Minnesota Center for Environmental Advocacy

Using law, science, and research to protect Minnesota's environment, its natural resources, and the health of its people.

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March 15, 2016

The Honorable LauraSue Schlatter
Administrative Law Judge
Office of Administrative Hearings
600 North Robert Street
St. Paul, MN 55101

VIA ELECTRONIC FILING

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

Dear Judge Schlatter:

In connection to Phase II or the Criteria Pollutants portion of the above-referenced docket, please find enclosed the Initial Post-Hearing Brief filed on behalf of Clean Energy Organizations. Also attached is an Affidavit of Service.

Please do not hesitate to contact me should you have any questions or concerns.

Sincerely,

/s/ Leigh Currie
Leigh Currie
Staff Attorney

LC/em

Enclosure

cc: Attached service list

STATE OF MINNESOTA

OFFICE OF ADMINISTRATIVE HEARINGS

FOR THE MINNESOTA PUBLIC UTILITIES COMMISSION

In the Matter of the Investigation into the Environmental and Socioeconomic Costs Under Minn. Stat. § 216B.2422, Subd. 3

MPUC Docket No. E-999/CI-14-643, E-999/CI-00-1636

OAH Docket No. 80-2500-31888

PHASE II—CRITERIA POLLUTANTS INITIAL POST-HEARING BRIEF

of

CLEAN ENERGY ORGANIZATIONS

MARCH 15, 2016

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INTRODUCTION

Minnesota Center for Environmental Advocacy, Fresh Energy, and Sierra Club (collectively, “Clean Energy Organizations” or “CEOs”) submit that a preponderance of the evidence shows that updated values for fine particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2) and nitrogen oxides (NO_x) should be calculated by:

(1) Including damages caused by increases in pollution concentrations in areas outside of Minnesota;

(2) Running a reduced-form integrated assessment model such as InMAP a sufficient number of times to capture geographic variability;

(3) Using the two concentration response functions from the two most widely studied and respected cohorts in the epidemiological literature to create a range of values that captures uncertainty; and

(4) Using the Value of Statistical Life recommended by the U.S. Environmental Protection Agency.

The first two steps are necessary to fulfill the requirement of calculating damages based on *actual damages*. The remaining steps are, to varying degrees, matters of professional judgment. CEOs submit that rather than relying on the professional judgment of any single witness in this proceeding, the ALJ should recommend that the Commission rely on the professional judgment of the Scientific Advisory Board and the U.S. Environmental Protection Agency.

PROCEDURAL HISTORY

In 1993, the Minnesota Legislature enacted Minnesota Statute § 216B.2422, subdivision 3, which required the Public Utilities Commission (“the Commission”) to “quantify and establish” environmental costs of electricity generation. Minn. Stat. § 216B.2422, subd. 3(a) (2014). The Commission established interim external cost values in 1994, and permanent values in 1997. Order Establishing Environmental Cost Values, Docket No. 93-538, (Jan. 3, 1997) (Ex. 306, hereinafter referred to as “1997 Commission Order”.) In 1997, the Commission established values for SO_2, coarse particulate matter ("PM_{10}"), Carbon Monoxide ("CO"), NO_x, Lead ("Pb"), and Carbon Dioxide ("CO_2"). 1997 Commission Order at 33. The ranges adopted in that proceeding are in the table below (in 1995 dollars):

		Urban	Metropolitan Fringe	Rural	Within 200 Miles of Minnesota
SO_2	$/ton	112 - 189	46 - 110	10 - 25	10 - 25
PM_{10}	$/ton	4,462 - 6,423	1,987 - 2,886	562 - 855	562 - 885
CO	$/ton	1.06 - 2.27	0.76 - 1.34	0.21 - 0.41	0.21 - 0.41
NO_x	$/ton	371 - 978	140 - 266	18 - 102	18 - 102
Pb	$/ton	3,131 - 3,875	1,652 - 1995	402 - 448	402 - 448
CO_2	$/ton	.30 - 3.10	.30 - 3.10	.30 - 3.10	.30 - 3.10

The Commission, based on the prospect of federal regulation of SO_2, set SO_2 cost values at 0 after 2000. *Id*. In 2001, the Commission began to update external cost values to account for inflation, Order Updating Externality Values, Pub. Util. Comm'n Docket No. E-999/CI-00-1636 at 10 (May 3, 2001), but declined to establish an external cost for fine particulate matter ("$PM_{2.5}$") or Mercury. Order Deferring Further Action, Pub. Util. Comm'n Docket No. E-999/CI-00-1636 at 4 (Oct. 5, 2001). The Commission continues to use the values established in 1997 today, adjusted only for inflation. *See* Notice of Updated Environmental Externality Values, Pub. Util. Comm'n Docket No. E-999/CI-00-1636 (May 27, 2015). For SO_2 and $PM_{2.5}$, the Commission applies no cost values.

In 2013, CEOs moved for the Commission to re-open the environmental externality docket because the current values for some pollutants do not reflect the current science and underestimate the costs of pollution. Specifically, the Clean Energy Organizations requested that the Commission establish cost values for $PM_{2.5}$ and SO_2, and update the values for NO_x and CO_2.

Memorandum in Support of Clean Energy Orgs.' Motion, Pub. Util. Comm'n Dockets No. E-999/CI-93-583, E-999/CI-00-1636, & E-999/CI-14-643, at 15-16 (Oct. 9, 2013). After initial public comment, the Commission agreed to investigate the environmental and socioeconomic costs of electricity generation for SO_2, $PM_{2.5}$, NO_x, and CO_2. Order Reopening Investigation and Convening Stakeholder Group to Provide Recommendations for Contested Case Proceeding, Pub. Util. Comm'n Dockets No. E-999/CI-00-1636 & E-999/CI-14-643, at 5 (Feb. 10, 2014).

When it re-opened the investigation, the Commission also directed the Department of Commerce and the Pollution Control Agency to convene a stakeholder group to help the Commission determine the scope of that investigation. *Id.* at 6. With respect to SO_2, $PM_{2.5}$, and NO_x (collectively referred to as the "criteria pollutants"), the agencies recommended that:

- Consideration of external damages from both CO_2 and criteria pollutants should not be limited to just those damages within Minnesota.
- Whether non-human health impacts of criteria pollutants will be taken into consideration will depend on whether the contractor has credible and accurate methods and models to do so.
- For criteria pollutants, a photochemical modeling approach should be taken to determine the most credible externality values for Minnesota electric generator emissions. If a photochemical modeling approach is too costly or time consuming, then a reduced form modeling approach would be the next best option for estimating criteria pollutant externality values.

Dep't of Commerce & Pollution Control Agency, Comments of the Minnesota Dep't of Commerce and the Minn. Pollution Control Agency, Pub. Util. Comm'n Docket No. E-999/CI-00-1636 (June 10, 2014).

The Commission referred the matter to the Office of Administrative Hearings ("OAH") for contested case hearings on the issue of the appropriate values for SO_2, $PM_{2.5}$, and NO_x. Notice and Order for Hearing, Pub. Util. Comm'n Dockets No. E-999/CI-00-1636 & E-999/CI-14-643 at 8 (Oct. 15, 2014). The Commission "require[d] 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." *Id.* at 4. The Commission made this recommendation based on its determination in the previous proceeding that "the damage-cost approach is superior because it appropriately focuses on actual damages from uncontrolled emissions." *Id.* The Commission approved the Department of Commerce, Division of Energy Resources ("the Department")'s request to hire a consultant and further stated that:

> having considered the relative merits of damage modeling approaches discussed by the Agencies, [it] 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.

Id. at 5.

The Honorable LauraSue Schlatter on behalf of the OAH bifurcated the hearings and testimony on CO_2 from those for the criteria pollutants. First Prehearing Order, Office of Admin. Hearings, Docket No. 80-2500-31888, Pub. Util. Comm'n Docket No. E-999/CI-14-643 at 12 (Dec. 9, 2014).

The CEOs, the Department, and Peabody Energy Corporation had intervened with the Public Utilities Commission and were parties when the matter was submitted to OAH. In December 2014, intervention was granted to Otter Tail Power, Minnesota Power, Lignite Energy Council, Northern States Power doing business as Xcel Energy ("Xcel Energy"), Minnesota Large Industrial Group ("MLIG"), Great River Energy, and Minnesota Chamber of Commerce. *Id.* at 2, 4. In March and April, 2015, the Minnesota Pollution Control Agency, Doctors for a Healthy Environment, Clean Energy Business Coalition, and Interstate Power and Light Company intervened as well. Order Granting Intervention to Minn. Pollution Control Agency, Office of Admin. Hearings, Docket No. 80-2500-31888, Pub. Util. Comm'n Docket No. E-999/CI-14-643 at 2 (Mar. 3, 2015); Order Granting Intervention to Doctors for a Healthy Env't, Clean Energy Bus. Coal., and Interstate Power and Light Co., OAH, Docket No. 80-2500-31888, Pub. Util. Comm'n Docket No. E-999/CI-14-643 at 3 (Apr. 16, 2015).

The Department and Minnesota Pollution Control Agency (collectively "the Agencies"), Xcel Energy, and CEOs pre-filed direct testimony proposing damages for SO_2, $PM_{2.5}$, and NO_x on August 5, 2015. These three parties and MLIG pre-filed rebuttal testimony on October 30, 2015, and the Agencies, Xcel Energy, and CEOs pre-filed surrebuttal testimony on December 4, 2015. A hearing was held January 12–14, 2016, at which time opportunity was provided for cross-examination of all witnesses.

FACTUAL BACKGROUND

Ambient air pollution is estimated to kill over three million people per year globally. (Ex. 119, schedule 1 at 9283.) Approximately 95 percent of these three million deaths are caused by fine particulate matter, $PM_{2.5}$. (Ex. 119, schedule 1 at 9283.) SO_2, and NO_x emissions combine with other chemicals in the ambient air, and transform into $PM_{2.5}$. (Ex. 115 at 10:2–4.) When inhaled over long periods of time ("chronic exposure"), $PM_{2.5}$ impacts human respiratory and cardiovascular systems, and increases mortality. (Ex. 808 at 14:20–15:4; ex. 115 at 22:14–17.) Although $PM_{2.5}$ emissions are governed by National Ambient Air Quality Standards promulgated by the Environmental Protection Agency ("EPA"), the EPA recognizes that evidence continues to grow in support of "health effects [ ] at lower ambient $PM_{2.5}$ concentrations, including effects in areas that likely me[e]t the current standards." (Ex. 444A (Air Quality Designations for the 2012 Primary Annual Fine Particle ($PM_{2.5}$) NAAQS) at 3089.) Assessing damages caused by $PM_{2.5}$ must account for the health impacts caused by its inhalation.

Methodology of Damage Calculations

In order to assess the damages of air pollutants like $PM_{2.5}$, researchers employ one general approach:

> The first step documents where and in what amounts emissions occur. The second step, air quality monitoring, connects emissions to estimates of ambient pollutant concentrations (i.e., the concentration of harmful pollutants in the air). With concentration estimates produced by the model, the next stage tabulates exposures. This phase combines the predicted concentrations with data on entities that are sensitive to contact with ambient pollution. The exposure stage requires spatially detailed data on populations that have been shown to exhibit sensitivity to air pollution exposure, for example, human populations. Exposures are then translated to physical environmental and health effects using dose-response functions. Finally, these effects are reported in monetary terms.

(Ex. 808 at 6:1–11.) Essentially, researchers turn emissions into damages with four key steps: modeling emissions, estimating exposure, assigning a dose-response function, and valuing damages. (Ex. 808 at 5.)

For the first step, air quality modeling, researchers may employ either reduced-form or photochemical models. (Ex. 808 at 5.) These models differ by the detail with which they recreate air quality data and chemical processes, with reduced-form models recreating processes in a less-detailed or "reduced" manner, as the term suggests. (Ex. 808 at 5, n. 1; ex. 115 at 6:2–13.) Any model used should consider the fact that $PM_{2.5}$ can travel long distances, but can also be highly spatially variable near emission sources. (Ex. 115 at 6; ex. 808 at 10:13–17.) Modeling emissions also involves determining from where those emissions emanate. The source of emissions dramatically influences exposure, so how many sources to model, their heights, and where those sources are located become important decisions.

The second step involves comparing population locations to the air quality results of the model. (Ex. 115 at 7:15–19 (InMAP inputs census data to track exposure); ex. 808 at 14:17–18, 23:6–25:20 (AP2 models exposure to $PM_{2.5}$ and ozone).) Generally, this can be done by using census data for the areas where pollution travels to correlate pollution and population.

The third step of modeling translates exposures into health effects based on public health, or epidemiological studies. The best estimates of the correlation between exposure to pollution and increased risk of premature mortality are derived from cohort studies. A cohort study is a public health study that observes a population over a period of time. (Ex. 117 at 4:12.) Based on these observations, epidemiologists can then link outcomes such as disease and death with behaviors and environmental exposures. (Ex. 117 at 4:12–14.) The long-term nature of cohort studies (as opposed to cross-sectional studies) is important when trying to assess increased mortality risks from chronic exposure, like those due to $PM_{2.5}$. (Ex. 117 at 4:12–5:2.) Cohort studies produce concentration-response functions that can be applied to exposure data. (Ex. 808 at 6:6–7.) Concentration-response functions calculate the effects of a stressor, such as $PM_{2.5}$, on a specific population or fraction of a population. (Ex. 808 at 6:14–23.) In the context of air pollution and public health, concentration-response functions are "typically mathematical functions that use ambient air concentration estimates as inputs and produce changes to the incidence rates of adverse effects (e.g. premature mortality or asthma exacerbations) as outputs." (Ex. 808 at 6:17–20.) In other words, a concentration-response function is a description of the relationship between exposure concentrations and increased disease or mortality. (Ex. 441 at 17.) After the third step in the damage estimation process, modelers will have therefore calculated likely health impacts in exposed populations.

