Appendix I

Sulfur Dioxide and Mercury Emissions

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This appendix assesses sulfur dioxide and mercury emissions that could potentially affect Washington State as a result of the Proposed Action. These pollutants are chemically transformed, deposited, and, in some cases, reemitted into the atmosphere.

The objective of the analysis was to determine the amount of sulfur dioxide and mercury emissions that would be found over Washington State specifically attributable to the sulfur and mercury emitted from coal combustion in Asia from coal that passed through the proposed coal export terminal. This analysis reviews the combustion of coal in Asia and addresses how much of the sulfur dioxide or mercury emitted following coal burning can return to Washington State. These sulfur compounds were monitored at White Pass, Washington and mercury compounds at Mount Bachelor, Oregon. A full description of methods, analyses, and findings of the sulfur dioxide and mercury emissions analysis is provided in the *SEPA Coal Technical Report* (ICF International 2016a). A description of coal market scenarios that were used in this analysis is provided in the *SEPA Coal Market Assessment* (ICF International 2016b).

Methods

This section describes the sources of information and methods used to evaluate the potential impacts related to sulfur dioxide and mercury associated with the construction and operation of the Proposed Action.

Information Sources

The following sources of information were used to inform the sulfur dioxide and mercury emissions analysis.

- Various journal articles, including the following.
    - *Journal of Geophysical Research* (Heald et al. 2006; Huebert et al. 2001; Maxwell-Meier et al. 2004; Park et al. 2004; Price et al. 2003; Prospero et al. 1985; Strode et al. 2008; Weiss-Penzias et al. 2006)
    - *Atmospheric Chemistry and Physics* (McKendry et al. 2008; Ohara et al. 2007; Pirrone et al. 2010)
    - *Atmospheric Environment* (Jaffe et al. 2003; Jaffe et al. 2005; Pacyna et al. 2000; Park et al. 2006; Wilson et al. 2006)
    - *Environmental Science and Technology* (Seigneur et al. 2004; Zhang et al. 2015)
    - *Journal of Atmospheric Chemistry* (Andrea et al. 1988)
    - *Environmental Chemistry* (Jaffe and Strode 2008)
    - *Environmental Pollution* (Wuebbles et al. 2007)
- Atmospheric Chemistry Modeling Group, GEOS-Chem website

- *Technical Background Report for the Global Mercury Assessment* (United Nations Environmental Programme 2013)
- *The Scientific Basis, Chapter 5 Aerosols, their Direct and Indirect Effects, Contribution of Working Group I to the Third Assessment Report* (Intergovernmental Panel on Climate Change 2001)

Impact Analysis

The following methods were used to evaluate the potential impacts of the Proposed Action related to sulfur dioxide and mercury emissions in the study area. Details of the analyses can be found in the *SEPA Coal Technical Report*.

1. A literature review was conducted on the current state of the science for the air monitoring and modeling of sulfur dioxide and mercury emissions in the Pacific Northwest.
2. The best understanding of the source-to-receptor relationship from the global chemical transport model (GCTM) that has been done to date was used. Those findings were applied to answer the objective of this analysis. A global chemical transport model is the standard type of computer model used to predict air pollutant concentrations when complex atmospheric chemistry is important.
3. To apply the GCTM source contribution results, the emission inventory for sulfur dioxide and mercury emissions used in the GTCM for each country where the coal would be burned was identified. The projected sulfur dioxide and mercury emissions in Asia (China, Japan, South Korea, Hong Kong, and Taiwan) for four scenarios evaluated in the *SEPA Coal Market Assessment* was used to estimate the mercury or sulfur emissions attributable to the Asian emissions. Finally, the impacts from a long-range transport episode and on an annual basis were identified based on the GTCM modeling results for the Proposed Action.
4. Based on the literature review, emission inventory uncertainties, and GCTM modeling, an upper bound on the sulfur dioxide and mercury emissions attributable to coal that would pass through the coal export terminal was estimated.

The *SEPA Coal Market Assessment* analyzes scenarios to determine sulfur dioxide and mercury emissions resulting from coal exported from the proposed coal export terminal being combusted in Asia. Both the Proposed Action and a No-Action Alternative were examined under each scenario to determine the effect of the Proposed Action on the U.S. and Pacific Basin coal markets. The scenarios analyzed in this report are as follows.

- **2015 Energy Policy Scenario**. The 2015 Energy Policy scenario is intended to represent the potential impact of new international climate and energy policies on international coal demand. Functionally, this scenario is the same as the Past Conditions (2014) scenario except for two parameters. First, the international thermal coal demand is derived from an international policy perspective. Second, this scenario includes the Clean Power Plan in the form in which it was originally proposed, which will reduce coal consumption in the United States. The final Clean Power Plan was released in August 2015, after the modeling was completed for the coal market assessment and greenhouse gas analysis. This scenario more accurately reflects current global conditions and is the preferred scenario for purposes of this study.
- **Lower Bound Scenario**. The Lower Bound scenario is designed to result in a reasonable lower estimate of global carbon dioxide emissions from the power sector.

