this appraisal report.

- That significant professional assistance in estimating the minimum bonus price was provided by Mr. Kevin Gunesch, Norwest Associate Mining Engineer and Gary Stubblefield, Vice President Norwest.

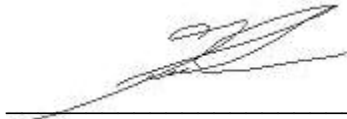
Signed



John E. Trygstad
Candidate Member, American Society of Appraisers



Gary M. Stubblefield, P.E.
Vice President, Norwest Corporation



Kevin Gunesch, P.E.
Associate Mining Engineer, Norwest Corporation

COMPARABLE LEASE SALES APPROACH

INTRODUCTION

The Comparable Lease Sales Approach examines the prices paid for similar coal properties in the area to determine the fair market value (FMV) of the new lease. It is generally assumed that the Comparable Lease Sales Approach provides the best indication of value when reliable sales data are available. The basis for this estimation is the value the competitive market would determine for a property given that:

- Prices are determined in a competitive market.
- Prices result from the negotiation between a knowledgeable buyer and seller.
- Neither the buyer nor seller is under any undue pressure to complete the transaction.
- Variations in the appraisal property and the comparable properties can be accounted for by a technically based monetary adjustment.

The following sections give an overview of Comparable Lease Sales within the last 10 years. These lease sales are discussed in terms of the bonus paid, bonus per ton of recoverable coal, coal quality, strip ratio, proximity to transportation, and geologic and mine method comparability to the appraisal property. A bonus bid price per recoverable ton amount for the entire Otter Creek property is determined based on these comparisons. This unit value is then multiplied by the recoverable tonnage of Montana state coal within Otter Creek Tracts 1 through 3 to determine the dollar value.

SELECTED COMPARABLE LEASES

A database consisting of 31 federal lease sales was compiled by Norwest for the Powder River Basin (PRB) area (see Table 2.1). These sales included 12 lease modifications (MOD) and 19 lease by application (LBA) sales. The MOD sales are modifications of current leases that add a small incremental tonnage to an existing lease. These small sales are not considered as competitive sales since they are inherently attached to a current lease and mining operation and not an openly competitive sale. A quick review of the MOD sales indicates that bonus bids on these leases were typically in the range of \$0.04/ton to \$0.05/ton, while bonus bids on LBAs ranged from \$0.11/ton up to \$0.97/ton.

TABLE 2.1 FEDERAL COAL LEASE SALES- POWDER RIVER BASIN, MONTANA AND WYOMING (from 1991) 10/30/08													
TRACT	APPLICANT	HIGH BIDDER	BLM SERIAL NO.	CASE TYPE	SALE DATE	TOTAL BONUS	TRACT ACRES	BONUS (\$/ACRE)	TONS RECOV. (MMT)	BONUS (\$/TON)	MINING RATIO (BCY:TON)	HEAT VALUE (BTU/LB)	Na as % Ash
Spring Creek	Spring Creek Coal	Spring Creek Coal	MTM 94378	LBA	4/17/2007	\$19,902,200	1,117.7	\$17,806.39	108.60	\$0.1833	2.89	9,331	8.38
Decker Modifications	Decker Coal Co.	Decker Coal Co.	MTM037604/ MTM057934	MOD	4/18/2006	\$456,320	100.4	\$4,545.02	4.960	\$0.0920	2.76	9,546	1.27
West Roundup	Triton Coal	Peabody Energy	WYW151134	LBA	2/16/2005	\$317,697,610	2,812.51	\$112,958.75	327,186 *	\$0.9710	4.30	8,790	1.60
West Antelope	Antelope Coal	Antelope Coal	WYW151643	LBA	12/15/2004	\$146,311,000	2,809.13	\$52,084.10	194,961 *	\$0.7505	3.00	8,858	1.86
West Hay Creek	Triton Coal	Kiewit Mining Group	WYW151634	LBA	11/17/2004	\$42,809,400	921.16	\$46,473.49	142,698 *	\$0.3000	2.00	8,346	1.75
Little Thunder	Ark Land Co.	Ark Land Co.	WYW150318	LBA	9/22/2004	\$610,999,950	5,083.50	\$120,192.77	718,719 *	\$0.8501	3.40	8,884	1.20
NARO South	Powder River Coal	Powder River Coal	WYW154001	LBA	6/29/2004	\$274,000,000	2956.725	\$92,670.10	297,469 *	\$0.9211	2.80	8,929	2.00
Rosebud	Western Energy	Western Energy	MTM80697	Mod	2/17/2004	\$11,250	30.0	\$375.00	0.250	\$0.0450	4.63	8,382	0.5
N. Jacob's Ranch	Jacob's Ranch Coal	Jacob's Ranch Coal	WYW146744	LBA	1/16/2002	\$379,504,652	4,982.2	\$76,171.49	537,542 *	\$0.7060	3.51	8,792	1.29
Spring Creek	Kennecott	Kennecott	MTM88405	LBA	11/27/2000	\$1,740,200	150.0	\$11,601.33	15.860	\$0.1097	2.08	9,370	8.63
Horse Creek	Antelope Coal	Antelope Coal	WYW141435	LBA	9/7/2000	\$91,220,121	2,818.7	\$32,362.54	275,577 *	\$0.3310	2.60	8,890	1.49
Spring Creek	Kennecott	Kennecott	MTM69782	MOD	10/1/1999	\$13,860	10.0	\$1,386.00	0.330	\$0.0420	1.92	9,361	9.56
Rosebud	Western Energy	Western Energy	MTM80697	LBA	6/16/1999	\$4,416,000	1,401.0	\$3,152.03	27.600	\$0.1600	3.51	8,382	10.3
Thundercloud	Kerr-McGee	Ark Land Co.	WYW136458	LBA	10/1/1998	\$158,000,009	3,545.5	\$44,563.50	412,000 *	\$0.3835	2.57	8,810	1.45
Powder River	Peabody	Peabody	WYW136142	LBA	6/30/1998	\$109,596,500	4,224.2	\$25,944.91	532,024 *	\$0.2060	3.00	8,742	1.84
Decker	Kennecott	Kennecott	MTM57934-A/ MTM61685	MOD	6/10/1998	\$478,400	320.0	\$1,495.00	7.360	\$0.0650	2.35	9,512	1.27
Spring Creek	Kennecott	Kennecott	MTM69782	MOD	4/10/1998	\$163,170	25.0	\$6,526.80	3.366	\$0.0485	1.48	9,350	8.72
N. Rochelle	Bluegrass Coal	Bluegrass Coal	WYW127221	LBA	9/25/1997	\$30,576,340	1,481.9	\$20,632.78	157,610 *	\$0.1940	2.91	8,680	na
Antelope	Kennecott	Kennecott	WYW128322	LBA	12/4/1996	\$9,054,600	617.2	\$14,670.45	60,364	\$0.1500	1.70	8,776	1.21
Spring Creek	Kennecott	Kennecott	MTM69782	MOD	6/16/1995	\$166,000	60.0	\$2,766.67	4.380	\$0.0379	1.88	9,357	na
Eagle Butte	Cyprus-Anax	Cyprus-Anax	WYW124783	LBA	4/5/1995	\$18,470,400	1,059.2	\$17,438.40	163,300	\$0.1131	1.99	8,376	8.72
Spring Creek	Kennecott	Kennecott	MTM69782	MOD	11/23/1994	\$19,509	15.0	\$1,300.60	0.465	\$0.0420	1.67	9,237	na
Caballo	Exxon	Exxon	WYW125698	MOD	2/2/1994	\$25,217	20.2	\$1,246.82	0.917	\$0.0275	1.76	8,500	na
Spring Creek	NERCO	NERCO	MTM69782	MOD	9/1/1993	\$1,000	10.0	\$100.00	0.020	\$0.0500	2.10	8,183	na
Scotia Bay	Thunder Basin	Thunder Basin	WYW2313	MOD	5/30/1993	\$64,000	10.2	\$6,268.36	1.030	\$0.0621	1.43	8,752	na
West Rocky Butte	Peabody	Peabody	WYW122586	LBA	1/7/1993	16,500,000	463.2	\$35,621.76	56,700	\$0.2910	3.75	8,354	na
N. Antelope	Peabody	Peabody	WYW119554	LBA	9/28/1992	\$86,987,765	3,064.0	\$28,389.89	403,500	\$0.2156	2.23	8,752	na
W. Black Thunder	Thunder Basin	Thunder Basin	WYW118907	LBA	8/12/1992	\$71,909,282	3,492.5	\$20,589.69	429,000	\$0.1676	2.72	8,839	na
Jacobs Ranch	Kerr-McGee	Kerr-McGee	WYW117924	LBA	9/26/1991	\$20,114,930	1,708.6	\$11,772.62	147,424	\$0.1364	2.46	8,540	na
E.Black Thunder	Thunder Basin	Thunder Basin	WYW2313	MOD	4/29/1991	\$300,155	102.8	\$2,920.93	5,000	\$0.0600	0.70	8,508	na
West Decker	Kiewit	Kiewit	MTM37604	MOD	1/1/1991	\$494,650	160.0	\$3,091.56	7.610	\$0.0650	4.20	9,610	na

* Reserves expressed as TONS MINABLE
MOD- Lease Modification
LBA- Lease By Application

The significantly higher bonus bids for LBA sales reflect higher interest and importance placed on these typically larger tracts. The highest bids occurred more recently on coal lease sales in the lower PRB (Wyoming) where two or more companies with neighboring mines competed for large tonnage lease tracts. Because of the obvious difference between bid amounts on LBA sales compared to MOD sales and the fact that Otter Creek is not adjacent to existing mines, Norwest did not consider MOD sales further in this analysis.

Of the remaining 19 LBA sales a total of three leases were selected for further analysis. These sales represent all Montana LBA sales completed in the area since 1999. Table 2.2, below, illustrates the selected LBA sales with their respective parameters of coal quality and strip ratios which are key contributors in determining mining cost and marketability of the coal from a particular property.

Table 2.2 Selected LBA Sales

Tract	Sale Date	Number of bidders	BLM Serial No.	Case Type	Total Bonus	Tract Acres	Bonus (\$/Acre)	Recoverable Tons (million)
Spring Creek 1	4/17/2007	1	MTM 94378	LBA	\$19,902,200	1,117.7	\$17,806.39	108.60
Spring Creek 2	11/27/2000	1	MTM 88405	LBA	\$1,740,200	921.2	\$46,473.49	142.698
Rosebud	6/16/1999	1	MTM 80697	LBA	\$4,416,000	1,401.0	\$3,152.03	27.600

Tract	Sale Date	Bonus (\$/ton)	Strip Ratio (BCY/ton)	Heating Value (Btu/lb)	% Sulfur	% Ash	% Moisture	Na as % Ash
Spring Creek 1	4/17/2007	\$0.1833	2.89	9,331	0.35	3.80	25.71	8.38
Spring Creek 2	11/27/2000	\$0.1097	2.08	9,370	0.34	3.65	25.53	8.63
Rosebud	6/16/1999	\$0.1600	3.51	8,382	0.81	10.3	25.41	10.3

The common thread among these three leases is the high sodium content when compared to other LBAs included in Table 2.1. These other LBAs reach a maximum sodium content of 2%. High sodium coals face a limited market because of the slagging problems they cause in most electric generating plant boilers.

Heat content, expressed as Btu/lb of coal, does not show a strong correlation to the LBA bid price, but is important in selling coal because most electric utilities buy Btus rather than tons.

Ash and sulfur are higher in the Rosebud lease than in either of the Spring Creek leases, but as will be established later in this report, these attributes do not impact the bid price significantly.

**MAJOR INFLUENCE
FACTORS**

Geology

Each tract contained in Table 2.1 is within the PRB which extends from northern Wyoming into Montana. The coal deposits within the PRB exhibit similar geologic conditions with a low number of thick coal seams covered by a minimal amount of overburden resulting in low overburden volume to coal tons, referred to as strip ratio. Coal mines in the PRB employ a strip mining method, usually with a combination of draglines and truck shovel fleets for overburden and coal removal.

Coal Quality

All coal within the region is classified as sub-bituminous with heating values between 8,300 Btu and 9,500 Btu/lb, as-received. Coal quality differs somewhat between the southern PRB (Wyoming) and the northern PRB (Montana). Heating values in the Northern PRB are typically above 9,300 Btu/lb, while the lower PRB coals fall below 8,800 Btu/lb. An exception is the Rosebud Mine in Montana with a heating value of about 8,400 Btu/lb. Coal sales contracts typically purchase Btus rather than tons so heat content must be considered in determining bid values. This can be done by comparing Otter Creek heat content to that of the selected comparison mines and adjusting for the difference.

Nearly all mines in the PRB have low (under 0.5%) sulfur content and are considered Compliance Coal (they produce less than 1.2 lbs of sulfur dioxide (SO₂) per million Btu when burned in a utility boiler). Here again, Rosebud is an exception at 0.8% sulfur or 1.93 lbs SO₂ per million Btu. Otter Creek sulfur content at 0.28% is in the same range as Spring Creek and thus will not significantly influence this valuation.

An important difference in coal quality among PRB coals is the weight percent of sodium contained in the ash. Coals with high sodium content share a limited market due to slagging problems they cause in certain types of power plant boilers. This limits the market for high sodium coals to a small number of mid-western electric generating plants and some industrial plants. LBA tracts in Table 2.1 with high sodium content include Spring Creek at 8 to 9%, Eagle Butte at 8.72% and Rosebud at 10.3%. These tracts

received lower unit bonus bids than most of the other LBA tracts. Charts 2.1 through 2.3 are scatter plots comparing bid price to quality parameters, including heat content, sulfur and sodium in ash. There is no clear pattern in Charts 2.1 and 2.2, indicating that bid price is not tied strongly to heat content or sulfur percent. There is however, a relationship of bid price to sodium in ash. It is clear from Chart 2.3 that the high sodium LBAs are grouped in the lower price range (\$0.11 - \$0.19); whereas the other lease sales with low sodium levels had bid prices in a wide range, i.e. from \$0.15/ton up to \$0.97/ton. This reflects the limited market for high sodium coal.

Chart 2.1 Bonus Bid vs. Heat Content

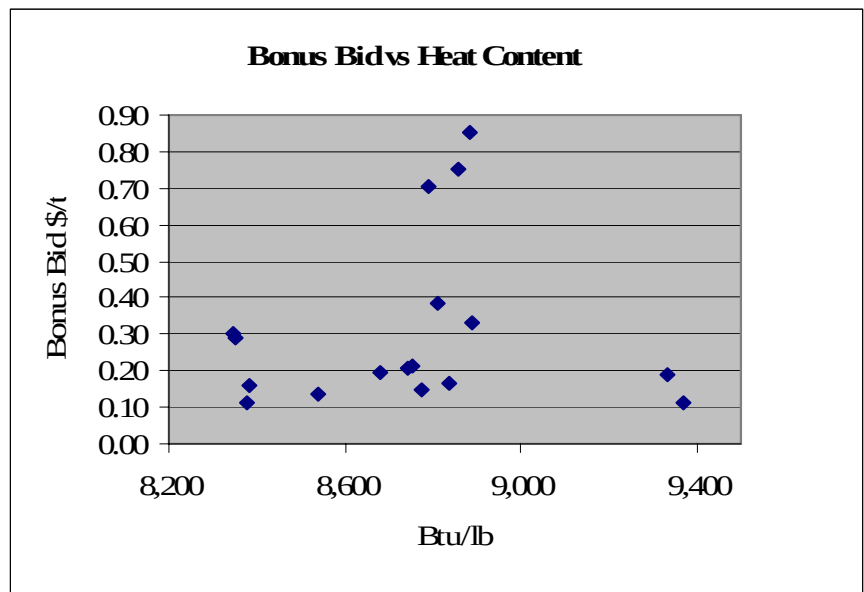


Chart 2.2 Bonus Bid vs. Sulfur Content

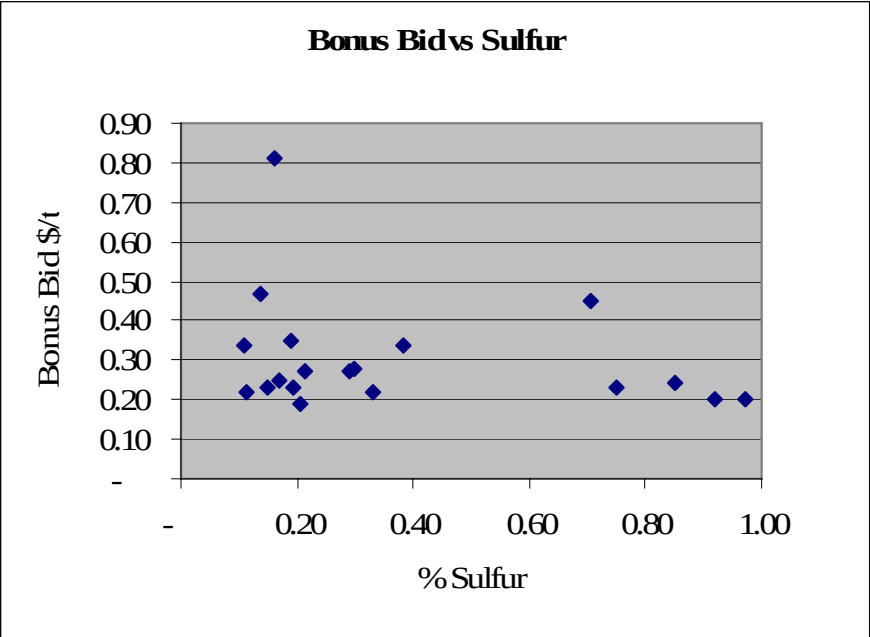


Chart 2.3 Bonus Bid vs. Sodium Content

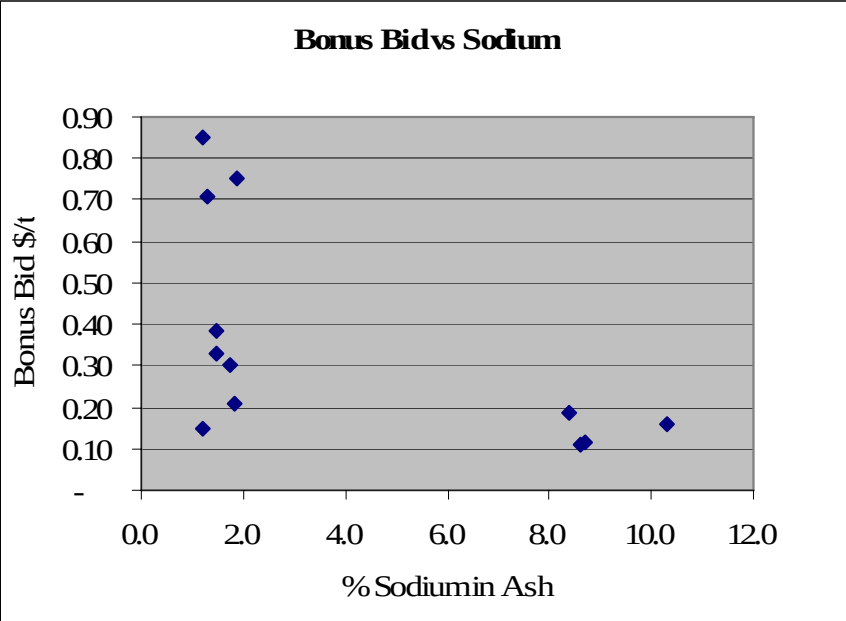
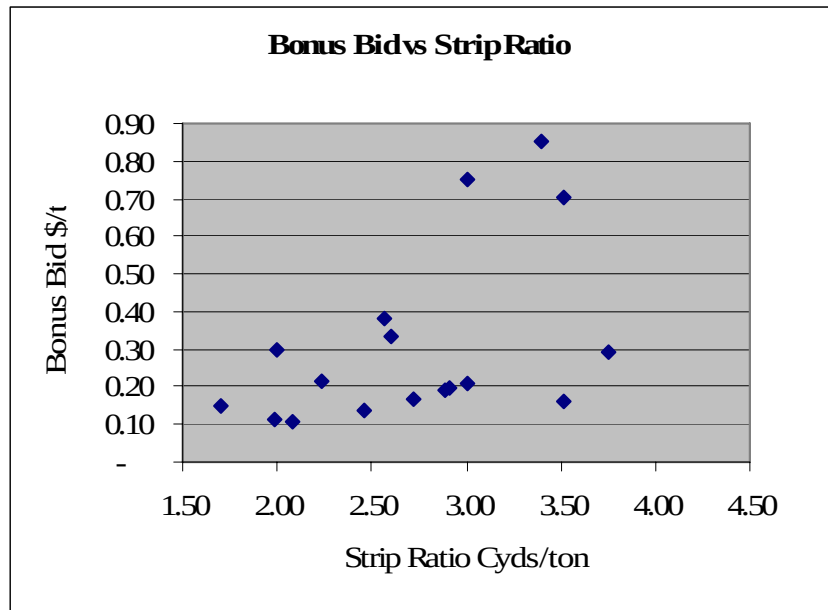


Chart 2.4 Bonus Bid vs. Strip Ratio



Market Prices

It seems reasonable that market prices would influence the LBA bid price. The three Montana coal tracts listed in Table 2.2 sold in 1999, 2000 and 2007 respectively. The average coal prices for PRB coals during those specific years are shown in Table 2.3 below.

