**Methane Analysis for Vessels Carbon Solutions Inc.**

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**February 15, 2021**

**Impacts of Elk Creek (CO) and Cambria 33 (PA) abandoned mine projects**

We analyzed the total impacts for the 8 years (CO) and 9 years (PA) of the two projects for which there is methane reduction data along with the impact of projected future emissions without action from the Elk Creek area (see Appendix I for emissions data and Appendix II for Methods). Before discussing the results it is important to bear several factors in mind. Impacts are evaluated annually (e.g., avoided deaths per year) and would persist as long as the difference between the methane emissions and a reference case is maintained (i.e., the leaks do not resume and one can assume they would still be taking place had action not been taken). Ozone-related effects begin in the same year as emissions changes, heat-related effects are averages over the period 1-3 decades after emissions changes. Monetized values do not include discounting of future impacts which would lower heat-related impacts by around half using a 2% discount rate, for example. Though many impacts are quantified here, others likely exist but reliable data to allow their quantification is not yet available. For instance, the reduction in premature deaths associated with climate change is only based on heat-exposure. Though this is currently probably the largest cause of premature death in the US associated with climate, being larger than the impacts of fires, floods and storms combined, the full effects would likely be larger if additional impacts such as fires, vector-borne diseases, and severe weather were included (though cold-related deaths would likely be reduced). Similarly, reduced hospital admissions have only been directly linked to ozone exposure and not to climate change in this analysis, while conversely reductions in labor productivity have been linked to heat and not to ozone, in both cases based on the availability of underlying data.

Examining the results of the analysis, the table below shows that for the two cases examining the impact of the total methane reductions achieved in CO and PA during the past ~10-15 years, there are clear benefits for public health, agriculture, and the economy. These are produced by both the reduction in climate change and the reduction in surface ozone that occurs in response to methane emissions decreases, even though both those changes are themselves quite small (e.g., global mean annual average temperature change of less than one-thousandth of a degree). In terms of public health, the benefits of reduced ozone exposure are both larger and occur more quickly than those in response to reduced climate change. The impacts are substantial, with roughly 175 premature deaths per year avoided due to the two projects, 13 thousand tonnes of crop losses per year avoided and 28 million lost

hours of work per year avoided. Crop losses include wheat, soybeans, corn (maize) and rice. Labor losses primarily affect heavy outdoor labor, especially construction and agriculture and to a lesser extent transportation and utility work.

Using standard methods to assign monetary value to the reduced risk of premature death, as done routinely by government agencies such as the US EPA, the methane emissions reductions from these two projects have provided public health benefits valued at nearly $300 million per year. This very large value associated with reduced risk of death is supplemented by another roughly $6 million per year in tangible losses to agriculture and heat-sensitive sectors of the labor market and another roughly $100,000 in decreased medical spending due to reduced ER visits and hospitalizations.

We next turn to the impact of projected methane emissions from the Elk Creek Permit Area Abandoned Mine Project over the next 30 years if no further mitigation action is taken. The analysis in this case finds larger (but still small) physical changes, with a reduction in global mean annual average temperature of 2 thousandths of a degree and a reduction of 16 parts per trillion in surface ozone concentrations (Figure 1). Translating to more relatable impacts, unabated methane emissions from this area over the next 30 years would be expected to lead to more than 2,000 additional premature deaths per year by 2050, more than 5,000 additional asthma-related ER visits per year, more than 175,000 tonnes of crop yield losses per year and more than 370 million annual lost work hours due to heat. The combined valuation of these impacts is just over $4 billion per year by mid-century.

