BEFORE THE MINNESOTA OFFICE OF ADMINISTRATIVE HEARINGS
600 NORTH ROBERT STREET
ST. PAUL, MINNESOTA 55101

FOR THE MINNESOTA PUBLIC UTILITIES COMMISSION
SUITE 350
121 SEVENTH PLACE EAST
ST. PAUL, MINNESOTA 55101-2147

Beverly Jones Heydinger	Chair
Nancy Lange	Commissioner
Dan Lipschultz	Commissioner
Mathew Schuerger	Commissioner
John Tuma	Commissioner

In the Matter of Further Investigation into Environmental and Socioeconomic Costs under Minnesota Statute § 216B.2422, Subdivision 3

OAH Docket No. 80-2500-31888
MPUC Docket No. E-999/CI-14-643

INITIAL BRIEF OF THE MINNESOTA DEPARTMENT OF COMMERCE, DIVISION OF ENERGY RESOURCES AND MINNESOTA POLLUTION CONTROL AGENCY

CRITERIA POLLUTANTS

Dated: March 15, 2016

Respectfully submitted,

LINDA S. JENSEN
Attorney Reg. No. 0189030
Telephone: 651-757-1472
445 Minnesota Street, Suite 1800
St. Paul, MN 55101-2134

Attorney for Minnesota Department of Commerce and Minnesota Pollution Control Agency

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I. INTRODUCTION

The Minnesota Department of Commerce, Division of Energy Resources (DOC-DER or Department) and the Minnesota Pollution Control Agency (MPCA) (collectively, the Agencies) respectfully submit this Initial Brief to provide the Administrative Law Judge (ALJ) and the Minnesota Public Utilities Commission (Commission or MPUC) with analysis of the facts and law as to the appropriate cost values under Minn. Stat. § 216B.2422, subd. 3 for fine particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2), and nitrogen oxides (NO_x) (together, the criteria pollutants).

II. SUMMARY OF AGENCIES' CONCLUSIONS AND RECOMMENDATIONS

The Agencies recommend that the ALJ find that the results formulated by the Agencies' witness Nicholas Z. Muller using the AP2 integrated assessment model are appropriate environmental cost values for the criteria pollutants under Minn. Stat. § 216B.2422. For example, the results of the AP2 model indicate that the statewide average 2015 cost value ranges are (in 2011 dollars per ton):

	Low Damage Assumptions			**High Damage Assumptions**		
Year	**$PM_{2.5}$**	**SO_2**	**NO_x**	**$PM_{2.5}$**	**SO_2**	**NO_x**
2015	26,574	12,288	1,206	143,108	65,551	6,338

DOC Ex. 808 at 72 (Muller Direct), DOC Ex. 809 at NZM-2, p. 73, Table 14 (Muller Direct Attachments).

The Agencies also recommend that the ALJ find that the AP2 integrated assessment model (IAM), and the related data sources, parameters, and assumptions proposed by the Agencies, are reasonable and practicable to use because:

- AP2 is a reliable, peer-reviewed model;
- use of a reduced-form model such as AP2 appropriately balances simplicity and accuracy in the prediction of ambient pollutant concentrations;

- the modeling results are based on accurate spatial variability assumptions and data regarding emission source locations and attributes and accurately capture the distribution of damages across source locations;

- the modeling results are based on reliable data;

- AP2 has an appropriate scope with regard to the impacts analyzed, including exposure to both ambient $PM_{2.5}$ and ground level ozone (O_3);

- the modeling results reflect human health effects, including not only mortality risk but also morbidity (illness) states;

- the modeling results were based on reliable, transparent parameters for the concentration-response functions (which link exposures to estimated physical effects such as impacts on mortality rates) and the value of a statistical life (VSL) (which reflects the monetary value to an individual of a small change in their mortality risk);

- uncertainties in key parameters such as mortality risk and VSL were appropriately addressed by using estimated ranges of marginal damages that bracket what could be considered reasonable values for the per-ton damage estimates, rather than a single point;

- the modeling results reflect marginal (rather than average) damages;

- the modeling results are a reasonable reflection of all damages caused by the criteria pollutants, including damage occurring outside of Minnesota, and are not constrained to reflect damages only within an arbitrarily defined grid-box;

- because of its relatively simple structure, reduced-form models such as AP2 can perform multiple sensitivity analyses around a variety of different modeling assumptions so that the Commission can readily see how damages change when modeling assumptions are changed;

- AP2 performed as well as or superior to other proposed models including its ability to match its modeled ambient air concentrations with observed monitored pollution data.

The Agencies' recommendation conforms to the Commission's prior decisions that: (1) the parties to this proceeding should evaluate the environmental cost of pollutants using a damage cost approach;[1] (2) that, "having considered the relative merits of damage modeling

[1] MPUC Dockets E-999/CI-00-1636 and E-999/CI-14-643, *Notice and Order for Hearing* at 4-5 (October 15, 2014). The Commission stated, "[t]he Commission is persuaded that a damage-cost approach can be used for the emissions under investigation, and will therefore require it…."

approaches … [the Commission] prefers reduced-form modeling in this case" because, [w]hile the photochemical modeling approach may offer the greatest precision, its complexity renders it slower and more expensive than reduced-form modeling" and (3) that the Agencies' consultants must use reduced-form modeling to estimate damage costs.[2] The Agencies' recommendation satisfies the Commission's obligation, with respect to the criteria pollutants "to the extent practicable, [to] quantify and establish a range of environmental costs associated with each method of electricity generation." Minn. Stat. § 216B.2422, subd. 3.

III. PROCEDURAL HISTORY[3]

On February 10, 2014, the Commission issued an order in Docket No. E-999/CI-00-1636 reopening its investigation into environmental costs of different methods of generating electricity under Minn. Stat. § 216B.2422, subd. 3. The Commission determined that the investigation would be best resolved in the context of a contested case proceeding conducted by the Office of Administrative Hearings (OAH).[4]

On October 15, 2014, the Commission issued its *Notice and Order for Hearing* in which it referred the matter to OAH for a contested case proceeding, indicated that Administrative Law Judge (ALJ) LauraSue Schlatter was assigned,[5] and set forth the scope of the investigation, as follows:[6]

> The Commission will investigate the appropriate cost values for $PM_{2.5}$, SO_2, NO_x, and CO_2. …

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[2] *Id.* at 4-5.

[3] A complete procedural history—of both the CO_2 and criteria pollutant aspects of this contested case proceeding--is appended hereto as Attachment A.

[4] MPUC Docket E-999/CI-00-1636 and E-999/CI-14-643, *Order Reopening Investigation and Convening Stakeholder Group to Provide Recommendations for Contested Case Proceeding* at 3 and 5 (February 10, 2014).

[5] MPUC Docket E-999/CI-00-1636 and E-999/CI-14-643, *Notice and Order for Hearing, id.* at 5-6 and 8. (October 14, 2014). ALJ Jeffery Oxley also is assigned to the CO_2 matter.

[6] *Notice and Order for Hearing, id.*at 4-5.

> The Commission will require parties in the contested case proceeding to evaluate the costs using a damage cost approach, as opposed to (for example), market-based or cost-of-control values. … Where a damage cost can be reasonably estimated, it represents a superior method of valuing an emission's environmental cost. The Commission is persuaded that a damage-cost approach can be used for the emissions under investigation, and will therefore require it.

The Commission also authorized the Department, on a discretionary basis, to work with the Office of Management and Budget to retain a consultant under Minn. Stat. § 216B.62, subd. 8. If a consultant was retained, the Commission required that the consultant use reduced-form modeling to estimate damage costs.[7]

With respect to the criteria pollutants, $PM_{2.5}$, SO_2, and NO_x, the Commission directed parties to "thoroughly address:"[8]

- The appropriate values for $PM_{2.5}$, SO_2, and NO_x under Minn. Stat. § 216B.2422, subd. 3.

On March 27, 2015 the ALJ issued an *Order Regarding Burdens of Proof* that provides, in part, as follows:[9]

> 2. A party or parties proposing that the Commission adopt a new environmental cost value for one or more of the criteria pollutants – SO_2, NOx, and/or $PM_{2.5}$ – bears the burden of showing, by a preponderance of the evidence, that the cost value being proposed is reasonable, practicable, and the best available measure of the criteria pollutant's cost.
>
> 3. A party or parties proposing that the Commission retain any environmental cost value as currently assigned by the Commission bears the burden of showing, by a preponderance of the evidence, that the current value is reasonable and the best available measure to determine the applicable environmental cost.
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> . . . .
>
> 5. A party or parties, opposing a proposed environmental cost value must demonstrate, at a minimum, that the evidence offered in support of the proposed values is insufficient to amount to a preponderance of the evidence. …

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[7] *Notice and Order for Hearing, id*. at 5-6, 8.
[8] *Id.*
[9] MPUC Docket No. E-999/CI-14-643, *Order Regarding Burdens of Proof* at 2 -3 (March 27, 2015).

> 6. Any proponent of an environmental cost value, including existing environmental cost values, shall file direct testimony in support of its proposal according to the schedule set forth in the Second Prehearing Order in this matter.
>
> 7. A party advocating for retention of an existing cost value may not refer by reference to evidence or testimony from the Commission's CI-93-583 docket or related dockets, but must introduce any evidence on which it intends to rely in this docket, whether the evidence is drawn from an older docket or is new evidence.
>
> . . . .
>
> 10. The Administrative Law Judge incorporates the following portions of the Commission's Notice and Order for Hearing into this Order:
>
> > a. the parties will use a damage cost approach; and [Footnote omitted]
> > b. any DOC consultant must use reduced-form modeling. [Footnote omitted]

On January 12-14, 2016 the evidentiary hearing was held in the Commission's large hearing room.

IV. ARGUMENT

The Commission is required "to the extent practicable, [to] quantify and establish a range of environmental costs associated with each method of electricity generation." Minn. Stat. § 216B.2422, subd. 3. Each electric utility must use the environmental externality values in conjunction with other factors when evaluating resource options in all proceedings before the Commission. Minn. Stat. § 216B.2422, subd. 3(a). The most common application of environmental externalities is in electric utility Integrated Resource Planning (IRP).[10]

The ranges of values the Agencies recommend for $PM_{2.5}$, SO_2, and NO_x comport with Minn. Stat. § 216B.2422 subd. 3. The Agencies' recommendation fulfills the Commission's

[10] The Commission has also applied the estimates of environmental externalities to other analyses such as in large energy facility certificates of need and in the determination of the "value of solar." In this latter instance, the Commission employed the federal government Interagency Working Group's (IWG's) social cost of carbon (SCC) as one component in the methodology used to determine the appropriate rate that should be paid to distributed solar generation. Agencies Ex. 800 at 64 (Hanemann Direct).

directives[11] that the parties to this proceeding evaluate the environmental cost of emitted pollutants using a damage cost approach, and that the Agencies' consultants use reduced-form modeling to estimate damage costs. Reduced-form modeling, with its relative simplicity, makes an accurate analysis practicable, in part because an IAM using a reduced-form air quality module does not rely *solely* on a photochemical process IAM, but can use it, as the AP2 IAM does, as one test for verifying the accuracy of the AP2's estimates. The damage ranges estimated by AP2 are reasonable, practicable, and provide the best available estimates of each criteria pollutant's cost.

In contrast, the proposal of Northern States Power Company (Xcel) and its witness, Dr. William Desvousges, is impracticable because it is based entirely on the use of the Comprehensive Air Quality Model with Extensions (CAMx) model, a photochemical process model that, because of the large number of simulations required and the computational burden associated with photochemical process modeling, make CAMx ill-suited to the task. Xcel and its witness, Dr. Desvousges, modeled only three (hypothetical) plant locations,[12] and because the model didn't account for the significant heterogeneity in damages based on location of the emissions source, it inaccurately assumed that the resulting values were representative of all other (existing or future) source locations in the state. The Agencies' witness, Dr. Muller,

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[11] MPUC Dockets E-999/CI-00-1636 and E-999/CI-14-643, *Notice and Order for Hearing* at 4-5 (October 15, 2014). The Commission stated, "[t]he Commission is persuaded that a damage-cost approach can be used for the emissions under investigation, and will therefore require it" and "[t]he Commission will … require, if a consultant is retained, that the consultant use reduced-form modeling to estimate damage costs."

[12] Dr. Desvousges used only three hypothetical source locations, combined into one run the hypothetical plants at the Sherburne County and City of Marshall locations**, and** mistakenly modeled emissions from a hypothetical plant by combining SO_2 and NO_x rates from a coal-fired power plant and $PM_{2.5}$ emission rates from a natural gas plant. This approach is not representative of real emission rates. His claims notwithstanding, Dr. Desvousges did not use emissions and stack parameters identical to Sherco Unit 1. DOC Ex. 810 at 33-38 (Muller Rebuttal); DOC Ex. 813 at 3 (Muller Opening Statement).

explained that this erroneous assumption is not supported by the scientific literature, and resulted in an inaccurate proposed distribution of damages across source locations. DOC Ex. 810 at 33-36 (Muller Rebuttal); DOC Ex. 813 at 3 (Muller Opening Statement). Compounding that error, Xcel chose to count damages only within a grid-box that only included Minnesota and a few adjacent counties, which greatly reduced its damage estimates, and for which choice there is no scientific basis (*id*. at 2). The result of counting damages that occur only in the grid box is that Xcel proposed a known inaccurate damage value for the Commission to use in its proceedings. *Id*. at 2.

The Agencies' disagreement with the Clean Energy Organizations (CEO) and its witness, Dr. Julian Marshall, is limited and less substantive: Dr. Marshall should have included non-mortality and O_3 impacts and, to account for uncertainties associated with the mortality risk parameter and the VSL, should have employed a range of parameter values. *Id*. at 3.

1. THE AGENCIES' EXPERT WITNESS

The Agencies provided testimony from an expert environmental and natural resource economist, Dr. Nicholas Muller, who developed environmental cost estimates (also referred to as "damages") for SO_2, NO_x, and $PM_{2.5}$ emissions produced by fossil fuel-fired power plants in and near the state of Minnesota. Dr. Muller's testimony presented the methods that he used to develop damages, as well as the damage estimates themselves. DOC Ex. 808 at 2 (Muller Direct).

Dr. Muller is an Associate Professor of Economics with tenure at Middlebury College, a Research Associate with the National Bureau of Economic Research, and a Visiting Associate Professor of Economics at Carnegie Mellon University. Dr. Muller earned a B.S. degree with honors from the University of Oregon in Planning, Public Policy, and Management, and earned a Masters of Public Administration with joint specialization in public finance and environmental policy from the School of Public and Environmental Affairs at Indiana University-Bloomington. DOC Ex. 808 at1 (Muller Direct).

Dr. Muller earned a Ph.D. in environmental and natural resource economics from the School of Forestry and Environmental Studies at Yale University. His dissertation focused on modeling the damages from air pollution in the contiguous United States. He has served as a consultant to the National Academies of Science, the U.S. Department of Justice, and to environmental non-profit organizations. He has sub-contracted for the U.S. Environmental Protection Agency (EPA or USEPA) and the U.S. Department of the Interior. Since 2007, Dr. Muller has taught economics and environmental policy at Middlebury College, and he earned tenure in 2013. Dr. Muller has testified as an expert witness for the U.S. Department of Justice, and provided testimony as to the environmental and human health impacts from a large power plant's emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x). His curriculum vitae was included in the evidentiary record as DOC Ex. 809 at NZM-1 (Muller Direct Attachments). DOC Ex. 808 at 1-2 (Muller Direct).

2. THE ANALYTIC FRAMEWORK USED TO ASSESS AIR POLLUTION EXTERNALITIES

The Commission directed[13] that the parties to this proceeding evaluate the environmental cost of pollutants using a damage cost approach. Dr. Muller explained, from his perspective as an environmental economist, that the damage cost approach is appropriate because it is the approach typically employed to estimate the impacts from air pollution emissions: the basic idea is to use a computerized model that accomplishes the following tasks:

(1) documents where emissions occur and in what quantities,

[13] MPUC Dockets E-999/CI-00-1636 and E-999/CI-14-643, *Notice and Order for Hearing* at 4-5 (October 15, 2014). The Commission stated, "[t]he Commission is persuaded that a damage-cost approach can be used for the emissions under investigation, and will therefore require it."

(2) emulates how emitted pollutants form ambient air pollutants that have detrimental impacts on human health and the environment, and how these pollutants move or disperse through the environment,
(3) estimates the extent to which human populations and other receptors (e.g., crops) are exposed to this pollution,
(4) links exposure to specific health and other impacts, and
(5) monetizes those impacts.

Dr. Muller stated that the most common way these tasks are accomplished is by use of an IAM.

A. Overview of The Five Steps IAMs Take to Determine The Cost of Pollutants

IAMs simulate the relationship between emissions and impacts, and then monetize those impacts (referred to as damages). For decades, IAMs have been widely used by academics and policymakers to evaluate air pollution policies. DOC Ex. 808 at 4 (Muller Direct).

A standard air pollution IAM consists of five modules, said Dr. Muller, one for each step of the analysis. The steps in the model include: emissions, air quality modeling and ambient concentrations, exposures, human health and environmental impacts, and monetary valuation.

Figure 1

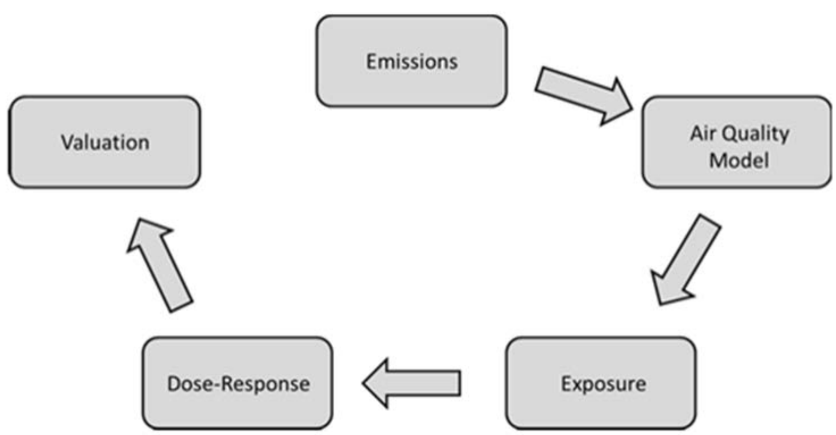

Figure 1: Structure of Integrated Assessment Model Applied to Air Pollution.

