Application No.: A.21-12-009
Exhibit No.: __________
Witness: Julie E. Goodman, PhD, DABT, ATS, FACE
Anne E. Smith, PhD

Application of Southern California Edison Company (U 388-E) For Approval of Its Building Electrification Programs.	Application A.21-12-009 (Filed December 20, 2021)
And Related Matters.	

REBUTTAL TESTIMONY OF

JULIE E. GOODMAN, PHD, DABT, ATS, FACE

AND

ANNE E. SMITH, PHD

ON BEHALF OF

SOUTHERN CALIFORNIA GAS COMPANY

BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF CALIFORNIA

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CHAPTER I: INDOOR AIR QUALITY AND ALLEGED HEALTH IMPACTS FROM GAS APPLIANCES (TESTIMONY OF JULIE E. GOODMAN)

Section 1: Summary of Rebuttal Testimony and Qualifications.

I am submitting this rebuttal testimony on behalf of Southern California Gas Company ("SoCalGas"). I address the numerous factual contentions contained in the direct testimony of Cara Bottorff, submitted on behalf of Sierra Club, dated July 25, 2022. To the extent that SCE has made similar factual contentions in its Building Electrification ("BE") Application and supporting testimony (submitted on December 20, 2021), my testimony and analysis applies equally to those contentions. The Sierra Club's contentions relating to indoor air quality and the use of natural gas in buildings are not relevant to SCE's BE Application because virtually all of the gas appliances that SCE proposes to replace with electric appliances are normally vented to the outside and are not generally recognized as impacting indoor air quality. But in any event, several statements that Ms. Bottorff makes are unsupported and are presented in a misleading fashion. As discussed in more detail below:

- All of the natural gas appliances proposed to be replaced as part of SCE's BE Program are outdoor-vented heat pumps and water heaters. The small fraction of appliances that are stoves are propane stoves on Catalina Island. Given this, the portions of the Sierra Club testimony that focus on indoor air quality are not relevant to SCE's application. The Sierra Club simply lists air pollutants that can be emitted/formed from building-related usage of natural gas, without any references to the airborne exposure levels and doses that are key determinants of whether exposures to these air pollutants may increase the risk of adverse health impacts.
- The Sierra Club does not accurately acknowledge that there are numerous other sources of these pollutants indoors and outdoors, which can be more significant contributors to total personal exposures than natural gas appliances.
- The Sierra Club provides a limited and misleading discussion of published scientific research bearing on indoor air quality and related health impacts from building-related natural gas usage.
- The Sierra Club fails to acknowledge the important role of ventilation for mitigating gas combustion-related air emissions indoors.
- The Sierra Club fails to acknowledge that there remain indoor air pollutant exposures with the use of electrical cooking appliances, as cooking activities themselves are sources of air pollutants that include particulate matter (PM), volatile organic compound (VOC), carbon monoxide (CO), and nitrogen dioxide (NO_2).

I am a fellow of both the American College of Epidemiology and the Academy of Toxicological Sciences (ATS), and I am currently on the Board of Directors of ATS. I am a Principal at Gradient, an environmental and risk sciences consulting firm. From 2009 to 2017, I was an adjunct faculty member in the Department of Epidemiology at the Harvard T.H. Chan School of Public Health. More information can be found in Attachment 1.

I received an S.B. degree in environmental engineering science from the Massachusetts Institute of Technology in 1996. I received an Sc.M. in epidemiology and a Ph.D. in environmental health sciences/toxicology from the Johns Hopkins Bloomberg School of Public Health in 2000 and 2002, respectively. From 2002 to 2004, I was a Cancer Prevention Fellow at the National Cancer Institute (NCI), where I conducted several molecular epidemiology studies on colon, breast, and prostate cancers and was instrumental in the development of "Polymorphism Interaction Analysis," a statistical tool for cancer risk assessment. In 2004, I joined Gradient. My consulting practice consists of assessing human health risks from chemicals in consumer products, pharmaceuticals, and medical devices, as well as from workplace and environmental exposures. My primary responsibilities at Gradient include the design, oversight, analysis, and interpretation of epidemiology studies; the evaluation of chemical exposures, toxicity evidence, and apparent health effects clusters; and the development of systematic reviews. I have published over 150 articles on epidemiology, toxicology, and risk assessment in peer-reviewed journals, books, and meeting proceedings. I was on the editorial boards of *Carcinogenesis* and *The Open Biomarkers Journal* and was a managing editor of the *Journal of Environmental Protection Science*, and I have served as a peer reviewer for over 35 journals.

Section 2: The Sierra Club and SCE rely on several claims related to potential impacts to Indoor Air Quality, yet all of the natural gas appliances covered by SCE's Building Electrification Program are outdoor-vented.

The Sierra Club's testimony (at 5-7) includes numerous references to potential indoor air quality impacts and potential health impacts, referring to the use of gas stoves inside homes. Likewise, SCE's BE Application includes "indoor air quality and health benefits" among the list of points supporting the claim that its BE Program is in the public interest and will benefit consumers.[1] However, references to natural gas stoves are not relevant to SCE's BE Application. As explained by SCE in its Application, its BE request includes replacement of appliances through three programs: (i) BE Ready Home (for residential customers); (ii) BE Ready Catalina (for residents of Santa Catalina Island); and (iii) BE Business (for non-residential customers).[2] Virtually all of the appliances targeted for replacement within those three programs are natural gas appliances that are vented outside.[3] In total, the three programs target replacing approximately 250,543 appliances, of which only 378 appliances are cooking stoves.[4] Moreover, the 378 cooking stoves targeted for replacement are all fueled by propane and are part of the BE Ready Catalina Program.[5] The remainder of the targeted appliances include only heat pump HVACs and heat pump water heaters. Given that all of the natural gas appliances targeted for replacement are vented outdoors and thus do not in the normal course have indoor emissions, references in the Sierra Club's testimony to indoor air quality related to gas appliances that are vented indoors are not relevant to consideration of SCE's BE Application.[6]

Section 3: The Sierra Club lists several pollutants that can be generated from building-related usage of natural gas, but has not demonstrated indoor concentrations are sufficient to cause adverse health effects.

In response to the question "Can you describe the health impacts of using gas in buildings," the Sierra Club testimony simply lists air pollutants that *can be* emitted or formed

[1] SCE BE Application at 11-2.
[2] SCE BE Application at 8.
[3] See SCE's Testimony in Support of its Application for Approval of its Building Electrification Programs, Volume 2: Portfolio and Programs at 22-24.
[4] See SCE BE Application Portfolio Benefits, provided in response to Data Request from CalAdvocates-001, Question 7.
[5] *Id*. See also SCE's Testimony in Support of its Application for Approval of its Building Electrification Programs, Volume 2: Portfolio and Programs at 52, fn. 85.
[6] For the same reason, to the extent SCE's BE application and supporting testimony make reference to indoor air quality generally and to gas stoves in particular as purported sources of indoor air pollution, these claims are not relevant to SCE's application and should not be considered.

from building-related usage of natural gas, including several US EPA criteria air pollutants (carbon monoxide [CO], nitrogen dioxide [NO_2], fine particulate matter [$PM_{2.5}$]) and formaldehyde. Importantly, there are no references to the airborne exposure levels and doses that are key determinants of whether exposure to these air pollutants may increase the risk of adverse health impacts.

The Sierra Club indicates that a recently published study[7] reported that distribution-grade natural gas can contain "at least 21 different hazardous air pollutants," but does not acknowledge that this study is solely a hazard identification study that provides information on levels of volatile organic compounds (VOCs) present in distribution-grade natural gas at the point of the residential end user, and that it does not provide information on indoor air exposure levels or potential health risks. Although lacking measurements of indoor exposure levels associated with the detected VOCs in natural gas, this study reported findings demonstrating that the measured concentrations of the different VOCs are all reassuringly low and thus represent trace constituents of natural gas; specifically, besides methane and ethane, each VOC including benzene, toluene, ethylbenzene, xylenes (BTEX), and hexane was measured at mean levels of <0.0001%. The study authors acknowledged that their measured concentrations of VOCs including BTEX "are likely lower compared to other source types," such as gasoline and household chemical products (*e.g.*, pesticides, paint, adhesives, cleaning agents, personal care products). For benzene specifically, the authors reported that a mean benzene air concentration of 0.004 ppb would correspond to a quantity of natural gas present in an indoor or outdoor environment coinciding with the odor detection threshold for the odorant in natural gas; this estimated benzene concentration is a small fraction of the typical background levels of benzene in indoor and outdoor air.

Chemicals are ubiquitous in the environment due to both natural and manmade sources. When humans come in contact with chemicals in the environment, whether *via* inhalation or another exposure pathway, this does not automatically lead to an adverse effect. It is well known that most substances exhibit a dose-response relationship, where response levels increase as the

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[7] Michanowicz, DR; Dayalu, A; Nordgaard, CL; Buonocore, JJ; Fairchild, MW; Ackley, R; Schiff, JE; Liu, A; Phillips, NG; Schulman, A; Magavi, Z; Spengler, JD. 2022. "Home is where the pipeline ends: Characterization of volatile organic compounds present in natural gas at the point of the residential end user." *Environ. Sci. Technol.* 56(14):10258-10268. doi: 10.1021/acs.est.1c08298.

dose increases. Moreover, it is also a basic principle of toxicology that there are safe threshold levels that reflect doses below which no adverse health effects are expected to occur.[8]

The words "toxic," "hazardous," and "harmful" are thus not inherent properties of chemicals, but are dependent on the amount, duration, and frequency of exposure (*i.e.*, the exposure dose), as well as the route of exposure (*e.g.*, inhalation, ingestion, dermal contact).[9] For both contaminant chemicals that we contact in the environment as well as other types of chemicals that we routinely encounter such as natural chemicals in food, excessive amounts can be harmful, while smaller quantities are not. Notably, all substances are potentially toxic with sufficient dose, even water.[11] Quite simply, the body's response to a chemical (*e.g.*, health restoration, health maintenance, neutral, or deleterious) depends on the amount taken in; in other words, the dose. Dose differentiates a safe intake from that amount that may be dangerous, and this relationship is expressed quantitatively as a dose-response relationship.

In summary, despite the well-recognized importance of dose and exposure in determining whether air pollutants and other substances may pose potential health risks, the Sierra Club testimony largely does not consider dose and implies that the mere presence of certain air pollutants in gas combustion emissions is associated with increased health risk. As discussed below, each of the air pollutants listed by the Sierra Club as being present in gas combustion emissions has numerous other common sources both indoors and outdoors, further underscoring the importance of understanding the concentrations and exposure contributions from gas combustion emissions relative to other common exposures.

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[8] Aleksunes, LM; Eaton, DL. 2019. "Principles of toxicology." In *Casarett and Doull's Toxicology: The Basic Science of Poisons (Ninth Edition)*. (Ed.: Klaassen, CD), McGraw-Hill Education, New York, NY, p25-64.
[9] Paustenbach, DJ; Madl, AK. 2014. "The practice of exposure assessment." In *Hayes' Principles and Methods of Toxicology* (Sixth Edition). (Eds.: Hayes, AW; Kruger, CL), CRC Press, Boca Raton, FL, p453-525.
[215-0946]
US EPA. 1989. "Risk Assessment Guidance for Superfund (RAGS). Volume I: Human Health Evaluation Manual (Part A) (Interim final)." Office of Emergency and Remedial Response, NTIS PB90-155581, EPA-540/1-89-002, 287p., December.
[10] Aleksunes *supra* note 8.
[11] Farrell, DJ; Bower, L. 2003. "Fatal water intoxication (Letter)." *J. Clin. Pathol.* 56:803-804. doi: 10.1136/jcp.56.10.803-a.
[12] Aleksunes *supra* note 8.

Section 4: There are numerous other common sources of pollutants both indoors and outdoors.

The Sierra Club testimony fails to acknowledge that these criteria air pollutants and formaldehyde are everyday constituents of indoor and ambient (outdoor) air due to a multitude of common sources, including both natural and anthropogenic sources. Any combustion source, whether indoors (*e.g.*, woodstove or fireplace, furnace, candles, cigarette smoking) or outdoors (*e.g.*, motor vehicle, fire pit, construction equipment, forest fire), is a source of criteria pollutants such as $PM_{2.5}$ and NO_2, as well as numerous air pollutants including formaldehyde. The critical question is thus not whether these normal air constituents are present, but at what concentrations and exposure levels they are present. The Sierra Club ignores this critical question, and its testimony is thus misleading because it does not provide the proper context for assessing the health significance of any potential indoor exposures from gas appliance usage.

The wide range of common ambient, indoor, and personal sources of exposure to these air pollutants can be illustrated in greater detail using $PM_{2.5}$ and formaldehyde as examples. $PM_{2.5}$ is always present in both outdoor and indoor air due to a multitude of common sources. Outdoor $PM_{2.5}$ has a diverse number of natural and human sources, including windblown dust, fires, bioaerosols, vehicle exhaust, road debris, construction activity, and industrial emissions. There are routine indoor exposures to airborne $PM_{2.5}$ from a variety of ordinary personal and other sources. Each of us generates airborne PM, including $PM_{2.5}$, both indoors and outdoors every day through typical daily activities, such as cooking (baking, frying, grilling, barbecuing, toasting, etc.), dusting, vacuuming, cleaning, mowing the lawn, driving a car, smoking, or burning candles and incense.

Aside from our homes, indoor-generated PM is common in other places we visit on an everyday basis. Wu *et al.*[13] conducted a study of indoor particle levels in California office buildings and reported that significant fractions of the $PM_{2.5}$ concentrations inside dental offices, hair salons, and gyms/daycares were attributable to indoor sources, including dental practices (*e.g.*, drilling and polishing, as well as aerosolized saliva), use of hair appliances such as hair dryers and curling irons, and resuspended particles from frequent sweeping/cleaning as well as

[13] Wu, XM; Apte, MG; Bennett, DH. 2012. "Indoor particle levels in small- and medium-sized commercial buildings in California." *Environ. Sci. Technol.* 46(22):12355-12363. doi: 10.1021/es302140h.

significant human movements (*e.g.*, during exercise and children playing). As noted by Wu *et al.*[14]:

> Potential indoor sources in commercial buildings without cooking include particle resuspension due to occupant movement, which have been found to increase PM in residential settings. In addition, use of laser printers can also generate ultrafine particles, as can ozone-initiated secondary reactions with terpenes used in cleaning products. Indoor PM levels also result from outdoor particles infiltrating into the building, which has been explored in residential buildings, but less so in commercial buildings.

As for formaldehyde, photochemical oxidation of hydrocarbon combustion products emitted from sources that include automobiles, power plants, and manufacturing facilities is considered to be the main source in outdoor air, but other common sources include manufacturing-related emissions, direct emissions from combustion processes, and small amounts produced naturally by plants, animals, and humans.[15] In residential indoor air, formaldehyde is ubiquitous due to a number of common indoor sources. For example, building materials, such as composite wood, coatings, fiberglass insulation, and paper products, are well known to be major sources of formaldehyde inside residential homes.[16] Besides natural gas combustion, other indoor formaldehyde sources include permanent press fabrics, personal care products, and cooking activities (discussed more below).[17] In addition, chemical reactions between ozone and VOCs (*e.g.*, terpenes, glycol ethers) emitted by common household cleaning

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[14] *Id.*

[15] Agency for Toxic Substances and Disease Registry (ATSDR). 2010. "Addendum to the Toxicological Profile for Formaldehyde." 151p., October.

[16] Hult, EL; Willem, H; Price, PN; Hotchi, T; Russell, ML; Singer, BC. 2014. "Formaldehyde and acetaldehyde exposure mitigation in US residences: In-home measurements of ventilation control and source control." *Indoor Air* doi: 10.1111/ina.12160.

[17] *Id.*

Logue, JM; Klepeis, NE; Lobscheid, AB; Singer, BC. 2014. "Pollutant exposures from natural gas cooking burners: A simulation-based assessment for Southern California." *Environ. Health Perspect.* 122(1):43-50. doi: 10.1289/ehp.1306673.

