Attachment 1

Analysis of Potential Use and Destruction of Methane Emissions at West Elk Mine

October 20, 2017

RAVEN RIDGE RESOURCES
INCORPORATED

Table of Contents

List of Tables

List of Figures

List of Maps

List of Exhibits

Executive Summary

Raven Ridge Resources, Incorporated was engaged by Earthjustice to analyze methane emissions data from the West Elk coal mine reported by Mountain Coal Company for adherence to EPA regulations subpart FF. The goal of this analysis was to understand the character of the emissions from the coal mine and develop a conceptual design for abatement of methane emissions to the atmosphere. Emissions data for the years 2011 through 2016 was collated, sorted and analyzed to determine the pattern of emissions, the concentration of methane in the ventilation air and from gas produced from boreholes drilled into mined out areas of the coal mine. These mined-out areas are gob and the boreholes are thus termed gob vent boreholes. Management of the West Elk coal mine utilize the mine's ventilation system and drainage boreholes to remove gas from the mine that may endanger miners. From 2011 through 2016 3.2 billion cubic feet of methane has been admitted to the atmosphere. This is enough methane to have generated 8.5 MW of electricity, which is equivalent to the amount of electricity typically used by 5500 homes on annual basis.

Due to commercial and institutional issues that restrict sale of electricity generated by the mine to the electrical grid and overall low energy prices, a conceptual design was developed that envisions gathering and destroying gas that is emitted from gob vent boreholes; flaring was determined to be the most cost-effective and economic option. During the period from 2011 through 2016, the amount of gas emitted from gob vent boreholes amounted to 1.13 billion cubic feet cubic feet of methane gas. Presently the conceptual design envisions capturing the gas for newly drilled gob vent boreholes, but could be expanded to include gas that could be drained from existing boreholes. Gas captured and transported by the gathering system would be destroyed by an enclosed flare. Such flares are presently being used to destroy gas being drained from the Oxbow mine which is located nearby.

A detailed economic model was constructed based on the conceptual project design using inputs supplied by consulting engineers and vendors. Our analysis used a project life of 10 years and demonstrates that it is technically and economically feasible to safely gather and destroy the drained gas by using an industry standard enclosed flare. Revenue from the project is derived solely from the creation and sale of carbon credits. A carbon market was created by the California Air Resources Board and allows carbon emission reduction projects to generate verifiable credits that can be used by industries included in the program. The predicted economic performance of the proposed project is favorable.

Economic performance of the project was gaged by standard financial industry metrics such as, net present value, internal rate of return, return on investment and time to achieve investment pay back. The project will require a total of 12.54 million dollars of capital expenditures and 3.5 million dollars of operating expense over the project life. With a forecast of 6.7 billion cubic feet of gas produced through GVBs over a 10-year period, net total emissions of 2.64 million tonnes of CO_2e would be destroyed over that period, or about 720 thousand tonnes of carbon. The net present value of the project is $6.51 million USD, the internal rate of return is 121.5%, return on investment is 80.6%, with the project paying out before the end of the first year, meaning that revenue generated from the sale of carbon credits is greater than the sum of the initial investment and operating expenses in the initial year, and every year thereafter during the project life.

Introduction and Previous Studies and Findings from Work Conducted at West Elk Mine

Introduction

Raven Ridge was contracted by Earthjustice to perform an independent evaluation of publicly available methane emissions data submitted for the West Elk Mine, by Mountain Coal Company. Data reported to EPA and available to the public includes volumes and concentrations of methane liberated from the West Elk Mine for the years 2011 through 2016. This data was used to generate forecasts of methane emissions that could be liberated from the proposed lease expansion areas if Mountain Coal Company is allowed to mine the coal contained within the lease areas. These forecasts comprise gas that could be emitted from the drainage and ventilation systems. Raven Ridge used this data to develop a conceptual design for abating the emissions.

Prior EPA Work

Beginning in December 2003, Raven Ridge Resources, Incorporated (Raven Ridge), as a contractor to the United States Environmental Protection Agency's (USEPA) Coalbed Methane Outreach Program (CMOP), organized meetings with West Elk Mine management and various stakeholders, including project developers, electricity providers, US Forest Service (USFS) and US Bureau of Land Management (USBLM), to discuss the feasibility of siting a power generation facility at the mine, utilizing excess CMM drained from the mine workings. At the time, the mine was using a portion of the drained CMM to heat the intake air, while the remaining majority of the drained gas was vented to the atmosphere. Over the course of these meetings, discussions evolved around the amount of gas available for use, types of equipment best suited for the mine's application, ownership of the power distribution system, wheeling the power to market, the potential to generate greenhouse gas emission reduction credits, and other obstacles and challenges of power generation in the North Fork Valley. At the same time, West Elk Mine management evaluated proposals to generate liquefied natural gas (LNG) using the excess drained CMM, and to develop the ventilation air methane (VAM) resources.

Discussions continued at the beginning of April 2004, regarding power generation at the mine and its distribution through Tri-State Generation & Transmission, via the local cooperative power distributor, Delta-Montrose Electric Association (DMEA). A representative of Aspen Ski Company also participated in the discussions, as did representatives of Holy Cross Energy, the electricity provider to the Aspen region. However, West Elk Mine management decided not to move forward with developing a power project at that time.

In 2007, Raven Ridge, representing an industry client, resumed discussions with MCC, a subsidiary of Arch Coal and owner of the West Elk Mine, in their offices in Grand Junction, and with Arch's corporate management in St. Louis. Arch again expressed interest in pursuing a methane recovery and use project at the mine, but ultimately decided against project implementation.

Techno-Economic Study Commissioned by MCC

Arista Midstream Services was commissioned by MCC in 2009 to evaluate an earlier study to determine the viability of operating a methane recovery and use project at the West Elk lease site, utilizing the methane liberated from the mine via gob vent boreholes and ventilation air, as VAM. While many of Arista's assumptions seem reasonable and applicable, many of the costs used in the economic analysis seem excessive and unnecessary. Further, the study did not recognize that some of the costs included in the analysis should be considered as a "cost of mining". These costs would be accrued as activities which are a routine part of normal mining procedures at West Elk and should not be chargeable to a methane use project. The end uses considered for the gas in the Arista study were:

- flaring (destruction),
- generating electricity for use at the mine, and
- conversion of the methane into LNG for sale into wholesale or retail markets.

No consideration was given to selling the electricity into the regional grid, and subsequently, none of the options proved viable under the conditions considered. In addition, a study by the Verdeo Group commissioned by the USFS and the USBLM was carried out to look at the viability of siting VAM destruction technology at one of the exhaust shafts to destroy the methane and sell the carbon emission reduction credits on the markets in operation at the time. Verdeo Group also evaluated the options for selling any emission reduction credits generated from other end-use options under the compliance cap-and-trade programs that were emerging in 2009.

In 2010, Power Consulting, an independent group, was contracted to review and comment on the inputs, assumptions and conclusions made by these organizations. They concluded that the costs offered by Arista/MCC were extremely high and unreasonable, and by lowering the costs and incorporating revenue from the sale of environmental attributes, all of the end-use options evaluated could meet MCC's economic thresholds.

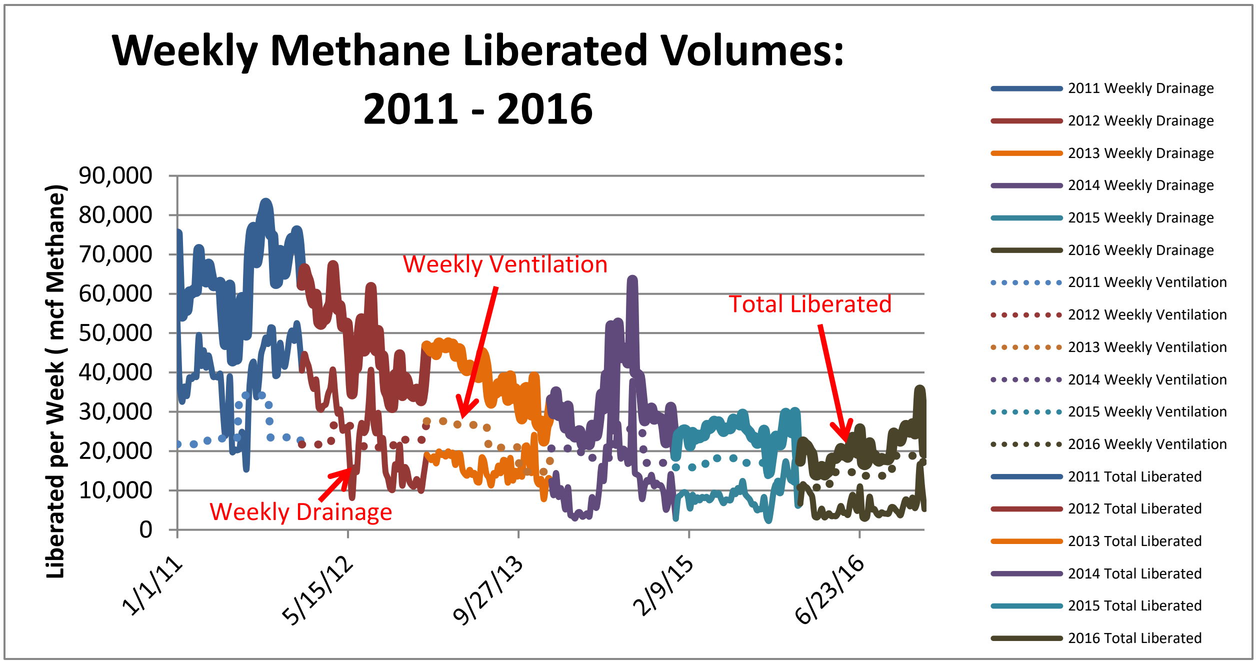
MWCC Methane Emissions Data Reported under Subpart FF

All greenhouse gas (GHG) data reported by U.S. coal mines under the Subpart FF reporting rule is available on the U.S. Environmental Protection Agency's EnviroFacts site for the years 2011 through 2016; recorded first by mine, and then by source (individual borehole or vent shaft). Ventilation data is reported quarterly, including total air flow, and in a different table, methane concentration. Drainage data is reported weekly, with volume and concentration data also in different tables. All data is reported in units of standard cubic feet per minute (scfm), a common unit used in the mining industry to describe flow of air and other gases. This data is collected from GVBs that were drilled above longwall panels active during each of the years 2011 through 2016, and from the Deer Creek ESM shaft and the Sylvester Gulch exhaust vent shaft. The locations of the GVBs and vent shafts can be seen on **Map 1**. Other data is also available such as temperature, pressure, and type of monitoring device used to record the data, but was not included in this study.

MCC uses the term "methane drainage well", or MDW, when referring to gob drainage wells, wells drilled from the surface to intersect sections of the mine where coal has been extracted. The industry standard term is "gob vent borehole", or GVB, which is the term used in this study to distinguish from pre-mine drainage wells that could be drilled in advance of mining.

Results of our initial evaluation of methane liberation from the West Elk Mine for the years 2011 through 2016 is expressed graphically in **Figure 1** below.

Figure 1: Graphic Representation of Publicly Available Methane Liberation Data for West Elk Mine



Methane liberated from the West Elk Mine was noticeably higher in 2011 and 2012 but rapidly decreased to levels seen in 2013 - 2016. For this reason, only data from 2013 – 2016 was used in our analysis, as the higher methane emissions may be related to mining conditions and production rates unique to those years.

The total methane liberated during the period 2011 through 2016 was 3.25 billion cubic feet, 2.12 billion cubic feet, or 65 percent of total methane liberated was emitted to the atmosphere via the two ventilation exhaust shafts, and 1.13 billion cubic feet, or 35 percent of methane liberated, was drained via the GVBs. By employing a more aggressive drainage program, by more closely monitoring the GVBs and allowing the boreholes to produce for a longer period of time, it may be possible to capture a larger portion of the liberated methane which would otherwise be emitted by the ventilation system, thereby reducing the overall ratio of methane liberated via the exhaust shafts. Any acts to manage methane in the mine by increasing GVB production must be evaluated by management and make the safety of the miner paramount. In that regard, it is important to monitor the boreholes to ensure that there is no increased oxygen levels detected in the gob caused by increasing suction at the mine.

Total methane liberated by the mine is equivalent to the carbon dioxide (CO_2) emissions that would be generated from the consumption of 3.55 million barrels of oil. The volume of drained gas alone is sufficient to power an 8.5 MW power station, which would service approximately 5,525 homes. It would take 1.8 million acres of U.S. Forest lands one year to sequester the equivalent volume of greenhouse gases liberated as methane from the West Elk Mine between 2011 and 2016.

Probabilistic Analysis of Emissions Data

To capture the range of uncertainty associated with the data reported by MCC, such as GVB production, the number of GVBs in operation at any one time, and VAM emissions, probability distribution functions were developed by using curve-fitting routines, using Crystal Ball™ to model these variables. Crystal Ball™ is an Excel spreadsheet add-in application used for predictive modeling, simulation, optimization and reporting. The probability distribution functions resulting from the curve fitting are mathematical descriptions of these variables that incorporate the full range of historical values and uncertainty related to the available data sets.

The probability distribution functions generated in this fashion were then used to forecast probabilistic outcomes by using the probability distribution functions to calculate parameters that indicate the economic performance of the capture and use scenarios explored in this analysis. Forecasts presented in this report are outputs of a Monte Carlo simulation conducted using Crystal Ball™. A Monte Carlo simulation is a re-iterative process that randomly samples the probability distributions so that every possible value in the data set is used in combination with the other variables for calculating potential outcomes. The resultant is also a mathematical model, or probability distribution that forecasts the range of possible outcomes.

This re-iterative process allows for the full range of input values to be used in order to determine the most likely outcome, or p_{50} value. The p_{50} value is the median value of the distribution, meaning that there is a 50 percent probability that the value will be greater than the value presented, and a 50 percent probability that the value will be less than the value presented.

Other probabilistic outcomes are calculated indicating the probability of that value occurring:

- The p_{10} value is used to mean that there is a 10 percent probability that the value will be greater than the value presented, and a 90 percent probability that the value will be less than the value presented.
- The p_{90} value is used to mean that there is a 90 percent probability that the value will be greater than the value presented, and a 10 percent probability that the value will be less than the value presented.

Ventilation Air Methane Analysis

Presently, West Elk mine management reduces the amount of methane emitted into the mine's workings using a combination of dilution and evacuation of the methane via the ventilation system by using boreholes to drain areas of the mine where coal has been extracted. These areas are known as the gob and they are largely closed off to the active portions of the mine. The low concentrations of methane in the ventilation air indicate that the system is working to effectively keep the miners safe from potential methane related accidents. This is the primary goal of methane management, but a secondary goal should be to reduce the overall emissions of methane to the atmosphere and there is potential to lower the amount of methane that is exhausted by the ventilation system. About two-thirds of the methane liberated by mining is vented, therefore, it is important to understand the volume and concentrations of the methane in the VAM. Our analysis shows that while it may not be possible to achieve a positive economic outcome by using one of several commercially available options for destruction of methane by oxidation, it is technically feasible to do so without endangering miners or adding criteria pollutants to the environment. Moreover, there is a potential to reduce the amount that is vented by working to increase gob drainage and investigating other potential in-mine drainage schemes.

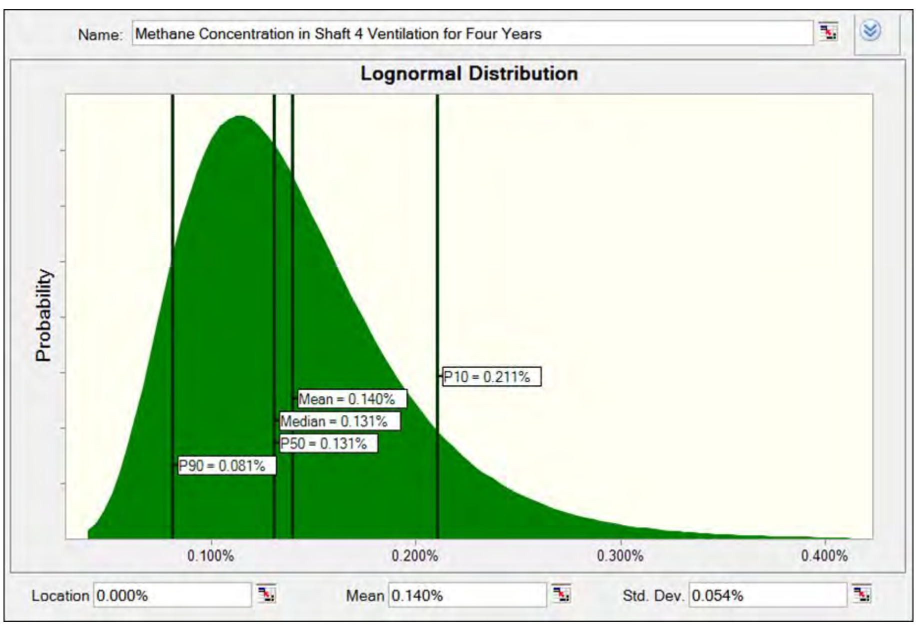
West Elk ventilation air data is reported quarterly, with total volumes and methane concentration data reported separately. The reported data is acquired from four unique locations at mine:

- flow from three sites within the mine, all of which exits the Deer Creek, or East South Mains (ESM) Shaft;
- the remaining ventilation air volume exits the Sylvester Gulch Shaft.

This analysis uses the data collected from the Deer Creek (ESM) shaft, as this shaft recorded the largest volume of VAM with the highest methane concentration. Concentration of methane ventilation air is key to safe effective operation of VAM destruction units. Methane concentration in ventilation air ranges from 0.059 percent to 0.321 percent in air, and the total volume ranges from 777,220 scfm to 1,030,234 scfm. The probabilistic analysis was carried out to determine:

- p_{50} methane concentration in the ventilation stream for ESM shaft for years 2013-2016, as shown in **Figure 2**, and
- p_{50} methane volumes in the ventilation stream for ESM shaft for years 2013-2016, shown in **Figure 3**.

Figure 2: Probability Distribution for Methane Concentration in ESM Shaft

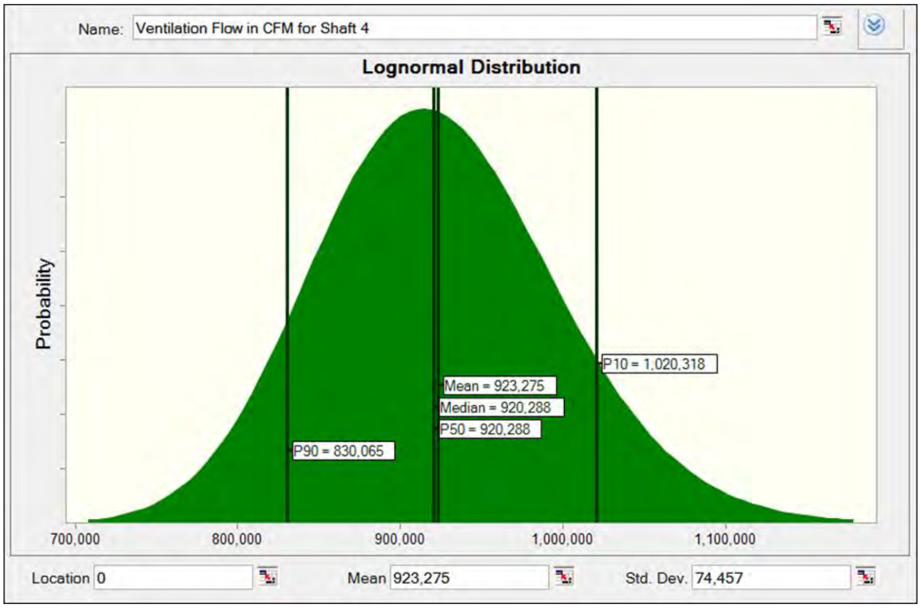


p_{50} = Median, there is a 50 percent probability that the methane concentration in the shaft will be 0.131 percent.

p_{10} = There is a 10 percent probability that the methane concentration in the shaft will be 0.211 percent or greater.

p_{90} = There is a 90 percent probability that the methane concentration in the shaft will be 0.081 percent or greater.

Figure 3: Probability Distribution of Total Ventilation Flow for ESM Shaft



p_{50} = Median, there is a 50 percent probability that the ventilation flow in the Deer Creek ESM shaft will be 920,288 scfm.

p_{10} = There is a 10 percent probability that the ventilation flow in the Deer Creek ESM shaft will be 1,020,318 scfm or greater.

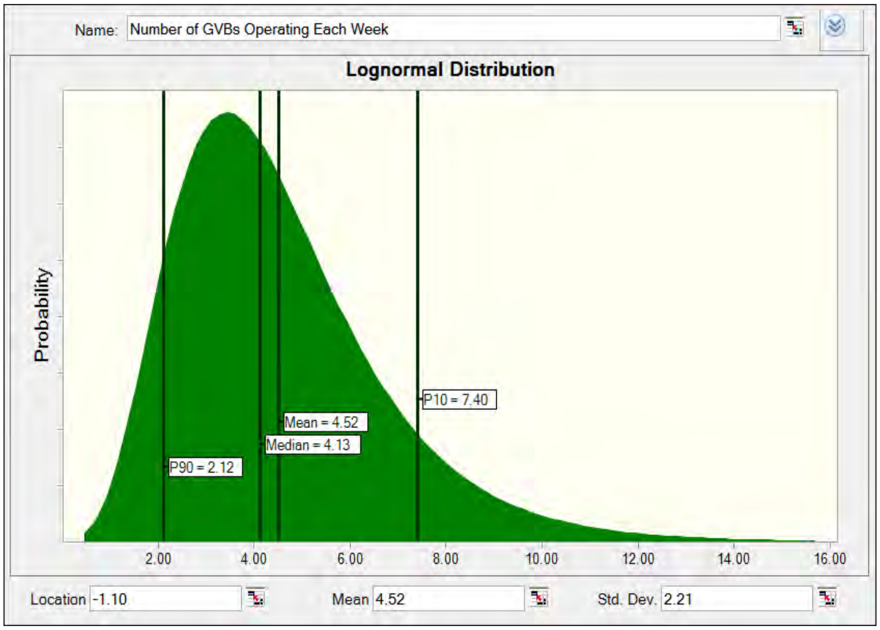
p_{90} = There is a 90 percent probability that the ventilation flow in the Deer Creek ESM shaft will be 830,065 scfm or greater.

GVB Production Analysis

The GVB data is reported on a weekly basis for each operating GVB, with methane concentration and volumes reported separately. Methane concentration in the GVBs ranges from 26.06 percent to 91.89 percent. Curve fitting and probabilistic analysis was carried out to determine the following:

- Number of GVBs operating at each week, shown as **Figure 4**;
- Weekly production of all operating GVBs, shown in **Figure 5;**
- Methane concentration in gob gas, shown in **Figure 6**;
- Number of Weeks each GVB is operating, **Figure 7**;
- p_{50} production volumes for the years 2013 through 2016; and
- p_{50} duration that each GVB is operating for the years 2013 through 2016 in weeks.

Figure 4: Probability Distribution of Number of GVBs Operating each Week

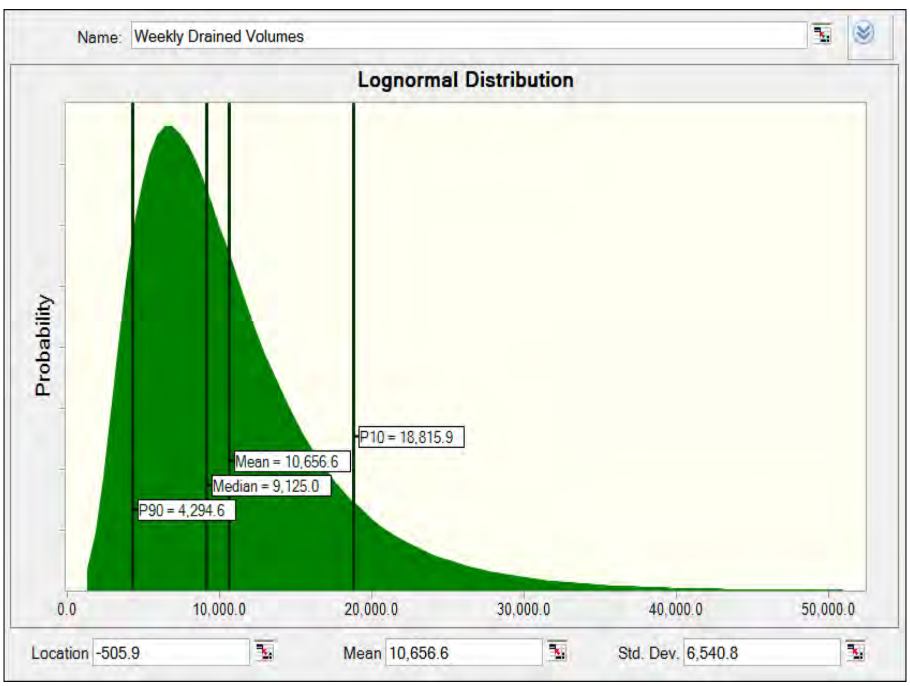


p_{50} = Median, there is a 50 percent probability that 4.13 wells are in service during any given week.

p_{10} = There is a 10 percent probability that there are at least 7.4 wells operating during any given week.

p_{90} = There is a 90 percent probability that there are at least 2.12 wells operating during any given week.

Figure 5: Probability Distribution of Weekly Production for all Operating GVBs

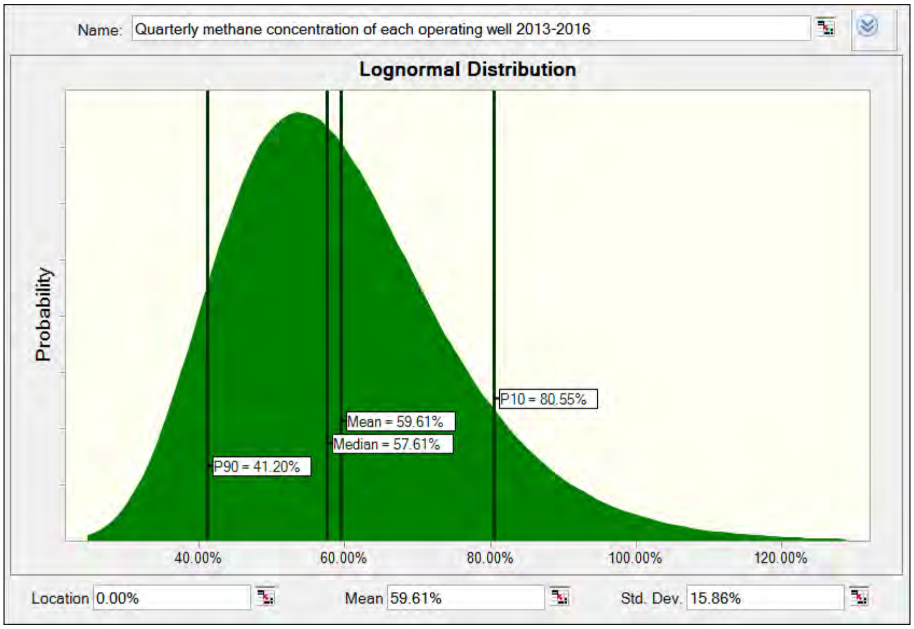


p_{50} = Median, there is a 50 percent probability that weekly methane production will be 9,125 scfm.

p_{10} = There is a 10 percent probability that weekly methane production will be 18,816 scfm or greater.

p_{90} = There is a 90 percent probability that the weekly methane production will be 4,295 scfm or greater.

Figure 6: Probability Distribution of Methane Concentration in Gob Gas

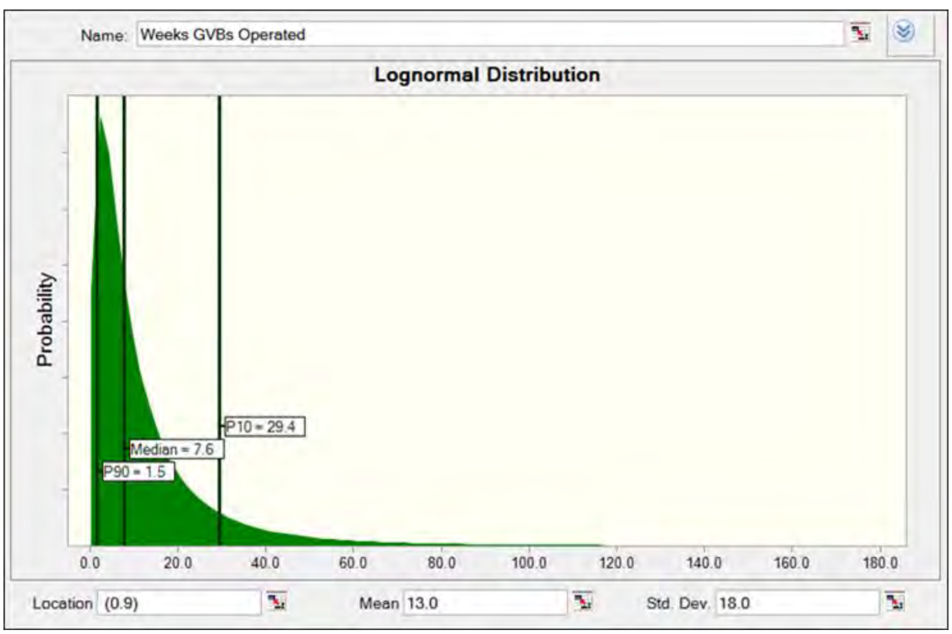


p_{50} = Median, there is a 50 percent probability that weekly methane concentration in all the GVBs will be 57.61 percent.

p_{10} = There is a 10 percent probability that weekly methane concentration in all the GVBs will be 80.55 percent or greater.

p_{90} = There is a 90 percent probability that the weekly methane production will be 41.20 percent or greater.

Figure 7: Probability Distribution of the Number of Weeks each GVB Operates



p_{50} = Median, there is a 50 percent probability that GVBs will operate for 7.6 weeks.

p_{10} = There is a 10 percent probability that GVBs will operate for at least 29.4 weeks

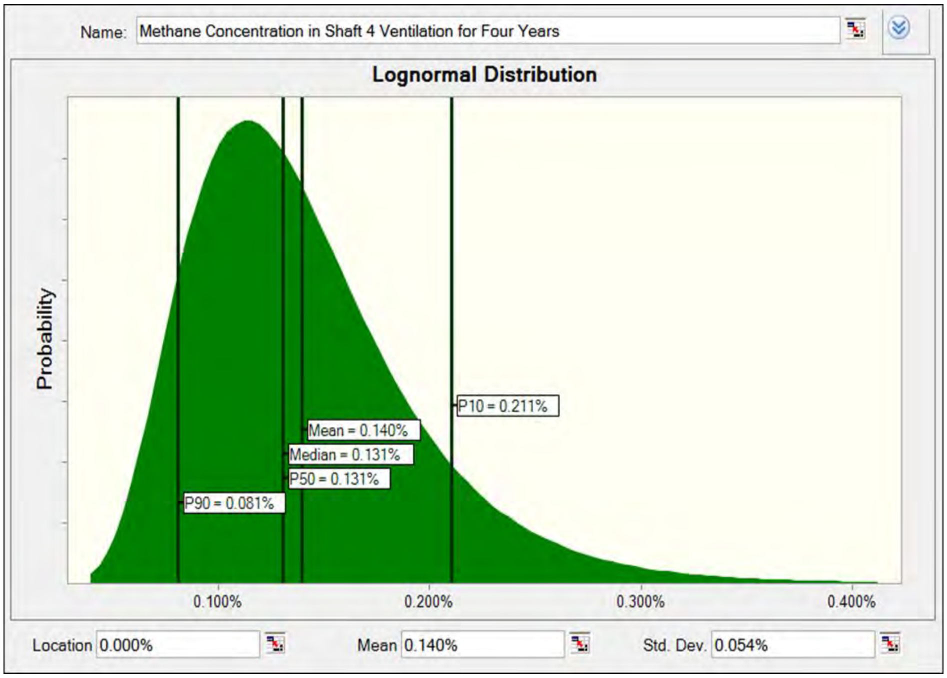
p_{90} = There is a 90 percent probability that GVBs will operated for at least 1.5 weeks.

Considerations for Capture and Use of CMM at the West Elk Mine

Presently, methane is liberated from the West Elk Mine in two forms; via GVBs where the gas concentration ranges from 30 percent to as high as 90 percent by volume in air, with a p_{50} value of 56.87

percent, and via ventilation exhaust shafts as VAM, in concentrations ranging from negligible to greater than 0.3 percent in air, with a p_{50} methane concentration of 0.131 percent for the Deer Creek shaft (**Figure 8**).

Figure 8: Probability Distribution of Methane Concentration in the Deer Creek ESM Shaft



p_{50} = Median, there is a 50 percent probability that the methane concentration in the Deer Creek ESM shaft will be 0.131 percent.

p_{10} = There is a 10 percent probability that the methane concentration in the Deer Creek ESM shaft will be 0.211 percent or greater.

p_{90} = There is a 90 percent probability that the methane concentration in the Deer Creek ESM shaft will be 0.081 percent or greater.

CMM Capture

The West Elk Mine regularly employs GVBs as a component of its methane ventilation program, with the production from GVBs ranging between 12 and 71 percent of total methane liberated, and an average contribution of 41 percent since the mine began reporting this information in 2011.

The general practice for the mine is to vent this gas to the atmosphere, occasionally transporting gas to burners located in Sylvester Gulch to heat the air that is pumped into the mine. This is only done during the winter months and utilizes only a very small percentage of drained gob gas. The method that the mine uses to gather and transport the gas for this task is the same concept that is envisioned for the capture and use projects evaluated in this study, with the exception that in this study we assume that all available gas produced from active GVBs will be utilized or destroyed, rather than vented. Given that methane has a global warming potential (GWP) of greater than 36 times that of CO_2 when measured over a 100-year period and 87 times that of CO_2 when measured over a 20-year period, destruction of this gas, as opposed to venting it, will have a positive impact on the local and regional environment. For the purposes of this study, a GWP of 25 is used to calculate project emission reductions and the amount of carbon emissions credits generated, as 25 is the value that is currently used by the carbon markets.

The Grand Mesa, Uncompaghre and Gunnison National Forests (GMUG) overlie the mine. The GMUG has been negatively impacted by climate change in recent years, and therefore, GMUG management is actively practicing what the Department of Agriculture (DoA) terms, “climate smartness”. This involves managing the forest’s natural resources to be resilient to disturbances like wildfires, insect and disease infestations and frequent, extreme weather events. These are events that can be attributed to climate change, and reducing methane emissions supports the DoA program and USFS’s efforts in practicing climate smartness.

Post-mine drainage from the surface

Design and installation of the GVBs used in this analysis incorporate best practices and the safety features that West Elk currently employs, including flame arresters and safety controls and monitoring, as well as all safety practices normally utilized in the oil and gas industry. It is also envisioned that all access roads and gas gathering lines will utilize existing roads and right-of-ways, not requiring any additional surface disturbance. Placement and timing of the drilling of GVBs will still be supervised by the mine and the length of time that the GVBs produce must be managed by mine personnel, as they are now, so as not to allow the gas concentration of any well to approach explosives levels. Our analysis has shown that MCC typically operates GVBs as long as mining continues on a longwall panel, but if desired, mine management could operate many of the GVBs for longer periods. With a methane mitigation system in place, this would allow for the destruction of more gas rather than eventually allowing it to escape through the ventilation system.

Abatement of drained CMM from GVBs

Several end-uses for the gob gas were considered in this study, but after a preliminary evaluation, flaring was determined to be the most cost-effective and economic at this time. Our conceptual design envisions that available GVB production from the new leasehold will be gathered and transported to a central location along existing roads and right-of-ways within the new leasehold boundary where an enclosed flare will be sited; no additional roads or right-of-ways will be required for gas gathering operations. Drained gas will be treated at the wellhead so that the moisture in the gas will not freeze, and then transported via 6-inch SDR 11[1] plastic pipe to the flare site.

The proposed flare, which will be an enclosed flare designed to destroy drained gas at 99.9 percent efficiency, would be mounted onto a concrete pad with an additional four feet of buffer, and surrounded by an enclosed fence. It will be designed to avoid over firing of the unit which could lead to air starvation and incomplete combustion. The unit is designed to shut off in cases of over firing or any type of instability in the operation. Immediately prior to shutdown, the system is equipped with a purge blower which creates a safe atmosphere within the flare, ensuring that no flames escape out the top. The system is also equipped with a UV scanner; if the pilot flame is lost, the main flame automatically shuts down. During all shutdown cases, the system immediately goes into safe mode, whereas gas is prohibited from contact with the flare unit. Also, the flare chamber is internally lined with refractory material, minimizing the impact of the flare on the outside shell temperature which further reduces any

[1] SDR 11 means that the outside diameter of the pipe is eleven times the thickness of the pipe wall.

chance of heat radiation.[2] . All personnel operating on the flare unit will be trained by the original equipment manufacturer (OEM) to handle combustion devices, and will be required to wear fire-proof clothing and personal methane gas detectors while working on the unit. Maintenance on the unit is nominal, requiring a scheduled preventive review only every six months, which can be performed by trained mine personnel. Also, because the flare is enclosed, it will not give off light, whereas any artificial light at this location can potentially have a negative impact on the local ecosystems. It has been proven that artificial light disrupts animal's nocturnal activity, interfering with their reproduction and thus reducing natural wildlife populations. Given the intrinsic safety of the flare, with proper installation, operation and maintenance performed by properly trained personnel, the flare should not endanger the surrounding forest, the mine or its workers.

Economic Evaluation of CMM Abatement

Raven Ridge analyzed the option of reducing methane emissions at the mine as an investment opportunity. Our analysis was performed by calculating a string of annual free cash flow values, which are calculated by subtracting outflows of investment capital, operating capital, loan repayment, and other costs from the revenues or inflows from sales of verified carbon emission reductions. To allow comparison of the economic performance of the proposed investment opportunity at the coal mine against other investment opportunities which may be available to MCC, Raven Ridge performed a discounted cash flow analysis.