- **Upper Bound Scenario**. The Upper Bound scenario is designed to result in a reasonable upper bound of global carbon dioxide emissions from the power sector.
- **Past Conditions (2014) Scenario**. The Past Conditions (2014) scenario represents the state of the energy markets as of 2014 and therefore, assumes no climate policies enacted. Consequently, it does not include the Clean Power Plan effective in late 2015 and does not therefore reflect current energy policy conditions. The international demand for coal varies by country, using "business-as-usual" projections described in the *SEPA Coal Market Assessment*.

Existing Conditions

This section describes existing sulfur dioxide and mercury emissions findings for Washington State, their source, and projected changes in the future.

Sulfur Dioxide

Natural sources of sulfur dioxide make up about 25 to 33% of the sulfur dioxide in the earth's atmosphere. The primary sources are volcanoes and the atmospheric oxidation of oceanic dimethyl sulfide,[1] with a small fraction coming from wildfires (Intergovernmental Panel on Climate Change 2001). Anthropogenic[2] sulfur dioxide emissions originate mainly from fossil fuel combustion, with coal combustion being the largest source, representing about 53% of all anthropogenic sources of sulfur dioxide globally. Other important anthropogenic sources of sulfur dioxide include the burning of petroleum products for both transportation and industrial process (26%) and the smelting of metals (9%). In China, the country with the highest sulfur dioxide emission rates, coal combustion is responsible for about 84% of sulfur dioxide emissions (Ohara et al. 2007).

Most emissions of sulfur dioxide are deposited locally or regionally, with the remainder of sulfur dioxide being converted to sulfate aerosol, remaining in the atmosphere and transported longer distances. Sulfur dioxide is removed in the lower layer of the atmosphere via four processes: absorbed in rain, trapped in clouds and then washed-out, interaction with sea salts in the air, and removed via direct contact with the ocean surface. Nearly all sulfur is deposited within the first 1,000 kilometers from its point of origin; therefore, sulfur deposition over Washington State resulting from Asian emissions cannot be determined. However, in the absence of the four removal processes, sulfur dioxide is capable of being transported long distances. These conditions occur most frequently during the spring (Maxwell-Meier et al. 2004).

Studies and Findings

Since it is not possible to determine sulfur dioxide deposition over Washington State, this analysis involved reviewing over two dozen peer-review publications. The studies spanned 15 years and included sulfur dioxide emission inventories, emission projections, and coal consumption in Asia. Also included were air monitoring studies in the Pacific Northwest and across the United States that addressed impacts associated with the long-range transport of Asian sulfur dioxide emissions, and

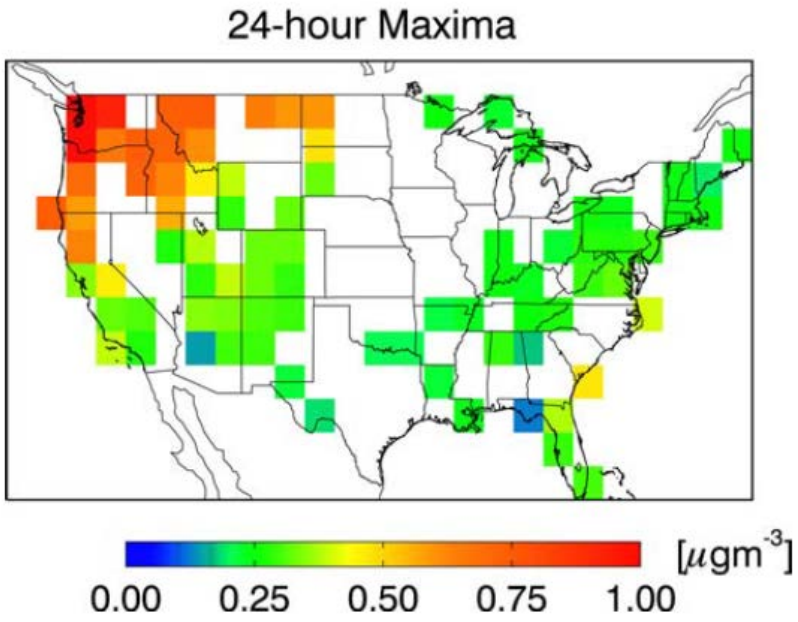
[1] Blooms of algae floating near the ocean's surface, which includes microscopic animals, krill, and other crustaceans, emit a gas known as dimethyl sulfide.

[2] Anthropogenic actions are caused by human activity.

GTCM studies that focused on assessing the fate and transport of coal combustion in Asia to North America.