Missia, DA; Demetriou, E; Michael, N; Tolis, EI; Bartzis, JG. 2010. "Indoor exposure from building materials: A field study." *Atmos. Environ.* 44:4388e4395. doi: 10.1016/j.atmosenv.2010.07.049. 214-8970

Nazaroff, W; Singer, BC. 2004. "Inhalation of hazardous air pollutants from environmental tobacco smoke in US residences." *J. Expo. Anal. Environ. Epidemiol.* 14:S71-S77.

Fortmann, Roy; Kariher, P; Clayton, R. [ARCADIS Geraghty & Miller, Inc.]. 2001. "Indoor Air Quality: Residential Cooking Exposures (Final)." Report to California Air Resources Board (CARB). 231p., November 30.

products have been recognized to be an indoor source of formaldehyde and other aldehydes for many years.[18]

We are routinely exposed to formaldehyde inside motor vehicles, with one study reporting an average formaldehyde concentration of 39.7 μg/m^3 based on in-vehicle sampling in three U.S. cities.[19] Similarly, small, gasoline-powered lawn and garden equipment such as chainsaws, lawnmowers, and trimmers is also a common source of formaldehyde exposure. For example, as part of the US EPA Small Engine Exposure Study (SEES), Baldauf *et al.*[20] measured formaldehyde concentrations in excess of 1,200 μg/m^3 during the operation of chainsaws and push lawnmowers. Moreover, literature studies[21] have also reported evidence of non-residential indoor exposures to formaldehyde, including in retail stores, grocery stores, and restaurants. For example, Nirlo *et al.*[22] measured indoor formaldehyde concentrations that ranged from approximately 6 μg/m^3 in a home improvement store up to over 80 μg/m^3 in an office supply store.

Overall, given the many other common sources of exposure to $PM_{2.5}$, formaldehyde, and other air pollutants, it is especially important to understand how any incremental exposures associated with natural gas appliances compare to other everyday exposures. The Sierra Club testimony generally disregards exposure and dose, and does not demonstrate that natural gas appliances contribute meaningful air pollutant exposures relative to other common exposure

[18] Nazaroff, W; Weschler, C. 2004. "Cleaning products and air fresheners: Exposure to primary and secondary air pollutants." *Atmos. Environ.* 38:2841-2865.
205-3978
Singer, BC; Destaillats, H; Hodgson, AT; Nazaroff, WW. 2006. "Cleaning products and air fresheners: Emissions and resulting concentrations of glycol ethers and terpenoids." *Indoor Air* 16(3):179-191. doi: 10.1111/j.1600-0668.2005.00414.x.
Norgaard, AW; Kudal, JD; Kofoed-Sørensen, V; Koponen, IK; Wolkoff, P. 2014. "Ozone-initiated VOC and particle emissions from a cleaning agent and an air freshener: Risk assessment of acute airway effects." *Environ. Int.* 68:209-218. doi: 10.1016/j.envint.2014.03.029.
[19] Health Effects Institute; Mickey Leland National Urban Air Toxics Research Center. 2005. "Relationships of Indoor, Outdoor, and Personal Air (RIOPA). Part I. Collective Methods and Descriptive Analyses." HEI Research Report 130; NUATRC Research Report 7. 144p., November.
[20] Baldauf, R; Fortune, C; Weinstein, J; Wheeler, M; Blanchard, F. 2006. "Air contaminant exposures during the operation of lawn and garden equipment." *J. Expo. Sci. Environ. Epidemiol.* 16:362-370.
[21] Loh, MM; Houseman, EA; Gray, GM; Levy, JI; Spengler, JD; Bennett, DH. 2006. "Measured concentrations of VOCs in several non-residential microenvironments in the United States." *Environ. Sci. Technol.* 40(22):6903-911. doi: 10.1021/es060197g.
Nirlo, EL; Crain, N; Corsi, RL; Siegel, JA. 2014. "Volatile organic compounds in fourteen U.S. retail stores." *Indoor Air* doi: 10.1111/ina.12101.
[22] Nirlo *supra* note 21.

sources. As discussed in the next section, study findings indicate that factors besides the cooking appliance energy source, including cooking methods (*e.g.*, frying *vs*. broiling *vs*. grilling), types of cooking oils used, and types of food cooked, are generally the key drivers of cooking-related $PM_{2.5}$ emissions.

Section 5: The Sierra Club suggests that gas cooking appliances are a significant source of indoor fine particulate matter ($PM_{2.5}$) emissions, but fails to acknowledge that it is the cooking itself – and not the type of fuel used – that generally drives cooking-related $PM_{2.5}$ emissions.

The Sierra Club testimony can be interpreted as implying that there is an absence of indoor air pollutant emissions and exposures with usage of electric cooking appliances. This is not the case.[23] The Sierra Club-sponsored 2020 UCLA report[24], which is cited in the Sierra Club testimony and provided in excerpt form as an appendix to the testimony, acknowledges that cooking on both gas and electric stoves can result in PM generation and states that "the $PM_{2.5}$ concentrations observed cannot solely be attributed to the appliances" – although it does not clarify their relative emissions.

It is well-accepted that food preparation methods such as frying, grilling, sautéing, and broiling are sources of $PM_{2.5}$ emissions, regardless of whether a gas or electric cooking appliance is used. Cooking-related $PM_{2.5}$ emissions are generated by the heating of cooking oils, burning of food, and mechanical cooking processes like the frying and sautéing of food. There is a growing body of study findings indicating that factors besides the cooking appliance energy source, including food preparation method, types of cooking oils used, and types of food cooked, are generally the key drivers of cooking-related $PM_{2.5}$ emissions.[25] Consistent with this, for their analysis of $PM_{2.5}$ emission rate data for 541 cooking events from 13 studies, researchers from the Lawrence Berkeley National Laboratory (LBNL) reported that stove fuel type "did not show

[23] Likewise, to the extent SCE's BE application and supporting testimony suggest that gas stoves are a large source of indoor air pollution (e.g., SCE Testimony Volume 1 at 22), these claims are not supported by available literature on $PM_{2.5}$ and ignore that it is the act of cooking itself, not the source of the fuel, that is the major driver of indoor $PM_{2.5}$ emissions while cooking.

[24] UCLA. 2020. "Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California." Report to Sierra Club National, Oakland, CA. Fielding School of Public Health, Dept. of Environmental Health Sciences, 68p., April.

[25] Lawrence Berkeley National Laboratory (LBNL). 2012. "Compilation of Published $PM_{2.5}$ Emission Rates for Cooking, Candles and Incense for Use in Modeling of Exposures in Residences." Report to US Dept. of Energy (US DOE); US Dept. of Housing and Urban Development (HUD); US EPA; California Energy Commission. Environmental Energy Technologies Division, 29p., August.

significant differences in emission rates when data from multiple studies were compared."[26] In addition, for boiling and simmering experiments conducted on gas cooktops and in gas ovens in nine California homes where pots of water were used as heat sinks to eliminate emissions associated with food preparation (*i.e*., no use of food or oils), Singer *et al*.[27] reported "negligible increases" in indoor $PM_{2.5}$ concentrations for the majority of experiments in their study, further supporting the key role of cooking oils and food cooking as $PM_{2.5}$ sources. Reflecting the body of evidence indicating that oven/range fuel type is not considered to be a key driver of cooking-related $PM_{2.5}$ emissions, LBNL investigators assumed that the same amount of PM would be emitted during cooking activities with gas, propane, or electric burners for their modeling simulations designed to determine minimum range hood capture efficiency standards for maintaining acceptable indoor pollutant levels for NO_2 and $PM_{2.5}$.[28]

Moreover, the Sierra Club cites Tessum *et al*.[29] as reporting findings supporting residential gas combustion and commercial cooking as being "among the largest sources of relative disparities" in $PM_{2.5}$ exposure for people of color (POC), Blacks, Asians, and Hispanics. However, for all of these racial-ethnic groups, findings from Tessum *et al*. indicated the relative contributions of $PM_{2.5}$ from residential gas combustion and commercial cooking are quite small (<10%).

In addition, research studies have demonstrated air emissions of other pollutants besides just $PM_{2.5}$ with cooking using both gas and electric appliances. The Fortmann *et al*. report (sometimes referred to as the 2001 California Air Resources Board cooking and indoor air quality study) reported findings from 32 tests performed to measure indoor air quality impacts during typical cooking activities with gas and electric ranges.[30] This study demonstrated that air pollutants including $PM_{2.5}$, NO_2, CO, and formaldehyde are emitted during cooking with both

[26] *Id*. 222-9632

[27] Singer, BC; Pass, RZ; Delp, WW; Lorenzetti, DM; Mallalena, RL. 2017. "Pollutant concentrations and emission rates from natural gas cooking burners without and with range hood exhaust in nine California homes." *Building Environ.* 122:215-229. doi: 10.1016/j.buildenv.2017.06.021.

[28] Lawrence Berkeley National Laboratory (LBNL). 2020. "Simulations of Short-Term Exposure to NO_2 and $PM_{2.5}$ to Inform Capture Efficiency Standards (Final)." Report to California Energy Commission; US Dept. of Energy (US DOE) Sustainable Energy and Environmental Systems Dept., 27p., March 30.

[29] Tessum, CW; Paolella, DA; Chambliss, SE; Apte, JS; Hill, JD; Marshall, JD. 2021. "$PM_{2.5}$ polluters disproportionately and systemically affect people of color in the United States." *Sci. Adv.* 7(18):eabf4491. doi: 10.1126/sciadv.abf4491.

[30] Fortmann *supra* note 17.

gas and electric appliances. It also showed that PM is produced during electric as well as gas cooking events, with some of the highest measured $PM_{2.5}$ concentrations for frying of tortillas in oil on an electric range. Findings indicated NO_2 and CO emissions during some electric range cooking activities, such as broiling. Findings for cooking experiments where fish was broiled using a gas range or an electric range, and for oven cleaning tests of gas and electric ranges, indicated similar generation of formaldehyde emissions with gas and electric ranges. In addition, in a study where air measurements were made in 352 California homes, there was no evidence of increased indoor formaldehyde concentrations in homes with gas appliances.[31]

In summary, the Sierra Club testimony fails to acknowledge the growing body of study findings that indicate that switching from gas to electric cooking appliances will not contribute to meaningful reductions in some air pollutant emissions, including $PM_{2.5}$, that result primarily from the heating or burning of cooking oils/food and food preparation methods, and not from the cooking appliance fuel type.

Section 6: The Sierra Club provides a misleading discussion of indoor NO_2, citing to limited study findings that lack the necessary context to understand their reliability, representativeness, and key limitations, and that do not demonstrate the health significance of the differences between NO_2 levels in homes with gas cooking appliances *versus* homes with electric cooking appliances.

The Sierra Club testimony provides a misleading discussion of indoor NO_2, citing selected findings from a small number of studies without providing the proper context for these study findings needed to understand their reliability, representativeness, and key limitations. In particular, the Sierra Club highlights findings from the Logue *et al.* study[32] as supporting the indoor NO_2 air quality impacts of cooking with gas, specifically stating, "One study estimated that during a typical winter week, NO_2 levels exceed ambient air quality standards in 55-70% of Southern California homes that cook with gas." However, there is no mention that these findings are derived from a modeling-based simulation study that made predictions of short-term indoor NO_2 concentrations from gas cooking based on a set of modeling assumptions[33] rather than from an air monitoring study where short-term NO_2 concentrations were measured in actual Southern

[31] Mullen, NA; Li, J; Russell, ML; Spears, M; Less, BD; Singer, BC. 2016. "Results of the California Healthy Homes Indoor Air Quality Study of 2011-2013: Impact of natural gas appliances on air pollutant concentrations." *Indoor Air* 26(2):231-245. doi: 10.1111/ina.12190.
[32] Logue *supra* note 17.
[33] Modeling assumptions included NO_2 emission rates during gas cooking, cooking appliance operation patterns, occupancy patterns, and kitchen/home ventilation.

California homes, and the findings are specific to exposure simulations from this modeling-based study where no usage of exhaust ventilation hoods was assumed. Moreover, the Sierra Club makes no mention of other findings from this study[34] that showed how potential air quality impacts can be "mitigated substantially" with usage of vented exhaust hoods.

Besides modeling-based simulation studies like Logue *et al*.[35] that typically employ conservative assumptions intended to err on the side of overestimating indoor air concentrations, there is a relative scarcity of published scientific studies reporting measurements of short-term NO_2 concentrations in residential homes during gas cooking activities. The Singer *et al*. study[36], discussed above, included measurements of short-term NO_2 concentrations made during boiling and simmering experiments conducted on gas cooktops and in gas ovens in nine California homes. While this study reported some findings of 1-hour NO_2 concentrations exceeding the 1-hour US EPA NO_2 National Ambient Air Quality Standard (NAAQS) of 100 ppb in a subset of the study homes during the gas cooking experiments, these results were for experiments without range hood exhaust ventilation and the reported NO_2 concentrations were also likely biased high. As described by the study authors, NO_2 concentrations were not directly measured in their study, and they were instead "inferred" as the difference between nitrogen oxide (NO_x) and nitric oxide (NO) measurements collected using chemiluminescence monitors. They acknowledged that these "inferred" NO_2 concentrations likely include "non-negligible amounts of nitrous acid (HONO)"- *i.e*., due to HONO bias, they are overestimates of NO_2 concentrations. On top of the likely high bias of the NO_2 concentrations, the 1-hour NAAQS exceedances reported in the study are for measurement periods without range hood exhaust ventilation; as discussed later in Section 8, NO_2 measurements conducted with use of vented kitchen range exhaust demonstrates the effectiveness of vented kitchen range hoods for reducing both kitchen and whole-house air concentrations.

Although not cited in the Sierra Club testimony, the Lebel *et al*. study[37] is a recent measurement-based study that has been cited as reporting evidence of short-term indoor NO_2

[34] Logue *supra* note 17.
[35] Logue *supra* note 17.
[36] Singer *supra* note 27.
[37] Lebel, ED; Finnegan, CJ; Ouyang, Z; Jackson, RB. 2022. "Methane and NO_x emissions from natural gas stoves, cooktops, and ovens in residential homes." *Environ. Sci. Technol.* 56(4):2529-2539. doi: 10.1021/acs.est.1c04707.

concentrations during gas cooking exceeding the 1-hour US EPA NO_2 NAAQS. However, it is important to note that this study employed a highly contrived study design, where small air volumes above stoves were sealed off from the remainder of the kitchen using plastic sheathing to measure NO_2 emission rates rather than indoor NO_2 exposure concentrations. This study thus did not measure indoor NO_2 concentrations representative of real-world exposure conditions.

The Sierra Club testimony further refers to homes with gas stoves having "50% to 400% higher NO_2 concentrations than homes with electric stoves," citing the 2020 report from the Rocky Mountain Institute (RMI).[38] In turn, the RMI report attributed this statement to the 2008 US EPA Integrated Science Assessment for Oxides of Nitrogen- Health Criteria report (referred to as the 2008 NO_x ISA[39]). While the 2008 US EPA NO_x ISA does in fact make this statement, it is based on studies published between 1986 and 2006, and the more recent 2016 Integrated Science Assessment for Oxides of Nitrogen- Health Criteria report (referred to as the 2016 NO_x ISA[40]) that updated and replaced the 2008 NO_x ISA does not include this statement.[41]

Two more recent studies reported longer-term average indoor NO_2 concentrations. Belanger *et al*.[42] reported monthly average indoor NO_2 concentrations in Connecticut and Massachusetts homes with and without gas cooking appliances, and Mullen *et al*.[43] reported ~6-day average indoor NO_2 concentrations in 352 California homes with and without gas cooking and other gas appliances. Although NO_2 measurements from both studies support higher indoor NO_2 concentrations in homes with gas cooking appliances, the indoor NO_2 measurements from both studies were consistently below the US EPA annual average NO_2 NAAQS of 53 ppb,

[38] Seals. BA; Krasner, A. 2020. "Health Effects from Gas Stove Pollution." Rocky Mountain Institute; Physicians for Social Responsibility; Mothers Out Front; Sierra Club. 38p. Accessed at https://www.psr.org/wp-content/uploads/2020/05/health-effects-from-gas-stove-pollution.pdf.