Discounted Cash Flow Analysis

Discounted cash flow analysis uses the string of annual cash flows to calculate the profit that will be realized over the life of the project. To make the future invested capital and profits relevant in today's monetary terms, a discount factor is used. This factor is used to discount future cashflows because we recognize cash flows in the future are worth less than cash flows realized in the present. This is to say, that even if the values occur in year six of a project that lasts 10 years, the values are brought forward to the present by discounting the future cash flows by an annual discount factor. We used a range of discount factors to analyze the investment, but we report the results using a discount rate of 10 percent, as it is a factor commonly used by analysts. As an example, the results of our analysis could be compared against an investment where the investment paid out in ten years and had a compound interest rate of ten percent per year.

Net present value (NPV) is the value that is calculated and commonly used to evaluate investment opportunities. It is a measurement of profit calculated from the present value of a string of annual free cashflows (positive or negative) over time using a discount rate. Again, in our analysis we use a ten percent discount rate, and based on our analysis, as explained later in the report the most likely NPV of the project is $6.51 million USD.

Internal rate of return (IRR) is used to evaluate an investment by comparing the annual rate at which the value of the project increases. The IRR is the discount rate at which the NPV of a string of annual cash

[2] P. Kondagari (2017), personal conversation with P. Kondagari, manager of enclosed combustion for Aereon, October 20, 2017.

flows is zero. As an example, in our analysis we calculate that the most likely outcome from analysis is that the project will achieve an IRR of 121.5 percent. This implies that it would require a discount rate of 121.5 percent to cause the NPV to be zero.

Return on investment (ROI) is used to indicate the efficiency at which invested capital generates profit. This indicator is simply calculated by subtracting the cost of investment from the gain in investment divided by cost of investment; or, in other words, divide the profit by the cost of the investment. Positive ROI indicates that the investment plus a profit is returned. Discounted cash flow is not used for this calculation so the ROI does allow an easy comparison of two investments that differ by the length of time before profit is returned. Using this analysis of this investment opportunity, the ROI for this project is most likely to be 80.6 percent, meaning that if implemented MCC could enjoy the return of their investment plus an additional 80 percent of the total cost of the project.

Flaring as an methane abatement option at West Elk

Through evaluation of the available gob gas and consultations with a representative of the local USBLM office as well as Holy Cross Energy and the DMEA, the utility that provides electricity to the West Elk Mine, the Raven Ridge team has determined that flaring is the best option for methane destruction at the mine.

An Excel-based model was constructed to evaluate the economic performance of siting a flare within West Elk's lease boundary. Aereon provided a quote for an Abutec HTC 18 Combustor flare a newer model of the same flare which has been installed and is operating at the North Fork LLC project at the Elk Creek mine just north of West Elk. This high temperature flare offers up to 99.9 percent destruction efficiency along with a completely enclosed flame. Flare design conditions are listed below in **Table 1**.

Table 1: Abutec Flare Process Data

Gas composition	**56.9% CH_4 & 43.1% AIR**
Maximum flow rate	2.86 MMSCFD
Rated heat release/HTF UNIT:	62 MMBTU/HR
Inlet Temperature:	100°F max
Inlet pressure:	30 psig
Retention time:	Minimum 0.3 SEC
Destruction rate efficiency:	99.9% DRE
Operating temperature:	Up to 1,800 °F
NO_x emissions requirement:	0.15 LBS/MMBTU
CO emissions requirement:	0.2755 LBS/MMBTU

All criteria pollutants are negligible at the stated destruction efficiency. The proposed flare could consume an increased 20 percent volume of gas without design modifications.

For modeling purposes, 2.86 million cubic feet of gas will be available daily, at a concentration of 56.9 percent methane (p_{50} value of GVB production). These parameters were submitted to Aereon to ensure that the recommended flare is compatible with the conditions present at West Elk. The cost of the flare and other materials, equipment and labor incorporated into the model is described in **Table 2**.

Table 2: Model inputs: Flaring Scenario

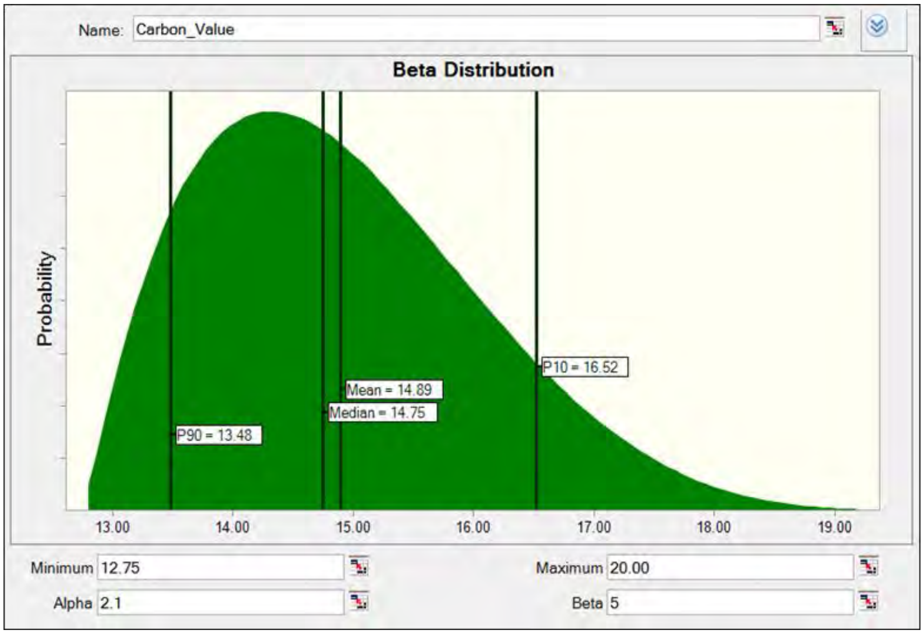
Item	Input Value	Comments
Project evaluation period	10 years	
GVBs	N/A	Cost of drilling and completion is a "cost of mining" and not charged to the project
GVB production	Lognormal distribution, median value is 11,403 scfm, p_{10} is 19,241, p_{90} is 5,589.	Results of data analysis (see figure below)
6 inch gathering line	16,969 ft.[3] annually at $16.96 per ft.	Price quote from Andrew Bates, drilling and completion Engineer with Protocom Consulting - Farmington, NM (Exhibit 2)
Wellheads	14 new GVBs installed annually, 5 GVBs operating at any one time, seven new wellheads installed annually, reusing when possible.	Number of GVBs employed based on forecasts discussed earlier in study. Wellhead cost quote from Andrew Bates.
Monitoring/control system	$405,000 installed at start-up	Quote from Arista report, Bates confirmed as reasonable
Annual operating and maintenance costs	Max extreme distribution, with likeliest value of $362,000.	Quote from Andrew Bates.
Flare system	$328,000 for system with $2,800 for installation	Quote from Aereon (Exhibit 3).
Carbon price	Beta distribution, with likeliest value of $14.75 per ton, max value is $20.00, min value is $12.75.	California Cap-And-Trade Program latest Joint Auction Settlement prices, with forecast for future prices through 2020.
Registration with California Climate Action Reserve.	$20,000 to validate project, $10,000 to verify annually	Verbal quote from verifier.
Federal Royalty	12.5 percent	BLM web-site
Project financing	80 percent debt financed at 8 percent interest	
Taxes	Pre-tax analysis	

The capital expenditures discussed in this study include the cost of the flare, the wellheads installed on each GVB, the gathering lines and the monitoring and control system. The cost of the flare and monitoring and control system is incurred in the first year; the cost of the wellheads and gathering lines are allocated annually for the life of the project.

[3] The length of gathering line is determined by taking the historical length of roads that are visible from satellite imagery (**Map 1**), and service the existing GVBs placed in the e-seam, and by dividing this length by the number of GVBs that were in place (**Exhibit 1**); the resultant value of 1,212 feet per GVB was used to determine the total length of gathering line that would be installed each year. It was forecasted that 14 GVBs will be placed into service each year for a total of 16,968 ft. of gathering line.

Probability distribution functions were generated for carbon price (**Figure 9**) and GVB weekly production (**Figure 10**) to capture the full range of possible values and their impact on uncertainty. The probability distribution for carbon price was constructed using historical California (CARB) and Quebec joint auction settlement prices and forecasts of future prices from published trading analytics (http://californiacarbon.info/).

Figure 9: Probability Distribution for Carbon Sales Price

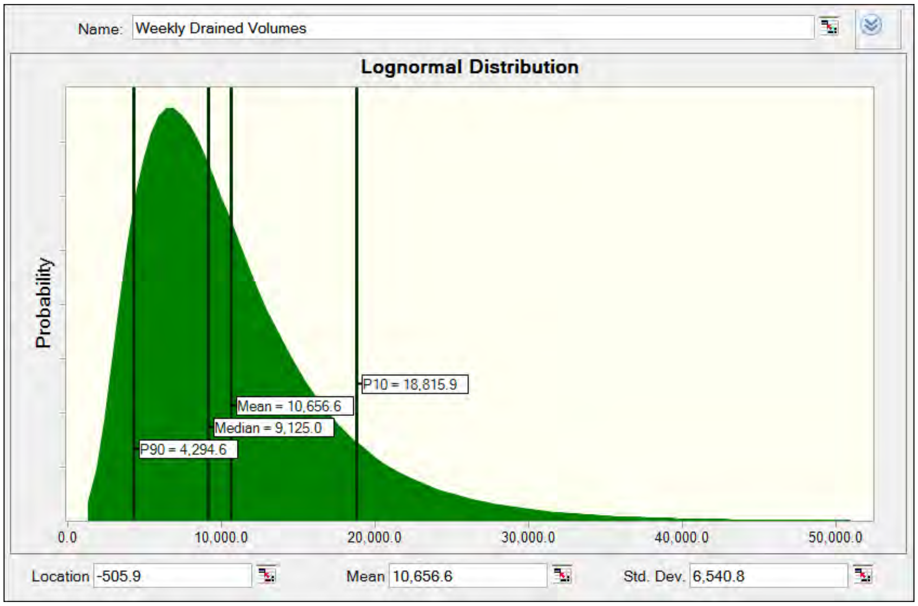


p50 = Median, there is a 50 percent probability that the carbon sales price will be $14.75

p10 = There is a 10 percent probability that carbon sales price will be $16.52 or greater.

p90 = There is a 90 percent probability that the carbon sales price will be $13.48 or greater.

Figure 10: Probability Distribution of Weekly Total GVB Production Rate (scfm)



p_{50} = Median, there is a 50 percent probability that the weekly total GVB production rate will be 9,125.0 scfm.

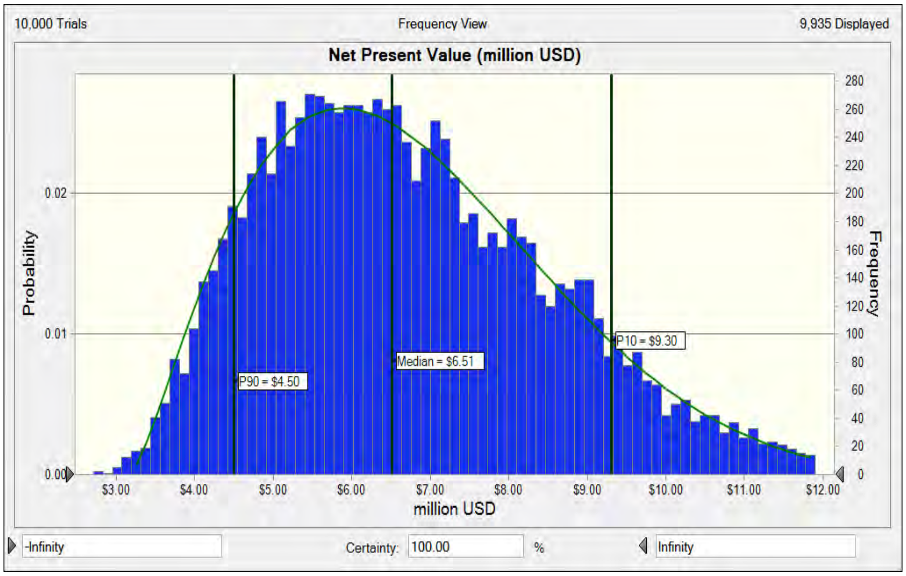
p_{10} = There is a 10 percent probability that the weekly total GVB production rate will be greater than 18,815.9 scfm.

p_{90} = There is a 90 percent probability that the weekly total GVB production rate will be greater than 4,294.6 scfm.

Results of CMM Destruction Economic Analysis

Once the economic model was set up, Monte Carlo simulations were run which incorporated the probability distributions of carbon price and GVB weekly production. The outputs of a Monte Carlo simulation are forecasts of Net Present Value (NPV) (**Figure 11**), Internal Rate of Return (IRR) (**Figure 12**) and Return on Investment (ROI) (**Figure 13**), which also are probability distributions. These forecasts are presented below and in **Table 3**.

Figure 11: Net Present Value Forecast (million USD)

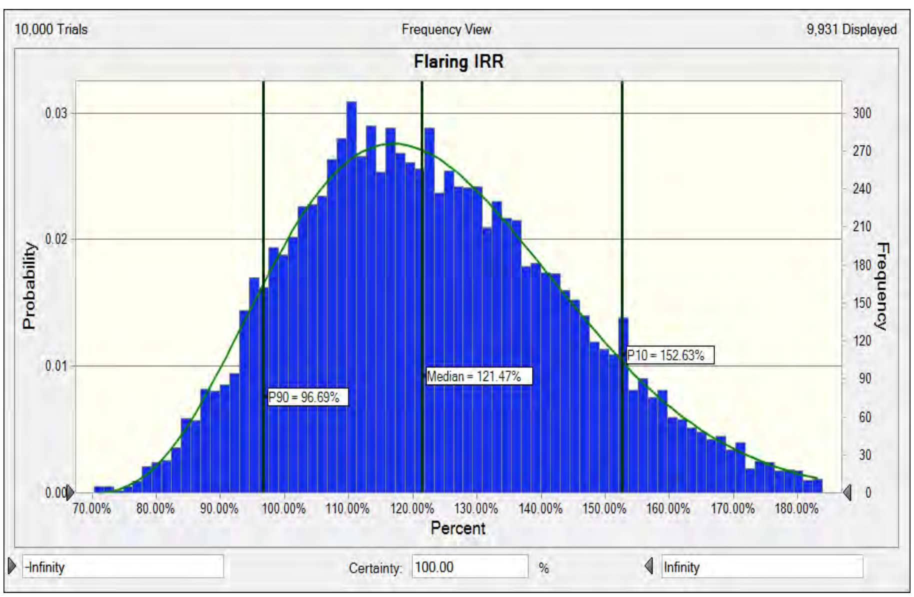


p_{50} = Median, there is a 50 percent probability that the project will result in an NPV of 6.51 million USD over a 10-year project life.

p_{10} = There is a 10 percent probability that the project will result in an NPV of 9.30 million USD or greater over a 10-year project life.

p_{90} = There is a 90 percent probability that the project will result in an NPV of 4.50 million USD or greater over a 10-year project life.

Figure 12: Internal Rate of Return Forecast (percent)

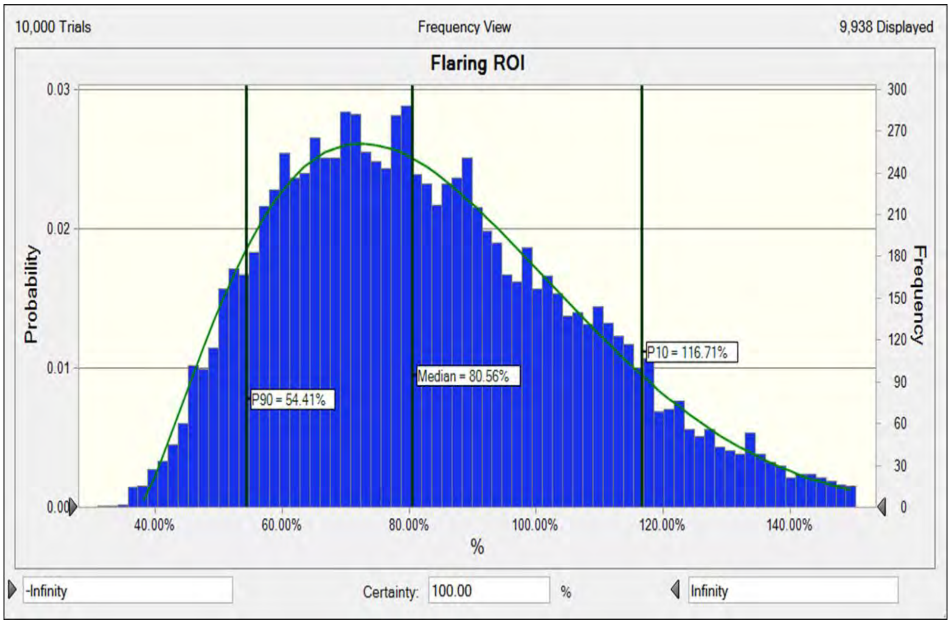


p_{50} = Median, there is a 50 percent probability that the project will result in an IRR of 121.47 percent over a 10-year project life.

p_{10} = There is a 10 percent probability that the project will result in an IRR of 152.63 percent or greater over a 10-year project life.

p_{90} = There is a 90 percent probability that the project will result in an IRR of 96.69 percent or greater over a 10-year project life.

Figure 13: Return on Investment (ROI)



p_{50} = Median, there is a 50 percent probability that the project will result in an ROI of 80.56 percent over a 10-year project life.

p_{10} = There is a 10 percent probability that the project will result in an ROI of 116.71 percent or greater over a 10-year project life.

p_{90} = There is a 90 percent probability that the project will result in an ROI of 54.41 percent or greater over a 10-year project life.

Summary of Findings:

Raven Ridge determined that a gob gas flaring project would be technically and economically viable at the West Elk mine. A similar project located at Oxbow's now shuttered Elk Creek mine began while the mine was active and continues at present as an idled mine methane emission abatement project. The proposed West Elk project would be capable of destroying 634.9 million cubic feet of gas per year amounting to 281.8 thousand tonnes of CO_2e or 76.9 thousand tonnes of carbon. The total capital needs for the project would be $12.54 million USD over a ten-year project life. Assuming a p_{50} forecast of 6.7 billion cubic feet of gas produced through GVBs over a 10-year period, net total emissions of 2.64 million tonnes of CO_2e would be destroyed over that period, or about 720 thousand tonnes of carbon.

The Flaring Project economic indicators are presented in **Table 3**.

Table 3: Economic Indicators - 10 Year Flaring Project

Economic Indicators - 10-yr Project	
Evaluation Scenario	***Flaring***
Gas Forecast - p_{50} (billion cubic feet)	6.7
Total Capital Expenditures (CAPEX in million USD)	$12.54
Total Operational & Maintenance Costs (OPEX in million USD	$3.50
Project Emission Reductions with GWP of 25 (million tCO_2e)	2.64
Project Emission Reductions (thousand tonnes Carbon)	720.32
CAPEX/Tonnes CO_2e	$6.07
CAPEX/Tonnes of C	$1.66
Total Cost of Carbon Reductions ($/tonne of CO_2e)	$20.90
Total Cost of Carbon Reductions ($/tonne of C)	$5.70
Carbon Price (USD/tCO_2e)	$14.75
Net Present Value (p_{50} NPV value in million USD)	$6.51
Internal Rate of Return (p_{50} IRR value in %)	121.5%
Return On Investment (p_{50} ROI value in %)	80.6%

The project shows a very positive economic outcome under the current scenario, paying out before the end of the first year, meaning that revenue generated from the sale of carbon credits is greater than the sum of the initial investment and operating expenses in the initial year, and every year thereafter during the project life. With a carbon price of $14.75, the project returns p_{50} values of $6.51 million USD for the NPV, 121.5 percent for the IRR, and 80.6 percent for the ROI. Even considering the very conservative p_{90} values, the project returns a favorable NPV of $4.5 million USD, an IRR of 96.7 percent and an ROI of 54.4 percent.

Recommendations for Improving Economic Performance of a Flaring Project

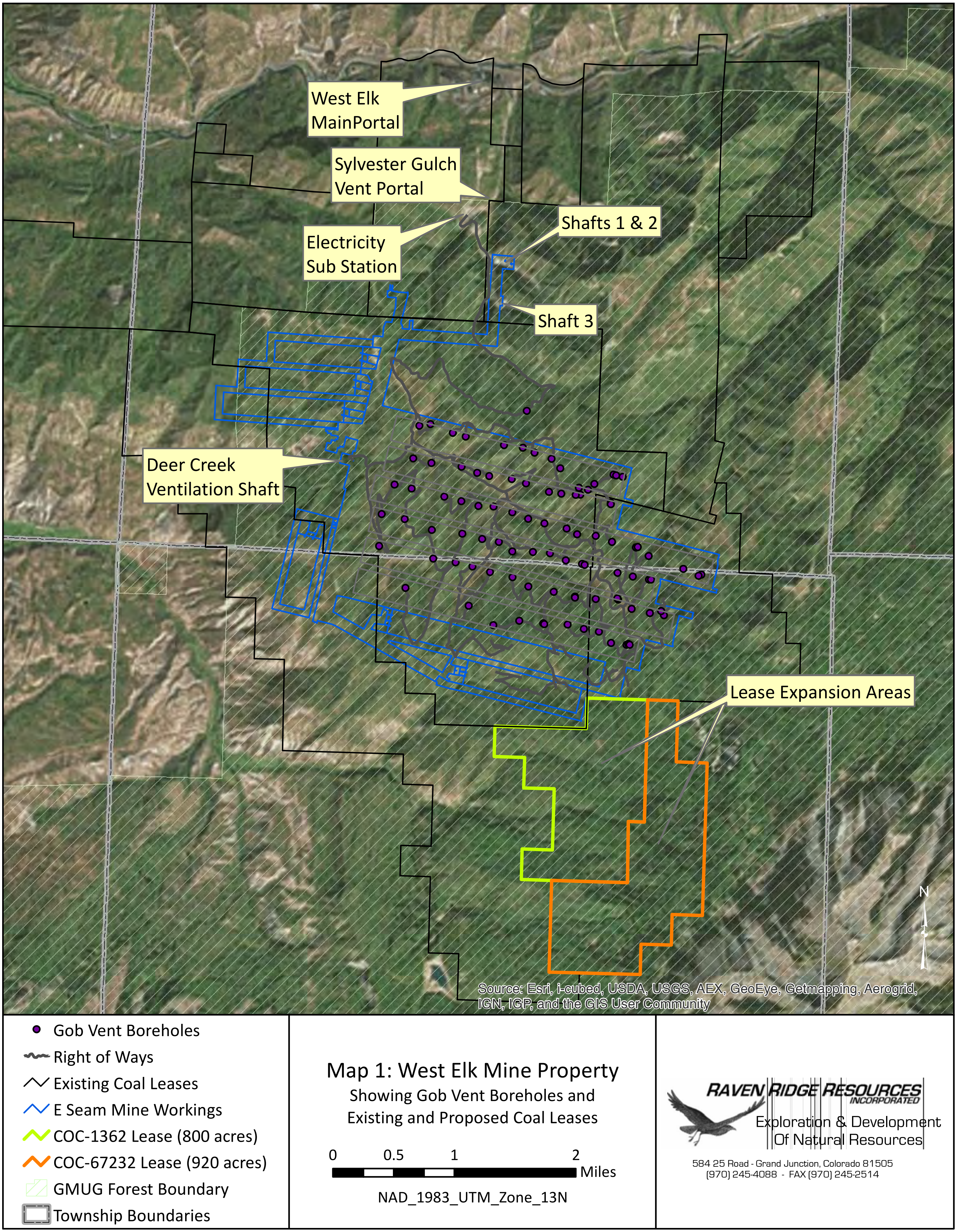
The available GVB production does not include any contribution from production from existing GVBs put into operation prior to project start-up. The current design of the flare can handle a 20 percent increase in gas without reconfiguring, thus transporting additional gob gas from these existing GVBs to the flare site to be destroyed would increase the economic outcome of the project.

The largest single capital expenditure is the flare system; however, it only represents three percent of total capital costs. Other remaining costs include the wellheads, gas gathering, monitoring equipment and controls. The operating and maintenance costs used in our analysis were just 17 percent of the operating and maintenance costs used by the firm hired by MCC in their analysis, which is the primary reason that our results are much more favorable; the reasons for this difference are our cost estimate calls for a significant reduction in all labor categories, the lack of need for the larger 10 inch SDR pipe and the cost associated with moving it, and a significant reduction by renting rather than purchasing compressors (**Table 4**)

Table 4: Gas Gathering System Cost Comparison Table

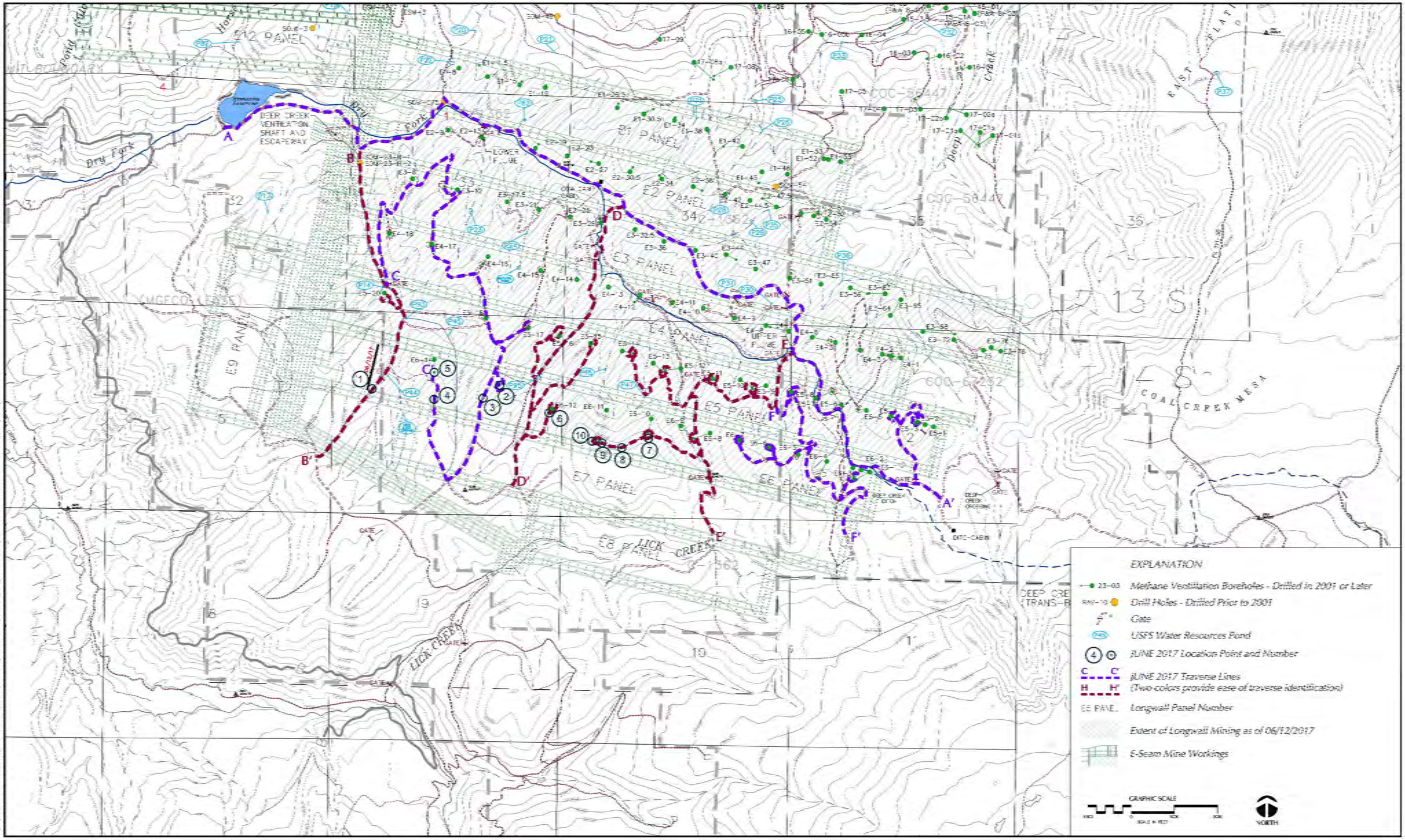
Cost Categories	MCC Estimate	Raven Ridge Estimate
Labor	888,000	98,000
Methanol	150,000	150,000
Compression	320,000	24,000
Winter Operations/labor	420,000	Included
Miscellaneous	100,000	90,000
Office	240,000	N/A
Total	**2,118,000**	**362,000**

Even with this, all cost assumptions should be refined once a final engineering design is developed. If a dialog is started with mine management, it is quite possible that the mine already has much of the equipment, such as wellheads and 6-inch plastic pipe, as well as trained personnel, possibly reducing the gas gathering capital and operating expenditures significantly. Any reduction in gas treatment and gathering could have a significant positive impact on project economics.



Map 1: West Elk Mine Property
Showing Gob Vent Boreholes and Existing and Proposed Coal Leases

Exhibit 1



WWE WRIGHT WATER ENGINEERS, INC.
2490 W. 26TH AVE. SUITE 100A
DENVER, CO 80211
(303)480-1700 FAX(303)480-1020

MOUNTAIN COAL COMPANY WEST ELK MINE

LOCATIONS OF OBSERVATIONS IN THE SOUTH OF DIVIDE AND DRY FORK MINING AREAS - JUNE 2017

PROJECT NUMBER	DATE	MAP
831-032.799	06/17	1

Exhibit 2

WEST ELK MINE GOB GAS GATHERING SYSTEM COSTS

WEST ELK MINE								
"E" Seam Gathering								
Description								
MATERIAL	Quantity	Units	Unit Cost	Total cost		Category Totals	Comments .	
				8"	10"			
10" SDR 11	46,072	ft	16		737,152		Pricing has increase **4** fold on Poly pipe	
10" SDR 11- Winter temp	6,000		16		96,000			
6" SDR 11	188,218		5	941,090				
Valves	1 Lot		50,000	50,000			these valves are$200-500 each	
12" plg traps	1 Lot		60,000		60,000		Need more explanation; so left it alone	
				991,090	893,152			
Total Materials						1,884,242		
INSTALLATION								
10" SDR 11 (Per Petty Quote)	46072	ft	23		1,059,656			
10" Poly -Temp top of ground	6000	ft	20		120,000		Roustabout to set and hookup in one day	
6" SDR 11 (per Petty quote)	188,218		10	1,882,180			This is low pressure only for collapse resistance	
Pig Traps	3	each	35,000		105,000			
				1,882,180	1,284,656			
Total Installation						3,166,836		
PROJECT MANAGEMENT								
Engineering								
Coordination & Inspection	120		1,000	120,000				
Contingenecy 10%				517,108			% tangible	33.1%
Total Project Management						637,108	% intangible	66.9%
TOTAL GATHERING COST						**$ 5,688,185.80**		
Total costs for 6" Pipe	3,191,824							
Cost per foot	16.96							
Total costs for 10" Pipe	2,496,362							
Cost per foot	47.94							

Exhibit 2

WEST ELK MINE GOB GAS GATHERING SYSTEM COSTS

WEST ELK MINE						
MDW WELLHEADS						
Description						
MATERIAL	Quantity	Units	Unit Cost	Total cost	Category Totals	Comments .
Exhauster	owned	1		0		
Relief Valve	1 Lot			5,000		
Separator	1 Lot			10,000		
Water tank-Heater	1 Lot			10,000		
Screw Compressor	1 Lot			20,000		Plan to lease with maintanence agreement
Fuel Conditioning System	1 Lot			15,000		
Meter Run Skid	1 Lot			10,000		
Methanol Injection	1 Lot			5,000		
BTU Monitoring	1 Lot			5,000		
Sat Communications	1 Lot			10,000		
Misc Valves, Fittings	1 Lot			5,000		
Total Materials				95000	95,000	
INSTALLATION						
Exhauster	owned			0		
Screw Compressor	1					Roustabout to set and hookup in one day
Wellhead Equipment	1			5,000		This is low pressure only for collapse resistar
Total Installation				5000	5,000	
PROJECT MANAGEMENT						
Engineering						
Coordination & Inspection	5			10,000		
Contingenecy 10%				13,500		
Total Project Management					23,500	
TOTAL COST PER WELL					**123,500**	
Number of wells	5				**$ 617,500.00**	**Total**

Exhibit 2

WEST ELK MINE GOB GAS GATHERING SYSTEM COSTS

WEST ELK MINE O&M							
Control System							
Description	Quanity		Unit Cost	Total cost	Sub- Totals	Annual Category Totals	Comments .
MATERIAL							
Chromatograph	1 Lot		75,000	75,000			
Control Valves	1 Lot		75,000	75,000			
Alarm Callout System	1 Lot		15,000	15,000			
SCADA System	1 Lot		50,000	50,000			
Gen Dehydrator	1 Lot		40,000	40,000			
Total Material			Monthly Rental			255,000	
INSTALLATION							
Chromatagraph	1 Lot		25,000	25,000			
Control Valves/Flare	1 Lot		50,000	50,000			
Gen Dehydrator	1 Lot		25,000	25,000			
SCADA / Alarm System	1 Lot		50,000	50,000			
TOTAL INSTALLATION						150,000	
TOTAL Control System Costs						**$ 405,000.00**	

Exhibit 2

WEST ELK MINE GOB GAS GATHERING SYSTEM COSTS

WEST ELK MINE O&M							
Basic Gathering System							
"E" Seam							
LABOR	Quantity	Unit Cost	w/30% Load	Total cost	Sub- Totals	Annual Category Totals	Comments .
Supervisor	0	100,000		100,000	0		
I&E Tech	1	80,000		80,000	80,000		
Mechanic / Operator	1	0		0	0		3 operators for 8 wells is more than a enough
Trucks (Field Operators)	1	18,000		54,000	18,000		vehicle, leasing, insurance, maintanence, fuel, etc
Annual Operating Total						98,000	
Methanol	50,000		3	150,000		150,000	
Compression			Monthly Rental				
Working Screw Type	6	400 Hp	3,000	18,000		18,000	
Sealed Screws	2	400 Hp	3,000	6,000		6,000	
Winter Operations							
Move Screw Compressors	11	12,500				0	
Move 10" temp poly							
Measurement/Scada	# of Meters	Cost/yr/Meter	Annual Sub				
Working ScreCompressors	5	10,000	50,000				
Sealed Screws	2	10,000	20,000				
System	2	10,000	20,000				
Total Measurement Costs						90,000	
							Office expense with 2 clerical personnel
Total Project Management							
TOTAL Annual Costs						**$ 362,000.00**	

Exhibit 3

AEREON

BUDGETARY PROPOSAL

HIGH TEMPERATURE COMBUSTOR

PROJECT NAME	HTF COMBUSTOR
CLIENT	RAVEN RIDGE RESOURCES, INCORPORATED
CLIENT LOCATION	USA
SALES CONTACT	NED SOUTHWICK REGIONAL SALES MANAGER - ROCKIES & BAKKEN ERIE COLORADO OFFICE +1 502.357.0118 | MOBILE +1 502.727.9350 | AEREON.COM NSOUTHWICK@AEREON.COM
TECHNICAL CONTACT	PHANINDRA KONDAGARI OFFICE +1 512.836.9473 x 172 PKONDAGARI@AEREON.COM
QUOTE NUMBER	17-10397 REV 0
DATE:	September 29, 2017

Exhibit 3

1.0 TECHNICAL AND COMMERCIAL SUMMARY

1.1 TECHNICAL SUMMARY

ABUTEC HTF COMBUSTOR

THE HIGH TEMPERATURE FLARE (HTF) IS OUR CONTROLLABLE COMBUSTOR LINE THAT OFFERS UP TO 99.9% DESTRUCTION EFFICIENCY, ALONG WITH A COMPLETELY ENCLOSED FLAME. MANUFACTURED IN THE UNITED STATES, THIS UNIT HAS BEEN INSTALLED AT OVER 100 SITES INTERNATIONALLY AND HAS BEEN SUCCESSFULLY PROVEN THROUGHOUT THE OIL-AND-GAS MARKET. PLEASE SEE BELOW FOR A DETAIL BREAKDOWN ON THIS COMBUSTOR UNIT:

ITEM	QTY	DESCRIPTION	PRICE
		HTF 18.0 COMBUSTOR	

1	1	COMBUSTION CHAMBER:
		• ~8.50 FEET OUTER DIAMETER CHAMBER
		• ~ 40 FT OVERALL HEIGHT (INCLUDES BASE FRAME)
		• (3) TYPE K THERMOCOUPLE WITH THERMOWELLS FOR TEMPERATURE INDICATION AND CONTROL
		• SETS OF COMBUSTION AIR LOUVERS WITH MOTORIZED ACTUATORS
		• 3" THICK CERAMIC FIBER INSULATION FOR THE COMPLETE COMBUSTION CHAMBER
		• DESIGN PRESSURE = AMBIENT
		• MATERIAL OF CONSTRUCTION
		  ◦ FLARE STACK ENCLOSURE: 304 STAINLESS STEEL
		  ◦ BASE FRAME / STAND: PAINTED CARBON STEEL
		• INCLUDES PURGE AIR BLOWER (UNCLASSIFIED)	

2	1	INTERNAL MULTI-NOZZLE BURNER ASSEMBLY: • HIGH SMOKELESS TURNDOWN OF PROPOSED WASTE GAS • INTERNAL BURNER CIRCLES WITH MULTIPLE PROPRIETARY DESIGN NOZZLES AND MIXING TUBES • 8 INCH FLANGED INLET LINE (WASTE GAS) • FLANGED INLET LINE (ASSIST GAS) • 304 STAINLESS STEEL PIPING • BURNER MATERIAL: 316 / 304 STAINLESS STEEL OR EQUIVALENT	
3	1	8 INCH DETONATION ARRESTOR: • PROTEGO OR EQUAL BRAND • CARBON STEEL CONSTRUCTION W/ STAINLESS STEEL TRIM	
4	1	8 INCH ACTUATED BUTTERFLY VALVE: • TRIPLE OFFSET VALVE DESIGN • PNEUMATICALLY ACTUATED • CARBON STEEL BODY AND SST TRIM • LUG OR WAFER DESIGN • SHIPPED LOOSE	
5	1	4 INCH PRESSURE REGULATOR (KIMRAY OR EQUAL)	
6	2	PILOTS AND IGNITION SYSTEMS: • IGNITION TRANSFORMER	

Exhibit 3

- IGNITION ELECTRODE
- PILOT DETECTION VIA IN-BUILT UV SCANNER

7 1 PILOT GAS VALVE TRAIN CONSISTING OF:
- VALVE TRAIN SHALL BE ½”
- CARBON STEEL PIPING, THREADED COMPONENTS AND FITTINGS
- QTY (1) MANUAL SHUT-OFF VALVE (BALL VALVE)
- QTY (1) AUTOMATIC SHUT-OFF VALVE (SOLENOID VALVE)
- QTY (1) STRAINER
- QTY (1) PRESSURE GAUGE
- QTY (1) BALL VALVE
- QTY (1) PRESSURE REGULATOR

8 1 AUTOMATIC CONTROL SYSTEM FOR FLARE OPERATION MONITORING:
- FULLY INTEGRATED CONTROL PANEL/CABINET (NEMA 4X 316SS CONTROLS ENCLOSURE)
- ALLEN-BRADLEY 1769 COMPACTLOGIX PLC SYSTEM
- TOUCHSCREEN HMI

9 1 DRAWING AND DOCUMENTATION PACKAGES:
- OPERATING AND MAINTENANCE INSTRUCTIONS
- PIPING & INSTRUMENTATION DRAWING
- GENERAL ARRANGEMENT DRAWING
- CONTROL PHILOSOPHY
- ELECTRICAL/ CONTROL PANEL DRAWINGS
- SPARE PARTS LIST

OPTIONS

10 1 LADDER AND PLATFORMS:
- ALLOWS ACCESS TO ALL TEMPERATURE MONITORS AND SAMPLE PORTS
- FOLLOWS OSHA GUIDELINES
- CARBON STEEL CONSTRUCTION, GALVANIZED

Exhibit 3

1.2 COMMERCIAL SUMMARY

1.21 PRICE SUMMARY

BASE SCOPE		
ITEMS	**QTY**	**PRICE**
ABUTEC HIGH TEMPERATURE FLARE SYSTEM	1	TBD
TOTAL FOR ABOVE ITEMS IN BASE SCOPE (EX-WORKS BASIS):		**$ 328,000.00**
OPTIONAL ITEMS		
ITEMS	**QTY**	**PRICE**
LADDER AND PLATFORMS	1	$ 17,230.00

1.22 VALIDITY

THE PRICES IN THIS QUOTATION ARE BUDGETARY.