Long-range transport of Asian anthropogenic sulfate emissions across the Pacific Ocean was first documented in the 1980s from observations at island sites (Prospero et al. 1985; Huebert et al. 2001). Aircraft observations of transpacific Asian gaseous plumes over the northeast Pacific provided subsequent evidence of sulfate aerosol transport in the lower free troposphere (the lowest portion of the earth's atmosphere) (Andreae et al. 1988; Price et al. 2003). Similarly, ground- and aircraft-based observations in the Pacific Northwest have identified episodes of trans-Pacific transport of sulfate aerosols (Jaffe et al. 2003; McKendry et al. 2008). Using satellite imagery, GTCM results, and surface air monitoring data for the western United States (Heald et al. 2006) demonstrated the high sulfate aerosol concentration due to trans-Pacific pollutant transport. They found that the springtime Asian sulfate aerosol concentrations were greatest in Washington State (White Pass) and southern British Columbia, Canada, with maximum 24-hour concentrations reaching approximately 1.5 micrograms per cubic meter (μgm^3) (Figure I-1).

Figure I-1. Asian Anthropogenic Enhancements of Sulfate Concentrations in Surface Air during Spring 2001 as Simulated by the GCTM



Source: Heald et al. 2006.

Park et al. (2004) used the GCTM model for two full-year simulations, which showed that 30% of the annual average background sulfate in both the western and eastern United States was due to trans-Pacific Asian transport. In Park et al. (2006), GCTM modeling with improved sulfate air chemistry showed that the annual average sulfate concentration in the western United States due to trans-Pacific Asian transport was 0.10 μg/m^3.

Mercury

The following discusses the nature of the emissions of mercury, how those pollutants behave and change in the atmosphere, and the form of those pollutants once they reach Washington State. This

discussion is followed by a description of the studies most relevant to this analysis, emphasizing the key findings from those papers, which were used to develop the impact assessment for combustion of coal that was exported from the proposed coal export terminal to Asia.

Overview

Mercury is a naturally occurring element found throughout the world. There are many natural sources that emit mercury into the atmosphere, including the weathering of mercury-containing rocks, volcanoes when they erupt, and geothermal activity. Most recent models of the flow of mercury through the environment find that natural sources account for about 10% of the annual mercury emission (United Nations Environment Programme 2013).

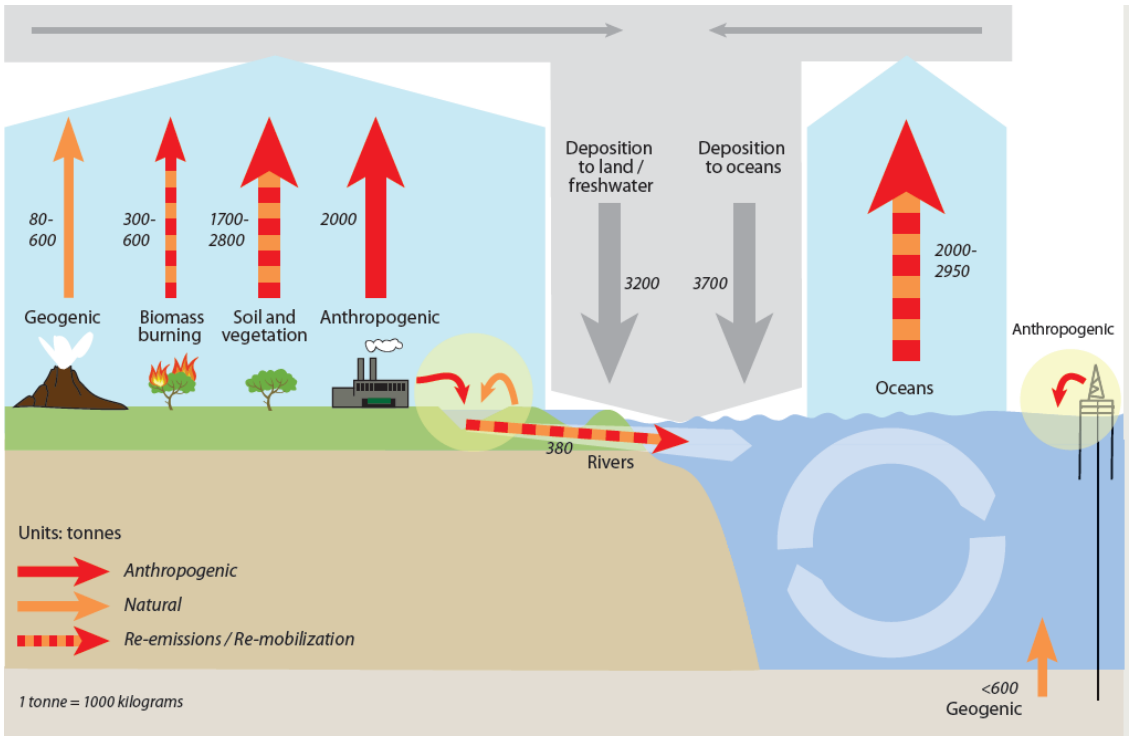
Anthropogenic sources of mercury emissions account for about 30% of the total amount of mercury entering the atmosphere each year. Globally, the largest source of emissions in this category is from small-scale gold mining (estimated at 37%), followed by coal combustion (24%). The next largest sources are from the primary production of nonferrous metals (aluminum, copper, lead, and zinc) and cement production. Together, these sources account for about 80% of the annual anthropogenic emission of mercury.