Table 2.3 Market Prices (\$/Ton)² vs Bonus Bid

	1999	2000	2007
Average Montana Coal Prices*	\$8.82	\$8.87	\$11.79
%Change		0.6	32.9
LBA Bid Amounts \$/ton	\$0.1883	\$0.1097	\$0.1600
%Change		-41.7	45.9

* These are nominal dollars, i.e. actual \$ paid in the given year

There does not appear to be a connection between the LBA bid amount and the average coal price in Montana during the specific years. In the period 1999 to 2000 average coal prices in Montana climbed less than 1%, yet bid prices dropped nearly 42%. Between years 2000 and 2007, average Montana coal price increased 33%; however the LBA bid price jumped almost 46%.

² Energy Information Administration/Coal Industry Annual 2000 and 2007.

Strip Ratio

Strip ratio, sometimes referred to as mining ratio, is a measure of the volume (cubic yards) of waste rock moved in order to recover one ton of coal. Typically, the higher the strip ratio, the greater the mining cost. Strip ratios for the selected sales vary from 2.0 bank cubic yards (BCY)/ton to 4.3 BCY/ton. One would expect that the unit bonus bid would vary inversely in proportion to strip ratio; however, this was not the case. In fact, the highest strip ratio tract, West Roundup, received the highest unit bonus bid at \$0.9710/ton. This contradiction may be explained by the fact that there were two bidders competing for that tract which created a highly competitive bidding process between the two parties (Arch Coal Company and Peabody Energy). In this particular case, the initial bid by Arch Coal Company was rejected, and then followed by re-offer bids from both parties (Bureau of Land Management, 2008). Chart 2.4 shows no distinctive trend with regard to strip ratio affecting LBA bid price.

Proximity to Transportation

Both Spring Creek and Rosebud mines have had rail service from their startup, whereas Otter Creek will have to fund construction of approximately 85 miles of main line to Miles City, MT. This is a significant cost (estimated at roughly \$187M) and even though Norwest assumes the cost will be recovered over time, this negatively impacts the value of Otter Creek coal.

COMPARABLE SALES VALUATION

Sodium Adjustment

Sodium content appears to be a primary factor influencing LBA bid prices in the Northern PRB. In recognition of this, Norwest has adjusted the actual bids on the Spring Creek and Rosebud leases to reflect the sodium content in Otter Creek coals. The Otter Creek tracts are characterized by sodium in ash content of 7.51%, which is only slightly lower than Spring Creek tracts at 8.38% and 8.63% respectively and well below the Rosebud tract (10.3% Na). This high sodium content will limit the market for Otter Creek coal as it does for coals produced at Spring Creek and Rosebud mines.

Table 2.4 Coal Quality Comparisons (As Received Basis)

Tract	Heating Value (Btu/lb)	% Sulfur	% Ash	% Moisture	Na as % Ash
Otter Creek	8,609	0.28	5.50	27.89	7.51
Spring Creek 1	9,331	0.35	3.80	25.71	8.38
Spring Creek 2	9,370	0.34	3.65	25.53	8.63
Rosebud	8,382	0.81	10.3	25.41	10.3

Spring Creek 1 (Tract MTM 94378) is the most recent sale (2007) and contains similar coal qualities as Otter Creek coal with regards to sulfur, ash, moisture, and most notably sodium. The bid price for this tract was \$0.1883/ton. If we adjust this bid amount on a straight line basis to reflect a sodium content of 7.51%, as in Otter Creek coal, we get a bid price of \$0.2045/ton ($8.38 / 7.51 \times \0.1883). In a similar manner, the bid price adjustment based on Spring Creek 2 (Tract MTM 88405, 2000) produces a theoretical bid price of \$0.1261/ton. Finally, adjusting the bid price of the Rosebud tract to match the sodium level at Otter Creek produces a theoretical bid of \$0.2194. The average of these three theoretical bid amounts is \$0.1833/ton which is coincidentally the same as the actual bid on the 2007 Spring Creek 1 LBA.

Btu Adjustment

The \$0.1833/ton value must further be adjusted for Btu content since most sales contracts call for a quantity of Btu rather than tons. Applying a Btu adjustment to the three comparison LBAs reduces the Otter Creek bid amount to \$0.1766/ton (see Table 2.5).

Transportation Adjustment

An adjustment to recognize that these three lease sales were associated with properties that already had access to rail transportation is necessary. Since the length of rail line required at these mines is unknown, the cost estimate for the rail line needed at Otter Creek was used to adjust the three lease sales. This was accomplished by dividing that cost by the total tons of recoverable coal at Otter Creek. This calculates to \$0.1429/ton (\$187M/1,308.6Mtons). This transportation adjustment was further reduced separately for each lease by discounting at a 2.5 percent *annual* rate over the time difference in months between the three lease sales and October, 2008. The resulting adjustments, shown in Table 2.5, average \$0.1227/ton and the final adjusted values averages **\$0.0539** per ton.

Table 2.5 Bonus Bid Adjustments

Lease	Lease Sale Date	Bid Price	Na as % Ash	Adjust Bid to 7.51 % Na	Heat Content Btu/lb	Addtn'l Adjust. for Btu	Adjust for No Railroad	Final Adjusted Value
Spring Creek 1	4/17/2007	\$0.1833	8.38	\$0.2045	9,331	\$0.1887	-\$0.1376	\$0.0511
Spring Creek 2	11/27/2000	\$0.1097	8.63	\$0.1261	9,370	\$0.1158	-\$0.1173	-\$0.0015
Rosebud	6/16/1999	\$0.1600	10.3	\$0.2194	8,382	\$0.2254	-\$0.1132	\$0.1122
Otter Creek			7.51	\$0.1833	8,609	\$0.1766	-\$0.1227	\$0.0539

Notes: Otter Creek adjustments are arithmetic averages of the three federal sales.

Summary of Adjustments

Bonus bids on three federal coal lease sales in Montana were adjusted to match Otter Creek coal Btu and Sodium qualities and for rail service as follows:

- First, the adjustment for sodium at Spring Creek 1 is calculated by dividing its sodium value (8.38) by the sodium value at Otter Creek 1 (7.51), then multiplying the result by \$0.1833/ton which yields an adjusted value of \$0.2045/ton. The same calculation applies to Spring Creek 2 and Rosebud sales. The average of these three bids, adjusted for sodium is \$0.1883/ton.
- Next, the adjustment for heat content (Btu/lb) is applied in a similar fashion, but now to the sodium adjusted values and this yields an average bid price for Otter Creek coal of \$0.1766/ton.
- Finally, the three comparable lease bids were adjusted downward to recognize that they had rail service at the time of the bid while Otter Creek does not. This was accomplished by discounting (\$0.1429/ton) downward to account for time differences between the lease dates of the comparable leases and October, 2008; then deducting these results from the adjusted Btu value on each lease. This gives a final average bid price of \$0.0539/ton.
- Multiplying this unit bonus bid amount by the recoverable unleased Montana State coal contained within the three Otter Creek Tracts (572.3Mtons) yields a total value under the Comparable Sales approach of \$30.8M.

INCOME APPROACH

GENERAL

The value of the remaining Montana state coal leases within the Otter Creek Tracts 1 through 3 was also determined through the Income Approach. This approach involves preparing a discounted cash flow analysis by estimating the annual costs and revenues associated with the development of the coal leases under realistic conditions. The cash flow is discounted to the net present value (NPV) by applying a reasonable discount rate. The discount rate chosen for this analysis is 10% which matches the rate currently used by the U.S. Department of Interior's Bureau of Land Management (BLM)³. The following sections describe the assumptions and methodologies used to calculate the NPV for the remaining coal leases with the Otter Creek Tracts.

GEOLOGIC MODEL

The coal tonnage and qualities within the Otter Creek Tracts 1 through 3 were determined through the use of a geologic model of the deposit compiled using public information and proprietary information provided by GNP-LP. The combination of the geologic data from both sources has produced the most definitive model of the Otter Creek deposit to date. This 3D computer model, prepared using Carlson Mining software, was used to determine the in-place coal tonnages and qualities used in the analyses.

LOGICAL MINING UNITS (LMUS)

Four logical mining units (LMUs) were identified in the 2005 Norwest study, which included Montana coal plus federal and private coal parcels. To simplify the valuation process, the two LMUs located on each side of Otter Creek were combined to form logical mining units, LMU 5 on the east side and LMU 6 on the west side. Economic models were created for each of these new LMUs assuming a greenfield surface mining development scenario for each. As discussed further in the text, the predicted coal market will absorb simultaneous coal production from both LMUs. Therefore, the NPVs from each model are combined to produce a single value for the entire coal property.

³ "H-3070-1 – Economic Evaluation of Coal Properties", U.S. Department of the Interior, BLM. Retrieved October 27, 2008 from <http://www.eia.doe.gov/cneaf/coal/page/coalnews/coalmar.html>.

ECONOMIC MODELS

The economic models for both LMUs (located in Appendix C) are identical in structure, i.e. calculating revenue and cost cash flows in the same manner. The only differences between the models are:

- Mining Rate (LMU5 = 21.2Mtpa, LMU6 = 12Mtpa)
- Capital Equipment Assumptions (which vary based on the mining and stripping requirements).

All other cost assumptions and methodologies in determining costs are the same throughout each model.

PRODUCTION SCHEDULE

The production schedule was adjusted to reflect a total of 5,500 net operating hours per year for major mobile equipment excluding the draglines which operate 6,000 hours per year. These annual operating hours are based on the following assumptions:

- 12 hour shifts
- 2 shift per day
- 7 days per week
- 50 weeks per year (allows for annual outage of 2 weeks)
- 80% availability
- 92% shift efficiency (15 min start up and shut down, 30 min lunch, effective work 11 of 12 hours per shift)
- 12% operating delays.

CAPITAL COSTS

Since the results of each separate model are combined into a single value, the capital for infrastructure as well as working capital, permitting, and exploration drilling is split equally between the separate models.

Equipment

The capital assumptions for each LMU were verified for major mobile equipment from the 2005 study. Capital equipment numbers and sizes for draglines, overburden shovels, and ancillary/support equipment were kept the same. Changes were made to the number of overburden trucks and to the coal loading/hauling fleets. The list below summarizes the assumptions used to verify the capital equipment numbers.

- Draglines were sized based on the annual stripping requirement and a productivity of 275,000 BCY/year/CY of bucket capacity.
- Overburden and coal trucks were sized based on truck match with the loading equipment.

- Overburden shovels were sized based on stripping volumes.
- Coal shovels were replaced with large wheel loaders which provide both economic models with a reduced capital cost since wheel loaders, being more mobile than shovels, are not constrained to a specific mine. This reduced the number of coal loading equipment in each LMU by one.
- Coal trucks were changed from 320-ton trucks to 240-ton trucks to match the loading height and bucket size of the wheel loader.
- Overburden and coal truck numbers were changed to reflect updated productivities and truck match with the coal loader.
- For each type of truck, a generic haul route was created using the geologic model and the pit layout and these routes were used to generate the updated productivity numbers using Caterpillar's fleet production calculation (FPC) software program. Appendix A contains the detailed FPC calculations and haul routes.

The calculated overburden truck productivity of 478 BCY/Operating Hour was based on the following haul parameters.

- One-way distance of 10,600 ft.
- 50 ft. elevation gain at an 8% grade
- 0% grade on the remaining length of haul
- Two 90° turns
- 4% rolling resistance.

The calculated coal truck productivity of 495 Tons/Operator Hour was based on the following haul parameters.

- One-way distance of 20,000 ft.
- 300 ft. (average overburden plus coal thickness) elevation gain at 8% grade
- 0% grade on the remaining length of haul
- Three 90° turns
- 4% rolling resistance.

The updated productivities reduced the number of overburden trucks by two in LMU5 and one in LMU6 while coal trucks were reduced by four in LMU5 and three in LMU6.

The capital cost and the hourly operating cost for each piece of mobile equipment was taken from "Mine and Mill Equipment Costs" for 2007⁴

⁴ "Mine And Mill Equipment Costs – An Estimator's Cost Guide", 2007, InfoMine USA, Inc., Spokane Valley WA.

and then inflated 10% to estimate the 2008 costs, except for draglines which are based on manufacturer quotes. This 10% inflation is an approximation to account for steep increases in diesel fuel, lubricants and replacement parts during the past year. In addition, a 7% increase was added to haul trucks for initial tires due to a worldwide shortage of large truck tires. Finally 5% was added to shovels and draglines for delivery and/or erection costs.

Summary tables of all capital for each model are shown below.

Table 3.1 LMU5 Equipment Capital Summary

Equipment	Number	Cost (\$1,000,000s)
110 cyd -Dragline	3	449.0
30 cyd - Rock-Shovel	2	19.6
240-ton OB Trucks	10	35.4
R.T. Dozers	3	2.8
Dozers (D11)	4	7.5
Water Trucks	3	2.6
Motor Graders	3	5.7
OB-Coal Drills	3	9.4
Coal Wheel Loaders	2	11.8
240-ton Coal Trucks	10	35.4
Reclamation Scrapers	4	7.4
Reclamation Dozers (D11)	2	3.8
Miscellaneous Equipment	NA	0.8
Total	NA	591.2

Table 3.2 LMU6 Equipment Capital Summary

Equipment	Number	Cost (\$1,000,000s)
70 cyd - Dragline	2	240.0
30 cyd - Rock-Shovel	1	9.8
240 ton – OB Trucks	5	17.7
R.T. Dozers	2	1.9
Dozers (D11)	4	7.5
Water Trucks	3	2.6
Motor Graders	3	5.7
OB-Coal Drills	2	6.2
Coal Wheel Loaders	1	5.9
240-ton Coal Trucks	5	17.7
Reclamation Scrapers	2	3.7
Reclamation Dozers (D11)	1	1.9
Miscellaneous Equipment	NA	0.8
Total	NA	321.4

Equipment Replacement

Replacement of trucks, wheel loaders, and ancillary equipment occurs every 10 years in each model with replacement of all shovels every 20

years. Draglines are assumed to be life of mine assets with major repairs consisting of roller replacements at 10 year intervals and tub plus roller replacements at 20 year intervals. The total equipment replacement capital estimate is \$649.2M.

Facilities

Mine facilities including office, maintenance shop, warehouse, equipment wash bay, employee change/shower room, potable water system, etc. are required in the initial stages of the mine. The capital estimate for these facilities is \$29M. This scaled figure is taken from the 2005 Norwest report for an annual tonnage of 33.2Mtons. The 2005 estimates were based on experience from similar sized mining projects studied by Norwest. Since this is a shared facility, \$14.5M was added to each economic model.

Coal Processing Plant

Mined coal will be hauled by large end-dump trucks to a coal processing plant. Here the coal will be dumped into steel hoppers and fed via an apron feeder to a primary crusher. Crushed coal then flows onto a conveyor belt to a secondary crushing and sampling system where it is further reduced in size to approximately two inches. This coal can be sent directly to large (~15,000 ton capacity) storage and blending silos or sent directly to a weigh bin and loaded into a unit train. The capital cost of this coal handling plant is estimated at \$70M which is based on previous cost studies performed by Norwest scaled to an annual tonnage of 33.2Mtons. This is also a shared facility and was split equally between each economic model at \$35M.

Rail Line to Miles City, MT

The closest main rail line to Otter Creek passes through Miles City, MT located about 85 miles from the proposed mine. There is an approved rail line, the Tongue River Railroad, which if built would pass within about six miles of Otter Creek. There is no specific time frame for constructing this railroad. Valuation rules require the evaluator to consider only those improvements that are already in place and not speculate on proposed additions. As such, the cost of the entire rail line to Miles City must be included along with a rail spur and loading loop at the mine location. The impact is significant as the estimate for the rail line only (not including the six mile spur or loading loop) is \$187M. This cost was split equally between each economic model. Norwest assumes that Tongue River Railroad Company (TRRC) will own the main line and therefore be responsible for maintenance and property taxes.

Norwest further assumes that the developer must pay for the railroad up front, but will recover the cost with 4% annual compounded interest over the first 15 years of production. The up-front cost of the railroad is included in the cash flow calculation, but not in the capital expenditures. Likewise the recapture is included in the cash flow, but not in the income.

Had the Tongue River railroad been in place, front-end cash outflow would be reduced in years -2 and -1 resulting in a higher NPV of \$124.8M or \$0.10/ton of recoverable coal.

Working Capital

Working capital is money that is typically committed at the front end of a new project to cover operating costs for the first three months to a year. Working capital may vary over the life of the project and is recovered at the end of the project. For this study, working capital is set at \$12.5M, or about equal to three months of controllable cash costs. This shared cost is split equally between each economic model.

Permitting and Exploration Drilling

Capital costs for permitting and exploration drilling were added to each model with the total cost split equally among each model. Capital for permitting is estimated at \$5M with exploration drilling at \$3M

Total Capital

Adding equipment, facilities, coal handling plant, rail spur and loading loop, working capital, and permitting and exploration drilling gives a total estimated capital expenditure required for the project of \$1,711M (see Table 3.3). This capital will support a total production level of about 30Mtpa.

Table 3.3 Total Capital (Mine, Facilities, Plant, Rail Loop & Working Capital)

Capital Category	Cost (\$1,000,000s)
Mine Equipment (initial plus replacement)	1,566.9
Mine Facilities	29.0
Coal Plant	70.0
Rail Spur (6 mi.) & Loading Loop	24.6
Working Capital	12.5
Permitting and Exploration Drilling	8.0
Total Capital Required Over The Mine Life	1711.0

EQUIPMENT OPERATING COSTS

Mobile equipment hourly operating costs were estimated using Mine and Mill Equipment Costs guide. These costs were adjusted to reflect the following locally estimated costs.

- Diesel cost of \$3.63 per gallon
- Electricity cost of \$0.067 per kWh
- Lube cost of \$9 per gallon.

The plant operating cost from the previous model was adjusted to 2008 using the Mining Cost Service - Mill Cost Index⁵.

The productivity levels for each dragline were based on stripping 275,000 BCY/year/CY of bucket capacity, resulting in annual productivities of 19MBCY and 30MBCY for the 70cy and 110cy draglines respectively.

Productivity levels for shovels, loaders and trucks were adjusted to reflect updated productivities based on the following loading assumptions.

- Bucket cycle time of 0.5 min
- 85% loading/operator efficiency
- 15% swell factor
- 90% bucket fill factor
- 5,500 net operating hours per year.

The above assumptions resulted in an annual productivity of 13MBCY for the 30cy overburden shovel and 17Mtons for the 41cy coal wheel loader. Due to the overall tonnage requirements and match with truck fleet size, the wheel loader productivity was reduced to match the productivity of the five-truck coal fleet or 13.6Mtons annually.

The equipment hourly operating costs were combined with the productivity assumptions to generate unit costs for each piece of equipment or fleet. A summary table of equipment unit costs is shown below. The fleet cost for overburden and coal movement, support equipment, and reclamation are combined into a single unit cost.