1.23 DELIVERY

APPROVAL DRAWINGS SUBMITTALS:	**3 WEEKS AFTER ACCEPTANCE OF FIRM PO**
CLIENT REVIEW PERIOD:	AS REQUIRED, BUT NOT TO EXCEED 2 WEEKS
FABRICATION PERIOD:	**17 WEEKS AFTER RECEIPT OF APPROVED DRAWINGS**
TOTAL DELIVERY TIME:	**20 WEEKS AFTER ACCEPTANCE OF FIRM PO + CLIENT REVIEW**

* THE QUOTED DELIVERY IS BASED UPON OUR CURRENT PRODUCTION SCHEDULE / SHOP LOAD. AN UPDATED DELIVERY SCHEDULE WILL BE AVAILABLE AT TIME OF ORDER.

Exhibit 3

1.24 SHIPPING TERMS

☒ EX-WORKS: POINT OF MANUFACTURE

1.25 PACKING AND SHIPPING PREPARATION

EXPORT PACKING AND CRATING WHEN QUOTED AS AN OPTION ONLY INCLUDES TECHNOLOGY ITEMS AND DOES NOT INCLUDE STACKS, VESSELS, SKIDS, LADDERS AND PLATFORMS, OR UTILITY PIPING.

☒ INLAND FREIGHT PACKING

1.26 TERMS OF PAYMENT

PAYMENT TERMS SHALL BE FINALIZED AND ARE CURRENTLY UNDER NEGOTIATION.

1.27 INSTALLATION - COMMISSIONING

	DOMESTIC **
DAILY LABOR RATE	$1,400.00
TRAVEL RATE	$1,400.00
OVERTIME RATE	$200.00/HOUR
TRAVEL EXPENSES	COST + 20%
STANDARD WORK DAY	8-HOUR DAY

**DAILY RATE INCLUDES ACCOMMODATIONS, GENERAL EXPENSES, SUBSISTENCE, TOLLS, & LOCAL TRANSPORTATION

1.28 SPARE PARTS LIST

CONTROL SYSTEM	
PART	QUANTITY
HIGH TEMP STACK THERMOCOUPLE	1
IGNITION TRANSFORMER	1

Exhibit 3

2.0 TECHNICAL SUMMARY

2.1 DESIGN CONDITIONS

PROCESS DATA

GAS COMPOSITION	56.9% CH_4 and 43.1% AIR
MAX FLOW RATE	2.86 MMSCFD
RATED HEAT RELEASE PER HTF UNIT:	62 MMBTU/HR
INLET TEMPERATURE:	100°F MAX
INLET PRESSURE:	30 PSIG
RETENTION TIME:	MINIMUM 0.3 SEC
DESTRUCTION RATE EFFICIENCY:	99.9% DRE
OPERATING TEMPERATURE:	UP TO 1,800 °F
NOX EMISSIONS REQUIREMENT:	0.15 LBS/MMBTU
CO EMISSIONS REQUIREMENT:	0.2755 LBS/MMBTU

2.2 SITE CONDITIONS

AMBIENT TEMPERATURE:	30 – 100 °F
WIND SPEED FOR STRUCTURAL CALCULATIONS:	TBD
SEISMIC CLASSIFICATION:	TBD
ELEVATION (ABOVE MEAN SEA LEVEL):	TBD

2.3 UTILITIES

PILOT GAS:	IF NATURAL GAS IS USED: 65 SCFH @ 10 PSIG (PER IGNITOR)
ELECTRICAL:	1 PHASE, 60 HZ, 120VAC
ELECTRICAL AREA CLASSIFICATION	CLASS 1 DIV. 2
INSTRUMENT AIR:	N/A

Exhibit 3

2.4 DOCUMENTATION

FLARE INDUSTRIES WILL PROVIDE THE FOLLOWING DOCUMENTATION ALONG WITH THE EQUIPMENT ON THIS PROJECT:

- ☒ PIPING AND INSTRUMENTATION DIAGRAM (P&ID)
- ☒ MECHANICAL GENERAL ARRANGEMENT
- ☒ LADDER LOGIC DIAGRAMS
- ☒ CONTROL ENCLOSURES DRAWINGS
- ☒ OPERATING & MAINTENANCE MANUALS (UPON SHIPMENT)
- ☒ MANUFACTURING RECORD BOOKS (MRB)

2.5 QUALITY / NON-DESTRUCTIVE TESTING

- ☒ VISUAL INSPECTION
- ☒ DIMENSIONAL CHECK
- ☒ FACTORY ACCEPTANCE TEST: *IGNITION SYSTEM ONLY*
- ☒ DRY FILM THICKNESS: *PAINTED CARBON STEEL COMPONENTS ONLY*
- ☐ RADIOGRAPHY EXTENT: 100% FOR BUTT WELDS FOR PRODUCT CARRYING PIPE
- ☐ DYE PENETRANT EXAMINATION EXTENT: FILLET WELDS FOR PRODUCT CARRYING COMPONENTS
- ☐ ULTRASONIC TESTING EXTENT:
- ☐ MAGNETIC PARTICLE EXAMINATION EXTENT:
- ☐ HYDRO-TESTING EXTENT:
- ☒ PNEUMATIC TESTING EXTENT: ASME B31.3 ALLOWS PNEUMATIC TESTING AND THIS IS WHAT WE WILL PERFORM SINCE INTRODUCING WATER IN TO ASSEMBLED INSTRUMENTS AND VALVES IS NOT ADVISABLE. THUS PNEUMATIC TESTING SHALL BE CONSIDERED IN LIEU OF HYDROTESTING
- ☐ HARDNESS/IMPACT TESTING
- ☐ PMI

Exhibit 3

2.6 EXCLUSION LIST

THIS PROPOSAL IS OFFERED IN ACCORDANCE WITH THE BELOW TECHNICAL EXCLUSIONS. THESE ITEMS CAN BE INCLUDED IN OUR SCOPE OF WORK UPON CLIENT REQUEST, SUBJECT TO PRICE AND DELIVERY IMPACT.

CLARIFICATIONS

TECHNICAL EXCLUSIONS

1. CIVIL AND FOUNDATION DESIGN FOR ANY EQUIPMENT INCLUDING DEAD MEN, ANCHOR BOLTS OR NUTS, DESIGN OF ANCHOR BOLT LENGTH OR PROJECTION AS THIS IS PART OF CIVIL ENGINEERING FOUNDATION DESIGN.
2. THIS DESIGN IS EXCLUSIVE OF ALL EXTERNAL LOADINGS DUE TO UPSTREAM PIPING. WIND, SEISMIC AND TEMPERATURE LOADINGS HAVE BEEN CONSIDERED. ALLOWABLE NOZZLE LOADS OTHER THAN THOSE PUBLISHED BY API-537 ARE NOT CONSIDERED.
3. BOLT KITS AT BATTERY LIMIT FLANGED CONNECTIONS.
4. SUPPLY TO CUSTOMER OF SHOP DETAILS, FABRICATION DRAWINGS OR PROPRIETARY CALCULATIONS
5. INSTALLATION OF EQUIPMENT INCLUDING SUPPLY OF CRANES AND/OR PERSONNEL. GENERAL INSTALLATION INSTRUCTIONS AND ASSEMBLY DRAWINGS WILL BE PROVIDED, HOWEVER, DETAILED ERECTION INSTRUCTIONS AND DRAWINGS ARE EXCLUDED. THESE INSTRUCTIONS ARE MEANT TO PROVIDE GUIDANCE AND GENERAL STEPS TO COMPLETE THE INSTALLATION. THESE PROCEDURES ARE NOT INTENDED TO BE A SUBSTITUTE FOR EXPERIENCED INSTALLATION PERSONNEL. FIELD ASSEMBLY AND ERECTION OF THE FLARE IS OUTSIDE THE SCOPE OF WORK TO BE PROVIDED BY FLARE INDUSTRIES AND IS THE SOLE RESPONSIBILITY OF OTHERS. IT IS UNDERSTOOD THAT THE FIELD CONTRACTOR RETAINED FOR THIS PURPOSE IS FAMILIAR WITH THE ASSEMBLY AND ERECTION OF TALL TOWERS.
6. **ALL INTERCONNECTING PIPING, WIRE, AND CONDUIT BETWEEN EQUIPMENT WITHIN THE SKID LIMITS WILL BE THE VENDOR RESPONSIBILITY. ALL PIPING, WIRE, AND CONDUIT LEAVING THE SKID WILL BE THE OWNER'S RESPONSIBILITY. PLEASE NOTE THAT ITEMS WILL BE IN OUR SCOPE WITH RESPECT TO VBU SKID LIMITS AND HTF SKID LIMITS. ITEMS LEAVING THESE SKIDS SHALL BE BY OTHERS (INCLUDING ITEMS BETWEEN VBU AND HTF).**
7. THE IGNITION SYSTEM / CONTROL PANEL / PILOTS AND RELATED VALVE TRAINS ARE A FLARE INDUSTRIES' STANDARD PACKAGE. AS SUCH, THEY ARE DESIGNED AND/OR MANUFACTURED ACCORDING TO OUR STANDARDS AND PROCEDURES, USING OUR STANDARD COMPONENTS. ALL VALVE TRAIN COMPONENTS HAVE THE FOLLOWING CHARACTERISTICS: ½ TO ¾ INCH DIAMETER, THREADED FITTINGS, CARBON STEEL CONSTRUCTION. NO OTHER MATERIALS, DIAMETERS, FLANGE RATINGS, PIPING SPECIFICATIONS, OR ADDITIONAL MATERIALS OR INSTRUMENTATION ARE INCLUDED, NOR DO ANY CLIENT SUPPLIED SPECIFICATIONS APPLY, UNLESS SPECIFICALLY AGREED TO IN WRITING BY FLARE INDUSTRIES.
8. DISPERSION CALCULATIONS, NOZZLE LOAD CALCULATIONS, FINITE ELEMENT ANALYSIS OR OTHER STRESS ANALYSIS, APART FROM STRUCTURAL CALCULATIONS OF THE STACK.
9. NACE COMPLIANT CARBON STEEL IS NOT INCLUDED, UNLESS SPECIFICALLY MENTIONED UNDER THE SCOPE OF WORK SECTION OF THE PROPOSAL.
10. IF NACE COMPLIANT CARBON STEEL IS PROPOSED, MATERIALS WHICH EXCEED THE REQUIREMENTS OF NACE MR-01-75 ARE NOT CONSIDERED.
11. PASSIVATION OR PICKLING OF STAINLESS STEEL MATERIALS OR PROCEDURE, POST WELD HEAT TREATMENT, PROCEDURES, OR ASSOCIATED CHARTS.

Exhibit 3

12. ANY TESTING OR PROCEDURES NOT MARKED AS INCLUDED IN THE QUALITY / TESTING SECTION OF PROPOSAL.
13. AEREON OR ABUTEC STANDARD WELD PROCEDURES APPLY TO OUR EQUIPMENT, UNLESS OTHERWISE STATED IN OUR PROPOSAL. ANY REQUEST TO ALTER OR MODIFY OUR CURRENT WELD PROCEDURES BASED UPON CLIENTS' INTERNAL SPECIFICATIONS IS CURRENTLY EXCLUDED FROM OUR SCOPE OF SUPPLY. IF NEW PROCEDURES ARE REQUESTED BY THE CLIENT, PRICE AND DELIVERY IMPACT WILL APPLY.
14. HYDRO-TESTING OR PROCEDURES OF ANY PIECE OF EQUIPMENT OTHER THAN STAMPED ASME PRESSURE VESSELS, UNLESS SPECIFICALLY INDICATED IN THE PROPOSAL.
15. PAINTING OR COATING FOR STAINLESS STEEL, INTERNAL SURFACES OF EQUIPMENT OR GALVANIZED EQUIPMENT.
16. EXTERNAL INSULATION, INSULATION CLIPS OR HEAT TRACING OF ANY KIND. REFRACTORY OR INSULATION IS INCLUDED FOR ENCLOSED COMBUSTION DEVICES.
17. ARMORED CABLE OR CABLE TRAY OF ANY KIND. WE ARE SUPPLYING OUR STANDARD WIRE AND CONDUIT WITHIN OUR BATTERY LIMITS. MATERIAL CERTIFICATION AS PER BSEN 10204, 3.2 (FORMERLY 3.1A AND 3.1C).

Exhibit 3

COMMERCIAL EXCLUSIONS

1. WHEREAS REGARDS STATEMENTS IN CLIENT SPECIFICATIONS OR PURCHASE ORDERS CONCERNING SPECIFICATION ORDER OF PRECEDENCE, PLEASE BE ADVISED THAT FLARE INDUSTRIES' PROPOSAL, INCLUDING ITS INTEGRAL EXCLUSION LIST, PRECEDES AND PRECLUDES ALL OTHER DOCUMENTS OR AGREEMENTS WHETHER WRITTEN OR VERBAL.
2. FREIGHT COSTS AND LOGISTICS WILL BE OFFERED TO OUR CLIENTS AS AN OPTIONAL PRICE OR AS PART OF THE BASE PRICE, BUT NOT AT COST AS THE PHRASE "PREPAY AND ADD" IS SOMETIMES INTERPRETED.
3. FLARE INDUSTRIES STRICTLY PROHIBITS THE USE OR SALE OF OUR EQUIPMENT IN COUNTRIES SANCTIONED BY THE UNITED STATES GOVERNMENT SUCH AS: IRAN, SYRIA, SUDAN, NORTH KOREA, AND CUBA.
4. THIRD PARTY INSPECTION
5. ALL DOCUMENTATION WILL BE SUPPLIED IN ACROBAT PDF FORMAT, NOT WORD, EXCEL, AUTOCAD, OR ANY OTHER FORMAT.
6. PLEASE NOTE THAT DOCUMENTATION AND DRAWING DELIVERY DATES ARE AS STATED IN OUR PROPOSAL, HOWEVER, IF A VDS APPLIES TO THE PROJECT, ALL DELIVERY DATES MUST BE AGREED TO IN WRITING ON A DOCUMENT BY DOCUMENT BASIS.
7. DOCUMENTATION LEGALIZATION COSTS.
8. OUR OPERATING AND MAINTENANCE MANUALS AND QUALITY DOSSIERS WILL BE PROVIDED IN THE ENGLISH LANGUAGE. TRANSLATION OF THE OHM MANUALS IS AVAILABLE AT AN ADDITIONAL COST, HOWEVER, ONLY TEXT GENERATED BY FI WILL BE TRANSLATED. DRAWINGS, CUT SHEETS, DATA SHEETS AND/OR STANDARD DOCUMENTS WILL BE PROVIDED IN ENGLISH.
9. NO FI PRESENCE AT MEETINGS (INCLUDING, BUT NOT LIMITED TO, KICK-OFF MEETINGS, HAZOP MEETINGS, DRAWING REVIEW AND INSPECTION / CERTIFICATION MEETINGS) IS INCLUDED, UNLESS EXPLICITLY MENTIONED IN SECTION 1.3.
10. SPARE PARTS WHEN QUOTED DO NOT INCLUDE CROSS SECTIONAL DRAWINGS, EXPORT PACKING OR FREIGHT.
11. THERE ARE NO BANK GUARANTEES, PERFORMANCE BONDS, OR WARRANTY BONDS INCLUDED IN OUR SCOPE OF SUPPLY OR PRICE. COST FOR THESE REQUIREMENTS WILL BE ADDED ON TO OUR BASE PRICE QUOTED AS OPTIONS. ALL BOND AND/OR BANK GUARANTEE FORMATS, IF APPLICABLE, MUST BE AGREED TO IN WRITING BY FLARE INDUSTRIES.
12. STORAGE OF EQUIPMENT AFTER NOTIFICATION OF READINESS FOR SHIPMENT.

Exhibit 3

3.0 TERMS AND CONDITIONS

OUR PROPOSAL IS BASED UPON FLARE INDUSTRIES' "STANDARD TERMS AND CONDITIONS OF SALE." WE HAVE ATTACHED A COPY FOR YOUR REFERENCE.

Attachment 2

Incorporating the Social Cost of Carbon into National Environmental Policy Act Reviews for Federal Coal Leasing Decisions

Nathaniel Shoaff
Marni Salmon

Sierra Club
April 2015

INCORPORATING THE SOCIAL COST OF CARBON INTO NATIONAL ENVIRONMENTAL POLICY ACT REVIEWS FOR FEDERAL COAL LEASING DECISIONS

. . . .

EXECUTIVE SUMMARY

Climate change is the most critical environmental, economic, and political challenge of our time. In recent years, the Obama Administration has taken important steps to reduce domestic greenhouse gas emissions and make the United States a leader in the fight to combat global climate change. Initiatives to improve fuel efficiency standards, increase energy efficiency, reduce carbon dioxide emissions from coal-fired power plants, limit methane emissions, and to secure international agreements to reduce greenhouse gas emissions could all make a meaningful difference.

Yet these laudable efforts, aimed at staving off the most dire environmental and economic consequences of climate change, are increasingly undermined by agency decisions to expand the production of coal, oil, and natural gas extracted from public lands. For years, the Sierra Club and other organizations have urged the Department of Interior to reject proposed federal coal leases because of their massive impact on our climate. Last month, amidst scrutiny around whether American taxpayers are being short-changed on the sale of publicly-owned coal, Secretary of Interior Sally Jewell openly questioned whether the federal coal leasing program is being managed in line with President Obama's climate objectives.

The Department of Interior and Department of Agriculture, which are responsible for managing coal leases across millions of acres of public lands, are ideally situated to help the American people understand the climate impacts of mining and burning federally-owned coal. Yet to date, not only have these agencies allowed continued expansion of the federal coal program, they have resisted calls to better account for the climate impacts of the program as a whole or of their individual leasing decisions.

In this whitepaper, the Sierra Club calls on the Department of Interior and other federal agencies to use the social cost of carbon to fully evaluate and disclose the climate impacts of their decisions to lease federally-owned coal under the National Environmental Policy Act. Developed by economic and scientific experts at a dozen federal agencies and offices, the social cost of carbon relies on rigorous, peer-reviewed models to estimate the economic harm caused by each additional ton of carbon dioxide emitted into the atmosphere.

The social cost of carbon provides a simple metric, based on sound science, that allows decision makers to quantify the climate impacts of their decisions. It puts impacts in terms that both decision makers and the public can readily understand; it is widely used by federal agencies; and it does not require amending any statute or regulation to incorporate into the environmental reviews that agencies already undertake. The social cost of carbon is the best tool available to help federal agencies make informed and transparent decisions on important issues that affect our climate. The Department of Interior should immediately begin using the social cost of carbon to ensure it understands and discloses the true climate impacts of all federal coal leases.

. . . .

For more information on this whitepaper, contact:
Nathaniel Shoaff, Staff Attorney, nathaniel.shoaff@sierraclub.org, 415.977.5610
Marni Salmon, Associate Washington Representative, marni.salmon@sierraclub.org, 202.495.3025

I. INTRODUCTION

President Obama and Interior Secretary Sally Jewell recently called climate change "the single most pressing energy and environmental challenge of our time."[1] The President has bolstered these statements with an array of forward-looking climate policies, including efforts to reduce carbon dioxide (CO_2) emissions from power plants, foster the growth of renewable energy, increase the use of electric vehicles, improve fuel efficiency standards, and prioritize energy efficiency in buildings.[2] Unfortunately, at the same time that the Obama Administration is showing real leadership in addressing the causes and impacts of climate disruption, the U.S. Bureau of Land Management (BLM) continues to expand production of coal, oil, and natural gas on public lands.

Over 20 percent of our country's annual greenhouse gas (GHG) emissions (including nearly a quarter of domestic CO_2 emissions) originate from coal, oil, and gas extracted from public lands.[3] Keeping these dirty fuels in the ground is critical to safeguarding our climate, meeting international climate commitments, and achieving carbon emission reductions put forward in President Obama's Climate Action Plan. Beyond actually deciding to keep these fossil fuels in the ground, the Obama Administration should ensure that federal agencies tasked with managing public lands do so in an informed and transparent manner with regard to the climate impacts of energy development on those lands.

The Sierra Club calls on the Department of Interior and the Department of Agriculture, which together oversee energy development on hundreds of millions of acres of public lands, to use an existing tool known as the social cost of carbon to engage the public in an open, transparent, and thorough accounting of carbon impacts associated with federal coal leasing decisions.

Developed by a dozen federal agencies and offices in 2010 and updated in 2013, the social cost of carbon estimates the global financial cost of each ton of increased carbon pollution emitted into our atmosphere, taking into account such factors as diminished agricultural productivity, droughts and wildfires, increased intensity and duration of storms, ocean acidification, and sea-level rise, among others.[4] Climate disruption and

---

[1] Sally Jewell, Secretary of the Interior, Address at the Center for Strategic and International Studies 8 (Mar. 17, 2015), *available at* http://www.doi.gov/news/speeches/loader.cfm?csModule=security/getfile&pageid=1014220 (last visited April 21, 2015).
[2] *See, e.g.*, Exec. Order No. 13,693, 80 Fed. Reg. 15871 (Mar. 25, 2015).
[3] Claire Moser et al., *Cutting Greenhouse Gas from Fossil-Fuel Extraction on Federal Lands and Waters*, CENT. FOR AM. PROGRESS (Mar. 19, 2015), https://cdn.americanprogress.org/wp-content/uploads/2015/03/PublicLandsEmissions-brief.pdf.
[4] Howard Shelanski, *Refining Estimates of the Social Cost of Carbon*, WHITE HOUSE, (Nov. 1, 2013), http://www.whitehouse.gov/blog/2013/11/01/refining-estimates-social-cost-carbon.

the economic costs it imposes are already on the doorstep of the American people. The White House estimates that in 2012, climate-related disasters cost the American economy more than $100 billion[5] and it recently affirmed that "climate change is not a distant threat, we are already seeing impacts in communities across the country."[6]

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 CO_2 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 the National Environmental Policy Act (NEPA).

Over the past year and a half, the social cost of carbon has garnered considerable attention among agencies and offices that shape climate change policy in the United States. Since the interagency working group revised its estimates in 2013, the social cost of carbon has received renewed interest from members of Congress, conservation organizations, the federal courts, the Government Accountability Office, the Council on Environmental Quality (CEQ), and both the Department of the Interior and Department of Agriculture.

Of particular note, there has been a growing recognition that the social cost of carbon has a key role to play in the context of the NEPA. This statute requires agencies to analyze and disclose all environmental impacts—including those related to climate change—that may result from major federal actions. Using the social cost of carbon as part of the NEPA review process is an easy way for these agencies to analyze the climate impacts of their decisions based on sound, peer-reviewed science. The American people deserve federal agencies that address climate issues in a consistently transparent manner so that the public can have an informed and meaningful voice in key decisions that involve its input.

The social cost of carbon is particularly useful to agencies when preparing NEPA analyses for proposed coal leasing projects. In fact, recent authority indicates that agencies *must* use the social cost of carbon in this context. For example, in June 2014, the U.S. District Court for the District of Colorado invalidated BLM's environmental impact statement (EIS) for a proposed coal lease in Colorado's Sunset Roadless Area, in part because the

---

[5] *Climate Change and President Obama's Action Plan,* WHITE HOUSE, http://www.whitehouse.gov/climate-change (last visited Apr. 22, 2015).

[6] *Administration Announces Actions To Protect Communities From The Impacts Of Climate Change,* WHITE HOUSE (Apr. 7, 2015), https://www.whitehouse.gov/the-press-office/2015/04/07/fact-sheet-administration-announces-actions-protect-communities-impacts-.

agency failed to use the social cost of carbon to analyze the lease's climate impacts.[7] Following the *High Country Conservation Advocates* decision, the U.S. Department of Agriculture responded to a letter from two dozen conservation organizations by affirming that the social cost of carbon is an "appropriate tool for measuring and disclosing the social and economic implications" of federal coal leasing decisions.[8]

More recently, BLM prepared an internal memo acknowledging that some BLM field offices have begun using the social cost of carbon in NEPA reviews for mineral leases and explaining that it is in the process of crafting agency-wide guidance on this topic.[9] That initial memo, however, revealed some glaring holes in BLM's understanding of the social cost of carbon and its utility in the NEPA context. First, the memo notes that no court thus far requires BLM to use the social cost of carbon in its NEPA reviews, sidestepping the *High Country Conservation Advocates* decision that directed BLM to analyze the climate impacts of the West Elk coal lease in Colorado using the social cost of carbon.

Second, BLM incorrectly asserts that this tool merely estimates the cost to future generations. On the contrary, the federal estimates provide monetary values for each ton of carbon emissions starting in 2010 and continuing through the present day and up to 2050. Indeed, other federal agencies use the social cost of carbon to provide the *current* value of reducing carbon dioxide emissions. As just one example, the Department of Energy recently "calculate[d] a *present* value" of emission reductions by using the social cost of carbon in considering standards for home appliances.[10] Given its misstatements, BLM must revisit its understanding of what the social cost of carbon does and how it could be useful to the public in the coal leasing context before it crafts agency-wide guidance on this subject.

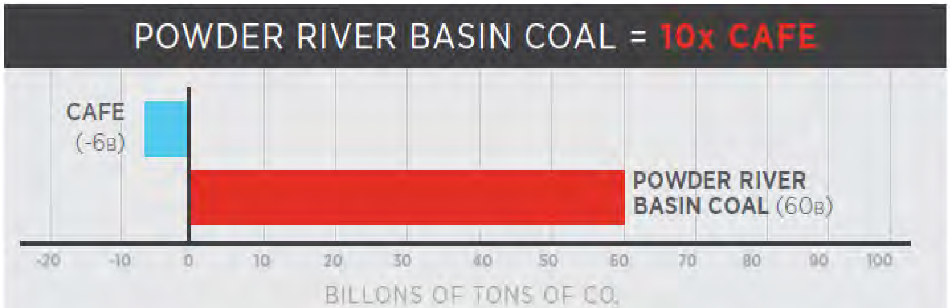
This paper asserts that BLM and the U.S. Forest Service should immediately begin utilizing the social cost of carbon as a tool to inform decision makers and the public of the climate impacts associated with federal coal leasing decisions. In the sections that follow, we provide a brief overview of the federal coal leasing program, explain BLM's obligation to analyze and disclose climate impacts under NEPA, include a short summary of the social cost of carbon, describe why it is useful for understanding the climate impacts of coal leasing decisions, and provide BLM and other agencies with a guide on how to incorporate this important tool into their NEPA reviews for federal coal leasing proposals.

---

[7] *High Country Conservation Advocates v. U.S. Forest Service*, --F.Supp.3d--, 2014 WL 2922751 at *8-11 (D. Colo. June 27, 2014).
[8] Letter from Robert Bonnie, Under Sec'y for Natural Res. and Env't, U.S. Dep't of Agric., to J. Nichols at 1 (Mar. 6, 2015) (on file with author).
[9] Memorandum from the Bureau of Land Mgmt. on Climate Change under NEPA 1 (undated memo) (on file with author).
[10] Energy Conservation Program, 79 Fed. Reg. 76,142, 76,168-69 (Dec. 19, 2014) (emphasis added).

II. BACKGROUND: THE FEDERAL COAL LEASING PROGRAM AND NEPA

A. The Obama Administration's Coal Problem



A Sierra Club 2014 report on climate and public lands notes that the Powder River Basin in Montana and Wyoming holds the largest minable coal reserves in the continental U.S.[11] Encompassing 14 million acres of public lands and mineral estates, the Powder River Basin generates approximately 407 million tons of coal each year, accounting for more than 41 percent of the nation's coal.[12] A 2013 U.S. Geological Survey assessment calculates the Powder River Basin has 25 billion short tons of economically recoverable coal.[13] If accurate, this equates to 60 billion metric tons of CO_2 that could potentially be released, equaling more than 10 times the savings from federal fuel efficiency (CAFE) standards.

The continued expansion of BLM's federal coal leasing program stands in stark contrast to the Obama Administration's meaningful steps to fight the economic and public health impacts caused by climate disruption. Since President Obama was elected, BLM has leased or processed applications to mine more than 5 billion tons of federal coal from public lands in the Powder River Basin, and it is in the process of finalizing land use plans that call for an additional 10 billion tons of coal extraction over the next 20 years.[14]

The Sierra Club and other conservation organizations have long advocated that BLM not pursue additional federal coal leases because of their massive climate impacts. Scientific

---

[11] *Dirty Fuels, Clean Futures: A Call for National Climate Action Plan That Keeps Dirty Fuels in the Ground,* SIERRA CLUB 9-10 (April 2014), *available at* http://content.sierraclub.org/ourwildamerica/sites/content.sierraclub.org.ourwildamerica/files/documents/dirty-fuels-clean-futures-report-2014.pdf.

[12] U.S. Energy Information Administration, Annual Coal Report, Table 1 (Apr. 23, 2015), http://www.eia.gov/coal/annual/pdf/table1.pdf.

[13] *Dirty Fuels, Clean Futures* at 9.

[14] *See* proposals for Antelope Ridge, Antelope Ridge North, Bell Ayr West, Hay Creek II, Maysdorf II south, North Hilight, South Hilight, West Hilight, North Porcupine, South Porcupine, Spring Creek II, West Jacobs Ranch, Decker and West Antelope II South, and the Buffalo Resource Management Plan.

research strongly supports this policy position. A recent peer-reviewed article published in the prestigious research journal *Nature* concluded that if we are to keep climate change below dangerous levels, 80 percent of global coal reserves, half of all gas reserves, and a third of oil reserves must stay in the ground through 2050.[15] As the President affirmed recently, "climate change can no longer be denied – or ignored."[16]

B. Climate Change Is a Fundamental Environmental Issue That Falls Squarely Within NEPA's Focus

Enacted in 1970, the National Environmental Policy Act (NEPA)[17] is our basic national charter for the protection of the environment and provides an ideal platform for federal agencies to engage the public in an informed dialogue around federal agency decisions that affect our climate. NEPA's core mandates require federal agencies to consider the environmental impacts of their decisions and to disclose those impacts to the public before the agency commits itself to action.[18] As summarized by the U.S. Supreme Court, these "twin aims," "place[] upon an agency the obligation to consider every significant aspect of the environmental impact of a proposed action," and "ensure[] that the agency will inform the public that it has indeed considered environmental concerns in its decisionmaking process."[19]

It is important to note that NEPA establishes procedural rather than substantive obligations for agencies considering major federal actions. As such, it does not and cannot require BLM or any other federal agency to arrive at any particular leasing decision on account of a proposed coal lease's environmental impacts. However, by fulfilling NEPA's procedural mandates to fully analyze and disclose climate impacts and other environmental effects of federal coal leasing proposals, BLM could very well reconsider the wisdom of locking in billions of tons of carbon pollution that will harm current and future generations.

Although industry has gone to great lengths to argue that climate impacts should not be considered under NEPA,[20] there is nothing that would make NEPA less applicable when considering climate impacts as compared to traditional impacts to land, air, and water.

---

[15] Christophe McGlade & Paul Ekins, *The Geographical Distribution of Fossil Fuels Unused When Limiting Global Warming to 2 [deg] C*, NATURE (Jan. 7, 2015), summary available at http://www.nature.com/nature/journal/v517/n7533/full/nature14016.html.

[16] Barack Obama, President of the United States, Weekly Address (Apr. 18, 2015), available at https://www.whitehouse.gov/the-press-office/2015/04/17/weekly-address-climate-change-can-no-longer-be-ignored-0.

[17] 42 U.S.C. 4321 et seq (2006).

[18] 42 U.S.C. §§ 4334-35 (2006).

[19] *Baltimore Gas & Electric Co. v. NRDC*, 462 U.S. 87, 97 (1983) (internal quotation and citation omitted).

[20] *See, e.g.*, Katie Sweenie, Comments on Consideration of Greenhouse Gas Emissions and Climate Change Effects in NEPA Reviews, 79 Fed. Reg. 77,802, NATIONAL MINING ASSOCIATION (Mar. 25, 2015), https://www.whitehouse.gov/sites/default/files/docs/nma_comments_on_ceq_ghg_nepa_guidance.pdf.

On the contrary, federal courts have recognized that "[t]he impact of greenhouse gas emissions on climate change is precisely the kind of cumulative impacts analysis that NEPA requires agencies to conduct."[21] The Council on Environmental Quality (CEQ), which promulgates NEPA regulations, agrees: "[c]limate change is a fundamental environmental issue, and . . . falls squarely within NEPA's focus."[22]

NEPA specifically requires federal agencies to analyze and disclose the environmental effects of their actions, including "ecological . . . aesthetic, historic, cultural, economic [and] health" impacts.[23] 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."[24] 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.

III. SOCIAL COST OF CARBON AND THE FEDERAL COAL LEASING PROGRAM

A. The Social Cost of Carbon Basics

The social cost of carbon was created by an interagency working group in 2010 that consisted of scientific and economic experts from a dozen federal agencies and offices, including EPA, and the Departments of Agriculture, Commerce, Energy, Transportation, and the Treasury.[25] The working group's primary goal was to help federal agencies engaged in rulemaking to quantify the economic benefit of federal actions that reduce CO_2 emissions. The result of their efforts was the social cost of carbon – a schedule of estimates of the global economic harm caused by each ton of CO_2 emissions in a given year, expressed as $/ton.[26] These values encompass damages from decreased agricultural productivity as a result of drought, human health effects, and property damage from increased flooding, among other factors.[27]

---

[21] *Center for Biological Diversity v. NHTSA*, 538 F.3d 1172, 1217 (9th Cir. 2008).
[22] Consideration of Greenhouse Gas Emissions and Climate Change Effects in NEPA Reviews, 79 Fed. Reg. 77,802, 77,822 (Dec. 24, 2014), available at http://www.gpo.gov/fdsys/pkg/FR-2014-12-24/pdf/2014-30035.pdf.
[23] 40 C.F.R. § 1508.8.
[24] 40 C.F.R. § 1502.22(b)(4).
[25] Interagency Working Group on Social Cost of Carbon, Technical Support Document: Social Cost of Carbon 2-3 (Feb. 10, 2010), http://www.epa.gov/otaq/climate/regulations/scc-tsd.pdf.
[26] Fact Sheet: Social Cost of Carbon, ENVTL. PROT. AGENCY (Nov. 2013), http://www.epa.gov/climatechange/Downloads/EPAactivities/scc-fact-sheet.pdf.
[27] Interagency Working Group, Technical Update of the Social Cost of Carbon 2 (May 2013), http://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf.

Although it was initially developed to help agencies craft regulatory impact assessments of proposed rules, the social cost of carbon need not and should not be limited to this application, as courts have recognized in cases such as *High Country Conservation Advocates.* This tool is particularly useful with regard to coal leasing because it allows decision makers to understand the impact of projects "that have small, or 'marginal,' impacts on cumulative global emissions."[28] As CEQ has confirmed, statements that a particular agency decision will result in only a small fraction of global GHG concentrations should not be used to avoid analyzing the impact of those emissions.[29] Such statements, according to CEQ, reflect the nature of climate change rather than the impact of any particular project.[30] Using the social cost of carbon in NEPA reviews, by contrast, would help agencies move beyond the frequent and problematic boilerplate statements about climate change by providing a scientifically defensible means of quantifying a lease's climate impacts.