Source: Figure 1 in technical appendix

Dr. Muller's Figure 1 showed these steps. DOC Ex. 808 at 4-5 (Muller Direct).

The first step documents where and in what amounts emissions occur. DOC Ex. 808 at 6 (Muller Direct).

The second step, air quality modeling, connects those emissions to estimates of ambient pollutant concentrations -- the concentrations across space of harmful pollutants in the air. DOC Ex. 808 at 6 (Muller Direct). Researchers study pollution and connect emissions to estimates of ambient pollutant concentrations in the air. The application of an IAM for air pollution begins with the use of a baseline or business-as-usual (BAU) emission scenario. BAU emissions are used to establish *baseline* estimates of pollutant concentrations, exposures, physical effects, and monetary damages. DOC Ex. 808 at 7-8 (Muller Direct).

The third step tabulates exposures. This step combines the predicted spatial concentrations with data on entities that are sensitive to contact with ambient pollution. The exposure step requires spatially detailed data on populations that have been shown to exhibit sensitivity to air pollution exposure, most importantly human populations. DOC Ex. 808 at 6 (Muller Direct).

In the fourth step, exposures are then translated to physical environmental and health effects using "dose-response functions" (also called "concentration response functions"). DOC Ex. 808 at 6 (Muller Direct). Not every person that comes into contact with air pollution shows or incurs adverse effects. Instead, changes in air pollution affect the fraction of the population that is likely to be impacted by exposure. To estimate this effect, IAMs employ concentration-response relationships. These are typically mathematical functions that use ambient concentration estimates of air pollutants such as $PM_{2.5}$ and O_3 as inputs, and produce changes to the incidence rates of adverse effects, such as premature mortality or asthma exacerbations, as outputs. Importantly, the functions that are used in IAMs are drawn from peer-reviewed research in the relevant scientific field. So, for concentration-response relationships pertinent to human health, IAMs use results from the epidemiology or public health literature. DOC Ex. 808 at 6 (Muller Direct).

Finally, in the fifth step, the monetary cost of these environmental and health effects is estimated. DOC Ex. 808 at 6 (Muller Direct). This fifth step, in which physical impacts are converted to monetary values, is important because exposure to the air pollutants under examination in this analysis spans different types, categories, or classes of impacts. That is, both human health and agricultural yields are affected. To report total effects, an accurate analysis must aggregate or combine the two types of impacts. Therefore it is common to monetize impacts so that they may be combined and/or compared. DOC Ex. 808 at 7 (Muller Direct).

One standard to applying IAMs involves the researcher systematically increasing or decreasing emissions at a particular source(s), and then determining the subsequent change in concentrations, exposures, physical effects, and monetized damage throughout the geographic area where those emissions have potential impacts. This approach is embodied in the EPA's Section 812 benefit-cost analyses of the entire federal Clean Air Act and in several regulatory impact analyses published by EPA. DOC Ex. 808 at 8 (Muller Direct).

A slightly different strategy involves changing emission data inputs to the model by a small amount (one ton, for example) at one particular source. Resulting outcomes are also compared to an emission counterfactual: specifically, the researcher compares the resulting outcome to the conditions that existed prior to the additional ton. This method is employed in analyses that seek to estimate marginal (per ton) impacts of emissions of specific pollutants emitted by particular sources. DOC Ex. 808 at 8 (Muller Direct). This is the strategy that Dr. Muller has employed to estimate damage-cost values.

B. The Commission Correctly Determined That a Reduced-Form IAM is Preferable to a Photochemical Process Model For Purposes of Performing Air Quality Modeling.

The Commission has determined that, in this proceeding, the use of a reduced-form model is preferable to the use of a photochemical process model:[14]

> **The Commission, having considered the relative merits of damage modeling** approaches discussed by the Agencies, **prefers reduced-form modeling in this case.** While the photochemical modeling approach may offer the greatest precision, its complexity renders it slower and more expensive than reduced-form modeling.

Dr. Muller approached the question of which type of model to use from his perspective as an environmental scientist. Dr. Muller explained that there are two different approaches to estimating pollution damage that the Commission could have adopted: process modeling and reduced-form modeling. DOC Ex. 808 at 8-9 (Muller Direct).

Photochemical process modeling attempts to reflect the full complexity associated with a particular context, application, or setting (in this case the complex dynamics of the atmosphere). Dr. Muller indicated that the potential drawbacks to this approach involve the computational burden associated with modeling highly complex systems. Further, as the photochemical process model becomes more complicated, there is corresponding loss of transparency that makes detecting and fixing errors, biases, or other model problems more difficult. *Id.*

In contrast, reduced-form models seek to represent the essential elements of a process while maintaining a simple modeling structure. The key to this methodology is to capture aspects of the natural and physical processes that are critical in determining outcomes. Dr. Muller explained that, if this is accomplished, reduced-form models can produce credible results

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[14] MPUC Dockets E-999/CI-00-1636 and E-999/CI-14-643, *Notice and Order for Hearing* at 4 (October 15, 2014) (emphasis added).

at a fraction of the computational time and cost of photochemical process models without producing biased results. *Id*. at 9.

Dr. Muller testified that the choice of model depends on the context; in a context featuring many iterations of a model, reduced-form modeling may be the only feasible choice because of budgetary and time constraints. DOC Ex. 808 at 9 (Muller Direct). Dr. Muller opined that, in this proceeding, where there is a need to estimate damages from the emissions of multiple pollutants from multiple power generation facilities, reduced-form modeling is preferable to photochemical process modeling because the model must be executed numerous times. DOC Ex. 808 at 9, 13 (Muller Direct).[15]

Multiple model runs are required for two main reasons. First, the scientific literature on air pollution damage assessments shows that the impacts of emissions vary significantly according to the location of the emission source. Therefore, to detect differences in the damage of an emission, the IAM must model the emission according to the location where it is released. To isolate the effect of a particular source's emission, only one (real or hypothetical) plant's emissions can be changed at a time. If the emissions of multiple plants are changed in a single run, disentangling the effect of each plant would not be possible. As a result, the modeling approach involves systematically changing emissions at one location while holding all other emissions fixed. After each run, impacts are tabulated and emissions are reset to their baseline levels before moving on to the next location. *Id*. at 10.

[15] Although the Commission's October 15, 2014 Referral Order specifically requires the use of reduced-form modeling, which Dr. Muller used, he also used elements of photochemical process modeling to inform his results throughout the development of the reduced-form model and to check the performance of the reduced-form model against the output of a photochemical process model and thereby verify the reliability of the reduced-form model's predictions. DOC Ex. 808 at 9-10 (Muller Direct).

The second important reason for needing many model runs, said Dr. Muller, is that the toxicity of different pollution types varies. Because of this variability, changes to emissions are focused on one pollutant at a time, for each emission source. So, for each modeled power plant, the model is implemented once for each modeled pollutant. *Id.* at 11.

In the present proceeding, Dr. Muller said, over 1,500 distinct model runs may be needed because, to accurately account for the well-established fact that impacts of emissions vary significantly according to the location of the emission source, the AP2 model treats each of the eighty-seven counties in Minnesota as a location of an emission source, as well as six existing large Minnesota power plants. *Id.* In addition, the AP2 IAM modeled almost 400 sources and source locations outside of the state. Multiplying these approximately 500 sources by the three different pollutants at issue yields about 1,500 model runs. *Id.*

Further, Dr. Muller explained, any reasonable implementation of any IAM is accompanied by an assessment of the "sensitivity" of the results to different parameter values in the IAM (such as the monetary value attributed to mortality risk – the VSL -- and the effect of exposure on mortality rates);[16] as a result, the 1,500 model runs are increased to 3,000 or 4,500 runs if two or three different parameters are tested. *Id*. In summary, because of the large number of simulations required of any model in this context, and the computational burden associated with photochemical process modeling, this analysis is well-suited to reduced-form modeling. Reduced-form modeling, with its relative simplicity makes an accurate analysis practicable, while reliance *solely* on a photochemical process model does not.

This is not to say that photochemical process IAMs have no place in the analysis. Dr. Muller explained that he used elements of photochemical process modeling to inform his results

[16] Sensitivity testing is discussed in detail section IV.5.C of this Initial Brief.

throughout development of the reduced-form model. DOC Ex. 808 at 9-10 (Muller Direct). Indeed, in reduced-form and photochemical process IAMs, four of the five steps and data sources shown in Dr. Muller's above Figure 1, in most applications of IAMs to air pollution, are nearly identical. DOC Ex. 808 at 11-12 (Muller Direct). It is only in the air quality modeling step that there are differences between reduced-form and photochemical process models.

In the air quality modeling step, there are three distinctions between the use of photochemical process air quality models and the air quality step of reduced-form IAMs: time, space, and chemistry. *Id.* at 11-12. For AP2, the time dimension is annual and seasonal averages; the spatial dimension is the county; and chemical reactions are modeled using constant conversion rates. *Id.* at 21. In contrast, a typical photochemical process air quality model defines space in terms of a grid (usually 12 km by 12 km), time is modeled in steps that may be as finely grained as a single minute, and these models contain explicit characterizations of atmospheric chemistry rather than constant rates of conversion. *Id.*

The Commission correctly determined that the complexity of a photochemical model is not necessary or appropriate for this proceeding. As indicated by Dr. Muller, the inputs to the subsequent modeling step of translating exposures to impacts generally do not use such temporally-specific ambient air concentration as inputs; rather it uses annual or seasonal averages. DOC Ex. 811 at 2-4 (Muller Surrebuttal).

3. THE AGENCIES RECOMMEND USE OF THE RESULTS OF THE AP2 IAM AS ENVIRONMENTAL COST VALUE ESTIMATES.

The Agencies, for several reasons, recommend using Dr. Muller's results using the AP2 model for the estimation of damages.

A. The AP2 IAM is Reliable.

First, the AP2 IAM, and its earlier version, APEEP, is reliable because it has been used in many peer-reviewed studies. DOC Ex. 808 at 12 (Muller Direct). See also DOC Ex. 809 at NZM-2 (Muller Direct Attachments). The National Academies of Science's National Research Council used APEEP in a large study of the social costs of energy production and use. DOC Ex. 808 at 12 (Muller Direct). Other reduced-form models have been used in the peer-reviewed literature by researchers interested in estimating the monetary damages from exposure to air pollution. Dr. Muller testified about other prominent examples of peer-reviewed publications featuring reduced-form models. DOC Ex. 808 at 12-13 (Muller Direct).

B. The AP2 IAM Has an Accurate, Relatively Simple, Air Quality Model.

The AP2 IAM uses an air quality model that connects emissions to concentration estimates and appropriately balances simplicity and accuracy in the prediction of ambient pollutant concentrations. Dr. Muller detailed the manner in which the AP2 model translates emissions to ambient concentration estimates and the extent to which the AP2 model compares favorably in a rigorous comparison with (1) a photochemical process air quality model, and (2) actual readings of the EPA's air quality monitors. DOC Ex. 809 at NZM-2 (Muller Direct Attachments); DOC Ex. 808 at 13-14, 20-36 (Muller Direct). This topic is addressed more fully below, in section IV 4 of this Initial Brief.

C. The AP2 IAM Used Reliable Data.

Third, AP2 employs data and parameter values that are reliable because they are widely used in the scientific literature that estimates the damages from air pollution (EPA, 1999, 2011). Dr. Muller explained that the AP2 model in this proceeding used 2011 data, including the EPA's 2011 emission data (the most recent year for which EPA has published a detailed emissions inventory), and 2011 population and vital statistics data. It also used the EPA's monitor readings for local air pollution (EPA, 2015e). Dr. Muller provided the details about the data used in AP2 and the sources of the data. DOC Ex. 809 at NZM-2, pp. 9 – 51 (Muller Direct Attachments); DOC Ex. 808 at 13-14 (Muller Direct).

D. The AP2 IAM Analyzed Exposure to Both $PM_{2.5}$ and O_3.

Fourth, the AP2 IAM has an appropriate scope with respect to the impacts included. The impacts analyzed in AP2 are the exposure to both ambient $PM_{2.5}$ and ground level ozone (O_3). Dr. Muller explained that exposures to $PM_{2.5}$ and O_3 capture the major impacts of emissions of NO_x, SO_2, and $PM_{2.5}$.

Dr. Muller explained that past research into the impacts of these two pollutants identified several categories of effects, including adverse impacts on human health (both premature mortality and illness), reduced crop and timber yields, reduced visibility, and acidification. These impacts were included in the analysis Dr. Muller performed using AP2. DOC Ex. 808 at 14 (Muller Direct).

CEO's Witness, Dr. Marshall, in contrast, incorporated only the effects of exposure to $PM_{2.5}$ on adult mortality rates into his damage estimates. He omitted from his analysis O_3, which is known to impact mortality and illness rates, as well as crop yields. These effects, explained Dr. Muller,[17] comprise approximately 10 percent of the damages from NO_x emissions. DOC Ex. 810 at 11-12 (Muller Rebuttal) (*citing* CEO Ex. 115 at 22-23 (Marshall Direct)).

E. The AP2 Model Included Morbidity And Agricultural Impacts.

Fifth, the AP2 IAM included morbidity as well as impacts to agriculture. Dr. Muller explained the specific illness states that he analyzed using AP2, including respiratory and cardiovascular effects, the two primary pathways for the association between exposure and

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[17] *See also* tables 3, 4, and 5 of DOC Ex. 809 at NZM-2 (Muller Direct) (listing health and agricultural impacts due to O_3 exposure modeled by the EPA or in Dr. Muller's analysis).

illness. DOC Ex. 809 at NZM-2, pp. 25-26 and 30-31 (Muller Direct Attachments). The crop impacts examined by Dr. Muller show that O_3 has adverse consequences on the yield of several economically important crops, including barley, corn, potatoes, soybeans, and spring wheat, each of which is an important component of the food supply.[18] DOC Ex. 808 at 14-15 (Muller Direct).

CEO Witness, Dr. Marshall, in contrast, incorporated only the effects of exposure to $PM_{2.5}$ on adult mortality rates into his damage estimates. This limited analysis omitted other environmental and social consequences of exposure, including the effects on rates of illness and reductions in yields of agricultural crops.

Dr. Muller's opinion is that these impacts should have been included; they are included in the EPA's regulatory impact analyses. He observed, however, that the result of not including these other effects is likely to be small. In the empirical analysis Dr. Muller conducted, morbidity effects contributed less than five percent of total impacts. DOC Ex. 810 at 11-12 (Muller Rebuttal) (*citing* CEO Ex. 115 at 22-23 (Marshall Direct)).

F. The AP2 Model is Accurate and Practicable.

Sixth, the AP2 model is practicable: because it is a reduced-form model, it can readily analyze an appropriate geographic scope of numerous emissions sources and exposures. The geographic scope of the analysis provided for this proceeding encompasses source locations in Minnesota as well as source locations in the contiguous U.S. that are within 200 miles of the state. The choice of 200 miles from the state of Minnesota as the limit of the sources included in the analysis stems from the use of this scope in*: In the Matter of the Quantification of Environmental Costs Pursuant to Laws of Minnesota 1993, Chapter 356, Section 3*, Docket No.

[18] Visibility effects, timber yields, and acidification were not included because they contribute a very small share to total damage, and because they rely on modeling techniques which, Dr. Muller explained, are quite uncertain. In his view, introducing considerable uncertainty to capture a very small additional component of damage is not justified. DOC Ex. 808 at 15 (Muller Direct).

E-999/CI-93-583, Order Establishing Environmental Cost Values, (Issued: January 3, 1997) and the related ALJ's Report upon which that Order was based. Generally, the use of 200 miles as the limit of sources within the analysis is based on the notion that emissions from these sources potentially have a meaningful effect on air quality in Minnesota, and that power generated by these sources may meet electricity demand in Minnesota. DOC Ex. 808 at 15-16 (Muller Direct). Dr. Muller provided these estimates for sources within and outside of Minnesota in order to give the Commission more options in terms of which sources to apply the estimates. The Commission may choose to disregard the damage values for some, all, or none of the sources outside of Minnesota. Including or excluding estimates for sources outside of Minnesota does not change the estimates for sources within Minnesota.

G. The AP2 Model Can Accurately Assess Future Impacts

Seventh, impacts are readily computed by the AP2 model not only for 2011, but also for future years. Dr. Muller estimated future marginal damages for 2015, 2020, 2025, 2030, 2035, and 2040, so, should it choose to do so, the Commission would be able to explore how damages change as population, vital statistics, and income change. *Id.* at 16.

H. Dr. Muller Chose Reliable Parameters.

Eighth, and most importantly, Dr. Muller chose input values and model assumptions regarding (1) the connection between pollution exposure and mortality rates (the concentration-response parameter) and (2) the monetary value attributed to mortality risk (the VSL) that are valid and reasonable because they have been used in many prior peer-reviewed studies. This is important because these two parameters have the most pronounced effect on the damage estimates determined by AP2 and the other models. Dr. Muller explained that the most widely-cited research on the first of these parameters, the connection of pollution exposure and mortality rates, features two studies: the American Cancer Society study and the Harvard Six-Cities study.

These are long-running analyses that have been subject to many rounds of peer-review. Further, their findings have been used by the EPA in multiple analyses of air pollution impacts. The research on the second parameter, the monetary values attributable to mortality risk, is also a mature field. Research in this area has been active since the 1970's. The values Dr. Muller used are representative of the two methodological approaches often used to develop these values, stated-preference and revealed-preference methods. DOC Ex. 808 at 17, 36-44 (Muller Direct).