[39] US EPA. 2008. "Integrated Science Assessment for Oxides of Nitrogen." National Center for Environmental Assessment (NCEA) - RTP Division, EPA/600/R-08/071. 260p., July.

[40] US EPA. 2016. "Integrated Science Assessment for Oxides of Nitrogen – Health Criteria (Final)." National Center for Environmental Assessment (NCEA), EPA/600/R-15/068, 1148p., January.

[41] SCE's BE Application and supporting testimony (e.g., SCE Testimony Volume 1 at 22) similarly make reference to the RMI report (*supra* n. 39) for assertions on indoor air pollution and risk of respiratory illness, but as explained here, the RMI report does not provide sufficient information to draw conclusions about real world exposures during gas cooking and any related health risks.

[42] Belanger, K; Holford, TR; Gent, JF; Hill, ME; Kezik, JM; Leaderer, BP. 2013. "Household levels of nitrogen dioxide and pediatric asthma severity." *Epidemiology* 24(2):320-330. doi: 10.1097/EDE.0b013e318280e2ac.

[43] Mullen *supra* note 31.

indicating that the higher longer-term average NO_2 concentrations associated with gas cooking appliances are not of potential health concern.

In summary, while there remain uncertainties in the available data regarding short-term NO_2 exposures during gas cooking and health risks under real-world residential conditions, data do not support increases to longer-term average NO_2 concentrations in homes with gas cooking appliances that are of potential health concern.

Section 7: The Sierra Club provides a limited and misleading discussion of published scientific research on health harms related to indoor air quality impacts from natural gas usage.

The Sierra Club testimony implies that a causal relationship has been established between the use of gas-fired residential cooking appliances and adverse health effects, such as childhood respiratory symptoms. However, the Sierra Club only cites a very limited number of health effect studies, and these studies have inherent limitations and uncertainties, and are not representative of the broader body of scientific literature. For example, the Sierra Club highlights the Lin *et al.* meta-analysis study[44] as "reporting that children living in homes using gas for cooking have a 42% higher risk of having asthma." This study has significant limitations and does not support the asserted conclusions. The study combined and integrated the data from 41 epidemiology studies of indoor NO_2 and gas cooking on asthma and wheeze in children published between 1977 and 2013. It reported weak, statistically significant associations between gas cooking and asthma and between indoor NO_2 and wheeze; however, these results are inconsistent with findings from the same study of no statistically significant increased risk of wheeze in relation to gas cooking or risk of asthma in relation to indoor NO_2. This study heavily relied on older cross-sectional study data (the majority from prior to 2000) and combined data from a heterogeneous set of studies in terms of locations, home characteristics, and ventilation, without any assessment of study quality, including whether the studies accounted for confounding factors like tobacco smoke. Interestingly, one of the senior authors of this study, Dr. Bert Brunekreef, was also an author of a much larger epidemiology study of over half a million children that was published in the same year (2013) and "reported **no association between gas cooking and lifetime asthma or current asthma in children** when compared to

[44] Lin, W; Brunekreef, B; Gehring, U. 2013. "Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children." *Int. J. Epidemiol.* 42(6):1724-1737. doi: 10.1093/ije/dyt150.

children who lived in households that used electric stoves for cooking" (emphasis added).[45] This study not only included a far larger sample size than all of the studies combined in the Lin *et al.* study, but also adjusted for sex, region of the world, language, gross national income, maternal education, parental smoking, and six other subject-specific covariates. The Sierra Club testimony does not mention the flaws and limitations of the Lin *et al*.[46] study or its inconsistent findings, nor does it mention this much larger, contemporaneous study and its conflicting findings.

In general, scientific studies addressing gas-fired residential cooking appliances and adverse health impacts such as childhood respiratory symptoms have significant limitations, including poor study quality, inadequate control of potential confounders, and potential sources of bias. As a result, available literature does not provide a reliable basis for causal inferences regarding the relationship between the use of gas-fired residential cooking appliances and adverse health effects, including childhood respiratory symptoms.

Section 8: The Sierra Club fails to acknowledge the important role of ventilation for mitigating indoor air emissions.

It is well-known that ventilation plays an important role in mitigating indoor air emissions associated with cooking activities, including gas combustion-related emissions. Yet, the Sierra Club testimony does not acknowledge this and provides no details on the effectiveness of different ventilation practices, such as outdoor-vented kitchen range hood fans. Instead, the Sierra Club testimony includes an excerpt from its sponsored UCLA report[47] that includes modeling-based exposure simulations that assumed no usage of exhaust ventilation hoods, and are thus highly conservative (*i.e*., more likely to overestimate potential risk) and arguably unrealistic for characterizing the full distribution of potential indoor air concentrations associated with gas stove usage. Other modeling-based exposure simulations conducted by the Lawrence Berkeley National Laboratory, which were funded by the California Energy Commission, demonstrate that effective kitchen exhaust ventilation can significantly reduce indoor air concentrations of NO_2 and PM associated with gas-fired kitchen appliances and cooking

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[45] Wong, GW; Brunekreef, B; Ellwood, P; Anderson, HR; Asher, MI; Crane, J; Lai, CK; ISAAC Phase Three Study Group. 2013. "Cooking fuels and prevalence of asthma: A global analysis of phase three of the International Study of Asthma and Allergies in Childhood (ISAAC)." *Lancet Respir. Med.* 1(5):386-394. doi: 10.1016/S2213-2600(13)70073-0.
[46] Lin *supra* note 44.
[47] UCLA *supra* note 24.

activities.[48] In addition, measurement-based studies, including the Singer *et al*. study[49] conducted by researchers at Lawrence Berkeley National Laboratory, as well as the Dobbin *et al*. study[50] conducted by researchers at Health Canada, National Research Council Canada, and Lawrence Berkeley National Laboratory, also demonstrate the important role of vented kitchen range exhaust for reducing both kitchen and whole-house air concentrations.

Overall, these studies show that with adequate ventilation, indoor air concentrations of pollutants such as NO_2 and $PM_{2.5}$ during cooking activities, including for usage of both gas and electric cooking appliances, can be maintained at levels below health-based ambient air quality standards that are set to be protective of public health.

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[48] LBNL *supra* note 28.
[49] Singer *supra* note 27.
[50] Dobbin, NA; Sun, L; Wallace, L; Kulka, R; You, H; Shin, T; Aubin, D; St-Jean, M; Singer, BC. 2018. "The benefit of kitchen exhaust fan use after cooking - An experimental assessment." *Building Environ.* 135:286-296. doi: 10.1016/j.buildenv.2018.02.039.

CHAPTER II:INAPPROPRIATE USE OF THE COBRA MODEL FOR COST BENEFITS (TESTIMONY OF ANNE E. SMITH)

Section 1: Scope of Testimony and Qualifications.

Q. Please state your name, occupation, and business address.

A. My name is Anne E. Smith. I am an economist and risk analyst, now an independent consultant operating under the business name of A. E. Smith Expert Consulting, LLC, 3122 Ordway Street, NW, Washington DC 20008.

Q. On whose behalf are you testifying?

A. I have been retained to present my testimony on behalf of Southern California Gas Company ("SoCalGas").

Q. Have you submitted any direct testimony in this proceeding?

A. No.

Q. What is the scope of your testimony?

A. I am an independent consultant retained solely to provide expert testimony on the analysis of economic benefits based on the COBRA model presented in the Direct Testimony of Ms. Cara Bottorff on behalf of the Sierra Club, dated July 25, 2022. The testimony that I provide here is based solely on my experience and expertise with these types of policy/risk analyses and the associated modeling tools. My role does not require and I do not take any policy position in this proceeding.

In my testimony, I address the ways that Ms. Bottorff has developed her monetary estimates of alleged health benefits from the proposed SCE BE program and from two alternative ways that she proposes SCE deploy its proposed BE budget to increase the share of those benefits obtained by people living in "ESJ Communities" within the SCE service territory.

Q. What are your key conclusions regarding Ms. Bottorff's testimony?

A. My main points based on a review of Ms. Bottorff's testimony, as explained further below, are as follows:

- COBRA is a highly simplified computational device that was intended as a screening tool only, and due to its acknowledged limitations, is not recommended for use in final cost-benefit decision making, as she suggests doing with her analysis for this proceeding.
- Putting aside COBRA's limitations, of the hundreds of millions of dollars that Ms. Bottorff calls "economic cost savings," only 0.5% of the estimates reflect claimed actual spending reductions on health. The other 99.5% of her reported dollar benefits do not represent (and will not be realized as) improvements in financial outcomes of public or

private institutions, nor improvements in consumers' cost of living; those 99.5% of her values, because they are based on WTP, are only useful when conducting acost-benefit analysis, which Ms. Bottorff has not presented.

- COBRA cannot address indoor air quality, and Ms. Bottorff has not presented any quantified estimates of health benefits related to indoor air pollution through any other type of analysis. It should be noted that SCE's BE program replaces primarily hot water heaters and furnaces, which are normally vented outside and are not described by Ms. Bottorff as the major source of indoor air quality concerns from gas-fired appliances.

- Ms. Bottorff's analysis of health benefits using COBRA has multiple technical and analytical flaws, resulting in substantial overstatement of region-wide lifecycle benefits and gross misrepresentation of benefits for certain communities. For example, her estimates of benefits to ESJ Communities assume that all the benefits from emissions reductions from BE in that community accrue to that community – but that assumption is not consistent with how COBRA works, nor is it consonant with outdoor air quality analysis. And she appears to have input the entire lifecycle emissions reductions (over 10-15 years) in a single year (2028) in the COBRA analysis, resulting in anomalies such as those emissions reductions exceed *all* building emissions for the entire county.

Q. Please describe your educational background.

A. I have a Ph.D. in economics from Stanford University, with a Ph.D. minor from Stanford Engineering School's Department of Engineering-Economic Systems (now called the Department of Management Sciences and Engineering). My Ph.D. studies included welfare economics, uncertainty analysis, decision analysis, probability analysis, theory of statistical inference, regression methods, and systems optimization. My Ph.D. dissertation, "Market Structure and Regulatory Design," addressed cost-benefit issues in regulations to control air pollution from consumer-operated technologies. Prior to my Ph.D., I received an M.A. in economics from Stanford University and a B.A. in economics, *summa cum laude*, from Duke University. I was inducted into Phi Beta Kappa while at Duke University.

Q. Please describe your professional background.

A. I have worked for government and private sector clients on a global basis, with the following employment history. From 1977 to 1979, I served as an economist in the Economic Analysis Division of the U.S. Environmental Protection Agency's ("EPA") Office of Policy Planning and Evaluation. From 1979 through 1985, I consulted on risk assessment, risk management, and cost-benefit analysis to support environmental policy decisions, working under contracts with U.S. EPA and governments in Europe, and I served on United Nations' committees convened in Geneva, Rome, and Thailand to write expert reports on several air and water quality management matters. From 1985 through 1998, I was employed by Decision Focus Incorporated (later named Talus Solutions, Incorporated), which was a decision analysis and risk assessment consulting firm that had substantial practices in environmental integrated assessment and in energy market modeling. (The COBRA tool that I provide testimony on in this proceeding is a form of integrated assessment model.) I was the head of its Policy Assessment Practice at the time of my departure. From 1998 through 2011, I was Vice President of CRA International, Incorporated ("CRA"), an economics consulting firm with a global practice related to energy and environmental issues, and served as the head of its Climate and Sustainability Group during the last few years of my tenure there. From 2011 through 2021, I was Managing Director (originally titled Senior Vice President) of NERA Economic Consulting, where I co-headed NERA's global environmental practice. I now have my own consulting company, A. E. Smith Expert Consulting, LLC.

Over the course of my career, I have also served on several committees of the National Academies of Sciences, Engineering and Medicine ("NASEM"), on EPA's Chartered Science Advisory Board, and on a committee of EPA's Board of Scientific Counselors. I am presently serving on a NASEM committee providing an expert peer review of a Department of Energy cost-benefit analysis of technological options to stabilize and dispose of low-activity radiological waste at the Hanford nuclear weapons site. I am also a past member of the Board of Directors of the Society for Benefit-Cost Analysis.

I provide a copy of my full CV as Attachment A to this testimony.

Q. Please describe the relevant types of matters you have addressed in your career.

A. I am an economist and decision analyst who has specialized for 40 years in the tools and methodologies of environmental risk assessment, cost-benefit analysis, integrated policy assessment, and engineering-economic optimization. During my employment at EPA, I supported the Agency's evaluations of air pollutant regulations, including issues related to the assessment of air pollutants' health risks, costs and benefits of regulations, and their impacts on employment and other market outcomes. From 1981 to 1983, while a consultant to EPA, I conducted a study for EPA's Office of Air Quality Planning and Standards, which demonstrated the use of decision analysis methodologies to estimate public health risks from ambient pollution to support the decision making regarding EPA's periodic review of the National Ambient Air

Quality Standards (NAAQS), and I have continued to work on this issue since, including publication of a paper that was awarded "Best Paper of 2016" by the journal *Risk Analysis.* I have testified on many occasions before EPA's Clean Air Scientific Advisory Committee ("CASAC"), before committees of the U.S. Congress, and in regulatory proceedings on air pollutant risk and regulatory issues.

During the past 35 years, I have also applied my Ph.D. training in engineering-systems modeling in many energy market studies. These studies have encompassed modeling of global fossil fuel supply and demand, of criteria pollutants, of carbon dioxide ("CO_2") emissions, and of air toxics from global and national energy systems under various regulatory schemes. I have conducted these studies in the U.S. and for entities in other countries, including in the U.K. and Australia. I have also provided analytical support to private companies on their business decisions in the context of compliance with emissions regulations and to assess their business risk from potential regulatory developments.

I have extensive experience in integrated assessment ("IA") modeling of air emissions regulations. IA modeling is the practice of integrating models from multiple disciplines, including models of emissions, atmospheric fate and transport, health and environmental risks, willingness-to-pay for health and environmental risk reductions, compliance cost, and economic impacts to assess the relative merits of potential regulatory actions. During 1988-1990, under a contract with the Office of the President, I provided advice and support to the Director of the U.S. National Acid Precipitation Assessment Program in the conduct of its IA of findings from a ten-year interagency research program on acidic deposition in the U.S. During the mid-1990s, the Western Governors' Association engaged me to prepare the IA tool that supported the air emissions management decisions of the Grand Canyon Visibility Transport Commission. In 1997-1998, the Southern Appalachian Mountains Initiative engaged me to provide expert advice on its air emissions IA analysis plan. During the same time, U.S. EPA engaged me to provide integrated assessment of climate policy options using an IA model of climate impacts that my company had developed under EPA funding. Since then, I have been very active in performing integrated analyses of public health risks from ambient $PM_{2.5}$ and ozone, and I am an expert on EPA's methods and tools, including BenMAP, reduced-form models, and its calculations of co-benefits in regulatory impact analysis.[51] I have written peer-reviewed papers on the limitations of the BenMAP model and developed my own integrated assessment tool to replicate BenMAP's calculations with an added capability to perform integrated uncertainty analysis on its projections. During my career, I have also conducted many other studies and written papers and reports on estimating societal value and preferences for air quality improvements; macroeconomic impact analysis; sound conduct of cost-benefit analyses and regulatory impact analyses; and other matters within my fields of expertise.

Section 2: COBRA-Based Estimates of Health Benefits Are a Rough Approximation from a Screening Tool, Are Mostly Not Economic "Cost Savings," and Do Not Address Indoor Air Quality.

Q. Ms. Bottorff uses the tool called COBRA to calculate what she describes as the health-related "economic cost savings" of the SCE BE program. What is COBRA?