Estimating the social cost of one additional ton of carbon dioxide requires making assumptions regarding inputs and estimates from complex systems. In order to capture these uncertainties, and to address the fact that climate impacts increase as carbon dioxide concentrations rise, the interagency working group established a range of estimates that increase over time. The estimates are based on the average social cost of carbon from three existing, peer-reviewed integrated assessment models (the DICE, PAGE, and FUND models) and use varying discount rates to reflect the time-value of money. These chosen discount rates are 5 percent, 3 percent, and 2.5 percent, and a fourth value intended to represent the potential for higher-than-average climate damages. The result is a table of average social cost figures specific to the year of emissions and each of the four discount rates – 5 percent, 3 percent, 2.5 percent, and the 95th percentile using a 3 percent discount rate.[31]

In May 2013, the working group revised its estimates of the social cost of carbon based on updates to underlying climate and economic models. The 2013 estimates were approximately 50 percent higher on average than the 2010 figures,[32] but there is strong evidence that the estimates are still too low,[33] as noted by Sierra Club and others.[34] BLM

---

[28] Interagency Working Group on Social Cost of Carbon, Technical Support Document 1 (Feb. 10, 2010).
[29] Consideration of Greenhouse Gas Emissions and Climate Change Effects in NEPA Reviews, 79 Fed. Reg. at 77,825.
[30] *Id.*
[31] *See* Appendix for the interagency working group's updated estimates, expressed in 2007 dollars.
[32] IWG, Technical Update of the Social Cost of Carbon at 2.
[33] Recent studies indicate that the federal social cost of carbon does not fully account for several critical variables such as the effect of climate change on economic growth rates. Frances C. Moore & Delavane B. Diaz, *Temperature impacts on economic growth warrant stringent mitigation policy*, 5 NATURE CLIMATE CHANGE 127-31 (Jan. 12, 2015); Weitzmann, M.L., *GHG Targets as Insurance Against Catastrophic Climate Damages*, Working Paper No. 16136, NAT'L BUREAU OF ECON. RES. (June 2010), available at http://www.nber.org/papers/w16136.

should acknowledge that the social cost of carbon may be too low and that it specifically addresses carbon dioxide emissions, but does not estimate damages from all GHGs. Although peer-reviewed studies have estimated the social cost of methane at a range of $450 to $2,300 per metric ton,[35] no federal agency or working group has endorsed these figures. The need for a thorough accounting of methane emissions and their impacts is particularly acute with underground coal mines, many of which release massive amounts of methane in order to keep the mines safe for coal miners. Agencies that approve leases at methane-intensive coal mines should explain this gap and provide a general assessment of the current science around the social cost of methane.

Despite these uncertainties, the social cost of carbon nonetheless reflects the best economic and scientific understanding available, and is intended to be updated to reflect the most current thinking on the topic. In July 2014, after prompting from Senator David Vitter and Representatives Tim Murphy, Duncan Hunter, and John Culberson, the Government Accountability Office affirmed the working group's 2010 and 2013 analyses and praised the group for its transparent process, accurate disclosure of scientific and economic uncertainties, and consensus-based decision making model.[36]

B. Why the Social Cost of Carbon Is Helpful to Decision Makers in the NEPA Process

The guiding principle of NEPA is that the public is entitled to a clear understanding of the likely impacts of federal agencies' decisions. The U.S. Supreme Court has called the disclosure of impacts the "key requirement of NEPA," holding that agencies must "consider and disclose the actual environmental effects" of a proposed project in a way that "brings those effects to bear on [an agency's] decisions."[37] The social cost of carbon provides decision makers and the public with an informative, accessible mechanism for both analyzing and understanding the climate impacts of a proposed decision.

First, although agencies such as BLM, the Forest Service, and the federal Office of Surface Mining (OSM) often quantify the *amount* of carbon dioxide or CO_2-e (carbon dioxide equivalent) emissions from mining and burning coal from federal leases, these agencies have not yet taken the next step of employing the social cost of carbon to tell the public about the *impact* of those emissions. An isolated calculation of the amount of carbon emissions that would result from a particular project does not provide any meaningful

---

[34] Sierra Club, Comments on the Interagency Working Group's (IWG) Technical Support Document: Social Cost of Carbon (SCC) 2-3 (Feb. 26, 2014), http://www.regulations.gov/#!documentDetail;D=OMB-2013-0007-0083.
[35] Alex L. Marten & Stephen C. Newbold, *Estimating the social cost of non-Co2 GHG emissions: methane and nitrous oxide*, 51 ENERGY POLICY 957 (Sept. 28, 2012).
[36] GOV'T ACCOUNTABILITY OFFICE, REGULATORY IMPACT ANALYSIS: DEVELOPMENT OF SOCIAL COST OF CARBON ESTIMATES (July 2014), available at http://www.gao.gov/assets/670/665016.pdf.
[37] *Baltimore Gas & Elec. Co. v. NRDC*, 462 U.S. at 96.

insight as to the effect that those emissions will have on our climate. By contrast, the social cost of carbon offers an actual estimate of the damage caused by each incremental ton of carbon emissions.

Second, the social cost of carbon describes those damage estimates in monetary terms, which are far easier for decision makers and the public to comprehend and contextualize than tons of CO_2-e. In doing so, the social cost of carbon provides a concrete assessment of a project's social and environmental impacts and provides a tangible sense of the scale of damage that both the public and decision makers can readily understand. As explained by one legal commentator, the social cost of carbon "allow[s] agencies to consider those GHG emissions . . . in a meaningful way," and that "assigning a price to carbon emissions – even a conservative price – makes the cost of those emissions concrete for agency decision makers."[38]

Of course, we do not imply that the impacts of climate change can be fully captured by a dollar figure. Droughts, floods, extreme weather events, rising sea levels, and other phenomena related to climate change present threats to our planet that extend far beyond economic harms. Agencies must analyze not only the quantitative (and monetizable) climate impacts of proposed actions, but the qualitative and non-monetizable impacts as well. Nevertheless, to the extent that a project's impacts can be quantified, the social cost of carbon is the best and most rigorous tool currently available for understanding the damages linked to carbon emissions, rather than simply the extent of the emissions themselves.

Third, although NEPA does not require agencies to conduct a cost-benefit analysis (*i.e.*, a comparison where a project gets approved only if the benefits outweigh the costs), BLM and other agencies routinely calculate a proposed project's economic benefit to the local county, measuring the dollar value of jobs, royalties, and taxes, among other factors.[39] Agencies often use these quantified economic benefits to justify approving the project, without any attempt to quantify the costs of the agency's decision.[40] Using the social

---

[38] Mark Squillace & Alexander Hood, *NEPA, Climate Change, and Public Land Decision Making*, 42 ENVTL. L. 469, 510, 517 (2012).

[39] *See, e.g.*, OFFICE OF SURFACE MINING RECLAMATION & ENFORCEMENT, BULL MOUNTAINS MINE NO. 1 ENVIRONMENTAL ASSESSMENT (Jan. 2015), http://www.wrcc.osmre.gov/initiatives/bullMountainsMine/BullMountainsMineEA.pdf; U.S. FOREST SERVICE, FINAL ENVIRONMENTAL IMPACT STATEMENT FOR PAWNEE NATIONAL GRASSLAND (Dec. 2014), http://a123.g.akamai.net/7/123/11558/abc123/forestservic.download.akamai.com/11558/www/nepa/95573_FSPLT3_2393686.pdf.

[40] *See, e.g.*, BUREAU OF LAND MGMT., ENVIRONMENTAL ASSESSMENT FOR THE WEST ELK COAL LEASE APPLICATIONS (June 2012); http://www.blm.gov/pgdata/etc/medialib/blm/co/information/nepa/uncompahgre_field/ufo_nepa_documents0.Par.96415.File.dat/12-13%20West%20Elk%20Coal%20Lease%20Mod%20EA.pdfp; BUREAU OF LAND MGMT., ENVIRONMENTAL IMPACT STATEMENT FOR THE WRIGHT AREA COAL LEASE APPLICATIONS; and OFFICE OF SURFACE MINING RECLAMATION & ENFORCEMENT, BULL MOUNTAINS MINE NO. 1 ENVIRONMENTAL ASSESSMENT (Jan. 2015),

cost of carbon in these contexts would provide a useful dollars-to-dollars comparison outside the parameters of a strict cost-benefit analysis, allowing the public to understand the scale of climate impacts of a proposed coal lease and its alternatives. It would further afford federal agencies the opportunity to weigh global economic harm caused by the climate impacts of the leasing decision against the extent of any local economic benefit in terms of jobs, taxes, etc., and thus allow agencies to make a fully informed decision.

By omitting any discussion of the economic harm caused by a project, federal agencies are effectively putting a zero on that side of the ledger, making it appear as though there is no quantifiable cost associated with a project. In the context of climate change, this is a demonstrably (and overwhelmingly) untrue assumption—the social cost of carbon allows decision makers and the public to estimate the climate-based costs of a proposed project. By ignoring the social cost of carbon, as most federal agencies do now when evaluating federal coal leases, they are quantifying purported economic benefits while ignoring an available and easy-to-use tool for similarly quantifying economic costs of the proposed project—precisely the sort of misleading analysis NEPA is designed to avoid.[41]

IV. HOW TO USE THE SOCIAL COST OF CARBON IN NEPA REVIEWS FOR FEDERAL COAL LEASES

A. The Flawed, Ad Hoc Approach to the Social Cost of Carbon in Leasing Decisions

BLM and other agencies have yet to settle on a consistent framework for when or how to incorporate the social cost of carbon into NEPA reviews. The result is an unpredictable and flawed ad hoc approach among (and even within) federal agencies tasked with making decisions on federal mineral leasing.

Recent proposals by former Deputy Secretary of the Interior David Hayes[42] and Resources for the Future[43] have separately explored whether the Department of the Interior should include a "carbon adder" price (or otherwise factor in the social cost of carbon) when selling federal coal in order to account for some of the economic consequences of increased carbon pollution. We acknowledge that there is room for debate on the market and economic consequences of adjusting federal coal prices to

---

http://www.wrcc.osmre.gov/initiatives/bullMountainsMine/BullMountainsMineEA.pdf.http://www.wrcc.osmre.gov/initiatives/bullMountainsMine/BullMountainsMineEA.pdf.

[41] *See Center for Biological Diversity v. NHTSA*, 538 F.3d 1172, 1217 (9th Cir. 2008); *High Country Conservation Advocates v. U.S. Forest Service*, --F.Supp.2d--, 2014 WL 20922751 (D. Colo. June 27, 2014).

[42] David Hayes and James Stock, *The Real Cost of Coal*, N.Y. TIMES (March 24, 2015), available at http://www.nytimes.com/2015/03/24/opinion/the-real-cost-of-coal.html.

[43] Alan Krupnick et al., *Putting a Carbon Charge on Federal Coal*, RESOURCES FOR THE FUTURE (March 2015), available at http://www.rff.org/Publications/Pages/PublicationDetails.aspx?PublicationID=22534.

account for climate impacts. However, agencies face no such difficulty when merely incorporating the social cost of carbon into their NEPA reviews; as noted earlier, NEPA's mandate is analytical and informational in nature, rather than substantive, so agencies are not bound by any particular course of action once they adequately consider and disclose the environmental impacts of their decisions – climate or otherwise.

Moreover, agencies with authority over federal coal leasing can offer no policy justification for failing to develop a consistent framework for using the social cost of carbon during their NEPA reviews. NEPA was designed to foster better decision making by requiring agencies to fully consider the environmental consequences of their actions. The social cost of carbon was designed specifically to help federal agencies make better decisions on climate. It can and should be used to that end in the coal leasing context.

Below is brief sampling of the disparate approaches agencies have taken on the social cost of carbon in recent NEPA analyses:

- Pawnee National Grassland Oil and Gas Leasing, Forest Service (Dec. 2014): The Forest Service declined to use the social cost of carbon to assess the climate impacts of oil and gas development on the Pawnee National Grassland, claiming that doing so without monetizing all benefits of energy production would be misleading.[44]

- Little Willow Creek Oil and Gas Leases, BLM (Feb. 2015): BLM used the social cost of carbon to analyze climate impacts from the Little Willow Creek oil and gas leases in Idaho, but provided little context and did not offer a range of estimates, nor did it use emission-year specific estimates.[45]

- Bull Mountain Coal Lease, OSM (Feb. 2015): OSM declined to use the social cost of carbon to evaluate a proposed 100 million-ton coal mine in Montana, claiming that doing so would be misleading because the agency had quantified some, but not all, of the economic benefits to the county.[46]

- Greens Hollow Coal Lease, Forest Services (Feb. 2015): The Forest Service refused to consider the social cost of carbon of a 56.6 million-ton coal lease in Utah,

[44] U.S. FOREST SERVICE, PAWNEE NATIONAL GRASSLAND OIL AND GAS LEASING FEIS at 317 (Dec. 2014), available at http://a123.g.akamai.net/7/123/11558/abc123/forestservic.download.akamai.com/11558/www/nepa/95573_FSPLT3_2393686.pdf.
[45] BUREAU OF LAND MGMT., ENVIRONMENTAL ASSESSMENT FOR LITTLE WILLOW CREEK 81-83 (Feb. 2015), available at https://www.blm.gov/epl-front-office/projects/nepa/39064/55133/59825/DOI-BLM-ID-B010-2014-0036-EA_UPDATED_02272015.pdf.
[46] BULL MOUNTAINS MINE NO. 1 ENVIRONMENTAL ASSESSMENT, App. C Response to Comments at 18-20 (Feb. 2015), available at http://www.wrcc.osmre.gov/initiatives/bullMountainsMine/BullMountainsMineEA_AppendixC.pdf.

arguing that the project emissions would be insignificant compared to global concentrations (an approach explicitly rejected by CEQ), and that, "[t]he tools necessary to quantify incremental climatic impacts of specific activities are presently unavailable."[47] This statement ignores the fact that the social cost of carbon, which the U.S. Department of Agriculture (the Forest Service's parent department) helped create, provides precisely the type of tool the Forest Service claims does not exist.

B. A Simple, Three-Step Guide to Using the Social Cost of Carbon in Federal Coal Leasing NEPA Reviews

As noted earlier, BLM and other federal agencies now consistently recognize their obligation to calculate the total direct and indirect CO_2 emissions from mining, transporting, and burning coal in their NEPA reviews for federal coal leases.[48] Taking the next logical step and disclosing the social cost of those CO_2 emissions is a relatively simple mathematical exercise that entails three steps:

1. **Identify the expected annual CO_2 emissions:** Quantify annual CO_2 emissions resulting from mining, transportation, and combustion, for the duration of a proposed coal lease.

   Because the combustion of mined coal accounts for the vast majority of the lifecycle CO_2 emissions associated with a lease, it is critical that agencies accurately tabulate those emissions. Mining companies already provide agencies with detailed information on the total amount of recoverable coal, the anticipated annual mining rate, and how many years mining will last. To determine CO_2 emissions from combustion, agencies use a ratio for the specific coal seam that calculates how much CO_2 will be emitted during combustion for each ton of coal mined.

2. **Basic Multiplication:** Plug those numbers for annual CO_2 emissions into the interagency working group's social cost of carbon matrix, multiplying the CO_2 emissions for a specific year by the range of social cost of carbon (SCC) values for that year, across all four discount rates.

3. **Basic Addition:** Add each year of SCC values to get the total range of SCC figures for the proposed lease, across all four discount rates.

[47] U.S. FOREST SERVICE, FINAL SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT FOR THE LEASING AND UNDERGROUND MINING OF THE GREENS HOLLOW FEDERAL COAL LEASE TRACT 285 (Feb. 2015), available at http://a123.g.akamai.net/7/123/11558/abc123/forestservic.download.akamai.com/11558/www/nepa/50297_FSPLT3_2423442.pdf.

[48] *See, e.g.*, OSM, BULL MOUNTAIN EA; BLM, WRIGHT AREA EIS.

C. Reference Example: Wright Area Coal Leases, Wyoming

In the Wright Area EIS, BLM evaluated proposals for six federal coal leases that would expand three massive surface mines in the Wyoming portion of the Powder River Basin.[49] We use the four of these leases that BLM has approved to serve as a reference point in our analysis for how the agency should use the social cost of carbon when evaluating federal coal lease proposals.[50]

The North Hilight, South Hilight, North Porcupine, and South Porcupine leases would expand two coal mines – Peabody's North Antelope Rochelle Mine and Arch Coal's Black Thunder Mine. In 2010, BLM finalized one EIS evaluating these leases and then finalized individual Records of Decision for each lease in the years that followed. Although the size of the leases makes their climate impact bigger than that of most mines, the nature and type of information relevant to a social cost of carbon analysis is typical of NEPA reviews for other federal coal leases.

As noted above, mining companies already supply BLM with information on annual production rates, the total amount of coal available in a lease, and the expected duration of mining activities. With this data, BLM can then predict total emissions by multiplying the expected quantity of coal by the amount of CO_2 that will be generated from burning each ton of coal mined. BLM calculates the latter value for a given coal seam by referencing an emissions factor that takes into account heat rate, sulfur contact, and other information about the composition of coal in that seam. For the Wright Area mines, the emissions factor is 1.659,[51] meaning that for each ton of coal produced, 1.659 metric tons of CO_2 is generated from burning that coal.

In the Wright Area EIS, BLM used then-current and projected annual mining rates and available reserves at each mine to determine that mining for the North and South Hilight leases would begin in 2017 and that mining in the North and South Porcupine tracts would start in 2018.[52] The agency also projected the following estimates of the anticipated annual mining rate, the total amount of recoverable coal, and the duration of mining as follows:[53]

---

[49] BLM, WRIGHT AREA FEIS (2010), available at http://www.blm.gov/wy/st/en/info/NEPA/documents/hpd/Wright-Coal.html. Although BLM's climate analysis is the subject of litigation pending in the federal district court in Wyoming, use of the social cost of carbon is not part of the litigation, nor was it used in the EIS or Records of Decision for any of the leases.

[50] The analysis below uses the quantified emissions estimates provided by BLM, which did not include transportation related emissions. For an analysis of transportation-related CO_2 emissions, see OSM's EA for the Bull Mountain Mine.

[51] WRIGHT AREA FEIS at 4-140.

[52] *Id.* at 2-13 to 2-64.

[53] *Id.* at 4-140.

	Annual Production (millions of tons)	Total Production (millions of tons)	Duration of Mining
North and South Highlight	135	957.1	7 years
North and South Porcupine	95	1,084.7	11 years

Using this information and the 2013 federal social cost of carbon values—which is all readily available to BLM—we can calculate the range of annual and cumulative climate-based costs that will result from these leases. All that is required at this point basic multiplication (step 2, above) and basic addition (step 3, above). The table on the following page presents the annual and cumulative results of this exercise. For years of overlapping production, the amount of coal mined and CO_2 generated is highest, and these figures taper off as lease reserves are depleted.

The social cost figures presented here for each discount rate are taken from the interagency working group's 2013 estimates, which reflect 2007 dollars. Converting to current dollars from 2007 figures is possible using information from other federal agencies, if desired.[54]

[54] *See* CPI Inflation Calculator, BUREAU OF LABOR STATISTICS, http://www.bls.gov/data/inflation_calculator.htm (last visited Apr. 22, 2015).

Social Cost of Carbon: Four Wright Area Coal Leases, Wyoming

Year of Project Operation	***Tons of Coal Produced (millions)***	***Tons of CO_2 Generated (million metric tons) †***	***SCC Discount Rate: 5%* ($ million)**	***SCC Discount Rate: 3.%* ($ million)**	***SCC Discount Rate: 2. 5%* ($ million)**	***SCC Discount Rate: 3% 95th percentile* ($ million)**
2017	135	223.9	12 x 223.9 = $2686.8	39 x 223.9 = $8732.1	60 x 223.9 = $13,434	116 x 223.9 = $25,972.4
2018	230	381.5	12 x 381.5 = $4578	40 x 381.5 = $15,260	61 x 381.5 = $23,271.5	120 x 381.5 = $45,780
2019	230	381.5	12 x 381.5 = $4578	42 x 381.5 = $16,023	62 x 381.5 = $23,653	124 x 381.5 = $47,306
2020	230	381.5	12 x 381.5 = $4578	43 x 381.5 = $16,404.5	64 x 381.5 = $24,416	128 x 381.5 = $48,832
2021	230	381.5	12 x 381.5 = $4578	43 x 381.5 = $16,404.5	65 x 381.5 = $24,797.5	131 x 381.5 = $49,976.5
2022	230	381.5	13 x 381.5 = $4959.5	44 x 381.5 = $16,786	66 x 381.5 = $25,179	134 x 381.5 = $51,121
2023	230	381.5	13 x 381.5 = $4959.5	45 x 381.5 = $17,167.5	67 x 381.5 = $25,560.5	137 x 381.5 = $52,265.5
2024	107	177.5	14 x 177.5 = $2485	46 x 177.5 = $8165	68 x 177.5 = $12,070	140 x 177.5 = $24,850
2025	95	157.6	14 x 157.6 = $2206.4	47 x 157.6 = $7407.2	69 x 157.6 = $10,874.4	143 x 157.6 = $22,536.8
2026	95	157.6	15 x 157.6 = $2364	48 x 157.6 = $7564.8	70 x 157.6 = $11,032	146 x 157.6 = $23,009.6
2027	95	157.6	15 x 157.6 = $2364	49 x 157.6 = $7722.4	71 x 157.6 = $11,189.6	149 x 157.6 = $23,482.4
2028	95	157.6	15 x 157.6 = $2364	50 x 157.6 = $7880	72 x 157.6 = $11,347.2	152 x 157.6 = $23,955.2
2029	39	64.7	16 x 64.7 = $1035.2	51 x 64.7 = $3299.7	73 x 64.7 = $4723.1	155 x 64.7 = $10,028.5
Total CO_2 Emissions and SCC Across Discount Rates	**Total tons of coal produced:** 2.04 billion tons	**Total CO_2 emissions:** 3.3 billion tons	**5% SCC:** $43,736.4 million	**3% SCC:** $148,816.7 million	**2.5% SCC:** $221,547.8 million	**95th % SCC:** $449,155.9 million

† BLM uses an emissions factor of 1.659 tonnes of CO_2 generated per ton of coal burned. Wright Area FEIS at 4-140.

V. CONCLUSION

Under NEPA, federal agencies are obligated to ensure that decision makers and the public are fully informed of the climate impacts of agency decisions. The social cost of carbon is a critical tool for fulfilling that obligation. Incorporating the social cost of carbon into their NEPA analyses will enable BLM and other federal agencies to better assess the climate impacts of coal leases and to frame those impacts in terms that both decision makers and the public can readily understand. Complete information about the costs of fossil fuel extraction is critical to putting the United States on the path towards reducing our carbon emissions, and the social cost of carbon is one of the best and most rigorous tools available for analyzing the climate impacts of mining and burning fossil fuels.

BLM and other agencies must incorporate this transparent and readily understandable metric into their NEPA analyses for federal coal leasing decisions. By doing so, these agencies will promote good governance, comply with existing legal mandates, and begin engaging in the "honest and open conversation" about the federal coal leasing program recently called for by Secretary Jewell.[55]

[55] Secretary Jewell speech, supra note 1.

APPENDIX

The following chart presents the updated social cost of carbon figures from the interagency working group's 2013 update (p. 18, Appendix A):

Appendix A

Table A1: Annual SCC Values: 2010-2050 (2007$/metric ton CO_2)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	11	32	51	89
2011	11	33	52	93
2012	11	34	54	97
2013	11	35	55	101
2014	11	36	56	105
2015	11	37	57	109
2016	12	38	59	112
2017	12	39	60	116
2018	12	40	61	120
2019	12	42	62	124
2020	12	43	64	128
2021	12	43	65	131
2022	13	44	66	134
2023	13	45	67	137
2024	14	46	68	140
2025	14	47	69	143
2026	15	48	70	146
2027	15	49	71	149
2028	15	50	72	152
2029	16	51	73	155
2030	16	52	75	159
2031	17	52	76	162
2032	17	53	77	165
2033	18	54	78	168
2034	18	55	79	172
2035	19	56	80	175
2036	19	57	81	178
2037	20	58	83	181
2038	20	59	84	185
2039	21	60	85	188
2040	21	61	86	191
2041	22	62	87	194
2042	22	63	88	197
2043	23	64	89	200
2044	23	65	90	203
2045	24	66	92	206
2046	24	67	93	209
2047	25	68	94	211
2048	25	69	95	214
2049	26	70	96	217
2050	26	71	97	220

Attachment 3

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 Greenhouse Gases, 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 the Interior
Department of Transportation
Department of the Treasury
Environmental Protection Agency
National Economic Council
Office of Management and Budget
Office of Science and Technology Policy

August 2016

See Appendix B for Details on Revisions since May 2013

Preface

The Interagency Working Group on the Social Cost of Greenhouse Gases (formerly the Interagency Working Group on the Social Cost of Carbon) has a longstanding commitment to ensure that the social cost of carbon estimates continue to reflect the best available science and methodologies. Given this commitment and public comments on issues of a deeply technical nature received by the Office of Management and Budget and federal agencies, the Interagency Working Group is seeking independent expert advice on technical opportunities to update the social cost of carbon estimates. The Interagency Working Group asked the National Academies of Sciences, Engineering, and Medicine in 2015 to review the latest research on modeling the economic aspects of climate change to inform future revisions to the social cost of carbon estimates presented in this technical support document. In January 2016, the Academies' Committee on the Social Cost of Carbon issued an interim report that recommended against a near-term update to the social cost of carbon estimates, but included recommendations for enhancing the presentation and discussion of uncertainty around the current estimates. This revision to the TSD responds to these recommendations in the presentation of the current estimates. It does not revisit the interagency group's 2010 methodological decisions or update the schedule of social cost of carbon estimates presented in the July 2015 revision. The Academies' final report (expected in early 2017) will provide longer term recommendations for a more comprehensive update.

Executive Summary

Executive Order 12866 requires agencies, 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 (SC-CO_2)[1] estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions. The SC-CO_2 is 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 SC-CO_2 estimates is described in the 2010 Technical Support Document on the Social Cost of Carbon (TSD) (Interagency Working Group on Social Cost of Carbon 2010). Through that process the Interagency Working Group (IWG) selected SC-CO_2 values for use in regulatory analyses. For each emissions year, four values are recommended. Three of these values are based on the average SC-CO_2 from three integrated assessment models (IAMs), at discount rates of 2.5, 3, and 5 percent. In addition, as discussed in the 2010 TSD, there is extensive evidence in the scientific and economic literature on the potential for lower-probability, but higher-impact outcomes from climate change, which would be particularly harmful to society and thus relevant to the public and policymakers. The fourth value is thus included to represent the marginal damages associated with these lower-probability, higher-impact outcomes. Accordingly, this fourth value is selected from further out in the tail of the distribution of SC-CO_2 estimates; specifically, the fourth value corresponds to the 95^{th} percentile of the frequency distribution of SC-CO_2 estimates based on a 3 percent discount rate. Because the present value of economic damages associated with CO_2 emissions change over time, a separate set of estimates is presented for each emissions year through 2050, which is sufficient to cover the time frame addressed in most current regulatory impact analyses.

In May of 2013, the IWG provided an update of the SC-CO_2 estimates based on new versions of each IAM (DICE, PAGE, and FUND). The 2013 update did not revisit other IWG modeling decisions (e.g., the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity). Improvements in the way damages are modeled were confined to those that had been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature. The IWG subsequently provided additional minor technical revisions in November of 2013 and July of 2015, as described in Appendix B.

The purpose of this 2016 revision to the TSD is to enhance the presentation and discussion of quantified uncertainty around the current SC-CO_2 estimates, as a response to recommendations in the interim report by the National Academies of Sciences, Engineering, and Medicine. Included herein are an expanded

[1] Throughout this Technical Support Document (TSD) we refer to the estimates as "SC-CO_2 estimates" rather than the more simplified "SCC" abbreviation used in previous versions of the TSD.

graphical presentation of the SC-CO_2 estimates highlighting a symmetric range of uncertainty around estimates for each discount rate, new sections that provide a unified discussion of the methodology used to incorporate sources of uncertainty, and a detailed explanation of the uncertain parameters in both the FUND and PAGE models.

The distributions of SC-CO_2 estimates reflect uncertainty in key model parameters chosen by the IWG such as the sensitivity of the climate to increases in carbon dioxide concentrations, as well as uncertainty in default parameters set by the original model developers. This TSD maintains the same approach to estimating the SC-CO_2 and selecting four values for each emissions year that was used in earlier versions of the TSD. Table ES-1 summarizes the SC-CO_2 estimates for the years 2010 through 2050. These estimates are identical to those reported in the previous version of the TSD, released in July 2015. As explained in previous TSDs, the central value is the average of SC-CO_2 estimates based on the 3 percent discount rate. For purposes of capturing uncertainty around the SC-CO_2 estimates in regulatory impact analysis, the IWG emphasizes the importance of considering all four SC-CO_2 values.

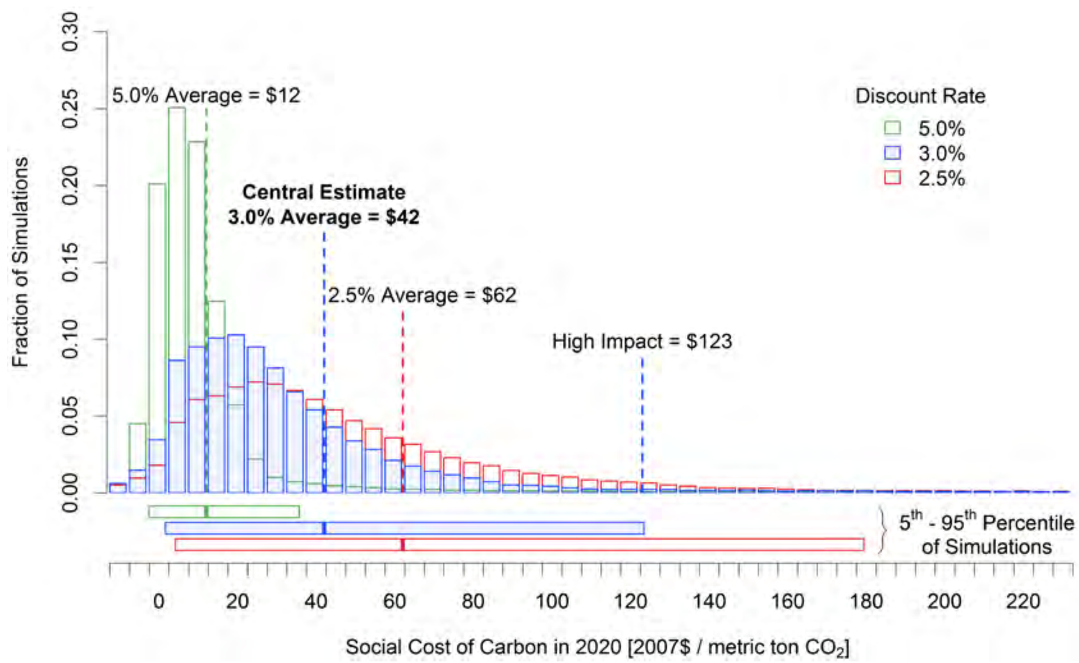
Table ES-1: Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per metric ton of CO_2)

Year	5% Average	**3% Average**	2.5% Average	High Impact (95th Pct at 3%)
2010	10	**31**	50	86
2015	11	**36**	56	105
2020	12	**42**	62	123
2025	14	**46**	68	138
2030	16	**50**	73	152
2035	18	**55**	78	168
2040	21	**60**	84	183
2045	23	**64**	89	197
2050	26	**69**	95	212

While point estimates are important for providing analysts with a tractable approach for regulatory analysis, they do not fully quantify uncertainty associated with the SC-CO_2 estimates. Figure ES-1 presents the quantified sources of uncertainty in the form of frequency distributions for the SC-CO_2 estimates for emissions in 2020. To highlight the difference between the impact of the discount rate on the SC-CO_2 and other quantified sources of uncertainty, the bars below the frequency distributions provide a symmetric representation of quantified variability in the SC-CO_2 estimates for each discount rate. When an agency determines that it is appropriate to conduct additional quantitative uncertainty analysis, it should follow best practices for probabilistic analysis.[2] The full set of information that underlies the frequency distributions in Figure ES-1, which have previously been available upon request, are now available on Office of Management and Budget's (OMB) website for easy public access.

[2] See e.g. OMB Circular A-4, section on *Treatment of Uncertainty*. Available at: https://www.whitehouse.gov/omb/circulars_a004_a-4/#e.

Figure ES-1: Frequency Distribution of SC-CO_2 Estimates for 2020[3]



[3] Although the distributions in Figure ES-1 are based on the full set of model results (150,000 estimates for each discount rate), for display purposes the horizontal axis is truncated with 0.1 to 0.6 percent of the estimates lying below the lowest bin displayed and 0.2 to 3.7 percent of the estimates lying above the highest bin displayed, depending on the discount rate.

I. Purpose

The purpose of this document is to present the current schedule of social cost of carbon (SC-CO_2) estimates, along with an enhanced presentation and discussion of quantified sources of uncertainty around the estimates to respond to recommendations in the interim report of the National Academies of Sciences, Engineering, and Medicine (National Academies 2016).[4] Because the last substantive update to the SC-CO_2 estimates occurred in May 2013, this document maintains much of the earlier technical discussion from the May 2013 TSD. The SC-CO_2 estimates themselves remain unchanged since the July 2015 revision.

E.O. 13563 commits the Administration to regulatory decision making "based on the best available science."[5] Additionally, the IWG recommended in 2010 that the SC-CO_2 estimates be revisited on a regular basis or as model updates that reflect the growing body of scientific and economic knowledge become available.[6] By early 2013, new versions of the three integrated assessment models (IAMs) used by the U.S. government to estimate the SC-CO_2 (DICE, FUND, and PAGE) were available and had been published in the peer-reviewed literature. While acknowledging the continued limitations of the approach taken by the IWG in 2010 (documented in the original 2010 TSD), the May 2013 TSD provided an update of the SC-CO_2 estimates based on the latest peer-reviewed version of the models, replacing model versions that were developed up to ten years earlier in a rapidly evolving field. It did not revisit other assumptions with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity. Improvements in the way damages are modeled were confined to those that had been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature. The agencies participating in the IWG continue to investigate potential improvements to the way in which economic damages associated with changes in CO_2 emissions are quantified.

Section II summarizes the major features of the IAMs used in this TSD that were updated in 2013 relative to the versions of the models used in the 2010 TSD. Section III presents the SC-CO_2 estimates for 2010 – 2050 based on these versions of the models. Section IV discusses the treatment of uncertainty in the analysis. Section V provides a discussion of other model limitations and research gaps.

II. Summary of Model Updates

This section briefly reviews the features of the three IAMs used in this TSD (DICE 2010, FUND 3.8, and PAGE 2009) that were updated by the model developers relative to the versions of the models used by the IWG in 2010 (DICE 2007, FUND 3.5, and PAGE 2002). The focus here is on describing those model updates that are relevant to estimating the social cost of carbon, as summarized in Table 1. For example, both the DICE and PAGE models now include an explicit representation of sea level rise damages. Other

---

[4] In this document, we present all social cost estimates per metric ton of CO_2 emissions. Alternatively, one could report the social cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).
[5] http://www.whitehouse.gov/sites/default/files/omb/inforeg/eo12866/eo13563_01182011.pdf
[6] See p. 1, 3, 4, 29, and 33 (Interagency Working Group on Social Cost of Carbon 2010).

revisions to PAGE include: 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. The DICE model's simple carbon cycle has been updated to be more consistent with a more complex climate model. The FUND model includes 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. Changes made to parts of the models that are superseded by the IWG's modeling assumptions—regarding equilibrium climate sensitivity, discounting, and socioeconomic variables—are not discussed here but can be found in the references provided in each section below.

Table 1: Summary of Key Model Revisions Relevant to the IWG SC-CO_2 Estimates

IAM	Version used in 2010 IWG Analysis	Version Used since May 2013	Key changes relevant to IWG SC-CO_2
DICE	2007	2010	Updated calibration of the carbon cycle model and explicit representation of sea level rise (SLR) and associated damages.
FUND	3.5 (2009)	3.8 (2012)	Updated damage functions for space heating, SLR, agricultural impacts, changes to transient response of temperature to buildup of GHG concentrations, and inclusion of indirect climate effects of methane.
PAGE	2002	2009	Explicit representation of SLR damages, revisions to damage function to ensure damages do not exceed 100% of GDP, change in regional scaling of damages, revised treatment of potential abrupt damages, and updated adaptation assumptions.

A. DICE

DICE 2010 includes a number of changes over the previous 2007 version used in the 2010 TSD. The model changes that are relevant for the SC-CO_2 estimates developed by the IWG include: 1) updated parameter values for the carbon cycle model, 2) an explicit representation of sea level dynamics, and 3) a re-calibrated damage function that includes an explicit representation of economic damages from sea level rise. Changes were also made to other parts of the DICE model—including the equilibrium climate sensitivity parameter, the rate of change of total factor productivity, and the elasticity of the marginal utility of consumption—but these components of DICE are superseded by the IWG's assumptions and so will not be discussed here. More details on DICE2007 can be found in Nordhaus (2008) and on DICE2010 in Nordhaus (2010). The DICE2010 model and documentation is also available for download from the homepage of William Nordhaus.

Carbon Cycle Parameters

DICE uses a three-box model of carbon stocks and flows to represent the accumulation and transfer of carbon among the atmosphere, the shallow ocean and terrestrial biosphere, and the deep ocean. These parameters are "calibrated to match the carbon cycle in the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC)" (Nordhaus 2008, p. 44).[7] Carbon cycle transfer coefficient values in DICE2010 are based on re-calibration of the model to match the newer 2009 version of MAGICC (Nordhaus 2010, p. 2). For example, in DICE2010, in each decade 12 percent of the carbon in the atmosphere is transferred to the shallow ocean, 4.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 94.8 percent remains in the shallow ocean, and 0.5 percent is transferred to the deep ocean. For comparison, in DICE 2007, 18.9 percent of the carbon in the atmosphere is transferred to the shallow ocean each decade, 9.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 85.3 percent remains in the shallow ocean, and 5 percent is transferred to the deep ocean.

The implication of these changes for DICE2010 is in general a weakening of the ocean as a carbon sink and therefore a higher concentration of carbon in the atmosphere than in DICE2007 for a given path of emissions. All else equal, these changes will generally increase the level of warming and therefore the SC-CO_2 estimates in DICE2010 relative to those from DICE2007.

Sea Level Dynamics

A new feature of DICE2010 is an explicit representation of the dynamics of the global average sea level anomaly to be used in the updated damage function (discussed below). This section contains a brief description of the sea level rise (SLR) module; a more detailed description can be found on the model developer's website.[8] The average global sea level anomaly is modeled as the sum of four terms that represent contributions from: 1) thermal expansion of the oceans, 2) melting of glaciers and small ice caps, 3) melting of the Greenland ice sheet, and 4) melting of the Antarctic ice sheet.