I. The AP2 Model Calculated Marginal Damages.

Ninth, AP2 estimated the impacts of SO_2, NO_x, and $PM_{2.5}$ emissions in terms of marginal damages per ton emitted. Marginal damages (rather than average values) are preferable because integrated resource planning involves modeling incremental resource additions or subtractions for which per-ton or incremental measures of pollution impact can be applied. In microeconomics, the term "marginal" refers to a small change to an existing level of some variable. Marginal damages provide a credible estimate of impacts from an emission source if the quantity of emissions from that source is changed by a discrete incremental amount.

To determine marginal damage, Dr. Muller first determined ambient concentrations, exposures, physical impacts, and damages associated with baseline emissions for a particular source or source group. He then added a ton of a pollutant, such as SO_2, to the source's baseline emissions, after which he determined the changes in each of ambient concentrations of $PM_{2.5}$ and O_3, exposures to these ambient pollutants, human health and environmental impacts, and monetary damages. The measure of the change is a marginal damage. Because the only change from the baseline is the additional emitted ton, a change in damages estimated by AP2 is strictly attributable to the added ton emitted by the specific source. DOC Ex. 808 at 18 (Muller Direct).

Dr. Muller explained that an alternative to the calculation of marginal damages would be to compute average damages for each source and pollutant, and that prior research has shown that the average and marginal damages for the pollutants covered in the analysis are quite similar. DOC Ex. 808 at 17 (Muller Direct). However, marginal damages more accurately reflect the damage, over a baseline of existing damage, of an additional emitted ton of a pollutant since the damages of that ton are not averaged with previous emissions. *Id.* at 17-18. Dr. Desvousges' and Dr. Marshall's estimates also reflect marginal damages.

J. The AP2 Model Can Produce Damage Estimates for Existing and Future Proposed Emission Source Locations and Attributes.

The sources of air pollution modeled in the AP2 analysis includes a sample of particularly large electric generating units that are modeled at the plant level, and smaller facilities modeled according to the county in which they are located. In addition, because the damages were determined for purposes of electric power resource planning, marginal damages were also calculated for each county in Minnesota, whether or not an active power plant was located in the county, for each pollutant. *Id*.

AP2 has the functionality to sample very large industrial point sources at the plant level. In this proceeding, this functionality was used to apply AP2 to six large power plants within the state of Minnesota. These emission sources were the: Sherburne County (also known as Sherco), Riverside, Black Dog, Clay Boswell, A.S. King, and High Bridge power plants. *Id.* at 18. These plants have an effective height of emissions of over 500 meters under average local weather conditions. Effective height is defined as stack height plus plume rise. DOC Ex. 808 at 19 (Muller Direct). The capacity of AP2 to analyze very large industrial point sources at the plant level was also used in this proceeding to compute marginal damages for large power plants within 200 miles of the state border of Minnesota. The full list of these plants is shown in DOC Ex. 809 at NZM-2, p. 46 (Muller Direct Attachments); DOC Ex. 808 at 19 (Muller Direct).

In addition, the AP2 model estimated marginal damages for $PM_{2.5}$, NO_x, and SO_2 for every county in the state of Minnesota. Dr. Muller explained that power plants currently operate in some counties; the marginal damages calculated by AP2 for those counties represent these plants. For counties with no operational power plants; the marginal damages for each of those counties represent the damage from emissions if a power plant were to be located in that county in the future. Thus, the marginal damage estimates produced for counties currently without plants are planning values the Commission can use in resource planning and resource acquisition proceedings. DOC Ex. 808 at 18-19 (Muller Direct).

In addition, marginal damages are estimated for each pollutant emitted from all counties within 200 miles of the state of Minnesota. The purpose of computing these county-based marginal damages is the same as for those counties within the state of Minnesota. If a county currently has an active power plant, the marginal damages represent the damages from that plant(s). If a county does not have a plant, then the marginal damages reflect planning values that indicate what the damages from emissions would be if a power plant were located in each county in the future. *Id*. at 19-20.

K. Appropriate Geographic Range of Damages.

Using AP2, Dr. Muller appropriately calculated all damages. In contrast, Xcel Witness, Dr. Desvousges, employed a small grid box for use with CAMx, and he did not count any damages beyond the grid box. His stated rationale for this was that he had attempted to replicate the study area of the original environmental cost study performed in the 1990s. DOC Ex. 810 at 26-27 (Muller Rebuttal); DOC Ex. 811 at 12 (Muller Surrebuttal).

Dr. Muller disagreed with the use of this grid-box approach for the current investigation, explaining that there is no scientific basis for limiting the damages considered to this small area. Further, he said, he knew of no practical reason to limit the analysis produced by a state-of-the-science photochemical air quality model to a geographically-constrained grid box solely because of precedent. There is no need to be consistent with modeling limitations that existed in the 1990's. DOC Ex. 813 at 3 (Muller Opening Statement); DOC Ex. 810 at 26-27 (Muller Rebuttal) (*citing* Xcel Ex. 604 at 20 (Desvousges Direct); DOC Ex. 811 at 12 (Muller Surrebuttal).

Moreover, Dr. Muller explained, the use of the grid box was inconsistent with Dr. Desvousges' own analysis; in numerous places, Dr. Desvousges' analysis showed that emissions produced by the source locations he modeled reached beyond the grid box.[19] As a result, impacts were missed, or omitted, from Dr. Desvousges' analysis, and the environmental cost values estimated by Dr. Desvousges are lower than they would be if the scope of damages was not so geographically constrained. DOC Ex. 810 at 28-29 (Muller Rebuttal).

Dr. Muller opined that there is no scientific basis for the artificial truncation of the analysis based on the limits of the box Dr. Desvousges drew around Minnesota. DOC Ex. 810 at 27-29 (Muller Rebuttal). Dr. Muller did not find compelling the justification that Dr. Desvousges offered -- of adherence to a methodology used in the first study on the

[19] Dr. Muller pointed, for example, to Figure 2.4 in Xcel Ex. 604 at WHD-1, Schedule 2, p. 24 (Desvousges Direct), which shows the effects of emissions from the three hypothetical electric generating units on air quality within the model domain box. Focusing on the left-hand column of the Figure, in the western margin of the top two graphs, concentrations gradually decline with distance from the facility location. For the top left Figure, concentrations decline as emissions move westward from the plant from 0.02 micrograms per cubic meter (shown in orange) smoothly to lighter orange, yellow, green, and then blue. Similar effects are observed at the western margin of the left-center plot and in the northeastern margin for the bottom left plot. *In contrast, the southern and southeastern margins of these Figures, which correspond directly to the spatial limits of the grid box are artificially truncated where the effect of emissions from these plants is still between 0.005 and 0.01 micrograms per cubic meter.* DOC Ex. 810 at 26-28 (Muller Rebuttal). Dr. Muller provided numerous other examples showing that Dr. Desvousges was aware that SO2, NOx, and PM2.5 flow across the boundaries of the grid box. DOC Ex. 810 at 29-32 (Muller Rebuttal); DOC Ex. 811 at 12-15 (Muller Surrebuttal).

environmental cost values for emissions from power plants in Minnesota that was conducted some twenty years ago. DOC Ex. 810 at 32 (Muller Rebuttal).

Finally, Dr. Muller explained that the EPA's modeling has shown that the CAMx model predicted impacts from NO_x emissions on ambient $PM_{2.5}$ in many distant states such as Colorado, Connecticut, Wyoming, Florida, and Texas (among other states) due to emissions from plants in Minnesota. This directly refutes Dr. Desvousges' claim that impacts of NO_x and SO_2 emissions are local. DOC Ex. 811 at 15 (Muller Surrebuttal).

4. THE AP2 AIR QUALITY MODEL ESTIMATED AMBIENT POLLUTION CONCENTRATIONS AS WELL AS OR BETTER THAN CAMX.

Despite its reduced-form functions, the air quality model in AP2 is effective at replicating or surpassing the quality of the $PM_{2.5}$ predictions generated by a photochemical process air quality model. DOC Ex. 808 at 22 (Muller Direct). The Agencies recommend adoption of Dr. Muller's modeling results using AP2 in part because of the model's good performance combined with ease of use and transparency.

A. A General Description of the AP2 Air Quality Model.

Dr. Muller provided a general explanation of how the data in AP2's air quality model is organized: it is organized in a transparent manner, as a simple table, based on geographic distinctions. Rows of the table represent pollutant sources, and columns represent locations receiving pollution. Locations receiving pollution are the counties in the lower 48 states. Within this structure, each entry in the matrix characterizes how air pollution concentrations in a particular location change for each ton emitted from a specified source. The sum across all columns within a particular row indicates how air pollution levels change in all locations due to a one-ton emission from a source. Conversely, the sum across all rows within a particular column, indicates how air pollution concentrations in a county change due to a one ton emission from all sources. DOC Ex. 808 at 20 (Muller Direct).

The relationships embodied in the matrix reflect annual and seasonal averages which are derived using location-specific average weather data such as wind direction, wind speed, and temperature. The goal of using average weather data is to attempt to emulate typical conditions that are important in dictating how pollution moves in the atmosphere. DOC Ex. 808 at 20 (Muller Direct).

The air quality modeling accounts for the conversion of emitted pollutants into other substances. In particular, some gases discharged by power plants are reactive. They combine with other substances in the atmosphere to form different pollutants. For example, SO_2 emissions combine with ambient ammonium to form ammonium sulfate, which is an important component of $PM_{2.5}$. AP2 represents these (and other) reactions using constant rates of conversion that are defined as a function of wind speed. DOC Ex. 808 at 21 (Muller Direct).

To summarize, the reduced-form elements of AP2 include the time dimension, which is annual and seasonal averages; the spatial dimension, which is the county; and chemical reactions, which are modeled using constant conversion rates. *Id.*[20]

B. Performance of the AP2 Air Quality Model— $PM_{2.5}$ and O_3.

The air quality model in AP2 replicates or surpasses the quality of the ambient $PM_{2.5}$ predictions generated by the air quality model of CAMx. DOC Ex. 808 at 22 (Muller Direct). As

[20] In contrast, a typical photochemical process air quality model, including CAMx, defines space in terms of a grid (usually 12 km by 12 km), and time is modeled in steps that may be as finely grained as a minute. Photochemical models contain explicit characterizations of atmospheric chemistry rather than constant rates of conversion. Photochemical air models are designed to explicitly emulate environmental conditions to a different degree of detail than a reduced-form air model like AP2. DOC Ex. 808 at 21 (Muller Direct).

previously noted, the Agencies recommend adoption of AP2 in part because of its good performance combined with ease of use and transparency.

Dr. Muller explained the process he followed to assess the performance of AP2's air quality model. He compared the AP2 concentration estimates with two alternative sources of ambient concentration estimates. First, Dr. Muller evaluated the AP2 2011 output against 2011 output from CAMx, a state-of-the-art process model often used by the EPA and the Minnesota Pollution Control Agency (EPA 2015a).[21] This evaluation was performed for both of the ambient pollutants modeled in the analysis: $PM_{2.5}$ (inclusive of total $PM_{2.5}$, sulfate and nitrate), and O_3. Second, Dr. Muller evaluated AP2 results against data consisting of ambient monitor readings that are publicly available from the EPA. These data are actual readings of pollution from various locations in the United States in 2011. DOC Ex. 808 at 22 (Muller Direct).

1. The AP2 air quality model was shown to perform well when testing for $PM_{2.5}$, using mean fractional bias (MFB) and the mean fractional error (MFE).

Dr. Muller explained how he evaluated the relative performance of the air quality modules in AP2 and CAMx. He evaluated the models' performance according to two standard statistical measures, the mean fractional bias (MFB) and the mean fractional error (MFE). The formulas used to calculate MFB and MFE are shown in DOC Ex. 809 at NZM-2, p. 12 (Muller Direct Attachments). DOC Ex. 808 at 23 (Muller Direct). These two diagnostics have been established in prior air quality modeling performance studies. Using the MFB and MFE metrics,

[21] "Regulatory Impact Analysis of the Final Revisions to the National Ambient Air Quality Standards for Ground-Level Ozone." EPA-452/R-15-007. Office of Air and Radiation, Office of Air Quality Planning and Standards. Research Triangle Park, NC, 27711 (EPA 2015a).

model performance is judged, said Dr. Muller, according to the following standards described in authoritative work of Boylan and Russell, 2006:[22]

> *"the model performance goal for major components of $PM_{2.5}$ has been met when both the mean fractional error (MFE) and the mean fractional bias (MFB) are less than or equal to approximately +50% and ± 30%, respectively."*

Again, directly quoting from Boylan and Russell (2006):

> *"the model performance criteria for major components of $PM_{2.5}$ has been met when both the mean fractional error (MFE) and the mean fractional bias (MFB) are less than or equal to approximately +75% and ± 60%, respectively."*

DOC Ex. 808 at 23 (Muller Direct).

Dr. Muller pointed out that the performance *goals* are more stringent than performance *criteria*. Thus, the two standards reflect different degrees of stringency with respect to model evaluation. In particular, the performance goals embody or reflect the level of accuracy that is "close to the best a model can be expected to achieve;" the goals establish a very high standard for evaluation of a model. The model performance *criteria* indicate an acceptable level of accuracy for modeling applications. While less stringent than the model performance goals, the criteria provide a standard for establishing adequate performance of a model. DOC Ex. 808 at 23-24 (Muller Direct). Dr. Muller evaluated AP2's county-level ambient concentration estimates at three spatial scales: (1) all states in the contiguous U.S.; (2) states within the Great Plains and Great Lakes U.S. Bureau of Economic Analysts (USBEA) regions; and (3) within Minnesota. DOC Ex. 808 at 24 (Muller Direct). The results of the air quality model performance evaluation that compares the $PM_{2.5}$ predictions of AP2 against those of CAMx shows that AP2 performs very well.

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[22] Boylan, James W., and Armistead G. Russell, "PM and light extinction model performance metrics, goals, and criteria for three-dimensional air quality models." *Atmospheric Environment* 40.26: 4946-4959, 2006.

Table 1 in Dr. Muller's Direct Testimony, reproduced below, shows the results of the $PM_{2.5}$ estimation comparison of AP2 and CAMx. AP2 predicted national average $PM_{2.5}$ levels that are about 2.5% lower than CAMx (8.12 versus 8.33 μg/m3). Both the MFB and MFE results are well within the model performance goals set forth in Boylan and Russell (2006). This implies that AP2 performed "close to the best a model can be expected to achieve," relative to the CAMx model. DOC Ex. 808 at 24-25 (Muller Direct).

Table 1: Air Quality Model Diagnostics: AP2 and CAMx Comparison for $PM_{2.5}$

Region	AP2 Estimate ($\mu g/m^3$)	CAMx Estimate ($\mu g/m^3$)	MFB	MFE	Rho	PE (Rho)	N
National	8.12[A] (3.48)[B]	8.33 (2.83)	0.05	0.20	0.80	0.88	3,109
Great Lakes & Great Plains	9.13 (3.52)	9.37 (2.48)	0.07	0.18	0.83	0.99	972
Minnesota	9.72 (4.23)	8.87 (1.92)	0.01	0.27	0.79	0.99	87

A = arithmetic mean; B = standard deviation; N = number of counties.

DOC Ex. 808 at 25 (Muller Direct). DOC Ex. 809 at NZM-2, p. 81, Table 17 (Muller Direct Attachments).

2. The AP2 air quality model performed well when testing $PM_{2.5}$ results using two additional diagnostics.

Dr. Muller subjected AP2 and CAMx to two additional diagnostics, the results of which are also provided in Table 1 above. Both of these diagnostic tests are described in detail in DOC Ex. 809 at NZM-2, p. 15 (Muller Direct Attachments)).

The correlation (shown as "Rho" in Table 1) is a standard measure, used in applied statistical analyses, of the association between two variables. This measure can range from -1 to 1. Two variables are said to be "positively correlated" if higher-than-average values of one variable tend to occur with higher-than-average values of the other variable. Dr. Muller explained that this is an intuitive and useful check in the current context, because one could conclude the AP2 air quality model results were consistent with the CAMx air quality model results if, in counties where CAMx predicted higher-than-average $PM_{2.5}$ levels, AP2 did too, and vice versa. In that case, the predictions of the two models are considered positively correlated across space. As can be seen in Table 1, this diagnostic showed that the correlation at the national level is 0.80, which is evidence of a strong positive correlation between the two models. DOC Ex. 808 at 25 (Muller Direct). The AP2 air quality model can be said to replicate the CAMx air quality model because, in counties where AP2 predicted higher-than average $PM_{2.5}$ levels, CAMx did too, and vice versa.

The next column of Table 1 shows the population-weighted exposure (PE) measure, which, Dr. Muller explained, "digs a bit deeper" into the performance of the two models. This diagnostic is helpful because ultimately, he said, damages are primarily a function of adverse human health effects. The PE metric is computed to ascertain whether the predicted exposures of human populations to ambient pollution produced by the two models are correlated. This is a measure of population exposure used in the peer-reviewed literature. Dr. Muller reported that the results of this diagnostic suggest that, at the national level, the population exposures predicted by the two models are *very highly positively* correlated. DOC Ex. 808 at 25-26 (Muller Direct).

Table 1 also shows the results when AP2 is evaluated just within the Great Lakes and Great Plains regions. Over the nearly 1,000 counties within these regions, AP2 also achieved the model performance goals described above. Both CAMx and AP2 predicted higher $PM_{2.5}$ levels within these regions than the national average. The Rho value increases slightly (relative to the national level) to 0.83. And the Rho for population exposure indicates that the predictions from the two models are almost perfectly positively correlated. Dr. Muller explained that this means that the spatial pattern of population exposure produced by the two models was strikingly similar. DOC Ex. 808 at 26 (Muller Direct).