The fourth and final step converts health impacts into a damage evaluation with a multiplier. This multiplier for the increased risk of premature mortality is termed the Value of a Statistical Life ("VSL"), although economists do not agree on a single estimate value. (Ex. 118 at

2:10–14.) Researchers derive VSL estimates from "the monetary value that people place on risk to their life or well-being." (Ex. 115 at 25:5–6.) They assess that value in two primary ways: revealed preference studies and stated preference studies. These terms refer to estimates of the monetary value people attribute to an increase or decrease in mortality risk. (Ex. 118 at 3:4–7.) One type of revealed preference study is known as the hedonic wage study. Hedonic wage estimates are based on the "revealed preferences," or "the preferences people expressed through their actual behavior" with respect to wage increases they required in order to assume additional on-the-job risk; while stated preference estimates are based on what surveyed individuals reported they would be willing to pay for a decrease in risk. (Ex. 118 at 3:4–7, 13–15.) Stated preferences tend to produce much lower VSLs than revealed preferences. (Ex. 118 at 6:18–7:3.) The EPA Science Advisory Board recommends the federal government use both types of studies, and also recommended a specific value that pulled from both types of studies in EPA's own meta-analysis.[1] (Ex. 118 at 3:16–17.) Meta-analyses are important to reduce uncertainty because VSL estimates vary to a significant extent. (Ex. 118 at 2:11–14.) According to Dr. Marshall: "To calculate an externality value, which is the economic damages attributable to each ton of pollution emitted, we multiply the number of deaths caused per ton of emissions by a value of statistical life ("VSL") to get dollars of damages per ton of emissions." (Ex. 115 at 24:17–19.)

[1] The EPA defines a meta-analysis as "a statistical method of pooling data and/or results from a set of comparable studies of a problem." EPA Guidelines for Preparing Economic Analyses, December 2010, at xiv. "Pooling in this way provides a larger sample size for evaluation and allows for a stronger conclusion than can be provided by any single study." *Id.* "A meta-analysis considers the relevant field of research, excludes studies which are thought to be irrelevant, and synthesizes results of various studies into one result (estimate of strength of association). Meta-analysis is a useful tool to understand and deal with heterogeneity across individual studies." (Ex. 117 at 910.)

CEOs' Damage Calculations

Despite the same general approach, each modeler made different decisions at each of these four steps. Dr. Marshall calculated damages from $PM_{2.5}$, NO_x, and SO_2 using the reduced-form model known as the Intervention Model for Air Pollution, or "InMAP." (Ex. 115 at 5:5–14.) InMAP is a reduced-form model that relies on the output of more complex models in order to include only those atmospheric processes that are most important for answering the question at hand. (Ex. 115 at 6:9–12.) Dr. Marshall, one of InMAP's authors/designers, testified that he and Dr. Christopher Tessum designed the model to be more practical to run than comprehensive air pollution models and to improve upon weaknesses of other reduced-form models. (Ex. 115 at 8:18–20.) InMAP leverages pre-processed physical and chemical information from the output of the state-of-the-science chemical transport model (WRF-Chem). (Ex. 115 at 9:18–20.) Phenomena modeled by WRF-Chem include (but are not limited to):

- Weather conditions, including wind speed and direction, clouds and precipitation;
- Transport of air pollution in the atmosphere by wind and turbulence after it is emitted;
- Transformation of pollutants into different types of pollutants as they interact with sunlight and with each other; and,
- Removal of air pollution by surfaces, clouds, and precipitation.

(Ex. 115 at 10:15–20.) Output from WRF-Chem is used to calculate wind speed in six directions in each InMAP grid cell. (Ex. 116 at 10:19–111.) Because the majority of $PM_{2.5}$ impacts occur due to annual exposures, relying on WRF-Chem's output captures the most important information from WRF-Chem while freeing up computational capacity within InMAP. (Ex. 115 at 9:18–20.) InMAP can perform simulations that are several orders of magnitude less computationally intensive than comprehensive photochemical model simulations. (Ex. 119, schedule 1 at 9284–9302.)

Using InMAP, Dr. Marshall first calculated impacts caused by emissions from each county in Minnesota and counties within 200 miles of Minnesota at three different effective stack heights. (Ex. 115 at 17:13–18.) An effective stack height is the height of the smoke stack plus the additional height that the emission plume rises due to buoyancy and initial upward velocity of the emissions. (Ex. 115 at 19:7–9.) In InMAP, each vertical grid layer represents a range of effective stack heights where all emissions within the range cause the same projected impacts. (Ex. 115 at 19:10–13.) The vertical centers of these three ranges are 29 m, 310 m, and 880 m. (Ex. 115 at 19:15–16.) The lowest grid cell represents the 25^{th} percentile of effective stack heights, the middle grid cell represents the 75^{th} percentile of effective stack heights, and the highest grid cell represents the average height, weighted by SO_2 emissions (as recorded by U.S. EPA's 2011 National Emissions Inventory). (Ex. 115 at 19:16–20.)

Modeling stack height is important because elevation of the source of emissions can have a large impact on the transport of pollutants. (Ex. 115 at 20:5–7.) In addition, natural gas plants tend to have shorter effective stack heights than coal plants. (Ex. 115 at 20:7–8.) Results from a variety of effective stack heights will allow for a better estimate of the actual damages from power plants whose location and stack height are known. (Ex. 115 at 20:8–10.)

Dr. Marshall also calculated "generic" values based on the weighted average of damages from emissions from existing power plants in Minnesota. (Ex. 115 at 18:13–18.) The generic values (in year 2015 dollars) calculated by Dr. Marshall are:

- $PM_{2.5}$: $125,000 - $218,000 /ton
- SO_2: $16,000 - $28,000 /ton
- NO_x: $14,000 - $24,000 /ton

(Ex. 115 at 28:6–9.)

Dr. Marshall made four key decisions related to this general process of calculating the criteria pollutant damages: the geographic scope of damages that should be considered; that it is important to account for the variation of damages based on specific plant location; which concentration-response function to use; and which Value of a Statistical Life (VSL) to use. Dr. Marshall calculated damages based on changes to ambient air concentrations calculated by InMAP throughout the contiguous U.S., and to account for the geographic variability of damages based on emission location, he calculated changes in $PM_{2.5}$ concentrations caused by emissions of the three pollutants from each county in Minnesota and counties that fall within 200 miles of the Minnesota border. (Ex. 115 at 17:13–18:2.) For VSL, Dr. Marshall selected the EPA Science-Advisory-Board-recommended figure, which is the central tendency value of a meta-analysis of 26 studies. (Ex. 115 at 25:10–15.) Dr. Marshall used the concentration response functions found in Krewski et al. (2009) and LePeule et al. (2012). (Ex. 115 at 21:13–22:13.) These two studies are the same epidemiological studies as the EPA uses for regulatory impact analysis, and are the most recent studies involving the largest and most widely analyzed cohorts—the Harvard Six Cities cohort and the American Cancer Society cohort. (Ex. 115 at 21:13–22:13.)

These decisions by Dr. Marshall form the basis of CEOs' recommended damages, and represent the best available and most reasonable decisions and inputs to use for this exercise.

STATEMENT OF THE ISSUE

The Commission has asked the parties to address, and the ALJ to make a recommendation on, "[t]he appropriate values for $PM_{2.5}$, SO_2, and NO_x under Minn. Stat. § 216B.2422, subd. 3." Notice and Order for Hearing, Pub. Util. Comm'n Docket Nos. E-999/CI-00-1636, E-999/CI-14-643/ at 8 (Oct. 15, 2014).

BURDEN OF PROOF

The ALJ's March 27, 2015 Order established that: "A party or parties proposing that the Commission adopt a new environmental cost value for one or more of the criteria pollutants—SO_2, NO_x, 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." Order Regarding Burdens of Proof, Pub. Util. Comm'n Docket No. E-999/CI-14-643/OAH Docket No. at 2 (Mar. 27, 2015). The Order further states that "[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." *Id.* at 3.

ARGUMENT

As noted, all three of the air pollution modelers who offered damages in this proceeding followed the same process: first, each determined the size, type, number, and location of emission sources that they would model; second, each used their air-pollution model of choice to model these emission sources and calculate the resulting changes in the concentration of SO_2, $PM_{2.5}$, and NO_x in the ambient air across the contiguous United States; third, each correlated these changes in concentration (within a specified geographic scope) to impacts using census data and concentration response functions; and lastly, each monetized these impacts using a Value of Statistical Life.

CEOs assert that there are four primary decisions that must be made by the Commission to establish up-to-date damage cost values for SO_2, $PM_{2.5}$, and NO_x: (1) what geographic scope of damages leads to the most reasonable and best available damages; (2) what is the most practicable and reasonable way to account for the geographic variability in damages based on emission location; (3) which concentration-response functions lead to the most reasonable and best available damages; and (4) what VSL leads to the most reasonable damages based on the best available information.

CEOs will demonstrate that a preponderance of the evidence in the record establishes that:

- The geographic scope of damages must be national (the contiguous U.S.).
- Damages at a county level are the most accurate and practicable way to account for geographic variability.
- The two concentration response functions from the two most widely studied cohorts in the epidemiological literature lead to the best available and most reasonable damages.
- The Value of Statistical Life recommended by the U.S. Environmental Protection Agency leads to the most reasonable damages based on the best available information.

I. THE GEOGRAPHIC SCOPE OF DAMAGES MUST BE NATIONAL.

At the close of the evidentiary hearing, the ALJ asked parties to specifically address the geographic scope of damages, identifying two main issues: (1) whether damages outside of Xcel Energy's "Minnesota Domain"[2] can be modeled with sufficient certainty; and (assuming they can) (2) whether such damages are then required to be included by the Commission in its ranges

[2] Dr. Desvousges designed his Minnesota Domain to estimate damages within Minnesota and approximately 100 miles from Minnesota. (Tr. Vol. 7 at 55–56.)

as a matter of law, whether such damages are prohibited from being included as a matter of law, or whether including or excluding national damages is a policy question for the Commission. (Tr. Vol. 8 at 157–58.) The first part of the ALJ's question—whether damages can be modeled a national scale with sufficient certainty—hinges first on whether such calculations are practicable (i.e. do they meet the definition of practicable under the statute) and second on whether the *results* of such modeling are sufficiently certain (i.e. does the record show by a preponderance of the evidence that damages based on a national scale are more likely to be accurate than damages based on a Minnesota Domain).

This record demonstrates by a preponderance of the evidence that modeling damages at a national scale is practicable and the results are sufficiently certain to recommend a range to the Commission based on a national scale. In fact, such a range is *required* by the statute and this Commission's precedent.

A. It Is Practicable To Calculate National Changes In Ambient Air Concentrations Based On Minnesota Emissions.

The relevant statute requires the Commission to establish a range of environmental costs of electricity generation "to the extent practicable." Minn. Stat. § 216B.2422, subd. 3. The statute does not define "practicable," but, generally, terms in statutes must be construed according to common and approved usage. Minn. Stat. § 645.08 (2014). The ALJ in the previous proceeding followed this directive and gave a common-sense reading of what is "practicable":

> The common and approved usage of "practicability" is "feasible," or capable of being accomplished. *See* Webster's New Universal Unabridged Dictionary (2d Ed. 1983). As will be discussed more fully below, there are some pollutants which are impossible to value, in the sense that there is just not enough data in this record to establish a value for them. As the ALJ interprets the term practicability, it is not practicable for the Commission to establish values for those pollutants at this time.

Findings of Fact, Conclusion, Recommendation and Memorandum, Docket no. E-999/CI-93-583 at 10 (Mar. 22, 1996) (Ex. 305, hereinafter "1996 ALJ Report"). This approach was approved by the Commission and the CEOs urge the ALJ to recommend it again; practicability in this proceeding should be based on whether there are enough data in the record to establish a value for a particular pollutant at a national scale. It is clear that there are robust data supporting national-scale damages.

All three modelers used their models to calculate changes in concentrations of these pollutants at a national scale. Dr. Marshall used InMAP to calculate the changes in the concentration of pollutants in the ambient air in approximately 50,000 grid cells across the "entire contiguous U.S." due to emissions from Minnesota and within 200 miles of Minnesota. (Ex. 115 at 18:3–5.) Dr. Marshall then used detailed census data to determine populations within these grid cells and extrapolated damage numbers based on how the changes in concentration of pollutants impacted these populations. (Ex. 115 at 18:5–12.) Dr. Muller similarly used AP2 to model impacts "within the contiguous U.S." from emissions within Minnesota and from counties within 200 miles of Minnesota. (Ex. 808 at 15:16–18.)

Even Dr. Desvousges calculated changes in ambient air concentrations at a national scale. When asked if "[i]n fact, in this proceeding CAMx was run in a way that it also calculated changes in ambient concentrations of pollutants across the U.S.," Dr. Desvousges confirmed that CAMx "did also provide that information as part of the calculations." (Tr. Vol. 7 at 57.) He also agreed that CAMx predicted changes in concentrations outside of the Minnesota Domain. (Tr. Vol. 7 at 57.) Dr. Desvousges simply chose not to use these data for policy reasons. (Ex. 608 at 45:17–21.) Modeling changes in concentration nationally is unquestionably practicable and common in the industry. There is ample evidence in the record to support national damages for all three criteria pollutants.