The parameters of the four components of the SLR module are calibrated to match consensus results from the IPCC's Fourth Assessment Report (AR4).[9] The rise in sea level from thermal expansion in each time period (decade) is 2 percent of the difference between the sea level in the previous period and the long run equilibrium sea level, which is 0.5 meters per degree Celsius (°C) above the average global temperature in 1900. The rise in sea level from the melting of glaciers and small ice caps occurs at a rate of 0.008 meters per decade per °C above the average global temperature in 1900.

The contribution to sea level rise from melting of the Greenland ice sheet is more complex. The equilibrium contribution to SLR is 0 meters for temperature anomalies less than 1 °C and increases linearly from 0 meters to a maximum of 7.3 meters for temperature anomalies between 1 °C and 3.5 °C. The contribution to SLR in each period is proportional to the difference between the previous period's sea

[7] MAGICC is a simple climate model initially developed by the U.S. National Center for Atmospheric Research that has been used heavily by the Intergovernmental Panel on Climate Change (IPCC) to emulate projections from more sophisticated state of the art earth system simulation models (Randall et al. 2007).
[8] Documentation on the new sea level rise module of DICE is available on William Nordhaus' website at: http://nordhaus.econ.yale.edu/documents/SLR_021910.pdf.
[9] For a review of post-IPCC AR4 research on sea level rise, see Nicholls et al. (2011) and NAS (2011).

level anomaly and the equilibrium sea level anomaly, where the constant of proportionality increases with the temperature anomaly in the current period.

The contribution to SLR from the melting of the Antarctic ice sheet is -0.001 meters per decade when the temperature anomaly is below 3 °C and increases linearly between 3 °C and 6 °C to a maximum rate of 0.025 meters per decade at a temperature anomaly of 6 °C.

Re-calibrated Damage Function

Economic damages from climate change in the DICE model are represented by a fractional loss of gross economic output in each period. A portion of the remaining economic output in each period (net of climate change damages) is consumed and the remainder is invested in the physical capital stock to support future economic production, so each period's climate damages will reduce consumption in that period and in all future periods due to the lost investment. The fraction of output in each period that is lost due to climate change impacts is represented as a sigmoid, or "S"-shaped, function of the temperature anomaly in the period.[10] The loss function in DICE2010 has been expanded by including a quadratic sub-function of SLR. In DICE2010 the temperature anomaly coefficients have been recalibrated to avoid double-counting damages from sea level rise that were implicitly included in these parameters in DICE2007.

The aggregate damages in DICE2010 are illustrated by Nordhaus (2010, p. 3), who notes that "…damages in the uncontrolled (baseline) [i.e., reference] case … in 2095 are $12 trillion, or 2.8 percent of global output, for a global temperature increase of 3.4 ^{o}C above 1900 levels." This compares to a loss of 3.2 percent of global output at 3.4 ^{o}C in DICE2007. However, in DICE2010, annual damages are lower in most of the early periods of the modeling horizon but higher in later periods than would be calculated using the DICE2007 damage function. Specifically, the percent difference between damages in the base run of DICE2010 and those that would be calculated using the DICE2007 damage function starts at +7 percent in 2005, decreases to a low of -14 percent in 2065, then continuously increases to +20 percent by 2300 (the end of the IWG analysis time horizon), and to +160 percent by the end of the model time horizon in 2595. The large increases in the far future years of the time horizon are due to the permanence associated with damages from sea level rise, along with the assumption that the sea level is projected to continue to rise long after the global average temperature begins to decrease. The changes to the loss function generally decrease the IWG SC-CO_2 estimates slightly given that relative increases in damages in later periods are discounted more heavily, all else equal.

B. FUND

FUND version 3.8 includes a number of changes over the previous version 3.5 (Narita et al. 2010) used in the 2010 TSD. Documentation supporting FUND and the model's source code for all versions of the model

---

[10] The model and documentation, including formulas, are available on the author's webpage at http://www.econ.yale.edu/~nordhaus/homepage/RICEmodels.htm.

is available from the model authors.[11] Notable changes, due to their impact on the SC-CO_2 estimates, are adjustments to the space heating, agriculture, and sea level rise damage functions in addition to changes to the temperature response function and the inclusion of indirect effects from methane emissions.[12] Each of these is discussed in turn.

Space Heating

In FUND, the damages associated with the change in energy needs for space heating are based on the estimated impact due to one degree of warming. These baseline damages are scaled based on the forecasted temperature anomaly's deviation from the one degree benchmark and adjusted for changes in vulnerability due to economic and energy efficiency growth. In FUND 3.5, the function that scales the base year damages adjusted for vulnerability allows for the possibility that in some simulations the benefits associated with reduced heating needs may be an unbounded convex function of the temperature anomaly. In FUND 3.8, the form of the scaling has been modified to ensure that the function is everywhere concave and that there will exist an upper bound on the benefits a region may receive from reduced space heating needs. The new formulation approaches a value of two in the limit of large temperature anomalies, or in other words, assuming no decrease in vulnerability, the reduced expenditures on space heating at any level of warming will not exceed two times the reductions experienced at one degree of warming. Since the reduced need for space heating represents a benefit of climate change in the model, or a negative damage, this change will increase the estimated SC-CO_2. This update accounts for a significant portion of the difference in the expected SC-CO_2 estimates reported by the two versions of the model when run probabilistically.

Sea Level Rise and Land Loss

The FUND model explicitly includes damages associated with the inundation of dry land due to sea level rise. The amount of land lost within a region depends on the proportion of the coastline being protected by adequate sea walls and the amount of sea level rise. In FUND 3.5 the function defining the potential land lost in a given year due to sea level rise is linear in the rate of sea level rise for that year. This assumption implicitly assumes that all regions are well represented by a homogeneous coastline in length and a constant uniform slope moving inland. In FUND 3.8 the function defining the potential land lost has been changed to be a convex function of sea level rise, thereby assuming that the slope of the shore line

[11] http://www.fund-model.org/. This report uses version 3.8 of the FUND model, which represents a modest update to the most recent version of the model to appear in the literature (version 3.7) (Anthoff and Tol, 2013a, 2013b). For the purpose of computing the SC-CO_2, the relevant changes (between 3.7 to 3.8) are associated with improving consistency with IPCC AR4 by adjusting the atmospheric lifetimes of CH_4 and N_2O and incorporating the indirect forcing effects of CH_4, along with making minor stability improvements in the sea wall construction algorithm.

[12] The other damage sectors (water resources, space cooling, land loss, migration, ecosystems, human health, and extreme weather) were not significantly updated.

increases moving inland. The effect of this change is to typically reduce the vulnerability of some regions to sea level rise based land loss, thereby lowering the expected SC-CO_2 estimate. [13]

[13] For stability purposes this report also uses an update to the model which assumes that regional coastal protection measures will be built to protect the most valuable land first, such that the marginal benefits of coastal protection is decreasing in the level of protection following Fankhauser (1995).

Agriculture

In FUND, the damages associated with the agricultural sector are measured as proportional to the sector's value. The fraction is bounded from above by one and is made up of three additive components that represent the effects from carbon fertilization, the rate of temperature change, and the level of the temperature anomaly. In both FUND 3.5 and FUND 3.8, the fraction of the sector's value lost due to the level of the temperature anomaly is modeled as a quadratic function with an intercept of zero. In FUND 3.5, the coefficients of this loss function are modeled as the ratio of two random normal variables. This specification had the potential for unintended extreme behavior as draws from the parameter in the denominator approached zero or went negative. In FUND 3.8, the coefficients are drawn directly from truncated normal distributions so that they remain in the range $[0,\infty)$ and $(-\infty,0]$, respectively, ensuring the correct sign and eliminating the potential for divide-by-zero errors. The means for the new distributions are set equal to the ratio of the means from the normal distributions used in the previous version. In general the impact of this change has been to decrease the range of the distribution while spreading out the distributions' mass over the remaining range relative to the previous version. The net effect of this change on the SC-CO_2 estimates is difficult to predict.

Transient Temperature Response

The temperature response model translates changes in global levels of radiative forcing into the current expected temperature anomaly. In FUND, a given year's increase in the temperature anomaly is based on a mean reverting function where the mean equals the equilibrium temperature anomaly that would eventually be reached if that year's level of radiative forcing were sustained. The rate of mean reversion defines the rate at which the transient temperature approaches the equilibrium. In FUND 3.5, the rate of temperature response is defined as a decreasing linear function of equilibrium climate sensitivity to capture the fact that the progressive heat uptake of the deep ocean causes the rate to slow at higher values of the equilibrium climate sensitivity. In FUND 3.8, the rate of temperature response has been updated to a quadratic function of the equilibrium climate sensitivity. This change reduces the sensitivity of the rate of temperature response to the level of the equilibrium climate sensitivity, a relationship first noted by Hansen et al. (1985) based on the heat uptake of the deep ocean. Therefore in FUND 3.8, the temperature response will typically be faster than in the previous version. The overall effect of this change is likely to increase estimates of the SC-CO_2 as higher temperatures are reached during the timeframe analyzed and as the same damages experienced in the previous version of the model are now experienced earlier and therefore discounted less.

Methane

The IPCC AR4 notes a series of indirect effects of methane emissions, and has developed methods for proxying such effects when computing the global warming potential of methane (Forster et al. 2007). FUND 3.8 now includes the same methods for incorporating the indirect effects of methane emissions. Specifically, the average atmospheric lifetime of methane has been set to 12 years to account for the feedback of methane emissions on its own lifetime. The radiative forcing associated with atmospheric methane has also been increased by 40% to account for its net impact on ozone production and stratospheric water vapor. This update to the model is relevant for the SC-CO_2 because most of the damage functions are non-linear functions of the temperature anomaly, which represents the fact that as the climate system becomes more stressed an additional unit of warming will have a greater impact on damages. Accounting for the indirect effects of CH_4 emissions on temperature will therefore move the model further up the damage curves in the baseline, making a marginal change in emissions of CO_2 more impactful. All else equal, the effect of this increased radiative forcing will be to increase the estimated SC-CO_2 values, due to greater projected temperature anomaly.

C. PAGE

PAGE09 (Hope 2013) includes a number of changes from PAGE2002, the version used in the 2010 TSD. The changes that most directly affect the SC-CO_2 estimates include: explicitly modeling the impacts from sea level rise, revisions to the damage function to ensure damages are constrained by GDP, a change in the regional scaling of damages, a revised treatment for the probability of a discontinuity within the damage function, and revised assumptions on adaptation. The model also includes revisions to the carbon cycle feedback and the calculation of regional temperatures.[14] More details on PAGE09 can be found in Hope (2011a, 2011b, 2011c). A description of PAGE2002 can be found in Hope (2006).

Sea Level Rise

While PAGE2002 aggregates all damages into two categories—economic and non-economic impacts—PAGE09 adds a third explicit category: damages from sea level rise. In the previous version of the model, damages from sea level rise were subsumed by the other damage categories. In PAGE09 sea level damages increase less than linearly with sea level under the assumption that land, people, and GDP are more concentrated in low-lying shoreline areas. Damages from the economic and non-economic sectors were adjusted to account for the introduction of this new category.

Revised Damage Function to Account for Saturation

In PAGE09, small initial economic and non-economic benefits (negative damages) are modeled for small temperature increases, but all regions eventually experience economic damages from climate change, where damages are the sum of additively separable polynomial functions of temperature and sea level rise. Damages transition from this polynomial function to a logistic path once they exceed a certain proportion of remaining Gross Domestic Product (GDP) to ensure that damages do not exceed 100 percent of GDP. This differs from PAGE2002, which allowed Eastern Europe to potentially experience large benefits from temperature increases, and which also did not bound the possible damages that could be experienced.

[14] Because several changes in the PAGE model are structural (e.g., the addition of sea level rise and treatment of discontinuity), it is not possible to assess the direct impact of each change on the SC-CO_2 in isolation as done for the other two models above.

Regional Scaling Factors

As in the previous version of PAGE, the PAGE09 model calculates the damages for the European Union (EU) and then, assumes that damages for other regions are proportional based on a given scaling factor. The scaling factors in PAGE09 are based on the length of each region's coastline relative to the EU (Hope 2011b). Because of the long coastline in the EU, other regions are, on average, less vulnerable than the EU for the same sea level and temperature increase, but all regions have a positive scaling factor. PAGE2002 based its scaling factors on four studies reported in the IPCC's third assessment report, and allowed for benefits from temperature increases in Eastern Europe, smaller impacts in developed countries, and higher damages in developing countries.

Probability of a Discontinuity

In PAGE2002, the damages associated with a "discontinuity" (nonlinear extreme event) were modeled as an expected value. Specifically, a stochastic probability of a discontinuity was multiplied by the damages associated with a discontinuity to obtain an expected value, and this was added to the economic and non-economic impacts. That is, additional damages from an extreme event, such as extreme melting of the Greenland ice sheet, were multiplied by the probability of the event occurring and added to the damage estimate. In PAGE09, the probability of discontinuity is treated as a discrete event for each year in the model. The damages for each model run are estimated either with or without a discontinuity occurring, rather than as an expected value. A large-scale discontinuity becomes possible when the temperature rises beyond some threshold value between 2 and 4°C. The probability that a discontinuity will occur beyond this threshold then increases by between 10 and 30 percent for every 1°C rise in temperature beyond the threshold. If a discontinuity occurs, the EU loses an additional 5 to 25 percent of its GDP (drawn from a triangular distribution with a mean of 15 percent) in addition to other damages, and other regions lose an amount determined by their regional scaling factor. The threshold value for a possible discontinuity is lower than in PAGE2002, while the rate at which the probability of a discontinuity increases with the temperature anomaly and the damages that result from a discontinuity are both higher than in PAGE2002. The model assumes that only one discontinuity can occur and that the impact is phased in over a period of time, but once it occurs, its effect is permanent.

Adaptation

As in PAGE2002, adaptation is available to help mitigate any climate change impacts that occur. In PAGE this adaptation is the same regardless of the temperature change or sea level rise and is therefore akin to what is more commonly considered a reduction in vulnerability. It is modeled by reducing the damages by some percentage. PAGE09 assumes a smaller decrease in vulnerability than the previous version of the model and assumes that it will take longer for this change in vulnerability to be realized. In the aggregated economic sector, at the time of full implementation, this adaptation will mitigate all damages up to a temperature increase of 1°C, and for temperature anomalies between 1°C and 2°C, it will reduce damages by 15-30 percent (depending on the region). However, it takes 20 years to fully implement this adaptation. In PAGE2002, adaptation was assumed to reduce economic sector damages up to 2°C by 50-90 percent after 20 years. Beyond 2°C, no adaptation is assumed to be available to mitigate the impacts of climate change. For the non-economic sector, in PAGE09 adaptation is available to reduce 15 percent of the damages due to a temperature increase between 0°C and 2°C and is assumed to take 40 years to fully implement, instead of 25 percent of the damages over 20 years assumed in PAGE2002. Similarly, adaptation is assumed to alleviate 25-50 percent of the damages from the first 0.20 to 0.25 meters of sea level rise but is assumed to be ineffective thereafter. Hope (2011c) estimates that the less optimistic assumptions regarding the ability to offset impacts of temperature and sea level rise via adaptation increase the SC-CO_2 by approximately 30 percent.

Other Noteworthy Changes

Two other changes in the model are worth noting. There is a change in the way the model accounts for decreased CO_2 absorption on land and in the ocean as temperature rises. PAGE09 introduces a linear feedback from global mean temperature to the percentage gain in the excess concentration of CO_2, capped at a maximum level. In PAGE2002, an additional amount was added to the CO_2 emissions each period to account for a decrease in ocean absorption and a loss of soil carbon. Also updated is the method by which the average global and annual temperature anomaly is downscaled to determine annual average regional temperature anomalies to be used in the regional damage functions. In PAGE2002, the scaling was determined solely based on regional difference in emissions of sulfate aerosols. In PAGE09, this regional temperature anomaly is further adjusted using an additive factor that is based on the average absolute latitude of a region relative to the area weighted average absolute latitude of the Earth's landmass, to capture relatively greater changes in temperature forecast to be experienced at higher latitudes.

III. SC-CO_2 Estimates

The three IAMs were run using the same methodology detailed in the 2010 TSD (Interagency Working Group on Social Cost of Carbon 2010). The approach, along with the inputs for the socioeconomic emissions scenarios, equilibrium climate sensitivity distribution, and discount rate remains the same. This includes the five reference scenarios based on the EMF-22 modeling exercise, the Roe and Baker equilibrium climate sensitivity distribution calibrated to the IPCC AR4, and three constant discount rates of 2.5, 3, and 5 percent.

As was previously the case, use of three models, three discount rates, and five scenarios produces 45 separate frequency distributions of SC-CO_2 estimates in a given year. The approach laid out in the 2010 TSD applied equal weight to each model and socioeconomic scenario in order to reduce the dimensionality down to three separate distributions, one for each of the three discount rates. The IWG selected four values from these distributions for use in regulatory analysis. Three values are based on the average SC-CO_2 across models and socioeconomic and emissions scenarios at the 2.5, 3, and 5 percent discount rates, respectively. The fourth value is included to provide information on the marginal damages associated with lower-probability, higher-impact outcomes that would be particularly harmful to society. As discussed in the 2010 TSD, there is extensive evidence in the scientific and economic literature of the potential for lower-probability, higher-impact outcomes from climate change, which would be particularly harmful to society and thus relevant to the public and policymakers. This points to the relevance of values above the mean in right skewed distributions. Accordingly, this fourth value is selected from further out in the tails of the frequency distribution of SC-CO_2 estimates, and, in particular, is set to the 95th percentile of the frequency distribution of SC-CO_2 estimates based on a 3 percent discount rate. (A detailed set of percentiles by model and scenario combination and additional summary statistics for the 2020 values is available in Appendix A.) As noted in the 2010 TSD, “the 3 percent discount rate is the central value, and so the central value that emerges is the average SC-CO_2 across models at the 3 percent discount rate” (Interagency Working Group on Social Cost of Carbon 2010, p. 25). However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the IWG emphasizes the importance and value of including all four SC-CO_2 values.

Table 2 shows the four selected SC-CO_2 estimates in five year increments from 2010 to 2050. Values for 2010, 2020, 2030, 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 linear interpolation. The full set of revised annual SC-CO_2 estimates between 2010 and 2050 is reported in the Appendix and the full set of model results are available on the OMB website.[15]

Table 2: Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per metric ton of CO_2)

Year	5% Average	**3% Average**	2.5% Average	High Impact (95th Pct at 3%)
2010	10	**31**	50	86
2015	11	**36**	56	105
2020	12	**42**	62	123
2025	14	**46**	68	138
2030	16	**50**	73	152
2035	18	**55**	78	168
2040	21	**60**	84	183
2045	23	**64**	89	197
2050	26	**69**	95	212

As was the case in the 2010 TSD, the SC-CO_2 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, and because GDP is growing over time and many damage categories are modeled as proportional to gross GDP. The approach taken by the IWG is to compute the cost of a marginal ton emitted in the future by running the models for a set of perturbation years out to 2050. Table 3 illustrates how the growth rate for these four SC-CO_2 estimates varies over time.

[15] https://www.whitehouse.gov/omb/oira/social-cost-of-carbon.

Table 3: Average Annual Growth Rates of $SC\text{-}CO_2$ Estimates between 2010 and 2050

Average Annual Growth Rate (%)	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010-2020	1.2%	3.2%	2.4%	4.4%
2020-2030	3.4%	2.1%	1.7%	2.3%
2030-2040	3.0%	1.9%	1.5%	2.0%
2040-2050	2.6%	1.6%	1.3%	1.6%

The future monetized value of emission reductions in each year (the $SC\text{-}CO_2$ 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. As previously discussed in the 2010 TSD, damages from future emissions should be discounted at the same rate as that used to calculate the $SC\text{-}CO_2$ 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 to the base year of the analysis using the same rate.

Current guidance contained in OMB Circular A-4 indicates that analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the IWG (including OMB) determined that a modified approach is more appropriate in this case because the climate change problem is highly unusual in a number of 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—and conversely, greenhouse gases emitted elsewhere contribute to damages in the United States. Consequently, to address the global nature of the problem, the $SC\text{-}CO_2$ must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Other countries will also need to take action to reduce emissions if 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. For example, the United States joined over 170 other nations and signed the Paris Agreement on April 22, 2016, signaling worldwide commitment to reduce GHG emissions. The United States has been active in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. Using a global estimate of damages in U.S. regulatory analyses sends a strong signal to other nations that they too should base their emissions reductions strategies on a global perspective, thus supporting a cooperative and mutually beneficial approach to achieving needed reduction. Thirteen prominent academics noted that these "are compelling reasons to focus on a global [$SC\text{-}CO_2$]" in a recent article on the $SC\text{-}CO_2$ (Pizer et al. 2014). In addition, adverse impacts on other countries can have spillover effects on the United States, particularly in the areas of national security, international trade, public health, and humanitarian concerns. When these considerations are taken as a whole, the IWG concluded that a global measure of the benefits from reducing U.S. emissions is appropriate. For additional discussion, see the 2010 TSD.

IV. Treatment of Uncertainty

Uncertainty about the value of the SC-CO_2 is in part inherent, as with any analysis that looks into the future, but it is also driven by current data gaps associated with the complex physical, economic, and behavioral processes that link GHG emissions to human health and well-being. Some sources of uncertainty pertain to aspects of the natural world, such as quantifying the physical effects of greenhouse gas emissions on Earth systems. Other sources of uncertainty are associated with current and future human behavior and well-being, such as population and economic growth, GHG emissions, the translation of Earth system changes to economic damages, and the role of adaptation. It is important to note that even in the presence of uncertainty, scientific and economic analysis can provide valuable information to the public and decision makers, though the uncertainty should be acknowledged and when possible taken into account in the analysis. This section summarizes the sources of uncertainty that the IWG was able to consider in a quantitative manner in estimating the SC-CO_2. Further discussion on sources of uncertainty that are active areas of research and have not yet been fully quantified in the SC-CO_2 estimates is provided in Section V and in the 2010 TSD.

In developing the SC-CO_2 estimates, the IWG considered various sources of uncertainty through a combination of a multi-model ensemble, probabilistic analysis, and scenario analysis. For example, the three IAMs used collectively span a wide range of Earth system and economic outcomes to help reflect the uncertainty in the literature and in the underlying dynamics being modeled. The use of an ensemble of three different models is also intended to, at least partially, address the fact that no single model includes all of the quantified economic damages. It also helps to reflect structural uncertainty across the models, which is uncertainty in the underlying relationships between GHG emissions, Earth systems, and economic damages that are included in the models. Bearing in mind the different limitations of each model (discussed in the 2010 TSD) and lacking an objective basis upon which to differentially weight the models, the three IAMs are given equal weight in the analysis.

The IWG used Monte Carlo techniques to run the IAMs a large number of times. In each simulation the uncertain parameters are represented by random draws from their defined probability distributions. In all three models the equilibrium climate sensitivity is treated probabilistically based on the probability distribution described in the 2010 TSD. The equilibrium climate sensitivity is a key parameter in this analysis because it helps define the strength of the climate response to increasing GHG concentrations in the atmosphere. In addition, the FUND and PAGE models define many of their parameters with probability distributions instead of point estimates. For these two models, the model developers' default probability distributions are maintained for all parameters other than those superseded by the IWG's harmonized inputs (i.e., equilibrium climate sensitivity, socioeconomic and emissions scenarios, and discount rates). More information on the uncertain parameters in PAGE and FUND is presented in Appendix C.

For the socioeconomic and emissions scenarios, uncertainty is included in the analysis by considering a range of scenarios, which are described in detail in the 2010 SC-CO_2 TSD. As noted in the 2010 TSD, while the IWG considered formally assigning probability weights to the different socioeconomic scenarios selected, it came to the conclusion that this could not be accomplished in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socioeconomic pathways. Thus, the IWG determined that, because no basis for assigning differential weights was available, the most transparent way to present a range of uncertainty was simply to weight each of the five scenarios equally for the consolidated estimates. To provide additional information as to how the results vary with the scenarios, summarized results for each scenario are presented separately in Appendix A. The results of each model run are available on the OMB website.

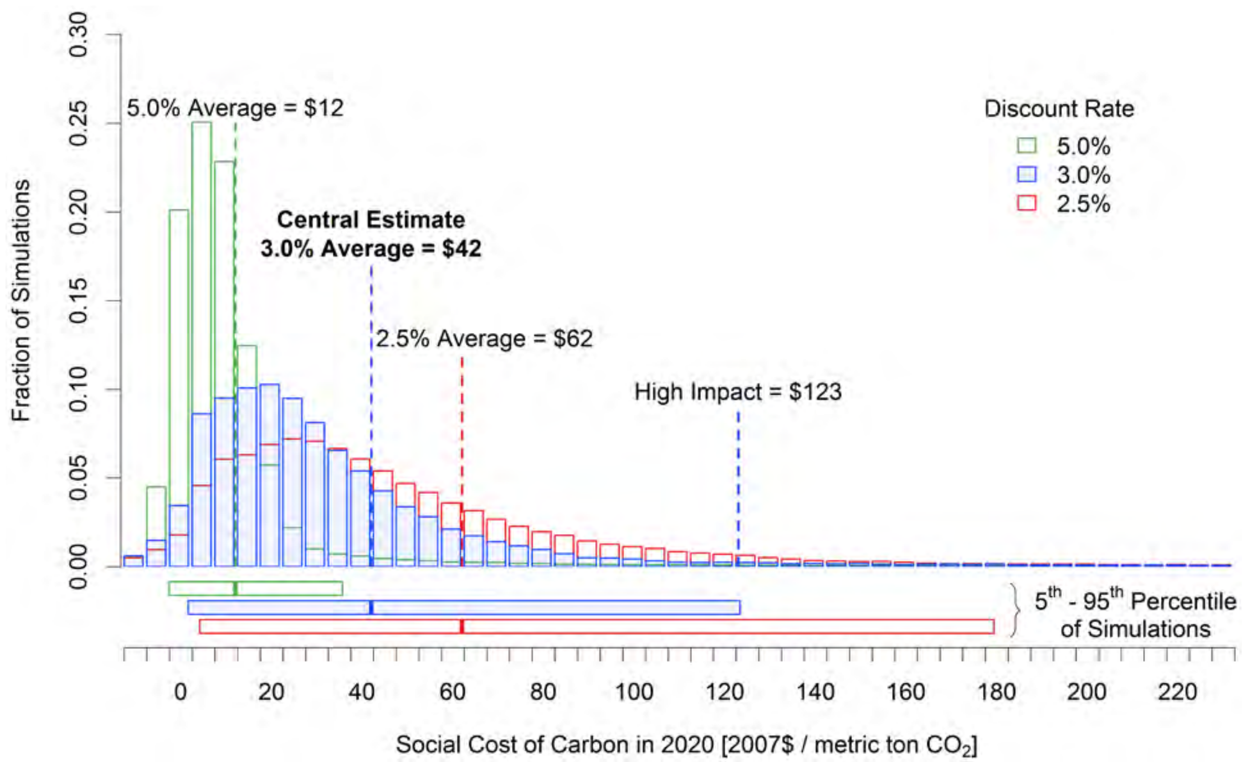
Finally, based on the review of the literature, the IWG chose discount rates that reflect reasonable judgements under both prescriptive and descriptive approaches to intergenerational discounting. As discussed in the 2010 TSD, in light of disagreement in the literature on the appropriate discount rate to use in this context and uncertainty about how rates may change over time, the IWG selected three certainty-equivalent constant discount rates to span a plausible range: 2.5, 3, and 5 percent per year. However, unlike the approach taken for consolidating results across models and socioeconomic and emissions scenarios, the SC-CO_2 estimates are not pooled across different discount rates because the range of discount rates reflects both uncertainty and, at least in part, different policy or value judgements.

The outcome of accounting for various sources of uncertainty using the approaches described above is a frequency distribution of the SC-CO_2 estimates for emissions occurring in a given year for each of the three discount rates. These frequency distributions reflect the uncertainty around the input parameters for which probability distributions were defined, as well as from the multi-model ensemble and socioeconomic and emissions scenarios where probabilities were implied by the equal weighting assumption. It is important to note that the set of SC-CO_2 estimates obtained from this analysis does not yield a probability distribution that fully characterizes uncertainty about the SC-CO_2 due to impact categories omitted from the models and sources of uncertainty that have not been fully characterized due to data limitations.

Figure 1 presents the frequency distribution of the SC-CO_2 estimates for emissions in 2020 for each of the three discount rates. Each of these distributions represents 150,000 estimates based on 10,000 simulations for each combination of the three models and five socioeconomic and emissions scenarios.[16] In general, the distributions are skewed to the right and have long right tails, which tend to be even longer for lower discount rates. To highlight the difference between the impact of the discount rate on the SC-CO_2 and other quantified sources of uncertainty, the bars below the frequency distributions provide a symmetric representation of quantified variability in the SC-CO_2 estimates conditioned on each discount rate. The full set of SC-CO_2 results through 2050 is available on OMB's website. This may be useful to analysts in situations that warrant additional quantitative uncertainty analysis (e.g., as recommended by OMB for rules that exceed $1 billion in annual benefits or costs). See OMB Circular A-4 for guidance and discussion of best practices in conducting uncertainty analysis in RIAs.

[16] Although the distributions in Figure 1 are based on the full set of model results (150,000 estimates for each discount rate), for display purposes the horizontal axis is truncated with 0.1 to 0.6 percent of the estimates lying below the lowest bin displayed and 0.2 to 3.7 percent of the estimates lying above the highest bin displayed, depending on the discount rate.

Figure 1: Frequency Distribution of SC-CO_2 Estimates for 2020 (in 2007$ per metric ton CO_2)



As previously described, the SC-CO_2 estimates produced by the IWG are based on a rigorous approach to accounting for quantifiable uncertainty using multiple analytical techniques. In addition, the scientific and economics literature has further explored known sources of uncertainty related to estimates of the SC-CO_2. For example, researchers have published papers that explore the sensitivity of IAMs and the resulting SC-CO_2 estimates to different assumptions embedded in the models (see, e.g., Hope (2013), Anthoff and Tol (2013a), and Nordhaus (2014)). However, there remain additional sources of uncertainty that have not been fully characterized and explored due to remaining data limitations. Additional research is needed in order to expand the quantification of various sources of uncertainty in estimates of the SC-CO_2 (e.g., developing explicit probability distributions for more inputs pertaining to climate impacts and their valuation). The IWG is actively following advances in the scientific and economic literature that could provide guidance on, or methodologies for, a more robust incorporation of uncertainty.

V. Other Model Limitations and Research Gaps

The 2010 SC-CO_2 TSD discusses a number of important limitations for which additional research is needed. In particular, the document highlights the need to improve the quantification of both non-catastrophic and catastrophic damages, the treatment of adaptation and technological change, and the way in which inter-regional and inter-sectoral linkages are modeled. While the more recent versions of the models discussed above offer some improvements in these areas, further research is still needed. Currently, IAMs do not include all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature due to a lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research.[17] These individual limitations do not all work in the same direction in terms of their influence on the SC-CO_2 estimates; however, it is the IWG's judgment that, taken together, these limitations suggest that the SC-CO_2 estimates are likely conservative. In particular, the IPCC Fourth Assessment Report (Meehl et al. 2007), which was the most current IPCC assessment available at the time of the IWG's 2009-2010 review, concluded that SC-CO_2 estimates "very likely…underestimate the damage costs" due to omitted impacts. Since then, the peer-reviewed literature has continued to support this conclusion, as noted in the IPCC Fifth Assessment report (Oppenheimer et al. 2014).

Another area of active research relates to intergenerational discounting, including the application of discount rates to regulations in which some costs and benefits accrue intra-generationally while others accrue inter-generationally. Some experts have argued that a declining discount rate would be appropriate to analyze impacts that occur far into the future (Arrow et al. 2013). However, additional research and analysis is still needed to develop a methodology for implementing a declining discount rate and to understand the implications of applying these theoretical lessons in practice.

The 2010 TSD also discusses the need to more carefully assess the implications of risk aversion for SC-CO_2 estimation as well as the substitution possibilities between climate and non-climate goods at higher temperature increases, both of which have implications for the discount rate used. EPA, DOE, and other agencies continue to engage in research on modeling and valuation of climate impacts that can potentially improve SC-CO_2 estimation in the future. See the 2010 SC-CO_2 TSD for the full discussion.

---

[17] See, for example, Howard (2014) and EPRI (2014) for recent discussions.

References

Anthoff, D. and Tol, R.S.J. 2013a. The uncertainty about the social cost of carbon: a decomposition analysis using FUND. *Climatic Change* 117: 515–530.

Anthoff, D. and Tol, R.S.J. 2013b. Erratum to: The uncertainty about the social cost of carbon: A decomposition analysis using FUND. *Climatic Change*. Advance online publication. doi: 10.1007/s10584-013-0959-1.

Arrow, K., M. Cropper, C. Gollier, B. Groom, G. Heal, R. Newell, W. Nordhaus, R. Pindyck, W. Pizer, P. Portney, T. Sterner, R.S.J. Tol, and M. Weitzman. 2013. Determining Benefits and Costs for Future Generations. Science 341: 349-350.

Electric Power Research Institute. 2014. Understanding the Social Cost of carbon: A Technical Assessment. www.epri.com.

Fankhauser, S. 1995. Valuing climate change: The economics of the greenhouse. London, England: Earthscan.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland. 2007. Changes in Atmospheric Constituents and in Radiative Forcing. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Hansen, J., G. Russell, A. Lacis, I. Fung, D. Rind, and P. Stone. 1985. Climate Response Times: Dependence on climate sensitivity and ocean mixing. *Science* 229: 857–859.

Hope, Chris. 2006. "The Marginal Impact of CO_2 from PAGE2002: An Integrated Assessment Model Incorporating the IPCC's Five Reasons for Concern." *The Integrated Assessment Journal*. 6(1): 19–56.

Hope, Chris. 2011a. "The PAGE09 Integrated Assessment Model: A Technical Description" Cambridge Judge Business School Working Paper No. 4/2011 (April). Accessed November 23, 2011: http://www.jbs.cam.ac.uk/research/working_papers/2011/wp1104.pdf.

Hope, Chris. 2011b. "The Social Cost of CO_2 from the PAGE09 Model" Cambridge Judge Business School Working Paper No. 5/2011 (June). Accessed November 23, 2011: http://www.jbs.cam.ac.uk/research/working_papers/2011/wp1105.pdf.

Hope, Chris. 2011c. "New Insights from the PAGE09 Model: The Social Cost of CO_2" Cambridge Judge Business School Working Paper No. 8/2011 (July). Accessed November 23, 2011: http://www.jbs.cam.ac.uk/research/working_papers/2011/wp1108.pdf.

Hope, C. 2013. Critical issues for the calculation of the social cost of CO_2: why the estimates from PAGE09 are higher than those from PAGE2002. *Climatic Change* 117: 531–543.

Howard, Peter. 2014. Omitted Damages: What's Missing from the Social Cost of Carbon. http://costofcarbon.org/files/Omitted_Damages_Whats_Missing_From_the_Social_Cost_of_Carbon.pdf.

Interagency Working Group on Social Cost of Carbon. 2010. Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866. February. United States Government. http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf.

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C. Zhao. 2007. Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Narita, D., R. S. J. Tol and D. Anthoff. 2010. Economic costs of extratropical storms under climate change: an application of FUND. *Journal of Environmental Planning and Management* 53(3): 371-384.

National Academy of Sciences (NAS). 2011. *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia*. Washington, DC: National Academies Press, Inc.

National Academies of Sciences, Engineering, and Medicine (National Academies). 2016. Assessment of Approaches to Updating the Social Cost of Carbon: Phase 1 Report on a Near-Term Update. Washington, D.C.: National Academies Press. Available at: http://sites.nationalacademies.org/DBASSE/BECS/Social_Cost_of_Carbon_Near_Term_Update/index.htm.

Nicholls, R.J., N. Marinova, J.A. Lowe, S. Brown, P. Vellinga, D. de Gusmão, J. Hinkel and R.S.J. Tol. 2011. Sea-level rise and its possible impacts given a 'beyond 4°C world' in the twenty-first century. *Phil. Trans. R. Soc. A* 369(1934): 161-181.

Nordhaus, W. 2014. Estimates of the Social Cost of Carbon: Concepts and Results from the DICE-2013R Model and Alternative Approaches. *Journal of the Association of Environmental and Resource Economists* 1(1/2): 273-312.

Nordhaus, W. 2010. Economic aspects of global warming in a post-Copenhagen environment. *Proceedings of the National Academy of Sciences* 107(26): 11721-11726.

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

Oppenheimer, M., M. Campos, R.Warren, J. Birkmann, G. Luber, B. O'Neill, and K. Takahashi, 2014: Emergent risks and key vulnerabilities. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1039-1099.

Pizer, W., M. Adler, J. Aldy, D. Anthoff, M. Cropper, K. Gillingham, M. Greenstone, B. Murray, R. Newell, R. Richels, A. Rowell, S. Waldhoff, and J. Wiener. 2014. Using and Improving the Social Cost of Carbon. *Science* 346: 1181–82.