As a gas with a residence time of around a decade, methane is readily distributed around the world by wind and diffusion and therefore the impacts of methane emissions or abatement are also global. We analyzed the portion of the societal benefits that take place within the US. We use the Elk Creek projected emissions as our example, but the ratio of US to global benefits would be the same for the other projects. We find that the portion of the global benefits that occurs within the US varies substantially across impacts. The largest fraction of global benefits takes place in the US for crop yields (20%) and the smallest for lost work hours (<1%). Premature deaths associated with ozone and heat are largely (~95%) outside the US, where populations are more vulnerable to the respiratory and cardiovascular diseases exacerbated by ozone exposure. A higher share (16-26%) of monetized benefits are in the US due to our greater wealth, which translates to a willingness to pay larger amounts for risk reduction, so that nearly $1 billion of the $4 billion in value associated with the Elk Creek projected emissions is within the US. Of that, the bulk comes from ozone-related impacts, indicating that those high-value benefits would be realized rapidly and are not affected by the subjective choice of a discount rate for future well-being.

Table 1. Annual societal benefits due to the methane emissions associated with the indicated projects or projections.

| ***Health*** | Elk Creek Achieved | PA Cambria Achieved | Elk Creek Projected | Elk Creek Projected US portion |
|---|---|---|---|---|
| Reduced Premature Deaths Due to Ozone Exposure | 109 | 22 | 1744 | 94 |
| Heat-related avoided premature deaths | 39 | 8 | 617 | 26 |
| Reduced Asthma-related Emergency Room Visits due to Ozone Exposure | 332 | 68 | 5308 | 14 |
| Reduced Hospital Admissions for Persons 65 and over due to Ozone | 7 | 1 | 105 | 1 |
| ***Agriculture*** | | | | |
| Increase in Yield of 4 staple crops due to Climate and Ozone Response to Methane (ktonnes) | 11 | 2 | 179 | 36 |
| ***Labor*** | | | | |
| Global lost work hours due to extreme heat (millions) | 23 | 5 | 370 | 0.1 |
| ***Monetization*** (millions 2018 $US) | | | | |
| Valuation of Reduced Risk of Death Due to Ozone Exposure | 194 | 39 | 3092 | 788 |
| Valuation of heat-related avoided premature deaths | 54 | 11 | 863 | 136 |
| Valuation of Increase in Crop Yields due to Climate and Ozone Response to Methane | 3 | 1 | 47 | 10 |
| Global lost work due to heat valuation | 2 | 0 | 35 | 1 |
| Valuation of reduced ER visits and Hospital Admissions | 0.1 | 0.02 | 1.6 | 0.4 |