The final tests reported in Table 1 are for the 87 counties in Minnesota. Here too AP2 achieved the model performance goals. The MFB value of 0.01 indicates that AP2 produced nearly unbiased results when compared to the CAMx photochemical process model. Again, the model-predicted $PM_{2.5}$ levels are positively correlated and the PE results suggest near perfect positive correlation between the output of the models in terms of population exposure, which is ultimately most important to the eventual estimation of effects on human health. DOC Ex. 808A and 808 at 26 (Muller Direct).

3. The AP2 air quality model performed well, effectively replicating or matching estimates of the sulfate and nitrate species of $PM_{2.5}$ relative to CAMx.

Dr. Muller also performed diagnostics on the sulfate and nitrate species of $PM_{2.5}$ and prepared a second table, Table 2 to his Direct Testimony, which compares the predictions of sulfate and nitrate $PM_{2.5}$ produced by the AP2 and CAMx models. This separate analysis is helpful for comparing the performance of AP2 and CAMx, he explained, because $PM_{2.5}$ is comprised of several different components, or species. Sulfate and nitrate are the most important of these species because the Commission requires damage estimates for NO_x and SO_2. Emissions of these pollutants directly contribute to concentrations of nitrate and sulfate $PM_{2.5}$, respectively. DOC Ex. 808 at 27 (Muller Direct).

Table 2, which is reproduced below, is like Table 1 above, in that the results are arranged according to national, regional, and state spatial scales. As can be seen, AP2 performed well when compared with CAMx. For both species and for each spatial scale, the MFB and MFE diagnostics suggest that AP2 performed according to the very stringent model performance goals in all but two categories (sulfate $PM_{2.5}$ in the state of Minnesota and nitrate $PM_{2.5}$ at the national scale). And, in those two cases AP2 remained well within the model performance criterion. Dr. Muller explained that this result shows that the model performed acceptably relative to CAMx. *Id*.

The AP2 model also performed well compared with CAMx using the alternative diagnostics. At each spatial scale, the sulfate predictions of AP2 are strongly positively correlated with those produced by CAMx, and the computed Rho values are 0.89 or higher. The population exposure correlations are all above 0.90 for sulfate. For each spatial scale, AP2's predictions for nitrate are less strongly correlated than for sulfate, but the AP2 model meets the model performance criteria at each scale for nitrate. DOC Ex. 808 at 27-28 (Muller Direct).

Table 2: Air Quality Model Diagnostics: AP2 and CAMx Comparison for Major $PM_{2.5}$ Species

National	**AP2 Estimate ($\mu g/m^3$)**	**CAMx Estimate ($\mu g/m^3$)**	**MFB**	**MFE**	**Rho**	**PE (Rho)**	**N**
Sulfate	1.81[A] (1.17)[B]	1.75 (0.65)	-0.16	0.36	0.91	0.94	3,109
Nitrate	1.00 (0.70)	0.98 (0.69)	0.05	0.56	0.62	0.76	3,109
Great Lakes & Great Plains	**AP2**	**CAMx**	**MFB**	**MFE**	**Rho**	**PE (Rho)**	**N**
Sulfate	1.64 (1.10)	1.72 (0.58)	-0.21	0.34	0.96	0.99	972
Nitrate	1.54 (0.73)	1.70 (0.57)	-0.12	0.34	0.37	0.96	972
Minnesota	**AP2**	**CAMx**	**MFB**	**MFE**	**Rho**	**PE (Rho)**	**N**
Sulfate	0.91 (0.30)	1.37 (0.14)	-0.44	0.44	0.89	0.99	87
Nitrate	1.76 (1.19)	1.88 (0.46)	-0.16	0.32	0.43	0.97	87

A = arithmetic mean; B = standard deviation; N = number of counties.

DOC Ex. 808 at 27-28 (Muller Direct); DOC Ex. 809 at NZM-2, p. 83, Table 18 (Muller Direct Attachments).

4. The AP2 air quality model performed well with respect to total $PM_{2.5}$, effectively replicating or matching EPA air quality monitoring data.

AP2 performed as well as CAMx when evaluated against the U.S. EPA's air pollution monitoring data for 2011. These data (known as Air Quality System data or "AQS data") are actual measurements of $PM_{2.5}$ from the ambient air in the U.S. in 2011. Dr. Muller prepared a third table, Table 3, which is reproduced below. Table 3 summarizes the comparison of predictions by AP2 and CAMx for total $PM_{2.5}$ with the U.S. EPA's air pollution monitoring data for total $PM_{2.5}$ for 2011. DOC Ex. 808 at 28 (Muller Direct).

Table 3: Air Quality Model Diagnostics: AP2, CAMx, and AQS Comparison for Total $PM_{2.5}$

	Summary Statistics			AP2[C]			CAMx[C]			
Spatial Scale	**AP2 Est.** ($\mu g/m^3$)	**CAMx Est.** ($\mu g/m^3$)	**AQS observed value** ($\mu g/m^3$)	**MFB**	**MFE**	**Rho**	**MFB**	**MFE**	**Rho**	**N**
National	8.72[A] (4.06)[B]	9.07 (3.55)	9.63 (2.41)	-0.18	0.32	0.56	-0.12	0.27	0.52	606
Great Lakes & Great Plains	10.69 (4.08)	10.87 (2.68)	9.99 (2.31)	0.02	0.22	0.59	0.08	0.14	0.77	142
Minnesota	11.53 (5.21)	10.78 (3.01)	8.09 (1.76)	0.26	0.40	0.72	0.27	0.28	0.83	10

A = arithmetic mean; B = standard deviation; C = model diagnostics using AQS monitoring data; N = number of counties.

DOC Ex. 808 at 28 (Muller Direct); DOC Ex. 809 at NZM-2, p. 84, Table 19 (Muller Direct Attachments). As can be seen in Table 3, beginning at the national scale, AP2 and CAMx performed to a similar degree of accuracy when evaluated against the AQS monitoring data. The national scale involves EPA monitor readings from all of the 606 counties in the U.S. within which the EPA's $PM_{2.5}$ monitoring stations are located, and annual average $PM_{2.5}$ levels are used in the comparison. Dr. Muller explained that both models performed within the model performance goals established above, although AP2 predictions are slightly more strongly correlated with the AQS data than CAMx's predictions. At the regional scale, again, both models performed within the performance goals.[23] DOC Ex. 808 at 29 (Muller Direct). And, limiting the performance evaluation to the State of Minnesota tells a similar story: both models satisfied the performance goals.[24] DOC Ex. 808 at 29-30 (Muller Direct).

5. The AP2 air quality model was effective at replicating or matching estimates of tropospheric (or ground-level) O_3 generated by CAMx.

Dr. Muller performed diagnostics comparing the predictions of the air quality model in AP2 to that of CAMx regarding ozone (O_3) and he prepared Table 4 to his Direct Testimony, reproduced below, which compares AP2's estimation of O_3 concentrations to estimates generated by CAMx. Performance tests for O_3 proceeded similarly to the tests for $PM_{2.5.}$ Dr. Muller compared AP2 to CAMx at the national, regional, and state scales, and compared both models to the EPA's monitor readings of ambient O_3. DOC Ex. 808 at 30 (Muller Direct).

Table 4: Air Quality Model Diagnostics: AP2 and CAMx Comparison for O_3

Region	AP2 Estimate (ppb)	CAMx Estimate (ppb)	MFB	MFE	Rho	PE (Rho)	N
National	48.48[A] (6.64)[B]	50.16 (5.34)	-0.04	0.10	0.51	0.970	3,109
Great Lakes & Great Plains	47.83 (4.53)	47.74 (4.65)	0.00	0.08	0.47	0.998	972
Minnesota	46.50 (3.42)	41.75 (2.27)	0.11	0.11	0.63	0.999	87

A = arithmetic mean, ppb: parts per billion; B = standard deviation ; N = number of counties. Values are 8-hour daily maximums, averaged over the O_3 season.

DOC Ex. 808 at 30 (Muller Direct); DOC Ex. 809 at NZM-2, p. 85, Table 20 (Muller Direct Attachments). At each spatial scale, AP2 performed well according to the MFE and MFB

[23] AP2's MFB value is lower than CAMx, implying less bias in AP2's predictions, and over the 142 counties with monitors in the Great Lakes and Great Plains regions, CAMx's predictions are more strongly correlated with the AQS data. DOC Ex. 808 at 29 (Muller Direct).

[24] CAMx's predictions are more strongly correlated to the AQS data. Both models over-predict $PM_{2.5}$ levels with respect to the observed AQS readings. Dr. Muller explained that the degree to which one can draw meaningful inferences based on the Minnesota-specific results must be tempered by the observation that there are only 10 counties with $PM_{2.5}$ monitors in the state. DOC Ex. 808 at 29-30 (Muller Direct).

statistics. Both MFB and MFE do not exceed 0.11 which is well within the model performance goals employed in the $PM_{2.5}$ analysis. The Rho values are positive ranging from 0.47 at the regional scale up to 0.63 in Minnesota. The population exposures are nearly perfectly correlated. Thus, Table 4 provides strong evidence of adequate performance for AP2 with respect to its estimation of O_3 concentrations. DOC Ex. 808 at 30 (Muller Direct).

6. The AP2 air quality model performed well with respect to O_3, replicating or matching EPA air quality monitoring data.

AP2 performed as well as CAMx when evaluated against the U.S. EPA's air pollution monitoring data for 2011. Dr. Muller prepared Table 5, reproduced below, which summarizes a comparison of the predictions of AP2 and CAMx for O_3, with the AQS monitor data-- the actual readings of O_3 from the ambient air -- collected and made publicly available by the U.S. EPA in partnership with state and local agencies. DOC Ex. 808 at 31 (Muller Direct).

At the national scale, AP2 and CAMx both significantly under-predicted O_3 relative to the AQS readings. The MFE and MFB values are quite similar across both models. AP2 and CAMx satisfy the goals for MFE and satisfy the less stringent model criteria for MFB. At the regional scale, again, the model performance is very similar for CAMx and AP2. Within the State of Minnesota, AP2 outperforms CAMx in terms of both the MFE and MFB statistics.

Finally, the Rho value for CAMx is larger than AP2, but this final comparison relies on only 14 counties with O_3 monitoring stations in Minnesota (in 2011). DOC Ex. 808 at 31 (Muller Direct).

Table 5: Air Quality Model Diagnostics: AP2, CAMx, AQS Comparison for O_3

	Summary Statistics			AP2[C]			CAMx[C]			
Region	**AP2 Estimate ppb**	**CAMx Estimate ppb**	**AQS ppb**	**MFB**	**MFE**	**Rho**	**MFB**	**MFE**	**Rho**	**N**
National	50.29[A] (7.81)[B]	50.69 (5.60)	77.79 (10.85)	-0.43	0.43	0.45	-0.42	0.42	0.54	794
Great Lakes & Great Plains	51.12 (5.65)	48.79 (4.62)	77.61 (10.42)	-0.41	0.41	0.48	-0.45	0.45	0.51	184
Minnesota	48.35 (5.87)	42.31 (2.44)	67.91 (8.80)	-0.34	0.34	0.70	-0.46	0.46	0.78	14

A = arithmetic mean; B = standard deviation; N = number of counties; C = model diagnostics using AQS monitoring data. Values are 8-hour daily maximums, averaged over the O_3 season.

DOC Ex. 808 at 31 (Muller Direct); DOC Ex. 809 at NZM-2, p. 86, Table 21 (Muller Direct Attachments).

Dr. Muller concluded, based on the above assessment of AP2's air quality estimates, that the air quality modeling component of AP2 performed well, in predicting both ambient $PM_{2.5}$ and O_3, according to the MFB and MFE diagnostic statistics, when compared to the predictions produced by CAMx. Importantly, these predicted concentrations from AP2 and CAMx are annual average for $PM_{2.5}$ (expressed in $\mu g/m^3$) and seasonal averages for O_3 (expressed in ppb). Dr. Muller explained that, although there is temporal variability around these averages within a given year, it is appropriate to evaluate a model based on average predictions, because the concentration-response functions for mortality (the largest contributor to damages), which relate increases in mortality rates to changes in air pollution, employ "central tendency measures" of air pollution, such as annual averages. DOC Ex. 808 at 32-33 (Muller Direct).

7. The effective performance of the AP2 air quality model's "wind direction" feature is corroborated by a comparison of AP2's predicted dispersion of $PM_{2.5}$ with observed data drawn from an independent source, a windrose plot.

To further explain how AP2 estimates air pollution damage, Dr. Muller demonstrated that the dispersion pattern predicted by AP2 corresponds to readily-available independent wind direction and wind speed data. Dr. Muller discussed a map, Figure 2 below, which shows the predicted effects on $PM_{2.5}$ concentrations due to the emission of 100 tons[25] of primary $PM_{2.5}$ from the Sherburne County plant.[26] The map shows the second step in the application of AP2 to compute air pollution damage –the air quality model. Figure 2 shows that, following the perturbation to emissions at Sherco, AP2 predicted air quality changes in all receptor counties, with the largest change in ambient concentrations occurring near the source. While the majority of the change in concentration occurred within 200 miles or so of the plant, Figure 2 shows that emissions from SherCo affected $PM_{2.5}$ levels throughout the eastern half of the U.S. DOC Ex. 808 at 32-33 (Muller Direct).

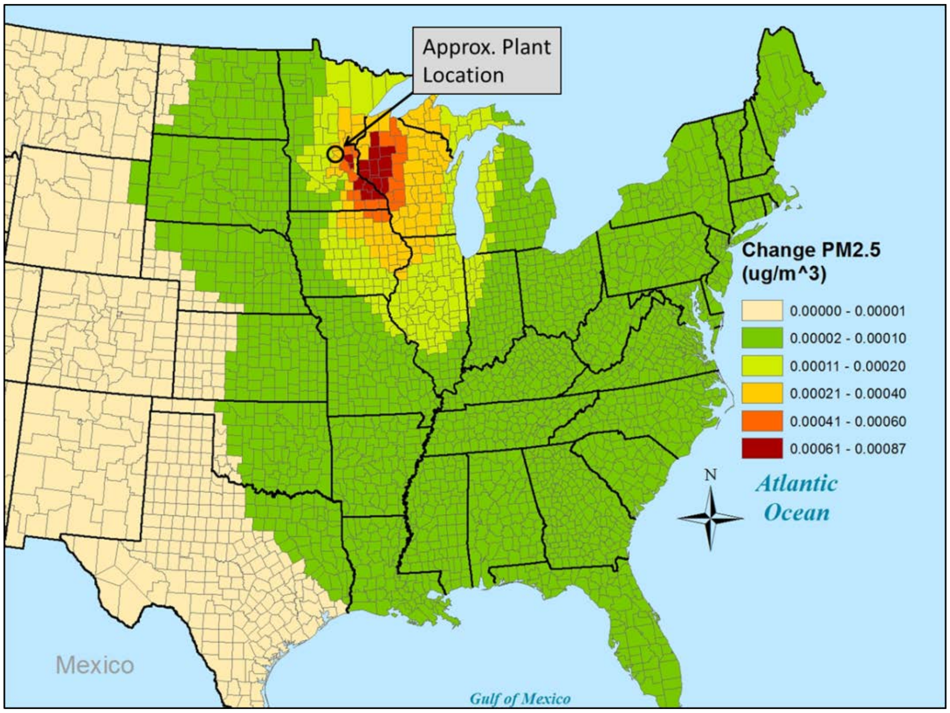
Figure 2 also shows that more of the emitted pollution travels southward or southeastwards from the source. This demonstrates an important feature of the AP2 air quality

[25] 100 tons was used in the example because the change in concentration associated with one ton is quite small and difficult to characterize clearly on this particular map legend. DOC Ex. 808 at 32-33 (Muller Direct).

[26] The Sherburne County plant, also known as Sherco, is a coal-fired power plant in Becker, with a combined capacity of 2,400 megawatts (MW). It is the largest power plant in Minnesota.

model: the air quality model in AP2 employs annual average wind speed and direction data to emulate dispersion of emissions across space. DOC Ex. 808 at 33 (Muller Direct).

Figure 2: Estimated Change in Ambient PM2.5 Concentrations Due to Emission of Primary PM2.5 from Sherburne County Power Station



Source – Derived from AP2 outputs, using high damage scenario.

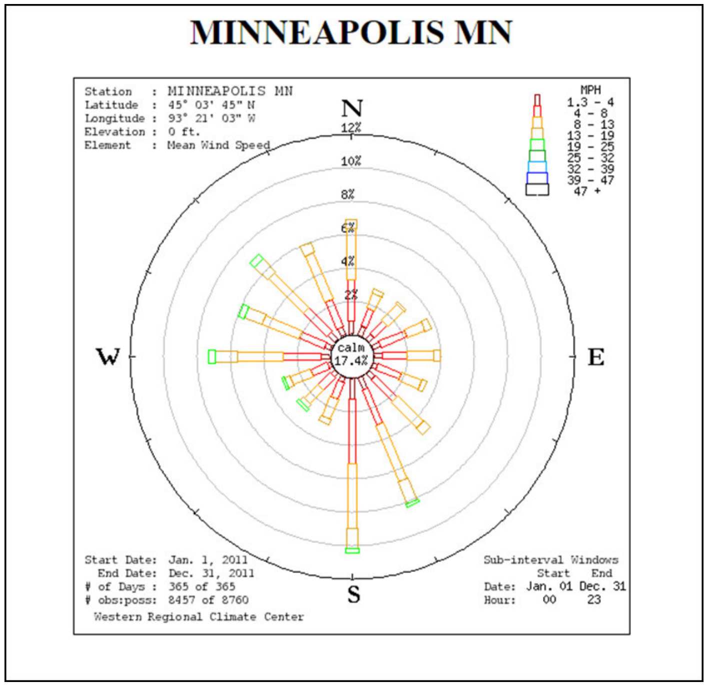
DOC Ex. 808 at 33 (Muller Direct).