A. COBRA stands for the "CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool" and is a simplified form of what is called an "integrated assessment" tool. I will provide a more detailed discussion of its provenance and capabilities later, but in very brief terms, it is a computational tool that takes estimates of outdoor pollutant emissions provided by a user to roughly project the effects of those emissions changes on regional-scale ambient (i.e., "outdoor") $PM_{2.5}$ changes and associated average population-wide health impacts from those changes. It then assigns a monetary (i.e., "dollar") value to each separate type of health impact; this monetization step allows disparate types of health impacts to be added together into a single summary "benefit" estimate that can be of use in comparing societal costs and benefits, but does not necessarily represent financial savings or economic activity improvements. EPA—which developed and maintains COBRA—represents COBRA as a highly simplified analytic tool that is expressly intended only as a screening tool to help decide whether the resources required for a full cost-benefit analysis are warranted, and not as the final input to cost-benefit support for a major public policy decision.

Q. Does COBRA provide any estimates for health effects from indoor air pollution?

A. No. Ms. Bottorff acknowledges (at 22) that she has not quantified indoor air pollution benefits, and admits that "COBRA also does not account for indoor air quality

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[51] The COBRA tool that Ms. Bottorff relies upon is one of several tools that other groups have used to compute co-benefits, although the EPA Office of Air and Radiation generally uses other tools and computational methods to calculate the co-benefits that it uses in its regulatory impact analyses.

benefits." Nevertheless, parts of Ms. Bottorff's testimony (at 5-7) discuss indoor air quality; to the extent she might imply that her COBRA analysis supports that discussion, it would be misleading.

Q. Are COBRA-estimated benefits properly described as "economic cost savings"?

A. No, that is not what COBRA calculates. COBRA produces estimates of benefits for ten types of health risk endpoints.[52] The two mortality benefits estimates, which account for about 99% of COBRA benefits values[53]—as well as five other types of health risk endpoints estimated by COBRA (in other words, seven out of the ten total), are based on peoples' stated willingness to pay to avoid certain risks ("WTP") rather than actual financial costs (e.g., spending).[54] WTP estimates are intended only for use in cost-benefit analysis, a tool derived from welfare theory, but do not reflect actual savings in either societal or personal health care costs, nor increases in measured economic activity.

WTP estimates are *not* comparable to the outputs of an economic impact analysis, and even if the WTP estimates show a net benefit, that does *not* imply that economic outcomes in the affected region will improve if the policy is implemented. WTP-based benefits estimates (if reliably estimated) only mean that the local population might be willing to pay the costs of the program in return for estimated improvements in their health risks. Ms. Bottorff fails to explain the meaning of her public health benefits estimates, and repeatedly calls them "cost savings" (*see, e.g.*, at 2). She never indicates that they are primarily a non-financial measure of public welfare, or societal well-being, and do not represent actual economic costs.

Q. Are any of Ms. Bottorff's benefits estimates actual spending reductions?

A. The values that COBRA assigns to three of the ten types of health endpoints that COBRA estimates are based on actual costs (e.g., cost of illness or lost earnings from illness).[55] These are, specifically, non-fatal heart attacks, hospital admissions, and emergency room visits for asthma. Although the COBRA document describes the value for "work loss days" as being based on WTP, I would conservatively classify benefits estimates for that health endpoint also as

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[52] See slide 6 of EPA presentation at https://www.epa.gov/sites/default/files/2021-03/documents/how_cobra_works_mar2021_508.pdf (provided in Attachment B).
[53] This statement can be confirmed by comparing the values for "$Mortality" to those for "$Total Health Costs" in any column of Ms. Bottorff's Appendices A, B and C.
[54] See slide 6 of Attachment B.
[55] See slide 6 of Attachment B.

a form of economic cost savings because it is derived from estimates of lost earnings. These four measures of health benefits, in aggregate, represent a small portion (i.e., 0.5%) of her total benefits estimates.

For example, Ms. Bottorff's table of COBRA scenario results for the SCE program as-proposed (her Appendix A) shows that these actual health cost reductions add up to $1.1 million to $2.4 million), which are both -.5% of her totals for nationwide health benefits (i.e., the $219 million to $491 million that she presents in her summary statement at p. 3, line.22). The remaining 99.5% of Ms. Bottorff's "economic cost" estimate is based on estimates of WTP for risk reductions to the general public. This 0.5% fraction occurs for every subset of the benefits calculations that she presents (e.g., for residential and commercial, and for California-only and SCE-impacted only), and also to Ms. Bottorff's alternative proposals for how to target BE spending (i.e., in her Appendices B and C).

- ***In sum, the vast majority of COBRA benefits estimates provided by Ms. Bottorff do not represent actual economic cost savings and are only rough approximations of a value concept that is different from "cost savings."***

Q. Separate from her use of the outdoor-only COBRA analysis, has Ms. Bottorff provided any estimates of health benefits risks due to indoor air pollution?

A. No. Ms. Bottorff discusses indoor air quality (at 5-7), and that discussion appears to focus primarily on emissions from unvented appliances such as gas stoves. It is unclear how those particular impacts to indoor air quality are relevant here, given that it appears that SCE's proposed program outside of Catalina Island would replace only HVAC and water heaters, which are required to vent to the outside.[56] In any event, she has not provided any quantitative estimates of health benefits for reductions in indoor air pollution in her testimony. The only quantified estimates of health benefits in her testimony come from her COBRA runs and, as she has acknowledged, COBRA does not address indoor air pollution impacts.[57] In fact, COBRA *cannot* make indoor air impact estimates, as stated on the COBRA website:

[56] See column D of SCE Response to Data Request Cal. Advocates-SCE-001, Q.7, Attachment "BE Application Portfolio Benefits.xlsx," provided in Attachment D to my testimony.
[57] Bottorff Testimony at 22, line 8.

> "*COBRA cannot be used to model health impacts of changes in indoor air quality. COBRA only analyzes the health impacts associated with changes in outdoor air quality*."[58]

Section 3: Limitations of the COBRA Model for Reliably Estimating Outdoor Air Health Impacts.

Q. You have mentioned that COBRA performs a simplified version of "integrated assessment." What is the meaning of integrated assessment in the context of air quality policy?

A. A full integrated health risk assessment for a policy that would affect outdoor air emissions involves the integration of modeling of emissions changes due to the policy with air quality modeling to project how those changes will affect ambient air concentrations of key pollutants such as $PM_{2.5}$ or ozone. The resulting projections of levels of ambient pollution are then used to make estimates of particular health effects levels across the affected region. Needless to say, all of these modeling steps can require substantial temporal, spatial, technological, and demographic details.

A cost-benefit analysis of policy options can then take these projected changes in health effects and use multipliers to assign a monetary value to each type. Monetization summarizes the relative societal importance of all the various health endpoints (e.g., risk of heart attacks vs. risks of exacerbation of asthma), because they are then all stated in dollar units which can be added up. They can also be aggregated across multiple years into a single present value, through an economics methodology called discounting.

In the profession, these monetized health effects estimates are referred to as "benefits," as contrasted to the non-monetized array of different health outcome projections, which are often referred to as health impacts or health effects.

All of these analysis steps introduce significant uncertainties, not just of a statistical nature but also of an epistemic nature, meaning that many of the relationships or parameters of the models are unknown as a matter of scientific knowledge. However, a full integrated risk analysis can, if done well, provide information about the range of uncertainty that accumulates across the many steps of the analysis.

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[58] https://www.epa.gov/cobra/cobra-questions-and-answers#6.

Q. Are there concerns with using COBRA to model health benefits estimates?

A. Yes. The COBRA model is a very simplistic model from among the many available types of tools that are used to estimate public health impacts from outdoor ("ambient") $PM_{2.5}$. Several of these simplifications substantially limit the reliability of its projections, particularly for the type of emissions reductions that might ensue from a BE program such as SCE has proposed.

Q. Can you describe some of the limitations of COBRA?

A. Among the integrated assessment methods available for air quality health risk assessment, COBRA is among the simplest, belonging to a category known within the profession as reduced form tools ("RFTs"). RFTs are considered helpful to provide general insights that are known to be imprecise and even inaccurate, but which might serve a screening function by indicating the relative merits of conducting more state-of-the-art sophisticated modeling for a limited number of policy options that might be under consideration.

EPA's introductory materials and its Users Manual clearly state that COBRA is an initial screening tool. Attachment B, for example, provides an EPA presentation that describes COBRA as providing only a "quick and dirty" estimate of air quality.[59] It goes on to advise potential users that COBRA is "best used as [a] "'screening'" tool" (emphasis in original) that would then be "followed "up with comprehensive AQ [i.e., air quality] analysis and health impact assessment" to assess the cost-benefit merits of a particular strategy. Such screening tools can be helpful in the early phases of policy consideration *as long as users clearly explain their limitations and provided the users do not apply them incorrectly, or interpret their results inconsistently with the limitations of the tool*. Although they are simpler to run than the more sophisticated tools that they try to approximate, they can still be misapplied and their results can still be misinterpreted. As I explained above, Ms. Bottorff has not properly explained the meaning of the COBRA benefits estimates, and has generally misrepresented them as "economic cost savings." As I will explain below, she also has conducted a flawed analysis using COBRA, and the conclusions she draws from her COBRA outputs fail to respect the limitations associated with the simplifications of COBRA.

[59] See slide 9 of Attachment B (https://www.epa.gov/sites/default/files/2021-03/documents/how_cobra_works_mar2021_508.pdf.)

- ***In brief, the COBRA tool supports only a simplified analysis that makes crude approximations not reliable for a cost-benefit decision-making phase; furthermore, its results can be rendered not useful even for screening purposes if there are flaws in how the user applies it, or interprets the results.***

Q. How does COBRA reduce or simplify the elements of a full integrated analysis and how does that affect Ms. Bottorff's analysis?

A. COBRA's most important simplifications are in the emissions projection step and in the air quality projection step. I will first address the simplification in the emissions projection step.

COBRA does not itself estimate the emissions changes that are projected to result from whatever policy, regulatory or program changes one wishes to evaluate—these are user inputs. Those inputs are thus calculated in the manner the user chooses when attempting to develop a COBRA model run to reflect a particular policy, regulation, or program. In the case of Ms. Bottorff's analysis of the SCE BE program, she has used an off-the-shelf set of emissions factors (lbs. per MMcf) associated with natural gas consumption in residential space heaters taken from a COBRA User Fact Sheet.[60] These factors come from other studies that have suggested them as reasonable averages for gas-fired residential or commercial heating systems, and have been adopted as part of EPA's "AP-42 Compilation of Air Emissions Factors," which is a database of emissions factors available for use in making general approximations of emissions from sources that do not have actual monitoring data. Ms. Bottorff provides no analysis of whether these specific emissions factors are appropriate for the SCE BE program or are representative of the gas appliances prevalent in SCE's service territory today.

AP-42 factors were first developed in 1972, and the most recent comprehensive update of these factors was in 1995.[61] In addition to providing access to the full 1995 AP-42 document, the EPA AP-42 website posts documents that describe any updates since 1995, on a chapter-by-chapter basis. That website includes a document dated 1998 summarizing updates since 1995 for emissions factors for natural gas combustion which indicates there have been no updates of

[60] COBRA User Fact Sheet: Analyzing Avoided Natural Gas Emissions Using COBRA. Available at: cobra-fact-sheet-natural-gas.pdf (epa.gov).

[61] https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors.

emissions factors for residential gas combustion since 1981.[62] Those emissions factors used by Ms. Bottorff thus appear to reflect the operations of residential gas furnaces that were in place 40 or more years ago. Ms. Bottorff provides no discussion of whether the more recent vintages of residential heating and water heaters that could be replaced under a BE program in the 2020s may have different average emissions rates per therm due to technology changes since the 1970s.

Even if the emissions factors she uses remain reasonable, Ms. Bottorff makes other potentially problematic simplifications. For example, she does not include a baseline of whether the equipment being replaced might be replaced anyway even in the absence of the SCE program within the timeline over which she estimates benefits (the "lifecycle"). If such replacements were to occur anyway, sometime during the but-for lifecycle period, her analysis is overstating the benefits of the specific program. Instead, her analysis implicitly assumes that the gas-fired appliances to be replaced by electric appliances under SCE incentives would, but for the SCE program, remain in place for the next 10 to 15 years. Even if the gas-fired appliances that will be replaced under SCE funding vary in age from brand-new to 15 years old (the typical useful life reported by SCE for HVACs), it would be reasonable for Ms. Bottorff's baseline to assume that some of these existing units would be replaced anyway by the end of the analysis lifecycle. Even without the SCE incentives, the growing regulatory pressures to electrify would imply that some fraction of these baseline replacements would be with electric rather than gas-fired equipment (and perhaps more, in light of regulatory developments). Without having accounted for this baseline turnover, at least with some rough assumptions, Ms. Bottorff has overstated the *lifecycle* reduction of emissions that she inputs into the COBRA tool. In the alternative, she would need to make the case that none of those HVAC and water heating functions would be electrified in the next 10-15 years if the SCE program were not to take effect.

[62] See Chapter 1 of the 1995 "AP-42, Fifth Edition Compilation of Air Pollutant Emissions Factors, Volume 1: Stationary Point and Area Sources," https://www.epa.gov/sites/default/files/2020-09/documents/background_document_ap-42_section_1.4_natural_gas_combustion.pdf at p: 3.6 ("The NOx emission factor for residential furnaces is based on test data from 41 sources (2-3) Since no new data for NOx from residential furnaces were obtained during this revision, this factor remains unchanged from the previous version of Section 1.4."); at p. 3.11, one finds that references 2 and 3 are studies published in 1981 and 1975, respectively.

Q. Do you see any other flaws in how Ms. Bottorff has applied her estimates of emissions reductions in COBRA to estimate the lifecycle benefits of the SCE program?

A. Yes, I do see a significant flaw in how Ms. Bottorff has used COBRA to estimate lifecycle emissions. The COBRA FAQ sheet (#8) explains "To analyze multiple years of emissions changes, you must conduct a COBRA run for each year to be analyzed. These results can be added together."[63] However, Ms. Bottorff does not appear to have conducted a COBRA run for each year to be analyzed; instead, she appears to have simply input the entire 10 to 15 years-worth of emissions reductions into the single COBRA model year 2028 and estimated benefits as if these aggregated emissions reductions were to occur in a single year.[64]

If Ms. Bottorff did indeed take this approach of entering all of the lifecycle emissions changes into a single model year, her results unreliable for three reasons: (1) having to reallocate where the projected emissions changes will occur to avoid greater than 100% reductions in COBRA's baseline of emissions; and (2) failure to account for baseline ("but for") appliance turnover when estimating benefits that accrue later than 2028, and (3) failure to use discounting to correctly estimate a present value of lifecycle benefits.

Evidence that she took this flawed approach when applying COBRA appears in a comment she makes in her testimony when describing how she set up her COBRA model: "In a few cases where the estimated emissions reductions for a particular pollutant in a certain county are greater than the baseline emissions, the control emissions are set to zero and the additional reductions are redistributed among the remaining counties."[65] This tells us that the emissions reductions from the SCE program that she used for her COBRA analysis were so large that at times they exceeded the annual emissions from gas-fired combustion in *all* buildings in a county. If she had done a proper year-by-year lifecycle analysis, this "greater-than-100% reduction" phenomenon should not have affected her analysis. Her method of simply moving the emissions reductions that exceeded 100% in one county to all the other counties only further demonstrates the flaws in her benefits analysis.

Although COBRA does not have baseline data after 2028, Ms. Bottorff had several options available for doing a multi-year analysis to estimate lifecycle results more accurately.

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[63] https://www.epa.gov/cobra/cobra-questions-and-answers#8.
[64] See Bottorff Testimony at 15 n 50. ("These health impacts are modeled in the single year 2028 based on COBRA's base year availability but they would accrue over the lifecycle of this proposal.")
[65] Bottorff Testimony at 14, lines 21-23.