⁵ “Mining Cost Service”, InfoMine USA, Inc., Spokane Valley WA, 99206

Table 3.4 Equipment Unit Cost Summary

Equipment	\$/Unit	Units
OB Removal Dragline	0.23	BCY
OB Truck – Shovel	0.71	BCY
Coal Loading – Haulage	0.76	TON
Other Support Equipment	0.48 ¹	TON
Coal Handling Plant	0.19	TON
Reclamation	0.33 ¹	TON

¹ Average values for LMUs 5&6.

OTHER CONTROLLABLE UNIT COSTS

Other unit costs include labor, explosives, and other supplies and services.

Labor

A labor unit cost was estimated using the 2007 labor cost data from Mining Cost Service and ton per man-hour data from the Mine Safety and Health Administration (MSHA) for the Decker, Absaloka, and Spring Creek mines for the period 2000 through 2007. This cost was escalated to reflect current 2008 labor costs.

The published average hourly wage in the Mining Cost Service for Montana union employees is \$24.62. The average hourly wage for salaried employees is \$41.11 based on an annual salary of \$85,000 and 2,080 working hours per year. This is based on a breakout of 15% top management at \$135,000/year, 40% senior management at \$90,000/year, and 45% mid/entry level at \$65,000/year.

Benefits were added as a percentage of hourly wages; 55% was added for union employees while 45% was added for salary employees. A weighted average between union and salary employees was taken based on 443 union employees and 95 salary employees (scaled breakout based on Mining Cost Service data). This weighted average hourly wage was escalated to 2008 costs based on the mine labor cost index. The final calculated hourly wage was \$44.33/hr. This cost was then converted to a cost per ton of \$1.43 using the average productivity number of 31 tons per man-hour from 2000 to 2007 for similar Montana mines.

Explosives

An explosives unit cost was calculated using assumed powder factors and unit prices of \$0.44/lb for ANFO and \$0.74/lb for emulsion. An additional 15% was added for explosive accessories.

Powder factors of 0.6lb/BCY for dragline overburden, 1.0lb/BCY for shovel overburden and 0.30lb/ton for coal were used. This was

combined with an allowance for 10% wet holes (emulsion used) to calculate a total cost per ton. This cost was then escalated to 2008 costs by using the Mining Cost Service index for explosives. The final calculated explosive cost used in the economic model was \$0.36/ unit, whether a BCY of waste or a ton of coal.

Other Supplies and Services

A unit cost for other supplies and services was included in the 2005 analysis. This cost was updated to a 2008 cost of \$0.12/ton using the producer price index.

NON-CONTROLLABLE COSTS

Non-controllable costs include taxes, fees, royalties, reclamation bonding, general insurance, corporate overhead, and other costs.

Taxes, Fees, and Royalties

Taxes, fees and royalties were added to each economic model in accordance with Montana and Federal regulations. The rates for each are listed below:

- | | |
|--|---|
| • Black Lung Tax | \$0.55/ton |
| • Severance Tax | 15% |
| • Gross Receipts Tax | 5% |
| • Reclamation Fee | \$0.35/ton |
| • Resource Indemnity Trust Tax | 0.4% |
| • Royalty Payments (Montana and Other) | 12.5% |
| • Property Taxes (Powder River County) | 3% assessed value
(851.56 mill levy) |
| • Lease Annual Fee | \$3.0/acre |
| • Montana Corporate Income Tax | 6.75% |
| • Federal Corporate Income Tax | 35% or 20% AMT |

Property taxes were included for mobile mining equipment and fixed facilities (office, shop, warehouse, train loadout and rail spur, etc.). Property tax was not included on the main line railroad as this railroad right of way is owned by the Tongue River Railroad Company. Any property tax would be their responsibility.

Other Non-Controllable Costs

The reclamation bond premium of \$1.5M/year was estimated using an insurance premium rate of 1.5% and a \$100M bond value for each model.

General insurance, corporate overhead, and an allowance for other costs were escalated to 2008 costs from the previous model to 1.2 cents/ton, 10.8 cents/ton, and 6.0 cents/ton respectively.

COAL PRICE

The coal price used in each analysis was calculated based on the following data sources:

- FOB Mine Price for 8,800 Btu/lb PRB coal: SNL Energy, Vol. 4, Issue 35, September 2008
- Burlington Northern Santa Fe (BNSF) common carrier pricing rates.

This analysis was performed for two specific power plant locations to give a range of coal prices. The locations used in the analysis are Fergus Falls, MN and Miles City, MT.

The FOB mine price for PRB coal averaging 8,800 Btu/lb of \$11/ton was obtained from a current SNL Energy's Coal Report⁶. Rail shipping rates were obtained from BNSF for revision 7 of their common carrier rates set in February of 2008. These rates determined the shipping prices of \$7.11/ton and \$22.17/ton for Miles City and Fergus Falls respectively. By adding the FOB mine price to the rail shipping rates, delivered prices of \$18.11/ton and \$33.17/ton are calculated for Miles City and Fergus Falls respectively. These delivered prices were used as the basis to calculate the FOB Otter Creek Mine price, assuming 8,800 Btu/lb coal, by subtracting out the rail shipping cost as if the coal originated from Otter Creek. By subtracting the shipping cost from Otter Creek to both Miles City and Fergus Falls (\$2.04/ton and \$13.14/ton respectively) from the delivered prices resulted in FOB Otter Creek Mine Prices of \$16.07/ton and \$20.03/ton. From these ton unit prices, a price per MBtu was calculated based on 8,800 Btu/lb. This unit price per MBtu was then used to determine the Btu adjusted prices per ton for Otter Creek. In addition, an allowance for reduced sulfur was added to the final FOB mine price for Otter Creek based on a Sulfur credit of \$145/ton of SO₂. This sulfur allowance accounted for \$0.41 of the unit price.

In summary, the final Otter Creek FOB mine prices ranged from \$16.10/ton to \$19.97/ton. The higher of these two prices was used in the analysis. Table 3.5 shows the average price used in each model

⁶ "SNL Energy's Coal Report", Sept. 8, 2008. Volume 4, Issue 35. SNL Financial LC Charlottesville VA 22902.

utilizing the higher rate. The detailed price calculations are shown in Appendix B.

Table 3.5 Average Coal Price for Each Model

Model	Coal Price (\$/ton)
LMU5	\$19.82
LMU6	\$20.22
Weighted Average	\$19.97

DISCOUNTED CASH FLOW ANALYSIS AND NPV

A cash flow for each model was created using mining rates of 21.2Mtpa for LMU5 and 12Mtpa for LMU6. The detailed model for each LMU depicting annual cash flows by year is shown in Appendix C.

The mine plan developed by Norwest for the combined Otter Creek area was based on achieving a consistent mined coal quality and smoothing the strip ratio from year to year to avoid wide fluctuations in overburden removal requirements. This plan concentrates mining on private coal lands in the initial production years. NPVs were calculated utilizing this mine plan for each LMU using a 10% discount rate. Table 3.6 summarizes the NPV's from each economic model.

Table 3.6 NPV Summary (10% Discount Rate)

Economic Model	NPV @10%(\$1,000s)
LMU5	28,152
LMU6	57,174
Total	\$85,326

VALUATION

The overall value of the unleased Montana state coal according to the above analysis hinges on the manner in which both analyses (LMUs 5 and 6) are combined in an overall project. The unleased Montana state coal refers to Montana owned coal within the Otter Creek tracts which has not yet been leased. Sections 16 and 36 of Township 4S Range 45E were initially owned by Montana prior to receiving the remaining coal lease areas from the federal government; these two sections have already been leased. The remaining coal with the tracts is held in private leases. The majority of these private leases are owned by GNP-LP. The total recoverable tons for the entire property are 1,308.6Mtons of which 572.3Mtons are unleased Montana state coal.

In a review of the market analysis information provided to the DNRC by Global Energy Decisions⁷, the potential market for Otter Creek coal will reach 30Mtpa by 2011 and 33Mtpa by 2015. Taking into account lead time for permitting and mining construction activities (approximately five years total) it is likely that full production for each LMU would not be realized until late 2014. Since the combined full production of each LMU is 33.2Mtpa, it is feasible that the market could handle the simultaneous startup of both LMUs. This would suggest that the manner in which to combine the NPVs from both LMUs is simply to sum the two values. This results in an Overall NPV of \$85.3M for the entire lease area.

The bonus bid amount for the entire coal property is calculated by summing the NPVs for LMU5 and 6 and dividing by the recoverable tons for the entire property. The result equates to a bonus bid of \$0.0652/ton (\$85.3M/1,308.6Mtons). Multiplying this bonus amount by the amount of unleased Montana state coal yields an overall value under the Income Approach of \$37.3M (\$0.0652/ton x 572.3Mtons).

⁷ Memo to: Monte Mason From: Doug Day, Global Energy Decisions, Dated: May 11, 2007. Re: MT Economic Benefits.

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APPENDIX A

DETAILED FPC CALCULATIONS AND HAUL ROUTES

Caterpillar Inc.
Fleet Production and Cost Program

FPC

Job Name:	Otter Creek State Coal Valuation
Description:	Verificaiton of Overburden Truck number assumption. A generic haul route to produce the same productivity is calculated within FPC. This haul route is then compared with the mine plan layout to determine its practicality. Specific gravity of 2.3 (CAT handbook) and 15% swell was assumed.
Prepared For:	Montana DNRC
Prepared By:	Norwest Corp
Date:	July 24, 2008

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Due to the many variables involved in earthmoving projects and the consequent possibility of inadvertant errors or omissions in preparing reports of this character, neither Caterpillar Inc. nor the dealer can or does represent or warrant, expressly or implicitly, either the accuracy of this report or that the Caterpillar or competitive equipment referred to in the report will in fact achieve the performance indicated on the job to which this report relates.

240 Truck
July 24, 2008

Fleet Production and Cost Analysis

OB Truck Prod Check final
Montana DNRC

Norwest Corp

July 24, 2008

Description:

Material Qty (BCY)	1
lbs per BCY	3,875
lbs per LCY	3,370

Distance feet	Rolling Resistance %	Grade %	Haul mph Limit	Return mph Limit	Description
625	4.00	8.00			ramp up 50 ft
4,375	4.00	0.00			haul along pit
50	4.00	0.00	5.00	5.00	turn
500	4.00	0.00			haul perpendicular to pit
50	4.00	0.00	5.00	5.00	turn
5,000	4.00	0.00			haul along pit

Caterpillar Inc.
Fleet Production and Cost Program

FPC

Job Name:	Otter Creek State Coal Valuation
Description:	Verificaiton of Coal Truck number assumption. A generic haul route to produce the same productivity is calculated within FPC. This haul route is then compared with the mine plan layout to determine its practicality. Density of 77.6lbs/ft ³ from model for bank, 15% swell is assumed.
Prepared For:	Montana DNRC
Prepared By:	Norwest Corp
Date:	July 24, 2008

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Due to the many variables involved in earthmoving projects and the consequent possibility of inadvertant errors or omissions in preparing reports of this character, neither Caterpillar Inc. nor the dealer can or does represent or warrant, expressly or implicitly, either the accuracy of this report or that the Caterpillar or competitive equipment referred to in the report will in fact achieve the performance indicated on the job to which this report relates.

Fleet Production and Cost Analysis

Coal Truck Prod Check final 240tonGen Coal Haul 20,000 ft.

240 Truck

Montana DNRC

Norwest Corp

July 24, 2008

Operating Schedule		1 994F HL	1 793C
Operator Efficiency (%)			90.00
Sched Hrs per Year			33.62
Fleet Estimates			7.00
Fleet Availability (%)			235.31
Tons per Sched Hr			97.54
Total Tons			0.60
Sched Hrs Required			0.10
Total \$			0.70
\$ per Ton			
Tons per Year			
Years Required			
		HAULER CYCLE TIMES Load with Exchange 4.40 Haul 15.55 Dump and Maneuver 0.50 Return 8.09 Potential Cycle Time 28.54 Wait on Slow Hauler 0.00 Wait to Load, Bunching NONE 0.00 Total Cycle Time 28.54	
		POTENTIAL PRODUCTION Tons per Hour 3,208.79 494.75 Avg mph 15.85	

Fleet Production and Cost Analysis

Coal Truck Prod Check final 240ton

Montana DNRC

Norwest Corp

July 24, 2008

Description:

Material Qty (Tons)	1
lbs per BCY	2,095
lbs per LCY	1,822

Distance feet	Rolling Resistance %	Grade %	Haul mph Limit	Return mph Limit	Description
3,750	4.00	8.00			ramp up 250 ft
4,000	4.00	0.00			haul
50	4.00	0.00	5.00	5.00	turn
4,000	4.00	0.00			haul
50	4.00	0.00	5.00	5.00	turn
4,000	4.00	0.00			haul
50	4.00	0.00	5.00	5.00	turn
4,000	4.00	0.00			haul

APPENDIX B

DETAILED PRICE CALCULATIONS

FOB Otter Creek Mine Coal Price Estimation using Fergus Falls, MN

	PRB 8,800	Otter Creek
Dist. Spring Creek to Fergus Falls, MN		814
Dist. Spring Creek to Otter Creek		273
Dist. Otter Creek to Fergus Falls, MN		541
Dist. South PRB to Fergus Falls, MN	913	
BNSF Price Spring Creek to Fergus Falls, MN		19.54
BNSF Price PRB to Fergus Falls, MN	22.17	
Price per ton-mile	0.024	0.024
Adjusted Price to Otter Creek		13.14

Dist. to Fergus Falls	913	541
\$/ton FOB Mine ¹	11.00	
\$/ton Shipping ²	22.17	13.14
BTU/ton	8,800	9,100
\$/MBTU	1.8847	

FOB Fergus Falls Price	\$ 34.30
FOB Otter Creek Price	\$ 21.16
SO2 Credit	\$ 0.41
Adjusted FOB Otter Creek Price	\$ 21.58

PRB 8,800	
SO2 (lb/MBTU)	0.8
S (lb/MBTU)	0.4
S (lb/ton)	7.04
S%	0.35%

Otter Creek	
S%	0.21%

SO2 Credit	
Diff S%	0.14%
SO2 (lb/ton)	5.68
Credit (\$/ton S)	\$145.00
Credit (\$/ton coal)	\$ 0.41

Total Price per Ton FOB Fergus Falls for PRB 8800 BTU Coal	33.17
minus shipping for Otter Creek	13.14
FOB Otter Creek for PRB 8800 quality coal	20.03
\$/MBTU FOB Otter Creek	1.138246

1. Value from SNL Energy Coal Report Vol. 4 Iss. 35 - 09/08/2008

2. Values from BNSF common carrier pricing (effective 02/07/2008) and adjusted for distance

FOB Otter Creek Mine Coal Price Estimation using Miles City, MT

	PRB 8,800	Otter Creek
Dist. Otter Creek to Miles City, MT		85
Dist. South PRB to Miles City, MT	293	
Price per ton-mile from Fergus Falls Scenario	0.024	0.024
Adjusted Price to Otter Creek	7.11	2.04

Dist. to Miles City	293	85
\$/ton FOB Mine ¹	11.00	
\$/ton Shipping ²	7.11	2.04
BTU/ton	8,800	9,100
\$/MBTU	1.0292	

FOB Miles City Price	\$ 18.73
FOB Otter Creek Price	\$ 16.69
SO2 Credit	\$ 0.41
Adjusted FOB Otter Creek Price	\$ 17.10
Coal to Liquid Plant (no S credit)	\$ 16.69

PRB 8,800	
SO2 (lb/MBTU)	0.8
S (lb/MBTU)	0.4
S (lb/ton)	7.04
S%	0.35%

Otter Creek	
S%	0.21%

SO2 Credit	
Diff S%	0.14%
SO2 (lb/ton)	5.68
Credit (\$/ton S)	\$145.00
Credit (\$/ton coal)	\$ 0.41

Total Price per Ton FOB Miles City for PRB 8800 BTU Coal	18.11
minus shipping for Otter Creek	2.04
FOB Otter Creek for PRB 8800 quality coal	16.07
\$/MBTU FOB Otter Creek	0.913317

1. Value from SNL Energy Coal Report Vol. 4 Iss. 35 - 09/08/2008

2. Values from BNSF common carrier pricing (effective 02/07/2008) and adjusted for distance

APPENDIX C

ANNUAL CASH FLOWS BY YEAR

LMU5 (East, Tracts 1&2) Otter Creek MT State Coal Valuation Model

	Basis	Units	Year -5	Year -4	Year -3	Year -2	Year -1	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6 To 10	Year 11 To 15	Year 16 To 20	Year 21 To 25	Year 26 To 30	Year 31 To 35	Year 36 To 40	Year 41 +	Totals
PRODUCTION																					
Tons Produced (000s)	95.0%	tons/yr						9,053	22,316	22,316	22,316	22,316	111,579	111,579	111,579	111,684	111,579	111,579	109,158	316	877,368
Tons Sold Montana (000s)								1,229	4,583	11,374	8,169	12,061	55,591	44,153	53,924	36,663	42,493	67,459	26,823	0	364,521
Tons Sold Other (000s)								7,371	16,617	9,826	13,031	9,139	50,409	61,847	52,076	69,437	63,507	38,541	76,877	300	468,979
Tons Sold (000s)		Recovery						8,600	21,200	21,200	21,200	21,200	106,000	106,000	106,000	106,100	106,000	106,000	103,700	300	833,500
BCY - DRAGLINE Produced (000s)								18,875	54,625	68,625	67,000	75,875	366,625	372,250	365,125	366,375	369,375	381,000	374,125	625	2,880,500
BCY - TRUCK/SHOVEL Produced (000s)								630	1,385	4,305	4,825	11,835	67,345	75,855	77,370	93,640	134,830	235,795	183,220	210	891,245
Total Units (BCY+ tons)								28,105	77,210	94,130	93,025	108,910	539,970	554,105	548,495	566,115	610,205	722,795	661,045	1,135	4,605,245
Strip Ratio (BCY /ROM Ton)								2.27	2.64	3.44	3.39	4.14	4.09	4.23	4.17	4.34	4.76	5.82	5.37	2.78	3.28
BTU/lb (DB)								11,862	11,900	11,953	11,949	11,927	11,935	11,915	11,901	11,896	11,919	11,957	11,953	11,925	11,925
Sulfur % (DB)								0.28	0.28	0.28	0.27	0.28	0.28	0.28	0.28	0.29	0.29	0.29	0.27	0.24	0.28
LbSO2/MBTU								0.47	0.47	0.47	0.45	0.47	0.47	0.47	0.46	0.49	0.49	0.49	0.46	0.40	0.47
Sodium in Ash%								7.93	7.84	7.49	8.03	7.41	6.73	6.73	6.79	6.80	6.72	6.88	7.43	7.36	6.96
REVENUE																					
Coal Sales Price (FOB Mine)	\$	19.82	\$/TON					19.75	19.79	19.95	19.90	19.85	19.91	19.87	19.82	19.74	19.74	19.74	19.85	19.76	19.82
Total Revenue from Coal Sales								169,853	419,614	422,893	421,869	420,823	2,110,797	2,106,279	2,100,563	2,094,057	2,092,702	2,092,444	2,058,526	5,929	16,516,347
CASH PRODUCTION COSTS																					
Controllable Costs																					
Labor	1.43	\$/TON						12,299	30,318	30,318	30,318	30,318	151,588	151,588	151,588	151,731	151,588	151,588	148,299	429	1,191,967
Equipment, Materials and Supplies																					
OB Removal Dragline	0.23	\$/BCY						4,256	12,317	15,473	15,107	17,108	82,665	83,934	82,327	82,609	83,285	85,907	84,356	141	649,486
OB Truck - Shovel	0.71	\$/BCY						450	988	3,072	3,443	8,445	48,055	54,127	55,208	66,818	96,210	168,254	130,739	150	635,958
Explosives	0.37	\$/UNIT						13,640	36,534	42,745	42,339	48,170	239,169	244,357	242,298	248,805	264,950	306,280	282,724	533	2,012,543
Coal Loading - Haulage	0.76	\$/TON						6,546	16,138	16,138	16,138	16,138	80,689	80,689	80,689	80,765	80,689	80,689	78,938	228	634,474
Other Support Equipment	0.44	\$/TON						3,766	9,284	9,284	9,284	9,284	46,420	46,420	46,420	46,464	46,420	46,420	45,413	131	365,010
Other Supplies & Services	0.12	\$/TON						1,028	2,533	2,533	2,533	2,533	12,667	12,667	12,667	12,679	12,667	12,667	12,393	36	99,607
Coal Handling Plant	0.19	\$/TON						1,667	4,108	4,108	4,108	4,108	20,541	20,541	20,541	20,560	20,541	20,541	20,095	58	161,519
Reclamation	0.35	\$/TON						3,036	7,484	7,484	7,484	7,484	37,422	37,422	37,422	37,457	37,422	37,422	36,610	106	294,255
Total Controllable Costs								46,687	119,704	131,155	130,754	143,588	719,216	731,745	729,161	747,888	793,773	909,768	839,567	1,812	6,044,818
\$/SALES TON								5.43	5.65	6.19	6.17	6.77	6.79	6.90	6.88	7.05	7.49	8.58	8.10	6.04	7.25
NON-CONTROLLABLE COSTS																					
Black Lung Tax	0.550	\$/Ton						4,730	11,660	11,660	11,660	11,660	58,300	58,300	58,300	58,355	58,300	58,300	57,035	165	458,425
Severance Tax	15.0%	% of Revenue						17,500	43,314	43,671	43,559	43,445	218,164	217,671	217,048	216,328	216,192	216,163	212,724	561	1,706,340
Gross Receipts Tax	5.0%	% of Revenue						5,853	14,458	14,577	14,540	14,502	72,741	72,577	72,369	72,129	72,084	72,074	70,928	207	569,038
Reclamation Fees	0.350	\$/Ton						3,010	7,420	7,420	7,420	7,420	37,100	37,100	37,100	37,135	37,100	37,100	36,295	105	291,725
Resource Indemnity Trust Tax	0.4%	% of Revenue						468	1,157	1,166	1,163	1,160	5,819	5,806	5,790	5,770	5,767	5,766	5,674	17	45,523
Royalty Payments MT State	12.5%	% of Revenue						3,035	11,339	28,360	20,320	29,926	138,374	109,667	133,575	90,449	104,864	166,456	66,557	0	902,923
Royalty Payments Other	12.5%	% of Revenue						18,197	41,113	24,502	32,414	22,677	125,475	153,618	128,996	171,308	156,723	95,099	190,759	741	1,161,621
Property Taxes	16,682	\$000s						16,703	16,746	16,746	16,746	16,746	83,732	83,732	83,732	83,732	83,732	83,732	83,732	16,746	686,562
Lease Rental Fee	19	\$000s						19	19	19	19	19	97	97	97	97	97	97	97	19	798
Reclamation Bonding (premium)	1,500	\$000s						1,500	1,500	1,500	1,500	1,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	1,500	61,500
General Insurance	0.012	\$/Unit						336	923	1,125	1,112	1,302	6,453	6,622	6,555	6,765	7,292	8,638	7,900	14	55,035
Corporate Overhead + Joint Facilities	0.108	\$/Unit						3,023	8,304	10,124	10,005	11,714	58,076	59,596	58,993	60,888	65,630	77,739	71,098	122	495,313
Other	0.060	\$/Unit						1,679	4,613	5,624	5,558	6,508	32,264	33,109	32,774	33,827	36,461	43,189	39,499	68	275,174
Total Non-Controllable Cash Costs								76,053	162,566	166,495	166,017	168,579	844,097	845,396	842,829	844,284	851,743	871,855	849,798	20,265	6,709,975
\$/SALES TON								8.84	7.67	7.85	7.83	7.95	7.96	7.98	7.95	7.96	8.04	8.23	8.19	67.55	8.05
TOTAL CASH COSTS								122,740	282,270	297,650	296,771	312,167	1,563,313	1,577,141	1,571,989	1,592,172	1,645,515	1,781,622	1,689,364	22,076	12,754,793
\$/SALES TON								14.27	13.31	14.04	14.00	14.72	14.75	14.88	14.83	15.01	15.52	16.81	16.29	73.59	15.30