The dispersion pattern predicted by AP2, as can be seen in Figure 2, corresponds to reliable and readily-available data on wind direction and wind speed for Minneapolis in 2011, as shown in Figure 3 below.[27] The windrose plot prepared using that wind direction data shows the

[27] A windrose is a graphic tool used by meteorologists to give a succinct view of the distribution, at a particular location, of wind speed and direction. The windrose plot prepared by Dr. Muller was created using an online utility on July 13th, 2015 provided by the Western Regional Climate Center (one of the six regional climate centers that are federal/state cooperative efforts managed by the federal National Oceanic and Atmospheric Administration (NOAA)). The utility is located at *http://www.wrcc.dri.edu/cgi-bin/wea_windrose.pl?laKMIC*

direction from which the wind blows, not the direction it blows towards. DOC Ex. 808 at 35 (Muller Direct).

Figure 3: Windrose plot for Minneapolis, MN 2011.



Source–Western Regional Climate Center, *http://www.wrcc.dri.edu/cgi-bin/wea_windrose.pl?laKMIC*, accessed July 13, 2015.

The plot shows that the wind blows from the due westerly direction nearly 8% of the time. Dr. Muller said that, summing the frequencies from due west to due north indicates that winds in Minneapolis blew from this quadrant nearly one-third of the time. This quadrant is the most frequent wind direction. The significant increase in pollution concentrations to the southeast of the source, as seen in Figure 2 above, is consistent with the windrose plot in Figure 3. DOC Ex. 808 at 36 (Muller Direct). The inclusion of this plot corroborates one of the most fundamental features of the air quality model in AP2 – wind direction. Or, to state it differently, using observed data drawn from an independent source, the broad patterns seen in the windrose plot are also evident in the plot showing dispersion of $PM_{2.5}$ predicted by AP2. DOC Ex. 808 at

36 (Muller Direct). This demonstrates the good performance of AP2 when its results are compared with independent, reliable data.

5. ESTIMATION OF DAMAGES AND PARAMETER CHOICES NEEDED TO ACCOUNT FOR UNCERTAINTY.

After the air quality model within the AP2 IAM has predicted concentration changes (step 2 of an IAM), the resulting concentration changes are used by AP2 to model damages. The remaining steps are: first, to compute the change to exposures (step 3); next (step 4), to estimate physical health effects and reduced crop yields that result from exposure to the pollutant (the "dose response" or "concentration response"), and finally (step 5), to estimate the monetary damages, by county.

Dr. Muller explained that AP2 used data and parameters drawn from reliable public health and agronomy literatures to accomplish step 4. In step 5, which converts the adverse impacts to monetary units, AP2 used data drawn from reliable non-market valuation literature in economics. DOC Ex. 808 at 36 (Muller Direct).

Aside from the air quality modeling step, the next most important aspect of an IAM for purposes of estimating damage is how the IAM models impacts on human health (inclusive of both mortality and various illnesses) and on agricultural yields.[28] Dr. Muller explained that prior research has shown that damages are very sensitive to the values for the following two parameters in an IAM:

- the dose-response function that captures the effect of $PM_{2.5}$ on adult mortality rates, and
- the monetary value attributed to mortality risk.

DOC Ex. 808 at 39 (Muller Direct).

[28] The specific illness states and crops modeled are listed in DOC Ex. 809 at NZM-2, pp. 34, 42 (Muller Direct); DOC Ex. 808 at 39 (Muller Direct).

A. The Dose-Response Parameter in AP2 is Acceptable Because it is Based on Two Credible Studies.

The dose-response functions (also referred to as concentration-response functions) link exposures to $PM_{2.5}$ and O_3 to estimated physical effects such as impacts on mortality rates. For use in the AP2 IAM, Dr. Muller selected mortality dose-response functions derived from credible sources, which are the most recently available updates to two landmark studies: (1) the Harvard Six-Cities study (Dockery *et al*., 1993), with the most recent update being Lepeule et al., (2012)(the "Lepeule study"); and (2) the American Cancer Society study (Pope et al., 1995) with the most recent update being Krewski et al., (2009)(the "Krewski study"). DOC Ex. 808 at 39-40 (Muller Direct).

Dr. Muller explained that these two studies have been widely used by government agencies and academic researchers.[29] Although both are considered credible, the results of these two studies produce markedly different estimates of the effect that $PM_{2.5}$ has on adult mortality rates. Specifically, the Lepeule study suggests that a one unit increase in ambient $PM_{2.5}$ concentration (typically expressed in terms of micrograms per cubic meter, or $\mu g/m^3$) is associated with a 1.4 percent increase to adult mortality rates. The Krewski study showed

[29] In response to criticism of Dr. Desvousges, Dr. Muller explained that the Krewski *et al*. (2009) and Lepeule *et al*. (2012) studies, which connect exposure to $PM_{2.5}$ to adult mortality impacts, are the most widely used set of results in this area. He noted that, in contrast, Dr. Desvousges' approach, which was to create his own distribution of impacts based on his own arbitrary choice of studies and weighting factors, was, in fact, inconsistent with standard practice in this area DOC Ex. 811 at 20-21 (Muller Surrebuttal) (*citing* Xcel Ex. 605 at 31 (Desvousges Rebuttal) *and* "Regulatory Impact Analysis of the Final Revisions to the National Ambient Air Quality Standards for Ground-Level Ozone." EPA-452/R-15-007. Office of Air and Radiation, Office of Air Quality Planning and Standards. Research Triangle Park, NC, 27711 (EPA 2015a); "Regulatory Impact Analysis of the Clean Power Plan Final Rule." EPA-452/R-15-003. Office of Air and Radiation, Office of Air Quality Planning and Standards. Research Triangle Park, NC, 27711 (EPA 2015 b); "Regulatory Impact Analysis for the Proposed Cross-State Air Pollution Rule (CSAPR) Update for the 2008 Ozone National Ambient Air Quality Standards (NAAQS)." EPA-452/R-15-009. Office of Air and Radiation, Office of Air Quality Planning and Standards. Research Triangle Park, NC, 27711. (EPA, 2015c).

reports that a one unit change (again, in $\mu g/m^3$) is associated with an only 0.6 percent increase to adult mortality rates, an amount less than half the value estimated by the Lepeule study. DOC Ex. 808 at 39-40 (Muller Direct).

Because the largest share of air pollution damage is due to mortality effects, using either one of these credible studies has a significant impact on the magnitude of damage estimates: using the relationship reported in the Lepeule study increases mortality effects by more than a factor of two relative to the results in the Krewski study. Because mortality effects comprise the vast majority of air pollution damages, this has an appreciable effect on total damages. Therefore, in order to take this uncertainty into account, Dr. Muller chose to use both of these highly credible studies to estimate a range of impacts that ultimately translated into a range of damage value estimates. DOC Ex. 808 at 39-40 (Muller Direct).

CEO Witness Dr. Marshall argued that it is more appropriate to use a value of 0.78 percent for the impact on mortality rates of $PM_{2.5}$ exposure than the 0.60 percent (low) value that Dr. Muller used. The higher value of 0.78 accounts for ecological covariates while the lower value does not. Dr. Muller disagreed with Dr. Marshall, explaining that the value used in AP2 is employed by most other researchers, as well as the EPA in its recent regulatory impact analyses (EPA, 2015a; 2015b; 2015c). He did acknowledge however, that the value Dr. Marshall employed in InMAP lies within the range of values that Dr. Muller proposed (0.60 percent and 1.4 percent) and that the appropriate value to use is a matter of professional judgment. DOC Ex. 811 at 51 (Muller Surrebuttal) (*citing* CEO Ex. 116 at 3 (Marshall Rebuttal).

B. AP2 Provided a Range of Values for the Monetary Value Attributed to Mortality Risk, Based on Two Credible Estimates of the Value of a Statistical Life.

Dr. Muller explained that the monetary value attributed to mortality risk is another parameter used in an IAM that has been shown by prior research to be a parameter to which damage estimates are particularly sensitive. Here, too, Dr. Muller chose two credible sources of values to incorporate into AP2 in order to provide an upper and lower value as bounds of a range within which an accurate monetary value attributed to mortality risk is found.

Dr. Muller stated that the value attributed to mortality risk is modeled in AP2, and most other IAMs, using the Value of a Statistical Life (VSL) approach. The VSL is widely used in the context of environmental policy analysis, especially for air pollution impact assessments, such as those of the EPA. The VSL is a measure of the monetary value to an individual of a small change in their mortality risk. More formally, the VSL is defined as the maximum rate at which an individual would pay to reduce his mortality risk (which is the chance of dying) by a small amount usually within the current year. DOC Ex. 808 at 40 (Muller Direct).

The VSL is derived from a rate, measured in units of money per unit of probability. The value of a statistical life is not an estimate of how much someone would pay to avoid certain death or of how much compensation someone would require to accept certain death. The VSL is the rate at which an individual is willing to trade small changes in risk for money. Dr. Muller explained that individuals routinely make such tradeoffs, such as when consumers purchase bottled water because of the belief that municipal sources may contain harmful bacteria, or when consumers purchase safety devices like bicycle helmets, smoke detectors, or fire extinguishers. These actions reveal (implicit) tradeoffs of risk for money. Thus, one source of empirical estimates of the VSL comes from such behaviors. DOC Ex. 808 at 40-41. (Muller Direct).

More generally, Dr. Muller explained, VSL estimates may be estimated using “stated preference” or “revealed preference” techniques. Dr. Muller said these two approaches estimate the empirical equivalents of the conceptual values described above. Stated preference analyses feature direct elicitation of values on highly structured surveys. In contrast, revealed preference studies use evidence from market transactions like those described above in which the non-market good or service[30] of interest is a part of the identified transaction. For the VSL, revealed preference studies tend to derive workers' value for mortality risk (on-the-job) through wage premia observed in particularly risky occupations. These studies identify the effect on wages of incremental changes to on-the-job risks of death. DOC Ex. 808 at 41 (Muller Direct).

There is no one VSL that is universally accepted in the literature as the "right" value. Because of this, Dr. Muller's analysis used both types of VSL estimates (stated and revealed preference) and generated a range of damage estimates. At the upper end of the range, Dr. Muller's analysis used the VSL applied by the EPA which is mostly based on revealed preference techniques and which, in 2011 dollars, is approximately $9.5 million (2010 income levels). In the pursuit of a range of damage estimates, Dr. Muller's analysis also used the results from a reliable meta-analysis of stated preference studies that reports a VSL of approximately $3.7 million in 2011 dollars. Using the higher value produces mortality damage estimates that are about 2.5 times larger than when the lower VSL is used. DOC Ex. 808 at 41-42 (Muller Direct).

Dr. Muller explained that the VSL used by the EPA is a credible VSL estimate because of the large number of times this VSL had been used in air pollution-related policy analyses. DOC Ex. 808 at 42 (Muller Direct). Further support showing that the EPA's VSL is credible

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[30] In the field of economics, changes that affect human wellbeing are classified as market and non-market. Market effects involve changes in market prices, and changes in revenue and net income, in the quantity or quality of market commodities, or in the availability of commodities. Non-market changes are changes in the quantity, quality or availability of things that matter to people, even though they are not obtained through the market. Agencies Ex. 800 at 14-15. (Hanemann Direct).

comes from a more recent "meta-analysis"[31] of revealed preference studies (Viscusi, 2015) that produces preferred VSL estimates that span the EPA's VSL estimate, ranging from $7.2 to $10.5 million (using 2010 incomes). Dr. Muller concluded that, because the EPA's VSL is derived from a meta-analysis of mostly revealed preference studies (21 out of the 26 studies included in the EPA VSL are revealed preference) and due to the similarity of the EPA's VSL to the range of estimates reported by Viscusi (2015), the EPA's VSL is credible, and it was appropriate to use it as the high-end estimate. DOC Ex. 808 at 42 (Muller Direct).

For the second, low-end estimate, Dr. Muller employed the $3.7 million VSL reported in Kochi et al., (2006), also a meta-analysis, which analyzed several stated preference VSL studies. He explained that AP2 applies the VSL uniformly across persons of all ages, races, income groups, and genders, as is the standard approach in federal government analyses. DOC Ex. 808 at 42 (Muller Direct).

In contrast to the methodology followed by Dr. Muller, the methodology proposed by CEO Witness, Dr. Marshall, for running InMAP employed a single VSL. Dr. Muller explained that, although the VSL that Dr. Marshall used is reasonable, employment of a single VSL failed to recognize the uncertainty associated with different approaches used to empirically estimate the VSL. DOC Ex. 810 at 36 (Muller Rebuttal) (*citing* DOC Ex. 808 at 41-42 (Muller Direct) *and* CEO Ex. 115 at 25 (Marshall Direct)).

Dr. Muller explained that his strategy of employing both stated and revealed preference methods produces VSL estimates that vary by nearly a factor of three. Dr. Muller opined that it is important to explicitly recognize the variation in VSLs produced using different techniques in

[31] Meta-analysis refers to a statistical approach to combining results from multiple studies within a particular field or area of research. The goal of meta-analysis is to synthesize existing research by identifying areas of agreement, or discrepancies among existing studies.

the estimation of environmental cost values from emissions because reliance on one approach, or one VSL, will yield a damage estimate that gives a false sense of precision. DOC Ex. 810 at 16 (Muller Rebuttal).

In response to criticisms of Xcel Witness Dr. Desvousges, Dr. Muller explained that the VSLs employed for use in AP2 were reported in "meta-analyses," which are statistical summaries that synthesize the results from many studies. That is, he used the results from a multitude of articles, each of which has estimated a VSL. He explained that Dr. Desvousges' suggestion that he used results from only two studies is misleading. He observed, however, that Dr. Desvousges' proposed VSL lies within the range of the two VSLs that were used in AP2, and that he therefore did not fundamentally disagree with the VSL that Dr. Desvousges used; he disagreed only with the statement that the VSLs used in AP2 were not representative of research in this area when in fact, the upper bound VSL has been employed by the EPA in many regulatory impact analyses and benefit-cost analyses for air pollution.[32]

Responding to a further claim made by Dr. Desvousges, that the VSL value that Dr. Muller chose for the low-end VSL value does not represent the best estimate available because it only included the results of stated preference studies, Dr. Muller reiterated that the low-end VSL was chosen precisely *because* it reflects stated preference studies. DOC Ex. 811 at 17 (Muller Surrebuttal) (*citing* Xcel Ex. 605 at 47 (Desvousges Rebuttal) and DOC Ex. 808 at 42 (Muller Direct)). Dr. Muller explained that the choice was appropriate because the study is credible and

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[32] DOC Ex. 811 at 15-17 (Muller Surrebuttal) (*citing* EPA, *The Benefits and Costs of the Clean Air Act, 1990–2010. Prepared for U.S.* Congress by U.S. EPA, Office of Air and Radiation/Office of Policy Analysis and Review, Washington, DC, November; EPA report no. EPA-410-R-99-001 (1999) at *http://www.epa.gov/air/sect812/1990-2010/fullrept.pdf and* EPA, *The Benefits and Costs of the Clean Air Act 1990 to 2020: EPA Report to Congress*. Office of Air and Radiation, Office of Policy, Washington, DC. March (2011). Available at *http://www.epa.gov/oar/sect812/feb11/fullreport.pdf*).

contrasts with the high-end VSL taken from an EPA meta-analysis in which most studies (21 of 26) were revealed preference studies. In addition, a recent meta-analysis of revealed preference studies by Viscusi (2015) showed VSL values consistent with the EPA estimate.[33]

C. Uncertainty

Dr. Muller testified that there is considerable uncertainty in modeling damages from environmental pollutants and generally accepted strategies to cope with these uncertainties. Dr. Muller explained that, to address the three types of uncertainty that manifest in an examination of environmental pollution damages, it is preferred and quite common to conduct sensitivity analyses. A sensitivity analysis is comprised of a series of model simulations that test how different data sources, parameter values, or models affect outcomes of interest.

Reduced-form models such as AP2 are well suited to perform sensitivity analyses because of the ease with which they can be run. In the context of this criteria pollutant valuation, a sensitivity analysis regarding parameter uncertainty, for example, might consist of using alternative VSLs or alternative concentration-response parameters to assess the amount by which damage estimates vary depending on the parameter used. DOC Ex. 808 at 44 (Muller Direct). The need to include a variety of parameter choices reinforces why the Commission made the correct choice when directing the Agencies to use reduced-form modeling.

Dr. Muller stated that one way to characterize uncertainty is to decompose it into three types: input uncertainty, parameter uncertainty, and model uncertainty. *Id.*

1. Input Uncertainty

Dr. Muller explained that input uncertainty refers to the data that is used to "populate" the IAM. For example, emissions provided by the EPA are comprised of both measured emissions

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[33] W. Kip Viscusi, "The Role of Publication Selection Bias in Estimates of the Value of a Statistical Life," *American Journal of Health Economics* Vol. 1(1): 27-52. 2015.

from large stationary sources like power plants and estimated emissions from sources like vehicles, homes, and small commercial establishments without a monitored smokestack. The uncertainty or imprecision associated with emission estimates is an example of input uncertainty. DOC Ex. 808 at 43 (Muller Direct).

2. Model Uncertainty

Dr. Muller stated that model uncertainty refers to divergences in outputs produced by different models that use the same input data and parameter values. Sources of model uncertainty center on temporal, chemical, and spatial resolution, among other factors. DOC Ex. 808 at 43 (Muller Direct).

As discussed in section IV.4.B. above, Dr. Muller explored model uncertainty by analyzing and reporting how the ambient pollution estimates produced by AP2 compared to those of CAMx. Differences in pollution predictions between AP2 and CAMx are an example of model uncertainty. The ambient concentrations were fed through the remaining stages of the IAM and differences manifested in outcomes such as predicted physical effects and damages. DOC Ex. 808 at 44 (Muller Direct).

3. Parameter Uncertainty

Dr. Muller stated that parameter uncertainty is exemplified by the discussion in above sections IV.5.A and IV.5.B of this brief regarding choices the researcher faces for mortality concentration-response and the VSL. In certain contexts, multiple credible parameter values exist. The variation in damage estimates that comes specifically from the different parameter values is an example of parameter uncertainty. DOC Ex. 808 at 43 (Muller Direct).