The third category of mercury emissions is reemissions, which account for about 60% of the mercury emitted to the air annually. Mercury previously deposited from air onto soils, surface waters, and vegetation from past emissions can be emitted back to the air. Reemission is a result of the conversion of inorganic and organic forms of mercury to elemental mercury, which is volatile and, therefore, readily returns to the air. Mercury may be deposited and reemitted many times as it cycles through the environment.

Reemitted mercury should not be considered a natural source—originally, it may have been either natural or anthropogenic, but by the time it is reemitted, its specific origin cannot be identified other than from atmospheric modeling. Estimating reemission rates is done using global modeling approaches based on data of atmospheric levels of mercury and an understanding of chemical transformations and other processes that affect how mercury moves between air, land, and water. The models act to balance the amount of mercury in circulation at any given time consistent with observational data. This analysis conservatively assumes that the reemitted mercury is all anthropogenic. Figure I-2 shows the current global mercury emission cycle.

Mercury is mostly released in its elemental form, which has a lifetime in the atmosphere of 6 to 24 months; therefore, it can be transported globally. The chemical speciation of mercury has been further studied by Pacyna et al. (2006). Across industries, about 53% of mercury in gases is in elemental form (Hg^0), 37% is gas-phased oxidized mercury (Hg^{II}) and 10% is particle-bound mercury. This is important because the latter two phases of mercury have much shorter lifetimes—as in, days or weeks—which means they are deposited locally close to the source of emission.

Figure I-2. Global Mercury Cycle (metric tons/year)



Source: United Nations Environment Programme 2013.

Studies and Findings

Various studies have examined the long-range transport of Asian mercury emissions to North America (Jaffe et al. 2003, 2005; Weiss-Penzias et al. 2006). Weiss-Penzias et al. (2006) found that total mercury (elemental + reactive and particle) from March 28 to May 19, 2004, at Mount Bachelor, Oregon, had periods where the air mass originated from East Asia, with an average increase in total mercury during these periods of 0.16 nanograms per cubic meter (ng/m^3) attributable to emissions from northern China, Korea, and Japan.[3] Two pollution events in this time period were examined in detail and showed that travel time from East Asia to the Pacific Northwest was about 10 days. Back-trajectories for the April 25, 2004 episode at several elevations above and below the Mount Bachelor site elevation, along with back-trajectories for the same date on the corners of a 1 degree of latitude by 1 degree longitude box around the Mount Bachelor location and at multiple elevations, all showed similar flow from East Asia.

Because of the large amount of coal consumed in East Asia, which is projected to increase, and because studies show long-range transport from East Asia to North America is a frequent occurrence, several global modeling studies have been conducted to explore the impact of mercury emissions from East Asia on North America. The first such assessment was presented by Seigneur et al. (2004), who reported that Asian mercury emissions were estimated to contribute between 5 and 36% of the total mercury deposition in the United States. The most extensive modeling study of East Asian mercury emission impacts on the Pacific Northwest was conducted by Strode et al. (2008).

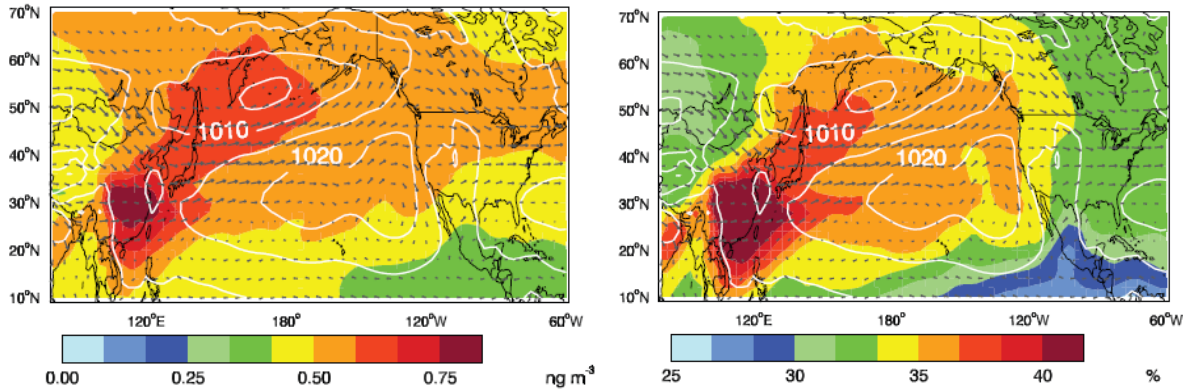
[3] This was based on the analysis of thousands of back trajectories using the National Oceanic and Atmospheric Administration's HYSPLIT trajectory model and mercury-to-carbon monoxide measurement ratios.