LMU6 (West, Tract 3) Otter Creek MT State Coal Valuation Model

	Basis	Units	Year -5	Year -4	Year -3	Year -2	Year -1	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6 To 10	Year 11 To 15	Year 16 To 20	Year 21 To 25	Year 26 To 30	Year 31 To 35	Year 36 To 40	Year 41 +	Totals
PRODUCTION																					
Tons Produced (000s)	95.0%	tons/yr						5,053	12,632	12,632	12,632	12,632	63,158	63,158	63,158	63,158	63,158	63,158	63,158	2,421	500,105
Tons Sold Montana (000s)								106	344	1,490	4,178	4,480	22,658	25,016	30,372	21,483	21,521	32,102	42,181	1,913	207,844
Tons Sold Other (000s)								4,694	11,656	10,510	7,822	7,520	37,342	34,984	29,628	38,517	38,479	27,898	17,819	387	267,256
Total Tons Sold (000s)		Recovery						4,800	12,000	12,000	12,000	12,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	2,300	475,100
BCY - DRAGLINE Produced (000s)								12,125	25,875	26,500	28,000	26,875	142,000	153,000	166,375	166,750	166,125	175,250	173,625	6,500	1,269,000
BCY - TRUCK/SHOVEL Produced (000s)								210	630	1,285	1,495	1,395	11,210	23,880	38,620	39,505	62,285	81,905	117,535	7,230	387,185
Total Units (BCY+ tons)								17,135	38,505	39,785	41,495	40,270	213,210	236,880	264,995	266,255	288,410	317,155	351,160	16,030	2,131,285
Strip Ratio (BCY /ROM Ton)								2.57	2.21	2.32	2.46	2.36	2.55	2.95	3.42	3.44	3.81	4.29	4.85	5.97	2.54
BTU/lb (DB)								12,047	12,012	11,934	11,933	11,930	11,912	11,925	11,983	11,969	11,941	11,944	11,936	11,962	11,946
Sulfur % (DB)								0.28	0.28	0.29	0.29	0.29	0.30	0.29	0.27	0.28	0.28	0.28	0.27	0.26	0.28
LbSO2/MBTU								0.47	0.46	0.49	0.49	0.48	0.51	0.49	0.45	0.47	0.47	0.46	0.45	0.44	0.47
Sodium in Ash%								0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
REVENUE																					
Coal Sales Price (FOB Mine)	\$ 20.22	\$/TON (AVG)						20.28	20.16	20.01	20.07	20.09	20.12	20.20	20.31	20.27	20.22	20.23	20.33	20.39	20.22
Total Revenue from Coal Sales								97,337	241,916	240,158	240,849	241,079	1,206,922	1,211,903	1,218,581	1,216,022	1,213,387	1,213,710	1,219,557	46,890	9,608,312
CASH PRODUCTION COSTS																					
Controllable Costs																					
Labor	1.43	\$/TON						6,864	17,161	17,161	17,161	17,161	85,804	85,804	85,804	85,804	85,804	85,804	85,804	3,289	679,428
Equipment, Materials and Supplies																					
OB Removal Dragline	0.23	\$/BCY						2,734	5,834	5,975	6,313	6,060	32,018	34,498	37,514	37,598	37,457	39,515	39,148	1,466	286,130
OB Truck - Shovel	0.71	\$/BCY						150	450	917	1,067	995	7,999	17,040	27,558	28,189	44,444	58,444	83,868	5,159	276,280
Explosives	0.36	\$/UNIT						7,918	18,249	18,706	19,316	18,879	98,628	107,075	117,109	117,558	125,465	135,723	147,859	6,585	939,071
Coal Loading - Haulage	0.76	\$/TON						3,654	9,135	9,135	9,135	9,135	45,673	45,673	45,673	45,673	45,673	45,673	45,673	1,751	361,654
Other Support Equipment	0.51	\$/TON						2,438	6,095	6,095	6,095	6,095	30,473	30,473	30,473	30,473	30,473	30,473	30,473	1,168	241,296
Other Supplies & Services	0.12	\$/TON						574	1,434	1,434	1,434	1,434	7,170	7,170	7,170	7,170	7,170	7,170	7,170	275	56,777
Coal Handling Plant	0.19	\$/TON						930	2,325	2,325	2,325	2,325	11,627	11,627	11,627	11,627	11,627	11,627	11,627	446	92,067
Reclamation	0.31	\$/TON						1,500	3,751	3,751	3,751	3,751	18,753	18,753	18,753	18,753	18,753	18,753	18,753	719	148,490
Total Controllable Costs								26,762	64,433	65,498	66,596	65,834	338,145	358,113	381,681	382,846	406,867	433,183	470,376	20,857	3,081,192
\$/SALES TON								5.58	5.37	5.46	5.55	5.49	5.64	5.97	6.36	6.38	6.78	7.22	7.84	9.07	6.49
NON-CONTROLLABLE COSTS																					
Black Lung Tax	0.550	\$/Ton						2,640	6,600	6,600	6,600	6,600	33,000	33,000	33,000	33,000	33,000	33,000	33,000	1,265	261,305
Severance Tax	15.0%	% of Revenue						10,019	24,973	24,782	24,882	24,882	124,788	125,331	126,059	125,780	125,493	125,528	126,165	4,800	993,457
Gross Receipts Tax	5.0%	% of Revenue						3,360	8,345	8,281	8,306	8,314	41,616	41,797	42,040	41,947	41,851	41,863	42,075	1,620	331,415
Reclamation Fees	0.350	\$/Ton						1,680	4,200	4,200	4,200	4,200	21,000	21,000	21,000	21,000	21,000	21,000	21,000	805	166,285
Resource Indemnity Trust Tax	0.4%	% of Revenue						269	668	662	664	665	3,329	3,344	3,363	3,356	3,348	3,349	3,366	130	26,513
Royalty Payments MT State	12.5%	% of Revenue						270	866	3,728	10,481	11,251	56,972	63,161	77,106	54,423	54,402	81,171	107,172	4,875	525,878
Royalty Payments Other	12.5%	% of Revenue						11,897	29,374	26,291	19,625	18,884	93,893	88,327	75,217	97,579	97,272	70,543	45,273	986	675,161
Property Taxes	9,790	\$000s						9,812	9,855	9,855	9,855	9,855	49,274	49,274	49,274	49,274	49,274	49,274	49,274	9,855	404,000
Lease Rental Fee	9	\$000s						9	9	9	9	9	46	46	46	46	46	46	46	9	380
Reclamation Bonding (premium)	1,500	\$000s						1,500	1,500	1,500	1,500	1,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500	1,500	61,500
General Insurance	0.012	\$/Unit						205	460	475	496	481	2,548	2,831	3,167	3,182	3,447	3,790	4,197	192	25,470
Corporate Overhead + Joint Facilities	0.108	\$/Unit						1,843	4,141	4,279	4,463	4,331	22,932	25,477	28,501	28,637	31,020	34,111	37,769	1,724	229,228
Other	0.060	\$/Unit						1,024	2,301	2,377	2,479	2,406	12,740	14,154	15,834	15,909	17,233	18,951	20,983	958	127,349
Total Non-Controllable Cash Costs								44,528	93,291	93,040	93,536	93,379	469,638	475,242	482,106	481,633	484,885	490,126	497,819	28,719	3,827,941
\$/SALES TON								9.28	7.77	7.75	7.79	7.78	7.83	7.92	8.04	8.03	8.08	8.17	8.30	12.49	8.06
TOTAL CASH COSTS								71,290	157,724	158,539	160,132	159,213	807,783	833,355	863,787	864,479	891,751	923,308	968,195	49,576	6,909,133
\$/SALES TON								14.85	13.14	13.21	13.34	13.27	13.46	13.89	14.40	14.41	14.86	15.39	16.14	21.55	14.54

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Exhibit 8

Analysis of the Tongue River Railroad Draft Environmental Impact Statement

Prepared for Sierra Club and Earthjustice

September 23, 2015

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1. EXECUTIVE SUMMARY

The Tongue River Railroad Company (TRRC) has issued a proposal to construct and operate a 42-mile rail line in the Powder River to transport coal from mines that could be developed at several sites in Montana, collectively referred to as “Tongue River coal”. The Surface Transportation Board’s (STB) Office of Environmental Analysis (OEA) conducted an analysis to assess the potential economic and environmental impacts of the construction and operation of the Tongue River Railroad on coal production, coal markets, and rail transportation.

STB did not provide access to IPM model input and output files, nor as to technical model documentation, thus severely limiting our ability to do a complete and thorough review of the DEIS analysis. STB’s analysis hinges on things that occur on the margin, whether that is with respect to coal production or electric sector dispatch. STB did not document whether or not it considered if the presence of Tongue River coal might:

1. Lead to variation in the delivered prices of coal;
2. Cause existing coal plants to increase their production of electricity, and thus lead to increased greenhouse gas emissions; and
3. Delay the expected retirements of certain existing coal plants.

Without the necessary data, we cannot perform an analysis of the extent to which the presence of Tongue River coal might lead to any or all of those outcomes. For these reasons, we recommend that agency officials and the public view the IPM modeling analysis and the conclusions of the DEIS with skepticism.

We can, however, make the following criticisms of the DEIS analysis:

1. STB minimizes the greenhouse gas emissions associated with the Tongue River Railroad and associated coalmines by looking at a 20-year analysis period rather than over the 55-year expected life of the mines;
2. The agency omitted certain reasonable scenarios, i.e. a high natural gas price sensitivity, that would result in greater emissions of greenhouse gases.
3. It seems likely that Tongue River coal will be exported for international use rather than for domestic use from the information contained in the DEIS. By STB’s own analysis, the scenarios with higher volumes of exported coal have much higher volumes of greenhouse gas emissions.

Lack of the necessary data, as well as criticisms outlined above undermine STB’s conclusions that the greenhouse gas impacts of the Tongue River railroad and associated coalmines would be negligible.



2. INTRODUCTION

The Tongue River Railroad Company (TRRC) proposes to construct and operate a 42-mile rail line in the Powder River Basin between Coalstrip, Montana and the Ashland and Otter Creek areas of Montana. The rail line would transport low-sulfur, bituminous coal from mine sites that could be developed in Rosebud and Powder River Counties in Montana, which includes the proposed Otter Creek Mine (collectively referred to as “Tongue River coal”) which would introduce more than one billion tons of new coal into the market over the 55-year life of the mine. To assess the potential economic and environmental impacts of the construction and operation of the Tongue River Railroad on coal production, coal markets, and rail transportation, the Surface Transportation Board’s (STB) Office of Environmental Analysis (OEA) conducted an analysis and summarized its findings in a Draft Environmental Impact Statement (DEIS). OEA’s analysis examined 21 scenarios and came to the following conclusions:

- Tongue River coal production could induce coal mining.¹ Production in the new mines would range between 20 million and 72 million tons per year, depending on the scenario.²
- For each ton of Tongue River Coal produced, production of other Powder River Basin coal would decline by 0.76 tons on average, and production of total U.S. non-Tongue River coal would decline by 0.95 tons on average,³ thus leading to small increases in overall coal production and resulting greenhouse gas emissions.⁴
- Production of coal from Tongue River would not affect the amount of Powder River Basin coal exported to the countries in the Pacific Basin (i.e., Japan, China, South Korea, Thailand, Singapore, and the Philippines);⁵ however, if any or all of the proposed coal terminals in the United States and Canada are built or expanded, there would likely be increases in coal production and transport from the Powder River Basin, regardless of the existence of Tongue River. These increases could be small or large.⁶

In order to arrive at these conclusions, OEA: 1) analyzed production costs for Tongue River coal; 2) conducted a resource analysis of Tongue River coal, examining factors such as stripping ratio,⁷

¹ DEIS Appendix C, page C.1-1

² DEIS Appendix C, page C.7-9

³ DEIS Appendix C, page C.8-6

⁴ DEIS Appendix C, page C.1-2

⁵ DEIS Appendix C, page C.1-1

⁶ DEIS Appendix C, page C.1-2

⁷ The stripping ratio refers to the ratio of coal to waste material (known as “overburden”) that is extracted during mining. For example, a 4:1 stripping ratio means that mining one cubic meter of coal would require also mining four cubic meters of waste rock. Surface mining tends to have higher stripping ratios due to the fact that overburden must be removed prior to coal extraction. This may also be referred to as the overburden ratio.



production quantity, distance to railroad, and ability to obtain mining rights in order to assess economic competitiveness; and 3) used ICF International’s Integrated Planning Model (IPM) to simulate operations in the U.S. electric sector, and capture interactions between coal from Tongue River and the domestic and international coal markets.⁸ This report examines STB’s use of the IPM model, the input assumptions, the output results, and the agency’s conclusions.⁹

Section 3 describes general economic principles that are applicable to the Tongue River Analysis. The remainder of this report examines and critiques the input assumptions used by STB, to the extent possible. The lack of detail provided in the DEIS on the assumptions, data inputs, and methodologies used by STB in its analysis prohibits adequate third-party review of the study. Several requests for IPM model input and output files were made, and while we received certain input and output variables, we did not receive the model files that were requested. The reasons that these files are necessary for an adequate review are described in Section 4, and our correspondence is documented. Section 5 critiques STB’s conclusion that Tongue River coal would primarily be used domestically, and instead describes the evidence that supports the conclusion that the coal from these mines would be more likely to be exported. By STB’s own analysis, the export scenarios show much larger volumes of CO₂ emissions, and do not support STB’s conclusion that the greenhouse gas effects of the Tongue River Railroad are minor.

3. GENERAL ECONOMIC PRINCIPLES APPLICABLE TO THE TONGUE RIVER ANALYSIS

In general terms, a new source of coal that has a less expensive delivered price¹⁰ than some other coals currently being purchased should “shift the supply curve” for coal. This means that the total amount of coal that can be purchased for less than any given price will increase relative to a scenario without the new source of coal.

It would be reasonable to expect that, in this event, more coal will be purchased in total by coal plants if a new and cheaper source of coal were to enter the market, especially among the coal sources that are “on the margin” (the coal sources with the highest delivered prices that are currently being purchased); and either (or both):

⁸ DEIS Appendix C, page C.1-6

⁹ Synapse did not attempt to independently verify production costs for the Tongue River coal, nor did we do a resource analysis, and this report does not address the economic viability of the Tongue River Railroad or the associated coal mines. The focus of this report is the IPM modeling used to support STB’s conclusions. Accordingly, this report assumes that the railroad and coalmines would be constructed in order to evaluate the likely market and climate impacts, but it does not endorse the STB’s conclusions on the economic viability of the proposals.

¹⁰ Typically, the delivered price of coal is the sum of the minemouth price plus the cost of transportation.



1. Some existing coal plants increase their production of electricity, which requires that there is variation in power plants bids into the wholesale electric market, especially among electric sources that are on the margin. In a wholesale electric market, power plants are dispatched based on their bids, which typically represent the variable operating cost of the power plant. A large portion of this variable cost is fuel cost. Plants that are on the margin are those plants with the highest bid (and thus the highest variable cost) needed to meet load in a given hour. To the extent that a new and cheaper source of fuel enters the market, it may lower the operating costs, and thus the bid prices, of some existing coal plants. These plants may be called upon to generate more electricity, displacing certain other higher-priced generators on the margin.
2. Some existing coal plants postpone their retirements based on their expected purchase of less expensive coal.

If more coal is purchased and used, there are more CO₂ emissions from coal combustion, and more CO₂ from the electric generating sector as a whole. STB's analysis does show small increases to total coal generation and total coal emissions in scenarios in which Tongue River coal enters the market, but the agency's modeling results are consistent with a coal market in which there is little variation in the delivered price of coal within a region. That is, if STB were assuming more variation in the price of delivered coal, we would expect a greater increase to coal generation and coal emissions compared to scenarios without Tongue River coal. The information provided to us by STB regarding coal prices did not include supply curves¹¹ or delivered prices for coal and is, therefore, not appropriate to allow the kind of meaningful third-party review expected in a public process. When asked directly for the files that would allow us to analyze this variation at the margin, STB declined to provide them.

By STB's own analysis, the "total U.S. coal CO₂ emissions from the incremental consumption of Tongue River coal averaged over 2018 to 2037 would range from an increase of 0.4 to 6.4 million metric tons per year and would average an increase of 2.4 million metric tons of CO₂ per year."¹² (Note this is just for the domestic part of STB's analysis. The international portion of the analysis is discussed in Section 5.) Under EPA's recently finalized Clean Power Plan, which regulates CO₂ emissions from existing electric generators with a goal of cutting CO₂ emissions from the electric sector by 32 percent by 2030, any increase is too much and is inconsistent with the emission reduction targets the rule is designed and modelled to achieve. While the Clean Power Plan rule is mentioned in the DEIS, the STB did not include the emission reduction goals in its analysis of the environmental impacts of the Tongue River Railroad.