Dr. Muller explained that an IAM can address uncertainty in key parameters by estimating marginal damages as a range that brackets what could be considered reasonable values for the per-ton damage estimates. Parameters for which there may be a need for development of a range can be identified by considering whether: (1) there is disagreement among experts as to the "true" or "preferred" value, and (2) the parameter has a significant effect on the damage estimates.

The development of the damage ranges in AP2 for the concentration response function, discussed in section IV.5.A. above and the for the VSL, discussed in section IV.5.B above, are the most prominent examples in this context.[34] For each of the high- and low-damage values, marginal damages were estimated by AP2 for each source and/or source county and for each emitted criteria pollutant. DOC Ex. 808 at 44-45 (Muller Direct).

The need to include a variety of parameter choices reinforces why the Commission made the correct choice, when directing the Agencies to use reduced-form modeling. Because it is instructive to test how the model results depend on different parameters used in the model, it is necessary to run the model many times. That is, with approximately 500 sources and source locations, iterating through even a small number of alternative parameter values requires a very large number of executions of the model. The need to cycle through a multitude of model runs further bolsters the case for using a reduced-form model. DOC Ex. 808 at 45 (Muller Direct).

D. Graphical Representation of Changes in Damages for a Given Change in Air Quality.

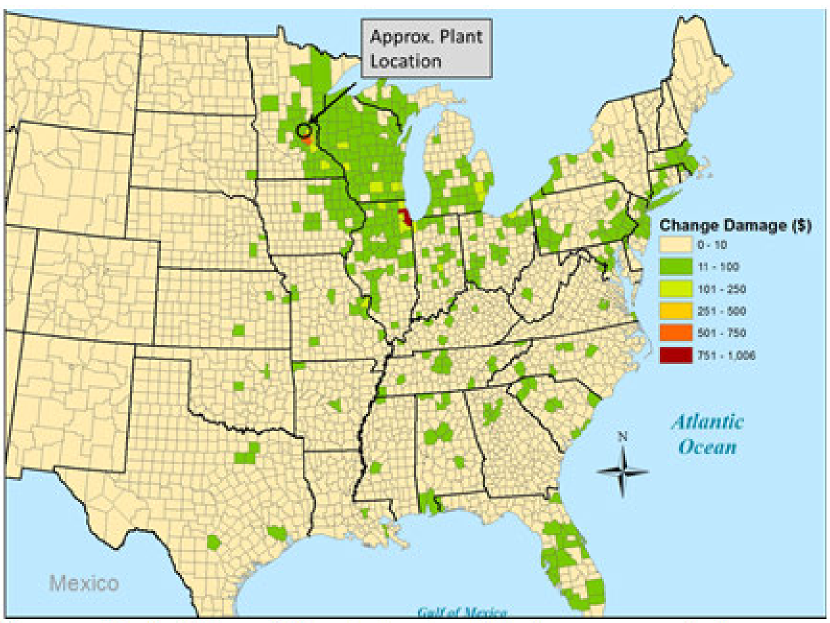
Dr. Muller provided a graphical representation of the change in damages that occurs from the emission of a ton of a criteria pollutant. He prepared Figure 4, which is a map showing the change in damage from the emission of one ton of primary $PM_{2.5}$ from the Sherburne County power station. Figure 4 employs the "high damage" assumptions in the AP2 model, for illustrative purposes.

[34] The parameter choices that comprise the high-end damage estimate and the low-end damage estimate are discussed in DOC Ex. 809 at NZM-2, pp. 26-27 (Muller Direct Attachments).

In other words, findings from the Lepeule et al., (2012) study are used for the concentration-response function for PM-related mortality and the higher value for mortality risk (EPA's VSL) is also employed. The set of morbidity dose-response functions reflected in Figure 4 also correspond to the high-damage assumptions. DOC Ex. 809 at NZM-2, p. 26 (Muller Direct Attachments) describes the assumptions used in the high-damage (and the low-damage) scenarios in more detail. DOC Ex. 808 at 36-37 (Muller Direct).

The largest change in damage from the increase in primary $PM_{2.5}$ emissions at the Sherburne County power station occurs in the Twin Cities metropolitan area and the Chicago metropolitan area. The Twin Cites metro area incurs relatively large changes in ambient $PM_{2.5}$ due to its proximity to the source and its relatively large population. Chicago is farther away so

Figure 4: Estimated Change in Monetary Damages Due to Emission of Primary $PM_{2.5}$ from Sherburne County Power Station.



Source – Derived from AP2 outputs using high damage scenario.

it incurs a lower change in air quality, but its large population renders it relatively more susceptible to exposures and impacts. The change in damage in each of these two metropolitan areas exceeds $500, which is quite large. More distant from the source, damage changes above

$10 tend to manifest in counties with large human populations. Examples of this pattern include the counties that encompass large cities on the eastern seaboard, as well as some larger cities in the Midwest.

In each receptor county (i.e., the counties experiencing a change in air quality due to the increased emissions in Sherburne County), the model tabulated the change in exposure, human health and agricultural impacts, and their monetary equivalents. These effects were then added up to estimate the total (across space) impact due to the emission from, in this example, the Sherburne County power plant. DOC Ex. 808 at 37 (Muller Direct).

6. PRACTICABILITY OF APPLICATION

Dr. Desvousges indicated his belief that county- and source-specific environmental cost values are not practical for application. Xcel Ex. 605 at 3 (Desvousges Rebuttal). However, the county- and source-specific values can easily be grouped or averaged for ease of use and application. For example, the Commission could compute the mean damages for each pollutant over all sources. This would yield just three values (one for each pollutant) which could be applied to all plants. This is the simplest approach, and would be readily applicable in resource planning in which the location of a potential new power plant is typically not known.

A second option would be to group the values according to quantiles of the distribution of values, as was done by Dr. Muller in his Direct Testimony (DOC Ex. 808 at 51-62). Under this approach, facilities or source locations falling into each quantile would have a common damage value for each pollutant – computed as the average damage value for each pollutant – or common value range. This would greatly reduce the complexity of working with county- and source-specific values and yet it would reflect the spatial heterogeneity in the damage values, as more fully discussed below.

A third approach is to compute average damage values (for each pollutant) within each land-use designation; urban, metro-fringe, and rural. Importantly, there is significant variation in the environmental cost values within each land-use designation. (DOC Ex. 811 at 25-26 (Muller Surrebuttal); DOC Ex. 813 (Muller Opening Statement).

Returning to the second option, analyses conducted by Dr. Muller illustrate the appropriateness of grouping values according to quantiles of the distribution of values. For example, Dr. Muller prepared a map, Figure 5, which displays the marginal damage values for emissions of primary $PM_{2.5}$ using the high-damage scenario. The values shown on the map indicate the total damage caused by an additional ton of emission produced in each county. These values include damages within and outside the county where the emission is produced. Further, the damages are inclusive of receptor counties inside and outside the state but within the continental U.S. Also, Figure 5 includes marginal damage values for sources outside (but within 200 miles of) the state of Minnesota.[35] DOC Ex. 808 at 51 (Muller Direct).

Figure 5 shows that the highest damages occur when emissions are released in or near large cities. Sources in the highest damage category (shown in dark red) are counties in the Minneapolis-St. Paul area and counties around the Chicago metropolis. The maximum value (in Minnesota) corresponds to emissions produced in Anoka County, which is adjacent to both Ramsey and Hennepin Counties. Emissions released in Hennepin and Ramsey counties yield the second- and third-highest cost values, respectively. The strong association between high damage and high population corresponds to prior literature that finds that human health damages comprise the largest share of monetary impacts from air pollution emissions. Conversely, the

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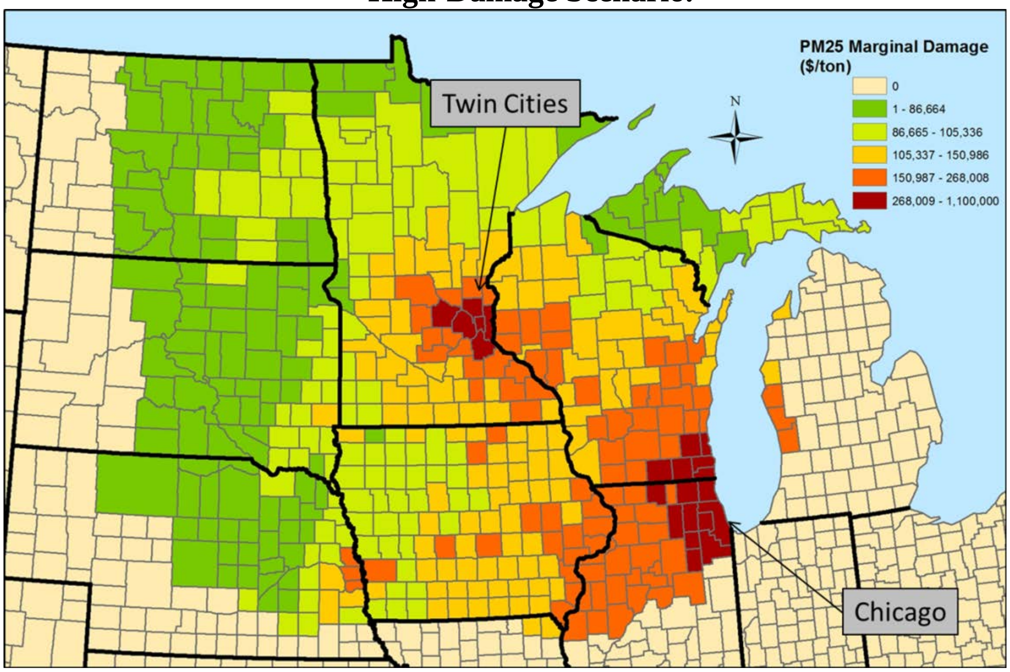
[35] Note that as explained earlier in this Initial Brief, including marginal damage value estimates for sources outside of Minnesota was done to provide additional information for the Commission to use at its discretion. Inclusion or exclusion of these values for sources outside of Minnesota does not change the marginal damage estimates for sources within Minnesota.

lowest cost value in Figure 5 is attributed to emissions from Lake of the Woods County, which is located along the Canadian border, far from major population centers. DOC Ex. 808 at 51-52 (Muller Direct).

Figure 5: Marginal Damages for Emissions of Primary $PM_{2.5}$ Inclusive of Sources both within and outside the State of Minnesota, High-Damage Scenario.



DOC Ex. 808 at 53 (Muller Direct); DOC Ex. 809 at NZM-2, Figure 3 (Muller Direct Attachments).

Dr. Muller explained that the groupings embodied in Figure 5 are defined intervals from the distribution of $PM_{2.5}$ marginal damages, as shown in Table 7 of his Direct Testimony. That is, the marginal damages are first ranked from lowest to highest. The sources with marginal damages below the 25^{th} percentile are assigned to the first group shown in green in Figure 5, with damages less than \$86,665. Sources above the 25^{th} percentile but below the 50^{th} percentile are in the next category. These sources have damages that fall between \$86,665 and \$105,337. Sources with damages above the median (50^{th} percentile) but below the 75^{th} percentile are displayed in light orange; the range of damages for this group is from \$105,337 to \$150,986. Sources above the 75th percentile but below the 95th percentile are shown in dark orange. The marginal damage values for this category range from \$150,987 up to \$286,008. The final group contains the sources with the highest 5% of damages. The sources tend to be located directly in or adjacent to the two major metropolitan areas within the scope of this study: Minneapolis – St. Paul and Chicago. DOC Ex. 808 at 54 (Muller Direct).

Table 7: Groupings of Environmental Cost Values for 2011 Model Year. All Counties Receiving Pollution from Minnesota Sources (\$/ton emitted)

Percentile	$PM_{2.5}$	SO_2	NO
0 – 25th	< 86,664	< 22,537	< 4,348
25th – 50th	86,665 – 105,336	22,538 – 59,160	4,349 – 4,752
50th – 75th	105,337 – 150,986	59,161 – 65,908	4,753 – 4,753
75th – 95th	150,987 – 268,008	65,909 – 79,702	5,344 – 8,196
95th – 100th	268,009 – 1,100,000	79,703 – 127,140	8,197 – 28,687

DOC Ex. 808 at 54 (Muller Direct). Similar analyses can be done for each pollutant, and for low- and/or high-damage scenarios, to establish a common damage value range for each group of counties falling within the same quantile range. While Dr. Muller's analysis involved five quantiles, the Commission could establish fewer (or more).

Dr. Muller explained that the spatial distribution of marginal damages does not change depending upon whether the high- or low-damage approach is employed. The $PM_{2.5}$ damages estimated using the high-damage approach are about 5.4 times larger than the damages estimated using the low-damage approach. Similarly, the SO_2 damages estimated using the high damage approach are about 5.4 times larger than the damages estimated using the low damage approach, and the NO_x damages are 5.3 times larger. DOC Ex. 808 at 60 (Muller Direct). But, despite the change in the *magnitude* of damage, the spatial pattern of costs per ton remains stable. For example, within Minnesota the source locations that produce the three highest environmental costs for $PM_{2.5}$ emissions are Anoka, Hennepin, and Ramsey counties for both approaches. The lowest cost per ton for $PM_{2.5}$ emissions is associated with emissions from Lake of the Woods County under both approaches. DOC Ex. 808 at 60 (Muller Direct).

Dr. Muller stated that the effect of the two modeling approaches on the geographic distribution of SO_2 damages is similar to the effect reported for $PM_{2.5}$. The highest damage per ton occurs for SO_2 emissions is from Anoka county, with Hennepin and Wright counties ranked second and third, respectively, under both modeling approaches. The lowest three damages per ton of SO_2 emissions are from Big Stone, Lincoln, and Pipestone Counties for both . Like the other two pollutants, the spatial pattern or distribution for NO_x costs remains very similar when either the high or low damage assumptions are used.

7. THE AP2 MODEL WILL BE AVAILABLE IN THE FUTURE FOR USE BY THE STATE OF MINNESOTA.

The results of the AP2 modeling that Dr. Muller conducted for this proceeding can be updated in the future. AP2 is publicly available to anyone, including the State of Minnesota. In addition, Dr. Muller stated that it is his intention to make the current version of the model available along with detailed instructions on how to use the model. These instructions will include where the key data elements are located so that they readily can be changed according to the Commission's preferred settings and if new or superior data become available. Earlier versions of the model are also publicly available upon request. DOC Ex. 808 at 48, 71 (Muller Direct); DOC Ex. 811 at 11-12 (Muller Surrebuttal); Tr. Vol. 1 at 33-34 (Agencies' Opening Statement); Tr. Vol. 3 at 9, 15 (Muller Testimony).

8. THE COMMISSION HAS THE DISCRETION TO DETERMINE WHAT CONSTITUTES AN ENVIRONMENTAL COST FOR PURPOSES OF MINN. STAT. § 216B.2422.

At the close of the criteria pollutant evidentiary hearing, the ALJ requested that the parties address the following question:

> Does Minn. Stat. § 216B.2422 require the Commission, if it is practicable to do so, to calculate environmental damage based on the national impact of emitted pollutants? Does recent case law or anything else require or prohibit the Commission from doing so? Or is the geographic scope of damages discretionary, a policy question for the Commission to decide, that is neither required nor prohibited?

Minn. Stat. § 216B.2422 subd. 3 (a) provides that:

> The commission shall, to the extent practicable, quantify and establish a range of environmental costs associated with each method of electricity generation. A utility shall use the values established by the commission … when evaluating and selecting resource options in all proceedings before the commission ….

A statute's plain meaning may not be disregarded if the language is clear and unambiguous. Minn. Stat. § 645.16. The statute here, however, does not define the term "environmental costs," (nor does any other Minnesota statute or rule). By not defining the term, the Minnesota legislature left to the Commission's discretion the definition of the "environmental costs" to be quantified.

The Agencies conclude that the Commission, when establishing environmental costs, has the discretion to take into account both in-state and out-of-state damages associated with electric power generation when it determines what constitutes "environmental costs," and that the constraints on the Commission's exercise of its discretion are that (1) the decision must establish a range of costs; (2) it must be practicable to quantify and establish the range of costs; and, (3) the decision needs to be supported by the evidentiary record.[36] The Agencies are unaware of any

[36] And otherwise must be consistent with the standards for agency decision-making described in Minn. Stat. § 14.69 (a) to (f) (2015).

state or federal law that either requires or prohibits the Commission from consideration of out-of-state damages in implementing environmental damage cost values.

The Department presented substantial evidence from Drs. Hanemann, Gurney, and Muller to support a finding that it is imminently practicable to quantify a range of damages for each of the pollutants at issue in this docket, $PM_{2.5}$, SO_2, NO_x, and CO_2, and that sound testimony on environmental science and economics had demonstrated the impacts and damages that occur within and without Minnesota. Further, with the benefit of modern computer models and the corresponding development of environmental science and economics that has occurred since the first environmental cost docket, the current record demonstrates that it is practicable to set an estimate of the range of damage values for the emissions at issue in this proceeding that is not constrained to impacts in Minnesota. As Drs. Muller and Hanemann testified, there is no scientific basis not to count damages that occur beyond the boundary of Minnesota. DOC Ex. 800 at 12 (Hanemann Direct); DOC Ex. 801 at 13-16 Hanemann Rebuttal; DOC Ex. 813 at 3 (Muller Opening Statement). DOC Ex. 810 at 26-27 (Muller Rebuttal) (*citing* Xcel Ex. 604 at 20 (Desvousges Direct); DOC Ex. 811 at 12 (Muller Surrebuttal).