In the 1990s, in contrast, there were no data in the record on damages outside of Minnesota:

> One of the significant limitations of the TER study identified by [Department expert] Dr. Thayer was the scope of the geographic region analyzed by the study. The study did not include the effects of emissions transported much more than roughly 60 miles (100 kilometers) from the location of the plants in each scenario. Dr. Thayer testified that substantial research shows that some emissions are transported long distances and affect sensitive resources much farther than 100 km downwind of the emissions source. . . . Although the air quality impacts of a given source diminish with distance, the total number of people affected can increase significantly. . . . Dr. Thayer noted that if the Chicago metropolitan area had been included in the TER analysis, the total environmental damages may have been much greater.

1996 ALJ Report at 26. This deficiency has been, rightly, corrected by the record in this contested case, and there is no longer an argument that changes to ambient air concentrations cannot be practicably calculated on a national scale.

B. Changes In Ambient Air Concentrations Calculated By The Three Models At A National Scale Are Sufficiently Certain To Recommend A Range To The Commission.

All parties to this proceeding agree that damagescannot be calculated with absolute certainty at any scale. Each party proposed ways of accounting for uncertainty. In the earlier proceeding, the Commission found that the scientific evidence needed to calculate these damages "does not provide definitive answers[,]" and that "[u]sing a range of values appropriately acknowledges the uncertainty attending the quantification of environmental costs." 1997 Commission Order at 15. This approach was approved by the court of appeals:

> While we acknowledge the concerns about the uncertain and speculative nature of the available data, we are disinclined to prohibit the state from directing its instrumentalities to engage in environmentally-conscious planning strategies. Hopefully, the administrative process ensures the use of the best information

> available and takes precautions to guard against the dangers surrounding the use of such data. Here, the process adequately explained its decisions.

In the Matter of the Quantification of Environmental Costs Pursuant to Laws of Minnesota 1993, Chapter 356, Section 3, 578 N.W.2d 794, 800–01 (Minn. Ct. App. 1998).

Despite this acknowledgement that adopting a range of damages sufficiently accounts for uncertainty, some parties suggested that changes in ambient air concentrations at locations distant from Minnesota—despite being calculated by the models—were so uncertain that it would be more accurate to exclude rather than include these damages. (Ex. 608 at 46:4–17.) CEOs disagree.

The argument that changes outside of Minnesota should not be used to calculate damages because they are so small falls apart because the evidence overwhelmingly demonstrates that (1) pollution travels outside of Minnesota and goes *somewhere*—meaning that the values *cannot* be zero—and (2) small changes in concentration nevertheless cause measurable damage.

1. Changes in concentrations outside of the Minnesota Domain may be small, but they are not zero.

The ALJ is presented with two options grounded in the preponderance of the evidence standard: either changes in ambient air concentrations outside of Minnesota are more likely to be zero than the positive values calculated by all three models, or the changes are more likely to be those calculated by the models than they are likely to be zero. This is an easy choice because there is simply *no* evidence in the record that the changes in concentrations of pollution levels outside of the Minnesota Domain are zero.

Despite claims that the models are overestimating changes in concentrations at distant locations and that these changes should instead be zero (ex. 608 at 44), there is no evidence in the record to support an assertion that the concentrations outside of the Minnesota Domain are more likely to be zero than those calculated by the models. It is indisputable that Minnesota emissions travel long distances. (Ex. 115 at 12:5–6; 1996 ALJ Report at 26; 1997 Commission Order at 15.) The state-of-the-science models all demonstrate that the pollution lands both inside and outside of Minnesota, and in some instances at locations very distant from Minnesota. The record is clear that the changes in concentrations outside of the Minnesota Domain are *not* zero. Emissions have to go somewhere, and they increase the ambient concentration in the places they go. (Tr. Vol. 8 at 25:14–19.) Not a single model predicted pollution staying within the Minnesota Domain. Ignoring a preponderance of the evidence in favor of a concept for which there is *no* evidence would be arbitrary and capricious.

Because all three models have shown that there are calculable impacts outside Dr. Desvousges's Minnesota Domain, the burden of production and persuasion shifts to Xcel Energy to disprove what the models show. Yet Dr. Desvousges has provided no record evidence to prove his assertion that the majority of impacts occur within his grid box. He testified that he "did not calculate impacts beyond the box" or even whether "the majority of pollutants stay with[in the] box." (Tr. Vol. 7 at 61:10; 63:15–16.) He also testified that he did not calculate whether or not the majority of damages are within the Minnesota Domain. (Tr. Vol. 7 at 57:18–21.) In response to questions about how he distinguished between "impacts" and "damages," Dr. Desvousges explained: "damages to me are the monetization of [impacts or effects]. . . . But damages to me have a very specific meaning. It means that we have monetized those effects or impacts using whatever method that we've used." (Tr. Vol. 7 at 133.) By not monetizing modeled impacts outside of his box, Dr. Desvousges's final cost proposals do not reflect what CAMx showed would occur.

Moreover, ignoring these small changes in places outside of Minnesota can greatly distort the per-ton damages. In discussing EPA's modeling of air pollution impacts, Dr. McClellan explained that although particulate matter's attributable mortality risk above the baseline might be small "when used in company with standard baseline data for specific cities with populations measured in the millions, the calculated number of excess deaths is large." (Ex. 441, schedule 2 at 78.)

By failing to calculate damages based on impacts outside of the Minnesota Domain, Dr. Desvousges fails to give a damage estimate that reflects the *actual* changes in concentration CAMx modeled. Dr. Marshall, however, used these continental U.S. CAMx results to calculate damages. (Ex. 119 at 12:6–17.) Dr. Marshall presented his calculations of damages using CAMx's results in Tables 1–3 of his surrebuttal testimony:

Table 1. CAMx and InMAP Estimates of Damages per Ton Emissions for the Sherburne County Generator

	Primary $PM_{2.5}$	NO_x	SO_2
CAMx MN domain	$24,000	$7,000	$12,000
CAMx U.S. domain	$60,000	$20,000	$51,000
InMAP U.S. domain	$57,000	$9,000	$14,000

Table 2. CAMx and InMAP Estimates of Damages per Ton Emissions for the Black Dog Generator

	Primary $PM_{2.5}$	NO_x	SO_2
CAMx MN domain	$38,000	$8,000	$16,000
CAMx U.S. domain	$78,000[3]	$23,000	$57,000
InMAP U.S. domain	$223,000	$24,000	$21,000

Table 3. CAMx and InMAP Estimates of Damages per Ton Emissions for a Generator in Marshall, MN

	Primary $PM_{2.5}$	NO_x	SO_2
CAMx MN domain	$13,000	$6,000	$9,000
CAMx U.S. domain	$49,000	$19,000	$46,000
InMAP U.S. domain[4]	$62,000	$12,000	$37,000

(Ex. 119 at 14.)

Including these changes in concentration outside of Dr. Desvousges's Minnesota domain would have more than doubled Dr. Desvousges's damages. (Ex. 119 at 13.) Similarly, Dr. Muller pointed out multiple pieces of evidence showing that emissions from Minnesota sources reach beyond the grid box, including the figures in Dr. Desvousges' own testimony (Ex. 810 at 26–29).

Ignoring the fact that the majority of damages occur outside of the Minnesota Domain, Dr. Desvousges argues that all calculated impacts outside of the Minnesota Domain should be zeroed out rather than estimated based on CAMx results due to uncertainty. Dr. Desvousges claims that CAMx results should not be used to calculate national scale damages because he

[3] Dr. Marshall's testimony indicates that the 36-km resolution CAMx simulation may substantially underpredict impacts of $PM_{2.5}$ emissions in this specific case.
[4] InMAP results are the high-stack results for Lyon County, MN.

chose to use a coarse resolution[5] for the modeling at this level. Replacing less-than-perfect estimations with zero values is not appropriate on this record. (*See* ex. 119 at 11:19–12:5.)

In 1997, ALJ Klein explicitly rejected an attempt by Dr. Desvousges to substitute zero values that were in conflict with the expert modeling he supplied to the 1990s externalities record. "Although the TER study was sponsored by NSP, NSP did not adopt its conclusions as set forth above. Instead, NSP has proposed that in each case, the range begin with zero, and extend to the median of the TER numbers." 1996 ALJ Report at 28. ALJ Klein found that this suggested distortion of the study's findings "increases rather than decreases the uncertainty inherent in establishing environmental cost values." *Id.* at 29. Dr. Desvousges's attempt to zero-out the values beyond his grid box is contradicted by his own CAMx modeling in this record. The distortion he applied to his numbers increases uncertainty instead of decreasing it. There is no valid reason to support deliberately inaccurate values.

2. The fact that changes are small does not make associated damages uncertain.

The record clearly shows small changes in concentration outside of the Minnesota Domain. These small changes can be used to calculate damages with sufficient certainty. Even though epidemiological studies arguably compare larger differences in concentration, the evidence supports their use to calculate damages from small changes as well. The best epidemiological studies available demonstrate that population-level mortality impacts (the main cause of damage cost estimates in all three experts' values) change with small changes in

[5] As Environ explained: "The CAMx 'flexi-nest' feature was used to define the 12 km MN domain where the 12 km resolution meteorological and low-level emission inputs are obtained by interpolating the 36 km resolution input data." (Ex. 604, Schedule 3, at 12.) As can be seen in this statement, the finer data was "interpolated" from the national data, which is what CAMx actually estimated—CAMx modeling is national and interpolation could occur wherever Environ chose to set its box. (*See also* Tr. Vol. 7 at 133–34.)

ambient air pollution levels. These functions are linear—there is a constant proportional relationship between a change in concentration and any corresponding change in risk of premature mortality. (*See* ex. 117, schedule 3 at 967–68; ex. 809, attachment 2 at 6; ex. 811 at 33:6–13.) When a model calculates a very small change in the concentration of a pollutant, therefore, the corresponding change in increased mortality risk will also be very small. But it is *not zero*. No party has offered evidence of a non-linear response function. Neither EPA nor the leading epidemiological studies disagree with the modeling of small changes to calculate damages.[6] A preponderance of the evidence demonstrates that when pollution concentration increases, risk of premature mortality increases.

The record here contains the best information available in the scientific field of modeling emissions impacts. It is evident from all three models that the best science available can and does contemplate damages within the continental U.S. and that the leading epidemiological studies support calculating an increased risk of mortality based on such small changes. While the results inevitably reflect uncertainty, that uncertainty is a normal part of this type of modeling—it has been deemed acceptable by expert scientists in the field as well as by Minnesota courts evaluating the last environmental cost values proceeding.

C. National Damages Are Required By Minn. Stat. § 216B.2422, Subd. 3.

The ALJ asked, once it was established that national damages are practicable and can be calculated with sufficient certainty to recommend a range to the Commission, whether

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[6] *See, e.g.*, Krewski, D. et al., (2009) *Extended Follow-Up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality* (ex. 117, schedule 2); Lepeule, J. et al., (2012) *Chronic exposure to fine particles and mortality: An extended follow-up of the Harvard six cities study from 1974 to 2009* (ex. 117, schedule 3); Hoek G, et al. (2013) *Long-term air pollution exposure and cardio- respiratory mortality: a review* (ex. 117, schedule 5); and Jerrett M, et al. (2013) *Spatial Analysis of Air Pollution and Mortality in California* (ex. 117, schedule 6).

calculating damages based on a national scale was required by law, prohibited by law, or whether it was a policy judgment left to the Commission.

The relevant law states:

> 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 in conjunction with other external factors, including socioeconomic costs, when evaluating and selecting resource options in all proceedings before the commission, including resource plan and certificate of need proceedings.

Minn. Stat. § 216B.2422, subd. 3(a). Both the plain language of this statute and the Commission's previous interpretation of this statute *require* damages to be calculated at a national scale.

1. The plain language of the statute requires national-scale damages.

There is nothing in the above statutory language that would support a decision by the Commission to discount its cost values for policy considerations rather than accurately valuing projected actual damages. The statute makes the Commission's process in setting values mandatory by using the directive "shall" – as in, the Commission "shall, to the extent practicable quantify and establish a range of environmental costs associated with each method of electricity generation." Minn. Stat. § 216B.2422 Subd. 3. The only limitation in this statutory language with respect to quantifying these costs is practicability. In the previous proceeding, as discussed, practicability meant that damages were limited to a Minnesota Domain because there were no data with which to calculate damages using a different scale. There is no such limitation here; we have the data. When a statute is clear and unambiguous, "the letter of the law shall not be disregarded under the pretext of pursuing the spirit." Minn. Stat. § 645.16 (2014).

Instead, Dr. Desvousges admits that this is a policy decision. He claims that "[t]he scope upon which the values are to be determined is not solely a scientific decision. The determination of the appropriate scope upon which to assess damages is partly scientific but also involves public policy decisions." (Ex. 608 at 45:17–21.) While this may be true, it is not up to Dr. Desvousges, Xcel Energy, or even the Commission, to make this policy determination. It was up to the Minnesota Legislature and it made no such determination to discount values. The "range of environmental costs associated with each method of electricity production" is not limited to environmental costs incurred in Minnesota. Limiting damages to damages "incurred in Minnesota" would require additional statutory language. The canons of statutory construction prohibit adding words to a statute to "supply that which the legislature purposefully omits or inadvertently overlooks." *In re Comm'n Investigation of Issues Governed by Minnesota Statutes, Section 216A.036*, 724 N.W.2d 743, 747 (Minn. Ct. App. 2006).