¹¹ While STB did provide what it defined as "coal supply curves," this data only includes annual coal capacity, price, and coal resources available for four areas of the Powder River Basin. It does not include the delivered costs for coal, nor does it contain information for any other coal mines in the United States, as "the remaining coal supply curve data is data that is proprietary to ICF." Email communication from Danielle Gosselin on August 31, 2015. It is thus impossible to construct a true supply curve for coal as projected by STB.

¹² DEIS Appendix C, page C.10-9

4. TRANSPARENCY IN THE EIS PROCESS

Synapse’s review of the DEIS report and the associated IPM analysis found them to be largely inauditable, meaning that they lack the transparency and verifiable data necessary for independent review, and thus do not provide the useful, objective tools necessary to inform a public decision-making process meant to ensure the public good. Our review of STB’s analysis found that the agency produced a report using data that are not publicly available and therefore not auditable without the release of additional information. That is, the lack of detail on the assumptions, data inputs, and methodologies used by STB in its analysis greatly impedes adequate third-party review of the study. Analyses that are included in a productive public discourse should be defensible and have well-defined methodology and assumptions, combined with the use of publicly available information. For these reasons, we recommend that agency officials and the public view the IPM modeling analysis and the conclusions of the DEIS with skepticism, at least up to and until the STB makes all of the assumptions, data inputs, and methodologies available to the public for review and comment as part of a supplemental DEIS. That type of wholly transparent analysis is necessary before it can be determined that the development of the Tongue River Railroad and the associated coal mines will not result in significant environmental impacts.

The following sections describe the IPM model and the obstacles we encountered in our attempt to review the input assumptions used by STB and the output results of the agency’s analysis of Tongue River.

4.1. Obstacles to the Public Review Process

Due to proprietary nature of the IPM, CoalDOM and GMM models, they not available for license to users outside of ICF. While there may be exceptions, generally any party that would like to analyze scenarios using IPM must contract with ICF to do the modeling. We were able to identify specific overt weaknesses in the STB’s analysis, but unless the model input and output files and user documentation is made available, it is impossible for anyone attempting to evaluate the IPM methodology and results—including those that contract ICF to run its model, such as the STB here—to have a full understanding of the input assumptions, calculations, and output results used in a particular analysis. Government agencies engaged in IPM modeling will at times provide these files to intervenors or the public for analysis. For example, the U.S. Environmental Protection Agency (EPA) secures the IPM files and model documentation for its proposed and final rulemakings related to clean air policies and provides those files to the public for review and to use as a reference during the public comment period, most recently for the final Mercury and Air Toxics (MATS) Rule¹³ and the final Clean Power Plan Rule.¹⁴

We made several attempts to obtain the IPM input and output files from STB, as well as the technical model documentation, which provide the basis for the agency’s analysis and underlie its conclusions.

¹³ See <http://www.epa.gov/airmarkets/programs/ipm/toxics.html>

¹⁴ See <http://www.epa.gov/airmarkets/programs/ipm/cleanpowerplan.html>

None of those materials were made available despite our repeated attempts to obtain the necessary information. We asked for the detailed IPM input and output files for the scenario runs,¹⁵ and attempted to make our requests very specific by asking for files with the following formats and/or extensions: the System Summary Report, and anything with a .DAT, .RPE, .CAR, or .TAC file extension.¹⁶ Given the “black box” nature of the IPM model, we had to base our more specific requests on our knowledge of the IPM modeling that has been done for the U.S. EPA, requesting files with the same extensions as those that inform the agency’s modeling of environmental rules. In our original request, we also asked for information on specific input and output variables, as well as any work papers or workbooks that ICF used to develop the input assumptions or analyze the output results.

More than a month after our original request, STB sent a CD with certain of the specific input variables for which we had asked¹⁷, which included: energy demand by model region; capital costs for certain new types of generating units; pollution control retrofit options available to existing coal-fired generators; a list of the types of constraints that are used in the IPM model; emission allowance caps that are in place in the model for SO₂ and NO_x; and data for what STB calls “coal supply curves,”¹⁸ which consists of annual coal capacity, price, and coal resources available for four regions in the Powder River Basin.

The agency also sent certain output variables for which we had asked, which included: coal and natural gas prices; new capacity that was added over the study period, by type, year and scenario; electric generation by fuel type and by year for each scenario; fuel consumption by fuel type and by year for each scenario; and generation, fuel consumption, and emissions by year, region and capacity type for each of the scenarios studied by STB.

The data that were sent by STB was only a small fraction of what is needed to review an analysis of this magnitude. STB’s results and conclusions depend on things that happen at the margin. We would need delivered prices for coal in order to construct proper coal supply curves, the variable operating costs for all of the generating units in the U.S., data on wholesale electric prices for each of the time periods modeled in STB’s analysis, and the resulting electric generation from each of the generating units in each of the modeled time periods. We would need fuel consumption and resulting emissions by generating unit, by time period. In addition to a list of the types of constraints that are included in IPM, we would need to see how they were applied—in what quantities and in which regions. We would need to understand the model settings—how does the IPM model respond and reflect changes in fuel prices, and fuel supply? This data is voluminous, and the data that we did receive from STB pales in comparison to that which was withheld by the agency. Without that additional data, what we did receive from STB is of little practical use.

¹⁵ Email request by Rachel Wilson on July 14, 2015.

¹⁶ Email requests by Rachel Wilson on July 30, 2015 and August 4, 2015.

¹⁷ Data CD sent by STB, received by Synapse on August 21, 2015.

¹⁸ We do not consider these data to actually represent coal supply curves, as one would need the delivered costs for coal in order to construct a true supply curve.

After asking again for modeling input and output files, we were informed that the IPM model platform had changed and the file extensions that we had asked for were no longer used or created by IPM.¹⁹ Model input and output files in the new format with the new file extensions were requested, as was a stand-alone technical document for the IPM model.²⁰ The response from STB was that there are no readily available substitutes for the files to which we referred, that there was no stand-alone technical document, and that while a user's manual for IPM exists, it is proprietary.²¹

Given the limited data availability, despite repeated attempts by us to obtain the necessary files, we must conclude that STB's study of the Tongue River Railroad and the associated coal mines lacks the transparency necessary for third party review and verification. The study does not provide critical data needed to confirm or critique its results, as described above. The IPM input and output files are necessary in order to identify both simply transcription errors that may have a dramatic impact on results, as well as erroneous input assumptions or a misrepresentation of output results. By presenting its conclusions in the DEIS document but refusing to give any of the necessary data or assumptions, STB is essentially providing an answer to an equation and asking us to trust that it is correct without showing any of its work.

The results of STB's domestic analysis hinge on what happens on the margin, both in terms of coal supply and electric sector dispatch. As mentioned in Section 3, the variation in the delivered price of coal from that of those coal mines with the highest delivered prices currently being purchased in the market (those mines that are on the margin) would cause more coal to be purchased and burned (creating more emissions of greenhouse gases) if:

1. Existing coal plants increase their production of electricity, which would require variation in the price bid into the wholesale electric market by participating generating units, especially among those generating units with the highest price bids—those that are on the margin; and/or
2. Some existing coal plants postpone their retirements based on anticipated lower operating costs resulting from the purchase of less expensive coal.

STB failed to document this analysis. Lacking the opportunity to analyze model input and output files, and the ability to review technical documentation, we are unable to do our own analysis at the margin for both coal supply or electric system dispatch, and cannot determine how sensitive the IPM model is to price changes in U.S. coal supply.

STB makes two important conclusions in its analysis: 1) that the production and use of Tongue River coal would displace other Powder River Basin coal production at a ratio of one ton to 0.76 tons and other domestic coal production at a ratio of approximately one ton to 0.95 tons; and 2) that Tongue River coal

¹⁹ Email correspondence from Danielle Gosselin on August 31, 2015.

²⁰ Email request by Rachel Wilson on September 10, 2015.

²¹ Correspondence from Danielle Gosselin on September 11, 2015.



would lead to small increases in overall coal production and resulting greenhouse gas emissions. These conclusions seem contradictory. If Tongue River coal were a perfect substitute for other domestic coal, both in the Powder River Basin and in other parts of the United States, we would expect to see a 1:1 displacement ratio, but the STB's conclusion is that one ton of Tongue River coal only displaces 0.76 tons of Powder River Basin coal, and 0.95 tons of other domestic coal. Emissions must, then, be greater, and STB's assertion that Tongue River Coal will increase neither coal production nor emissions cannot be true.

The IPM model does appear to be sensitive to price changes in coal supply. Without the IPM model files, however, we cannot perform an analysis of electric system dispatch or the production of electricity in STB's 21 scenarios to verify that this is true, or to measure the magnitude of that sensitivity. Perhaps just as importantly, it cannot be verified that ICF performed this analysis either. The information needed to review the STB's methodology on this important factor is not in the DEIS, it is not in Appendix C, and it is not in any of the documents the STB provided after we asked for this specific information. This is especially important given that IPM is not capable of doing a chronological dispatch, instead having a set number of load periods. Because the generating unit that is on the margin can change on an hourly basis, IPM thus cannot accurately represent decisions made by individual generating units about whether or not to generate electricity. In the DEIS and related appendices, the STB failed to document whether it even considered critical factors that are necessary to any economically justifiable examination of this issue, including the extent to which the presence of Tongue River coal might: 1) lead to variation in the delivered prices of coal; 2) cause existing coal plants to increase their production of electricity, and thus lead to increased greenhouse gas emissions; and 3) delay the expected retirements of certain existing coal plants. Without the necessary data, we are unable perform this analysis.

4.2. The IPM Model

IPM is an electric simulation model, proprietary to ICF International, which contains both capacity expansion²² and power plant dispatching²³ capabilities. The model provides a least-cost forecast for a given set of future conditions, seeking to minimize both coal market costs and electric power sector costs. Model outputs include forecasts wholesale market power prices, power plant dispatch, transmission flows, emissions, capacity expansion and retirements, power plant retrofits, and fuel consumption and prices.

²² Capacity expansion models screen and evaluate supply- and demand-side options to meet future energy needs in response to user-input demand growth in a specific service area or region, making decisions about 1) the type of resource to build; 2) where to build a specific resource; 3) the quantity of that resource to build; 4) the timing of new resource builds.

²³ Power plants are operated, or "dispatched," in order to meet electric demand over the course of a day. The variable operating costs of each generator determine which units in a power system are dispatched first. Plants with the lowest costs tend to be dispatched first, and plants with higher operating costs are dispatched sequentially as electricity demand increases.

Two additional proprietary ICF models feed into the IPM model: 1) the Coal Depletion Optimization Model (CoalDOM) and 2) the ICF International Gas Market Model (GMM). CoalDOM builds supply curves for coal in the 40 U.S. coal supply regions and 25 international supply regions using data on coal reserves and cost of production, and matches them to 178 demand regions in the United States and Canada, and 26 international demand regions. The GMM model conducts a similar exercise for natural gas. According to the DEIS, the CoalDOM and GMM models provide information for the IPM model, which “determines the least cost means to meet power sector demand for coal as part of an integrated optimal solution for power, fuel, and emissions markets. Thus, IPM is able to determine the optimal sourcing of coal for each power plant based on the predicted coal prices and transportation costs.”²⁴ IPM is a highly sophisticated model, but it does have certain clear user-defined weaknesses that limit its value in STB’s analysis.

The first weakness is that IPM’s 20-year analysis period is too short to capture the total lifecycle greenhouse gas emissions from the Tongue River Railroad and the associated coalmines. As stated in the DEIS, IPM is typically used to look ahead 20 to 40 years in the future.²⁵ OEA chose to do its analysis from 2018 to 2037, which is at the low end of the range of IPM’s capabilities, to reflect the “period of reasonably foreseeable coal production and transport by the proposed rail line.”²⁶ The agency has forecasts for a number of important input variables that extend further into the future than 20 years, however, including peak demand and annual energy²⁷ and natural gas prices,²⁸ which extend through 2044. In addition, the mine plan submitted by Otter Creek Mine Company for its mining permit application is for a 55-year period,²⁹ beginning in 2018 and ending in 2072. If STB’s low projection of 20 million tons of coal mined per year from the Otter Creek mine alone were summed over the expected life of the mine, this project opens up approximately 1.1 billion tons of coal. While the Otter Creek Mine Company may decide not to mine additional coal after 2037, the IPM analysis supports the development and mining of coal from Tongue River, and does not indicate that mining after 2037 would become unfavorable. Mining that occurs in any years subsequent to 2037 would result in additional emissions of greenhouse gas and other air pollutants, which are not accounted for in OEA’s analysis. An additional 35 years of mining beyond OEA’s analysis period would lead to significantly higher air emissions than are presented in the DEIS.

The second weakness in the IPM modeling is in STB’s analysis of scenarios, as the agency chooses scenarios that present lower projected greenhouse gas emissions and omitted certain scenarios where emissions would be higher. For example, the majority of scenarios analyzed used a reference natural gas price, but the agency examined two scenarios that include a low natural gas price, because low natural

²⁴ DEIS Appendix C, page C.5-22

²⁵ DEIS Appendix C, page C.5-3

²⁶ DEIS Appendix C, page C.15-14

²⁷ DEIS Appendix C, page C.5-21

²⁸ DEIS Appendix C, page C.7-15

²⁹ DEIS Appendix C, page C.1-12, Footnote 13

gas prices increase competition with coal.³⁰ It did not, however, examine any scenarios with higher natural gas prices, which are common sensitivities and might be expected given the volatile history of natural gas prices. By examining low natural gas price scenarios, STB was attempting to determine whether Tongue River coal could be economically competitive, and assumed that this was certain under high natural gas prices, but it ignored the greenhouse gas implications of such a scenario. Under reference natural gas prices, Tongue River coal production is at its maximum, but total U.S. greenhouse gas emissions increases are small due to the fact that the Tongue River coal displaces other coal. Under increased natural gas prices, however, natural gas-fired generators become less competitive with coal-fired generators, and we would expect to see coal taking over for some gas-fired generators. As coal generation rises on the whole, Tongue River coal would displace smaller amounts of coal from other domestic sources, leading to a greater increase in greenhouse gas emissions under those scenarios. The scenarios that STB did examine are all weighted equally with no assigned probabilities. Omission of scenarios that would have resulted in higher greenhouse gas emissions skews STB's results and minimizes the potential emissions impact of the Tongue River Railroad and associated coalmines.

5. TONGUE RIVER COAL IS MORE LIKELY TO BE EXPORTED

Based on the results of its IPM modeling analysis, STB concludes that most or all of the coal produced from the mines connected to the Tongue River Railroad will be burned domestically. Several important input assumptions were made by the agency that have a direct and significant impact on the modeling results, and that are unsupported by current evidence and industry trends. Those assumptions are that: 1) domestic coal demand continues to be robust during the analysis period; and 2) Tongue River coal is of equivalent quality to other domestic coal. Rather, given the growing number of international coal plants, the ability of those coal plants to utilize blends of high-sodium coal, and the vertical integration of Arch Coal, it seems that the goal of the Tongue River Railroad and the associated mines is in fact to produce coal for export rather than for domestic use. STB points out in the DEIS that "Tongue River would be closer to export terminals than most other U.S. coal sources...(and) (p)roximity to terminals makes Tongue River coal more attractive for exporting."³¹ As STB's own analysis shows, the scenarios in which Tongue River coal is exported have much higher emissions than when coal is burned domestically.

5.1. Demand for coal is more robust in the Pacific Basin

STB states that coal production in the Powder River Basin has increased significantly since 1970, and more than doubled between 1993 and 2008, charting this rise in Figure 2-1 in Appendix C of the DEIS. Similarly, STB states that Powder River Basin coal prices have increased over the last 20 years, and "higher prices will increase the economic feasibility of potentially induced coal production and rail

³⁰ DEIS Appendix C, page C.7-16

³¹ DEIS Appendix C, page C.1-8



transportation.”³² In the DEIS, STB appears to assume that domestic coal production and coal prices will remain at high levels; however, evidence points to the contrary.

As noted by STB, Powder River Basin coal has historically displaced other U.S. coal at existing power plants as well as met much of the demand from new coal-fired power plants that have come online over the past 40 years.³³ During the period of rapid Powder River Basin production growth between 1993 and 2008, a number of new coal plants were still coming online or were proposed, and existing coal units were switching from higher-sulfur Eastern coal to low-sulfur Powder River Basin coal in order to comply with the Acid Rain Program established by the 1990 Clean Air Act Amendments. Natural gas prices have historically been quite volatile, and coal was the fuel of choice for many power producers.

Conditions are significantly different now. STB recognizes that there are no new coal plants being proposed in the United States at this time, and in fact, many coal plants are retiring due to the combination of increased environmental regulations for SO₂, NO_x, and Hg and low natural gas prices. Between 2012 and 2020, approximately 60 GW of coal is expected to retire in the Energy Information Administration’s (EIA’s) 2014 Annual Energy Outlook Reference Case. This estimate does not include retirements resulting from compliance with the Environmental Protection Agency’s (EPA’s) Clean Power Plan, which will likely lead to retirements of additional plants between 2020 and 2030.

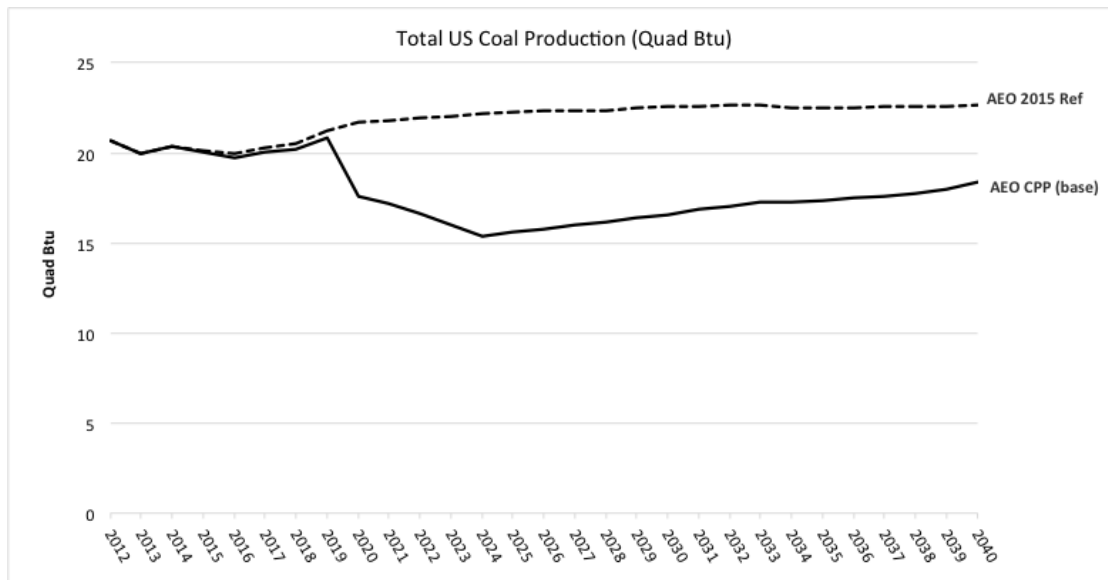
While STB acknowledges that future initiatives or regulations that limit carbon dioxide (CO₂) emissions could affect the domestic coal market,³⁴ it does not include the proposed Clean Power Plan in its IPM analysis, thus assuming that the rule, when it comes into effect, will have no impact on the market for Tongue River coal. This assumption is highly unlikely. EIA recently performed an analysis of the impacts of the proposed Clean Power Plan, concluding that U.S. coal production will fall precipitously under the Clean Power Plan base scenario relative to the AEO 2015 Reference Case forecast (see Figure 1).