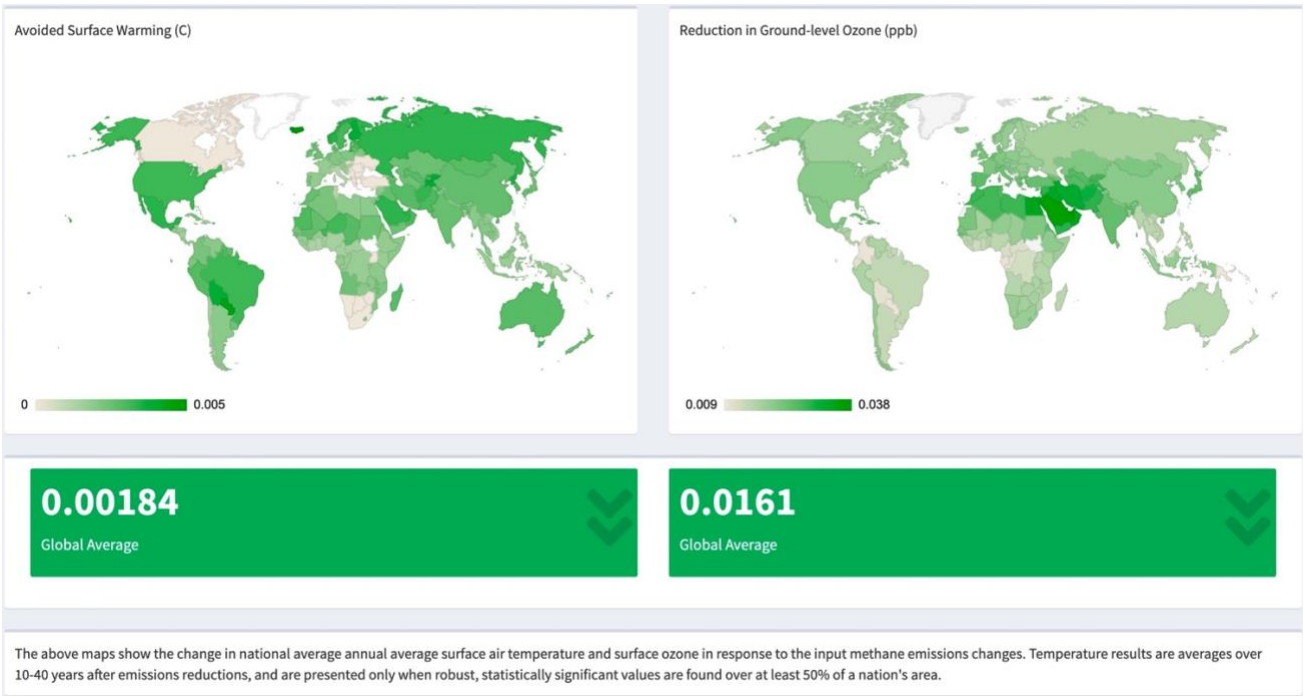


Figure 1. Change in annual average surface temperature and surface ozone in response to the Eagle Creek projected methane emissions over 2021-2050.

*Appendix I: Methane data from Vessels Carbon Solutions*

1. **Elk Creek Permit Area Abandoned Mine Project (Colorado)**

Total measured and recorded $CH_4$ emissions destruction from Colorado coal mines by Vessels Carbon Solutions Inc. from 2012 to 2019 in thousand metric tons (kt) of $CH_4$.

| Year | Annual $CH_4$ Destroyed kt |
|---|---|
| 2012 | 0.71 |
| 2013 | 4.03 |
| 2014 | 21.03 |
| 2015 | 13.81 |
| 2016 | 13.64 |
| 2017 | 11.50 |
| 2018 | 6.79 |
| 2019 | 5.69 |
| **Total** | **77.20** |

2. **Pennsylvania Cambria 33 Abandoned Mine Methane Capture and Use Project**

Total measured and recorded $CH_4$ emissions destruction by Vessels Carbon Solutions Inc. from 2008 through 2019 in thousand metric tons (kt) of $CH_4$ from Pennsylvania Cambria 33 Abandoned Mine Methane Capture and Use Project. The Project did not operate during 2015-2017.

| Year | Annual $CH_4$ Destroyed kt |
|---|---|
| 2008 | 1.79 |
| 2009 | 2.48 |
| 2010 | 1.63 |
| 2011 | 1.95 |
| 2012 | 1.45 |
| 2013 | 1.47 |
| 2014 | 1.37 |
| 2015 | - |
| 2016 | - |
| 2017 | - |
| 2018 | 1.22 |
| 2019 | 2.39 |
| **Total** | **15.75** |

3. **Future projections: Total Estimated $CH_4$ emissions from Elk Creek Permit Area Abandoned Mine Project Colorado 2021-2050 with no action taken**

The table below shows the estimated total methane ($CH_4$) that will be emitted by all abandoned mines that are part of the Elk Creek Permit Area Abandoned Mine Project from 2021 to 2050 thousand metric tons (kt) of $CH_4$. Low, mid and high-case scenarios were forecasted, and the high-case is presented below.

| Year | Annual $CH_4$ Emitted kt |
|---|---|
| 2021 | 64.68 |
| 2022 | 61.90 |
| 2023 | 59.44 |
| 2024 | 57.05 |
| 2025 | 54.87 |
| 2026 | 52.74 |
| 2027 | 50.93 |
| 2028 | 49.17 |
| 2029 | 47.43 |
| 2030 | 45.88 |
| 2031 | 44.35 |
| 2032 | 42.97 |
| 2033 | 41.67 |
| 2034 | 40.44 |
| 2035 | 39.29 |
| 2036 | 38.14 |
| 2037 | 37.06 |
| 2038 | 36.04 |
| 2039 | 35.05 |
| 2040 | 34.25 |
| 2041 | 33.30 |
| 2042 | 32.49 |
| 2043 | 31.68 |
| 2044 | 30.89 |
| 2045 | 30.20 |
| 2046 | 29.49 |
| 2047 | 28.81 |
| 2048 | 28.21 |
| 2049 | 27.55 |
| 2050 | 26.96 |
| **Total** | **1,233** |