Randall, D.A., R.A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R.J. Stouffer, A. Sumi and K.E. Taylor. 2007. Climate Models and Their Evaluation. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Appendix A

Table A1: Annual SC-CO_2 Values: 2010-2050 (2007$/metric ton CO_2)

Year	5% Average	**3% Average**	2.5% Average	High Impact (95th Pct at 3%)
2010	10	**31**	50	86
2011	11	**32**	51	90
2012	11	**33**	53	93
2013	11	**34**	54	97
2014	11	**35**	55	101
2015	11	**36**	56	105
2016	11	**38**	57	108
2017	11	**39**	59	112
2018	12	**40**	60	116
2019	12	**41**	61	120
2020	12	**42**	62	123
2021	12	**42**	63	126
2022	13	**43**	64	129
2023	13	**44**	65	132
2024	13	**45**	66	135
2025	14	**46**	68	138
2026	14	**47**	69	141
2027	15	**48**	70	143
2028	15	**49**	71	146
2029	15	**49**	72	149
2030	16	**50**	73	152
2031	16	**51**	74	155
2032	17	**52**	75	158
2033	17	**53**	76	161
2034	18	**54**	77	164
2035	18	**55**	78	168
2036	19	**56**	79	171
2037	19	**57**	81	174
2038	20	**58**	82	177
2039	20	**59**	83	180
2040	21	**60**	84	183
2041	21	**61**	85	186
2042	22	**61**	86	189
2043	22	**62**	87	192
2044	23	**63**	88	194
2045	23	**64**	89	197
2046	24	**65**	90	200
2047	24	**66**	92	203
2048	25	**67**	93	206
2049	25	**68**	94	209
2050	26	**69**	95	212

Table A2: 2020 Global SC-CO_2 Estimates at 2.5 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario[18]	PAGE									
IMAGE	6	10	15	26	55	123	133	313	493	949
MERGE Optimistic	4	6	8	15	32	75	79	188	304	621
MESSAGE	4	7	10	19	41	104	103	266	463	879
MiniCAM Base	5	8	12	21	45	102	108	255	412	835
5th Scenario	2	4	6	11	24	81	66	192	371	915
Scenario	DICE									
IMAGE	25	31	37	47	64	72	92	123	139	161
MERGE Optimistic	14	18	20	26	36	40	50	65	74	85
MESSAGE	20	24	28	37	51	58	71	95	109	221
MiniCAM Base	20	25	29	38	53	61	76	102	117	135
5th Scenario	17	22	25	33	45	52	65	91	106	126
Scenario	FUND									
IMAGE	-14	-2	4	15	31	39	55	86	107	157
MERGE Optimistic	-6	1	6	14	27	35	46	70	87	141
MESSAGE	-16	-5	1	11	24	31	43	67	83	126
MiniCAM Base	-7	2	7	16	32	39	55	83	103	158
5th Scenario	-29	-13	-6	4	16	21	32	53	69	103

Table A3: 2020 Global SC-CO_2 Estimates at 3 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	4	7	9	17	36	87	91	228	369	696
MERGE Optimistic	2	4	6	10	22	54	55	136	222	461
MESSAGE	3	5	7	13	28	72	71	188	316	614
MiniCAM Base	3	5	7	13	29	70	72	177	288	597
5th Scenario	1	3	4	7	16	55	46	130	252	632
Scenario	DICE									
IMAGE	16	21	24	32	43	48	60	79	90	102
MERGE Optimistic	10	13	15	19	25	28	35	44	50	58
MESSAGE	14	18	20	26	35	40	49	64	73	83
MiniCAM Base	13	17	20	26	35	39	49	65	73	85
5th Scenario	12	15	17	22	30	34	43	58	67	79
Scenario	FUND									
IMAGE	-13	-4	0	8	18	23	33	51	65	99
MERGE Optimistic	-7	-1	2	8	17	21	29	45	57	95
MESSAGE	-14	-6	-2	5	14	18	26	41	52	82
MiniCAM Base	-7	-1	3	9	19	23	33	50	63	101
5th Scenario	-22	-11	-6	1	8	11	18	31	40	62

[18] See 2010 TSD for a description of these scenarios.

Table A4: 2020 Global SC-CO_2 Estimates at 5 Percent Discount Rate (2007$/metric ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	1	2	2	4	10	27	26	68	118	234
MERGE Optimistic	1	1	2	3	6	17	17	43	72	146
MESSAGE	1	1	2	4	8	23	22	58	102	207
MiniCAM Base	1	1	2	3	8	20	20	52	90	182
5th Scenario	0	1	1	2	5	17	14	39	75	199
Scenario	DICE									
IMAGE	6	8	9	11	14	15	18	22	25	27
MERGE Optimistic	4	5	6	7	9	10	12	15	16	18
MESSAGE	6	7	8	10	12	13	16	20	22	25
MiniCAM Base	5	6	7	8	11	12	14	18	20	22
5th Scenario	5	6	6	8	10	11	14	17	19	21
Scenario	FUND									
IMAGE	-9	-5	-4	-1	2	3	6	10	14	24
MERGE Optimistic	-6	-4	-2	0	3	4	6	11	15	26
MESSAGE	-10	-6	-4	-1	1	2	5	9	12	21
MiniCAM Base	-7	-4	-2	0	3	4	6	11	14	25
5th Scenario	-11	-7	-5	-3	0	0	3	5	7	13

Table A5: Additional Summary Statistics of 2020 Global SC-CO_2 Estimates

Discount rate:	5.0%				3.0%				2.5%			
Statistic:	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis	Mean	Variance	Skewness	Kurtosis
DICE	12	26	2	15	38	409	3	24	57	1097	3	30
PAGE	21	1481	5	32	68	13712	4	22	97	26878	4	23
FUND	3	41	5	179	19	1452	-42	8727	33	6154	-73	14931

Appendix B

The November 2013 revision of this TSD is based on two corrections to the runs based on the FUND model. First, the potential dry land loss in the algorithm that estimates regional coastal protections was misspecified in the model's computer code. This correction is covered in an erratum to Anthoff and Tol (2013a) published in the same journal (*Climatic Change*) in October 2013 (Anthoff and Tol (2013b)). Second, the equilibrium climate sensitivity distribution was inadvertently specified as a truncated Gamma distribution (the default in FUND) as opposed to the truncated Roe and Baker distribution as was intended. The truncated Gamma distribution used in the FUND runs had approximately the same mean and upper truncation point, but lower variance and faster decay of the upper tail, as compared to the intended specification based on the Roe and Baker distribution. The difference between the original estimates reported in the May 2013 version of this TSD and this revision are generally one dollar or less.

The July 2015 revision of this TSD is based on two corrections. First, the DICE model had been run up to 2300 rather than through 2300, as was intended, thereby leaving out the marginal damages in the last year of the time horizon. Second, due to an indexing error, the results from the PAGE model were in 2008 U.S. dollars rather than 2007 U.S. dollars, as was intended. In the current revision, all models have been run through 2300, and all estimates are in 2007 U.S. dollars. On average the revised SC-CO_2 estimates are one dollar less than the mean SC-CO_2 estimates reported in the November 2013 version of this TSD. The difference between the 95th percentile estimates with a 3% discount rate is slightly larger, as those estimates are heavily influenced by results from the PAGE model.

The July 2016 revision provides additional discussion of uncertainty in response to recommendations from the National Academy of Sciences, Engineering, and Medicine. It does not revisit the IWG's 2010 methodological decisions or update the schedule of SC-CO_2 estimates presented in the July 2015 revision. The IWG is currently seeking external expert advice from the National Academies on the technical merits and challenges of potential approaches to future updates of the SC-CO_2 estimates presented in this TSD. To date, the Academies' committee has issued an interim report that recommended against a near-term update to the SC-CO_2 estimates, but included recommendations for enhancing the presentation and discussion of uncertainty around the current estimates. This revision includes additional information that the IWG determined was appropriate to respond to these recommendations. Specifically, the executive summary presents more information about the range of quantified uncertainty in the SC-CO_2 estimates (including a graphical representation of symmetric high and low values from the frequency distribution of SC-CO_2 estimates conditional on each discount rate), and a new section has also been added that provides a unified discussion of the various sources of uncertainty and how they were handled in estimating the SC-CO_2. Efforts to make the sources of uncertainty clear have also been enhanced with the addition of a new appendix that describes in more detail the uncertain parameters in both the FUND and PAGE models (Appendix C). Furthermore, the full set of SC-CO_2 modeling results, which have previously been available upon request, are now provided on the OMB website for easy access. The Academies' final report (expected in early 2017) will provide longer term recommendations for a more comprehensive update. For more information on the status of the Academies' process, see: http://sites.nationalacademies.org/DBASSE/BECS/CurrentProjects/DBASSE_167526.

Appendix C

This appendix provides a general overview of the parameters that are treated probabilistically in each of the three integrated assessment models the IWG used to estimate the SC-CO_2. In the DICE model the only uncertain parameter considered was the equilibrium climate sensitivity as defined by the probability distribution harmonized across the three models. By default, all of the other parameters in the model are defined by point estimates and these definitions were maintained by the IWG. In the FUND and PAGE models many of the parameters, beyond the equilibrium climate sensitivity, are defined by probability distributions in the default versions of the models. The IWG maintained these default assumptions and allowed these parameters to vary in the Monte Carlo simulations conducted with the FUND and PAGE models.

Default Uncertainty Assumptions in FUND

In the version of the FUND model used by the IWG (version 3.8.1) over 90 of the over 150 parameters in the model are defined by probability distributions instead of point estimates, and for 30 of those parameters the values vary across the model's 16 regions. This includes parameters related to the physical and economic components of the model. The default assumptions in the model include parameters whose probability distributions are based on the normal, Gamma, and triangular distributions. In most cases the distributions are truncated from above or below. The choice of distributions and parameterizations are based on the model developers' assessment of the scientific and economic literature. Complete information on the exact probability distributions specified for each uncertain parameter is provided through the model's documentation, input data, and source code, available at: http://www.fund-model.org/home.

The physical components of the model map emissions to atmospheric concentrations, then map those concentrations to radiative forcing, which is then mapped to changes in global mean temperature. Changes in temperature are then used to estimate sea level rise. The parameters treated probabilistically in these relationships may be grouped into three main categories: atmospheric lifetimes, speed of temperature response, and sea level rise. First, atmospheric concentrations are determined by one box models, that capture a single representative sink, for each of the three non-CO_2 GHGs and a five box model for CO_2, that represents the multiple sinks in the carbon cycle that operate on different time frames. In each of these boxes, the lifetime of additions to the atmospheric concentration in the box are treated as uncertain. Second, parameters associated with speed at which the climate responds to changes in radiative forcing are treated as uncertain. In the FUND model radiative forcing, R_t, is mapped to changes in global mean temperature, T_t, through

$$T_t = T_{t-1} + \frac{1}{\theta_1 + \theta_2 ECS + \theta_3 ECS^2}\left(\frac{\psi ECS}{\ln(2)} R_t - T_{1-t}\right),$$

where the probability distribution for the equilibrium climate sensitivity, ECS, was harmonized across the models as discussed in the 2010 TSD. The parameters θ_i define the speed at which the temperature anomaly responds to changes in radiative forcing and are treated as uncertain in the model. Third, sea level rise is treated as a mean reverting function, where the mean is determined as proportional to the current global mean temperature anomaly. Both this proportionality parameter and the rate of mean reversion in this relationship are treated as uncertain in the model.

The economic components of the model map changes in the physical components to monetized damages. To place the uncertain parameters of the model associated with mapping physical endpoints to damages in context, it is useful to consider the general form of the damage functions in the model. Many of the damage functions in the model have forms that are roughly comparable to

$$D_{r,t} = \alpha_r Y_{r,t} \beta_{r,t} \left(\frac{y_{r,t}}{y_{r,b}} \right)^{\gamma} \left(\frac{N_{r,t}}{N_{r,b}} \right)^{\phi} T_t^{\delta}, \quad (1)$$

where α_r is the damage at a 1 °C global mean temperature increase as a fraction of regional GDP, $Y_{r,t}$. The model considers numerous changes that may reduce a region's benchmark vulnerability to climate change. For example, γ represents the elasticity of damages with respect to changes in the region's GDP per capita, $y_{r,t}$, relative to a benchmark value, $y_{r,b}$; ϕ represents the elasticity of damages with respect to changes in the region's population, $N_{r,t}$, relative to a benchmark value, $N_{r,b}$; and the projection $\beta_{r,t}$ provides for an exogenous reduction in vulnerability (e.g., forecast energy efficiency improvements the affect space cooling costs). Once the benchmark damages have been scaled due to changes in vulnerability they are adjusted based on a non-linear scaling of the level of climate change forecast, using a power function with the exponent, δ.

Some damage categories have damage function specifications that differ from the example in (1). For example, agriculture and forestry damages take atmospheric concentrations of CO_2 and the rate of climate change into account in different forms, though the method by which they calculate the monetized impact in these cases is similar with respect to accounting for GDP growth and changes in vulnerability. In other cases the process by which damages are estimated is more complex. For example, in estimating damages from sea level rise the model considers explicit regional decision makers that choose levels of coastal protection in a given year based on a benefit-cost test. In estimating the damages from changes in cardiovascular mortality risk the model considers forecast changes in the proportion of the population over the age of 65 and deemed most vulnerable by the model developers. Other damage categories may also have functional forms that differ slightly from (1), but in general this form provides a useful framework for discussing the parameters for which the model developers have defined probability distributions as opposed to point estimates.

In many damage categories (e.g., sea level rise, water resources, biodiversity loss, agriculture and forestry, and space conditioning) the benchmark damages, α_r, are treated as uncertain parameters in the model and in most case they are assumed to vary by region. The elasticity of damages with respect to changes in regional GDP per capita, γ, and the elasticity with respect to changes in regional population, ϕ, are also treated as uncertain parameters in most damage functions in the model, though they are not assumed to vary across regions. In most cases the exponent, δ, on the power function that scales damages based on the forecast level of climate change are also treated as uncertain parameters, though they are not assumed to vary across regions in most cases.

Figure C1 presents results of an analysis from the developers of the FUND model that examines the uncertain parameters that have the greatest influence on estimates of the SC-CO_2 based on the default version of the model. While some of the modeling inputs are different for the SC-CO_2 estimates calculated by the IWG these parameters are likely to remain highly influential in the FUND modeling results.

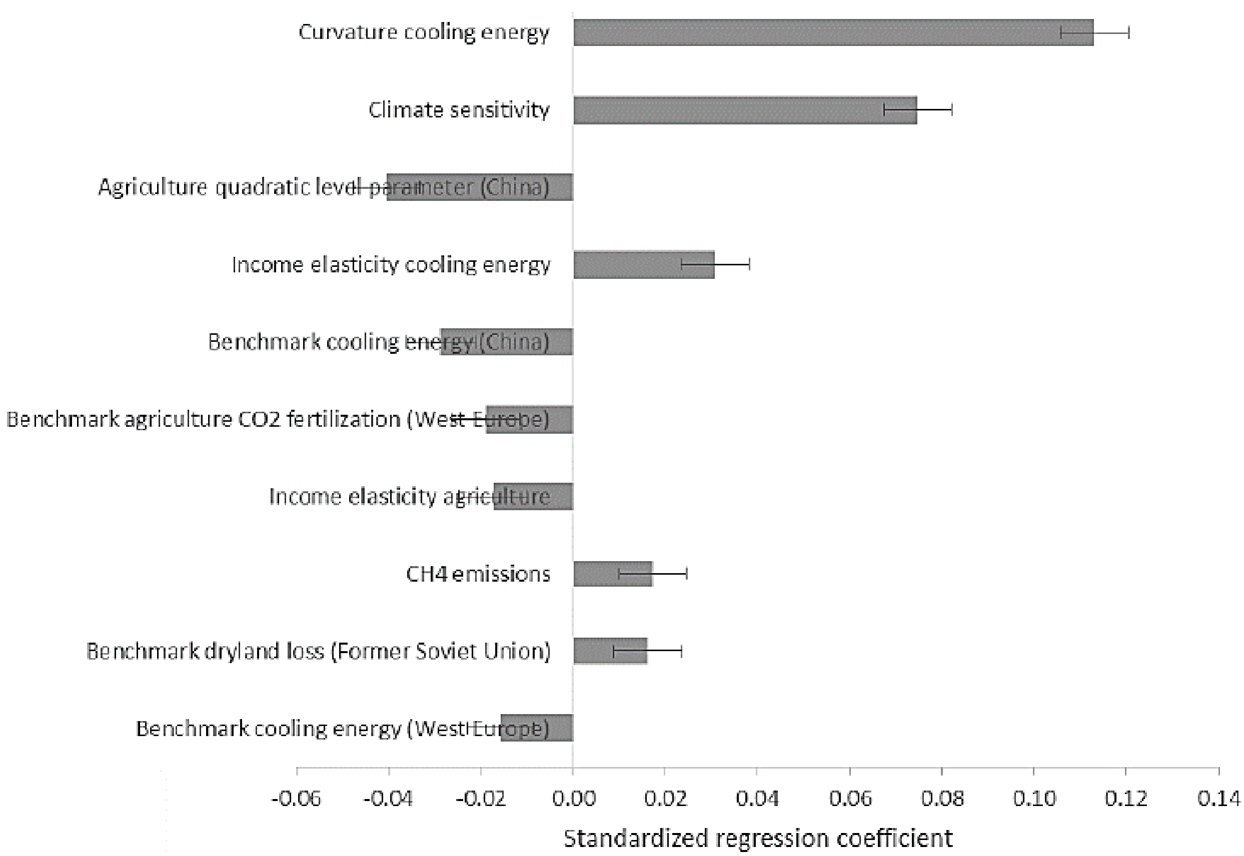


Figure C1: Influence of Key Uncertain Parameters in Default FUND Model (Anthoff and Tol 2013a)[19]

Default Uncertainty Assumptions in PAGE

In the version of the PAGE model used by the IWG (version PAGE09) there are over 40 parameters defined by probability distributions instead of point estimates.[20] The parameters can broadly be classified as related to climate science, damages, discontinuities, and adaptive and preventive costs. In the default version of the model, all of the parameters are modeled as triangular distributions except for the one variable related to the probability of a discontinuity occurring, with is represented by a uniform distribution. More detail on the model equations can be found in Hope (2006, 2011a) and the default minimum, mode, and maximum values for the parameters are provided in Appendix 2 of Hope (2011a). The calibration of these distributions is based on the developer's assessment of the IPCC's Fourth Assessment report and scientific articles referenced in Hope (2011a, 2011b, 2011c). The IWG added an uncertain parameter to the default model, specifically the equilibrium climate sensitivity parameter, which was harmonized across the models as discussed in the 2010 TSD.

In the climate component of the PAGE model, atmospheric CO_2 concentration is assumed to follow an initial rapid decay followed by an exponential decline to an equilibrium level. The parameters treated probabilistically in this decay are the proportion of the anthropogenic CO_2 emissions that enter the atmosphere, the half-life of the CO_2's atmospheric residence, and the fraction of cumulative emissions that ultimately remains in the atmosphere. A carbon cycle feedback is included to represent the impact of increasing temperatures on the role of the terrestrial biosphere and oceans in the carbon cycle. This feedback is modeled with probabilistic parameters representing the percentage increase in the CO_2 concentration anomaly and with an uncertain upper bound on this percentage.

The negative radiative forcing effect from sulfates is modeled with probabilistic parameters for the direct linear effect due to backscattering and the indirect logarithmic effect assumed for cloud interactions. The radiative forcing from CO_2, all other greenhouse gases, and sulfates are combined in a one box model to estimate the global mean temperature. Uncertainty in the global mean temperature response to change in radiative forcing is based on the uncertain equilibrium climate sensitivity parameter and uncertainty in the half-life of the global response to an increase in radiative forcing, which defines the inertia of the climate system in the model. Temperature anomalies in the model vary geographically, with larger increases over land and the poles. Probabilistic parameters are used for the ratios of the temperature anomaly over land relative to the ocean and the ratio of the temperature anomaly over the poles relative to the equator. The PAGE model also includes an explicit sea level component, modelled as a lagged function of the global mean temperature anomaly. The elements of this component that are treated

[19] Based on a coefficients of standardized regression of parameter draws on the SC-CO_2 using FUND 3.8.1 under Ramsey discounting with a pure rate of time preference of one percent and rate of relative risk aversion of 1.5. The 90 percent confidence intervals around the regression coefficients are presented as error bars.

[20] This appendix focuses on the parameters in the PAGE model related to estimating the climate impacts and principle calculation of the monetized damages. There are over 60 additional parameters in the model related to abatement and adaptation, which may be highly relevant for purposes other than estimating the SC-CO_2, but are not discussed here.

probabilistically include: sea level rise from preindustrial levels to levels in the year 2000, the asymptotic sea level rise expected with no temperature change, the predicted sea level rise experience with a temperature change, and the half-life of the sea level rise.

In the economic impacts module, damages are estimated for four categories: sea level rise, economic damages, non-economic damages, and damages from a discontinuity. Each damage category is calculated as a loss proportional to GDP. The model first calculates damages for a “focus region” (set to the European Union) assuming the region’s base year GDP per capita. Damages for other regions are assumed to be proportional to the focus region’s damage, represented by a regional weighting factor.

Economic damages, non-economic damages, and damages from sea level rise are modeled as polynomial functions of the temperature or sea level impact, which are defined as the regional temperature or sea level rise above a regional tolerable level. These functions are calibrated to damages at some reference level (e.g., damages at 3°C or damages for a ½ meter sea level rise). The specification allows for the possibility of “initial benefits” from small increases in regional temperature. The variables represented by a probability distributions in this specification are: the regional weighting factors; the initial benefits; the calibration point; the damages at the calibration point; and the exponent on the damage functions.

The damages from a discontinuity are treated differently from other damages in PAGE because the event either occurs or it does not in a given model simulation. In the PAGE model, the probability of a discontinuity is treated as a discrete event, where if it occurs, additional damages would be borne and therefore added to the other estimates of climate damages. Uncertain parameters related to this discontinuity include the threshold global mean temperature beyond which a discontinuity becomes possible and the increase in the probability of a discontinuity as the temperature anomaly continues to increase beyond this threshold. If the global mean temperature has exceeded the threshold for any time period in a model run, then the probability of a discontinuity occurring is assigned, otherwise the probability is set to zero. For each time period a uniform random variable is drawn and compared to this probability to determine if a discontinuity event has occurred in that simulation. The additional loss if a discontinuity does occur in a simulation is represented by an uncertain parameter and is multiplied by the uncertain regional weighting factor to obtain the regional effects.

Damages for each category in each region are adjusted to account for the region’s forecast GDP in a given model year to reflect differences in vulnerability based on the relative level of economic development. Specifically, the damage estimates are multiplied by a factor equal to the ratio of a region’s actual GDP per capita to the base year GDP per capita, where the ratio exponentiated with a value less than or equal to zero. The exponents vary across damage categories and in each case are treated as uncertain parameters.

Finally, in each region damages for each category are calculated sequentially (sea level rise, economic, non-economic, and discontinuity, in that order) and are assessed to ensure that they do not create total damages that exceed 100 percent of GDP for that region. Damages transition from a polynomial function to a logistic path once they exceed a certain proportion of remaining GDP, and the proportion where this transition begins is treated as uncertain. An additional parameter labeled the “statistical value of civilization," also treated as uncertain, caps total damages (including abatement and adaptation costs described below) at some maximum level.

Figure C2 presents results of an analysis from the developers of the PAGE model that examines the uncertain parameters that have the greatest influence on estimates of the SC-CO_2 based on the default version of the model. Although some of the modeling inputs are different for the SC-CO_2 estimates calculated by the IWG, these parameters are likely to remain highly influential in the PAGE modeling results.

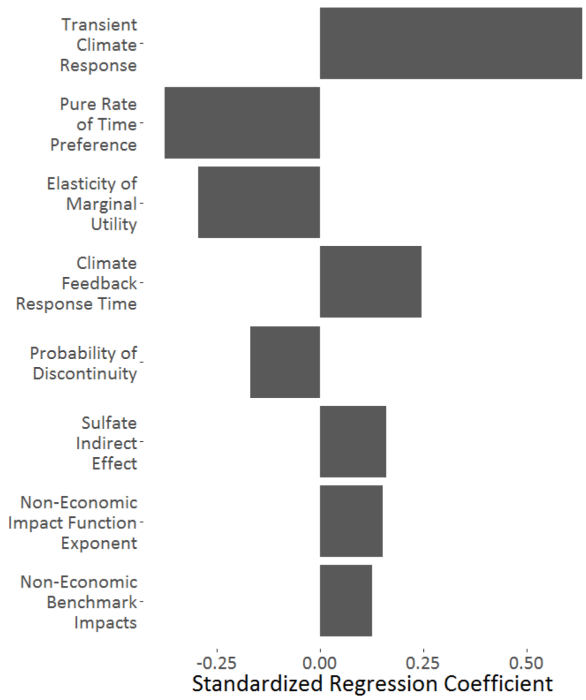


Figure C2: Influence of Key Uncertain Parameters in Default PAGE Model (Hope 2013)[21]

[21] Based on a standardized regression of the parameters. The values give the predicted increase in the SC-CO_2 in 2010 based on a one standard deviation increase in the coefficient, using the default parameters for PAGE09 under Ramsey discounting with an uncertain pure rate of time preference and rate of relative risk aversion.

Attachment 4

SOCIAL COST OF CARBON POLLUTION FACT SHEET

APRIL 2014

WHAT IS THE SOCIAL COST OF CARBON POLLUTION?

Scientists predict that climate change will lead, and in some cases has already led, to negative consequences such as the spread of disease, decreased food production, coastal destruction, and many more. The social cost of carbon pollution calculates the economic cost of these problems and estimates the damage done by each ton of carbon dioxide[1] that is spewed into the air. The current estimate is around $40.[2]

HOW IS THE SOCIAL COST OF CARBON POLLUTION USED?

The social cost of carbon pollution is used in official benefit-cost analyses of federal regulations that reduce greenhouse gas emissions. It allows us to compare the costs of limiting our pollution to the costs of climate change. In benefit-cost analyses, agencies use social cost of carbon pollution to measure the monetary benefits of regulations that reduce carbon emissions, and weigh them against the costs of the regulation.[3]

Decades of economic research have demonstrated that the "cost-free" behavior of using fossil fuels and emitting carbon dioxide has led to an over-reliance on fossil fuels. The social cost of carbon pollution removes that bias by accounting for the costs of pollution.

Many other nations use the social cost of carbon pollution (estimated independently from the U.S. number) or similar concepts in making regulatory decisions, including Canada, France, Germany, Mexico, Norway, and the United Kingdom. Some U.S. states also use the social cost of carbon pollution. Minnesota[4] recently used the U.S. social cost of carbon pollution to determine the value of solar energy.

Companies also use a cost of carbon pollution, but in a different way: the private sector considers climate change in financial planning. According to the London-based Carbon Disclosure Project (CDP), 29 companies based (or doing business) in the United States reported in 2013 that they use an internal price on carbon pollution in their financial planning to help weigh the risks and opportunities related to climate change.[5]

HOW IS THE SOCIAL COST OF CARBON POLLUTION ESTIMATED?

Economists estimate the social cost of carbon pollution by linking together a global climate model and a global economic model. The resulting models are called Integrated Assessment Models, or IAMs. This integration helps economists take a unit of carbon emissions (such as from driving a car or burning coal in a power plant) and translate that into an estimate of the cost of the impact that emissions have on our health, well-being, and quality of life in terms of dollars. The models are based on the best available science and economics from peer-reviewed publications.

The three most–cited models are William Nordhaus' **DICE model** (Yale University), Richard Tol's **FUND model** (Sussex University), and Chris Hope's **PAGE model** (Cambridge University).

In the United States:

President Obama formed the Interagency Working Group (IWG) on the Social Cost of Carbon in 2010 and again in 2013. To estimate the social cost of carbon pollution used in the United States, the IWG used: Nordhaus' DICE model, Tol's FUND model, and Hope's PAGE model.

The IWG made several slight changes to the models based on the most current economic and scientific literature. It then ran the three models using five different socio-economic and emission trajectories: four average (business as usual) trajectories and one best-case (optimistic) trajectory.[6] Averaging the results across the models and trajectories, the IWG produced four different social cost of carbon pollution estimates. All four are available for government agencies to use. The central estimate—around $40 for a unit of emissions in 2015—uses a 3 percent discount rate.

WHY ARE THERE MULTIPLE ESTIMATES?

The IWG produced four different social cost of carbon pollution estimates by using different discount rates. The discount rate is how economists measure the value of money over time—the tradeoff between what a dollar is worth today and what a dollar would be worth in the future.[7] Economists often measure the discount rate using various market interest rates, including the savings rate at your bank and the 30-year U.S. Treasury bond.

The current social cost of carbon pollution estimates for a unit of emissions in 2015 are $57, $37, and $11 using discount rates of 2.5 percent, 3 percent, and 5 percent, respectively. The fourth social cost of carbon pollution estimate of $109 uses a 3 percent discount rate and describes the 95th-percentile value for the social cost figure, in an attempt to capture the damages associated with extreme climatic outcomes. The estimate of $37, which uses a 3 percent discount rate, is considered the "central" estimate for a unit of emissions in 2015.[8] That $37 value is denoted in 2007 USD and equals around $40 in today's dollars.

The social cost of carbon pollution estimate decreases as the discount rate increases because a higher discount rate implies that people care less about future generations than they do about the present.

HOW ACCURATE IS THE SOCIAL COST OF CARBON POLLUTION?

The central social cost of carbon pollution estimate of around $40 is our best available estimate for now. Of course, there is uncertainty over the science and economics of climate change. This uncertainty is partly due to the complexity of the climate system, the imprecision of placing a monetary value on environmental services, the long-term time horizon over which climate change occurs, and the unprecedented rate of carbon emissions and level of carbon concentration that has entered the atmosphere since the industrial revolution. As science and economics improve and progress, this uncertainty will decline, but is unlikely to be eliminated.

IS THE SOCIAL COST OF CARBON POLLUTION UPDATED OVER TIME?

The U.S. government updates the social cost of carbon pollution estimates over time to account for new scientific and economic information. In 2013, the Interagency Working Group on the Social Cost of Carbon updated its 2010 estimates in line with updated versions of DICE, FUND, and PAGE. The IWG made no other changes to its modeling process between 2010 and 2013.

WHY DOES THE SOCIAL COST OF CARBON POLLUTION INCREASE OVER TIME?

As the effects of climate change intensify over time as more carbon fuels are used and more carbon is emitted, the social cost of carbon pollution increases. In this way, the cost of carbon pollution increases over time because the amount of carbon in the atmosphere increases over time. By 2050, the central estimate from the 2013 Interagency Working Group will be around $70.

DOES THE SOCIAL COST OF CARBON POLLUTION ESTIMATE CAPTURE ALL RELEVANT DAMAGES?

No. The models used by the Interagency Working Group on the Social Cost of Carbon omit several types of climate impacts; these omissions are often due to a lack of monetary damage estimates for many climate impacts to integrate into these underlying models Some of the omitted damages are the effects of climate change on fisheries; the effects of increased pest, disease, and fire pressures on agriculture and forests; and the effects of rising sea levels and resource scarcity due to migration. Additionally, these models omit the effects of climate change on economic growth and the rise in the future value of environmental services due to increased scarcity.

Although the models also fail to account for some climate benefits, omitted negative impacts are almost certainly to overwhelm omitted benefits. As a consequence, $40 should be interpreted as a lower-bound central estimate.

ARE THERE BENEFITS TO CARBON AND ARE THESE ACCOUNTED FOR?

Yes and yes. There are benefits to carbon and some of these benefits that are the result of climate change, such as potential increases in agricultural yields, are captured in the social cost of carbon pollution estimate; these benefits reduce the magnitude of the social cost of carbon pollution. Other benefits that are the result of climate change are omitted, including the lower cost of supplying renewable energy from wind and wave sources, the increased availability of oil due to higher temperatures in the Arctic, and fewer transportation delays from snow and ice are excluded. However, omitted negative impacts are almost certainly to overwhelm omitted benefits. As a consequence, $37 should be interpreted as a lower-bound central estimate.

The other benefits from the use of carbon fuels that are unrelated to climate change (such as economic output) are omitted from the social cost of carbon pollution, but they are *always* included in any analysis in which the social cost of carbon pollution is used. In a benefit-cost analysis, the cost of regulations, such as the potential loss of output, is always balanced against the benefits of carbon reductions as partially measured by the social cost of carbon pollution.

NOTES

1 There are many ways to measure a ton (2000 pounds) of carbon dioxide. In its simplest sense, a ton of carbon dioxide is the amount of carbon dioxide that the average U.S. car emits in 2 to 2.5 months. An important distinction is that, because carbon dioxide consists of carbon and oxygen, 3.67 tons of carbon dioxide is equivalent to 1 ton of carbon.

2 The precise, central value for a ton of carbon dioxide emitted in 2015 is $37, in 2007 USD (http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf).

3 In addition to considering the benefit of carbon reductions, benefit-cost analyses consider the cost of reduced use of carbon fuels, such as potential lost economic output and higher energy costs, which are not accounted for in the social cost of carbon pollution. Additionally, the social cost of carbon pollution includes the benefits from climate change. In this way, the costs of a regulation are always weighed against the social cost of carbon pollution and other regulatory benefits.

4 See: http://www.midwestenergynews.com/2014/03/12/minnesota-becomes-first-state-to-set-value-of-solar-tariff/

5 These companies include Microsoft, General Electric, Walt Disney, ConAgra Foods, Wells Fargo, DuPont, Duke Energy, Google, Delta Air Lines, Walmart, and PG&E. The Exxon Mobil Corporation uses $80 for a metric ton of CO2 emissions in 2040 (http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf); this exceeds the central U.S. SCC estimate for 2040.

6 A socio-economic and emission trajectory consists of specifying GDP, population, and greenhouse-gas-emission paths over time.

7 If offered $1 now or $1 in a year, almost everyone would choose to receive the $1 now. Most individuals would only wait until next year if they were offered more money in the future. The discount rate is how much more you would have to receive to wait until next year. Similarly, if individuals were asked to pay $1 now or $1 next year, most individuals would choose to pay $1 later. Most individuals would only pay now if they were asked to pay more money in the future. The discount rate is how much more you would have to pay in the future to be willing to pay $1 in the present.

8 $37 is considered the central estimate because it uses the central (i.e. middle) discount rate and is based on an average, rather than worse-than-expected, climate outcome; the average climate outcome is the standard assumption made by the IWG.

###

EDF ENVIRONMENTAL DEFENSE FUND Finding the ways that work

Institute *for* Policy Integrity *new york university school of law*

NRDC THE EARTH'S BEST DEFENSE

Attachment 5

B. BLM Must Quantify the Severity of Harm from Greenhouse Gas Emissions

1. Social Cost of Carbon Protocol

Research conducted by the National Research Council has confirmed that the negative impacts of energy generation from fossil fuels are not represented in the market price for such generation.[113] In other words, failing to internalize the externalities of energy generation from fossil fuels—such as the impacts to climate change and human health—has resulted in a market failure that requires government intervention. As aptly summarized by the White House Council of Economic Advisors in 2016:

> Climate change reflects a classic environmental externality. When consumers or producers emit greenhouse gases, they enjoy the benefits from the services provided by the use of the fuels, while not paying the costs of the damages from climate change. Since the price of goods and services whose production emits greenhouse gases does not reflect the economic damages associated with those gases, market forces result in a level of emissions that is too high from a social perspective. Such a market failure can be addressed by policy.[114]

Executive Order 12866 directs federal agencies to assess and quantify such costs and benefits of regulatory action, including the effects on factors such as the economy, environment, and public health and safety, among others. *See* Exec. Order No. 12866, 58 Fed. Reg. 51,735 (Sept. 30, 1993).[115] The Ninth Circuit has ruled that agencies must include the climate benefits of a significant regulatory action in federal cost-benefit analyses to comply with EO 12866.

> [T]he fact that climate change is largely a global phenomenon that includes actions that are outside of [the agency's] control ... does not release the agency from the duty of assessing the effects of its actions on global warming within the context of other actions that also affect global warming.

Ctr. for Biological Diversity v. Nat'l Highway Traffic Safety Admin., 538 F.3d 1172, 1217 (9th Cir. 2008) (quotations and citations omitted); *see also Border Power Plant Working Grp. v. U.S. Dep't of Energy*, 260 F. Supp. 2d 997, 1028-29 (S.D. Cal. 2003) (finding agency failure to disclose project's indirect carbon dioxide emissions violates NEPA).

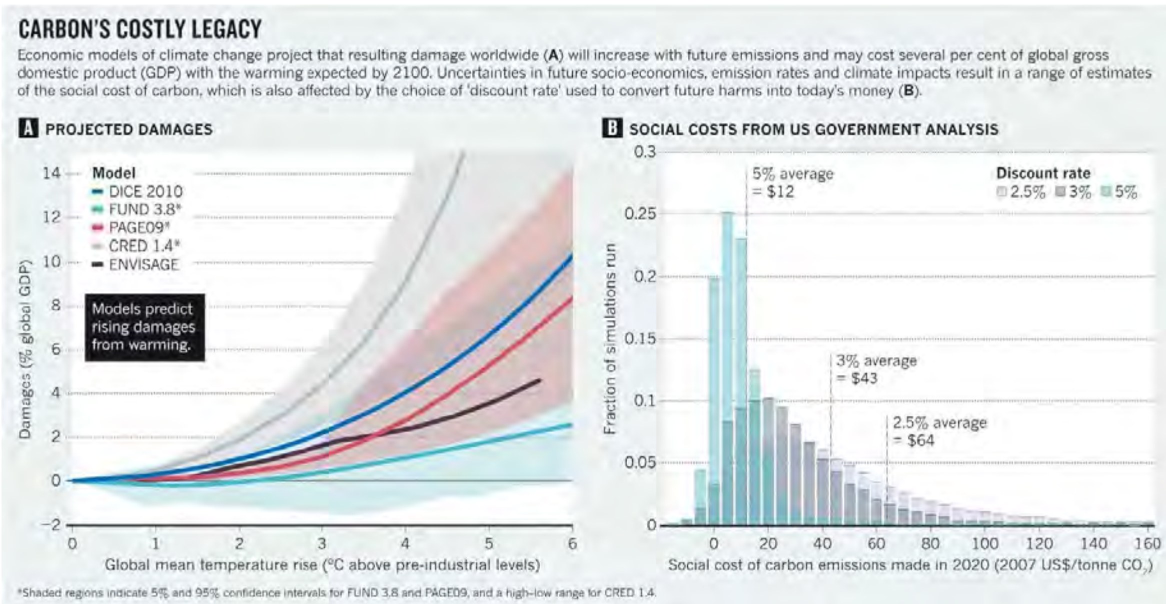
---

[113] *See, e.g.,* National Research Council, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* (2010) (attached as Exhibit 106); Nicholas Muller, et. al., *Environmental Accounting for Pollution in the United States Economy*, AMERICAN ECONOMIC REVIEW (Aug. 2011) (attached as Exhibit 107); *see also* Generation Investment Management, *Sustainable Capitalism,* (Jan. 2012) (attached as Exhibit 108) (advocating a paradigm shift to "a framework that seeks to maximize long-term economic value creation by reforming markets to address real needs while considering *all* costs and stakeholders.").