That study included both global modeling of mercury and an observational analysis and comparison of the models' findings using the Mount Bachelor-monitored mercury data.

The model results showed that the Asian anthropogenic percent contribution to Hg^0 at Mount Bachelor shows little variability between seasons, with an Asian anthropogenic contribution of 18% in spring (0.29 ng/m^3 for Hg^0 and 0.015 ng/m^3 for Hg^{II}) and in the annual average. Additionally, the modeling study showed that the regional contribution of Hg^{II} deposition (wet and dry) at Mount Bachelor was 14% (approximately 2,900 milligrams per square kilometer per year (mg/km^2-year) from Asian anthropogenic emissions. Finally, the model shows that mercury reaches the Mount Bachelor location only in the form of Hg^0 and Hg^{II}.

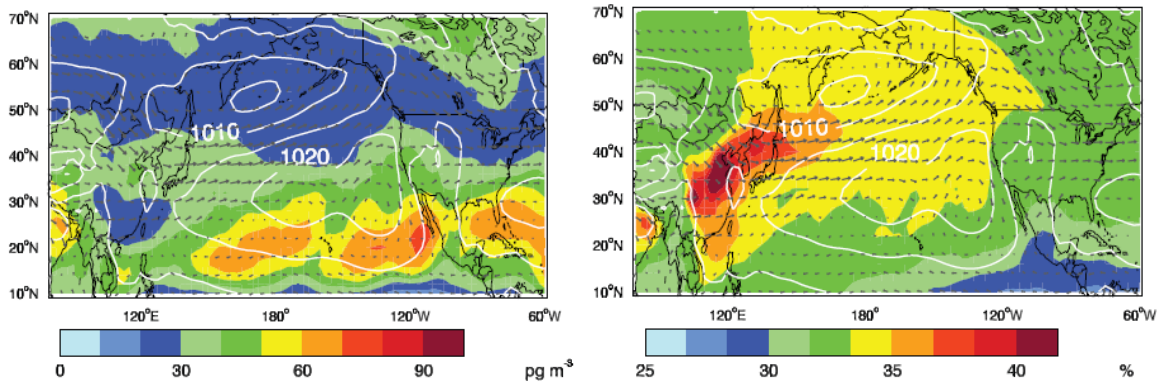
The general trans-Pacific transport of mercury from Asia to North America is shown in Figure I-3. The different mechanisms by which Asian Hg^0 reaches North America affect the latitudinal distribution of their contributions. Hg^0 is transported to the northeast from Asia with the prevailing winds. Consequently, the Asian influence is largest over Alaska, western Canada, and the northwestern United States. The relative contribution of Asian emissions to the Hg^0 concentration is no more than 36%.

Figure I-3. Maps of March–May 2004 Concentrations and Relative Percentage of Asian Hg^0



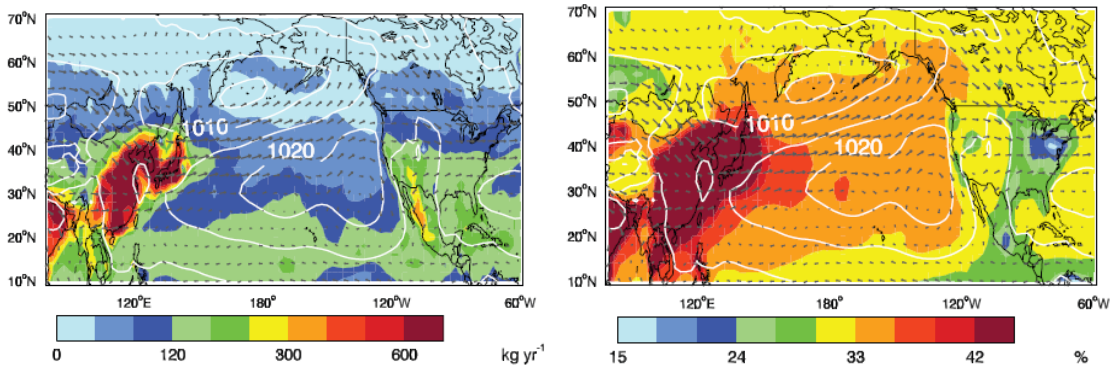
In contrast, Asian emissions influence North American Hg^{II} concentrations from oxidation of the global Asian Hg^0 pool within the atmosphere, rather than by direct transport of Hg^{II} from the emission source. The Asian Hg^{II} contribution is largest at low latitudes where high oxidant concentrations and descending dry air lead to higher concentration levels of Hg^{II} (Figure I-4).