As has been proven by this record, the actual impacts and areas affected by Minnesota emissions of criteria pollutants include numerous communities outside of the state. One cannot know the cost to society as a whole if part of the known damages are stricken from final values. To do anything other than calculate the damages at a national scale would be to fail to follow the legislature's command to accurately "quantify and establish a range of environmental costs" that occur within our society.

2. The Commission's previous interpretation of this statute requires a national-scale geographic scope.

Because calculating damages at a national scale is practicable and the results are sufficiently certain, doing so is required by statute. But even if the statutory language were ambiguous, the Commission has been clear that the quantification of these values should not incorporate policy judgments and that policy considerations are better applied when determining how to use the established values:

> [T]he Environmental Externalities Statute (Minn. Stat. § 216B.2422, subd. 3(a)) prescribes a two-stage process: Stage 1—quantification and establishment of a range of environmental costs to the extent practicable and Stage 2—use or application of the values in conjunction with other external factors (including socioeconomic costs) when evaluating and selecting resource options in all proceedings before the Commission. The current Order addresses Stage 1. Reasonable application of the range of environmental costs set in this Order will be addressed in future proceedings that address resource options. In those proceedings, the parties will address and the Commission will determine the reasonableness or practicality of applying environmental costs in the circumstances of those cases.

1997 Commission Order at 11, n. 4. Instead, the Commission has been clear that quantifying these environmental costs by setting the per-ton damages for these pollutants should "focus[] on *actual damages* from uncontrolled emissions." Notice and Order for Hearing, Pub. Util. Comm'n Dockets No. E-999/CI-00-1636 & E-999/CI-14-643 at 8 (Oct. 15, 2014) (emphasis added). This calls for an accurate quantification, reflecting the full scientific assessment of *actual damages*.

The evidence shows that *actual damages* from Minnesota-based emissions occur outside of the Minnesota Domain. The Commission has already recognized the fact that emissions travel long distances. "Air emissions from utility plants can travel great distances and do not recognize state borders. Acid rain, in particular, is widely recognized as the byproduct of sulfur dioxide emissions hundreds or even thousands of miles away." Order Establishing Interim Environmental Cost Values for Air Emissions Associated with Electric Generation, Docket No. E-999/CI-93-583 (March 1, 1994) at 5.[7] Neither of Xcel Energy's experts arguing for this geographic limitation has suggested these three pollutants do not travel interstate, and instead they are clear that these pollutants potentially will travel thousands of miles. Mr. Rosvold testified that "emissions of sulfur dioxide (SO_2), oxides of nitrogen (NO_x) and particulate matter (PM), pollutants . . . potentially contribute to the interstate transport of pollution." (Ex. 607 at

[7] This Commission Order is available on e-dockets using Document ID 182860.

4:15–17.) He also acknowledged "long-distance transport of pollution which can occur across state lines can make it difficult for downwind states to achieve $PM_{2.5}$ and ozone" compliance with federal standards. (Ex. 607 at 4:24–25.)

Pollutants are not constrained by arbitrary geo-political boundaries, and the plain language of the state and the Commission's precedent requires calculating actual damages at a national scale.

D. Federal Air Quality Standards Are Irrelevant To The Calculation Of Damages.

Xcel Energy attempts to justify its arbitrary geo-political boundary by claiming that federal regulations such as the National Ambient Air Quality Standards ("NAAQS") have taken care of interstate pollution. (Ex. 607; Ex. 608 at 46:10–11.) This position is inconsistent with the evidence in the record. Dr. Desvousges, for example, calculates damages based on relatively small changes to ambient levels in one NAAQS attainment area, the state of Minnesota. (Tr. Vol. 7 at 141.) Dr. Desvousges's average change in concentration in $PM_{2.5}$ was .0000198 $\mu g/m^3$. (Ex. 608 at 43, Tr. 2.) He agreed that some concentrations that he used to calculate damages were much lower than this, even within his Minnesota Domain. (Tr. Vol. 7 at 141.) Despite these very small changes, Dr. Desvousges used concentration response functions to calculate damages. (Ex. 604, schedule 2 at 7.) Based on Dr. Desvousges's own methods, it is illogical to suggest that similar small changes outside the state are somehow not significant—the federal regime that applies outside of Minnesota also applies inside the state. Regulatory regimes designed to control pollution are irrelevant to the quantification of the actual damages of future emissions.

ALJ Klein addressed this argument when explaining why he required a damage-cost approach rather than one based on regulatory costs:

> The ALJ believes the damage-cost approach is superior to the cost-of-control approach. Theoretically, values established in this proceeding should equal the per-unit cost or damage of residual emissions. This damage is the sum of all of the various impacts listed in the previous section, i.e., impacts on agricultural crops, human health, land use, etc. *Impacts that have already been eliminated through other controls or regulations are irrelevant, as are the costs of these controls and regulations*. The damage-cost approach appropriately focuses on actual damages from uncontrolled emissions.

1996 ALJ Report at 19 (emphasis added). From this reasoning, it is clear that this proceeding cannot simultaneously set damages using the "damage-cost" approach and accept an argument that ignores calculated damages based on the presence of other regulations.

The statute and the Commission's interpretation of that statute require the calculation of *actual* damages. That requires consideration of all damages that are practicable to calculate with sufficient certainty. In this proceeding, calculating actual damages means including national-scale damages that are both practicable to calculate and are sufficiently certain to recommend ranges to the Commission.

II. DAMAGES AT A COUNTY LEVEL ARE THE MOST ACCURATE AND PRACTICABLE WAY TO ACCOUNT FOR GEOGRAPHIC VARIABILITY.

The experts in these proceedings agree that the damages caused by criteria pollutant emissions vary by location. (Ex. 115 at 6:15–20; ex. 808 at 10:13–18; *see* ex. 609 at 60:8 (noting the significance of "the regional density of population" for damages).) Although they agree on the variability, they disagree on how to best assess damages by location. While Drs. Marshall and Muller modeled damages county-by-county to account for this variability, (ex. 119 at 4:19–20; *accord* ex. 810 at 2:6, 5:13–6:3), Dr. Desvousges simply reproduced the categories that the Commission currently applies. (Ex. 604 at 4:23–24.)

Using the photochemical model CAMx, Dr. Desvousges modeled a hypothetical power plant in three locations he felt would be "representative" of all Minnesota locations based on the categories "urban," "rural," and "metropolitan-fringe" ("metro-fringe"). (Ex. 604 at 18:12–19:2.) CAMx models emissions' interactions in great detail, and for all three scenarios Dr. Desvousges selected the Xcel Energy Sherburne County ("Sherco") coal facility to represent hypothetical emissions. The modeling team at Ramboll Environ input Sherco SO_2 and NO_x emissions data into CAMx for those pollutants, but input $PM_{2.5}$ emissions data based on Xcel Energy's Riverside natural gas facility. (Ex. 604A at 1.) Dr. Desvousges recommends the values modeled by CAMx for these three scenarios.

In contrast, Drs. Marshall and Muller each used reduced-form models to assess damages by county. Dr. Marshall used InMAP, a model he developed "with colleagues at the University of Minnesota," to assess emission impacts based on standardized emissions from one county at a time.[8] (Ex. 115 at 6:14–20, 8:16–18.) Likewise, Dr. Muller used AP2, a model he developed, (Tr. vol. 8 at 8, 69), to assess how damages vary by county. (Ex. 808 schedule 2 at 5-8.) The Agencies and the CEOs each recommend county-specific values based on their county-by-county modeling. In addition to calculating county-based values, Dr. Marshall calculated damages based on existing power plants, and developed a weighted average of these results to produce "generic values." (Ex. 115 at 18:14–18.) The CEOs also, therefore, recommend this set of generic values that the Commission may apply when the location and stack height of a new resource are not yet known.

The burden of proof is on each proponent of damages to show, by a preponderance of the evidence, that the values they propose are reasonable, practicable, and the best available measure of the costs of criteria pollutants. Order Regarding Burdens of Proof, Docket Nos. E-999/CI-14-

[8] Because InMAP is a simplified model, it does not assess the interactions between SO_2 and NO_x, and Dr. Marshall input emissions of 1,000 tons each of $PM_{2.5}$, SO_2, and NO_x into county scenarios. (Tr. Vol. 6 at 183.)

643, OAH 80-2500-31888 2 (Mar. 27, 2015). A preponderance of the evidence in this case shows that source location substantially influences these pollutants' impacts. Because of this, it is reasonable and practicable for the Commission to use county-by-county damages.

A. Source Location Substantially Influences These Pollutants' Impacts.

A preponderance of evidence demonstrates source location influences pollutants' impacts for several reasons. As Dr. Marshall testified:

> Damages attributable to marginal increases in emissions can vary by proximity of the emissions to people, the height of emissions, atmospheric conditions between the emissions and the people, and the baseline level of health of the people. Because each of these items is spatially variable (e.g. proximity to high- or low-population centers), our estimates of the damages attributable to emissions vary spatially based on the location of the emissions.

(Ex. 115 at 6:15–20.) Source location affects emissions' proximity to people and atmospheric conditions, and modelers must take this variation into account. Furthermore, emission impacts vary more due to source location than due to any other factor. Dr. Muller explained that "the impacts of emissions vary significantly according to the location of the emission source (Fann et al., 2009; Leve et al., 2009; Muller and Mendelsohn, 2009)." (Ex. 808 at 10:13–14.) Dr. Muller testified that "to detect differences in the damage of emissions, the IAM must model the emission according to where it is released." (Ex. 808 at 10:15–17.) Both Dr. Muller's AP2 modeling and Dr. Marshall's InMAP modeling did so. InMAP produced a large variation of values by source location, for example, with the high end of per-ton $PM_{2.5}$ damages for low stack heights ranging from $7,938 for Lake of the Woods County to $591,975 for Ramsey County. (Ex. 115 t1 at 27..) Dr. Marshall testified that InMAP results show that "the location of the emissions can cause differences in damages by up to a factor of 100." (Ex. 116 at 5:12–13; *accord* ex. 119 at 3:14–15.) This difference is greater than the difference between InMAP and CAMx modeled results, which only differ "up to a factor of 3.6." (Ex. 119 at 3:14–15.) Dr.

Marshall found that AP2 results also display "considerable spatial variation in the damage estimates." (Ex. 808 at 71:9–10.) These pollutants' impacts vary significantly based on location.

In addition to the evidence before the Commission now, in the initial proceedings to set environmental cost values, ALJ Klein recognized the significance of source location on environmental costs, and explained:

> [S]tates that set values for environmental costs *must* consider critical differences among the potential sites of new generating units. Among the most important factors are the proximity of the area to population centers, the surrounding air quality (including the concentration of the pollutant in question), and atmospheric conditions (including pollution reactions and pollution transport).

1996 ALJ Report at 19–20 (emphasis added). ALJ Klein recognized that the population of the areas where emissions disperse, surrounding air quality, and atmospheric conditions differ from site to site. "If these factors vary significantly among the likely sites of new generating units for Minnesota utilities, *then the damages attributable to emissions at these sites will also vary*." *Id.* at 20. (emphasis added). Because of these critical differences among locations, in 1997 "[t]he ALJ recommend[ed] that [the] Commission adopt geographically sensitive values to the extent practicable." *Id*. The Commission should adopt county-specific cost values because, as demonstrated below, they are practicable at this time.

B. County-By-County Cost Values Are Practicable And Reasonable.

As noted above, in 1996 ALJ Klein recognized the influence that emission location has on damage estimates. The Commission also followed his recommendation by adopting the most geographically-sensitive values available on the record: three categorical scenarios modeled by Dr. Desvousges. As the Commission noted, "[n]o further pinpointing of emission levels or costs per unit of emissions is necessary or possible at this time. In future proceedings, the parties addressing particular resource options will establish a record for the Commission's evaluation."

1997 Commission Order at 15. In contrast to 1997, these proceedings have produced two sets of values with greater geographic sensitivity than a categorical approach. County-by-county values are therefore practicable because there are data in the record to support these values.

The county-by-county values are also practicable for Commission use. As Dr. Marshall has explained, utilities and the Commission can apply individual values in the schedule based on stack height and source county of a given power plant. (Ex. 115 at 27:4–28:9.) When a utility evaluates potential sites for a new power plant, it can apply the generic values. (Ex. 115 at 27:4–28:9.) Although the CEOs propose a greater number of values than the Commission's current cost estimates, the change to the planning process would merely involve an analyst looking up a range on a chart instead of determining which of three ranges should apply. Applying county-by-county values for existing sources and generic values for new sources is practicable.

Xcel witnesses have testified, to the contrary, that applying county-specific values would be complicated. (Ex. 605 at 3; ex. 607 at 27.) Mr. Rosvold explained that in his estimate it would be complicated to apply county-specific values to new resources because in the Integrated Resource Planning process, utilities and the Commission "determines the size, type and timing needs under a resource plan[,]" but not the "specific location[.]" (Ex. 607 at 27.) This misstates both the statutory directive of how these values must be used, as well as the Commission's practice of how they are currently used. The statute requires utilities to use the values "in all proceedings before the commission, including resource plan and certificate of need proceedings." Minn. Stat. § 216B.2422, subd. 3(a). There are certainly proceedings in front of the Commission in which the location of a proposed new facility is known. Moreover, in practice, these values are used in resource planning to determine the economic viability of existing resources. Clearly the location of existing resources is known.