[114] White House Council of Economic Advisors, The Economic Record of the Obama Administration: Addressing Climate Change at 11 (Sept. 2016) (attached as Exhibit 37).

[115] *See also* Executive Order 13563, 76 Fed. Reg. 3821 (Jan. 18, 2011) (reaffirming the framework of EO 12866 and directing federal agencies to conduct regulatory actions based on the best available science).

In response, an Interagency Working Group ("IWG") was formed to develop a consistent and defensible estimate of the social cost of carbon—allowing agencies to "incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that impact cumulative global emissions."[116] In other words, SCC is a measure of the benefit of reducing greenhouse gas emissions now and thereby avoiding costs in the future.[117] The charts below depict, (A) dramatically increasing damages from global warming over time, as well as (B) the social cost of these carbon emissions based on 2013 TDS values.[118]



Leading economic models all point in the same direction: that climate change causes substantial economic harm, justifying immediate action to reduce emissions.[119] The interagency process to develop SCC estimates—originally described in the 2010 interagency technical support document ("TSD"), and updated in 2013 and 2015—developed four values based on the average SCC from three integrated assessment models (DICE, PAGE, and FUND), at discount rates of 2.5, 3, and 5 percent,[120] as well as a fourth value, which represents the 95th percentile

---

[116] *See* Interagency Working Group on the Social Cost of Carbon, United States Government, *Technical Support Document: Technical Update on the Social Cost of Carbon for Regulatory Impact Analysis – Under Executive Order 12866* (May 2013) at 2 (hereinafter 2013 TSD) (attached as Exhibit 109).
[117] *See* Ruth Greenspan and Dianne Callan, *More than Meets the Eye: The Social Cost of Carbon in U.S Climate Policy, in Plain English,* WORLD RESOURCES INSTITUTE (July 2011) (attached as Exhibit 110).
[118] *See* Richard Revesz, *et al., Global warming: Improve economic models of climate change,* NATURE 508, 173-175 (April 10, 2014) (attached as Exhibit 111).
[119] *See id.* at 174.
[120] The choice of which discount rate to apply—translating future costs into current dollars—is critical in calculating the social cost of carbon. The higher the discount rate, the less significant future costs become, which shifts a greater burden to future generations based on the notion that the world will be better able to make climate investments in the future. The underlying

SCC estimate across all three models at a 3 percent discount rate, and demonstrates the cost of worst-case impacts.[121] These models are intended to quantify damages, including health impacts, economic dislocation, agricultural changes, and other effects that climate change can impose on humanity. While these values are inherently speculative, a recent GAO report has confirmed the soundness of the methodology in which the IWG's SCC estimates were developed, therefore further underscoring the importance of integrating SCC analysis into the agency's decisionmaking process.[122] In fact, certain types of damages remain either unaccounted for or poorly quantified in IWG's estimates, suggesting that the SCC values are conservative and should be viewed as a lower bound.[123]

The updated interagency SCC estimates for 2020 are $12, $42, $62 and $123 per ton of CO_2 (in 2007$).[124] The IWG does not instruct federal agencies which discount rate to use, suggesting that the 3 percent discount rate ($42 per ton of CO_2) as the "central value," but further emphasizing "the importance and value of including all four SCC values[;]" i.e., that the agency should use the range of values in developing NEPA alternatives.[125]

In 2014, the district court for the District of Colorado faulted the Forest Service for failing to calculate the social cost of carbon, refusing to accept the agency's explanation that such a calculation was not feasible. *High Country Conservation Advocates v. U.S. Forest Service*, 52 F.Supp.3d 1174 (D.Colo. 2014) (a decision the agency decided not to appeal, thus implicitly recognizing the importance of incorporating a social cost of carbon analysis into NEPA decisionmaking). Notably, the *High Country Conservation Advocates* decision applies to the same geographic area (the North Fork Valley), and to the same coal field (the Somerset),

---

assumption of applying a higher discount rate is that the economy is continually growing. The IWG's "central value" of three percent is consistent with this school of thought—that successive generations will be increasingly wealthy and more able to carry the financial burden of climate impacts. "The difficultly with this argument is that, as climate change science becomes increasingly concerning, it becomes a weaker bet that future generations will be better off. If they are not, lower or negative discount rates are justified." WRI Report, at 9 (attached as Exhibit 110). "Three percent values an environmental cost or benefit occurring 25 years in the future at about half as much as the same benefit today." *Id.*

[121] *See* 2013 TSD at 2 (attached as Exhibit 109).

[122] GAO-14-663, *Social Cost of Carbon* (July 24, 2014).

[123] *See* Peter Howard, et al., *Omitted Damages: What's Missing From the Social Cost of Carbon*, ENVIRONMENTAL DEFENSE FUND, INSTITUTE FOR POLICY INTEGRITY, NATURAL RESOURCES DEFENSE COUNCIL (March 13, 2014) (attached as Exhibit 112) (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).

[124] *See* 2013 TSD (July 2015 Revision) at 3 (attached as Exhibit 109) (including a table of revised SCC estimates from 2010-2050). To put these figures in perspective, in 2009 the British government used a range of $41-$124 per ton of CO_2, with a central value of $85 (during the same period, the 2010 TSD used a central value of $21). WRI Report at 4 (attached as Exhibit 110). The UK analysis used very different assumptions on damages, including a much lower discount rate of 1.4%. The central value supports regulation four times a stringent as the U.S. central value. *Id.*

[125] *See* 2013 TSD at 12 (attached as Exhibit 109).

that is at issue here. In his decision, Judge Jackson identified the IWG's SCC protocol as a tool to "quantify a project's contribution to costs associated with global climate change." *Id.* at 1190.[126] To fulfill this mandate, they agency must disclose the "ecological[,] … economic, [and] social" impacts of the proposed action. 40 C.F.R. § 1508.8(b). Simple calculations applying the SCC to GHG emissions from this project offer a straightforward comparative basis for analyzing impacts, and identifying very significant costs.[127]

Notably, according to the IPCC, the 20-year GWP for methane—which is not only the planning lifespan of the RMP, but the relevant timeframe for consideration if we are to stem the worst of climate change—is 87.[128] BLM has historically used an outdated GWP when calculating methane's warming impact. The agency should avoid that temptation here, as it not only underestimates to relevant emissions and their impacts, but also near term benefits of avoiding this pollution.

CEQ provides that "[i]t is essential … that Federal agencies not rely on boilerplate text to avoid meaningful analysis, including consideration of alternatives or mitigation." *Id.* at 5-6 (citing 40 C.F.R. §§ 1500.2, 1502.2). Indeed, the EPA has also cautioned "against comparing GHG emissions associated with a single project to global GHG emission levels" because it erroneously leads to a conclusion that "on a global scale, emissions are not likely to change" as a result of the project.[129] Applying the SCC, as provided above, takes these abstract emissions and places them in concrete, economic terms. As noted by Judge Jackson, the SCC protocol provides a tool to quantify the costs of these emissions. *See High Country Conservation Advocates,* 52 F.Supp.3d at 1190. By failing to consider the costs of GHG emissions from the Proposed Action, the agency's analysis effectively assumes a price of carbon that is $0. *See id.* at 21 (holding that although there is a "wide range of estimates about the social cost of GHG emissions[,] neither the BLM's economist nor anyone else in the record appears to suggest the cost is as low as $0 per unit. Yet by deciding not to quantify the costs as all, the agencies effectively zeroed out the cost in its quantitative analysis."). The agency's failure to consider the SCC is arbitrary and capricious, and ignores the explicit directive of EO 12866.

An agency must "consider every significant aspect of the environmental impact of a proposed action." *Baltimore Gas & Elec. Co. v. Natural Resources Defense Council*, 462 U.S. 87, 107 (1983) (quotations and citation omitted). This includes the disclosure of direct, indirect, and cumulative impacts of its actions, including climate change impacts and emissions. 40 C.F.R.

[126] *See also id.* at 18 (noting the EPA recommendation to "explore other means to characterize the impact of GHG emissions, including an estimate of the 'social cost of carbon' associated with potential increases in GHG emissions.") (citing Sarah E. Light, *NEPA's Footprint: Information Disclosure as a Quasi-Carbon Tax on Agencies*, 87 Tul. L. Rev. 511, 546 (Feb. 2013)).

[127] It is important to note that, although the 2010 IWG SCC protocol did not address methane impacts, the 2013 IWG Technical Update explicitly addresses methane impacts. Thus, it is appropriate to calculate a SCC outcome that takes into account the full CO_2e emissions associated with the proposed leasing.

[128] *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, *Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis,* at 8-58 (Table 8.7) (Sept. 2013) (attached as Exhibit 113).

[129] *See* Light, 87 Tul. L. Rev. 511, 546.

§ 1508.25(c). The need to evaluate such impacts is bolstered by the fact that "[t]he harms associated with climate change are serious and well recognized," and environmental changes caused by climate change "have already inflicted significant harms" to many resources around the globe. *Massachusetts v. EPA*, 549 U.S. 497, 521 (2007); *see also id.* at 525 (recognizing "the enormity of the potential consequences associated with manmade climate change."). Among other things, the agency's analysis must disclose "the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity[,]" including the "energy requirements and conservation potential of various alternatives and mitigation measures." 42 U.S.C. § 4332(c); 40 C.F.R. § 1502.16(e). As explained by CEQ, this requires agencies to "analyze total energy costs, including possible hidden or indirect costs, and total energy benefits of proposed actions." 43 Fed. Red. 55,978, 55,984 (Nov. 29, 2978); *see also* Executive Order 13514, 74 Fed. Reg. 52,117 (Oct. 5, 2009) (requiring government agencies to disclose emissions information annually from direct and indirect activities). Failing to perform such analysis undermines the agency's decisionmaking process and the assumptions made.

Nor can the agency tout the benefits of coal, oil and gas development without similarly disclosing the costs. *See* 40 C.F.R. § 1502.23. For example, BLM identifies "tax impact from coal extraction in the planning area" as a benefit, with revenues "associated with the sales and income earned from extraction and transportation of coal." DEIS at 4-465. Although not quantified in the same way, BLM also assumes that "increased production of oil and gas on BLM-administered lands would result in a comparable increase in contributions to local counties and communities." *Id.* Accordingly, BLM relies on figures in Table 4-90 (Baseline Regional Economic Impacts for Coal), to suggest a substantial net economic benefit, including $556 million in annual output and $175 million in labor income. DEIS at 4-469. Setting aside that this economic data is based on wildly optimistic assumptions on future coal production and employment for 2,518 people—with a current reality of coal mines being shut down and present employment of around 250 people—this type of misleading and one-sided analysis is expressly forbidden under NEPA. *See Hughes River Watershed Conservancy v. Glickman*, 81 F.3d 437, 446-47 (4th Cir. 1996) ("it is essential that the EIS not be based on misleading economic assumptions); *Sierra Club v. Sigler,* 695 F.2d 957, 979 (5th Cir. 1983) (agency choosing to "trumpet" an action's benefits has a duty to disclose its costs).

2. Social Cost of Methane Protocol

In August 2016, the Interagency Working Group ("IWG") provided an update to the social cost of carbon technical support document,[130] and, for the first time, adopted a similar methodology for evaluating the climate impact of each additional ton of methane and nitrogen oxide emissions.[131] Given its recent endorsement by the IWG, BLM should use the social cost of

[130] Interagency Working Group, Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 (August 2016), (attached as Exhibit 324). The August 2016 update added some clarifying information around uncertainties in the modeling that supports the social cost of carbon, but did not adjust the damages values (the costs) published in the 2015 update.
[131] Interagency Working Group, Addendum to Technical Support Document on Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866: Application of the

methane to quantify the expected climate damage caused by the extraction and combustion of oil and gas extracted under BLM's Mancos RMPA.

Similar to the social cost of carbon, the social cost of methane provides a standard methodology that allows state and federal agencies to quantify the social benefits of reducing methane emissions through actions that have comparatively small impacts on cumulative global emission levels. The social cost of methane is intended to "offer a method for improving the analyses of regulatory actions that are projected to influence [methane or nitrogen oxide] emissions in a manner consistent with how [carbon dioxide] emission changes are valued."[132] Like the social cost of carbon, the social cost of methane is presented as a range of figures across four discount rates; it is based on results from three integrated assessment models; displayed in dollars per metric ton of emissions; and increases over time because emissions become more damaging as their atmospheric concentrations increase.[133] Like the social cost of carbon, the social cost of methane has been subject to peer review and will be updated by the IWG to ensure it reflects the best available scientific information.[134] The IWG estimates that each additional ton of methane emitted in 2020 will cause between $540 and $3,200 dollars (measured in $2007).[135]

BLM should use the best tools available to it in order to fully analyze and disclose the climate impacts of its proposal. Given that both the social cost of carbon and social cost of methane have been adopted by the IWG, which includes a dozen federal offices and agencies including the Department of Interior, BLM should use these tools to evaluate the climate impacts of its draft plan for the Uncompahgre planning area, which, as noted, anticipates generating more than half a billion tons of CO2-e over the next two decades.

****

C. *Expert Comments: Economic Scoping for the Mancos RMPA*

CONSERVATION ECONOMICS INSTITUTE, Dr. Evan E. Hjerpe, Executive Director, and Dr. Pete Morton, Advising Economist, prepared the following for Conservation Groups specifically for the Mancos RMPA and EIS:

CLIMATE CHANGE ECONOMICS AND FOSSIL FUEL DEVELOPMENT

The development of oil and gas fields on BLM lands provides both costs and benefits to society. The benefits to society include the fiscal benefits to national taxpayers via lease revenues and royalties paid to the U.S. treasury. The costs to society of fossil fuel development on public lands includes the cost of managing and administering oil and gas leases and a slew of social

---

Methodology to Estimate the Social Cost of Methane and the Social Cost of Nitrous Oxide (August 2016) (attached as Exhibit 325).

[132] *Id*. at 3.

[133] *Id*. at 7.

[134] *Id*. at 3.

[135] *Id*. at 7. For comparison purposes, the current social cost of carbon values for CO2 emissions in 2020 range from $120 to $123 per ton.

costs in terms of environmental and community damages. These economic damages (costs) include social costs associated with boom and bust natural resource extraction, but are heavily comprised of costs related to the pollution and community disruption generated by oil and gas development.

The pollution includes the release of greenhouse gases (GHGs), other volatile organic compounds (VOCs), particulates, degradation of plant and wildlife habitats, and potential acute pollution of water and surrounding environs associated with production and transportation failures. Communities are disrupted by increased traffic, noise, light pollution, and disruption of traditional religious practices. Pollution from oil and gas development is not contained on site. Rather, the pollution adversely affects the surrounding environments, regional environments, and in the case of greenhouse gases, extends globally. In economics jargon, pollution and community disruption are externalities. That is, most of the impacts are external to the production and consumer costs of oil and gas; it is not accounted for in the economic ledgers because it is passed on to other places and people over a period of time.

Externalities create market failures, where the private costs of oil and gas production on public lands (lease and production costs) do not cover the public, or social costs, of fossil fuel development (such as pollution). A.C. Pigou was one of the first economists to isolate and propose accounting for the social costs of externalities such as pollution in the 1920s and 1930s. Since Pigou, and entire field of environmental economics has been developed to account for externalities and to appropriately account for natural amenities. In environmental economics, pollution is characterized as a public "bad" resulting from "waste discharges" associated with the production of private goods.[136]

In cases of pollution and community disruption, as would happen under the proposed expansion of the Mancos Shale/Gallup Formation, the BLM should account for these externalities by estimating the social costs generated from the pollution and comparing them to the benefits of further oil and gas development. Social costs must be considered to whom all they apply. In regards to climate change and GHG emissions, these social costs must be considered locally, domestically, globally, and inter-temporally (future generations).

ACCOUNTING FOR CLIMATE CHANGE DAMAGES WITH THE SOCIAL COST OF CARBON

Emissions of GHGs are the primary cause of anthropogenic climate change. Released GHGs, and the resulting climate change, represents a special case of pollution both temporally and spatially. A number of pollutants, such as heavy metals and fine particulates, have a limited geographic scope of damage typically regional in nature. GHGs, on the other hand, mix with other GHGs in the atmosphere triggering global damages. Temporally, GHGs accumulate and cause climate change long into the future. That is, GHGs emitted today have both a marginal effect in the present and contribute to an increased total pollution effect for many years to come. The dispersed spatial and temporal effects of GHGs have led to specific accounting of their societal damages across the globe and for future generations. The concept of the Social Cost of

[136] Cropper, M. L., & Oates, W. E. (1992). Environmental economics: a survey. *Journal of economic literature*, *30*(2), 675-740.

Carbon (SCC) has been developed by inter-disciplinary biophysical and social scientists to properly account for the negative externalities generated by human activities that lead to climate change. The SCC was developed primarily for regulatory policy to help understand the monetary benefits of avoiding damages caused by releasing additional carbon dioxide into the atmosphere. These values are typically expressed as dollars per metric ton of carbon dioxide. The SCC utilizes integrated assessment models (IAMs) that combine climate science projections for the effect of increasing GHGs on temperatures, sea levels, and climate systems with projections of economic growth and emission controls. The models estimate climate damage functions, or the relationship between CO_2 emissions and the damage caused.[137] Damages include agricultural productivity losses, property damages, and human health effects. There are three primary IAMs (DICE, PAGE, and FUND) that allow for varying sensitivity analysis. The models are generally considered conservative as they have not included numerous other potential damages.

With the welfare of not only current generations, but future generations to come, at stake under escalating climate change scenarios, a contentious component of estimating the SCC (or SCM) is the concept of a discount rate. The discount rate devalues future costs and benefits as compared to current costs and benefits, often close to the long-term average rate of annual inflation (2-6%). As there is a societal preference, or time value, for $100 dollars today as opposed to next year, a discount rate attempts to account for this time preference when bringing future successive years of costs to a present value (PV). That is, the current society must place a value on economic damages caused by climate change to future generations in present dollars. The current generation must also choose whether or not they should pay for damages from current emissions. How far damages are projected into the future, and at what discount rate, have significant influence on the current (PV) value assigned to climate damages. The dramatic differences caused by varying discount rates can completely change the resulting SCC. A quick illustration:

- $1,000,000 of climate change damages in 50 years from now has a present value of $372,000 at a 2% discount rate, but only a present value of $34,000 at a 7% discount rate.

In the case of pollution and long term damages to the earth, some have called for very low discount rates. More equitable intergenerational valuation has been proposed by many, calling for discount rates of zero or approaching zero. Furthermore, a case can be made that costs and benefits related to the earth's natural capital (e.g., natural resources, ecosystems, and climatic/disturbance process) and the pollution/degradation of that natural capital should be assessed with very low discount rates. Critical planetary infrastructure should be devalued less than traditional financial investments. Turns out, they are not substitutes.

Most researchers recommend utilizing the global SCC for BCA in order to account for the externalities of our domestic emissions (e.g., Pizer et al. 2014, Greenstone et al. 2013, and Johnson and Hope 2012). However, a recent pub from Gayer and Viscusi (2016) make a compelling case for inclusion of a domestic SCC for US regulatory analysis in addition to the global SCC.

---

[137] Bell, R. G., & Callan, D. (2011). More than meets the eye: the social cost of carbon in US climate policy. *Environmental Law*.

For federal regulatory policy, benefit/cost analysis (BCA) is required for Regulatory Impact Analyses (RIA) and is often performed at the regional land management planning level for various alternatives under NEPA analysis. The SCC has been included in a number of federal rulemakings, including some BLM planning documents. However, given the role of fossil fuel development in climate change, it is critical that all planning associated with oil and gas development weigh the social costs of GHGs explicitly in land management planning. Only by fully accounting for reduced societal welfare due to climate change, can the Mancos RMPA examine the most economically efficient development strategy. For example, the most economically efficient alternative may very well be the "no-leasing" alternative, once market failures associated with pollution are fully internalized.

We recommend that the FFO conduct a full benefit/cost analysis that includes the SCC projected into the future. We suggest that the SCC be examined at both a global and domestic level, and that discount rates for the BCA include two levels, one at 3%, and one at the lower recommended discount rate for benefits and costs of critical natural capital changes (1%). We recommend using the 2020 estimates recommended for federal agency use by the IWG.
At the regional planning level, such as the Mancos RMPA, we recommend a further accounting of environmental and social damages resulting from oil and gas development pollution (in addition to the BCA proposed above). From the public's perspective, the benefits of a No-Leasing alternative can be viewed as damage avoided from pollution associated with oil and gas development alternatives. Natural resource damage assessments (NRDA) are an additional framework that can highlight potential damages resulting from pollution. NRDAs are measures of liability, or damage estimates to be paid to replace, offset, or mitigate lost economic values. The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), or Superfund, provided for liability of polluters of hazardous waste. The first legislation to identify injuries to natural resources as compensable damages was the Clean Water Act.[138] After these provisions were enacted, the federal government, states, and others filed legal claims to recoup damages from environmental contaminators and utilized natural resource damage assessments to estimate the value of the damages. The most publicized NRDA was conducted to determine compensation from damages from the Exxon Valdez oil spill to the Prince William Sound ecosystem in Alaska. These compensatory damages included lost use and passive use values to local and Native peoples.

While the FFO may not be able to fully quantify all regional aspects of environmental and social damages resulting from pollution, they can begin to provide a monitoring baseline for key pollutants and degradation that can be developed into overall damage functions. Similar to the damage functions estimated in the IAMs to determine the social costs of carbon, the FFO needs to catalog and quantify key pollutants and degradation stemming from action alternatives. Key categories needing monitoring and presentation to the public include all pollutants stemming from both the development of oil and gas and the eventual combustion of products extracted

[138] Kopp, R. J., & Smith, V. K. (2013). Valuing natural assets: the economics of natural resource damage assessment. Routledge.

from BLM lands, water use, air quality measures, seismic activity, and wildlife habitat fragmentation (more detail in section below).

The proposed baseline monitoring of pollutants and degradation can be initially qualitatively connected to regional economic damage functions, and eventually may be quantitatively estimated as damage functions. As previously noted, climate change is leading to greater drought conditions, wildfire risk, and decreased agricultural productivity in the Southwest. Regional BLM planning efforts cannot ignore the linkage between their leasing of oil and gas extraction to the immediate and surrounding climate change damages and other environmental and social costs.

As compared to further development alternatives from the FFO, a No Lease alternative would yield tremendous benefits in terms of the avoided impacts and resulting avoided social costs. Without a proper economic accounting of these damages, the BLM is unable to assess the economic efficiency of their land management alternatives. For Pareto efficiency gains, it is essential that firms pay not only the costs of their marginal damages, but also the total cost arising from their impacts.[139] If the free market cannot induce these payments, it is up to the BLM to ensure that these environmental damages are covered when leasing out public lands for fossil fuel extraction.

EXAMPLE BCA PARAMETERS FOR THE MANCOS RMPA

For our recommended BCA for the Mancos RMPA, we have reviewed some parameters related to SCC/SCM that will be helpful in conducting the BCA. The following parameters clearly indicate that incorporation of SCC in a BCA of the Mancos RMPA would have a significant effect on determining overall economic efficiency for different alternatives.
Based on GHG equivalencies,[140] the eventual combustion of one barrel of crude oil will produce .43 metric tons of CO_2. For one thousand cubic feet (mcf) of produced natural gas, .055 metric tons of CO_2 will be emitted.
Using the recommended "central value" of $42/metric ton of CO_2 stemming from the latest technical supporting document for the IWG's social cost of carbon (discussed above), we illustrate the economic efficiency effect of properly accounting for the climate change damages resulting from further approval of developing the Mancos Shale/Gallup Formation.
A SCC of $42 in current dollars, roughly translates into $18 of SCC per barrel of crude oil approved in the new Mancos RMPA, or:

- .43 metric tons of CO_2/barrel X $42 SCC = $18 of SCC/barrel of crude

A BCA for the FFO should compare public costs to public benefits. The benefits to the public and the U.S. Treasury include returned royalties of 12.5% per produced barrel of crude and

[139] Cropper, M. L., & Oates, W. E. (1992). Environmental economics: a survey. *Journal of economic literature*, *30*(2), 675-740.
[140] Available at: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

smaller amounts of bonus bids and rental rates.[141] Based on current prices of crude oil ($54/barrel),[142] the public royalty return on investment is:

- $54/barrel X .125 = $6.75 of royalty benefit to the public/barrel of crude

Under these price assumptions, the SCC of new oil production in the Mancos RMPA by itself is 267% greater than the royalty benefits. When including all the other social costs previously described, it is clear that the SCC + additional social costs far outweigh the benefits of further oil and gas expansion in the region.

For natural gas production it is even more dramatic. A SCC of $42 in current dollars, roughly translates into $2.30 per mcf of natural gas approved in the new Mancos RMPA, or:

- .055 metric tons of CO_2/mcf X $42 SCC = $2.30 of SCC/mcf of natural gas

The benefits of returned royalties at 12.5% of natural gas produced, at current gas prices around $3/mcf are:

- $3/mcf X .125 = $.38 of royalty benefit to the public/mcf of natural gas

Under current conditions, the SCC of new natural gas production considered in the Mancos RMPA by itself is 613%, or more than 6 times as great, as the natural gas royalty benefits. The parameters and simple illustrations reviewed above illustrate the importance of the BLM, and specifically the FFO, in accounting for the social costs of further oil and gas development on public lands. On the face of it, the social benefits of further oil and gas production in the Mancos Shale/Gallup Formation do not even come close to exceeding the social costs that will be incurred. Extrapolating these benefit/cost ratios to the potential production of some 1.5 billion barrels of crude oil and 2,000 new gas wells,[143] indicates that the social costs are billions of dollars greater in present value than the benefits of this production.

While there are range of SCC prices to be used, it should be noted that other industrialized nations, such as England, are using a SCC two times greater than the $42 used in this example.[144] Furthermore, the SCC only incorporates a portion of all social costs, and even only a portion of all climate change social costs. We further recommend an accounting of the social cost of methane, a GHG with 25 times the amount of warming power. In this region, a percentage of all natural gas developed is directly leaked into the atmosphere, estimated at 6% of gas production

---

[141] For example, royalties provided for more than 90% of federal onshore related oil and gas revenues in 2014. See, "Reported Revenues: Federal Onshore in All States for FY 2014 by Accounting Year." Office of Natural Resources Revenue.
[142] Current market prices for oil and gas are greater than the wellhead prices received and thus are an inflated measure of overall royalties returned to the public. We recommend the BLM utilize wellhead pricing and prices that reflect the true rate of royalty return.
[143] See the Reasonable Foreseeable Development (RFD) for Northern New Mexico final report, October 2014.
[144] *See* previous discussion of the Stern Review, etc.

in the San Juan Basin. This leakage, and the subsequent climate change damages, also needs to be included in the BCA.

Sensitivity analysis is recommend to model costs and benefits (and market prices) into the future. Additional estimates of fossil fuel combustion (and additional emitted metric tons of CO_2) that occur during extraction processes and during transportation of products should also be included.[145] Even the inclusion of a reduced domestic SCC would still indicate that the social costs are extremely high, and much greater than the zero price currently projected in the Mancos RMPA. Without proper accounting of social and environmental damages, the FFO planning process is skewed towards the promotion of oil and gas development.

IMPLEMENT FISCALLY RESPONSIBLE OIL AND NATURAL GAS DEVELOPMENT

The Trump Administration should be committed to implementing fiscally responsible oil and gas development on public land. Taxpayers expect economic efficiency and to receive fair market value for oil and gas resource developed on public land. Three significant issues related to fiscal responsibility include: 1) appraising fair market value and minimum bids for oil and gas lease sales based on quantities of oil and gas that is economically recoverable; 2) not offering leases for sale in places where the revenue and does not cover the costs to taxpayers or where natural gas waste is likely to occur; and 3) correctly estimating jobs and royalty revenue from proposed drilling based on economically recoverable resources. These issues should be addressed in the Mancos RMPA.

Implementing a fiscally responsible oil and natural gas development requires a quantitative understanding of the volume of oil and natural gas that can be extracted economically over a wide range of prices. Scientists use the concept of CO2 equivalent (CO2 –eq) to sum their climate change impacts. Estimates of economically recoverable resource can be converted CO2 equivalents (CO2 –eq) for use developing damage functions that provide an approximation of the social costs of carbon from extracting these resources. The revenues, benefits and jobs in local communities from planned oil and natural gas development in the planning area must also be based on quantities of oil and natural gas that are estimated to be economically recoverable based on a range of prices (Rose 2001, Morton and Kerkvliet 2014).[146]

Technically recoverable estimates of oil and gas are much larger than economically recoverable estimates because they ignore the economic and environmental costs from producing commercial quantities of oil and gas. Regardless of the technology chosen, technically recoverable oil and natural gas will not become an economically recoverable resource unless the market prices cover

---

[145] For example, GHG equivalencies for tanker trucks used to haul oil and gas are available.

[146] Rose, P. 2001. Risk Analysis and Management of Petroleum Exploration Ventures. AAPG Methods in Exploration Series, No 12. American Association of Petroleum Geologists. Morton, P. and J Kerkvliet, 2014. Redefining responsible oil and gas development. Presentation at University of Colorado, Center of the American West, FrackingSENSE Lecture Series, Boulder, CO. https://www.youtube.com/watch?v=KbSy_8KNjcY

the costs of extraction. The cost of extracting the oil or natural gas must be less than the market price in order to be economically recoverable (Morton et al. 2004).[147]

Economists may not agree on much but they do agree that you have to do the math. Continuing to rely on estimates of technically recoverable energy resources biases and distorts the RMP planning process in favor of oil and gas development -- because the economic costs of bringing the energy to market are not being considered. Relying on technically recoverable estimates will bias the RMP by exaggerating the local and regional jobs created and the royalty revenues estimated for oil and natural gas drilling proposals. We recommend that the BLM develop estimates of production from future leasing that may occur based on quantities of oil and gas that are economically recoverable.

A 2011 highly touted report from MIT included estimates of economically recoverable natural gas and indicates that at current wellhead prices less than half of our domestic technically recoverable natural gas is economically recoverable.[148] According to the MIT research, natural gas prices will have to increase dramatically – well past $30/MMBTU to recover all of the technically recoverable gas. Quite simply price matters. If current prices have to increase 8 to 10-fold in order to economically extract our nation's technically recoverable natural gas – taxpayers expect BLM planning to address this significant economic issue in planning documents.

We further recommend the BLM invest in a GIS mapping tools for estimating the volume of oil and gas that is economically recoverable projected to be produced in the future from additional leasing in the planning area. GIS methods using data from the USGS have been used to estimate undiscovered oil and gas by industry groups, government agencies, and environmental organizations (National Petroleum Council 1999, DOI-DOE-USGS 2003, 2006, 2008, Morton et al. 2002, LaTourrette, et al. 2002).[149]
Investing in a GIS based tool will help the BLM develop estimates of economically recoverable oil and natural gas -- which fully account for the market costs as well as the non-market

---

[147] Morton, P., C. Weller, J. Thomson, M. Haefele, and N. Culver. 2004. Drilling in the Rockies: How much and what cost? Special Energy Session of the 69th North American Wildlife and Natural Resources Conference, Spokane, WA. Wildlife Management Institute, Washington, DC.
[148] Massachusetts Institute of Technology, 2011. The Future of Natural Gas. An Interdisciplinary MIT Study.
[149] National Petroleum Council 1999. Natural Gas: Meeting the Challenges of the Nation's Growing Natural Gas Demand. U.S. Department of Interior and U.S. Department of Energy 2003, 2006, 2008. Scientific Inventory of Onshore Federal Lands' Oil and Gas Resources and Reserves and the Extent and Nature of Restrictions or Impediments to their Development. Phase 1, 2 and 3. Morton, P., C. Weller, and J. Thomson. 2002. Energy and Western Wildlands: A GIS analysis of Economically Recoverable Oil and Gas. The Wilderness Society, Washington, DC. LaTourrette, T., M. Bernstein, P. Holtberg, C. Pernin, B. Vollaard, M. Hanson, K. Anderson, and D. Knopman. 2002. Assessing Gas and Oil Resources in the Intermountain West: Review of Methods and Framework for a New Approach. RAND Science and Technology. Santa Monica, CA.

environmental costs (e.g. air and water pollution, loss of wildlife and bird habitat) from extracting and burning fossil fuels – for the basis of NEPA planning at the RMP level. LaTourrette, et al. 2002 in their economic analysis of oil and gas include GIS spatial data as proxies for non-market costs. Such an approach is worth building on.

Fiscally Responsible Leasing

The public expects to receive fair market value for oil and gas resources produced from public land. At the leasing level, implementing responsible oil and natural gas should take advantage of estimates of the volume of oil and natural gas that can be extracted economically to establish fair market value for taxpayers. Such information is critical for among other things, establishing the minimum bid for a lease sale. Estimating the economic value of oil and natural gas from a proposed lease area would make the BLM more consistent with how the U.S. Forest Service established fair market value and minimum bids for commercial timber sales. Taxpayers deserve no less.

The BLM continues to sell leasing rights for oil and gas based on per acre bids. In stark contrast, the USFS sells commercial timber based on an appraisal of the value of the millions of board feet being offered for sale – not the total acres within the sale boundary. We recommend the BLM follow the lead of the USFS and develop a more efficient appraisal process for estimating fair market value and setting minimum lease bids based on the estimated value of economically recoverable oil and gas covered by the lease.

We seriously question whether the current appraisal method of establishing minimum bids based on dollars per acre basis is fiscally responsible as it ignores the economic value of the good to be sold – which is the volume of oil and gas in the ground. Economics and fiscal prudence suggests that selling leasing rights based on estimates of the economically recoverable quantities of oil and gas underground is a more efficient appraisal method for setting minimum bids. We recommend the BLM begin appraising leases and establishing minimum bids based on estimates of the undiscovered economically recoverable oil and gas for a lease sale.

As part of this effort, we also recommend the BLM examine the benefits of a no-leasing alternative. A no new leasing alternative may lower BLM planning, leasing mitigation and enforcement cost in the short run as well as reclamation and monitoring costs in the long. A no new leasing alternative may be a more economically efficient alternative -- especially when non-market costs and budget constraints are considered (discussed below).

Eliminate Below Cost Lease Sales

Below cost timber sales – timber sales where the revenue was less than the cost to taxpayers -- were a huge issue for the Forest Service in the 1990s. The same fiscal arguments apply to the BLM setting minimum bids for oil and gas leasing sales below the cost to taxpayers of offering the lease for sale. When the BLM leases land for just $2 per acre – we question whether the revenue generated from that lease sale covers the BLM administrative costs of setting up the lease sale. Does $2 per acre even cover the social cost of carbon associated with the oil and gas covered by the lease? We doubt that $2 per acres covers the market and non-market costs associated with extracting and burning the oil and gas covered by the lease. A no more leasing alternative will by design directly eliminate future below cost lease sales and help mitigate climate change damages.

We question the fiscal responsibility of the BLM continuing to offer "below cost lease sales". Relevant questions that we recommend the BLM address is to estimate the administrative and oversight costs associated with offering oil and gas leases for sale. For the planning area, how much does BLM spend when it offers oil and gas leases for sale? Does the revenue from each oil and gas lease sale cover the cost to taxpayers of setting up and administering each lease sale? To the extent does below cost leasing occurs in the planning area, it represents an implicit subsidy that costs taxpayers and undercuts investors in oil and gas on private land. The BLM by offering "below cost leasing" – is distorting the energy markets and not providing taxpayers with a fair return on their resources.

We recommend that the BLM examine the potential for below cost leasing in the planning area by developing a predictive model for estimating where leases with low bids tend to occur. Do lease parcels that the receive $2 per acre bids tend to occur in wild areas far from roads? A well-designed regression model is one approach for examining where and how often below cost leasing occurs. The regression model would be analogous to the "transaction evidence approach" developed by the U.S. Forest Service for appraising the fair market value of timber. In addition to a goal of identifying and eliminating below cost leases, the predictive model could also be used to establish the fair market value of the oil and gas to be leased and for setting minimum bids of those leases.

We also recommend that the BLM eliminate lease sales where the public costs are greater than the public benefits. Again, one possibility is to develop a predictive model that includes spatial consideration of non-markets benefits and costs similar to the one developed by LaTourrette, et al. 2002.[150] The model could be linked to a benefit cost analysis which fully accounts for the social cost of carbon and methane as well as other non-market costs and benefits is needed to address this issue. As discussed above, estimates of economically recoverable oil and gas for a proposed leases sale can be converted to CO2 equivalents (CO2 –eq) for use in provide an approximation of the social costs of offering the proposed lease for sale. Leases should not be sold at a price less than the social costs of carbon associated with the oil and gas estimated to be under the lease.

Account for Community Concerns and Potential for Disruption

Since 2001, when the domestic drilling boom began, more than 400,000 oil and gas wells have been drilled on U.S. public and private land. In retrospect, the current drilling boom, like past drilling booms, was not done in a thoughtful way and caused more damage to communities and the environment than necessary. As has happened in earlier busts, rural towns that overbuilt

[150] LaTourrette, T., M. Bernstein, P. Holtberg, C. Pernin, B. Vollaard, M. Hanson, K. Anderson, and D. Knopman. 2002. Assessing Gas and Oil Resources in the Intermountain West: Review of Methods and Framework for a New Approach. RAND Science and Technology. Santa Monica, CA.

their infrastructure during the boom are now in fiscal trouble. Williston, North Dakota for example, took on $215 million in debt to build infrastructure, including a sewer plant and recreation center for the growing population (Healy 2016).[151] As quoted in Healy (2016), Nancy Hodur a research assistant professor at North Dakota State University stated the following - "Those communities out there were drinking out of a fire hose…A lot of those communities would come right out and say that pace of growth isn't good, isn't sustainable."

Quantifying and understanding the direct, indirect and cumulative effects from the recent drilling boom is key information for successfully implementing responsible oil and gas program in the future. We recommend the BLM quantitatively review economic and environmental data for local communities associated with the recent drilling boom and bust. We recommend the BLM use the planning process to look back and gain an understanding of lessons learned by communities from the extended domestic oil and gas drilling boom.