Figure I-4. Maps of March–May 2004 Concentrations and Relative Percentage of Asian Hg^{II}



Asian Hg^{II} deposition follows a similar pattern to Asian Hg^{II} concentration because both wet and dry deposition depend on Hg^{II} concentrations (Figure I-5).

Figure I-5. Maps of March–May 2004 Concentrations and Relative Percentage of Asian Total Hg Deposition



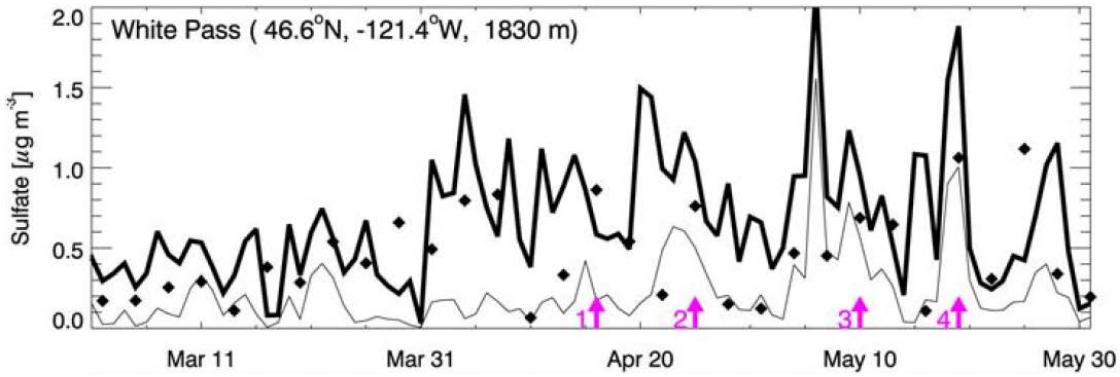
Impacts

This section describes the potential for sulfur dioxide and mercury emissions to affect Washington State as a result of construction and operation of the Proposed Action. The findings below are based on the scenarios presented in the *SEPA Coal Market Assessment*, which are summarized in Section A.1.1.2, *Impact Analysis*, as well as findings from studies reviewed for this analysis and listed in Section A5.9.1.1, *Information Sources*.

Sulfur Dioxide

Asian anthropogenic sulfur dioxide emissions total approximately 42,800 metric tons/year (MT/year). A more conservative emission total was used for this analysis. Only the countries that would potentially consume the coal exported from the proposed coal export terminal were used: Japan, Korea, China (includes Hong Kong), and Taiwan. The total sulfur dioxide emissions (as found in Ohara et al. 2007) for these countries was 29,800 MT/year. These were adjusted downward to reflect the sulfur dioxide emission source strength used in the GCTM by Park et al. (2006). This conservatively assumes that only Asian emissions from these countries contribute to the portion of Asian sulfate concentration in Washington State. The GCTM modeled concentrations are based on the concentrations reported for the western United States, because the annual average sulfur dioxide concentration is more uniformly dispersed. To estimate the episodic concentration, the 24-hour maximum modeled sulfate concentration of 1.5 $\mu g/m^3$ (Heald et al. 2006) was used as modeled at White Pass, Washington (Figure I-6).

Figure I-6. Time Series of Sulfate Concentration in Surface Air at White Pass, Washington



Note: The diamonds are observations, the thin gray line is the Asian anthropogenic contribution in the GCTM, and the thick black line the total GCTM values. The pink arrows are the start of the transpacific event as observed midway in the Pacific Ocean.

Table I-1 shows the annual and episodic sulfate concentrations from coal exported to Asia from the proposed coal export terminal for the Proposed Action minus the No Action by year starting in 2025. Overall the Past Conditions (2014), Lower Bound, and 2015 Energy Policy scenarios are very similar in magnitude for the first 5 years. The Upper Bound and 2015 Energy Policy scenarios are nearly identical by 2040. In all cases, the concentration is flat over the first 5 years but increases from 50% to more than doubling the concentration by 2040. Park et al. (2006) found the annual average Asian sulfate concentration for Washington State at 0.10 μg/m^3 or 100 ng/m^3 in 2000. Assuming that overall growth in coal combustion is balanced with reductions in sulfur dioxide emissions due to application of additional control technology, the maximum Proposed Action coal source contribution of just the Asian sulfate concentration in Washington State in 2040 would be less than 0.3%.

Table I-1. Annual Sulfate Concentration in Washington State from Coal Exported to Asia from the Proposed Coal Export Terminal (ng/m^3) by Scenario

	2025	2030	2040
2015 Energy Policy Scenario			
Annual	0.09	0.09	0.21
Episodic	1.33	1.33	3.18
Lower Bound Scenario			
Annual	0.08	0.10	0.17
Episodic	1.26	1.50	2.48
Upper Bound Scenario			
Annual	0.14	0.14	0.21
Episodic	2.10	2.10	3.16
Past Conditions (2014) Scenario			
Annual	0.09	0.09	0.16
Episodic	1.33	1.33	2.36

Notes:
ng/cm^3 = nanogram per cubic meter

Episodic maximum shows substantially higher concentrations over the annual average. Still, the exported coal maximum increase in sulfate concentration of 3.18 ng/m^3 relative to the episodic maximum Asian source sulfate concentration determined at White Pass, Washington, of 1,500 ng/m^3 (Heald et al. 2006) is a contribution of 0.2%.