**Appendix II: Methods**

The analysis of the impacts of methane mitigation is based upon the results produced in support of the 2021 Global Methane Assessment of the UN Environment Programme and the Climate and Clean Air Coalition.

Responses of the Earth system to methane changes are based upon a coordinated model study using the following models: the CESM2(WACCM6) model developed by the National Center for Atmospheric Research in Boulder, CO, USA; the GFDL AM4.1/ESM4.1 model developed by the National Oceanographic and Atmospheric Administration in Princeton, NJ, USA; the GISS E2.1/E2.1-G model developed by the National Aeronautics and Space Administration in New York, NY, USA; the MIROC-CHASER model developed jointly by the Atmosphere and Ocean Research Institute, University of Tokyo, the National Institute for Environmental Studies, Tsukuba, the Japan Agency for Marine-Earth Science and Technology, Yokohama, and Nagoya University, Nagoya, Japan; and the UKESM1 model developed by the UK Meteorological Office, Exeter, UK and the UK academic community. Impact evaluations use the multi-model mean of these models interpolated to the given emissions change. Analyses demonstrated that health and agriculture-related ozone changes scale approximately linearly with methane emissions changes, so that the interpolated results are highly accurate for current background atmospheric conditions. Labor impacts are less linear with methane emissions changes.

The impacts analyzed include the effects on climate change and ground-level ozone concentrations, and then via those environmental changes the resulting impacts on human health, agricultural crops and the economy. Human health impacts take place the same year as emissions change, whereas climate changes are reported for the average over 1-3 decades after emissions changes. Agricultural impacts are largely driven by ozone change, and hence quasi-immediate, but the climate-related impacts occur more slowly (those are especially important for tropical wheat). For premature deaths, results are based upon the relationship between ozone exposure and health impacts determined from the American Cancer Society Cancer Prevention Study II that followed more than 660,000 people for 22 years and quantified the increased risk of heart disease, cerebrovascular disease, pneumonia and influenza, chronic obstructive pulmonary disease and lung cancer with increased ozone exposure. Those increased risks are combined with data on public health conditions and population distributions to evaluate worldwide health burdens. For agriculture, relative yield losses are based on field studies of the response to ozone and meta-analyses of both measured and modeled responses to climate change. These are then applied to 2010 crop distributions from the Food and Agricultural Organization to obtain tonnes of yield changes.

Monetization is based upon a willingness-to-pay (WTP) measure of the value societies place upon reduced risk of premature death. This measure is often referred to as the value of a statistical life though it is in fact an expression of the value that people affix to small changes in mortality risks in monetary terms rather than the value of any individual's life. Though sometimes seen as controversial, society places an economic value on human health and potential future risks all the time. Sometimes this is done consciously, as when we purchase fire insurance even though the risk of fire in any single house is very small. At other times it is implicit, as when we make decisions about the need for specific

safety features on cars or roadways based in part on their cost. Economists have used both opinion questionnaires and so-called 'revealed preference' in which the analysis of market data shows the additional value attached to risk reduction (e.g. wage differentials for more dangerous jobs, spending on safety equipment). We use the current (2018) US EPA valuation for the US, with values adjusted elsewhere in the world based on income differentials.

All impacts described here are best estimates, but each has substantial uncertainty ranges resulting from both physical response uncertainties and especially from epidemiological uncertainties. Additional information on impacts and associated uncertainties can be found at: http://shindellgroup.rc.duke.edu/apps/methane/.