In addition to erroneously asserting that utilities never know the location of a proposed facility, Mr. Rosvold failed to explain how the Commission could apply Dr. Desvousges's categories without knowing a new source's location. That is, he did not explain how the Commission would know enough about a new source location to categorize it as urban, rural, or metro-fringe without knowing in which county it would fall. Even Dr. Desvousges explains that the Commission would apply "rural, metro-fringe or urban values [to out-of-state facilities] . . . *depending on the location of the emission source*." (Ex. 607 at 3 (emphasis added).) County-by-county values are no less practicable to apply than three categorical values for known sources, and Dr. Marshall's generic values are more practicable to apply to plants whose locations are unknown.

C. A Categorical Approach Is Not The Best Available Measure Of Damages.

Although the Commission currently applies a categorical approach to external cost values, this no longer represents the best available damage measures when it has access to modeling that accounts for damages in a more geographically precise way. Grouping data into three categories, and disavowing location specificity, "results in an unnecessary loss of information." (Ex. 119 at 21:15–22:2.) Dr. Desvousges's categorical modeling is unreasonable because: (1) the locations are not representative of all urban, metro-fringe, and rural locations in Minnesota; and (2) Dr. Desvousges's plant data are not representative of all (or any) power plants in the state. Dr. Desvousges did not provide any adequate justification for taking this flawed approach.

First, the locations modeled by Dr. Desvousges are not "representative" of urban, metro-fringe, and rural locations or plants. Drs. Muller and Marshall both testified that these three categories inadequately represent Minnesota counties. Dr. Desvousges modeled just one rural site, a hypothetical City of Marshall plant in Lyon County. (Ex. 604 at 18:12–15.) As Dr. Muller explained:

> There are a multitude of other rural sites (either extant power stations or hypothetical locations) in the state. They range from the eastern border with Wisconsin to the southern border near Iowa and up to the western border with the Dakotas. Given the long distances emissions travel, discharges of $PM_{2.5}$, SO_2, and NO_x across the range of rural sites in Minnesota are quite likely to have very different impacts based on wind direction, dispersal, and geographic location with respect to population centers in the state, among others.

(Ex. 810 at 34:15–21.) Dr. Desvousges argued that his rural value represented a conservative estimate because the hypothetical plant in Marshall would have a greater amount of emissions within Minnesota, (ex. 609 at 61:15–20), but admitted in cross-examination that damages based on this site "may not" be conservative if he had included national impacts. (Tr. Vol. 7 at 65.)

When you compare some of InMAP's county-specific results even within one of Dr. Desvousges's categories, the contrast between locations comes to the fore. Minnesota has many counties that may qualify as "rural," but the per-county damages assessed by InMAP for these counties would not easily translate into one "rural" range. For example, InMAP modeling for Lake of the Woods County produced a high stack height NO_x cost range of $715–$1,247. (Ex. 115, schedule 3 at 3.) For Winona County, Dr. Marshall's high stack height cost range for NO_x was much greater: $9,674–$16,876.[9] (Ex. 115, schedule 3 at 5.) Although these counties could both be called "rural" in lay terms, this large difference highlights the confusing process of grouping them into a single category.[10]

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[9] It becomes even murkier why one would apply a single category based on a hypothetical Marshall plant in Lyon County if one were to accept Dr. Desvousges's assertion that these values should reflect damages in Minnesota. Winona County sits so near the Minnesota border that one would expect Minnesota-specific damages attributable to emissions in the county to be miniscule and much lower than damages assessed for Marshall.

[10] For comparison, Dr. Desvousges's rural category for NO_x emissions is $1,985–$6,370. (Ex. 604 T.1 at 6.)

This confusion is only heightened by Dr. Desvousges's failure to define the categories or explain how the Commission can apply them to source locations.[11] As Dr. Marshall pointed out, any data can be grouped into three categories. (Ex. 119 at 21:15–16.) Although this means that the definition of categories matters, Dr. Desvousges admitted upon cross examination that he did not define the categories in his testimony. (Tr. Vol. 7 at 63–64.) On re-direct he agreed that he relied upon the structure of categories "performed in the prior hearing[,]" (tr. Vol. 7 at 137), but Xcel Energy has not submitted that "performance" into the record for this proceeding, contrary to the evidentiary requirements of the ALJ's order. Order Regarding Burdens of Proof, Pub. Util. Comm'n Docket No. E-999/CI-14-643 at 2 (Mar. 27, 2015) (Each "party . . . must introduce any evidence on which it intends to rely in this docket.").

Second, the plant data are not representative of other plants in the state. Dr. Desvousges selected Sherco Unit 1's stack parameters to calculate the emissions used for all three modeling scenarios. (Ex. 604 at 18:16–18.) Sherco Unit 1 has one of the tallest stack heights in the state, and taller stacks disperse pollutants farther than short stacks. (*See* ex. 609, schedule 2, T.2 at 4–5 (all three Sherco stacks are 198 meters tall, with one Allen S. King stack taller, and other stack heights all shorter than 198 meters).) On cross-examination concerning his comparison of all modelers' values, Dr. Desvousges admitted that Dr. Muller:

> us[ed] a much lower stack height than what we're using. So that makes a huge difference. It makes a huge difference. I think that's one of the things that I think that I've learned here, is this was driving some of these results, is what assumptions do you make about stack.

(Tr. Vol. 7 at 125; *see also* ex. 115 at 20:4–10 (explaining how stack height affects emission dispersion).) It remains unclear why Dr. Desvousges selected one of the highest stack heights in

[11] As mentioned above, Dr. Desvousges also failed to explain how to apply his categories to new source locations.

the state. Modeling this stack height means that Dr. Desvousges's proposed values are not representative of any of the power plants in the state that have shorter stack heights. In fact, almost every power plant in the state has a shorter stack height except for Sherco Unit 1. This decision is particularly concerning when coupled with Dr. Desvousges's decision to exclude damages outside of the rectangular box he drew around Minnesota. Because taller stacks tend to cause pollutants to disperse farther than shorter stack heights, if the Commission were to adopt Dr. Desvousges's methodology, it would be using emission sources with the greatest possible dispersion of pollutants to our neighbors and then ignoring the damages caused by those pollutants.

Like the stack height modeled, Dr. Desvouges's emission rate was not representative of power plants in the state. Although Dr. Desvousges made much of his decision to model a "representative" facility, Ramboll Environ modeled emissions data based in part on Sherco Unit 1 and, inadvertently, on Xcel Energy's Riverside facility. (Ex. 604A at 1.) Riverside is a natural gas facility, and no plant in the state has some emissions equivalent to a natural gas facility, and other emissions equivalent to a coal-fired facility. Even after he knew of the error, Dr. Desvousges testified about "rel[ying] on emissions from *a relatively typical power plant*[,]" claiming that inputting emissions from "actual facilities" made his values "more representative of facilities than [] Dr. Marshall's[.]"(Ex. 609 at 34:10, 65:2, 60:1–3.) Because of the conflicting sources of values, the emissions Dr. Desvousges modeled represent neither "actual" nor "typical" power plants.

Finally, Dr. Desvousges did not offer adequate support for a categorical approach to damage cost values. As discussed above, he unreasonably pointed to the "complication" of applying county-by-county values.[12] He also argued that a categorical approach "is the Commission precedent[.]"(Ex. 606 at 27:5–6.) Although it is true that the Commission adopted a categorical approach in 1997, it did so because it was the most geographically sensitive option at that time. The Commission also specifically required the Agencies to use reduced-form modeling in this proceeding, which suggests that such modeling has at least some merit for these proceedings. Dr. Desvousges asserts that the current values are "well-functioning" and "ha[ve] been used in the resource planning process for nearly 20 years," (ex. 606 at 27:6–8), but as Dr. Marshall explained, "the aim of these proceedings is to update the damage cost values to reflect current scientific capabilities, not to use the same methods from decades ago." (Ex. 119 at 10:9–11.) Dr. Desvousges would seemingly have the Commission hold onto the same processes as he used in the prior proceedings for the sake of holding onto them. A categorical approach is no longer the best available approach because the Commission has better options before it now.

III. A PREPONDERANCE OF THE EVIDENCE SHOWS THAT DAMAGES SHOULD BE CALCULATED USING THE CONCENTRATION-RESPONSE FUNCTIONS RECOMMENDED BY DRS. MARSHALL AND JACOBS.

The concentration-response functions used by Dr. Marshall are the best available from the current academic literature and are reasonable to use. Dr. Desvousges's alternative methodology—developed for this proceeding—cannot be considered the best available science on this subject. The concentration response functions represent the relationship between chronic

[12] Similarly, he also argued that the county-specific values give "a false illusion of precision and accuracy when the opposite is in fact true[.]" (Ex. 606 at 3:18.) Specifically, he stated that "[b]ecause the output values depend on the input parameters chosen, the uncertainty is compounded with each choice made." (Ex. 606 at 26:20–21.) Dr. Desvousges did not explain what additional "choices" Dr. Marshall made by running InMAP for many counties. Furthermore, as Dr. Marshall testified, "calculating geographically explicit values does not 'compound' the uncertainty and instead helps eliminate (or at least account for . . .) one source of uncertainty: plant location." (Ex. 119 at 21:8–10.) Accounting for this uncertainty is reasonable because, as has been established, damages depend greatly on source location.

exposure to $PM_{2.5}$ and an increased risk of premature mortality. Although air pollution exposure causes a range of health impacts, including stroke, heart attack, heart disease, asthma, lung disease, lung cancer, and acute lower respiratory infection, increased mortality risk from chronic $PM_{2.5}$ exposure causes most of the overall monetized health impacts from air pollution. (Ex. 115 at 22:14–23:8.) This relationship has been studied and defined over decades and relying on the best available studies is a reasonable approach. Contrary to Dr. Desvousges's contention, the fact that Minnesota is currently in attainment with the NAAQS is irrelevant to the question before the Commission.

A. The Two Cohort Studies Used By Dr. Marshall Offer The Best Available Estimates Of The Relationship Between Increased Mortality Risk And Concentration Of Fine Particulate Matter In The Ambient Air.

1. Dr. Marshall's concentration-response functions are supported by a preponderance of the evidence.

Dr. Marshall used the best available concentration-response functions derived from recent studies of the two largest and most widely studied cohorts in epidemiological research: the Harvard Six Cities cohort and the American Cancer Society cohort. (Ex. 117 at 11:16–17.)

The American Cancer Society cohort is a large observational study of approximately 500,000 individuals and their exposure to $PM_{2.5}$ over the course of twenty years. (Ex. 117, schedule 2 at 1.) The Harvard Six Cities Study, though smaller in scale, also took place over an approximately twenty-year period. (Ex. 117, schedule 2 at 6.) Spanning the course of decades and studying thousands to millions of people, these cohorts have served as the basis for many important publications. (Ex. 604, schedule 2 at 31, T. 3.2.1.2; 33–34.)

These cohorts are the focus of "the most widely cited research that connects pollution exposure and mortality rates" and "have been widely used by government agencies . . . and academic researchers." (Ex. 808 at 11, 16:17–20, 39:16–21; ex. 604, schedule 2 at 37.) The EPA

Scientific Advisory Board and the Health Effects Subcommittee recommend using the American Cancer Society and Harvard Six Cities cohorts to estimate health impacts of $PM_{2.5}$ to the exclusion of other health impact estimates. (Ex. 116 at 15:19–20, 16:1–17 (citing EPA, Regulatory Impact Analysis for the Final Revisions to the NAAQS for Particulate Matter, Executive Summary at 1 (2012).) Both of these cohorts are employed in the analyses of Drs. Marshall and Muller. (Ex. 116 at 3:3–11.)

Drs. Marshall and Muller each relied on the best available research—Krewski et al. (2009) and Lepeule et al. (2012)—for the concentration-response functions they used in their modeling. Krewski and Lepeule are among the most recent publications of the American Cancer Society cohort and the Harvard Six Cities cohort, respectively, and using the concentration response functions derived from these publications is therefore a reasonable approach. (Ex. 809 attach. 2, at 11; ex. 811 at 17:14–20.)

Lepeule et al. estimated that there is a 14 percent increased mortality risk per 10 $\mu g/m^3$ increase in $PM_{2.5}$ concentration, and Krewski et al. estimated a 7.8 percent increased mortality risk per 10 $\mu g/m^3$ increase in $PM_{2.5}$ after accounting for ecologic covariates.[13] (Ex. 116 at 3:3–10.) Dr. Marshall recommends using these two concentration-response functions for high- and low-end damage estimates to account for the uncertainty involved in estimating increased premature mortality risk attributable to increases in $PM_{2.5}$ concentrations. (Ex. 115 at 8:6–13.)

[13] Dr. Muller recommends the same 14 percent Lepeule et al. concentration-response function, but for his low-end estimate he uses a 6 percent concentration-response function rather than the 7.8 percent function used by Dr. Marshall. The 6 percent concentration-response function used by Dr. Muller from Krewski et al. does not account for ecologic covariates. (Ex. 116 at 3:10-13.)