³² DEIS Appendix C, page C.2-1

³³ DEIS Appendix C, page C.1-3

³⁴ DEIS Appendix C, page C.2-1

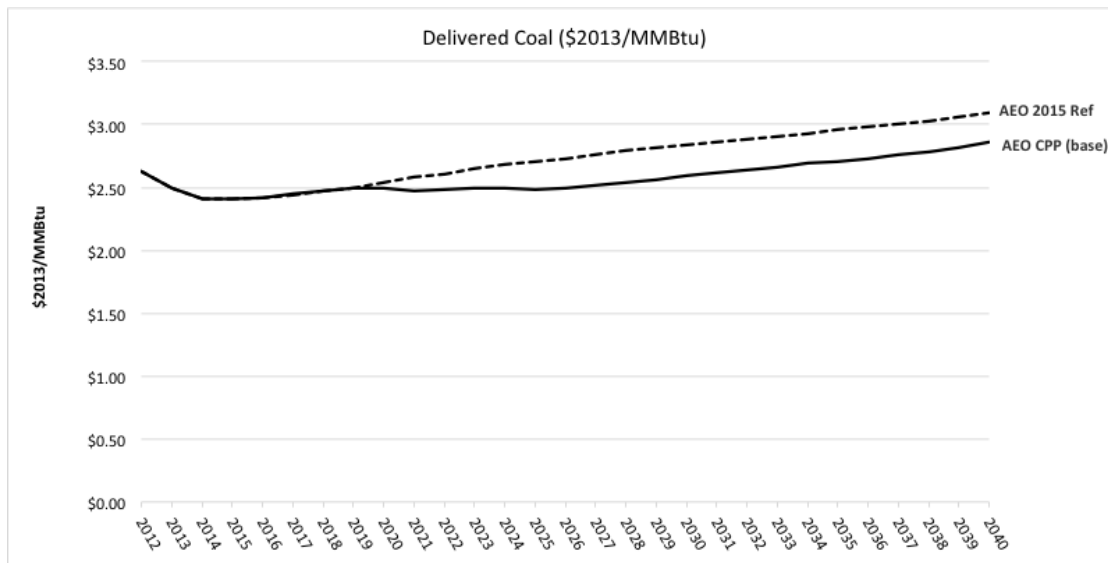
Figure 1. Comparison of total U.S. coal production under 2015 AEO Reference and Clean Power Plan scenarios



Source: U.S. EIA. "Analysis of the Impacts of the Clean Power Plan." May 22, 2015.

The EIA's analysis also forecasts declines in delivered coal prices under the Clean Power Plan scenario (see Figure 2).

Figure 2. Comparison of delivered coal prices under 2015 AEO Reference and Clean Power Plan scenarios



Source: U.S. EIA. "Analysis of the Impacts of the Clean Power Plan." May 22, 2015.

As shown in Table 5-6 in Appendix C of the draft DEIS, thermal coal demand from China and the rest of the Pacific Basin is approximately six to eight times that of the United States in the period from 2018 to

2037.³⁵ Thus, assuming the TRR is built and transports coal out of Montana, the only potential opportunity for this coal is on the international market. In contrast to domestic trends, coal plants continue to be built in the countries located in the Pacific Basin, particularly China. As more plants are built, coal demand grows. STB admits that “as the U.S. export terminal capacities increase, the additional Powder River Basin coal shipped to Asia would displace coal production in China, Indonesia, and Australia, **or would be used to meet the expected growing demand for coal in the Pacific Basin.**”³⁶ [Emphasis added.] If Tongue River coal were displacing coal burned in the countries of the Pacific Basin, we would expect to see a net CO₂ emissions increase of zero. Given that greenhouse gas emissions are much higher in the scenarios that have higher volumes of coal exports (see Section 5.4), it appears as though exported Tongue River coal is being burned used to meet international growth in the demand for coal in those scenarios.

5.2. Higher sodium coal is more suited to export

Coal from Montana has higher sodium content than coal from other regions. Of the Tongue River mines, the sodium content of coal is as follows: 7.4 percent for the Otter Creek mine; 6.5 percent for the Poker Jim Creek-O-Dell Creek mine, and 4.8 percent for the Canyon Creek mine as compared to 1.5 percent for the 13 coal mines in Wyoming.³⁷ STB admits that high sodium content is “an undesirable characteristic”³⁸ and can be problematic for power plants as it can cause ash to accumulate in boilers, creating slagging and fouling conditions. STB assumes, however, that the high sodium content is not a factor that would prevent Tongue River coal from being sold in the United States.³⁹ This assumption seems to be based on the fact that in 2011, there were 15 power plants that purchased coal with a sodium content of 8.2 percent⁴⁰ from the Spring Creek mine. This sample—15 power plants—represents just 2.5% of the 589 coal-fired power plants reported by EIA as being in operation in the United States in 2011,⁴¹ equivalent to one plant for every 39 in operation.⁴² The domestic market for higher-sodium coal appears to be extremely small.

STB states, “Buyers consider many trade-offs between coal quality and cost when purchasing Spring Creek coal or other higher-sodium coal when lower-sodium coal is available. Many factors affect these decisions, including the customer’s boiler and air pollution control equipment, coal quality, and

³⁵ DEIS Appendix C, page C.5-21

³⁶ DEIS Appendix C, page C.8-37

³⁷ DEIS Appendix C, Attachment A, page A-1

³⁸ DEIS Appendix C, Attachment A, page A-6

³⁹ DEIS Appendix C, page C.3-15

⁴⁰ DEIS Appendix C, Attachment A, pages A-2 and A-5

⁴¹ U.S. EIA. Table 4.1. Count of Electric Power Industry Power Plants, by Sector, by Predominant Energy Sources within Plant, 2003 to 2013. Available at: http://www.eia.gov/electricity/annual/html/epa_04_01.html

⁴² Total capacity, in megawatts, would be better metric by which to measure the percentage of coal-fired generation that could burn high-sodium coal; however, neither the names of the 15 power plants nor their capacities were provided in the DEIS.

transportation costs.”⁴³ The CoalDOM model that flows into IPM does include a quality variable for coal, but that refers to the rank (bituminous, lignite, and subbituminous) and sulfur content of the coal only.⁴⁴ There is no evidence in the DEIS that the CoalDOM or IPM models are able to consider differences in the sodium content of coal when making determinations about coal sales and consumption at power plants. There is also no evidence that the model is able to consider the trade-offs between coal quality and cost that are referenced by STB. Rather, STB has made the assumption that Tongue River coal is equivalent in quality to the coal that is currently being burned in the United States, and all resulting model outputs are based on this erroneous assumption.

STB notes that “(s)odium content concerns apply in both the domestic and export markets; however, in the export market, the coal is often a small part of a large blend of many coals and is of less concern in terms of boiler impact.”⁴⁵ Given the faulty assumptions identified above, and the increased marketability of high-sodium coal in international markets, the conclusion that Tongue River coal will primarily serve domestic markets is highly questionable. Instead, Tongue River coal seems more likely to be exported and consumed in China and the other countries of the Pacific Basin. According to STB’s own projections, these export scenarios have emissions that are much higher than those in which coal is burned domestically. Throughout the DEIS, STB states that the impacts on coal production and resulting CO₂ emissions of the Tongue River Railroad and coalmines are small. Focusing instead on the export scenarios, which STB admits have higher emissions, shows that STB may have in fact downplayed the climate impacts of the proposed Tongue River railroad and the associated coalmines throughout the DEIS.

5.3. Arch Coal’s vertical integration supports export

STB states “IPM seeks to minimize coal market costs as well as electric power sector costs.”⁴⁶ However, IPM does not capture other variables that may drive marketing decisions. Specifically, the proposed Tongue River Railroad would be co-owned by Arch Coal, a publicly-traded company with an interest in maximizing its profits by marketing to customers that are not are not reflected by the least-cost scenario. The goal of IPM is thus in direct conflict with Arch, the goal of which may reasonably be assumed to be profit maximization. STB admits this deficiency in the DEIS, stating that

OEA’s forecasts assumed competitive economics and certainty within each scenario. Note, however, that Arch Coal is the co-developer of the TRRC railroad, the Otter Creek Mine, and one of the export terminals, the Millennium Bulk Terminal. Hence, Arch Coal might choose to export rather than sell domestically when there are opportunities to

⁴³ DEIS Appendix C, Attachment A, page A-5

⁴⁴ DEIS Appendix C, page C.5-16

⁴⁵ DEIS Appendix C, Attachment A, page A-1

⁴⁶ DEIS Appendix C, page C.5-3

maximize profits over the suite of assets that include mines, railroads, and export terminals.⁴⁷

Given Arch Coal's vertical integration and goal of profit maximization, it seems reasonably likely that the goal of the company may be to develop coal mines for international export through its proposed export terminals.

Indeed, the proposed alignment of the Tongue River Railroad indicates that Arch has made such a marketing decision. As noted in STB's scoping report, on December 17, 2012, TRRC filed a supplemental application with STB that modified the company's preferred routing for the proposed line as the Colstrip Alternative between Colstrip, Montana, and Ashland/Otter Creek, Montana.⁴⁸ While TRRC's original proposal was to construct the railroad between Ashland and Miles City, Montana, the modified application proposed routing the railroad 50 miles to the west of Miles City, to the Forsyth Subdivision at Nichols Wye.⁴⁹ Such realignment would add significant transportation costs to Tongue River coal destined for domestic markets. On the other hand, the modified route would extend the transportation cost advantage for Tongue River coal destined for export from the West Coast. The IPM's inability to account for this apparent decision by Arch Coal to position its Tongue River coal mines for export results in a significant gap in OEA's analysis.

OEA's failure to account for the likelihood that Tongue River coal will be exported caused it to underestimate likely emissions from Tongue River coal because, as shown in the next Section, the export scenarios have higher emissions of CO₂.

5.4. Tongue River production and emissions increase significantly with exports

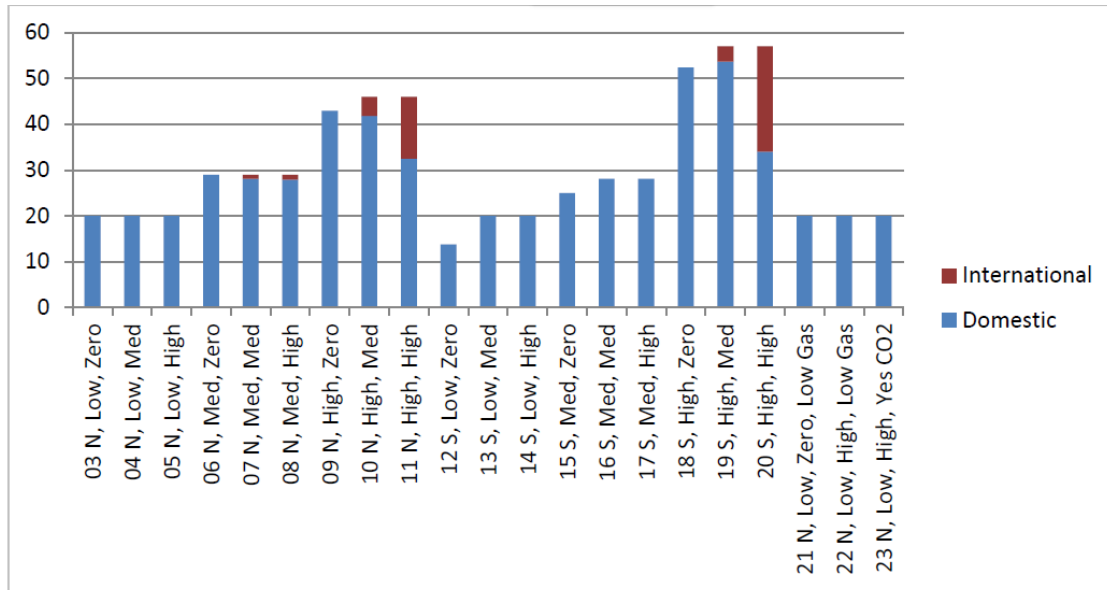
In most of the scenarios analyzed by STB, no coal from Tongue River is exported. Figure 3 shows the annual average domestic and international coal deliveries from Tongue River in the DEIS modeling. In one scenario the share of coal exported is 40 percent (scenario 20) but for most scenarios, all of the coal that is produced is sold domestically. For the northern rail alternative (noted as "N" in Figure 3), those scenarios with the highest share of exports (10 and 11) have the highest total production. The same is true for the southern alternative (noted as "S" in Figure 3), where scenario 19 and 20 have both the highest share of exports and total coal production.

⁴⁷ DEIS Appendix C, page C.8-19

⁴⁸ See http://www.tonguerivereis.com/documents/final_scope_of_study.pdf, at 1.

⁴⁹ See http://www.tonguerivereis.com/documents/final_scope_of_study.pdf, at 7.

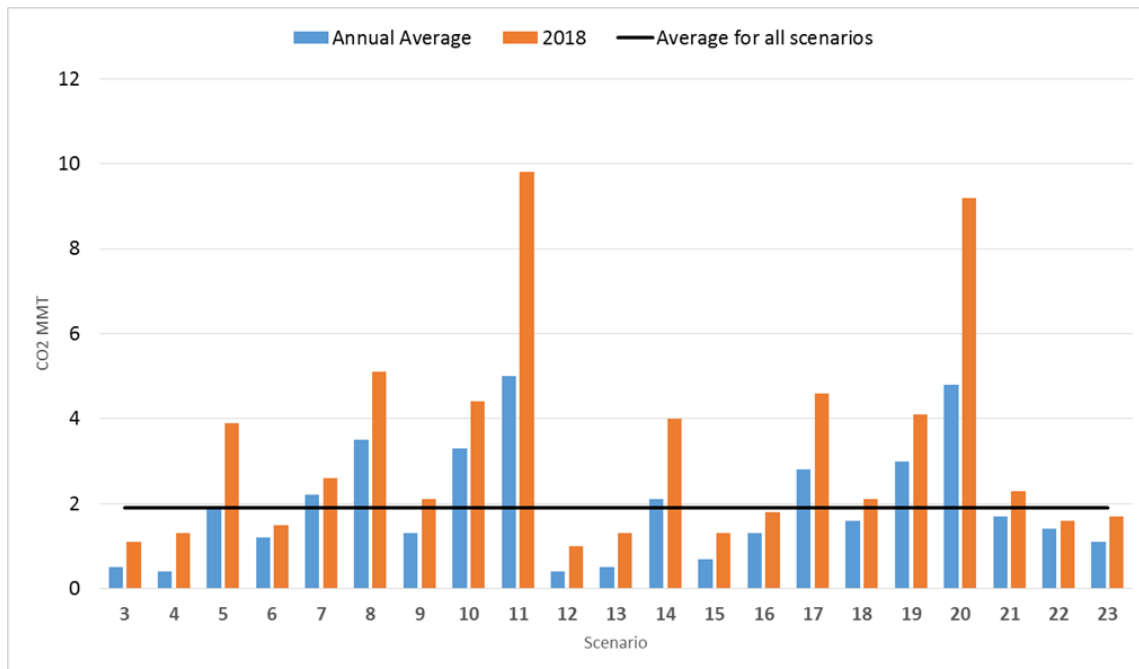
Figure 3: DEIS Tongue River coal production, by scenario (million tons/year)



Source: DEIS Appendix C, Figure 8-22, p. C.8-29

As with total coal production, shown above, CO₂ emissions are greater in scenarios with a higher share of coal exports. Figure 4 depicts the change in U.S. coal and natural gas emissions from the perspective of the annual average, the emissions in 2018, and the average across all scenarios.

Figure 4: Change in U.S. CO₂ emissions from coal and natural gas (million metric tons per year)



Source: DEIS Appendix C, Table 10-7, p. C.10-8.

Figure 4 depicts the change in U.S. coal and natural gas emissions from the perspective of the annual average, the emissions in 2018, and the average across all scenarios. On average, those scenarios with high shares of exports (11 and 20) generate about 5 million tons of CO₂ per year. In 2018, they each generate approximately double that: nearly 10 million metric tons in scenario 11 and 9 million tons in scenario 20. In both cases, this emission result is much higher than the 1.9 million metric ton average across all scenarios. Clearly, high coal production capacity and availability of exports lead to higher CO₂ emissions impacts of Tongue River coal. STB's results show that more coal would be burned in those scenarios with high international exports. This seems justified based on projections of international coal plant additions, yet there is no scenario in which all Tongue River coal is exported. This seems likely if the Tongue River railroad and the associated coalmines were to be constructed, and this scenario should have been considered and reported in STB's analysis.

6. CONCLUSIONS

STB did not provide access to IPM model input and output files, nor as to technical model documentation, thus severely limiting our ability to do a complete and thorough review of the DEIS analysis. Synapse's review of the DEIS report and the associated IPM analysis found them to be largely inauditable, meaning that they lack the transparency and verifiable data necessary for independent review, and thus do not provide the useful, objective tools necessary to inform a public decision-making process meant to ensure the public good. STB's analysis hinges on things that occur on the margin, whether that is with respect to coal production or electric sector dispatch. The agency did not document whether it considered the extent to which the mining of Tongue River coal might: 1) lead to variation in the delivered prices of coal; 2) cause existing coal plants to increase their production of electricity and thus lead to increased greenhouse gas emissions; and 3) delay the expected retirements of certain existing coal plants. Without the necessary data, we are unable to do that analysis. For these reasons, we recommend that agency officials and the public view the IPM modeling analysis and the conclusions of the DEIS with skepticism. The wholly transparent analysis described in Section 4 of this report is necessary before it can be determined that the development of the Tongue River Railroad and the associated coal mines will not result in significant environmental impacts.

We are, however, able to make the criticism that STB minimizes the greenhouse gas emissions associated with the Tongue River Railroad and associated coalmines by looking at a 20-year analysis period rather than over the 55-year expected life of the mines. The agency also omitted certain reasonable scenarios, i.e. a high natural gas price sensitivity, that would result in greater emissions of greenhouse gases. We can also draw the conclusion that it seems likely that Tongue River coal will be exported for international use rather than for domestic use from the information contained in the DEIS. There are several reasons that we have drawn this conclusion. First, the assumption that U.S. coal demand will remain robust is in direct conflict with the evidence that domestic demand for coal is currently declining, and will continue to decline as new environmental rules are implemented. In the Pacific Basin, on the other hand, demand for inexpensive coal continues to grow as new coal plants

come online and continue to be constructed. Second, coal from Tongue River has much higher sodium content than is typically used at domestic coal plants, and use of Tongue River coal can cause harmful slagging and fouling conditions in coal boilers when burned. International coal plants, by contrast, have experience blending higher-sodium coals with lower-sodium coals for use in their boilers, making Tongue River coal more suited to international export. Third, as the owner of the Tongue River railroad, the coalmines, and one of the proposed export terminals, Arch Coal has a financial interest in exporting Tongue River coal to the countries in the Pacific Basin. By STB's own analysis, the scenarios with higher volumes of exported coal have much higher volumes of greenhouse gas emissions.

In contrast to STB's conclusion the majority of the coal from the Tongue River mines would be burned domestically, the results of the analysis seem to point to the fact that Tongue River coal would in fact be primarily designated for export to China or other countries in the Pacific Basin. STB has presented no evidence that this coal would simply displace other coal that is burned at coal-fired power plants, and may in fact be used to meet increased international demand. STB's modeling excluded the scenario that estimated the environmental impacts if all of the coal from Tongue River was exported. In STB's own modeling scenarios, those with high exports had higher emissions than those in which the coal is used domestically. This undermines STB's conclusions that the greenhouse gas and climate impacts of the Tongue River railroad and associated coalmines would be negligible.



Exhibit 9

Fact Sheet: Social Cost of Carbon

Background

EPA and other federal agencies use the social cost of carbon (SCC) to estimate the climate benefits of rulemakings. The SCC is an estimate of the economic damages associated with a small increase in carbon dioxide (CO₂) emissions, conventionally one metric ton, in a given year. This dollar figure also represents the value of damages avoided for a small emission reduction (i.e. the benefit of a CO₂ reduction).

The SCC is meant to be a comprehensive estimate of climate change damages and includes, among other things, changes in net agricultural productivity, human health, and property damages from increased flood risk. However, it does not currently include all important damages. As noted by the [IPCC Fourth Assessment Report](#), it is “very likely that [the SCC] underestimates” the damages. The models used to develop SCC estimates do not currently include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature because of a lack of precise information on the nature of damages and because the science incorporated into these models naturally lags behind the most recent research. Nonetheless, the SCC is a useful measure to assess the benefits of CO₂ reductions.