There are federal regulations that require states to pay attention to, and in many cases hold states responsible for, impacts of their emissions in other states. The "good neighbor provision" in Section 110(a)(2)(D) of the Clean Air Act[37] requires every state, in their state implementation plans, to address any contributions to non-attainment in any other states. Additionally, EPA's Regional Haze Regulations (40 CFR Part 51) hold states responsible for the contributions of their emissions contributing to visibility impairments in national parks and wilderness areas in other states. Even though regional haze and visibility impairment are not

[37] This provision of the Clean Air Act led to the Cross State Air Pollution Rule.

impacts included in Dr. Muller's damage estimates, they are in large part caused by $PM_{2.5}$ pollution. Thus, federal regulations have recognized that air pollution does not stop at state borders and that states are required to consider impacts outside of their borders.

9. Summary of Dr. Muller's Testimony

Dr. Muller summarized his testimony as follows. He used a peer-reviewed IAM, AP2, to generate dollar-per-ton environmental cost values for emissions of $PM_{2.5}$, NO_x, and SO_2 from approximately 500 sources and source locations in and near to the state of Minnesota. He demonstrated that AP2, while quite simple in its structure, is able to generate pollution predictions that agree well with far more complex photochemical process air quality models as well as EPA monitor readings of air pollution. Further, the parameter values that AP2 used were transparently described and appropriately chosen. The parameters used were in accord with peer-reviewed research and federal government procedures in the field. He demonstrated the sensitivity of the results to different reasonable modeling approaches. DOC Ex. 808 at 70 (Muller Direct).

Dr. Muller's primary empirical results were summarized in Table 11 (reproduced below). Dr. Muller's primary empirical results indicate that, across the 93 sources and source locations in Minnesota, damages for each of the three pollutants considered differ by a factor of about five, depending on whether the high-damage or the low-damage approach to calculating impacts is used. In Dr. Muller's opinion, this range transparently characterizes the effect of two reasonable modeling strategies on the damage figures. He explained that both the dose-response functions and the VSLs used in generating this range are derived from credible sources. *Id*. at 71.

Table 11. Final Summary of Environmental Cost Values for 2011 through 2040. All Counties Receiving Pollution from Minnesota Sources. (Constant year-2011 USD).

	Low Damage Assumptions			High Damage Assumptions		
Year	**PM2.5**	**SO2**	**NOx**	**PM2.5**	**SO2**	**NOx**
2011	26,012 [A]	11,818	1,183	140,102	64,180	6,219
2015	26,574	12,288	1,206	143,108	65,551	6,338
2020	27,434	12,681	1,243	147,754	67,706	6,531
2025	28,950	13,347	1,311	155,920	71,331	6,880
2030	31,184	14,304	1,407	168,074	76,589	7,384
2035	33,327	15,241	1,494	179,752	81,742	7,837
2040	34,808	15,942	1,551	187,844	85,606	8,138

A = values reported in $/short ton. Values are average marginal damages across sources.

DOC Ex. 808 at 72 (Muller Direct); DOC Ex. 809 at NZM-2, p. 73, table 14 (Muller Direct Attachments). Dr. Muller stated that an additional important finding was the considerable spatial variation in the damage estimates. The highest damages were associated with emissions released in or near large cities. The lower damages were due to discharges in rural areas. He explained that this pattern, which had been reported in earlier work in this field, manifested because the human health impacts dominated the damage calculations. This pattern indicates which existing plants and possible plant locations generate larger environmental costs. *Id*.

Finally, Dr. Muller noted that there is no scientific basis for ignoring damages from sources in and around Minnesota that occur well beyond the state's border. Arbitrarily truncating damage estimates results in an underestimation of damages. DOC Ex. 810 at 22-32 (Muller Rebuttal).

V. CONCLUSION

The Agencies respectfully request a Recommendation from the Administrative Law Judges and an Order from the Commission, consistent with the principles, analyses and recommendations addressed in the Agencies' testimony and this Initial Brief, including a determination that:

(1) The results formulated by the Agencies' witness Dr. Nicholas Z. Muller, using the AP2 IAM are appropriate environmental cost values for the criteria pollutants under Minn. Stat. § 216B.2422;

(2) The AP2 IAM, and the related data sources, parameters, and assumptions proposed by the Agencies, are reasonable and practicable to use because:

- AP2 is a reliable, peer-reviewed model;
- use of a reduced-form model such as AP2 appropriately balances simplicity and accuracy in the prediction of ambient pollutant concentrations;
- the modeling results are based on accurate spatial variability assumptions and data regarding emission source locations and attributes and accurately capture the distribution of damages across source locations;
- the modeling results are based on reliable data;
- AP2 has an appropriate scope with regard to the impacts analyzed, including exposure to both ambient $PM_{2.5}$ and ground level ozone (O_3);
- the modeling results reflect human health effects, including not only mortality risk but also morbidity (illness) states;
- the modeling results were based on reliable, transparent parameters for the concentration-response functions (which link exposures to estimated physical effects such as impacts on mortality rates) and the value of a statistical life (VSL) (which reflects the monetary value to an individual of a small change in their mortality risk);
- uncertainties in key parameters such as mortality risk and VSL were appropriately addressed by using estimated ranges of marginal damages that bracket what could be considered reasonable values for the per-ton damage estimates, rather than a single point;
- the modeling results reflect marginal (rather than average) damages;
- the modeling results are a reasonable reflection of all damages caused by the criteria pollutants, including damage occurring outside of Minnesota, and are not constrained to reflect damages only within an arbitrarily defined grid-box;

- because of its relatively simple structure, reduced-form models such as AP2 can perform multiple sensitivity analyses around a variety of different modeling assumptions so that the Commission can readily see how damages change when modeling assumptions are changed;

- AP2 performed as well as or superior to other proposed models including its ability to match its modeled ambient air concentrations with observed monitored pollution data.

Dated: March 15, 2016

Respectfully submitted,

s/ **Linda S. Jensen**

LINDA S. JENSEN
Attorney Reg. No. 0189030
Telephone: 651-757-1472
445 Minnesota Street, Suite 1800
St. Paul, MN 55101-2134
Attorney for Minnesota Department of Commerce
and Minnesota Pollution Control Agency

ATTACHMENT A
TO AGENCIES' INITIAL POST HEARING BRIEF, CRITERIA POLLUTANTS

A COMPLETE PROCEDURAL HISTORY OF DOCKET 14-643

On February 10, 2014, the Minnesota Public Utilities Commission (Commission or MPUC) issued an Order in Docket No. E-999/CI-00-1636 reopening its investigation into environmental costs of different methods of generating electricity under Minn. Stat. § 216B.2422, subd. 3. The Commission determined that the investigation would be best resolved in the context of a contested case proceeding conducted by the Office of Administrative Hearings (OAH), and sought input on the scope of the investigation, whether to retain an expert, and the possible role of an expert, from a stakeholder group led by Minnesota Department of Commerce, Division of Energy Resources (DOC-DER or Department) and the Minnesota Pollution Control Agency (MPCA).[38]

On June 10, 2014, DOC-DER and MPCA filed a report noting a lack of agreement among participants to previous stakeholder meetings or in subsequent comments. The report included the agencies' recommendations concerning the scope and process of the investigation, and the retention of an expert.[39] The most contentious issue was the report's recommendations that the Commission should adopt the federal social cost of carbon without further proceedings.[40] On June 16, 2014, the Commission requested comments on the report and recommendations.

From June 25, 2014, through August 20, 2014, the Commission received comments from the following entities:[41]

[38] *Notice and Order for Hearing* at 1 and 4, MPUC Dockets E-999/CI-00-1636 and E-999/CI-14-643 (October 15, 2014).
[39] *Id.* at 3-4.
[40] *Id.* at 4.
[41] *Id.* at 1-2.

- Fresh Energy, Sierra Club, Izaak Walton League of America – Midwest Office, Will Steger Foundation, Center for Energy and the Environment, and the Minnesota Center for Environmental Advocacy (the Clean Energy Organizations or "CEO);
- Great River Energy, Minnesota Power, and Otter Tail Power Company (filing jointly);
- The Lignite Energy Council
- Peabody Energy Corporation (Peabody);
- The Minnesota Chamber of Commerce (the Chamber);
- The Minnesota Large Industrial Group
- The State of North Dakota
- Northern States Power Company d/b/a/ Xcel Energy (Xcel)

On October 15, 2014, the Commission issued its Notice and Order for Hearing in which it set forth the scope of the investigation, as follows:[42]

> The Commission will investigate the appropriate cost values for $PM_{2.5}$, SO_2, NO_x, and CO_2. The Commission will not further investigate at this time the environmental costs of other greenhouse gasses such as methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Because CO_2 represents 99% of greenhouse gas emissions, an accurate environmental cost value for CO_2 will account for almost all greenhouse gas costs. This will result in a more manageable proceeding and allow the parties to focus their resources.
>
> It would be premature at this stage to adopt the federal SCC values for CO_2 as the Agencies recommend. The Commission still believes that a contested case proceeding is necessary to fully consider the Agencies' proposed CO_2 cost values. The Commission will therefore not act at this time on the Agencies' proposal to adopt the federal SCC values immediately. But, in light of the record so far, the Commission will ask the Administrative Law Judge to determine whether the Federal Social Cost of Carbon is reasonable and the best available measure to determine the environmental cost of CO_2 and, if not, what measure is better supported by the evidence.
>
> The Commission will require parties in the contested case proceeding to evaluate the costs using a damage cost approach, as opposed to (for example), market-based or cost-of-control values. When last faced with the question of the

[42] Notice And Order For Hearing, *id.*, at 4-5.

> preferred approach to estimate environmental cost values, the Commission stated that, as between estimates based on damage or based on cost-of-control, the damage-cost approach is superior because it appropriately focuses on actual damages from uncontrolled emissions.
>
> Nothing in this proceeding justifies reaching a different conclusion now. Where a damage cost can be reasonably estimated, it represents a superior method of valuing an emission's environmental cost. The Commission is persuaded that a damage-cost approach can be used for the emissions under investigation, and will therefore require it.

The Commission further stated:

> The Commission, having considered the relative merits of damage modeling approaches discussed by the Agencies, prefers reduced-form modeling in this case. While the photochemical modeling approach may offer the greatest precision, its complexity renders it slower and more expensive than reduced-form modeling. As several participants acknowledged, reduced-form modeling will also provide credible results as a next-best alternative to photochemical modeling.

The Commission authorized DOC-DER, on a discretionary basis, to work with the Office of Management and Budget to retain a consultant under Minn. Stat. § 216B.62, subd. 8; further, if a consultant was retained, the Commission required that the consultant use reduced-form modeling to estimate damage costs. The Commission also referred the matter to OAH for a contested case proceeding, Administrative Law Judge (ALJ) LauraSue Schlatter assigned.[43]

Also in its October 15, 2014, Notice and Order for Hearing the Commission identified the issues for parties to "thoroughly address," as follows:[44]

- Whether the Federal Social Cost of Carbon is reasonable and the best available measure to determine the environmental cost of CO_2 under Minn. Stat. § 216B.2422 and, if not, what measure is better supported by the evidence.
- The appropriate values for $PM_{2.5}$, SO_2, and NO_x under Minn. Stat. § 216B.2422, subd. 3.

[43] Notice and Order for Hearing, *id.* at 5-6 and 8. ALJ Jeffery Oxley also is assigned to the CO_2 matter.
[44] Notice and Order for Hearing, *id.* at 5 and 8.

The Commission referred the above two issues to the OAH for separate contested case proceedings. The Initial Brief of DOC DER and MPCA (jointly, the Agencies) filed on November 24, 2015 addressed only the first issue, regarding Carbon Dioxide (CO_2); the Agencies' Initial Brief addressing the second issue, regarding the criteria pollutants $PM_{2.5}$, SO_2, and NO_x, was filed on March 15, 2016.

On December 9, 2014, following a prehearing conference on November 14, 2014, the ALJ issued the First Prehearing Order that:

1. Identified the following entities as parties: Clean Energy Organizations; DOC-DER; Peabody; Otter Tail Power; Great River Energy; Minnesota Power; Lignite Energy Council; the Chamber; Minnesota Large Industrial Group; and Northern States Power d/b/a/ Xcel Energy;

2. Established process to develop a public notice plan;

3. Allowed parties to submit memoranda on the question of the burden of proof as it applies to the Federal Social Cost of Carbon, alternative means of measuring the cost of CO_2, SO_2, NO_x, and $PM_{2.5}$; and

4. Adopted the following schedule:

Document or Event	Due Date
Public Notice Plan	January 30, 2015
Memoranda Regarding Burdens of Proof	February 4, 2015
Comments on Public Notice Plan	February 17, 2015
Responsive Memoranda Regarding Burdens of Proof	February 18, 2015
Second Prehearing Conference	March 3, 2015
Intervention Deadline	April 1, 2015
Public Notice Implementation	May 1, 2015

Document or Event	**Due Date CO_2**	**Due Date SO_2, NO_2, and $PM_{2.5}$**
Direct Testimony	June 1, 2015	TBD *(August 1, 2015)*
Public Hearing(s), if any (not bifurcated)	TBD *(August, 2015)*	TBD *(August 2015)*
Rebuttal Testimony	TBD *(September 1, 2015)*	TBD *(October 15, 2015)*
Surrebuttal Testimony	TBD *(October 1, 2015)*	TBD *(November 15, 2015)*
Deadline for Public Testimony	TBD *(October 1, 2015)*	TBD *(October 1, 2015)*
Status Conference	TBD *(October 5, 2015)*	TBD *(January 4, 2016)*
Evidentiary Hearing	TBD *(October 12-16, 2015)*	TBD *(approx. January 6-15, 2016)*
Issues Matrix	TBD *(November 12, 2015)*	TBD *(February 1, 2016)*
Initial Briefs	TBD *(November 24, 2015)*	TBD *(February 16, 2016)*
Reply Briefs, Proposed Findings of Fact and Comments, if any, on Issues Matrix	TBD *(December 15, 2015)*	TBD *(March 1, 2016)*
ALJ Report (May or may not be bifurcated)	TBD *(April 15, 2016, if bifurcated; or May 16, 2016 if not bifurcated)*	TBD *(May 16, 2016)*

On March 5, 2015, the ALJ issued a Protective Order.

On March 11, 2015, the ALJ filed a Recommendation for Public Hearings and Public Notice Plan that summarized for the Commission her consultation with the parties and Commission staff, consistent with the Commission's Notice and Order for Hearing, that stated her recommendation that the public should be offered the opportunity to provide input in writing as well as through public hearings, and that stated her request that the Commission agree to implement and bear the cost of the public notice plan and the public hearings in this matter.

On March 20, 2015, the ALJ granted MPCA's petition to intervene as a party.

On March 27, 2015, based on parties' legal memoranda and comments, the ALJ issued an Order Regarding Burdens of Proof that provides as follows:

> 1. A party or parties proposing that the Commission adopt a new environmental cost value for CO_2, including the Federal Social Cost of Carbon, bears the burden

of showing, by a preponderance of the evidence, that the value being proposed is reasonable and the best available measure of the environmental cost of CO_2.

2. A party or parties proposing that the Commission adopt a new environmental cost value for one or more of the criteria pollutants – SO_2, NOx, and/or $PM_{2.5}$ – bears the burden of showing, by a preponderance of the evidence, that the cost value being proposed is reasonable, practicable, and the best available measure of the criteria pollutant's cost.

3. A party or parties proposing that the Commission retain any environmental cost value as currently assigned by the Commission bears the burden of showing, by a preponderance of the evidence, that the current value is reasonable and the best available measure to determine the applicable environmental cost.

4. An environmental cost value currently being applied by the Commission is presumed to be practicable, as required by Minn. Stat. § 216B.2422, subd. 3. A party challenging an existing cost value on the grounds that it is not practicable bears the burden of demonstrating impracticability by a preponderance of the evidence.

5. A party or parties, opposing a proposed environmental cost value must demonstrate, at a minimum, that the evidence offered in support of the proposed values is insufficient to amount to a preponderance of the evidence. This requirement does not apply to a party challenging an existing cost value based on its alleged impracticability, as described in paragraph 4, above.

6. Any proponent of an environmental cost value, including existing environmental cost values, shall file direct testimony in support of its proposal according to the schedule set forth in the Second Prehearing Order in this matter.

7. A party advocating for retention of an existing cost value may not refer by reference to evidence or testimony from the Commission's CI-93-583 docket or related dockets, but must introduce any evidence on which it intends to rely in this docket, whether the evidence is drawn from an older docket or is new evidence.

8. A party may propose an environmental cost value not proposed in direct testimony in the party's rebuttal testimony only if the new cost value is offered in response to a cost value proposed in direct testimony.

9. The order in which the parties will conduct direct and cross-examination at the evidentiary hearings will be determined at later dates after rebuttal testimony has been filed, but at least two weeks before either evidentiary hearing.

10. The Administrative Law Judge incorporates the following portions of the Commission's Notice and Order for Hearing into this Order:

> a. the parties will use a damage cost approach; and [Footnote omitted]
> b. any DOC consultant must use reduced-form modeling. [Footnote omitted]

On April 16, 2015, the ALJ issued the Third Prehearing Order that encouraged parties to jointly file pre-filed testimony, briefs or other pleadings, and to share responsibilities for cross-examination of witnesses to the extent appropriate and consistent with their positions and interests in the docket, and ordered parties to be prepared to discuss their plans for sharing cross-examination at the prehearing status conferences on September 17 and December 18, 2015. Absent a specific demonstration of relevance, the ALJ determined that testimony as to the efficacy of renewable energy or renewable energy policy is presumed to be irrelevant to the proceedings and will be excluded.

On April 16, 2015, the ALJ granted the petitions to intervene as parties of Doctors for a Healthy Environment (DHE), the Clean Energy Business Coalition (CEBC) and Interstate Power and Light (IPL).

On May 27, 2015, following its April 23, 2015, meeting, the Commission issued its Order Requiring Public Hearing, as recommended by the ALJ.

May 29, 2015, the Commission provided the ALJ with its proposed date, time and place for a public hearing, as well as its proposed Notice Plan.

On June 1, 2015, parties filed Direct Testimony regarding CO_2.

On June 2, 2015, the Commission issued its Notice of Public Hearing and Comment Period.