2. Dr. Marshall's concentration-response function is preferable to Dr. Muller's.

Dr. Marshall's concentration-response functions are especially accurate because they account for ecologic covariates. In statistical analysis, covariates are "variables that are not of primary interest in an investigation, but are measured because it is believed that they are likely to affect the response variable and consequently need to be included." B.S. Everitt, Covariate, *The Cambridge Dictionary of Statistics* (4th ed. 2006). An ecologic covariate is an "aspect[] of an individual's environment besides increased levels of $PM_{2.5}$ that can increase or decrease the risk of premature mortality." (Ex. 117 at 6:2–17.) Drs. Jacobs and Marshall both testified that the adjusted 7.8 percent function is preferable to the unadjusted 6 percent function used by Dr. Muller. (Ex. 116 at 3:14–17; Ex. 117 at 7:17–19; 8:1–3.) Dr. Jacobs explained that adjusting for ecologic covariates can prevent other variables from biasing the results, rendering more accurate results than had ecologic covariates not been incorporated. (Ex. 117 at 6:18–22, 7:9–11, 7:17–19.) Thus, the concentration-response function used by Dr. Marshall that is adjusted for ecologic covariates is the best available function for obtaining the most accurate results.

3. Dr. Desvousges's concentration-response function is unreasonable and not supported by the evidence in the record.

Dr. Marshall's concentration-response function is also superior to Dr. Desvousges's for several reasons. Dr. Desvousges rejected the best available epidemiological studies and substituted his own number without a valid rationale. Dr. Desvousges generated his own concentration-response function, which was equivalent to a 6 percent increase in mortality risk per 10 $\mu g/m^3$ increase in $PM_{2.5}$. (Ex. 810 at 18:12–14.) To come up with this function, Dr.

Desvousges used a Monte Carlo[14] analysis involving selected values from three different studies. (Ex. 116 at 13:5–7, 14:1–9.) Dr. Desvousges "performed the Monte Carlo analysis to create a third distribution comprised of the product of the epidemiological concentration response functions by the VSL. He used the 25th and 75th percentiles from this third distribution in his modeling." (Ex. 116 at 14:7–9.)

Dr. Desvousges did not provide a justification for using the particular studies he relied upon in his Monte Carlo analysis: Hoek et al. (2013), Lepeule et al. (2012), and Jerrett et al. (2013)). (Ex. 604, schedule 2 at 41. It is unclear why Dr. Desvousges chose these three studies to use to create his new values. Dr. Desvousges's use of Jerrett et al. (2013), a study involving the American Cancer Society cohort, is particularly confusing. (Ex. 604, schedule 2 at 34.) Although Jerrett may be slightly more recent than Krewski et al. (2009), the Jerrett study involved only a small subset of the cohort, 73,711 people living in Los Angeles, whereas Krewski analyzed the entire "broad geographic scope" of the national cohort, which is a larger and more representative sample size. (Ex. 117 at 11:9–18.) Dr. Desvousges did not consider Krewski for inclusion. (*See* Ex. 604, t 3.2.1.2 sched. 2 at 31–33 (table showing studies Dr. Desvousges considered to include does not mention Krewski et al.) Nevertheless, Dr. Desvousges apparently rejected two publications on the American Cancer society cohort that focused on larger subsets than Jarrett. (*See id.*(listingPope et al. (2002) with 552,138 and Pope et al. (2015) with 669,046 participants).) There is no evidence to support Dr. Desvousges's choice to rely on the smallest subset of this cohort and to ignore Krewski et al. entirely.

Dr. Desvousges also improperly paired Hoek et al. (2013), which is not a cohort study but is instead a meta-analysis of other studies, with Jerrett et al. and Lepeule et al. (Ex. 604, schedule

[14] Monte Carlo sampling is a method in which random sampling from multiple sources is used to estimate a combined distribution. (Ex. 605 at 32:3-6.)

2 at 36.) Although meta-analyses can be useful, it is important to consider the studies within them. "Pooling" a meta-analysis with individual cohort studies is not a common practice; instead, the "new studies should [have] be[en] weighted along with the other studies according to their precision." (Ex. 117 at 10–11.)

In addition to his decision to eschew one of the best available studies from the American Cancer Society cohort and to pool individual studies with a meta-analysis, Dr. Desvousges assigned arbitrary and skewed weights to each of the three studies used in his Monte Carlo exercise. While Dr. Desvousges "reviewed the relevant academic literature on the topics of epidemiological concentration-response functions and the value of statistical life," he did not "weight[] his subset of selected studies according to the precision of the estimates"; instead, he assigned weights to different studies in an arbitrary manner. (Ex. 117 at 8:12–17.) He simply assigned 75 percent weight to Hoek, and 12.5 percent each to Jerrett et al. and Lepeule et al. Dr. Desvousges listed several factors that influenced his "professional judgment" as an economist but did not explain how any of these factors influenced his decisions. (Ex. 117 at 12:7–11, schedule 4.) Although Dr. Desvousges is not an epidemiologist, this is not an accepted methodology in epidemiology, because "[i]t interjects one researcher's bias into the results and undermines the purpose of including different studies—to acknowledge and account for the heterogeneity in results." (Ex. 117 at 12:15–17.)

Dr. Desvousges's statistical methods also obscure that his concentration-response function heavily favors just one study of the three he included (Ex. 117 at 45:25–27.) His testimony focuses on his inclusions of three studies and suggests that he gave equal weights to Lepeule (with a 14 percent concentration response function) and Jerrett (with a 3 percent concentration response function). Dr. Desvousges limited the pool of data used by selecting only the inter-quartile range from "the 25th percentile and 75th percentile values from the Monte Carlo simulation (i.e., looking only at the middle 50% of the data)," which decreased the range of values considered while increasing the proportion of data taken from Hoek. (Ex. 116 at 14:11–17.) He also assigned his middle value a weight of 75 percent, "giving essentially all of the weighting to Hoek." (Ex. 116 at 14:11–17.) Dr. Desvousges testified that 88.18 percent of the values within the center 50 percent inter-quartile range of his analysis are from the Hoek study, with 6.89 percent coming from Jerrett and only 4.94 percent from Lepeule. (Ex. 608 at 49:5–7.)This weighting and percentile selection all but removes Lepeule et al. (2012) and Jerrett et al. (2013), the other two studies comprising the data set, from the analysis. (*See* ex. 608 at 49–50.)

The Krewski and Lepeule concentration-response functions and their acceptance in the field of epidemiology are not in doubt. Even Dr. McClellan agreed that the Harvard Six Cities study is "one of the best studies ever conducted of the influence of air quality on health." (Ex. 441 app., *Hazard and Risk: Assessment and Management*, at 77.) The same cannot be said for the analyses used by Dr. Desvousges.

Dr. Desvousges appears to recognize the heterogeneity of concentration response functions derived from epidemiological studies, and yet settles on a function that is lower than or equivalent to the low function used by Drs. Marshall and Muller. Dr. Desvousges's opaque and unnecessary statistical manipulations obscure rather than control for the uncertainty of this parameter. The reasonable approach is that used by Drs. Marshall and Muller: use two recent analyses of the most widely studied and best available cohorts to create a range and transparently account for the uncertainty in this field.

B. The Fact That Minnesota Is Currently In Attainment With The NAAQS Is Irrelevant To The Question Before The Commission.

Dr. McClellan, in contrast to all of the other witnesses in this proceeding, contends that there is no increased risk of mortality at $PM_{2.5}$ concentrations below the NAAQS. (Ex. 441 at 21:11–17; ex. 119 at 28:5–12.) The fact that Minnesota is currently in attainment with the NAAQS is irrelevant to the question of the damages associated with $PM_{2.5}$, SO_2, and NO_x. MLIG and Dr. McClellan incorrectly imply that the Commission should set a threshold at the NAAQS level for $PM_{2.5}$ and automatically assume that there is no mortality risk attributable to any amount of $PM_{2.5}$ below that threshold. (MLIG's Opposition to CEOs' and Agencies' Motion to Strike Portions of the Rebuttal Testimony of McClellan at 7 (citing ex. 441 app. 2, at 10); ex. 441 at 21:11–17.) To the contrary, the best choice is to apply a concentration-response function uniformly, with no threshold. This is because (1) there is a linear relationship between premature mortality and $PM_{2.5}$ concentrationsand (2) NAAQS thresholds are not set at levels intended to eliminate all human health impacts.

1. The relationship between premature mortality and $PM_{2.5}$ concentrations is linear, with no threshold, and the range of concentrations studied in the epidemiological literature include concentrations below the NAAQS.

Epidemiological literature shows that there is a linear relationship between $PM_{2.5}$ concentration and mortality. (*See* ex. 117, schedule 3 at 967–68; ex. 809 attach. 2, at 6; ex. 811 at 33:6–13.) A linear function is one in which two variables are proportional, such that an increase or decrease in one of the variables by a certain increment results in a proportional increase or decrease in the other variable. Thus, if two variables with a linear relationship are plotted on a graph, the result is a straight line. In this case, the fact that $PM_{2.5}$ concentration and premature mortality share a linear relationship means that for every increase in $PM_{2.5}$ concentration, there is a directly proportional increase in premature mortality.

The literature further shows that there is no threshold below which the relationship between $PM_{2.5}$ and mortality is not linear; or below which there is no relationship. In this case, a threshold would be a low level of $PM_{2.5}$ concentration, where concentrations lower than the threshold level would have no appreciable effect on human health. Neither Lepeule et al. (2012) nor Krewski et al. (2009) found such a threshold for the mortality response to $PM_{2.5}$. (Ex. 117, schedule 3 at 967-68; Ex. 117, schedule 2 at 119.) Instead, the linear relationship exists at *all observed concentrations*. (Ex. 117, schedule 3 at 967-68; Ex. 117, schedule 2 at 119.) This means that the linear relationship exists even at concentrations below the NAAQS. The current primary NAAQS concentration for $PM_{2.5}$ is 12.0 $\mu g/m^3$ annual arithmetic mean, averaged over three years. (Ex. 444A at 3088.) Lepeule concluded that "[i]ncluding recent observations with $PM_{2.5}$ exposures well below the U.S. annual standard . . . down to 8 $\mu g/m^3$, the relationship between chronic exposure to $PM_{2.5}$ and all-cause, cardiovascular, and lung-cancer mortality was found to be linear without a threshold." (Ex. 117, schedule 3 at 970.) Similarly, Krewski found "no evidence of a threshold exposure level within the range of observed $PM_{2.5}$ concentrations" as low as 8 $\mu g/m^3$. (Ex. 117 sched. 2, at 119.)

The low concentrations studied in Krewski and Lepeule are in line with concentrations observed in Minnesota. EPA air quality data from 2014 observed Weighted Annual Mean $PM_{2.5}$ concentrations above 8 $\mu g/m^3$ in Minneapolis-St. Paul, Duluth, Rochester, and Winona, MN. (Ex. 443 at 5.) And although much of Minnesota is in attainment with the NAAQS, the 98th percentile daily average $PM_{2.5}$ concentration reached 29 $\mu g/m^3$ in Minneapolis-St. Paul in 2014. (Ex. 443 at 5.) The science does not support a conclusion that there is no increase in mortality attributable to $PM_{2.5}$ concentrations below the NAAQS threshold. Therefore, to assign a zero cost value to all $PM_{2.5}$ concentrations below the NAAQS threshold would amount to subtracting some amount of the actual damages from the calculation for no valid scientific reason.

2. The NAAQS are not set at a level intended to eliminate human health impacts; they are set based on policy and with an acceptable level of risk.

In addition to the fact that the scientific literature does not support a threshold level and instead supports a linear relationship between $PM_{2.5}$ exposure and an increased risk of premature mortality, NAAQS are not intended to eliminate human health impacts completely. Rather, the EPA sets primary NAAQS at levels "the attainment and maintenance of which . . . are requisite to protect the public health" while "allowing an adequate margin of safety." Clean Air Act, 42 U.S.C. § 7409(b)(1). NAAQS are determined using a policy-based consideration of "welfare, social, economic, and energy impacts," in addition to science. *Id.* at § 7409(d)(2)(C); (*see* ex. 444A at 3094-95 (describing a Policy Assessment the EPA prepared while updating NAAQS as "'bridg[ing] the gap' between the relevant scientific information and assessments and the judgments required of the Administrator.")).. The NAAQS mark the level the EPA Administrator has deemed "necessary" to protect the public health, 40 C.F.R. § 50.2(b), in light of many other associated policy concerns. As Dr. McClellan explained, EPA makes "policy judgments as to acceptable levels of risk if the science does not identify a threshold level below which there are no identifiable health risks." (Ex. 441 app., Roger O. McClellan, *Role of Science and Judgment in Setting National Ambient Air Quality Standards*, 5 Air Qual. Atmos. Health 243, at 243 (2011).) The Clean Air Act expressly "does not compel the elimination of *all* risk" by the NAAQS. (Ex. 441 app. at 247 (quoting *Whitman v. Am. Trucking Ass'ns*, 531 U.S. 457, 494 (2001) (Breyer, J. concurring)).) Dr. McClellan further acknowledged that "more recent NAAQS have been set at levels which the CASAC [Clean Air Scientific Advisory Committee] and EPA characterize as having residual health effects even if the Standard were to be attained." (Ex. 441 app. at 250.)

It does not follow, nor has any scientific body determined, that pollutants have *no* human health impacts in concentrations below these maximum allowable NAAQS levels. Thus, it would be inaccurate and unreasonable to assume that current attainment of NAAQS indicates that there is zero increase in premature mortality risk associated with $PM_{2.5}$ concentrations in Minnesota. The record demonstrates by a preponderance of the evidence that exposure to increased concentrations of $PM_{2.5}$ increases the risk of mortality at all observed levels, including those relevant to this proceeding.