The timing of the emission release (or reduction) is key to estimation of the SCC, which is based on a present value calculation. The integrated assessment models first estimate damages occurring after the emission release and into the future, often as far out as the year 2300. The models then discount the value of those damages over the entire time span back to present value to arrive at the SCC. For example, the SCC for the year 2020 represents the present value of climate change damages that occur between the years 2020 and 2300 (assuming 2300 is the final year of the model run); these damages are associated with the release of one ton of carbon dioxide in the year 2020. The SCC will vary based on the year of emissions for multiple reasons. In model runs where the last year is fixed (e.g., 2300), the time span covered in the present value calculation will be smaller for later emission years—the SCC in 2050 will include 40 fewer years of damages than the 2010 SCC estimates. This modeling choice—selection of a fixed end year—will place downward pressure on the SCC estimates for later emission years. Alternatively, the SCC should increase over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater levels of climatic change.

One of the most important factors influencing SCC estimates is the discount rate. A large portion of climate change damages are expected to occur many decades into the future and the present value of those damages (the value at present of damages that occur in the future) is highly dependent on the discount rate. To understand the effect that the discount rate has on present value calculations, consider the following example. Let’s say that you have been promised that in 50 years you will receive \$1 billion. In “present value” terms, that sum of money is worth \$291 million today with a 2.5 percent discount rate. In other words, if you invested \$291 million today at 2.5 percent and let it compound, it would be worth \$1 billion in 50 years. A higher

discount rate of 3 percent would decrease the value today to \$228 million, and the value would be even lower—\$87 million-- with a 5 percent rate. This effect is even more pronounced when looking at the present value of damages further out in time. The value of \$1 billion in 100 years is \$85 million, \$52 million, and \$8 million, for discount rates of 2.5 percent, 3 percent, and 5 percent, respectively. Similarly, the selection of a 2.5 percent discount rate would result in higher SCC estimates than would the selection of 3 and 5 percent rates, all else equal.

Process Used to Develop the SCC

An interagency working group was convened by the Council of Economic Advisers and the Office of Management and Budget in 2009-2010 to design an SCC modeling exercise and develop estimates for use in rulemakings. The interagency group was comprised of scientific and economic experts from the White House and federal agencies, including: Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy, EPA, and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. The interagency group identified a variety of assumptions, which EPA then used to estimate the SCC using three integrated assessment models, which each combine climate processes, economic growth, and interactions between the two in a single modeling framework.

SCC Values

The 2009-2010 interagency group developed a set of four SCC estimates for use in regulatory analyses. The first three values are based on the average SCC from three integrated assessment models, at discount rates of 5, 3, and 2.5 percent. SCC estimates based on several discount rates are included because the literature shows that the SCC is highly sensitive to the discount rate and because no consensus exists on the appropriate rate to use for analyses spanning multiple generations. The fourth value is the 95th percentile of the SCC from all three models at a 3 percent discount rate, and is intended to represent the potential for higher-than-average damages. See the [SCC Technical Support Document](#) (PDF, 51pp, 848K) for a complete discussion about the methodology and resulting estimates.

The interagency group recently updated these estimates, using new versions of each integrated assessment model and published them in May 2013. The 2013 interagency process did not revisit the 2009-2010 interagency modeling decisions (e.g., with regard to the discount rate, reference case socioeconomic and emission scenarios or equilibrium climate sensitivity). Rather, improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves and as used in the peer-reviewed literature.

The SCC estimates using the updated versions of the models are higher than those developed in the 2009-2010 modeling exercise. The four 2020 SCC estimates reported in the 2010 interagency group were \$7, \$28, \$44 and \$86 per metric ton (2011\$). The corresponding four updated SCC estimates for 2020 are \$13, \$46, \$68, and \$137 per metric ton (2011\$). The [May 2013 SCC Technical Support Document](#) (PDF, 22pp, 780K) provides a detailed discussion of the model updates relevant to these estimates.

The table below summarizes the four SCC estimates in certain years.

Social Cost of CO₂, 2015-2050 ^a (in 2011 Dollars)

Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95 th percentile
2015	\$12	\$39	\$61	\$116
2020	\$13	\$46	\$68	\$137
2025	\$15	\$50	\$74	\$153
2030	\$17	\$55	\$80	\$170
2035	\$20	\$60	\$85	\$187
2040	\$22	\$65	\$92	\$204
2045	\$26	\$70	\$98	\$220
2050	\$28	\$76	\$104	\$235

^a The SCC values are dollar-year and emissions-year specific.

Examples of SCC Applications to Rulemakings

EPA has used the SCC to analyze the carbon dioxide impacts of various rulemakings since the interagency group first published estimates in 2010. Examples of these rulemakings include:

- The Joint EPA/Department of Transportation Rulemaking to establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards (2012-2016)
- Amendments to the National Emission Standards for Hazardous Air Pollutants and New Source Performance Standards (NSPS) for the Portland Cement Manufacturing Industry
- Regulatory Impact Results for the Reconsideration Proposal for National Emission Standards for Hazardous Air Pollutants for Industrial, Commercial, and Institutional Boilers and Process Heaters at Major Sources
- Proposed National Emission Standards for Hazardous Air Pollutants (NESHAP) for Mercury Emissions from Mercury Cell Chlor Alkali Plants
- Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Commercial and Industrial Solid Waste Incineration Units Standards
- Final Mercury and Air Toxics Standards
- Joint EPA/Department of Transportation Rulemaking to establish Medium- and Heavy - Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards
- Proposed Carbon Pollution Standard for Future Power Plants
- Joint EPA/Department of Transportation Rulemaking to establish 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards

Limitations of SCC

The interagency group noted a number of limitations to the SCC 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. Additional details are discussed in the 2010¹ and 2013² SCC Technical Support Documents.

Next Steps

The U.S. government committed to updating the current estimates as the science and economic understanding of climate change and its impacts on society improves over time. For example, EPA and Department of Energy also hosted a [series of workshops](#) to inform SCC development. The first workshop focused on conceptual and methodological issues related to integrated assessment modeling and valuing climate change impacts, along with methods of incorporating these estimates into policy analysis. The second workshop reviewed research on estimating impacts and valuing damages on a sectoral basis. Papers based on the presentations from both workshops were published in a special issue of *Climatic Change* (April 2013). In addition, EPA funded a workshop on discounting in September 2011 that invited world-recognized experts to discuss how the benefits and costs of regulations should be discounted for projects with long horizons. In particular, it explored what principles should be used to determine the rates at which to discount the costs and benefits of regulatory programs when costs and benefits extend over very long horizons.

EPA and other agencies continue to engage in research on modeling and valuation of climate impacts to improve these estimates.

¹ See <http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf>

² See <http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf>

Exhibit 10

**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 (CO₂) 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 95th 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 CO₂, 2010 – 2050 (in 2007 dollars)

Discount Rate	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	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

¹ In this document, we present all values of the SCC as the cost per metric ton of CO₂ emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO₂ and the mass of carbon is 3.67 (the molecular weight of CO₂ 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 CO₂ in 2015 and \$26 per ton of CO₂ 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 CO₂ and a “global” SCC value of \$33 per ton of CO₂ 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 CO₂. 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 CO₂ (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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂. 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 CO₂ 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).

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 CO₂ 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 CO₂ fertilization (damages are generally negative but diminishing to zero).

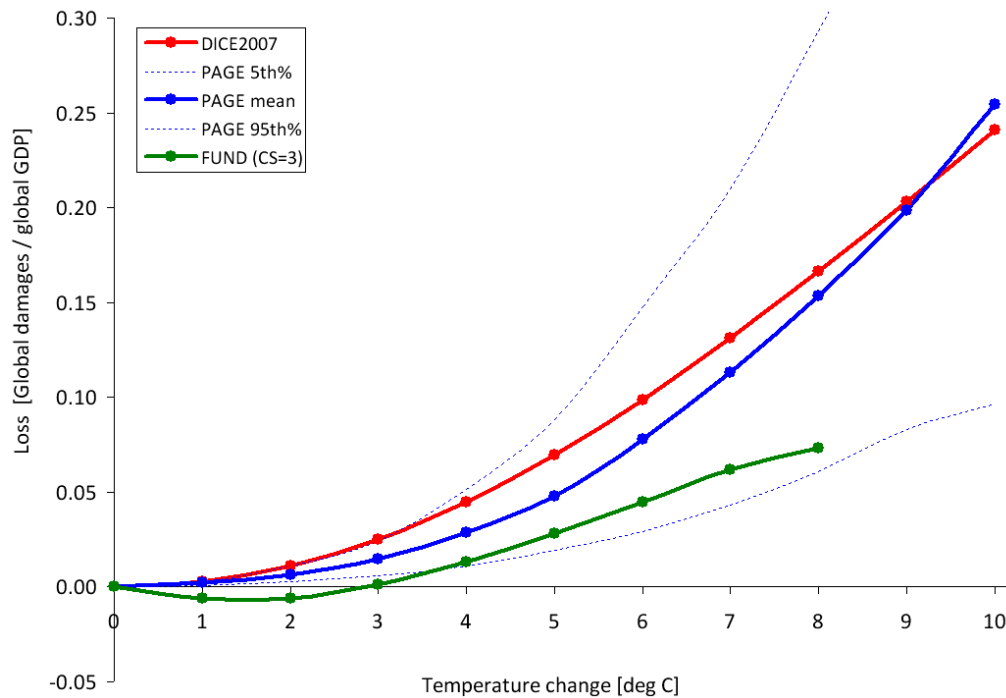
Adaptation is incorporated into FUND by allowing damages to be smaller if climate change happens more slowly. The combined effect of CO₂ fertilization in the agricultural sector, positive impacts to some regions from higher temperatures, and sufficiently slow increases in temperature across these sectors 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 models⁵



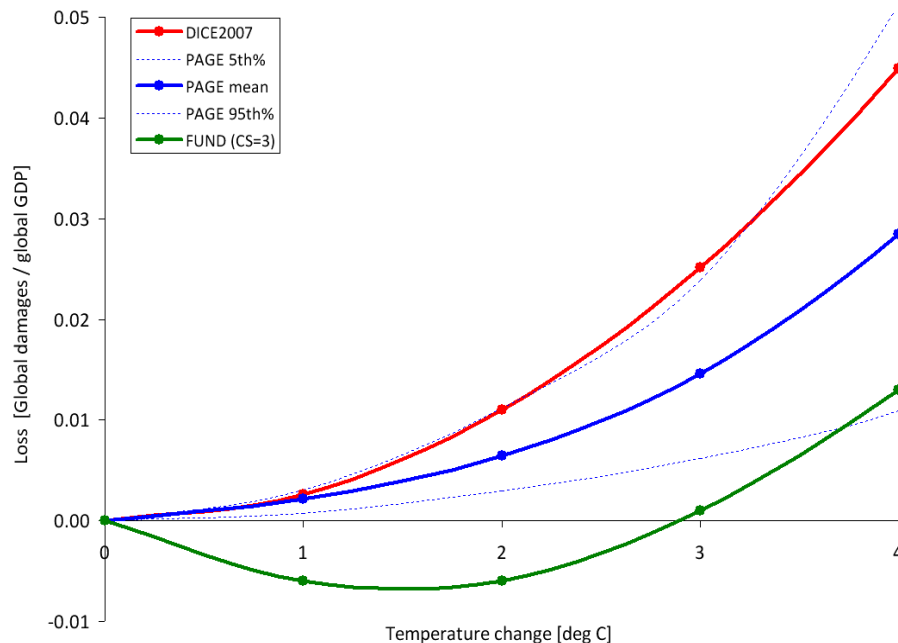
The damage functions for the three IAMs are presented in Figures 1A and 1B, using the modeler's default scenarios and mean input assumptions. There are significant differences between the three models both at lower (figure 1B) and higher (figure 1A) increases in global-average temperature.

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.

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-CO₂ Emissions

While CO₂ 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 CO₂. 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, CO₂ emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Likewise, damages from methane emissions are not offset by the positive effect of CO₂ fertilization. Thus, transforming gases into CO₂-equivalents using GWP, and then multiplying the carbon-equivalents by the SCC, would not result in accurate estimates of the social costs of non-CO₂ gases.

In light of these limitations, and the significant contributions of non-CO₂ emissions to climate change, further research is required to link non-CO₂ emissions to economic impacts. Such work would feed into efforts to develop a monetized value of reductions in non-CO₂ 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 CO₂ 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 CO₂, 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
5 th percentile	1.72	1.49	1.37	1.13
10 th percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50 th percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90 th percentile	5.86	5.14	4.93	4.69
95 th 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.

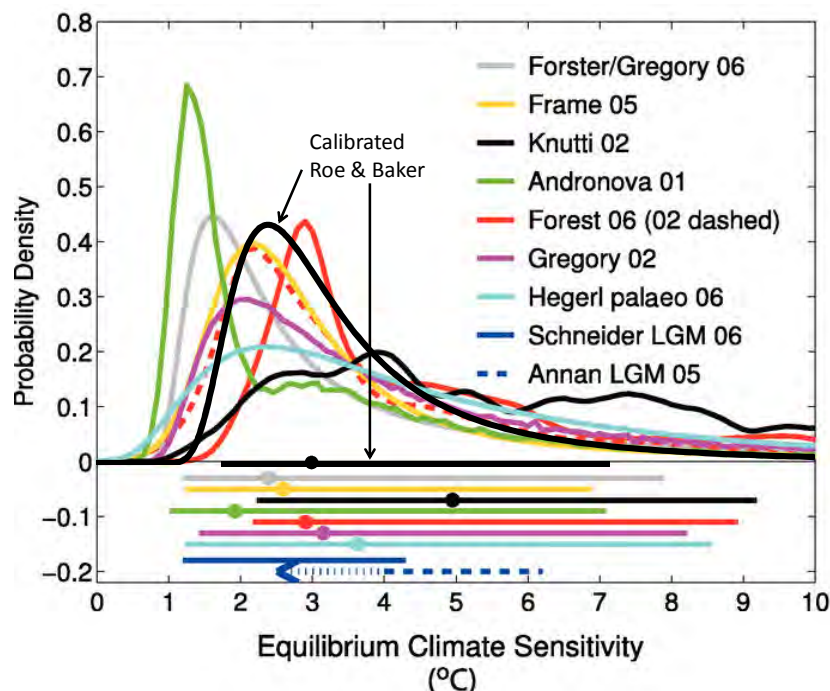
¹¹ Strictly speaking, “most likely” refers to the mode of a distribution rather than the median, but common usage would allow the mode, median, or mean to serve as candidates for the central or “most likely” value and the IPCC report is not specific on this point. For the distributions we considered, 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, CO₂ emissions, and non-CO₂ 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 CO₂ (only) concentrations ranging from 612 to 889 ppm in 2100. One represents an emissions pathway that achieves stabilization at 550 ppm CO₂e (i.e., CO₂-only concentrations of 425 – 484 ppm or a radiative forcing of 3.7 W/m²) 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 CO₂e 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 CO₂ Emissions (GtCO₂/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 (Holtmark 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 is 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 CO₂e 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 CO₂ emissions, each EMF scenario provides projections of methane, nitrous oxide, fluorinated greenhouse gases, and net land use CO₂ 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 CO₂ emissions to 83 percent below 2005 levels by 2050 (per the G-8 agreement) but all other countries continue along a BAU path CO₂ 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

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

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 $\rho = 0.1$ percent per year, $\eta = 1$ 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 $\eta = 1$). Using Stern's assumption that $\rho = 0.1$ 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 CO₂ (2007 dollars) in DICE and FUND. (All calculations are done in tons of CO₂ 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 CO₂ Values by Model, Socio-Economic Trajectory, and Discount Rate for 2010 (in 2007 dollars)

<i>Model</i>	<i>Discount rate: Scenario</i>	5%	3%	2.5%	3%
		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

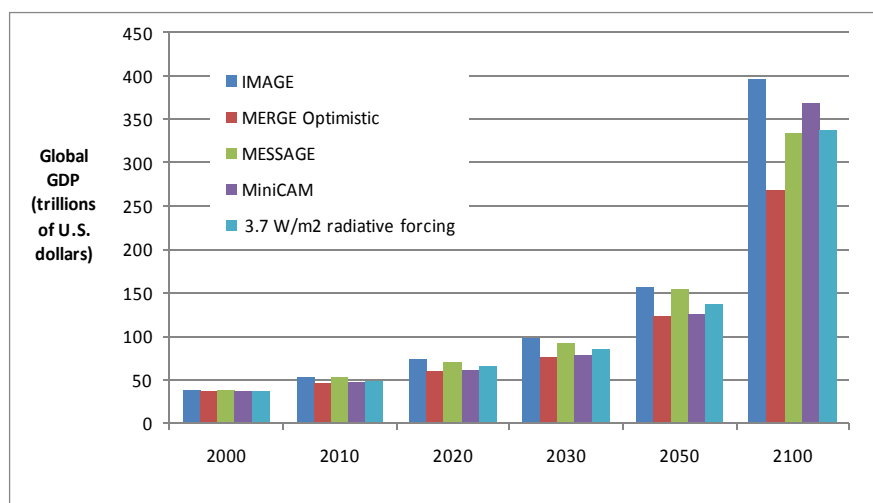
These results are not surprising when compared to the estimates in the literature for the latest versions of each model. For example, adjusting the values from the literature that were used to develop interim

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 $\rho = 1.5$ and $\eta = 2$. 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 $\rho = 0, 1$, 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 CO₂, 2010 – 2050 (in 2007 dollars)

Discount Rate	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	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%	3%	2.5%	3.0%
	Avg	Avg	Avg	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 CO₂ 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 CO₂ 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 CO₂ 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 shift 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 CO₂ in 2015 and \$26 per ton of CO₂ 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.

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Appendix

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

Discount Rate	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	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-CO₂ 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-CO₂) gases

In addition to fossil and industrial CO₂ emissions, each EMF scenario provides projections of methane (CH₄), nitrous oxide (N₂O), fluorinated gases, and net land use CO₂ 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-CO₂ EMF emissions only, we calculated the RF associated with the EMF atmospheric CO₂ 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-CO₂ 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.

FUND: Rather than relying on RF for these gases, the actual emissions from each scenario were used in FUND. The model default trajectories for CH₄, N₂O, SF₆, and the CO₂ emissions from land were replaced with the EMF values.

PAGE: PAGE models CO₂, CH₄, sulfur hexafluoride (SF₆), and aerosols and contains an "excess forcing" vector that includes the RF for everything else. To include the EMF values, we removed the default CH₄ and SF₆ factors³¹, decomposed the excess forcing vector, and constructed a new excess forcing vector that includes the EMF RF for CH₄, N₂O, and fluorinated gases, as well as the model default values for aerosols and other factors. Net land use CO₂ emissions were added to the fossil and industrial CO₂ emissions pathway.

DICE: DICE presents the greatest challenge because all forcing due to factors other than industrial CO₂ emissions is embedded in an exogenous non-CO₂ RF vector. To decompose this exogenous forcing path into EMF non-CO₂ 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-CO₂ sources is -0.06 W/m² in 2005, as reported in AR4, and increases linearly to 0.3 W/m² in 2105, based on GISS projections, and then stays constant after that time.

³⁰ Note EMF did not provide CO₂ concentrations for the IMAGE reference scenario. Thus, for this scenario, we fed the fossil, industrial and land CO₂ emissions into MAGICC (considered a "neutral arbiter" model, which is tuned to emulate the major global climate models) and the resulting CO₂ concentrations were used. Note also that MERGE assumes a neutral biosphere so net land CO₂ 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 CH₄ emissions and the initial atmospheric CH₄ is set to zero to avoid double counting the effect of past CH₄ emissions.

According to AR4, the RF in 2005 from CH₄, N₂O, and halocarbons (approximately similar to the F-gases in the EMF-22 scenarios) was $0.48 + 0.16 + 0.34 = 0.98 \text{ W/m}^2$ and RF from total aerosols was -1.2 W/m^2 . Thus, the -0.06 W/m^2 non-CO₂ forcing in DICE can be decomposed into: 0.98 W/m^2 due to the EMF non-CO₂ 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-CO₂ 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-CO₂ 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).