On August 4, 2015, the ALJ issued the Fourth Prehearing Order that identified the evidentiary hearing date for the CO_2 matter as September 24-30, 2015, and scheduled a prehearing conference to take place on August 14, 2015, for the primary purpose of discussing parties' plans for cross-examination, waiver of witness appearances and requests for dates or times certain regarding witness trial appearances.

On August 5, 2015, parties filed Direct Testimony regarding the criteria pollutants $PM_{2.5}$, SO_2, and NO_x.

On August 12, 2015, parties filed Rebuttal Testimony regarding CO_2.

On August 14, 2015, the ALJ held a prehearing conference regarding the CO2 matter.

On August 28, 2015, the ALJ issued the Fifth Prehearing Order setting forth the following changes to the CO_2 schedule:

Document or Event	New date	[Original Date]
Final CO_2 Prehearing Conference	**September 21, 2015** [time omitted]	[September 17, 2015]
Objections to any prefiled direct or rebuttal testimony or witness	**September 3, 2015**	[September 11, 2015]
Responses to objections to prefiled direct or rebuttal testimony or witness	**September 11, 2015**	
Objections to any surrebuttal testimony or witness	**Unchanged**	September 17, 2015
Response to surrebuttal objections	**September 18, 2015**	

On September 3, 2015, in the CO_2 matter, DOC-DER and MPCA filed a Notice of Motion and Motion to Strike direct and rebuttal testimony of witnesses Drs. Happer, Lindzen, Bezdek and Tol.

On September 3, 2015, in the CO_2 matter, Peabody filed a Motion to Exclude the Rebuttal Testimony of Shawn Rumery and Christopher Kunkle, and a Motion to Exclude the Direct and Rebuttal Testimony of Dr. Hanemann, Dr. Polasky in their entirety, and the statistical opinions of Mr. Martin.

On September 3, 2015, in the CO_2 matter, the Minnesota Large Industrial Group filed a Motion to Strike testimony of Dr. Hanemann, Dr. Polasky, and certain testimony of Mr. Martin.

On September 10, 2015, parties filed Surrebuttal Testimony regarding CO_2.

On September 11, 2015, certain parties filed responses to motions to strike or exclude testimony.

On September 15, 2015, in the CO_2 matter, Peabody filed a Motion to Exclude the Surrebuttal testimony of Dr. Peter Reich in its entirety, and certain testimony of Drs. John Abraham, Andrew Dessler, and Kevin Gurney.

On September 15, 2015, in the CO_2 matter, the Minnesota Large Industrial Group filed a Motion to Strike the Surrebuttal Testimony of Dr. Peter Reich.

On September 15, 2015, in the CO_2 matter, as to certain motions regarding direct and rebuttal testimony, the ALJ issued an Order on Motions By Peabody Energy Corporation, the Minnesota Department of Commerce, and the Pollution Control Agency to Exclude and Strike Testimony which:

- Denied the Agencies' motions to strike direct and rebuttal testimony, with a limited exception;
- Granted the Agencies' motion to strike certain rebuttal testimony of Mr. Happer; and
- Denied Peabody's motion to exclude the testimony of Mr. Rumery and Mr. Kunkle.

On September 15, 2015, in the CO_2 matter, as to certain other motions regarding direct and rebuttal testimony, the ALJ issued an Order On Motions by Minnesota Large Industrial Group and Peabody Energy Corporation to Exclude and Strike Testimony which:

- Denied motions of the Minnesota Large Industrial Group and Peabody to exclude the testimony of Drs. Hanemann and Polasky; and
- Denied motions of the Minnesota Large Industrial Group and Peabody to exclude certain parts of Mr. Martin's testimony.

On September 18, 2015, in the CO_2 matter, the Agencies filed their Response to Peabody Motion to Exclude Expert Witness Surrebuttal Testimony.

On September 18, 2015, in the CO_2 matter, the Clean Energy Organizations filed their Response to Minnesota Large Industrial Group's Motion to Strike Surrebuttal Testimony of Dr. Peter Reich, and Peabody Energy's Motion to Exclude Dr. Peter Reich and Certain Testimony of Drs. Abraham and Dessler.

On September 21, 2015, in the CO_2 matter, as to motions regarding surrebuttal testimony, the ALJ issued an Order On Motions by Minnesota Large Industrial Group and Peabody Energy Corporation to Exclude and Strike Testimony which:

- Denied both parties' motions to exclude the testimony of Dr. Reich with limited exception;
- Denied Peabody's motion to exclude certain testimony of Dr. Abraham; and
- Denied Peabody's motion to exclude certain testimony of Dr. Dressler.

On September 21, 2015, the Agencies filed a Motion to Amend Protective Order in order to accommodate discovery by the Agencies and to identify the MPCA as one of the government agencies that will possess protected data in this matter.

On September 23, 2015, granting the Agencies' motion to amend, the ALJ issued an Amended Protective Order.

On September 24 – 30, 2015, the evidentiary hearing in the CO_2 matter took place in the Commission's large hearing room.

On October 14, 2015, regarding the CO_2 matter and the criteria pollutants $PM_{2.5}$, SO_2, and NO_x, the ALJ issued her Sixth Prehearing Order that set forth the following schedule:

Document or Event	*Due Date CO_2*	**Due Date SO_2, NO_2, and $PM_{2.5}$**
Rebuttal Testimony		**October 30, 2015**
Status Conference		**November 2, 2015, 9:30 a.m.**
Objections to any prefiled direct or rebuttal testimony or witness		**November 6, 2015**
CO_2 Issues Matrix	*November 12, 2015*	
Responses to objections to direct or rebuttal testimony or witness		**November 18, 2015**
CO_2 Initial Briefs	*November 24, 2015*	
Surrebuttal Testimony		**December 4, 2015**
CO_2 Reply Briefs, Proposed Findings, Comments on Issues Matrix	*December 15, 2015*	
Status Conference – in person		**December 18, 2015, 9:30 a.m.**
Objections to any surrebuttal testimony or witness		**December 18, 2015**
Evidentiary Hearings (may be adjusted if status conferences indicate less time is needed		**January 6-8, and 11-15, 2016 - 9 a.m.**
Issues Matrix		**February 16, 2016**
Initial Briefs		**March 1, 2016**
Reply Briefs, Proposed Findings, Comments, if any, on Issues Matrix		**April 15, 2016**
ALJ Report	April 15, 2016	**June 15, 2016**

On October 30, 2015, parties filed Rebuttal Testimony regarding the criteria pollutants $PM_{2.5}$, SO_2, and NO_x. Also on October 30, the Clean Energy Organizations filed an Amended Notice of Appearance of Ms. Currie, Mr. Kingston, and Mr. Reuther on behalf of Fresh Energy, Sierra Club and Minnesota Center for Environmental Advocacy, and stated that the Izaak Walton League of America – Midwest Office League no longer wishes to maintain party status.

On November 3, 2015, counsel for the Agencies filed a letter setting forth parties' stipulation, only for purposes of the current docket, that there is no double-counting of SO_2–related damages between the proceedings concerning the Criteria Pollutant "track" and the Carbon "track."

On November 6, 2015, the Agencies and the Clean Energy Organizations each filed a Motion to Strike portions of the Rebuttal Testimony of Richard A. Rosvold filed on behalf of Xcel, and the Rebuttal Testimony of Roger O. McClellan, filed on behalf of the Minnesota Large Industrial Group, regarding the criteria pollutants.

On November 9, following a pretrial conference on November 2, 2015, the ALJ issued the Seventh Prehearing Order regarding the evidentiary hearing as to the criteria pollutants $PM_{2.5}$, SO_2, and NO_x, in which the schedule of proceedings was updated, as follows:

Document or Event	*Due Date CO_2*	**Due Date SO_2, NO_2, and $PM_{2.5}$**
Objections to any prefiled direct or rebuttal testimony or witness		**Friday November 6, 2015**
CO_2 Issues Matrix	*Thursday, November 12, 2015*	
Responses to objections to direct or rebuttal testimony or witness		**Wednesday, November 18, 2105**
CO_2 Initial Briefs	*Tuesday, November 12, 2015*	
Surrebuttal Testimony		**Friday, December 4, 2015**
CO_2 Reply Briefs, Findings, Comments on Issues Matrix	*Tuesday, December 15, 2015*	
Objections to any surrebuttal testimony or witness		**Friday, December 11, 2015**
Status Conference – in person		**Friday, December 18, 2015**
Responses to Objections to surrebuttal testimony or witness		**Friday, December 18, 2015**
Evidentiary Hearings (may be adjusted if status conferences indicate less time is needed		**January 11-15, 2016**
Issues Matrix		**Tuesday, February 16, 2016**
Initial Briefs		**Tuesday, March 1, 2016**
Reply Briefs, Proposed Findings of Fact and Comments, if any, on Issues Matrix		**Friday, April 15, 2016**
ALJ Report	April 15, 2016	June 15, 2016

On November 12, 2015, the parties filed a Joint Issues List regarding the CO_2 matter.

On November 18, 2015, Xcel and the Minnesota Large Industrial Group each filed opposition to the motions to strike rebuttal testimony, regarding the criteria pollutants $PM_{2.5}$, SO_2, and NO_x,.

On November 24, 2015, parties filed Initial Briefs regarding the CO_2 matter.

On November 24, 2015, the ALJ denied the motions to strike filed by the Agencies and the Clean Energy Organizations, regarding the criteria pollutants $PM_{2.5}$, SO_2, and NO_x.

On December 4, 2015, parties filed Surrebuttal Testimony regarding the criteria pollutants $PM_{2.5}$, SO_2, and NO_x.

On December 15, 2015, parties filed Reply Briefs and Proposed Findings, and Comments on the Joint Issues List, regarding the CO_2 matter.

On December 22, 2015, following a status conference on December 18, 2015, the ALJ issued the Eighth Prehearing Order regarding the criteria pollutants $PM_{2.5}$, SO_2, and NO_x, that updated the schedule, as follows:

Document or Event	Due Date CO_2	**Due Date SO_2, NO_2, and $PM_{2.5}$**
Deadline for e-Filing revisions or corrections to prefiled testimony or exhibits		**January 7, 2016**
Deadline for providing Court Reporter with Draft Exhibit List		**January 7, 2016**
Evidentiary Hearings		**January 12-14, 2016**
Issues Matrix		**Tuesday, March 1, 2016**
Initial Briefs		**Tuesday, March 15, 2016**
Reply Briefs, Proposed Findings of Fact and Comments, if any, on Issues Matrix		**Friday, April 15, 2016**
ALJ Report	*April 15, 2016*	**Wednesday, June 15, 2016**

On January 12-14 , 2016, the evidentiary hearing took place in the Commission's large hearing room, regarding the criteria pollutants $PM_{2.5}$, SO_2, and NO_x.

On March 1, 2016, parties filed a Joint Issues List regarding the criteria pollutants $PM_{2.5}$, SO_2, and NO_x.

On March 15, 2016, parties filed Initial Briefs regarding the criteria pollutants $PM_{2.5}$, SO_2, and NO_x.

STATE OF MINNESOTA

OFFICE OF THE ATTORNEY GENERAL

SUITE 1800
445 MINNESOTA STREET
ST. PAUL, MN 55101-2134
TELEPHONE: (651) 297-2040

March 15, 2016

The Honorable LauraSue Schlatter
Administrative Law Judge
Office of Administrative Hearings
600 North Robert Street
P.O. Box 64620
St. Paul, MN 55164-0620

RE: In the Matter of the Further Investigation in to Environmental and Socioeconomic Costs Under Minnesota Statute 216B.2422, Subdivision 3
PUC Docket No. E-999/CI-14-643
OAH Docket No. 80-2500-31888

Dear Judge Schlatter:

Enclosed please find Initial Post Hearing Brief of the Minnesota Department of Commerce, Division of Energy Resources, and the Minnesota Pollution Control Agency-Criteria Pollutants.

Respectfully submitted,

s/ **Linda S. Jensen**
Linda S. Jensen

Attorney for the Minnesota Department of Commerce and Minnesota Pollution Control Agency

445 Minnesota Street, Suite 1800
St. Paul, MN 55101-2131
Telephone: (651) 757-1472

Enclosure
cc: Service List

AFFIDAVIT OF SERVICE

RE: In the Matter of the Further Investigation in to Environmental and Socioeconomic Costs Under Minnesota Statute 216B.2422, Subdivision 3 (2014)
PUC Docket No. E-999/CI-14-643;
OAH Docket No. 80-2500-31888

STATE OF MINNESOTA)
) ss.
COUNTY OF RAMSEY)

I, Annabel Foster Renner, hereby state that on the March 15, 2016, I filed by electronic eDockets the attached **Initial Post Hearing Brief of the Minnesota Department of Commerce, Division of Energy Resources, and the Minnesota Pollution Control Agency-Criteria Pollutants** and eServed or sent by US Mail, as noted, to all parties on the attached service list.

See attached service list for PUC Docket No. E-999/CI-14-643;
OAH Docket No. 80-2500-31888

/s/ **Annabel Foster Renner**
ANNABEL FOSTER RENNER

Subscribed and sworn to before me on
this 15th day of March, 2016.

/s/ **LaTrice Woods**
Notary Public – Minnesota
My Commission Expires January 31, 2020.

Electronic Service Member(s)

Last Name	First Name	Email	Company Name	Delivery Method	View Trade Secret
Aafedt	David	daafedt@winthrop.com	Winthrop & Weinstine, P.A.	Electronic Service	No
Ahern	Michael	ahern.michael@dorsey.com	Dorsey & Whitney, LLP	Electronic Service	No
Al	Marc	marc.al@stoel.com	Stoel Rives LLP	Electronic Service	Yes
Brown	Hugh	brown.hugh@dorsey.com	Dorsey & Whitney LLP	Electronic Service	No
Brown	B. Andrew	brown.andrew@dorsey.com	Dorsey & Whitney LLP	Electronic Service	No
Cronin	Carl	carl.cronin@xcelenergy.com	Xcel Energy	Electronic Service	Yes
Currie	Leigh	lcurrie@mncenter.org	Minnesota Center for Environmental Advocacy	Electronic Service	No
DeBleeckere	Patricia	tricia.debleeckere@state.mn.us	Public Utilities Commission	Electronic Service	Yes
Denniston	James	james.r.denniston@xcelenergy.com	Xcel Energy Services, Inc.	Electronic Service	Yes
Dexter	Jessica	jdexter@elpc.org	Environmental Law & Policy Center	Electronic Service	No
Draxten	Brian	bhdraxten@otpco.com	Otter Tail Power Company	Electronic Service	No
Duncan	Tristan	tlduncan@shb.com	Shook Hardy & Bacon, L.L.P.	Electronic Service	No
Eknes	Bret	bret.eknes@state.mn.us	Public Utilities Commission	Electronic Service	Yes
Erickson	Jim	jim.g.erickson@xcelenergy.com	Xcel Energy	Electronic Service	Yes
Gerhardson	Bruce	bgerhardson@otpco.com	Otter Tail Power Company	Electronic Service	No
Gratz	Emerald	emerald.gratz@state.mn.us	Office of Administrative Hearings	Electronic Service	Yes
Grever	Thomas J.	tgrever@shb.com	Shook, Hardy &Bacon L.L.P.	Electronic Service	No
Hamilton	J Drake	hamilton@fresh-energy.org	Fresh Energy	Electronic Service	No
Jensen	Linda	linda.s.jensen@ag.state.mn.us	Office of the Attorney General-DOC	Electronic Service	Yes
Johnson	Kevin D.	kdjohnson@stoel.com	Stoel Rives LLP	Electronic Service	No
Johnson Phillips	Sarah	sjphillips@stoel.com	Stoel Rives LLP	Electronic Service	No
Kingston	Hudson	hkingston@mncenter.org	MN Center for Environmental Advocacy	Electronic Service	No
Klein	Brad	bklein@elpc.org	Environmental Law & Policy Center	Electronic Service	No
Lee	Kevin	kevin@kevinleelaw.com	N/A	Electronic Service	No
Massey	Jonathan	jmassey@masseygail.com	Massey & Gail LLP	Electronic Service	No
Moeller	David	dmoeller@allete.com	Minnesota Power	Electronic Service	No
Moratzka	Andrew	apmoratzka@stoel.com	Stoel Rives LLP	Electronic Service	No
Oxley	Jeff	jeff.oxley@state.mn.us	Office of Administrative Hearings	Electronic Service	Yes
Rebholz	Michelle	michelle.rebholz@state.mn.us	Public Utilities Commission	Electronic Service	Yes
Reuther	Kevin	kreuther@mncenter.org	MN Center for Environmental Advocacy	Electronic Service	No
Ross McCalib	Laureen	lrossmccalib@grenergy.com	Great River Energy	Electronic Service	No
Schlatter	LauraSue	LauraSue.Schlatter@state.mn.us	Office of Administrative Hearings	Electronic Service	Yes
Shaddix Elling	Janet	jshaddix@janetshaddix.com	Shaddix And Associates	Electronic Service	Yes
Stalpes	Sean	sean.stalpes@state.mn.us	Public Utilities Commission	Electronic Service	Yes
Stephenson	Donna	dstephenson@grenergy.com	Great River Energy	Electronic Service	No
Swanson	Eric	eswanson@winthrop.com	Winthrop Weinstine	Electronic Service	No
Thompson	SaGonna	Regulatory.records@xcelenergy.com	Xcel Energy	Electronic Service	Yes
Vaughn	Erin	evaughn@shb.com	Shook, Hardy &Bacon L.L.P.	Electronic Service	No
Wicker	Colin	wicker.colin@dorsey.com	Dorsey & Whitney LLP	Electronic Service	No
Williams	Alexis	williams@fresh-energy.org	Fresh Energy	Electronic Service	No
Winton	Cam	cwinton@mnchamber.com	Minnesota Chamber of Commerce	Electronic Service	No
Wolf	Daniel P	dan.wolf@state.mn.us	Public Utilities Commission	Electronic Service	Yes