COBRA allows users to enter baseline data for additional years.[66] Another approach would be to allocate the total lifecycle emissions to individual years, run each year's emissions on the 2028 baseline, then create a present value from the estimated stream of 15 years of benefits. This would not correct for the missing "but for" baseline of gas appliance turnover, but would at least correct for the failure to provide a present value of lifecycle benefits. She did not make any such attempt and instead ran a scenario in which all reductions over the 10- to 15-year lifecycle period are assumed to occur in a single year. Those reductions in her COBRA model run are almost 15 times larger than the SCE program would achieve in a single year, and, as she admits, her estimates of emissions changes exceeded the COBRA baseline's annual levels of emissions from all residential or commercial fuel combustion in at least some counties and for at least some of the five pollutant species.[67] Later in my testimony I will discuss the likely overstatement in her estimates from failing to present a correct present value for her lifecycle benefits estimates.

Q. Does COBRA also have limitations in how it simplifies the air quality projection step?

A. Yes, COBRA contains a set of linear multipliers that convert changes in annual emissions into annual average air quality on a county-by-county basis across the U.S., which represents a great simplification from full-scale air quality modeling. In contrast, full scale air quality modeling takes into account the most recently available meteorological patterns and simulates in 3-dimensional, temporally disaggregated detail the chemical interactions of the full mix of pollutants in the air. As the weather and climate change, the spatial patterns of air concentrations of secondary pollutants such as $PM_{2.5}$ can change. As the mix of pollutants changes in a region (e.g., as SO_2 declines more rapidly than VOCs, due to differential regulatory pressures), the ability of any single type of gaseous pollutant to convert into another form such as secondary $PM_{2.5}$ or ozone will change. COBRA's reduced-form air quality relationships have abstracted away all of these details in order to make quicker but cruder approximations of how regional air quality will respond to a given set of projected emissions changes.

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[66] FAQ #8 on the COBRA website (https://www.epa.gov/cobra/cobra-questions-and-answers#8) states, "Users also have the option to input custom datasets, including the emissions baseline, population and health incidence, for any year [other than just using the pre-installed default baselines for 2016, 2023 or 2028]."

[67] Bottorff Testimony at 14, line 21-23.

When an air quality model is simplified into a set of multipliers that define how much $PM_{2.5}$ will form in one location (a "receptor" location) as a result of a given reduction in tons of emissions in another location (a "source" location) – as COBRA has done – the resulting reduced form model has locked in the air pollutant conditions, weather patterns, and regulatory requirements as of the date of the simplification. COBRA's reduced form air quality model, called the source-receptor matrix ("S-R Matrix"), was first developed in about 1994 using 1990 climate/weather conditions, mix of air pollutants present, and a full-form model (called "CRDM") that was not as sophisticated computationally as today's standard full form air quality models.[68] The November 2021 version of the COBRA User's Manual states, "While comparative work to test the performance of COBRA's air quality model is ongoing, it is not yet fully validated."[69] The COBRA documentation and related papers do not appear to provide clear information on how or when EPA has updated that S-R Matrix since the 1990s, other than to mention one partial validation study by Levy et al. (2003) that addressed only seven power plant emissions in northern Georgia, which was done using "an earlier version of the S-R Matrix."[70] That Levy paper noted that COBRA had greatest difficulty in matching nitrate-$PM_{2.5}$ concentrations with the predictions of a more detailed model also used in that study.[71] This is an important point because I have estimated that nitrate-$PM_{2.5}$ accounts for about 90% of the benefits that Ms. Bottorff has reported in her testimony.[72]

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[68] EPA. "User's Manual for the Co-Benefits Risk Assessment Health Impact Screening and Mapping Tool (COBRA)", Version 4.1, November 2021, p. A-1. Available at: COBRA User's Manual, p. A-1, November 2021. Available at: https://www.epa.gov/system/files/documents/2021-11/cobra-user-manual-nov-2021_4.1_0.pdf. (Hereafter "COBRA User's Manual".)

[69] COBRA User's Manual, p. 17, November 2021.

[70] COBRA User's Manual, p. A-1.

[71] COBRA User's Manual, p. A-1.

[72] I made this estimate by inputting emissions for 655 million therms reduced gas usage into the 2023 baseline of the Web version of COBRA (COBRA Web Edition | CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool | US EPA). I broke the emissions per therm into the same 5 pollutants used by Ms. Bottorff (at 14, lines 13-15, referencing EPA, COBRA User Fact Sheet: Analyzing Avoided Natural Gas Emissions Using COBRA (March 2021, cobra-fact-sheet-natural-gas.pdf (epa.gov)). I ran these emissions in COBRA as entirely residential gas combustion and let COBRA spread them across 11 of the California counties that have substantial areas in SCE service territory. The resulting total benefits, although for a COBRA set up quite a bit simpler than Ms. Bottorff's and using a different baseline year, matched her reported dollar values within 9% for both US-wide and California only. After obtaining the total estimates, I ran COBRA again for each of the pollutant changes individually, all other scenario setting being identical. My individual pollutant values summed to the same value as the all-pollutants run, as one would expect of a fully linear model. I found that nitrate-

I have found no other indications in documentation provided on the COBRA website, or through general research, of other validation studies specific to the COBRA S-R Matrix, nor any clarification of when or how it was updated after the Levy analysis. It is interesting that the 2021 User's Manual, after citing only the Levy (2003) paper as a COBRA validation study, states (again), *"Because of the limited validation studies of the S-R Matrix, it should be treated as a screening tool that provides a crude estimate of the likely impact of a change in emissions on ambient $PM_{2.5}$ levels.* ***More sophisticated atmospheric dispersion models should be used to obtain detailed estimates of ambient air quality changes****."*[73] Ms. Bottorff does not provide any information about the degree of validation or updating of the COBRA S-R Matrix, nor has she followed the User Manual's advice to use a "more sophisticated model" to obtain more "detailed estimates" of air quality changes.

- ***In summary, Ms. Bottorff fails to acknowledge the limitations of the COBRA model or that the quality of the approximation that COBRA provides is unclear, nor does she explain the validity of the emissions reductions inputs.***

Q. Is there any evidence of how well other RFTs using similar S-R Matrixes approximate full form air quality modeling?

A. There is some. For example, there is another RFT (first named "APEEP", then "AP2" and "AP3") that is said to have used, at least originally, the same general approach for estimating S-R Matrix values as COBRA.[74] It is not at all clear how similar their S-R Matrix values were originally, nor remain today, as the APEEP matrix has been updated at least once.[75] In 2019, the EPA funded a study to compare how well four RFTs matched results from detailed

$PM_{2.5}$ from the NO_x emissions accounted for 92% of the total benefits. There is no reason to expect Ms. Bottorff to have a substantially different percentage due to nitrate-$PM_{2.5}$ in her own analysis, if she were to calculate it and report it.

[73] COBRA User's Manual, p. A-1. (emphasis added.)

[74] Gilmore, E. A., et al. "An Intercomparison of the Social Costs of Air Quality from Reduced-Complexity Models, *Environmental Research Letters* Vol. 14, 074016, 2019, at p.4 states "Both [COBRA and AP2] are built around the CRDM (Latimer, 1996) and then calibrated to existing air quality modeling and measurements. There are minor differences in the treatment of the elevated sources, the approach to the simplified [atmospheric] chemistry and the calibration approach."

[75] Muller, N. Z. and R. Mendelsohn, "The Air Pollution Emission Experiments and Policy Analysis Model (APEEP)," Technical Appendix, Yale School of Forestry and Environmental Studies, December 2006. https://www.researchgate.net/publication/253359043_The_Air_Pollution_Emission_Experiments_and_Policy_Analysis_Model_APEEP_Technical_Appendix.

3-dimensional air quality modeling of several types of emissions policies.[76] AP2 and AP3 were among the RFTs studied (but not COBRA). Health effects impact estimates from each RFT were compared to those produced by EPA's BenMAP model, which relied on full-form modeling of the respective policies using the CMAQ model at a 12 km x 12 km grid scale. Four of the five policy scenarios were for large stationary sources such as power plants, and one of them was for the Tier 3 vehicle standard. The last of these has the most similarities to how these models would be able to address air quality impacts from building emissions, as it was for ground level sources with most of the emissions reductions being of NO_X. The comparison found that AP2 and AP3 both overstated the health benefits of the Tier 3 rule by a factor of 2.7 to 4.3.[77] Most of this overstatement appeared to be due to the models' predictions of nitrate-$PM_{2.5}$.[78] The report concluded that "*the reduced-form tools considered in this analysis should be applied with caution to policies with large changes in NO_X emissions*."[79] Although this study did not address COBRA, it provides useful insight about the reliability of an RFT using a similarly-derived (and perhaps more recently updated) S-R Matrix in addressing air quality impacts and associated health benefits from reductions of NOx from essentially the ground level. It bears emphasizing that the overstatements of AP2 and AP3 were substantial, by a factor of 2.7 to 4.3.

- ***In short, EPA's own studies have found that RTF's – like COBRA – have reliability concerns for addressing air quality impacts, and in particular NOx emissions from near-ground sources.***

Q. How does the spatial simplification of the COBRA S-R Matrix limit Ms. Bottorff's analysis?

A. Another important aspect of the simplification of the COBRA S-R Matrix is that emissions and any changes in emissions are assumed to occur at the centroid of the county to which the user assigns them and the projected air quality changes are approximated at each receptor county's centroid. Modern full-scale modeling, even at the national scale, today typically uses a 12 km x 12 km grid. More localized policy impact modeling may use an even

[76] IEc, "Evaluating Reduced-Form Tools for Estimating Air Quality Benefits," Final Report, October 31, 2019. Available at: https://www.epa.gov/sites/default/files/2020-09/documents/adapted_rft_report_10.31.19.pdf.
[77] IEc, op. cit., p. ES-6, Exhibit ES-4. See Attachment C for a copy of the Exhibit.
[78] IEc, op. cit., p. 3-6 to 3-8, Exhibit 3-4. See Attachment C for a copy of the Exhibit.
[79] IEc, op. cit., p. 4-4.

smaller spatial scale. The SCE counties range in size up to 52,000 km^2 (San Bernadino),[80] which is roughly equivalent to a 228 km x 228 km scale. The most populous SCE county (Los Angeles) is where I estimate that a majority of Ms. Bottorff's total estimated benefits likely occur, and is equivalent in size to a 110 km x 110 km grid scale[81] – about 85 times larger in size than is typically considered appropriate for national scale studies. This county-level scale is of great significance in the potential precision of any risk effects or benefits calculations that COBRA can produce. It most certainly cannot distinguish benefits between programs that apply different amounts of funding to ESJ versus non-ESJ Communities, to the extent that both such types of communities exist within SCE's counties.

Section 4: Additional Flaws in Ms. Bottorff's Use of COBRA to Estimate Outdoor Air Pollution Health Benefits.

Q. Please explain whether specific other conclusions of Ms. Bottorff's testimony are unsupported or inaccurate.

A. Ms. Bottorff states on p. 3 of her testimony (lines 19-22) that, having modeled "the health benefits of reduced gas use from SCE's proposed program," she finds the "potential health cost savings of SCE's proposed program over its lifecycle are between $219 million and $491 million." I consider this inaccurate for two reasons. First, – and as I have already explained – she characterizes these dollar values as "cost savings," whereas the vast majority of those total values bears no relationship to any kind of a reduction in financial costs (e.g., "spending") to the affected public, to society at large, or to SCE or any other potential stakeholder. Only $1.1. million to $2.4 million (less than 0.5% of her totals) reflect potential actual health cost savings using the COBRA modeling tool. Ms. Bottorff fails to explain the meaning of her public health benefits estimates, and repeatedly calls them "cost savings" when they do not represent actual cost savings. She does not even mention the term willingness-to-pay or WTP in the main body of her testimony, and when she does use it in her Appendix D, she does not explain what it is.

Second, she does not make clear in this important summary paragraph that none of those benefits estimates are for indoor air pollution. Instead, she makes the ambiguous statement that her "testimony considers the <u>cost</u> of the negative health impacts of gas combustion <u>in</u> residential and commercial buildings" (at 3, ll. 17-19) and follows this with testimony (i.e., at 5-7) that

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[80] See San Bernadino County, CA at [List of the largest counties in the United States by area - Wikipedia](https://en.wikipedia.org/wiki/List_of_the_largest_counties_in_the_United_States_by_area).
[81] Ibid. (listing total area of Los Angeles County, CA as 12,308.5 km^2).

emphasizes the need to electrify homes because of indoor air pollution. Even if one could infer from her summary paragraph alone that its reported health benefits are entirely for outdoor air pollution exposures, she does not make it clear that these are health benefits to the general public across the entire contiguous U.S. from reduced outdoor air pollution and not benefits just to those who electrify their homes as a result of the SCE program, nor even just to the communities where those BE projects occur. In fact, the dollar values she reports in the quote above are for the entire population of the contiguous U.S. Her Appendix A also shows values for the counties where SCE's spending will occur; these are 14% lower, but they too are for the entire population at large across those counties. In brief, the benefits she claims are for crudely estimated outdoor air quality changes over a wide and spatially-aggregated region, and are not tied to any claimed improvement in indoor air quality from replacing gas appliances with electric appliances.[82]

Q. Does Ms. Bottorff make unsupported assumptions and calculations relating to the COBRA benefits to ESJ communities?

A. The second paragraph of her summary (at 3-4) states that if 70% or 100% of the SCE BE budget were to be dedicated to electrification activities in ESJ Communities, the "total health benefit from reductions in gas use to ESJ Communities" would be increased by 80% or 150%, respectively, while reducing the "overall health benefit" of the as-proposed program by "only" 6% or 20%, respectively. This statement has several flaws and inaccuracies, as I will explain.

It is important to note that the COBRA model that she has used to develop her estimates of overall health benefits is incapable of providing benefits estimates by community. COBRA distinguishes emissions changes only at a *county* level. Whether all of the reductions in a given county occur in ESJ Communities in non-ESJ Communities, COBRA can only return the single same estimate of benefits based on an estimate of the average risk reduction across the entire county's population.

Ms. Bottorff later explains (at 21), however, that she derives her percentages of benefits to ESJ communities in the SCE counties by assuming that people living in ESJ communities will

[82] Furthermore, it bears repeating that SCE's program proposes to electrify only a small fraction of gas-fired appliances that may be unvented (e.g., stoves) whereas it is my understanding that the studies cited by Ms. Bottorff (at 5-7) relating to the potential indoor air quality benefits of electrification address primarily unvented gas stoves as the source of those concerns. It is thus not clear from Ms. Bottorff's testimony what the extent of indoor air quality benefit would be from electrification of gas appliances that vent to the outside, as proposed for the SCE program.

enjoy a share of her estimated total (i.e., nationwide) outdoor air quality benefits that is equal to their communities' share of the equipment budget spent. That is (summarizing the calculations she conducts), she assumes that, if, for example, 30% of the SCE equipment spending occurs in ESJ communities, then 30% of the nationwide public health benefits will be gained by those communities. This is an unsupportable estimate: while perhaps 30% of the *emissions reductions* will occur in ESJ Communities if 30% of the electrification projects occur there, there is no logical reason why 30% of the nationwide overall health benefits would "*go to* ESJ Communities" (at 21, emphasis added). The gases such as NOx that are emitted from a building (or any other type of source) move through the atmosphere and can travel substantial distances before they convert into ambient $PM_{2.5}$ which is the outdoor pollutant that she has relied upon to estimate her public health benefits. As she herself notes (at 21), 13% of her total benefits are projected to occur outside of the entire set of SCE counties, even though fully 100% of the spending is assumed to occur within those counties. Indeed, over 6% of those projected benefits do not even occur within California.[83]

The fallacy of her calculation becomes even more apparent when considering her estimates of benefits (at 21) to ESJ Communities in her 100% ESJ Scenario. Here, because 100% of all SCE spending on BE occurs in ESJ Communities, she assumes that 100% of the COBRA-based overall benefits "go to" ESJ Communities, and states that their benefits are thus $175 million to $392 million. One can confirm from her Appendix C that this is the benefit range that COBRA estimated *for the entire contiguous US* for that scenario. It *exceeds* COBRA's estimated benefits for the entire set of SCE-impacted counties by 16%, at least a fair share of which benefits would occur in non-ESJ portions of those counties. These facts reveal the major errors in her interpretation of her COBRA results and the unreliability of her conclusions.