Mercury

Similar to the approach for determining sulfur dioxide, this study used a more conservative emission total for just the countries that would potentially consume the coal from the coal export terminal (Japan, Korea, China, which includes Hong Kong, and Taiwan). Total mercury emissions (as found in Pacyna et al. 2006) for these countries was 408 MT/year for Hg^0 and 285 MT/year for Hg^{II}. This conservatively assumes that only Asian emissions from these countries contribute to the portion of Asian mercury in Washington State. The GCTM modeled concentration and deposition results are based on the modeled concentrations as reported for Mount Bachelor.

Results from Scenario Comparison

To estimate the episodic concentration, it was conservatively assumed that the mercury impact in Washington State from Asia occurs in all Asian countries where coal from the coal export terminal would be exported. This greatly increases the scaling ratio and conservatively estimates the episodic mercury impact.

Table I-2 shows annual and episodic concentrations from coal (exported from the proposed coal export terminal) for the Proposed Action minus the No Action by year starting in 2025 for Hg^0, Hg^{II}, and total Hg. Overall the differences between the three scenarios relative to the Past Conditions (2014) scenario are relatively small, with the maximum total mercury emissions ranging from 0.57 to 0.69 picograms per cubic meter (pg/m^3) and the maximum episodic ranging from 2.8 pg/m^3 for the Lower Bound scenario to 3.7 pg/m^3 for the 2015 Energy Policy scenario. In all cases, the concentration is flat over the first 5 years and then increases by 30 to 67% by 2040. Also in all cases, Hg^0 is the dominant form of mercury. Strode et al. (2008) found the annual average Asian-originated Hg^0 for Mount Bachelor was 0.29 ng/m^3 or 290 pg/m^3 in 2000. Assuming that overall growth in coal burning is balanced with reductions in mercury emissions due to application of control technology implemented under the 2013 Minamata Convention on Mercury,[4] the fraction of Hg^0 exposure in Washington State in 2040 attributed to the Proposed Action would be less than 0.3%. Similarly, the Hg^{II} annual average for Mount Bachelor is 150 pg/m^3 and the maximum Proposed Action concentration would be 0.047 pg/m^3 or a little less than 0.1%. The episodic maximum shows substantially higher concentrations over the annual average. Still, the maximum contribution of 3.4 pg/m^3 from the coal exported from the proposed coal export terminal relative to the episodic Hg^0 at Mount Bachelor of 1,180 pg/m^3 is a contribution of less than 0.3%.

[4] The Minamata Convention on Mercury is a global treaty established to protect human health and the environment from the adverse effects of mercury. Controlling the anthropogenic releases of mercury throughout its lifecycle has been a key factor in shaping the obligations under the convention (United Nations Environment Programme 2016).

Table I-2. Annual and Episodic Net Mercury Concentration in Washington State as Elemental (Hg^0) and Oxidized Mercury (Hg^{II}) (pg/m^3) by Scenario

Hg^0	2025	2030	2040	Hg^{II}	2025	2030	2040	Hg^{Tot}	2025	2030	2040
2015 Energy Policy Scenario											
Annual	0.39	0.39	0.64	Annual	0.029	0.029	0.047	Annual	0.41	0.41	0.69
Episodic	2.1	2.1	3.4	Episodic	0.15	0.15	0.25	Episodic	2.2	2.2	3.7
Lower Bound Scenario											
Annual	0.39	0.39	0.53	Annual	0.029	0.029	0.039	Annual	0.41	0.41	0.57
Episodic	2.1	2.1	2.8	Episodic	0.15	0.15	0.21	Episodic	2.2	2.2	3.0
Upper Bound Scenario											
Annual	0.49	0.49	0.64	Annual	0.036	0.036	0.047	Annual	0.52	0.52	0.69
Episodic	2.0	2.0	2.6	Episodic	0.15	0.15	0.19	Episodic	2.1	2.1	2.8
Past Conditions (2014) Scenario											
Annual	0.39	0.39	0.63	Annual	0.029	0.029	0.046	Annual	0.41	0.41	0.67
Episodic	2.1	2.1	3.4	Episodic	0.15	0.15	0.25	Episodic	2.2	2.2	3.6

Notes:
pg/m^3 = picograms per cubic meter

Table I-3 shows the annual mercury deposition amounts associated with coal (exported from the proposed coal export terminal) over Washington State for the Proposed Action minus the No Action by year, starting in 2025. In the first 5 years, the deposition amounts are approximately the same across all scenarios except the Upper Bound scenario, which is higher. All show an increase in mercury deposition by 2040, with a maximum deposition amount of 9.2 milligrams per year per square kilometer (mg/yr-km^2). This amount represents less than 0.4% of the total Asian-sourced mercury deposition over Washington State as estimated by Strode et al. (2008) at 2,900 mg/yr-km^2.