Economic Development is Different than Economic Impacts

Short term job creation from an oil and gas drilling boom must be balanced with the longer-term perspective represented in economic development plans. Economic development is concerned with an improved standard of living and a diverse economy that can weather downturns in any particular industrial sector. Economic development is concerned with the long-term health of communities and regions. A healthy community includes a diverse economy, public facilities and services, a higher and equitable standard of living, and a clean environment. In contrast, the economic impact is a short-term measure of the jobs created from plans for developing oil and gas resources.

Economic development and healthy communities involve other economic criteria that are not included when estimating economic impact in terms of job creation. Unfortunately, decision-makers and the general public remain unaware of the limitations of economic impact studies and as a result the results are often misunderstood and misused by decision-makers.
The IMPLAN model is a commonly tool used by economists to estimate the jobs associated with oil and gas development as part of an economic impact analysis. The IMPLAN model is typically used to estimate the direct, indirect and induced jobs generated from marginal changes in investments and public policies. Direct jobs are created by direct hiring to perform the activity (i.e. drilling); indirect are jobs created by spending to support the work of direct jobs (e.g. pipe used by drillers to drill wells); and induced are jobs created when direct and indirect job holders spend their wages. So, jobs in the drilling pipe industry are indirect jobs, while bar and restaurant workers are induced jobs.

When reviewing the results of economic impact analysis, it is important to examine the short terms job creation from oil and gas drilling within the context of longer term community plans for sustainable economic development.

---

[151] J. Healy, 2016. Built Up by Oil Boom, North Dakota Now Has an Emptier Feeling http://www.nytimes.com/2016/02/08/us/built-up-by-oil-boom-north-dakota-now-has-an-emptier-feeling.html?_r=0

Short Term Economic Disruption

In the short term, drilling booms produce the "crowding out effect". Crowding out" can negatively affect agriculture, recreation and tourism, and hunting and fishing business. Higher housing costs, labor competition, air and water pollution can make the resource dependent regions less attractive to other industries than alternative locations. The potential for crowding out and economic displacement has implications for the choices faced by community leaders in distinguishing between short term economic impacts and longer term plans for sustainable development. If the pace and scale of development exceeds the assimilative socio-economic capacity of a county or community, businesses and residents can suffer economically. As pace and scale increase, there will be tradeoffs and non-compatibility issues which can lead to slower net job growth due to economic displacement.

In addition to job creation, the fiscal health of communities is also an issue with oil and gas development. As the scale of the drilling boom for oil and natural gas increases communities experienced an increase in traffic and crime that overwhelmed the assimilative capacity (e.g. roads, wastewater treatment facilities, enforcement staff) and budgets of communities and counties for handling these problems.

Local governments – counties and communities – are subjected to a wide range of demands for new services, staff, equipment, and expertise that impacts budgets. The additional the fiscal costs to local taxpayers from oil and natural gas development include land use planning, hiring additional expertise (i.e. legal counsel, oil and natural gas coordinator, community outreach, inspectors) purchasing monitoring equipment (i.e. infrared camera for emission detection), administration, oversight and inspection, the equipment for and training of emergency services so they are prepared for the kind of fire, accident, or spill incidents associated with drilling operations can produce. Public Health departments must be prepared to receive and respond to incident reports and citizen concerns about environmental health issues

Boxall et al (2005) also found that property values are negatively correlated with the number of gas wells.[152] The study's mean estimates indicate that when residential properties are within 4 km (about 2.5 miles) of oil and gas facilities, property values decline 4-8 percent. The impact can easily be twice that depending upon the level and composition of the nearby industry activities. Any decline in property values may result in a long term drop in tax revenue.

Long Term Economic Disruption

IMPLAN is a tool for estimating jobs in the short run but does not consider fiscal costs from these jobs nor the crowding out effect or business displacement or community disruption. The IMPLAN model also does not consider the long term economic costs associated boom and bust cycles and the resource curse.

---

[152] Boxall, P.C., W.H. Chan, M.L. McMillan. 2005.The impact of oil and natural gas facilities on rural residential property values: a spatial hedonic analysis. Resource and Energy Economics. 27: 248-269.

Natural resource extraction, including energy development – oil and gas drilling and mining – when properly managed can provide economic opportunities for resource producing regions. But an established and growing body of research indicates that countries, states and communities that are dependent on natural resource extraction suffer socio-economically.

Boom and bust cycles are a longstanding historic challenge for communities impacted by oil and natural gas drilling and production. While energy development can benefit communities, historically drilling booms bring an influx of non-local workers, a rise in crime and emergency service calls, increased demand for public services, more wear and tear on local infrastructure, and upward pressure on local wages and housing costs. Local governments need to provide basic services for a rapidly growing population, along with increased per capita service demand, resulting in fiscal burdens for taxpayers.

Economic theory suggests that an abundance of natural resources should promote economic growth by providing economies with ''natural capital.'' However, many academic studies have found that economies relying heavily on natural resource extraction are poor performers in terms of growing income, decreasing poverty, and improving lives. This poor performance has become known as the "resource curse". Avoiding the resource curse is a worthy goal for responsible oil and natural gas development.

Recent studies comparing U.S. states and counties find convincing evidence of a resource curse. Papyrakis and Gerlagh (2007) found that all twelve states with more than 5% of state earnings derived from the resource sector experienced negative economic growth during the 1980–1995 period.[153] James and Aadland (2011) found that a typical resource rich county whose economy was 20 percent dependent on resource extraction experienced slower per capital income growth compared to a county with 5 percent dependency.[154] James and Audland (2011) conclude "Although the resource curse appears to be waning over the sample period 1980–2005, it is always negative and statistically significant. The coefficient estimates imply sizable differences in standards of living if one extrapolates the annual growth differences to future generations." The strong evidence of boom and bust cycles and the resources curse shows that energy development is not a panacea. Instead it is a risky business that must be done wisely. If done irresponsibly, energy development threatens the economic health of local communities.

IMPLEMENT PHASED ENERGY DEVELOPMENT TO REDUCE COMMUNITY DISRUPTION

Phased energy development – which involves regulating the pace and scale of leasing and development – provides a cost-effective approach for managing fiscal and environmental risk

[153] Papyrakis, E. and R. Gerlagh. 2007. Resource abundance and economic growth in the United States. European Economic Review. 51: 1011-1039.

[154] James, A. and D. Aadland. 2011. The curse of natural resources: an empirical investigation of U.S. counties. Resources and Energy Economics. 33: 440-453.

(Haefele and Morton 2009).[155] Pace and scale are regulated because they are key variables for reducing and internalizing the externalized damages; managing risk; mitigating boom and bust cycles; and avoiding the resource curse.

A reduced pace will moderate the deluge of energy wealth and the hyperactivity that disrupts normal patterns of business and government. Regulating the pace of drilling is a fiscally and economically sound approach to oil and natural gas development. Slowing the pace and spreading drilling over years or even decades means there will be producing wells in the area for a longer time period, while reducing the dramatic spike in drilling peak in the earlier years. Many of the problems associated with the recent drilling boom in the Rockies are either caused by or exacerbated by the large scale and rapid pace of development (Haefele and Morton 2009). Slowing the pace and scale or oil and natural gas development can help reduce these problems by staying within the assimilative capacity of a community.

A reduced pace will promote carefully considered regulations that allow energy extraction to proceed with less environmental damage. In this regard, a no new leasing alternative can help slow the pace and scale of disruption and displacement in the short run and promote more sustainable economic development and healthier communities in the long run.

ESTIMATE NET FISCAL IMPACTS

Conventional wisdom assumes the net fiscal impacts are positive because of the millions in tax revenue reported. But the revenue reports based on royalties represent only gross revenues. Businesses survive or go broke based on the net revenues from the sale of goods and services. Estimated of gross revenue do not measure profit or the success of a business because they exclude the costs of doing business. Unfortunately, government estimates of oil and natural gas revenue leave out the fiscal and environmental costs of doing business – and therefore only report gross revenues.

Generating oil and natural gas revenues is not a cost-free endeavor – especially for impacted communities. Unfortunately, economic impact analysis does not consider the cumulative fiscal costs associated with oil and gas development. What has been missing from the economic conversation and fiscal calculus are the cumulative costs to taxpayers associated with collecting the gross revenue (i.e. proper oversight, frequent inspections, increased road maintenance costs, declining property value change, etc.). We recommend a new fiscal focus on estimating the net revenues that accrue from oil and natural gas development.

NONMARKET VALUE CONSIDERATIONS

The BLM must evaluate its oil and gas program within the context of the agency's larger legislative mission as steward of America's public land. One of the most important purposes of

[155] Haefele, M. and P. Morton. 2010. The Influence of the Pace and Scale of Energy Development on Communities: Lessons from the Natural Gas Drilling Boom in the Rocky Mountains, Western Economics Forum Vol. VIII, No. 2.

public lands, including BLM lands, is the provision of non-market public goods such as opportunities for solitude, outdoor recreation, clean air, clean water, biodiversity, and the preservation of wilderness and other undeveloped areas that would be underprovided if left entirely to market forces (Loomis 1993).[156] It is incumbent upon the BLM, as the administering body for oil and gas leasing of public lands, to provide for greater accounting of non-market social and environmental costs as well as greater transparency of the processes used to make these calculations.

The Federal Land Policy and Management Act (FLPMA) specifically incorporates such non-market resources as "the long-term needs of future generations" for recreation and "natural scenic, scientific and historical values" into the BLM's multiple use mandate.[157] FLPMA further defines multiple use to require the agency to encompass non-market values into management, directing the BLM to achieve:

> **harmonious** and coordinated management of the various resources without permanent impairment of the productivity of the land and the **quality of the environment** with consideration being given to the relative values of the resources and **not necessarily to the combination of uses that will give the greatest economic return** or the greatest unit output.[158] (emphasis added).

The Trump Administration should be committed to an oil and gas program grounded in stewardship of public land and one that holds oil and gas companies to the highest standard of fiscal and environmental responsibility. To accomplish this goal, the BLM should consider fully and carefully balancing the benefits of oil and gas production with the environmental costs of oil and gas exploration, production, and remediation. While increasing returns to the Treasury and increasing efficiency of oil and gas management are laudable goals, we also know that extracting and burning oil and natural gas has significant social and environmental costs.

Strategically in 2013, the BLM issued guidance for considering nonmarket environmental costs when preparing NEPA analyses for BLM resource management planning and other decision-making. From the document (BLM 2013):

> All BLM managers and staff are directed to utilize estimates of nonmarket environmental values in NEPA analysis supporting planning and other decision-making where relevant and feasible, in accordance with the attached guidance…The use of quantitative valuation methods should contribute to the analysis of one or more issues to be addressed in the environmental analysis supporting planning or other decision-making. A quantitative analysis of

---

[156] Loomis, J. B. 1993. Integrated Public Lands Management: Principles and Applications to National Forests, Parks, Wildlife Refuges, and BLM Lands. First Edition. Columbia University Press: New York, NY.
[157] 43 U.S.C. § 1702(c).
[158] Id.

> nonmarket values in EIS-level NEPA analyses is strongly encouraged where one or more of the criteria described in the attached guidance apply.[159]

As discussed above, we recommend that the BLM use this guidance to internalize the negative externalities by developing multiple damage functions associated with the social cost of carbon and other non-market costs associated with oil and gas production from public land. The table below provides a comprehensive framework that combines distributional impacts (i.e. jobs) with a total economic valuation of the local and regional damages associated with oil and natural gas extraction.[160] Estimating the local and regional damage functions included in this framework would provide valuable local information to inform and supplement the macro-level damage functions currently used in integrated climate assessment models.

Comprehensive Economic Framework: Jobs and Total Economic Damages from Oil and Natural Gas Development that Spillover into our Communities and Environment

Cost Category	Description of Cost	Methods for Estimating Cost
Direct Use Costs	Displacement or loss of land for habitat, recreation opportunities, hunting, farmland, grazing, reclamation costs, water quantity and drought.	Travel cost method, contingent valuation surveys.
Community Concerns	NOx, VOCs, ozone and kids' health, noise pollution, truck traffic and infrastructure costs, property values, loss of local control, displaced jobs and revenues due to "crowding out", natural amenities and quality of life issues, loss of retirement income, displaced farming due to competition for water, boom-bust cycles, revenue lag and fiscal risks, water treatment plants and recycled fracking water, draining of reservoirs for fracking water and the loss of fishing and recreation revenue.	Surveys of residents and businesses. Averting expenditure methods for estimating the costs of mitigating health and noise impacts. Change in recreation visitation, expenditures and business income. Documented migration patterns.
Science Benefits Foregone	Loss of natural areas for scientific study as an experimental control for adaptive ecosystem management.	Change in management costs, loss of information from natural studies foregone.

[159] U.S. Department of the Interior, Bureau of Land Management, 2013. Guidance on Estimating Nonmarket Environmental Values. Instruction Memorandum No. 2013-131, Change 1. http://www.blm.gov/wo/st/en/info/regulations/Instruction_Memos_and_Bulletins/national_instruction/2013/IM_2013-131__Ch1.print.html

[160] Morton, P., C. Weller, J. Thomson, M. Haefele, and N. Culver. 2004. Drilling in the Rockies: How much and what cost? Special Energy Session of the 69th North American Wildlife and Natural Resources Conference, Spokane, WA. Wildlife Management Institute, Washington, DC. 33 pages.

Comprehensive Economic Framework: Jobs and Total Economic Damages from Oil and Natural Gas Development that Spillover into our Communities and Environment		
Cost Category	**Description of Cost**	**Methods for Estimating Cost**
Off-site Damages	Fugitive methane emissions, water pollution from spills, noise pollution from compressor stations, visual impacts, erosion from well pads and roads, pipeline explosion risks, road dust on petroglyphs and snowpack, seismic activity from injection wells, decline in property values.	Contingent valuation surveys, hedonic pricing analysis of property values, preventative expenditures, well replacement costs, restoration and environmental mitigation costs.
Biodiversity Impacts	Loss and fragmentation of wildlife habitat by roads and well pads, pipelines are conduits for invasive weeds, endocrine disrupter's impact amphibians and fish, produced water holding ponds and bird deaths, noise impacts on wildlife species.	Replacement costs, restoration and environmental mitigation costs.
Ecosystem Services Lost or Compromised	Water lost from fracking, impacts to aquifer re-charge and wetland function, carbon lost via land use change, fossil fuels and climate change, decline in net primary productivity.	Change in productivity, replacement costs, increased water treatment costs for cities, preventative expenditures.
Passive Use Benefits Foregone	Loss of option, bequest and existence benefits generated by open spaces, parks, and wildlands.	Contingent valuation surveys, opportunity costs of not utilizing future information about the health, safety, and environmental impacts of oil and natural gas drilling.

Source: Adapted from Morton, P., et al. (2004). Drilling in the Rockies: How Much and at What Cost? Proceedings of a Special Energy Session of the 69th North American Wildlife and Natural Resources Conference, Spokane, WA. Wildlife Management Institute

ESTIMATE LOCAL AND REGIONAL DAMAGE FUNCTIONS

Integrated assessment models estimate global climate change damage functions based on increasing CO2 emissions. A goal of integrated assessment models (IAMs) is to estimate the economic efficiency of climate change policies in the context of a cost-benefit analysis. IAMs use mathematical relationships between economic activity and GHG emissions. Climate damage functions subsequently estimate the relationship between CO2 emissions and the global damage caused, in order to approximate how future damages might be reduced if CO2 emissions were also reduced.

In addition to global damage functions, local and regional damage functions should be developed to account for the damages that occur in oil and gas producing regions. We recommend the BLM identify relevant variables and methods appropriate for developing damage functions for use in regional BLM planning of oil and gas fuel development. Local and regional damage functions can be developed per unit of production (per barrel of oil and per mcf of gas) and for oil and gas development itself. Damage functions can also be estimated on per well basis, for each compressor station, waste pit and storage tank – and linked to an economic model for use in the benefit-cost analysis.

An example of a regional damage function from oil and gas development is the potential damage from earthquakes associated with the underground injection and disposal of waste water from oil and gas development. IAMs include monetary damages functions for floods and droughts – but not for earthquakes. Damage functions for increase regional seismic activity from underground injection could be developed using methods similar to those used in the IAMs. We recommend the BLM develop a predictive model on the relationship between underground injections and increased seismic activity. The results could be linked to an economic model that estimates appropriate damage functions around earthquakes and disposal of waste from oil and gas development based, for example, on the increased costs recorded by the insurance industry. Air pollution damage functions can be used, for example, to examine the health impacts to regional citizens from oil and gas development. IAMs include human health damage functions at the global level, but human health damage functions at the local and regional level are needed. Ozone pollution from oil and gas development exacerbates a range of health problems for local residents including respiratory illnesses and asthma. There are many health studies that can be referenced and used to develop local and regional human health damage functions that will supplement and inform global human health damage functions currently used in IAMs.

We recommend the RMP alternatives include implementation of the BLM's methane capture rule. As part of this analysis the BLM should include the many human health co-benefits generated by implementing the agency's methane capture rule. These human health co-benefits occur because the methane capture requirements also reduce air pollution from volatile organic chemicals (VOC), fine particulate matter (PM) and other hazardous air pollutants (HAP). We recommend that the BLM include these human health co-benefits in the BCA completed for the planning area.

Capturing Methane Pollution Increases Economic Efficiency

The BLM's own research on its methane capture rule indicates that implementing climate mitigation measure like capturing methane emissions improves economic efficiency. Morton and Hjerpe (2016)[161] conducted a case study of two counties in the San Juan Basin of northwest New Mexico to better understand regional impacts of the BLM's proposed methane capture rule and focus on natural gas wells as it is the dominant fossil fuel produced in the region. The analysis included: 1) a Net Present Valuation of the costs of complying with proposed LDAR requirements and the new revenues from the methane captured; and 2) estimated change in overall gas production and associated royalty payments to the state. The study examined 13,493

[161] Morton, P. and E. Hjerpe 2016., A Review of the Economic Factors Surrounding the Capture of Methane from Oil and Natural Gas Development on Federal Public Land, Conservation Economics Institute.

active federal gas wells in these two counties and determined that 8,718 (65%) of these wells produced less than 90Mcf per day.

The results indicate that the majority of marginal gas wells will not only reduce methane emissions and natural gas waste, but by capturing the methane for sale, production, revenues, royalties and profits will also increase as a result of the proposed rule. These findings are consistent with the economic literature and with the BLM's findings in the Regulatory Impact Analysis.[162] We therefore recommend the BLM include a plan alternatives that includes implementation of methane emissions mitigation measures in the planning area.

BUDGET CONSTRAINTS MUST BE CONSIDERED IN THE RMPA

The level of damages (non-market costs) associated with each plan alternative are directly influenced by budgets available to fully implement the alternative. If funding is less than planned, and the promised environmental protection measures are not implemented due to budget shortages, the non-market damages and costs will increase. If on the other hand, budgets are flush and environmental protection measures are implemented as planned, the non-market costs will in general be less. The negative externalities (i.e. damages) generated from each plan alternative must be estimated with due consideration of the effect budget constraints – for example, annual funding levels and bonding amounts available for reclamation, inspection mitigation and well closure – have on damage functions.

We recommend that the BLM take steps to reduce methane emissions from oil and gas operations by examining budgets to make sure climate change mitigation measures are enforceable. Without adequate funding, climate mitigation measures included in the RMP are not enforceable and are more likely to fail.

A fiscally and environmentally responsible oil and gas program requires sufficient funding for implementing management plans. Based on numerous investigations we know that the BLM does not have the information, staffing or budget to actually implement responsible oil and gas development (GAO 2010, 2011, 2013a,2013b, and 2014).[163] In addition, efforts to mitigate the

---

[162] U.S. Bureau of Land Management, Regulatory Impact Analysis for Revisions to 43 CFR 3100 (Onshore Oil and Gas Leasing) and 43 CFR 3600 (Onshore Oil and Gas Operations), Additions of 43 CFR 3178 (Royalty-Free Use of Lease Production) and 43 CFR 3179 (Waste Prevention and Resource Conservation) at 39 , (November 10, 2016).

[163] U.S. Government Accountability Office. 2005. Oil and Gas Development: Increased Permitting Has Lessened BLM's Ability to Meet Its Environmental Protection Responsibilities. Report to the Ranking Minority Member, Committee on Homeland Security and Governmental Affairs, U.S. Senate. U.S. Government Accountability Office. 2010. Oil and Gas Bonds: Bonding Requirements and BLM Expenditures to Reclaim Orphaned Wells. GAO-10-245. U.S. Government Accountability Office. 2011. Oil and Gas Bonds: BLM Needs a Comprehensive Strategy to Better Manage Potential Oil and Gas Well Liability. GAO-11-292. U.S. Government Accountability Office. 2013a. Oil and Gas Development: BLM Needs Better Data to Track Permit Processing Times and Prioritize Inspections. GAO-13-572. U.S.

damages from climate change require adequate funding to insure the measures are enforceable. The BLM can include very effective climate change mitigation strategies in the RMP, but if the costs of climate mitigation is not considered in the context of agency budgets, and funding for climate mitigation turns out to be lacking, the mitigation measures will not be enforceable. Unfortunately, history has shown that funding levels clearly affect the timing and implementation of management actions and proposals, often resulting in protective measures such as mitigation and reclamation not being implemented. Because these budgetary shortfalls result in the damage or destruction of sensitive resources, it is imperative to recognize that funding levels *do* affect the findings and decisions made in an RMP.

A decision to lease more land for drilling involves a budget commitment for planning, inspection and mitigation. In contrast, no new leasing may lower BLM planning, leasing mitigation and enforcement cost in the short run as well as reclamation and monitoring costs in the long run. The decision to lease public land is also a commitment to increase surface disturbance and fragment wildlife habitat. Increasing surface disturbance directly increases the risk of damage to cultural resources and wildlife. In contrast a no new leasing alternative will result in less surface disturbing activities and fragmentation of wildlife habitat. As such, the costs of implementing each alternative will vary as the pace and scale of proposed leasing and drilling increases. When the BLM provides a range of alternative in a RMP, the public needs to understand the cost of implementing each alternative will also range. In other words, a range of implementation costs is associated with the range of alternatives. For example, a no new leasing alternative may cost less and be a more efficient alternative when budget constraints are considered.

It is imperative for taxpayers to understand whether the expected budget will be sufficient to cost of implementing each alternative. The total costs of implementation and mitigation must then be compared to the expected budgets to assess the probability of mitigation measures being fully implemented. Management risks can be fully evaluated based on a range of budget expectations, which should be clearly stated and consistent across alternatives.

We recommend the BLM complete a cost-budget analysis to show the feasibility of implementing each alternative. Taxpayers are entitled to know if decision makers are selecting a more damaging and more costly alternative, when a less damaging, less costly alternative is available. For example, what effect might the current federal hiring freeze have on implementation of the plan? And longer term, what are the consequence of a reduction in the federal workforce on the BLM's ability to comply with the law and implement fiscally and environmentally responsible oil and gas development? These are significant questions that must be addressed in the plan.

Historical evidence indicates significant budget shortfalls have prevented the BLM from fully implementing and keeping the promises and environmental commitments made in past

---

Government Accountability Office. 2013b. Oil And Gas Resources: Actions Needed for Interior to Better Ensure a Fair Return. GAO-14-50: U.S. Government Accountability Office. 2014. Oil and Gas: Interior Has Begun to Address Hiring and Retention Challenges but Needs to Do More. GAO-14-205.

management plans. We recommend the BLM fully examine the uncertainty in budgets and the subsequent risks and damages from budget shortfalls. An analysis of costs and budgets is needed to help reduce budget uncertainty associated with each alternative.

There is federal precedence for completing a cost-budget analysis, as the U.S. Forest Service completed one in 2002 for the White River National forest plan in Colorado.[164] The Forest Service used two budget levels in the cost budget analysis used to develop the White River National Forest (WRNF) plan.

> Two budget levels were analyzed for each management alternative. The first is based on the Forest's "experienced budget" level, which represents the average annual budget between 1997 and 2000. The second is the "full budget" level, which represents the funding of all programs at a level one and one-half times as much as the experienced budget level. The purpose of the two budget levels was to describe to the public and the decision maker how production levels and effects change under varying budgets. (Page A3-236).

While an open checkbook would be a nice, public land management plans need to be grounded in fiscal reality. Consider the following statements from the USDA Forest Service in the 2002 FEIS for the WRNF plan:

> ...the purpose of this budget analysis is to show that outputs and achievements are restricted by the amount of funding allocated to the White River National Forest…It is not realistic, however, to have an unconstrained budget level…output levels based on unconstrained budget level would not ever be realized. (Page A1 -35).
>
> ****
>
> Achievement of any strategy or objective is partially based on the staffing and budget resources available…achievement levels in the draft and final documents were estimated using realistic budget estimates. Using budget constraints in achievement estimates help predict a realistic outcome. (Page A1 -31)

We recommend that the BLM present the public with a realistic plan by completing a cost-budget analysis for each alternative. If the U.S. Forest Service can develop a fiscally responsible forest plan in 2002 – a plan the correctly considers implementation costs and budgets – we believe the BLM is also capable of producing a fiscally responsible RMP in 2017. The Forest Service has long used linear programming models for planning, perhaps it's time for the BLM to try such an approach. We recommend the BLM explore the potential to develop a linear programming planning model with an objective function of maximizing net public benefits subject to agency budget constraints. Developing such a planning model would help the BLM

---

[164] USDA Forest Service, 2002. Final Environmental Impact Statement, Volume 1, White River National Forest, Colorado.

develop fiscally responsible RMPs for oil and gas development that can be implemented with expected budgets.

Since budgets should vary with the pace and scale of development, we recommend budget comparisons based on various levels of the pace and scale of development. If more leasing and drilling is allowed the oversight budgets must correspondingly increase. We recommend developing fully funded budgets at three levels: 1) budgets necessary for implementing responsible oil and gas development for the existing wells and associated road and pipeline infrastructure within the planning area; 2) additional budgets required from responsibly implementing new oil and gas development on public land already under lease but not currently developed; and 3) the additional budgetary commitments associated with continuing to offer additional more acres of public land in the planning area for lease.

Background

In a 1992 report to Congress, the U.S Office of Technology Assessment reviewed federal land management budgets and found that the funding received by public land management agencies had been significantly less than the budgets required to fully implement plans. [165] The lower-than-planned budgets prevented public agencies from producing many of the outputs and resource protections that were promised in land management plans.

The BLM's budget challenge persists today as current funding is insufficient for accomplishing the agency's twin goals of environmentally and fiscally responsible oil and gas development. The environmental risks from oil and gas development increase when mitigation and monitoring measures are not adequately funded (Morton et al. 2004).[166]

The impacts from budget shortfalls with respect to implementing responsible oil and gas development were documented in a June 2005 report issued by the General Accounting Office (GAO).[167] The GAO found that the increased volume of permits has resulted in more BLM staff resources devoted to issuing permits with less attention being paid to monitoring and enforcing compliance with environmental standards that apply to the activities conducted under the permits.

---

[165] U.S. Congress, Office of Technology Assessment (1992). Forest Service Planning: Accommodating uses, producing outputs, and sustaining ecosystems. OTA-F-505, Washington, DC

[166] Morton, P., C. Weller, J. Thomson, M. Haefele, and N. Culver. 2004. Drilling in the Rockies: How much and what cost? Special Energy Session of the 69th North American Wildlife and Natural Resources Conference, Spokane, WA. Wildlife Management Institute, Washington, DC.

[167] U.S. Government Accountability Office. 2005. Oil and Gas Development: Increased Permitting Has Lessened BLM's Ability to Meet Its Environmental Protection Responsibilities. Report to the Ranking Minority Member, Committee on Homeland Security and Governmental Affairs, U.S. Senate.

More evidence of unfunded mandates and broken promises comes from a May 2006 BLM document from the Pinedale Field Office in Wyoming titled "Commitments made in Decision Documents not yet achieved" (Bureau of Land Management, Pinedale Field Office. 2006). The authors found that 580 requirements and commitments had been cumulatively made in recent decision documents – many of which had not been achieved. One of the more prominent commitments BLM made repeatedly in several decision documents was to track NOx emissions from oil and gas development in southwest Wyoming. The authors of the 2006 document concluded that NOx monitoring had not been completed since 2000. The report details dozens of examples where funding was not allocated to successfully implement the plan and achieve the cumulative commitments made by the BLM in decision documents.

We recommend that the BLM fully examine past Mancos planning documents and examine the past commitments promised that were never achieved. Such information is critical for understanding the ability of the BLM to fulfill promises made in future management plans. Such information is needed as the BLM continues to be challenged to find the resources, staffing or budget to implement responsible oil and gas development. A 2013 GAO report stated the following:[168]

> In fiscal year 2012, companies received over $66 billion from the sale of oil and gas produced from federal lands and waters, and they paid $10 billion to the federal government for developing these resources according to the Department of the Interior. The federal government seeks a fair return on its share of revenue from leasing and production activities on federal lands and waters through the federal oil and gas fiscal system….In May 2007, GAO found, based on several studies, that the government received one of the lowest percentages of value of oil and gas produced in the world. In September 2008, GAO found that Interior had not evaluated the federal oil and gas fiscal system for over 25 years and recommended that a periodic assessment was needed.

These challenges were confirmed in a 2014 GAO report which stated:[169]

> Interior employs a wide range of highly-trained specialists and scientists with key skills to oversee oil and gas operations on leased federal lands and waters. GAO and others have reported that Interior has faced challenges hiring and retaining sufficient staff to carry out these responsibilities. In February 2011, GAO added Interior's management of federal oil and gas resources to its list of programs at high risk of fraud, waste, abuse, and mismanagement in part because of Interior's long-standing and continued human capital challenges.

---

168 U.S. Government Accountability Office. 2013. Oil and Gas Resources: Actions Needed for Interior to Better Ensure a Fair Return. GAO-14-50: U.S. Government Accountability Office. 2014.

169 U.S. Government Accountability Office. 2014. Oil and Gas: Interior Has Begun to Address Hiring and Retention Challenges but Needs to Do More. GAO-14-205

A 2015 GAO report titled Oil and Gas Resources: Interior's Production Verification Efforts and Royalty Data Have Improved, but Further Actions Needed stated the following:[170]

> The Department of the Interior has made considerable progress in improving both the verification of oil and gas produced from federal leases and the reasonableness and completeness of royalty data. Since fiscal year 2009, Interior has implemented 28 of 36 GAO recommendations made in these areas; however, key challenges remain, including the following:
>
> Interior has not updated its regulations for onshore oil and gas measurement in over 25 years and, as a result, they do not reflect newer measurement technologies and standards adopted by industry, hampering Interior's ability to have reasonable assurance that oil and gas are being measured accurately.

All of which begs the question of how much money BLM needs for its oil and gas program to have fiscally and environmentally sound management? In order to address this question, we recommend the BLM estimate the fully funded budgets necessary for successfully implementing responsible oil and gas development and comparing them with historic budgets. Comparing fully funded budgets with historic budgets provides an estimate of the additional revenue that must be captured in order to implement a fiscally and environmentally responsible oil and gas program.

Legal Mandate

The BLM must consider the impact of budget constraints on its ability to fulfill the promises made in a RMP with respect to protecting ecological and multiple use values. According to a Council of Environmental Quality memorandum on NEPA requirements [cited in NEPA Compliance Manual, 2nd Edition (1994)]:[171]

> [T]o ensure that environmental effects of a proposed action are fairly assessed, the probability of the mitigation measure being implemented must also be discussed. Thus the EIS and the Record of Decision should indicate the likelihood that such measures will be adopted or enforced by the responsible agencies. (Section 1502.16(h), and 1505.2).

The probability that a mitigation measure will be implemented (and that risks will decrease) is largely a function of budgets and funding levels. In order to discuss the probability of mitigation, the agency must examine data and compare the cost of proposed commitments with historic and projected budgets.

---

[170] U.S. Government Accountability Office. 2011. Oil and Gas Bonds: BLM Needs a Comprehensive Strategy to Better Manage Potential Oil and Gas Well Liability. GAO-11-292

[171] Freeman, L.R.; March, F,; Spensley, J.W. 1994. NEPA Compliance Manual, 2nd Edition. Government Institutes, Inc., Rockville MD

In order to fulfill NEPA's mandate and truly take a "hard look" at its actions, the government must do a full assessment of the environmental risks from proposed management. Examining the probability of mitigation measures being funded and implemented is a necessary part of analyzing environmental risks. Environmental risks tend to increase when mitigation measures are not funded and implemented. The relative risk associated with implementing each alternative is essential information for decision makers selecting a preferred alternative.

Assess and Address Bonding Shortfalls

Climate mitigation requires not only adequate implementation funding to insure mitigation requirements are enforceable, but importantly, performance bond dollar amounts that provide the BLM with essential revenue to cover long term mitigation, closure and reclamation costs of oil and gas well pads and infrastructure – including capping wells, decommissioning roads and compressor station sites, and cleanup of containment ponds. These bonds may be surety bonds, a third-party guarantee that an operator purchases from a private insurance company; or personal bonds accompanied by a financial instrument, such as a cashier's check or negotiable Treasury security. Unfortunately, federal bonding amounts are outdated and inadequate. The federal government, for example, only requires $25,000 for a statewide bond or $150,000 for a nationwide bond – no matter how many federal oil and gas wells a company has permitted and drilled.

Anderson et al. (2009) estimated that Wyoming has a current shortfall in bonding of around $814 million – a shortfall that will require taxpayers to clean up the messes. [172] U.S. GAO (2011) found that federal bonding amounts may not be sufficient to encourage operators to comply with reclamation requirements. In order to better internalize the externalities and improve fiscal responsibility, we recommend the BLM assess current reclamation and closure costs in the planning area and contrast those costs with the bonding amounts currently available. Is there a current shortfall in bonding for existing wells and infrastructure? If a bonding shortfall is present, a no new leasing option will help limit the current shortfall. The current shortfall in bonding for existing oil and gas wells should be examined as well as any additional shortfall from new wells proposed in each plan alternative.

If current bonding is less than climate mitigation needs, as well as reclamation and closure costs for current wells and infrastructure, any new additional wells will only serve to increase the fiscal liability for taxpayers. Under such fiscal conditions, a no new leasing option is warranted and should be evaluated in the RMP. for each alternative.

We recommend the BLM complete an analysis of closure and reclamation costs in the planning area and compare those costs with current bonding amounts. As part of this effort we recommend the BLM collect, analyze and make available to researchers site specific data on the closure and reclamation costs -- as well as the success of past reclamation efforts -- for well pads, roads, and pipelines on public land in the planning area.

---

[172] Andersen, M., R. Coupal, and B. White. 2009. Reclamation Costs and Regulation of Oil and Gas Development with Application to Wyoming. Western Economics Forum, Spring 2009

Attachment 6

Capturing methane released by mines is a work in progress

CHARLIE RICHMOND

Recently, I have been approached repeatedly about the venting of methane gas from the coal mines that are located in the North Fork Valley just east of Paonia. The methane is being vented to protect mine workers. Comments have varied from individuals who are worried about the future of the mines to those who are appalled by the idea that methane is being released into the atmosphere. Several organizations have gone so far as accusing the Grand Mesa, Uncompahgre and Gunnison National Forests of being irresponsible by not prohibiting methane venting.

A general consensus in almost all of the discussion is the opinion that the methane should be captured and put to beneficial use. The Forest Service agrees wholeheartedly that the vented methane should be contained and used to meet the energy needs of this country. We have been working diligently within our authority to achieve this objective. Like most public land management issues, however, nothing is ever as simple as it might seem. I am writing to explain this issue and to address some of the misinformation and perceptions that have been expressed regarding the Forest Service's ability to prevent venting methane gas.

Coal mining is among one of the most heavily regulated industries in the country. Many people assume that the Forest Service has control of mining operations that are located on the National Forest. This assumption is false. In reality, the Forest Service is a partner with the Bureau of Land Management, the Office of Surface Mining Reclamation and Enforcement, and the Colorado Division of Reclamation, Mining and Safety in managing federal coal resources. The Forest Service role is limited to providing measures to protect surface resources that should be included on leases by BLM, or in the mining plan and permit.

Currently, there are several obstacles to overcome before methane can be captured and used. First, there are no federal or state regulations which control or prohibit methane venting into the atmosphere, and there are no legal mechanisms that can be used to require capturing of the gas. This means that any effort to put the gas to beneficial use will be strictly voluntary.

Secondly, there is the issue of gas ownership; either the gas resource under the coal mine is not under lease, or the gas is under lease to a separate company. For the situation where there is no gas lease, the Grand Mesa, Uncompahgre and Gunnison National Forests are working to rectify this problem by forwarding gas lease parcel nominations to the BLM and, hopefully, getting these leases auctioned.

Lastly, the technology to successfully and economically capture and use the gas requires a great deal of site-specific research and development. The coal companies, the Environmental Protection Association and several private consultants are currently exploring capture options for the North Fork mines.

This forest recently entered into a memorandum of understanding with the Delta-Montrose Electrical Association to jointly promote opportunities for renewable energy sources on the national forest lands, including analyzing the feasibility of generating electricity from the methane. The forest also approached the federal Mine Safety and Health Administration about the feasibility of flaring the gas, which would burn off the methane to mitigate greenhouse gas released to the atmosphere. We were recently notified that flaring may be possible in the long term, after several years of testing have been completed (at an inactive, sealed mine where safety would not be jeopardized), but would not be approved in the near future.

Mines in the North Fork Valley continue to be a major economic driver for several western Colorado counties and produce about 40 percent of the coal mined in this state. These mines produce some of the cleanest coal in the United States. The coal meets the Clear Air Act standards for "compliant and super compliant" coal because of high British Thermal Unit values, low sulfur, ash, and mercury content. Unfortunately, along with clean coal, the mines also produce fairly large volumes of methane gas that can be very explosive and deadly for miners.

Finding just the right solution for utilization of methane, thereby reducing greenhouse gas emissions, will not happen overnight but is on the nearby horizon. The GMUG National Forests will continue to "lead the charge" with our partners to explore options because it is the right thing to do for the environment. We are committed to help these mines continue operating while providing for worker safety, and improving environmental compliance.

Charlie Richmond is forest supervisor for the Grand Mesa, Uncompaghre and Gunnison National Forests, headquartered in Delta.