Ms. Bottorff does not provide any rationale for her assumption that outdoor air quality benefits of building emissions reductions occur only within the local ESJ communities where the emissions reductions occur. But even if she were to do so, it is important to recognize that it would not be consistent with the model she uses to estimate her dollar benefit values, COBRA.

[83] I compute this by dividing the total benefit in California by the total overall benefits reported in her Appendix B (the 70% ESJ Scenario). The same fraction of benefits that occur outside of California also applies to the results in Appendix A and C (for the as-proposed and 100% ESJ scenarios, respectively).

To be clear, Ms. Bottorff has presented no calculations of health risk changes that could support estimates of impacts specifically in ESJ Communities. The only quantitative calculations of benefits that she has presented have been based on COBRA. COBRA does not discern any differences in air quality, population vulnerability, or numbers of people at sub-county levels. Therefore, the only possible quantitative estimate of changes in health benefits to a sub-population within a county (such as to ESJ Communities within the county) that her analysis could support would be the COBRA-based estimate of the change in the county's total health benefits estimate, multiplied by the fraction of the county's population in ESJ Communities. For example, she reports (at 21) that her COBRA-based projected total benefits decline by 6% and 20% for the 70% and 100% scenarios, respectively. Because COBRA cannot estimate any impacts at less than the county level, if one were to want to approximate the benefits specifically to ESJ Communities from her COBRA-based analysis, one could only assign each ESJ Community the same average change as COBRA projects for the county as a whole: e.g., -6% and -20% benefits, respectively. This lack of community-level detail in her results reflects the limitations of the COBRA model upon which she has relied solely for her quantitative analysis.

Moreover, Ms. Bottorff (at 3-4) summarizes the *trade-off* between gains to the ESJ Communities versus reductions in overall benefits (implicitly for non-ESJ Communities) only in percentage terms rather than in dollar terms. It is numerically improper to compare a percentage change in one population group's purported benefits to a percentage change in another population group's benefits without also reporting the absolute values of the changes. For example, she summarizes her conclusions (at 4) for her 70% ESJ Scenario that the ESJ Communities would see an 80% increase in their benefits relative to the as-proposed scenario "while <u>only</u> reducing the overall health benefit by 6%." This sort of percentage-based comparison can be extremely misleading if the benefits to each group are substantially different in dollar magnitude. <u>For example</u>, if one group's as-proposed benefits are worth $10 and the other group's as-proposed benefits are $1000, then the seemingly "good" trade-off of an increase in 80% for a reduction of 6% would actually represent a net societal welfare *loss*, because the first group's benefits would increase by $8 (i.e., 80% of $10) while the second group's benefits would decrease by $60 (i.e., 6% of $1000), and the net public health benefit would be -$52.

- ***In sum, Ms. Bottorff's estimates of benefits to ESJ communities are not supported by the COBRA model, either in absolute dollar terms or in percentage terms. ; COBRA can only project that the benefits from any emissions reductions would accrue equally to everyone in each modeled county. If there were any difference in how much outdoor air quality benefits would accrue to neighborhoods where BE funds were spent, COBRA is unable to provide insight or information on this point.***

Q. Is there some uncertainty about Ms. Bottorff's comparison of health benefits estimates between the SCE proposal and her alternative proposals?

A. Yes, there appear to be some mistakes in her numbers. Ms. Bottorff states in her testimony certain benefits estimate values that do not match the values in her Appendices B and C. For example, the values she states in her testimony for the 70% ESJ scenario (at p. 21, lines 6-11) are $205 million to $460 million, referenced to her Appendix B, and she describes this as a 6% reduction from the SCE as-proposed program (e.g., at p. 21 line 13 and elsewhere such as p. 4, l. 2). However, her Appendix B reports those values as $178 million to $400 million,[84] which implies a 19% reduction, not 6% from the as-proposed program scenario.[85] Furthermore, she states that the benefits in SCE-Impacted counties are $178 million to $399 million, but Appendix B reports those numbers as $154 million to $346 million.

Q. Does Ms. Bottorff properly use the discount rates suggested by the EPA for COBRA?

A. No, she does not. As an initial matter, Ms. Bottorff states that she is only using a 3% discount rate (which is used to reduce estimates of future amounts to present value), even though COBRA provides options for both a 3% and a 7% discount rate. The COBRA User's Manual states:

> *"Based on EPA's Guidelines for Preparing Economic Analyses (U.S. EPA, 2010a), it is recommended that COBRA users calculate monetized health benefits using both 3% and 7% discount rates and then evaluate whether the overall outcome of the analysis is affected by the choice of discount rate."*[86]

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[84] See column 1 of Ms. Bottorff's Appendix B.

[85] Ms. Bottorff's Appendix A and her testimony (e.g., at p. 3, l. 22) indicate the as-proposed total benefits are $219 million to $491 million. $178 million is 19% less than $219 million and $400 million is 19% less than $491 million.

[86] COBRA User's Manual, p. 23.

Ms. Bottorff has not provided any discussion of the issues in choosing a discount rate and has not mentioned the User's Manual advice to use both discount rates. She only states (at 15 lines 1-2) that 3% "is a typical discount rate when looking at health benefits." She does not substantiate this statement, nor address why she has ignored the COBRA recommendation based on EPA's *Guidelines*.

Moreover, there are other ways that she has failed to correctly apply discounting that potentially have larger effects on her estimates. The only way that Ms. Bottorff has applied a discount rate is to obtain a present value of the mortality benefits estimate, because COBRA assumes that estimated $PM_{2.5}$ mortality risks associated with exposure in any given year are spread over about 20 years then discounts them back to a single present value for the mortality risk benefit.[87] ""

However, Ms. Bottorff has not applied discounting to her purported lifecycle benefits, even though this has a more substantial impact on estimated benefits. I explained above, she has estimated benefits as if the entire 10 to 15 years-worth of emissions reductions all occur at once, in 2028. A correct analysis would have estimated benefits for each of those 10 to 15 years on an annual basis, then discounted those too. If she had done a correct lifecycle analysis, even by crudely assuming annual benefits in each year of the lifecycle are the same as the *annual* benefits in 2028, I conclude that all of her various lifecycle benefits estimates would be about 16% lower than she has reported, even using the 3% discount rate. Furthermore, using a 7% discount rate, I conclude that all of her resulting lifecycle benefits estimate would be about 39% lower than the values she has reported in her testimony.

The above overstatements in her benefits estimates relate to her failure to properly conduct a multi-year analysis to estimate lifecycle benefits, but they are only one of several sources of overstatement associated with her methods of using COBRA and her invalid interpretations of her COBRA-based results.

Q. Does this conclude your pre-filed rebuttal testimony?

A. Yes.

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[87] See COBRA User's Manual, p. F-8 ("Current EPA benefits analyses (U.S. EPA, 2006, p. 5-21) assume a 20-year lag structure [for $PM_{2.5}$ mortality benefits valuation], with 30 percent of premature deaths occurring in the first year, 50 percent occurring evenly over years 2 to 5 after the reduction in $PM_{2.5}$, and 20 percent occurring evenly over years 6 to 20 after the reduction in $PM_{2.5}$."

ATTACHMENT 1

CV of Julie E. Goodman, Ph.D., DABT, FACE, ATS

GRADIENT

Julie E. Goodman, Ph.D., DABT, FACE, ATS
Principal

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Areas of Expertise

Epidemiology, toxicology, systematic review, evidence integration, meta-analysis, carcinogenesis, dose-response analysis, product safety, risk assessment, risk communication.

Education & Certifications

Ph.D., Environmental Health Sciences/Toxicology, Johns Hopkins Bloomberg School of Public Health, 2002

Sc.M., Epidemiology, Johns Hopkins Bloomberg School of Public Health, 2000

S.B., Environmental Engineering, Massachusetts Institute of Technology, 1996

Diplomate, American Board of Toxicology (DABT), 2005; recertified 2010, 2015, 2020

Fellow, American College of Epidemiology (FACE), 2014

Fellow, Academy of Toxicological Sciences (ATS), 2014; recertified 2019

Professional Experience

2004 – Present GRADIENT, Boston, MA
Principal. Evaluate toxicity and epidemiology data in the context of causation analysis and human health risk assessments. Focus on substances in consumer products, pharmaceuticals, and medical devices, and chemicals in the workplace and the environment.

2009 – 2017 HARVARD T. H. CHAN SCHOOL OF PUBLIC HEALTH, Boston, MA
Adjunct Faculty Member. Department of Epidemiology. Co-instructor of course entitled, "Research Synthesis & Meta-analysis."

2002 – 2004 NATIONAL CANCER INSTITUTE, Bethesda, MD
Cancer Prevention Fellow. Conducted a number of molecular epidemiology studies analyzing the relationships between inflammatory gene polymorphisms and colon cancer risk. Instrumental in the development of a powerful statistical tool for cancer risk assessment.

Continuing Education Courses and Other Training

- Introduction to Open-Access Computational Toxicology Tools (web course), Society of Toxicology 2020 Annual Meeting, April 2020
- Protecting Human Research Participants Online Course, National Institutes of Health (NIH) Office of Extramural Research, 2015
- Tools and Technologies in Translational Toxicology, Society of Toxicology 2013 Annual Meeting, San Antonio, TX, March 2013

- Use of Expert Elicitation to Inform Decisionmaking, Society for Risk Analysis 2012 Annual Meeting, San Francisco, CA, December 2012
- Novel Statistical Challenges in Environmental Epidemiology Workshop, 3rd North American Congress of Epidemiology, Montreal, Canada, June 2011
- Comparative Biology of the Lung, Society of Toxicology 2010 Annual Meeting, Salt Lake City, UT, March 2010
- Introduction to the Benchmark Dose Methodology and Interactive Application of United States Environmental Protection Agency (US EPA) Benchmark Dose Software (BMDS), Version 2.1, Society for Risk Analysis 2010 Annual Meeting, Salt Lake City, UT, December 2010
- Green Innovation for Business Conference (Moderator, Green Chemistry and Greenwashing Workshops), Boston, MA, June 2009
- Decision-making for Recommendations and Communication Based on the Totality of Food-related Research, International Life Sciences Institute Workshop, Washington, DC, December 2008
- 2008 Board of Health Certification Program, Massachusetts Association of Health Boards, Marlborough, MA, November 2008
- What is Evolutionary Epidemiology? American College of Epidemiology Annual Meeting, Tucson, AZ, September 2008
- Research Ethics in Studying Genes and the Environment in Diabetes Among Ethnic Minorities, American College of Epidemiology Annual Meeting, Tucson, AZ, September 2008
- Use of Data for Development of Uncertainty Factors in Non-Cancer Risk Assessment, Society of Toxicology 47th Annual Meeting, Seattle, WA, March 2008
- International Society of Regulatory Toxicology and Pharmacology Workshop: Conducting and Assessing the Results of Endocrine Screening, Bethesda, MD, February 2008
- Assessment of Abuse Liability and Physical Dependence, Northeast Chapter Society of Toxicology Annual Meeting, Groton, CT, October 2007
- Practical Issues and Procedures for Preclinical Safety Testing, 2007 BioReliance Toxicology Technical Seminars, Boston, MA, October 2007
- Introduction to Pharmacoepidemiology: Practical Applications and Analytic Methods, American College of Epidemiology 25th Annual Meeting, Ft. Lauderdale, FL, September 2007
- SAS Programming I: Essentials, SAS Institute, Boston, MA, July 2007
- Introduction to Bayesian Modeling of Epidemiologic Data, Society for Epidemiologic Research 40th Annual Meeting, Boston, MA, June 2007
- Systematic Review and Meta-analysis, Society for Epidemiologic Research 40th Annual Meeting, Boston, MA, June 2007
- The Biology and Toxicology of the Peri- and Post-natal Development, Society of Toxicology 46th Annual Meeting, Charlotte, NC, March 2007
- Reproductive Toxicity Testing: Study Designs, Evaluation, Interpretation, and Risk Assessment, Society of Toxicology 45th Annual Meeting, San Diego, CA, March 2006
- Project Managers Bootcamp I, PSMJ Resources, Inc., Cambridge, MA, April 2005
- Development and Interpretation of Toxicokinetic Data for Risk and Safety Assessment, Society of Toxicology 44th Annual Meeting, New Orleans, LA, March 2005
- Survival Analysis, Graduate Summer Institute of Epidemiology and Biostatistics, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, June 2003
- Speaking on the Job, Cancer Prevention Fellowship Program, National Cancer Institute (NCI), Rockville, MD, February 2003
- Grants and Grantsmanship Workshop, Cancer Prevention Fellowship Program, NCI, Rockville, MD, January 2003
- Spotted Gene Expression Microarray Workshop, Advanced Technology Center, NCI, Gaithersburg, MD, October 2002
- Laboratory of Cellular Carcinogenesis and Tumor Promotion/Laboratory of Human Carcinogenesis/Laboratory of Experimental Carcinogenesis Interlaboratory Seminar, Monthly, 2002-2004
- Division of Cancer Prevention, Office of Preventive Oncology Colloquia Series on Cancer Prevention Topics, Weekly, 2002-2004

- Radiation Safety for Authorized Users, NIH Radiation Safety Branch, Bethesda, MD, Sept. 2002
- Molecular Prevention Course, NCI Summer Curriculum in Cancer Prevention, Rockville, MD, August 2002
- Principles & Practice of Cancer Prevention and Control Course, NCI Summer Curriculum in Cancer Prevention, Rockville, MD, July-August 2002

Professional Activities

- Chair, Communications Committee, Academy of Toxicological Sciences, 2021-Present
- Member, Evidence-based Toxicology Collaboration (EBTC) Interim Scientific Advisory Council (iSAC), November 2021-Present
- Member, Board of Directors, Academy of Toxicological Sciences, 2020-Present
- Member, Communications Committee, Academy of Toxicological Sciences, 2020-2021
- Canton, Massachusetts, COVID Task Force, 2020-Present
- Scientific Advisory Board Member, National Stone, Sand, and Gravel Association, 2019-Present
- Invited Lecturer, "Introduction to Meta-analysis," Northeastern College of Professional Studies, May 8, 2019
- Invited Participant, "Excellence in Risk Analysis," Society for Risk Analysis (SRA) Workshop, June 2018
- Reviewer, R21 Hurricane Applications, National Institutes of Health (NIH), January 2018
- Member, Regis College Doctoral Thesis Committee, 2015-2017
- Reviewer, R21 NIH Exploratory/Developmental Research Grant Proposal, NIH, September 2017
- Invited Panelist, Cancer Prevention Fellowship Program (CPFP) Alumni Career Panel, September 2016
- Reviewer, K99 Career Research Grant Proposal, NIH, July 2016
- Invited Lecturer, "An Introduction to Meta-analysis," Johns Hopkins Bloomberg School of Public Health, April 5, 2016
- Member, Scientific Advisory Council, Evidence-based Toxicology Collaboration (EBTC) at Johns Hopkins Bloomberg School of Public Health, December 2015-November 2021
- Invited Observer, *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*: *Volume 113: Some Organochlorine Insecticides and Some Chlorophenoxy Herbicides*, Lyon, France, June 2015
- Mentor, Society of Toxicology Mentor Match Program, January 2015-Present
- Member, Speaker Bureau, Society of Toxicology, July 2014-2016
- Chair, "Implementing NRC Recommendations: IRIS," SRA Annual Meeting, 2014
- Member, California Breast Cancer Research Program (CBCRP) Chemicals Testing and Occupational Exposures Review Panel, November 2014
- Proposal Reviewer, Scientific Panel, California Breast Cancer Research Program (CBCRP), June 2014
- Invited Epidemiology Panel Member, The International Council of Chemical Associations Long-Range Research Initiative and Joint Research Centre Workshop, "What is Safe? Integrating Multi-Disciplinary Approaches for Decision Marking about the Human Health and Environmental Impacts of Chemicals." Lugano, Switzerland, June 2014
- Proposal Reviewer, John Templeton Foundation, 2014
- Co-Chair, "Understanding Weight of Evidence: Exploring Different Approaches to Integrating Evidence from Diverse Data Streams," Society of Toxicology, 2014
- Co-Chair, "Epidemiology for Toxicologists: What the Numbers Really Mean," Society of Toxicology, 2014
- Best Paper Awards Selection Committee, Risk Assessment Section, Society of Toxicology, 2014
- Peer Reviewer, Provisional Peer-Reviewed Toxicity Values for Styrene-Acrylonitrile (SAN Trimer), US EPA Draft Document, December 2013
- Keynote Speaker and Scientific Committee Member, Isocyanates & Health Conference, April 2013
- Presidential Task Force Member, Strategic Plan, American College of Epidemiology, 2013
- Proposal Reviewer, National Science Foundation, 2013