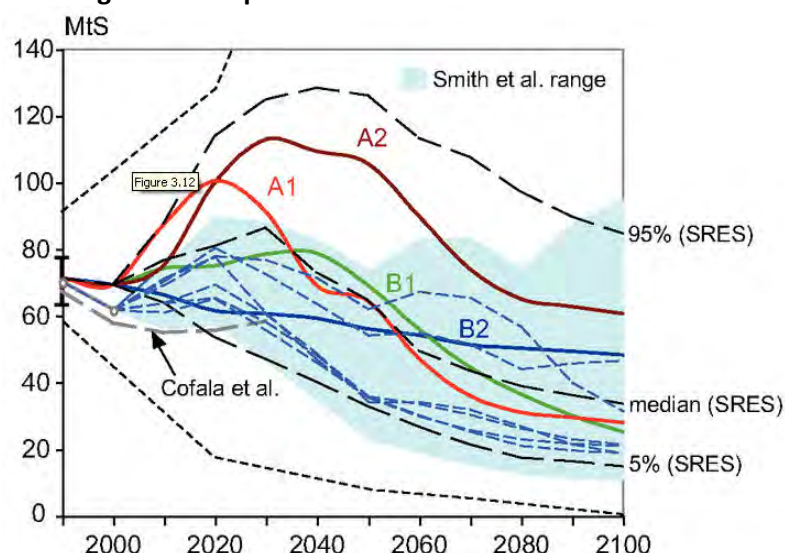
³² AR4 Synthesis Report, p. 44, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

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 SO₂ 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 CO₂ emissions are added to the fossil and industrial CO₂ 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 (CO₂/GDP) growth rate over 2090-2100 is maintained from 2100 through 2300.
4. Net land use CO₂ emissions decline linearly, reaching zero in the year 2200.
5. Non-CO₂ 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.

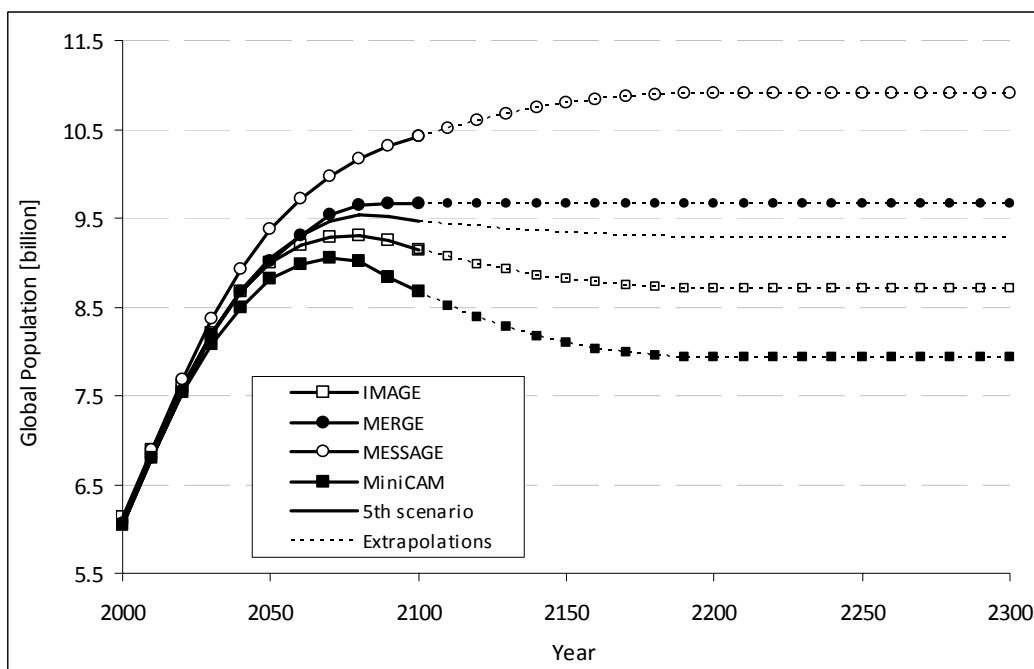
Maintaining the decline in the 2090-2100 carbon intensity growth rate (i.e., CO₂ per dollar of GDP) through 2300 assumes that technological improvements and innovations in the areas of energy efficiency and other carbon reducing technologies (possibly including currently unavailable methods) will continue 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 CO₂ 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-CO₂ 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 CO₂ emissions, net land CO₂ emissions, non-CO₂ radiative forcing, and CO₂ intensity (fossil and industrial CO₂ emissions/GDP) resulting from these assumptions.

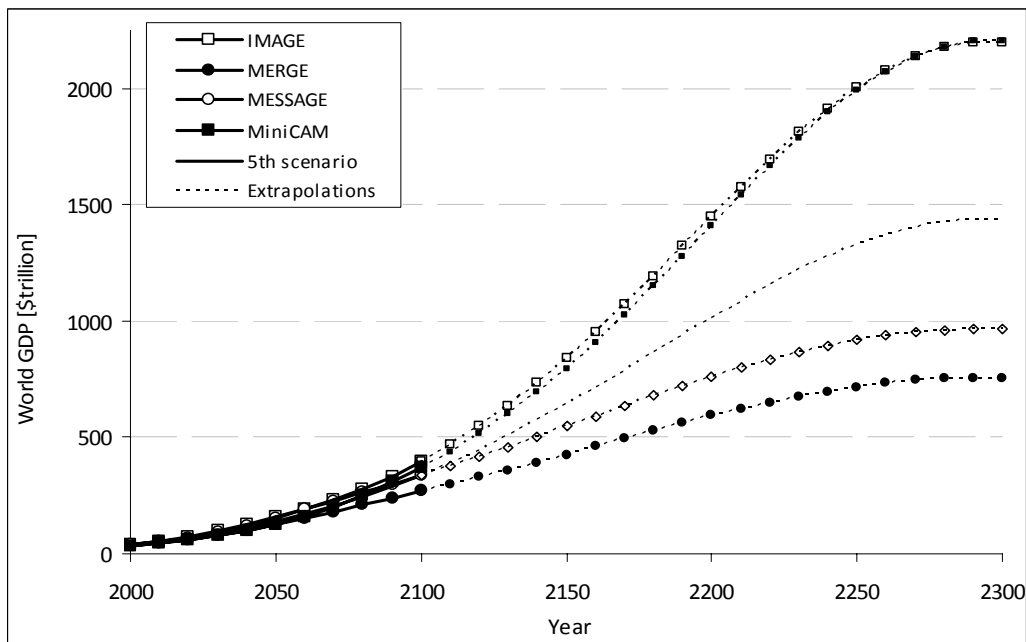
³⁵ United Nations. 2004. *World Population to 2300*.
<http://www.un.org/esa/population/publications/longrange2/worldpop2300final.pdf>

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



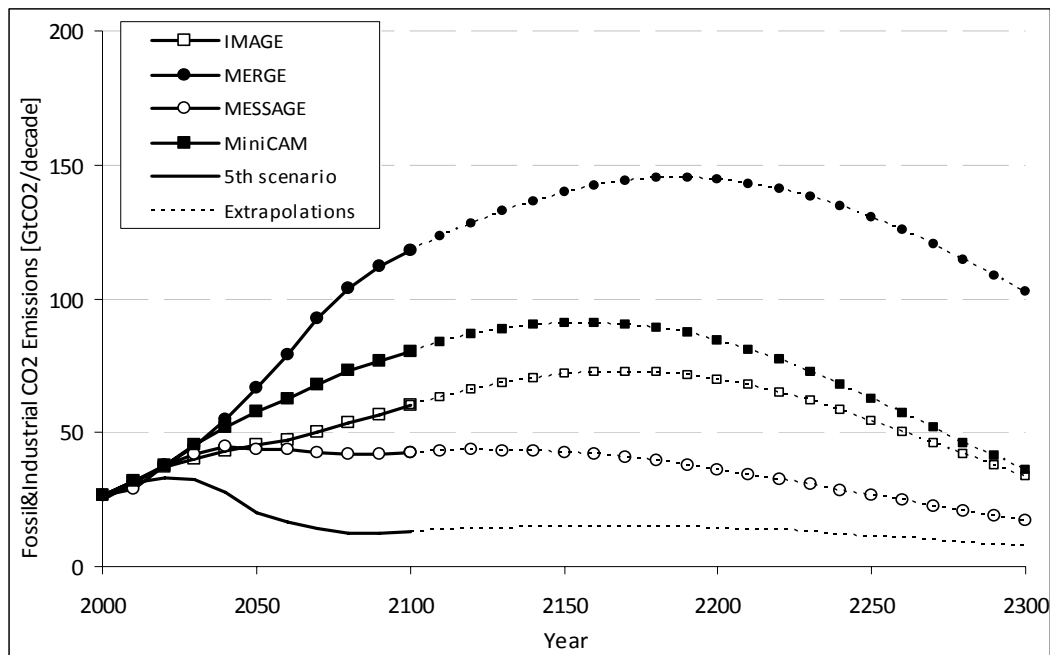
Note: In the fifth scenario, 2000-2100 population is equal to the average of the population under the 550 ppm CO₂e, full-participation, not-to-exceed scenarios considered by each of the four models.

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



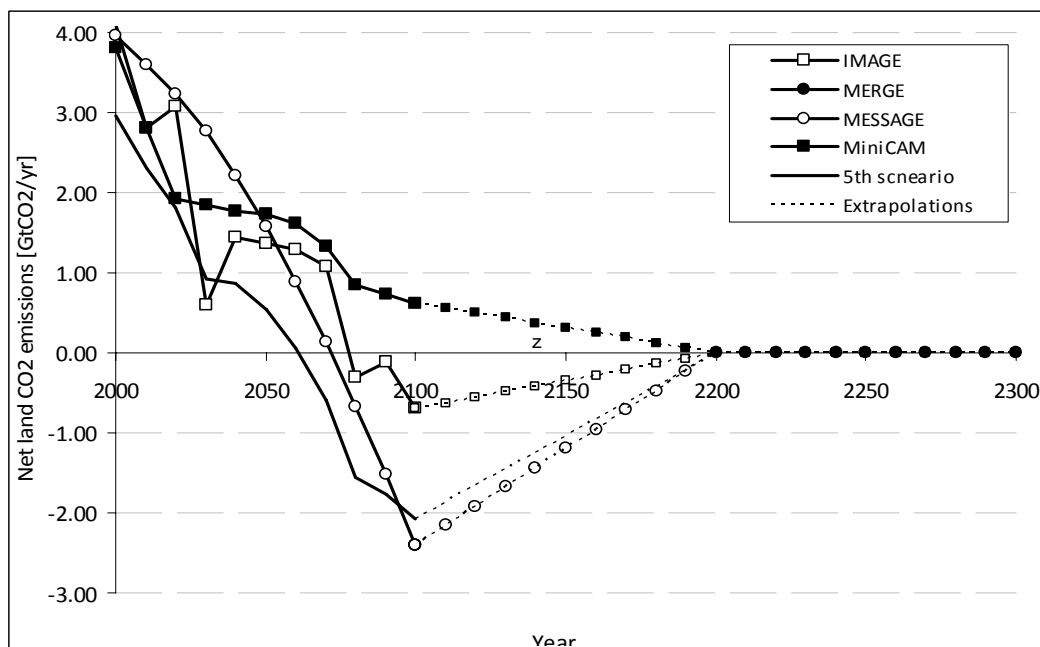
Note: In the fifth scenario, 2000-2100 GDP is equal to the average of the GDP under the 550 ppm CO₂e, full-participation, not-to-exceed scenarios considered by each of the four models.

Figure A4. Global Fossil and Industrial CO₂ Emissions, 2000-2300 (Post-2100 extrapolations assume growth rate of CO₂ intensity (CO₂/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.

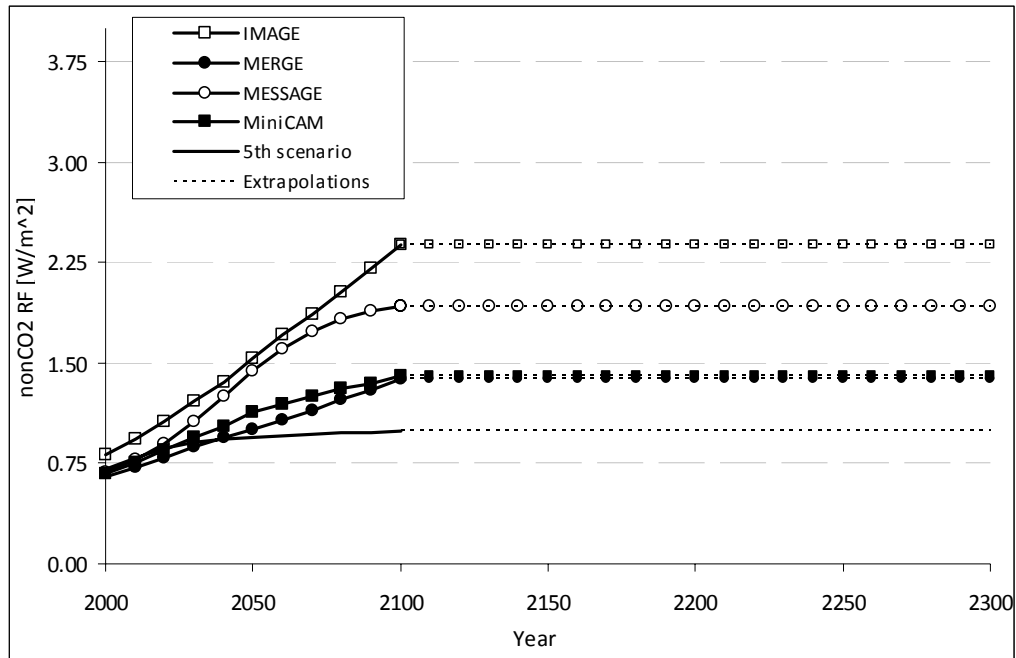
Figure A5. Global Net Land Use CO₂ Emissions, 2000-2300 (Post-2100 extrapolations assume emissions decline linearly, reaching zero in the year 2200)³⁶



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.

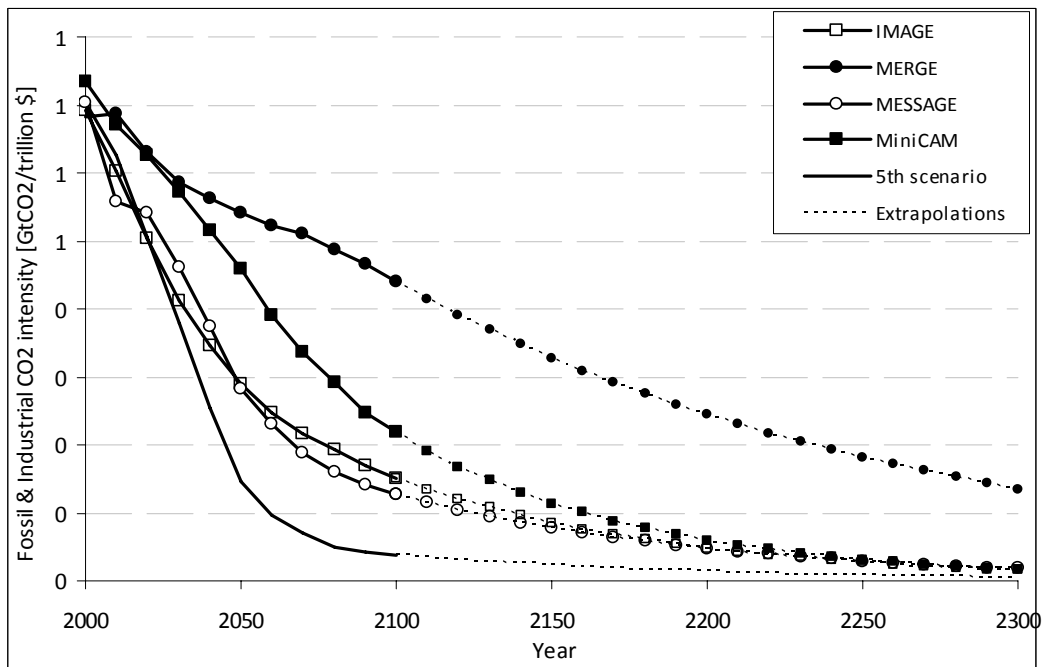
³⁶ MERGE assumes a neutral biosphere so net land CO₂ emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

Figure A6. Global Non-CO₂ Radiative Forcing, 2000-2300 (Post-2100 extrapolations assume constant non-CO₂ 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 CO₂ Intensity (fossil & industrial CO₂ emissions/GDP), 2000-2300 (Post-2100 extrapolations assume decline in CO₂/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 CO₂e, 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 CO₂)

<i>Percentile</i>	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
<i>Scenario</i>	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

<i>Scenario</i>	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

<i>Scenario</i>	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 CO₂)

<i>Percentile</i>	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
<i>Scenario</i>	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

<i>Scenario</i>	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

<i>Scenario</i>	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

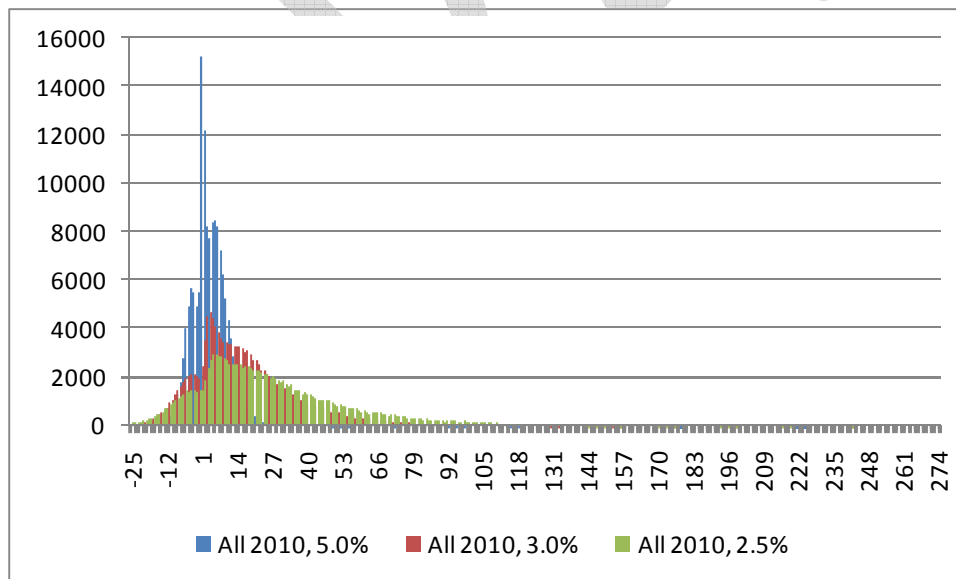
Table A4. 2010 Global SCC Estimates at 5 Percent Discount Rate (2007\$/ton CO₂)

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 CO₂), 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	

Exhibit 11

**Technical Support Document: -
Technical Update of the 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 Management and Budget
Office of Science and Technology Policy
Department of the Treasury

May 2013

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 (CO₂) emissions into cost-benefit analyses of regulatory actions that impact cumulative global emissions. 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.

The interagency process that developed the original U.S. government’s SCC estimates is described in the 2010 interagency technical support document (TSD) (Interagency Working Group on Social Cost of Carbon 2010). Through that 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 (IAMs), at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th 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.

While acknowledging the continued limitations of the approach taken by the interagency group in 2010, this document provides an update of the SCC estimates based on new versions of each IAM (DICE, PAGE, and FUND). It does not revisit other interagency modeling decisions (e.g., with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity). Improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature.

The SCC estimates using the updated versions of the models are higher than those reported in the 2010 TSD. By way of comparison, the four 2020 SCC estimates reported in the 2010 TSD were \$7, \$26, \$42 and \$81 (2007\$). The corresponding four updated SCC estimates for 2020 are \$12, \$43, \$65, and \$129 (2007\$). The model updates that are relevant to the SCC estimates include: an explicit representation of sea level rise damages in the DICE and PAGE models; updated adaptation assumptions, revisions to ensure damages are constrained by GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages in the PAGE model; an updated carbon cycle in the DICE model; and updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the transient response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions in the FUND model. The SCC estimates vary by year, and the following table summarizes the revised SCC estimates from 2010 through 2050.