IV. A PREPONDERANCE OF THE EVIDENCE SHOWS THAT DAMAGES SHOULD BE CALCULATED USING THE VALUE OF A STATISTICAL LIFE RECOMMENDED BY THE EPA SCIENCE ADVISORY BOARD.

As discussed, the final step that each modeler performed in calculating damages is to "monetize" the impacts from increased concentrations of pollutants using a VSL. Dr. Marshall used the EPA-recommended VSL; Dr. Muller used the EPA-recommended VSL as his "high" VSL value and used a second value from the academic literature as his "low" value; Dr. Desvousges created a VSL by manipulating data from certain studies, assigning weights to the resulting values, and then running his Monte Carlo analysis. Dr. Marshall's approach is the most reasonable.

A. The Central Value From The Meta-Analysis Used By EPA Is The Best Available VSL Estimate And Is Reasonable.

According to Dr. Polasky, a member of the EPA Science Advisory Board, there are three key elements that must be considered when choosing a VSL estimate: (1) the type of studies considered in a meta-analysis (either hedonic wage estimates or stated preference estimates); (2) the adjustment of VSL estimates to a base year; and (3) the adjustment of VSL estimates to reflect changes in income. (Ex. 118 at 2:17–21, 3:1.) Dr. Marshall's use of the EPA's central tendency value meets all three of these criteria and is the most reasonable and best available option before the Commission.

First, the EPA number draws from strong studies and reasonably summarizes them with a central tendency value or a mean. EPA established its value based on twenty-six studies, five of which were stated preference while the rest were hedonic wage studies. It selected these studies using explicit criteria, "and then fit the values to a probability distribution, giving each study equal weight." (Ex. 118 at 4:15–18.) Both hedonic wage and stated preference studies are included in those twnty-six studies, as the EPA Science Advisory Board recommends. (Ex. 118 at 3–4; *see* EPA Science Advisory Board, *Advisory on EPA's Issues in Valuing Mortality Risk Reduction* ii (Oct. 12, 2007), nepis.epa.gov/Adobe/PDF/P10007U3.pdf.)

Second, Dr. Marshall adjusted the EPA central tendency to account for both changes in currency value and for income growth from 1990 to 2014 resulting in a value of $9.8 million in 2015 dollars. (Ex. 115 at 25.) Dr. Marshall relied on the VSL that he determined is the best available estimate at this time—the value recommended by the EPA Science Advisory Board. Dr. Marshall's $9.8 million VSL is within the range of VSLs endorsed by Dr. Muller (the high-end value adjusted to 2015 dollars is $10.1 million). (Ex. 118 at 8:20, 9:2.) Dr. Muller acknowledged that he is "comfortable with this choice of VSL by Dr. Marshall." (Ex. 810 at 8:2.)

Third, and uniquely among experts in these proceedings, Dr. Marshall used a value that adjusts for real income. The EPA recommends adjusting for changes in real income as the value of reducing mortality risks increases as people get richer. (Ex.118 at 5.) The effect of income on the VSL is measured through income elasticity. (Ex.118 at 5.) Currently, the EPA uses an income elasticity value of 0.5, meaning for every 10 percent increase in real income, the VSL should increase 5 percent. (Ex.118 at 5:3–15.) By adjusting for income elasticity and growth of per capita GDP from 1990 to 2010, the EPA central value increased from $8.7 to $10.1 million (2014 dollars). (Ex.118 at 5.) This difference demonstrates the significance of accounting for real income and inflation in a VSL. Further, theoretical considerations and empirical research suggest that the current 0.5 elasticity is a conservative figure that may need to be updated to a higher value. (Ex.118 at 5 at 5:12–20; *accord* EPA, *Valuing Mortality Risk Reductions for Environmental Policy* 46 (Dec. 10, 2010).) Neither Dr. Muller nor Dr. Desvousges adjusted their VSL for changes in real income, which resulted in lower than expected outcomes and is in conflict with EPA and Science Advisory Board recommendations. (Ex. 118 at 7, 10; s*ee* EPA, *Valuing Mortality Risk Reductions for Environmental Policy* 46 (Dec. 10, 2010).)

The evidence supports the VSL recommended by the EPA Science Advisory Board and Drs. Marshall and Polasky because it is methodologically sound, meets Science Advisory Board recommendations, and accounts for changes in real income, unlike the VSLs proposed by Drs. Muller and Desvousges.

B. Dr. Muller's Methodology To Establish A VSL Is Flawed.

Dr. Muller's VSL suffers from a major methodological flaw. He paired the EPA-recommended central tendency value as a high-end value with a stated-preference-only value as a low-end value. (Ex. 808 at 41:24-42:3). It is inappropriate to use EPA's "measure of central tendency, or the mean of a probability distribution using both hedonic wage and stated preference studies," as the high end of a range. (Ex. 118 at 8:5–8; Ex. 115 at 25:11–15.) Because the EPA central tendency value incorporates *both* hedonic and stated preference studies, it should be considered a mid-range estimate, not a high- or low-end estimate. (Ex. 118 at 8:5–8; Ex. 116 at 2:10–18.)

Dr. Muller's range "compares apples and oranges." (Ex. 118 at 8:19-21.) The comparison is inappropriate because he selected a Kochi et al. stated preference estimate as his low-end estimate. (Ex. 808 at 42.) Although no necessarily a flawed study,[15] a stated-preference-only value such as the one Dr. Muller derived from Kochi et al. should be used as a low value only if paired with a revealed-preference study as the high-end value. (Ex. 118 at 8:4–10.) Dr. Muller paired it with a central tendency and, therefore, skewed his VSL low. (Ex. 118 at 8:8–10.) As Dr. Muller testified, "employing stated or revealed preference methods produces VSL estimates that vary by nearly a factor of three." (Ex. 810 at 16:11–12.) In the case of the Kochi et al. meta-analysis, the difference was even greater, with a hedonic wage value of $13.6 million and a stated preference value of $4.0 million. (Ex. 118 at 8:15–16.) Dr. Muller asserted that "it is important to explicitly recognize the variation in VSLs produced using different techniques in 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." (Ex. 810 at 16:12–16.) In spite of this apparent recognition of the variation that different approaches produce in a VSL, Dr. Muller created a range that obscured the difference between hedonic and stated preference studies when he used a value based on both as the high end of a range. If the Commission wishes to use a range for VSL, it should establish a range that takes a figure based

[15] One criticism of Kochi et al., however, is that it did not correct for income on the included studies before running the analysis, (Ex. 118 at 7:4–10). Dr. Polasky asserted that "given that most of the studies used by Kochi et al. are from before 2000, assuming 2000 income will lead to a lower income adjustment than the correct income adjustment; however, it is not possible to make the correct income adjustment as the Kochi et al. did not make income adjustments before running their analysis." (Ex. 118 at 7:6–10.)

entirely on hedonic wage studies as its high end, and not Dr. Muller's range. (Ex. 118 at 8:11-18).

Although two VSLs coupled with a high and a low concentration-response function would provide a greater range of values to consider, a single, methodologically sound, central-tendency value coupled with said concentration response functions would achieve a better balance in capturing uncertainty while creating a manageable range of values for the Commission to consider.

C. Dr. Desvousges's Methodology Is Unreasonable.

Dr. Desvousges used a distinctly different methodology than Drs. Marshall and Muller in creating a VSL estimate. Dr. Desvousges used four studies: Kochi et al. (2006), Mrozek and Taylor (2003), Viscusi and Aldy (2003), and Kniesner et al. (2012). (Ex. 118 at 9.) Dr. Desvousges derived seven different results from these four studies, including three from Kochi et al. that were manipulated through the addition of data that had been excluded from the source study's primary data. (Ex. 118 at 9; ex. 604, schedule 2 at 54.) After selecting these studies, Dr. Desvousges arbitrarily assigned weights to each study that were not associated with the studies' relative precision, a decision both Dr. Jacobs and Dr. Polasky criticized. (Ex. 117 at 8; *see* Ex. 118 at 9-10, Table 2.) After selecting the studies and assigning arbitrary weights, Dr. Desvousges subjected the studies to a Monte Carlo exercise to create a single distribution representing the "change in deaths multiplied by the resultant costs in VSL." (Ex. 117, schedule 4.) Dr. Desvousges's manipulation of study results followed by his Monte Carlo analysis were unnecessary and unreasonable.

1. Dr. Desvousges unjustifiably manipulated VSL study results.

Three of the seven VSLs used by Dr. Desvousges were derived from one study.[16] Dr. Desvousges manipulated the results from the Kochi et al. (2006) study to rely on three values, none of which was included in the final study results, and two of which he produced himself. Dr. Desvousges did not use the main findings of Kochi et al., but rather substituted the primary data set for a sensitivity analysis Kochi et al. included to demonstrate "the effects of excluding the negative estimates." (Ex. 118 at 10:19-21, 11:1–11 (quoting Kochi et al. (2006), at 390).)

Dr. Desvousges acknowledged that Kochi et al. excluded these negative VSL estimates found in the raw data from the resulting base model that Kochi et al. created. (Ex. 604, schedule 2 at 54.) Kochi et al. explained: "For certain specifications some authors found a negative VSL. However, in every case the authors rejected the plausibility of the negative estimates. We agree that negative VSL are highly implausible and exclude them from our primary data set." (Ex. 116 at 17:3–7 (quoting Kochi et al., *An Empirical Bayes Approach to Combining and Comparing Estimates of the Value of a Statistical Life for Environmental Policy Analysis,* 34 Environmental and Resource Economics 385 (2006)).)

Generally, studies are selected based on study design criteria rather than study results, but there are some circumstances in which it is appropriate to exclude studies based on irrational results. (Ex. 118 at 11:14–20 (citing EPA Science Advisory Board, Advisory on EPA's Issues in Valuing Mortality Risk Reduction, at D-8 (Oct. 12, 2007).) The EPA Science Advisory Board has stated that it is appropriate to exclude an entire study based on a finding of statistically significant negative values for mortality risk reduction. (Ex. 118 at 11:14–20.) Such negative

[16] The central values of the other VSLs were: $6.0 million from a subset of Mrozek and Taylor (2003) data; $3.4 million from a different subset of Mrozek and Taylor (2003) data; $8.4 million from Viscusi and Aldy (2003), and a uniform distribution between $4.0 million and $10 million from Kniesner et al. (2012). (Ex. 117, schedule 4.)

values would imply that the population would prefer a shorter lifespan over a longer one, which "is an implausible result for anything but extreme circumstances." (Ex. 118 at 11:14–20.) Dr. Desvousges himself admitted that "it is implausible that the true VSL would be negative." (Ex. 604, schedule 2 at 51–52.) Nevertheless, Dr. Desvousges argued that the exclusion of the negative values skews the central value upwards, making the range unrepresentative. (Ex. 608 at 52:6–20.) But the central value excluding irrational results *only* fails to represent irrational results. Dr. Desvousges's stance, in favor of irrational results is not shared by the study authors, the EPA, nor any of the other witnesses in this proceeding.

Dr. Desvousges's manipulations of Kochi et al. resulted in three VSLs. (Ex. 118 at 12:1–21.) The first value, $5.6 million, is the value from the sensitivity analysis that included negative values; the second value of $4.9 million includes additional stated preference studies that Kochi et al. excluded from the primary sample because they lacked standard error estimations; and the third value of $5.3 million excluded all non-U.S. hedonic wage studies. (Ex. 118 at 12:1–21.) The second and third values were based on sensitivity analyses conducted by Kochi et al. and were not the primary results. (Ex. 118 at 12.) Moreover, they were additionally manipulated in order to "represent" negative values. (Ex. 118 at 12:13–14, 19–21.) Because the inclusion of negative values decreased Kochi et al.'s VSL by 24 percent, Dr. Desvousges dropped the second and third values by 24 percent as well to make sure that they too accounted for the improbable and rejected negative values. (Ex. 118 at 12:13–14, 19–21.) Thus, of the three values Dr. Desvousges created out of Kochi et al.'s data, one was rejected by the study authors and two were not found in the study. This calls into question the validity of Dr. Desvousges's VSL. (Ex. 118 at 13:1–3.)

2. Dr. Desvousges's weighting of the VSLs for his Monte Carlo exercise was arbitrary and unreasonable.

Similar to his manipulations of study weights in the concentration-response analysis, Dr. Desvousges arbitrarily assigned weights to each VSL used in his Monte Carlo exercise. Dr. Polasky explained that "the purpose of a Monte Carlo exercise is to incorporate the quantifiable uncertainty into an analysis. When a modeler arbitrarily chooses the weights applied to various studies he or she is in effect selecting a preferred outcome." (Ex. 118 at 9–10; *see* ex.117 at 13.) Dr. Desvousges assigned the following weights to his VSLs:

Weight Assigned by Dr. Desvousges	VSL Study	Central Value (millions of $)
35%	Kochi et al. with negative values manipulation	5.6
10%	Kochi et al. imputed standard error manipulation and reduced by 24%	4.9
10%	Kochi et al. U.S. only data manipulation and reduced by 24%	5.3
5%	Mrozek & Taylor with NIOSH data manipulation	6.0
10%	Mrozek & Taylor with BLS data manipulation	3.4
15%	Viscusi & Aldy	8.4
15%	Knieser et al.	Uniform between 4.0 and 10.0

(Ex. 117, schedule 4.)