Table I-3. Annual Hg^{II} Net Deposition Amounts in Washington State (mg/yr-km^2) by Scenario

2025	2030	2040
2015 Energy Policy Scenario		
5.5	5.5	9.2
Lower Bound Scenario		
5.5	5.5	7.6
Upper Bound Scenario		
7.0	7.0	9.2
Past Conditions (2014) Scenario		
5.5	5.5	9.0

Notes:
mg/yr-km^2 = milligrams per year per square kilometer

Uncertainty—Sulfur Dioxide

As with any estimate of impacts, a level of uncertainty is inherent in this analysis. The largest source of uncertainty is associated with the Asian sulfur dioxide emissions. One approach to estimating the level of uncertainty in the inventories is to compare the estimated sulfur dioxide emissions developed by different researchers using different methods for development. Ohara et al. (2007) reports on inventory projects for sulfur dioxide emissions in East Asia, presenting ranges from a low of 22.6 million MT/year to 42.9 million MT/year, with an average of 31.5 million MT/year, suggesting an uncertainty of approximately ±35%. Historically, Asian emissions have been most uncertain from China, in terms of total sulfur dioxide emissions, due to uncertainties in activity levels, rapid changes in the type and amount of coal combusted, and level of controls. Sulfur content of Chinese coals varies from 0.6 to 2.1%. In recent years, refinements in the understanding of the sulfur content in the coal and improved understanding of coal plants control technology efficiencies and their use have led to a better understanding of the sulfur dioxide emission rates.

Another approach to estimating uncertainty is to compare modeled versus observed sulfate for the Pacific Northwest sulfate monitoring sites. This allows the TCTM to use a range to better estimate Asian sulfate pollution influence. This approach was used by Heald et al. (2006), who estimated a ±50% uncertainty in the model results for Asian sulfate enhancements over the northwest United States.

Given these uncertainties, the sulfur dioxide impacts in Washington State would be within ±50% of the estimate presented earlier and could be further reduced if GCTM modeling were specifically performed to assess the impacts for the countries expected to import the coal from the proposed coal export terminal and by using the most recent Asian sulfur dioxide inventories.

Uncertainty—Mercury

As with any estimate of impacts a level of uncertainty is inherent in the analysis. The largest source of uncertainties comes from the global estimates of mercury emissions to the air. These stem from various sources, including the availability of information on activity levels, but mainly from the lack of information concerning the mercury content of some raw materials and the validity of the assumptions regarding processes and technologies used to reduce mercury emission releases. However, recent methods used to produce the global inventory for 2010 (United Nations Environment Programme 2013) were compared with a number of national inventories and emissions reported under other systems covering the same period, and in general the level of agreement was found to be good. Other studies have also reported the average uncertainty associated with anthropogenic industrial emission of mercury at ±30% (Pirrone et al. 2010). In the Pacyna et al. (2006) study, the accuracy of the emission inventory was estimated by source categories as: fuel combustion ±25%, various industrial process ±30%, and waste disposal a factor of 2 to 5. Note that the dominant emissions are from fuel combustion and industrial processes.

Historically, Asian emissions have been most uncertain from China given the uncertainties in activity levels due partly to the rapid changes, type, and amount of coal combusted and level of controls. However, the recent work of Zhang et al. (2015) using a probabilistic process-based approach based on information of the mercury content in fuel and raw materials, the production process, and mercury removal efficiencies obtained from field tests yielded more accurate emission estimates and lowered uncertainties. They estimate total mercury emissions from China at 356 MT/year or about 40% lower than the number used in the GCTM modeling. The study also included was better understanding of the spatial allocation of those emissions.

Another source of uncertainty is the chemistry in the atmospheric transport model. The largest uncertainty in the atmospheric mercury models is the chemical mechanism used to determine how mercury changes forms in the air. Improved experimental data will help improve model performance by making sure that the correct reactions are simulated. The processes that lead from deposition to reemission also need to be better understood. Advances in this area are showing improvement, with model results becoming closer to estimates based on experimental data (United Nations Environment Programme 2013). However these chemical transformation uncertainties are, in general, less than the emission inventory uncertainties.

Given these uncertainties, the mercury impacts in Washington State would be within ±50% of the estimates presented earlier and could be further reduced if GCTM modeling were specifically performed to assess the impacts for the countries expected to import the coal from the proposed coal export terminal, by using the most recent Asian mercury inventories and applying the advances in understanding atmospheric mercury chemistry.