- Invited Participant, ILSI Health and Environmental Sciences Institute Emerging Issue Workshop: Evaluating Causality in Epidemiology, October 2012
- Invited Panel Member, "Using Mode of Action to Support the Development of a Multipollutant Science Assessment," US EPA Workshop, May 2012
- Editorial Board Member, *Carcinogenesis*, 2012-2014
- Invited Participant on "Improving Science-Based Regulation," The George Washington University Regulatory Studies Center and the Center for Risk Science and Public Health, January 2012
- Member, Massachusetts Environmental Justice Assistance Network, 2010-Present
- Board Member, American College of Epidemiology, 2011-2013
- Nominating Committee, Society of Toxicology, 2009-2011
- Elected Member, Canton, Massachusetts Board of Health, 2008-Present
- Editorial Board Member, *The Open Biomarkers Journal*, 2008-Present
- Managing Editor, *Journal of Environmental Protection Science*, 2008-2010
- Member, Canton, Massachusetts Medical Reserve Corps, 2007-Present
- Peer Reviewer, *Texas Commission on Environmental Quality, Development Support Document for Nickel and Inorganic Nickel Compounds, Preliminary Draft*, May 2009
- Invited Observer, *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Volume 100, Meeting C: Metals, Particles and Fibres*, Lyon, France, March 2009
- Abstract Awards Selection Committee, Risk Assessment Section, Society of Toxicology, 2008
- Secretary/Treasurer, Risk Assessment Specialty Section, Society of Toxicology, 2007-2009
- Editorial Board Member, *Journal of Environmental Protection Science*, 2007-2008
- Guest Lecturer, Cancer Epidemiology, University of Maryland, 2004
- Member, Cancer Prevention Fellowship Scientific Education Committee, NCI, 2003
- Guest Lecturer, Xenobiotic Metabolism, Johns Hopkins Bloomberg School of Public Health, 2001-2002
- Reviewer: *African Journal of Biotechnology; American Journal of Ophthalmology; American Journal of Pathology; Annals of Epidemiology; Applied Economics Letters; Biomarkers & Prevention; Cancer Epidemiology; Cancer Genetics and Cytogenetics; Cancer Research; Carcinogenesis; Chemical Research in Toxicology; Chemico-Biological Interactions; CHEST; Clinical Cancer Research; Critical Reviews in Toxicology; Environmental Health Perspectives; Environment International; Environmental Science & Technology; Epidemiology; Global Epidemiology; Human and Experimental Toxicology; Inhalation Toxicology; International Journal Of Environmental Health Research; International Journal of Environmental Research and Public Health; Journal of Cellular Biochemistry; Journal of Clinical Epidemiology; Jornal de Pediatria; Journal of Exposure Science and Environmental Epidemiology; Journal of Human and Ecological Risk Assessment; Journal of Occupational and Environmental Medicine; Journal of Toxicology and Environmental Health, Part A: Current Issues; Medical Journal of Australia; NeuroToxicology; PeerJ; Pharmacogenetics; Preventive Medicine Reports; Regulatory Toxicology and Pharmacology; Risk Analysis; Safety and Health at Work; Scientific Reports (Nature Publishing Group); Toxicology; Toxicology and Applied Pharmacology; Toxicological Sciences*

Honors and Awards

- Best Poster Award, Environment, Health & Safety Poster Session, Polyurethanes Technical Conference, October 2018
- Distinguished Alumna Award, Johns Hopkins University, April 2015
- Chauncey Starr Distinguished Young Risk Analyst Award, Society for Risk Analysis, 2014
- Best Overall Abstract, Risk Assessment Specialty Session, Society of Toxicology, San Antonio, TX, 2013
- International Dose-Response Society Outstanding New Investigator Award, 2012
- Top 10% Best Overall Abstracts in Risk Assessment, Risk Assessment Specialty Section, Society of Toxicology, Seattle, WA, 2008
- Fellows Award for Research Excellence: $1,000 Travel Award, National Institutes of Health, Bethesda, MD, 2004

- Honorable Mention Poster Presentation, Center for Cancer Research 4th Annual Fellows and Young Investigators Retreat, Williamsburg, VA, March 2004
- Graduate Student Travel Award, Gordon Research Conference on Hormonal Carcinogenesis, 1999, 2001
- Travel Award, Third World Congress on Alternatives and Animal Use in the Life Sciences, Bologna, Italy, 1999
- Howard Hughes Predoctoral Fellowship Award, 1997-2002
- NIEHS Training Grant Graduate Fellowship Award, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, 1996-1997
- Tau Beta Pi, National Engineering Honor Society, 1995-1996
- Chi Epsilon, National Civil Engineering Honor Society, 1994-1996

Professional Affiliations

American College of Epidemiology; Society for Risk Analysis; Society for Risk Analysis New England Chapter; Society of Toxicology; American Board of Toxicology; Academy of Toxicological Sciences; International Dose-Response Society

Selected Projects

Food company: Reviewed applicable US FDA requirements for new dietary ingredients and proposed a framework where alternative test data could be used to reduce or replace traditional animal toxicity testing.

Trade Organization: Created a database and conducted hazard assessments for approximately 800 chemicals.

Town: Reviewed a cancer cluster analysis conducted by the state and communicated findings to the community.

University: Described the main features of internal dose time courses that are important when pharmacodynamics are governed by an activation threshold. Presented the adverse outcome pathway (AOP) for NLRP3-induced chronic inflammatory diseases as a case study.

Trade Organization: Evaluated the Consumer Product Safety Commission's Final Rule: Prohibition of Children's Toys and Child Care Articles Containing Specified Phthalates, including the methods used to calculate Hazard Index values.

Cleaning Products Company: Determined whether several ingredients of several cleaning products could have caused or exacerbated several claimed health effects (such as respiratory effects) in individuals using the products or working in areas where the products were used.

Public School: Evaluated school facility information and environmental assessments that have been conducted on lead in school drinking water. Quantified typical student exposures and estimated health risks. Evaluated exposures and risks of PEX replacement pipes.

Research Organization: Estimated dietary phthalate intake based on data from the National Health and Nutrition Examination Survey (NHANES), a program of studies of United States residents conducted at the Centers for Disease Control and Prevention (CDC).

Trade Association: Reviewed and provided comments to the United States Environmental Protection Agency (US EPA) on its assessment plan for an updated arsenic health risk assessment.

Trade Organization: Developed a framework for a systematic, objective, and transparent evaluation of the evidence for non-cancer causation that requires reviewers to conduct a systematic study quality analysis and consider how the evidence from several realms impacts the interpretation of others.

Electric Utility: Evaluated the potential non-cancer and cancer health effects from exposure to coal combustion residuals (CCR) as a whole, and arsenic and chromium specifically, as reported in epidemiology and toxicity studies. Determined whether potential exposures to CCR contributed to current or future health effects, or warrant medical monitoring.

Trade Organization: Determined the safety of benzoic acid and its salts when used as preservatives in food and soft drinks based on an evaluation of pharmacokinetic data in rodents and humans, and human clinical studies of sodium benzoate administered as a therapeutic drug.

Children's Personal Care Product Manufacturer: Conducted a comprehensive hazard and risk assessment using data reported by various research and regulatory agencies, and specific risk assessments for individual preservatives, to determine whether there could be health risks for children from regular use of personal care products containing these preservatives.

Trade Organization: Evaluated the association between coffee generally, and acrylamide specifically, and cancer risk in the context of California's Proposition 65.

Trade Association: Conducted two comprehensive critical weight-of-evidence (WoE) reviews of studies bearing on the ability of very low BPA exposures to affect reproduction and development *via* endocrine disruption. These analyses were presented to several state legislative committees, all of which were considering bans on BPA.

Trade Organization: Conducted a survey of nearly 50 WoE frameworks to evaluate best practices for determining causation. Defined the key concepts of WoE analyses and their application to particular problems, and articulated the best practices from among the spectrum of approaches.

Food Manufacturer: Evaluated the significance of lead in imported hot sauces after a journal article reported that some of the products contained elevated levels of lead. Prepared a critique and summary of the study findings, and compared lead levels to US FDA limits. Evaluated the potential impact of the lead exposures on blood lead levels.

Trade Organization: Evaluated potential health risks from BPA in epoxy-lined metal cans based on both peer-reviewed scientific literature and regulatory agency risk assessments.

Personal Care Product Company: Conducted a risk assessment of zinc oxide in sunblock.

Trade Association: Critically evaluated the Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE) that US EPA uses in the risk assessments for ozone and PM as part of its NAAQS evaluation.

Chemical Company: Evaluated the utility of using epidemiology data in human health risk assessment and regulatory decision-making for the insecticide, chlorpyrifos.

Trade Organization: Performed an O_3 mortality risk assessment using US EPA's Environmental Benefits Mapping and Analysis Program (BenMAP). Evaluated mortality risks by conducting a series of sensitivity analyses to assess how alterative model inputs impacted risk results.

Hospitals: Conducted screening level risk assessment for contaminants, including hexavalent chromium and polycyclic aromatic hydrocarbons, in product residue on surgical instruments used for medical procedures at several hospitals.

Industrial Consortium: Contributed to a toxicity and risk assessment in a class-action lawsuit by residents claiming adverse health effects from TCE and PCE in groundwater. Participated in a quantitative analysis of ingestion exposure, showering exposure, potential health risks, and proposed medical monitoring.

Water Supply Company: Evaluated potential health effects of arsenic, lead, and chlorination disinfection byproducts in drinking water.

City: Evaluated whether a career as a firefighter is associated with brain or lung cancer.

Consumer Product Company: Reviewed the safety testing required for a pesticide to be registered in the US; the potential risks and benefits of DEET; and standards, guidelines, and recommendations for using DEET.

Law firm: Evaluated whether air pollution may have increased the incidence and prevalence of several health conditions, including several cancers, in a city in Israel.

Trade Organization: Evaluated whether there is a scientific consensus regarding the potential health effects of asbestos compared to other elongate mineral particles, and whether any differences should be considered for testing guidelines.

Consumer Product Company: Critically reviewed epidemiology studies of specific consumer products.

Mining Company: Assessed the potential health risks of residents exposed to nickel as result of residing near a surface lateritic nickel mine and ferronickel smelter based on air, water, soil, and sediment data collected as part of the mine's environmental monitoring program.

Trade Association: Conducted a systematic review ozone exposure and metabolic syndrome.

Trade Organization: Critically reviewed parabens and weight gain epidemiology, toxicology, and mode-of-action evidence.

Waste Disposal Company: Evaluated the scientific evidence regarding radiation exposure and renal cell carcinoma in general and the likelihood that this cancer could have been caused by exposure to radionuclides from living in proximity to a landfill containing radioactive waste.

Trade Organization: Reviewed a cancer cluster investigation and epidemiology studies of pediatric leukemia and lymphoma, pediatric brain cancer, and pediatric Ewing sarcoma.

Trade Organization: Critically reviewed epidemiology research on air pollution and COVID.

Trade Organization: Evaluated and provided comments on US EPA's draft risk evaluation for trichloroethylene. Focused on the meta-analyses of kidney cancer, liver cancer, and non-Hodgkin's lymphoma.

Non-Profit Research Institute: Developed an *in silico*-based health-protective screening approach for inhaled chemicals.

Law firm: Evaluated the potential human carcinogenicity of formaldehyde and methyl *tert*-butyl ether (MTBE).

Trade Organization: Conducted a systematic review of long-term exposure to fine particulate matter ($PM_{2.5}$) and all-cause mortality.

Waste Management Company: Evaluated whether specific health conditions, including cancer, were likely attributable to exposures to Radium 226, Thorium 230, or Uranium 238 that originated from a landfill.

Farm: Evaluated whether certain health conditions could be caused by exposures to nitrate in drinking water or hydrogen sulfide or ammonia in air and, if so, under what exposure conditions.

Trade Organization: Conducted a WoE analysis of talc and ovarian cancer, including a quantitative bias analysis of epidemiology studies.

Trade Organization: Evaluated the association between personal $PM_{2.5}$ exposures and ambient $PM_{2.5}$ concentrations, and the implications for the interpretation of epidemiology studies that estimate personal exposure based on ambient concentrations.

Private Company: Assessed whether appropriate epidemiology methods were used to evaluate a potential pediatric cancer cluster in a military housing complex. Evaluated whether public health and environmental investigations used methodologically sound analyses.

Consumer Product Company: Determined whether a framework for assessing the hazard of cleaning product ingredients was sufficient to support "non-toxic" claims on product packaging for a household cleaner.

Consumer Product Company: Evaluated the historical state of knowledge regarding the toxicity of butadiene and the development of myelodysplastic syndrome.

Railroad Company: Summarized the historical states of knowledge regarding the toxicity of vermiculite and asbestos in the railroad industry.

Trade Organization: Conducted a systematic review of metallic nickel and cancer.

Trade Organization: Evaluated best practices for evidence integration in National Ambient Air Quality Standards (NAAQS) Integrated Science Assessments (ISAs).

State Environmental Agency: Quantitatively evaluated how uncertainty and bias can impact epidemiology associations between air pollutants and respiratory morbidity at low exposures.

Law Firm: Evaluated the potential lung cancer, mesothelioma, and interstitial fibrosis risks from exposure to chrysotile asbestos from brakes based on epidemiology studies of vehicle brake repair workers and industrial hygiene, mode-of-action, and toxicology data.

Chemical Company: Evaluated and provided comments on US EPA's Toxicological Review of Libby Amphibole Asbestos. Interacted with several regulatory agencies throughout the interagency process of the Integrated Risk Information System (IRIS) review.

Trade Organization: Evaluated systematic review methods used by US EPA in IRIS and Toxic Substances Control Act (TSCA) evaluations.

Pesticide Companies: Evaluated the use of neurodevelopmental epidemiology studies by the US EPA in the re-registration process for organophosphate pesticides.

Consumer Product Company: Determined whether aspiration of a laundry pod caused long-term health effects in an infant.

Consumer Product Company: Evaluated the implications of a new toxicity study of an ingredient in a consumer product for adults and children who use the product and workers who manufacture the product. Provided an analysis of the potential Globally Harmonized System of Classification and Labeling of Chemicals (GHS) and Safety Data Sheet (SDS) implications of a the ingredient.

Trade Organization: Assessed whether a post-market skin patch epidemiology study should be used for risk assessment.

Trade Organization: Evaluated emission limits for several chemicals defined in certification guidelines for a consumer product.

Trade Organization: Reviewed and provided comments on Health Canada's Draft Screening Assessment Report and Risk Management Scope for talc.