By giving the Kochi et al. (2006) (plus negative values rejected by the study authors) data set a weight of 35 percent (more than double the weight of any other study included), Dr. Desvousges was incorporating his own subjective preference. (Ex. 118 at 9–10, Table 2.) Dr.

Desvousges gave the three Kochi et al. values a combined weight of 55 percent, preferring further his unreasonable manipulations of that study.

Moreover, the inclusion and weighting of Kniesner et al., a single study estimate in the Monte Carlo exercise, was inappropriate. Every other study included in the Monte Carlo exercise was a meta-analysis, yet Kniesner et al. was given equal weight (15 percent probability) as the Viscusi and Aldy (2003) and Mrozek and Taylor (2002) meta-analyses. (Ex. 118 at 9, 13, T. 2.) Because meta-analyses cover a range of studies and thus reduce the overall effect of errors contained in a single study, affording a single study the same weight as meta-analyses will give that single study's errors undue weight. As with Dr. Desvousges's concentration-response function, a general appeal to his professional judgment does not explain how he assigned weights (*See* ex. 117 at 12:11-13). Dr. Desvousges's use of manipulated data sets and preferential weighting is inappropriate and unreasonable and diminishes the validity of his VSL value.

V. A PREPONDERANCE OF THE EVIDENCE SUPPORTS USING INMAP TO CALCULATE DAMAGES.

Although the above four choices have the most substantial impact on damages, the Commission must still select a model to use for its own modeling, or a model's projected changes in concentrations upon which to base its cost values. A preponderance of the evidence supports using InMAP. InMAP offers advantages to the other models used in these proceedings: (A) it is a reduced-form model capable of many runs in a relatively short amount of time; (B) InMAP performed well when compared to the photochemical model WRF-Chem; and (C) InMAP improves on other reduced-form models. Alternatively, the Commission may also combine results from two or three models.

A. Reduced-Form Models Can Produce Credible Results While Being Capable Of Many Runs In A Relatively Short Amount Of Time.

InMAP is a reduced-form model that simplifies some of the chemical processes and meteorological data used to calculate changes in ambient air concentrations. Despite these simplifications, a preponderance of evidence in these proceedings shows that InMAP does not lose too much realism to effectively model emissions. As Dr. Muller explained, if reduced-form models capture critical aspects of air emission processes, “reduced-form models can produce credible results . . . without producing biased results.” (Ex. 808 at 9:8–12.) The simplifications allow for an important trade-off. A single simulation of CAMx can take multiple days on a high performance computing system. (Ex. 119, schedule 1 at 9283.) In contrast, each InMAP model run takes approximately forty-five minutes to complete on a desktop computer. (Ex. 119, schedule 1 at 9297.) As discussed above, accurately portraying damages from these pollutants requires incorporating their variability due to location. This, in turn, requires model runs at all relevant locations. (Ex. 808 at 10:13–23; *see* ex. 116 at 7:8–13 (two model runs is not sufficient to investigate location variability).) Due to computational intensity, the multiple model runs needed to accurately portray the geographic sensitivity of damages are not practicable with a comprehensive photochemical model like CAMx.

This computational intensity explains in part why Dr. Desvousges did not model all relevant locations—he only modeled three locations. (Ex. 609, schedule 2 at 13–14.) In addition to only modeling three locations, Dr. Desvousges combined two of those locations into one model run. (Ex. 810 at 35:12–15.) As Dr. Marshall has pointed out, the computational intensity of the CAMx model has also limited modelers’ ability to test the runs. (Ex. 116 at 7:5–19.) Dr. Desvousges was only able to fully test whether combining locations into one model run influenced results after two additional model runs, and he only completed the second after submitting rebuttal testimony. (Ex. 609 at 7:25–27.) Drs. Marshall and Muller both pointed out that the photochemical model used by Dr. Desvousges in these proceedings likely limited the scope of his modeling "because of the considerable time and expense required to run the complex" model. (Ex. 810 at 35:1–3.) Using photochemical models in this context is prohibitively time-consuming and results in the inability to capture the geographic sensitivity of damages.[17]

B. InMAP Performed Well Compared To Full Process Models.

Drs. Marshall and Tessum compared InMAP's ability to estimate pollutant concentration changes to that of WRF-Chem, a full-process model, across eleven scenarios and confirmed that the simplifications made to reduce computational intensity did not diminish the quality of the results. Because InMAP's purpose is to assess marginal changes in concentrations, they focused this evaluation on its ability to predict those "rather than total ambient concentrations." (Ex. 119, schedule 1 at 9295.) Among other evaluations, they:

> employ[ed] WRF-Chem to model 11 scenarios of emission changes that would result from the hypothetical adoption of alternative light-duty transportation technologies. These scenarios include emissions from transportation, electric generation, agriculture, and various industrial sources in proportions that vary [between] scenarios[.]

[17] In the hearings, Dr. Desvousges explained that running CAMx again to incorporate national damages would likely take "at least a month." (Tr. Vol. 7 at 129–31.) Although assessing only mortality impacts may speed the process up, changing other key modeling choices such as VSL and concentration-response function would add a bit of time to the process. (Tr. Vol. 7 at 129–31.) Should the Commission also assess the variability of damages by county using CAMx, this modeling would likely take 87 months—more than seven years.

(Ex. 119, schedule 1 at 9295.)[18] InMAP recreated the full-process model's results with excellent accuracy and precision for $PM_{2.5}$, and well for SO_2. (Ex. 119, schedule 1 at 9295–98; ex. 115 at 16:5–9.) InMAP and WRF-Chem's agreement was strongest when comparing primary $PM_{2.5}$, and weakest when comparing secondary $PM_{2.5}$ from NO_x. (Ex. 119, schedule 1 at 9298.) Because model results for $PM_{2.5}$, the primary driver of damages in these proceedings, correlate so well to WRF-Chem results, the simplifications of reduced-form models have little impact on the damages calculated by InMAP.

Part of ensuring InMAP's accuracy is the application of empirical correction factors to the NO_x calculation and one other calculation of the model. (Ex. 119, schedule 1 at 9301.) Dr. Desvousges claims that these corrections show that InMAP does not adequately model emissions. But this claim boils down to saying that correcting for biases makes InMAP biased. If anything, these two corrections highlight the care that Drs. Marshall and Tessum have taken to ensure the model is as accurate as it can be. As Dr. Marshall explained in cross-examination, calculations are:

> [e]mbedded in the model [in order] to represent many different processes. Chemical processes, physical processes. And there are equations that represent those physical and chemical processes. So [each coefficient provides] a correction factor for how those processes are represented mathematically.

(Tr. Vol. 6 at 153.) Contrary to Dr. Desvousges's assertion that Dr. Marshall applies these factors to correct InMAP *results*, they are embedded into the formulae of the model. (*See* ex. 606 at 77:20–21 ("InMAP results had to be calibrated twice").) As Drs. Marshall and Tessum explained

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[18] Dr. Desvousges criticized the choice of evaluation scenario, seeming to claim that air pollution models are not designed to assess emissions from vehicles because they are closer to the ground. (Ex. 606 at 76:9–11.) But Drs. Marshall and Tessum assessed a variety of emissions in the scenarios and compared the same height parameters in both InMAP and WRF-Chem. Dr. Desvousges also failed to provide evidence that photochemical or reduced-form model performance would be impacted by the height of emissions modeled, or would process low heights differently than tall ones.

in their published assessment of the model, InMAP applies correction factors to two algorithms in order to reduce bias between its intermediary calculations and WRF-Chem. (Ex. 119, schedule 1 at 9285, 9301, figs. 2-10 at 9312–20.) They did not apply correction factors to final results. The correction factors that Drs. Marshall and Tessum applied to calculations within InMAP do not cast doubt upon the model's reliability.

C. InMAP Improves On Other Reduced-Form Models.

In addition to the computational-intensity advantages inherent in any reduced-form model, InMAP offers two advantages over other reduced-form models that are significant to these proceedings: more realistic air chemistry, and variable grid cells that effectively "zoom in" on higher population areas.

First, InMAP produces realistic results because it captures more of the chemistry of "the transformation of gas-phase pollutants to particulate matter and particulate matter back to gas-phase chemicals[.]" (Ex. 115 at 13:3–9.) To do so, InMAP relies on "spatially explicit information" produced by WRF-Chem, a comprehensive or photochemical air quality model. (Ex. 115 at 13:3–4.) InMAP is an innovative model that captures emission chemistry in greater detail than other reduced-form models.

Second, InMAP divides the model domain "into three-dimensional grid cells," and "uses horizontal edge lengths ranging between 1 kilometer [ ] and 48 km, where areas with higher population density are covered with more, smaller, grid cells." (Ex. 115 at 9:8–13.) These grid cells permit the model to "zoom in" on high population areas, that is, to assess emission concentration changes with greater detail for high-impact locations. Similarly, grid cell heights vary vertically "between 57 m near ground level to 1,400 m at the top of the model." (Ex. 115 at 9:12–14.)

InMAP's variable grid cells offer advantages when modeling high-population areas over those of both AP2 and CAMx. Although it does not apply a spatial grid to the model domain, AP2's "spatial dimension is the county[.]" (Ex. 808 at 21:11.) This means that high-population counties are treated with the same level of detail as low-population counties. Similarly, photochemical air quality models "define[] space in terms of a grid cell (usually 12 km by 12 km[.]" (Ex. 808 at 21:19–20.) CAMx uses a static grid cell of "twelve-kilometer resolution." (Ex. 604 at 19:13.) Although these standard grid cells offer greater detail than InMAP over much of the modeled domain, a horizontal 12-by-12 or 144 km^2 cell provides *less* detail than InMAP in high population areas because InMAP horizontal cells can get as small as 1 km^2. InMAP's grid cells provide a more detailed assessment of air quality in high-population areas. The modelers agree that high-population areas are where damages from these pollutants concentrate.

Improvements in InMAP compared to other reduced-form models include:

- Calculating how pollution is transported based on the wind speed, direction, and turbulence properties in each grid cell;
- Providing a higher spatial resolution;
- Calculating the transformation of $PM_{2.5}$ precursors into $PM_{2.5}$ while allowing for transformation of gas-phase pollutants to $PM_{2.5}$ and $PM_{2.5}$ back to gas-phase chemicals; and
- Using coefficients for dry and wet deposition that vary spatially to account for pollutant removal.

D. The Commission Can Reasonably Combine Results From Different Models.

Accurately modeling the damages from these pollutants involves four key decisions: geographic scope of damages, how to incorporate location variability, concentration-response function, and VSL. As Dr. Marshall explained, these four decisions have a much larger impact on damage results than the model choice. (Ex. 119 at 7:18–8:2; *accord* ex. 813 at 2.) Should the Commission find that no single modeler made all four decisions in accordance with a preponderance of evidence in this proceeding, it may run InMAP with the assumptions it considers to represent the best available science. InMAP is publicly available, straightforward to operate, and each run takes approximately forty-five minutes on a standard desktop computer. (Ex. 119, schedule 1 at 9297.)

Alternatively, the Commission could standardize model assumptions and combine results from more than one model. As Dr. Marshall explained, "[a]doption of damage values based on the average of results produced by InMAP and AP2 would be consistent with a scientific approach called ensemble prediction." (Ex. 119 at 7:12–15.) As long as the Commission standardizes the assumptions of the models, it can rely upon more than one model.

CONCLUSION

The values developed in this proceeding are used to inform the Commission's decisions related to electricity generation. The Commission has already determined that the information it wants to inform these decisions are the *actual damages* of electricity generation. Once it has an estimate of actual damages, it is then up to the Commission as to how to use this information. This second stage inevitably involves policy considerations. Actual damages are just one piece of information used by the Commission. Because the Commission must always consider the policy implications of every decision, there is no need to inject policy into this stage of the proceedings. And, in fact, the Commission previously rejected attempts to do so. The focus of this stage of the process must be using the best available science to develop reasonable and practicable values.

This record demonstrates that to be as accurate as possible damages must:

- Consider national damages;

- Be geographically sensitive;
- Use the best available epidemiological studies to estimate the correlation between exposure and increased risk of premature mortality; and
- Use the best available VSL.

A preponderance of the evidence supports the county-by-county damages in Schedule 3 to Dr. Marshall's direct testimony and the following generic values:

- $PM_{2.5}$: \$125,000 – \$218,000 /ton
- SO_2: \$16,000 – \$28,000 /ton
- NO_x: \$14,000 – \$24,000 /ton

CEOs respectfully request that the ALJ recommend adopting the above damages, or, in the alternative, recommend that the Commission use the best available scientific literature to generate the necessary inputs and then calculate county-by-county values at a national scale using one or more of the models discussed in this proceeding.

Dated: March 15, 2016

/s/ Leigh Currie

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STATE OF MINNESOTA
OFFICE OF ADMINISTRATIVE HEARINGS
FOR THE PUBLIC UTILITIES COMMISSION

In the Matter of the Investigation into Environmental and Socioeconomic Costs Under Minn. Stat. § 216B.2422, Subd. 3

AFFIDAVIT OF SERVICE

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

STATE OF MINNESOTA)
)ss.
COUNTY OF RAMSEY)

Erin Mittag being duly sworn, says that on the 15th day of March, 2016, she served via electronic service the following:

- Phase II Initial Post-Hearing Brief filed on behalf of Clean Energy Organizations

on the following persons, in this action, by filing through e-dockets:

Attached Service List

E Mittag
Erin Mittag

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

Karen E Moss
Karen Moss

KAREN E. MOSS
NOTARY PUBLIC - MINNESOTA
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