Municipality: Evaluated whether childhood blood lead levels in a city appeared to be impacted by increases in water lead levels. Assessed the potential beneficial impact of the City's distribution of point-of-use water filters to residents.

Trade Organization: Developed detailed criteria for exposure characterization that can be used when designing future epidemiology studies and for evaluating completed studies to determine how their results should be considered in a regulatory setting.

Trade Organization: Determined whether nickel should be classified as a reproductive or developmental toxicant under California EPA's Proposition 65.

Consumer Product Company: Developed a statistical approach for a clinical study of a medical device.

Trade Organization: Performed a detailed quantitative analysis to determine the reliability and adequacy of the T25 Carcinogenic Potency Method for inhalation exposures of inorganic substances. This method is used to classify carcinogenic substances according to the European Union's guidance for Classification, Labelling and Packaging of Substances and Mixtures.

Law Firm: Evaluated the potential side effects and dose-response relationships for cosmetic botulinum toxin injections from reviews of clinical trials and FDA warning labels. Assessed whether claimed health effects in an individual existed prior to an injection with botulinum toxin, were included among the documented side effects of the toxin, or were indicative of systemic toxicity.

Trade Organization: Critically reviewed the draft recommendation for a non-health-based bisphenol A (BPA) occupational exposure limit (OEL) proposed by the Dutch Expert Committee on Occupational Health and Safety (DECOS). Derived and recommended a health-based BPA OEL that is consistent with European Commission directives.

Law Firm: Evaluated nickel concentrations in an urban neighborhood using air monitoring data. Assessed the cancer and non-cancer health risks of exposure to nickel in air and dust among residents.

Trade Organization: Evaluated the association between short-term exposures to $PM_{2.5}$ and hospital admissions for cardiovascular diseases.

Research Organization: Evaluated the impact of respiratory infections, outdoor pollen, and socioeconomic status on associations between $PM_{2.5}$ and ozone and pediatric asthma hospital admissions.

Research Organization: Critically reviewed the epidemiology literature on exposure to $PM_{2.5}$ and several birth outcomes.

Trade Organization: Reviewed and commented on the International Agency for Research on Cancer (IARC) Preamble, which summarizes the underlying scientific principles of the IARC Monographs, which evaluate the carcinogenic hazards of chemicals and other substances.

Baby Product Company: Evaluated whether a teething ring product contained more Bisphenol A than is permitted under Proposition 65.

Energy Company: Evaluated whether working on the site of a former Manufactured Gas Plant may have contributed to kidney cancer.

Steel Company: Assessed the state of knowledge related to employment in a steel mill or steel plant and asbestos-related disease to understand when the scientific community began to study the hazards of asbestos among steelworkers and when it was reasonable for a steel manufacturing company to have known that exposure to asbestos-containing materials could potentially lead to the development of respiratory disease in steelworkers.

Trade Organization: Evaluated US EPA's calculation of an inhalation unit risk (IUR) in its "Toxicological Review for Trichloroethylene in Support of Summary Information on the IRIS."

Trade Organization: Developed standards for epidemiology studies similar to good laboratory practice (GLP) standards, which are intended to assure the quality and integrity of non-clinical laboratory studies.

Manufacturer: Critically reviewed the quality of case-control studies conducted in North America that assessed the associations between captan exposure and the risk of multiple myeloma. Conducted a quantitative bias/uncertainty analysis of these studies.

Trade Organization: Evaluated the basis for the American Conference of Governmental Industrial Hygienists (ACGIH) lowering the Threshold Limit Value for toluene diisocyanate.

Law Firm: Evaluated exposure to O-toluidine and bladder cancer risk.

Law Firm: Evaluated exposures to landfill gases, including hydrogen sulfide, and potential health effects from these exposures in individuals residing near a municipal solid waste landfill. Evaluated potential odor impacts and the differences between odor perception and adverse health effects.

Trade Organization: Reviewed literature regarding several air toxics and health endpoints and provided recommendations on a proposed regulation in California to monitor communities for air pollution-attributable health effects.

Trade Organization: Critically reviewed the harmonized carcinogenicity classification and labeling for cobalt metal developed to comply with the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation by RIVM (Netherlands National Institute for Public Health and the Environment).

Toy Manufacturer: Evaluated whether brain injury could occur as a primary consequence of ingesting toy beads containing 1,4-butadiene, or as a secondary consequence of experiencing coma-like symptoms following ingestion of the beads.

Pharmaceutical Company: Assessed whether on-label use of a pharmaceutical increased cardiovascular disease risk based on randomized controlled trials and observational epidemiology studies.

US EPA: Contributed to the design of a model describing several frequently encountered toxicity endpoints in terms of a series of progressive pathophysiological steps.

Pharmaceutical Company: Performed an in-depth analysis of the toxicology and epidemiology data of a specific drug to determine whether the company could have anticipated potential adverse side effects in humans.

Pharmaceutical Company: In the context of a patent infringement lawsuit, performed an independent analysis of efficacy and toxicity data from animal experiments to determine if claims in the patent could be challenged.

Government Agency: Critically evaluated an epidemiology study of exposures and health outcomes in indigenous and Afro-Colombian communities living near a nickel mine and smelter and discussed with the government agency that conducted the study.

Chemical Company: Conducted a meta-analysis of epidemiology studies that evaluated the use of a pharmaceutical during labor and dystocia.

Trade Association: Evaluated whether atherosclerosis development is a plausible mode of action for PM in cardiovascular pathogenesis, and whether this is supported by epidemiology evidence.

Trade Association: Critically reviewed the draft recommendation for a non-health-based OEL for di- and triisocyanates proposed by the DECOS of the Health Council of the Netherlands.

Trade Organization: Developed a database of epidemiology studies of occupational exposures to pesticides and cancer.

Trade Organization: Critically reviewed the epidemiology literature on long-term exposure to ambient ozone and asthma development.

Manufacturer: Evaluated the health risks of potential carbon monoxide exposures at a proposed bridge near a manufacturing facility.

Consumer Product Company: Systematically reviewed epidemiology, toxicity, exposure and transport, and mechanistic studies to evaluate whether personal use of cosmetic talc increases ovarian cancer risk.

Trade Organization: Evaluated whether an alternative form of the sulfur dioxide (SO_2) NAAQS would be as public health protective as the then-current form.

Trade Organization: Critically reviewed the approach US EPA used to quantify health co-benefits when assessing the impacts of the Clean Power Plan. Evaluated the scientific validity of the models, data sources, and assumptions underlying US EPA's calculations.

Chemical Company: Evaluated whether exposure to odorous chemicals emitted from spray foam insulation in a residence posed a potential health risk. Compared residents' exposure to odor thresholds, toxicity criteria, and health effect levels for specific constituents emitted from the foam.

Law Firm: Assessed human health risks associated with coal-fired power plant emissions, including particulate matter, SO_2, and nitrogen oxides (NO_x), based on air modeling results and available measurement data.

Trade Organization: Conducted a systematic review of epidemiology studies that evaluated proximity to unconventional natural gas development (UNGD) and perinatal outcomes.

Chemical Company: Provided chemical-level assessments (*i.e.*, analysis of inventory status, occupational exposure limits, and available toxicity data) and product-level assessments (*i.e.*, evaluation of Good Manufacturing Practice and regulatory hurdles) for several cosmetics and consumer products.

Research Organization: Critically evaluated toxicity studies that investigated $PM_{2.5}$ and developmental and reproductive effects.

Utility Group: Evaluated potential exposures and health impacts of PM in general, as well as two specific types of PM associated with power plant operations (*i.e.*, diesel exhaust emissions and coal dust emissions).

Manufacturer: Assessed the potential health risks of saline-filled breast implants based on a review of the peer-reviewed literature and pre- and post-market studies of silicone- and saline-filled breast implants.

Pharmaceutical Company: Evaluated whether historical data support the patentability of a drug that lowers blood lipid levels. Reviewed the experimental methods (including statistics) and results of efficacy studies with the drug to confirm the original study conclusions.

Trade Associations: Facilitated research that addresses the causality of the relationship between $PM_{2.5}$ and mortality. Selected research candidates, developed a request for proposal, evaluated solicited proposals, coordinated selected researchers for data access, and organized a symposium for researchers to present and discuss their findings.

Utility Company: Evaluated health effects associated with potential exposures to chemicals, including coal tar and polycyclic aromatic hydrocarbons (PAHs) such as benzo[a]pyrene, resulting from recreational activities in the vicinity of a former manufactured gas plant site.

Chemical Company: Evaluated whether the PAHs in an asphalt roofing underlayment would require its classification under the Occupational Safety and Hazard Administration's (OSHA) hazard communication standard.

Manufacturer: Evaluated the incidence, prevalence, risk factors, and potential alternative causes of health complaints among office workers allegedly exposed to chemicals in indoor air *via* vapor intrusion of contaminated groundwater. Also assessed whether there were any disease clusters at the site.

Trade Organization: Provided written and oral comments to the Clean Air Scientific Advisory Committee (CASAC) on exposure, epidemiology, toxicity, and mode-of-action studies and their bearing on US EPA's development of NAAQS for ozone (O_3), PM, NO_x, and sulfur oxides (SO_x) on numerous occasions.

Manufacturer: Reviewed asbestos exposure data related to the handling and installation of electrical equipment and epidemiology evidence regarding mesothelioma, lung cancer, and laryngeal cancer in electricians.

US Army: Assessed several dose-response functions, animal models, and endpoints to obtain the most appropriate model-predicted risk estimate to use in establishing a risk-based inhalation exposure criterion for vanadium pentoxide.

Appliance Manufacturer: Evaluated evidence for a cancer cluster in a neighborhood where soil containing polychlorinated biphenyl (PCBs) was historically used as landfill in a recreation area.

State Environmental Agency: Conducted WoE evaluations of the association between short-term and long-term ozone exposure and cardiovascular effects.

State Environmental Agency: Evaluated how meta-analyses have been or could be applied in the evaluation of health effects of air pollutants. Assessed the strengths and limitations of methods, issues that arise in meta-analyzing different types of data, assumptions that can influence the interpretation of results, and how bias and heterogeneity can be addressed.

Law Firm: Assessed the impact of coal-fired power plant emissions on exposures to fine PM, SO_2, and nitrogen dioxide (NO_2) and whether these exposures likely contribute to adverse health effects in Colorado residents.

Mining Company: Evaluated methods used to derive a proposed standard for nickel by the Province of Quebec, Canada.

Utility Company: Reviewed the historical releases of compounds associated with manufactured gas plant processes, including PAHs such as benzo[a]pyrene, and the historical understanding of risk assessment, carcinogenesis, and the toxicity of these compounds.

State Environmental Agency: Reviewed epidemiology, controlled human exposure, experimental animal, and mechanistic studies of ozone and markers of inflammation and oxidative stress.

State Environmental Agency: Critically reviewed potential uses of Next Generation (NexGen) toxicity testing methods and associated interpretation techniques in assessing the risks associated with chemical exposures (*e.g.*, in high-throughput screening programs or detailed quantitative analyses for individual data-rich chemicals).

Trade Organization: Critiqued draft templates for tabulating epidemiology and experimental animal study data for hazard identification proposed by the Developmental and Reproductive Toxicant Identification Committee (DART IC) of California's Office of Environmental Health Hazard Assessment (CalOEHHA). Proposed an alternative set of tables to systematically present data for consideration in a full evidence integration process.

State Environmental Agency: Critically reviewed epidemiology, controlled human exposure, experimental animal, and mechanistic studies of ozone and outcomes related to asthma exacerbation.

State Environmental Agency: Evaluated the relationship between ozone concentrations and asthma hospitalizations in Texas from 2001-2011.

Trade Organization: Conducted sensitivity analyses to determine how alternative assumptions impact exposure and risk estimates calculated using the US EPA Air Pollutants Exposure (APEX) Model.

Health Care Company: Analyzed the health effects of perchloroethylene and its breakdown products (trichloroethylene, 1,1-dichloroethylene, 1,2-dichloroethylene, and vinyl chloride) to address community concerns with remediation requirements. Also reviewed the bases for soil and groundwater remediation goals.

Chemical Company: Analyzed health risks from exposure to PCBs in caulking in a school in Massachusetts by analyzing potential exposures at the school and epidemiology and toxicology evidence. Also summarized the state of knowledge regarding PCBs when the school was built.

State Environmental Agency: Organized and participated in a workshop focused on the scientific evidence for ozone effects and the societal implications of lowering the ozone NAAQS.

Utility Company: Characterized and communicated exposures to chemicals, including PAHs such as benzo[a]pyrene, for occupants of residential and commercial properties constructed on the site of a former manufactured gas plant.

Trade Association: Evaluated non-cancer effects of PM.

Chemical Company: Evaluated whether inflammation and oxidative stress caused by ozone exposure are key events leading to respiratory toxicity.

Chemical Company: Conducted a WoE evaluation of PM and biomarkers of cancer.

Chemical Company: Evaluated whether there was evidence of any developmental health effects clusters at an office building. Assessed likely explanations for health claims.

Trade Association: Proposed a framework for evaluating causation that provides a structure for integrating different realms of evidence, weighing the strength of evidence for causation, and assessing the potential impact of uncertainty on the body of evidence.

Trade Organization: Critically reviewed the epidemiology literature evaluating nickel exposure and reproductive and developmental effects. Determined whether it supported a prioritization of nickel for CalOEHHA's consideration under California's Proposition 65.

Trade Organization: Evaluated whether higher regulatory limits on heavy metals in finished medical marijuana products would provide an adequate margin of safety for patients, and whether certain hydrocarbon gases could be safely used in the production of cannabis concentrates used in medical marijuana infused products.

Law Firm: Evaluated whether exposures to diesel exhaust and jet fuel are associated with lung cancer based on a literature review, agency classifications, and key epidemiology studies on which classifications are based.

Electric Utility: Evaluated the scientific basis of health impacts associated with air quality regulations that would impact an electricity generation facility. Compared air quality data in the area around the facility to health-based NAAQS.

Trade Organization: Assessed the US EPA "Framework for Human Health Risk Assessment to Inform Decision Making" and compared it to US EPA's ongoing O_3 analysis. Focused on planning and "fit for purpose," WoE, transparency, reasonableness, consistency, at-risk factors, and uncertainty and variability.

Electric Utility: Analyzed air monitoring data to determine the potential public health impacts of stack air emissions of fine PM, O_3, NO_2, and SO_2.

Trade Organization: Conducted a quantitative analysis of controlled human exposure studies to address whether there is a subset of individuals who are susceptible to health effects of criteria air pollutants at particular exposure levels, but whose response is obscured by analyzing data at the group level.

Law Firm: Analyzed human health risks posed by chemicals measured in workplace indoor air that were alleged to have originated from groundwater contaminated by a nearby recycling facility. Focused on the epidemiology of the chemicals of concern at the levels measured in the workplace and the plaintiffs' health complaints, including cancer.

Smelter: Assessed whether a smelter's permit would likely allow for SO_2 emissions that could lead to adverse health effects in the community.

Trade Organization: Reviewed the basis for the California Environmental Protection Agency's (CalEPA's) proposal to list SO_2 as a Proposition 65 developmental and reproductive toxicant. Evaluated whether the underlying studies provided sufficient and robust evidence that SO_2 causes developmental and reproductive effects.

Trade Organization: Reviewed and critiqued the assumptions and uncertainties associated with the statistical models on which US EPA's 2011 Benefits and Costs of the Clean Air Act Report was based.

Chemical Company: Evaluated US EPA's proposed national emission standards for hazardous air pollutants (NESHAPs) for mercury from major industrial boilers. Evaluated the agency's statistical approach for establishing the maximum achievable control technology (MACT) limit and determined how alternative approaches would impact the MACT derivation.

Trade Organization: Conducted meta-analyses and meta-regressions of airway hyper-responsiveness in asthmatic volunteers exposed to NO_2 in clinical studies. Presented these analyses to the US Office of Management and Budget.

Trade Organization: Assessed what constitutes an adverse health effect *vs*. normal biological variation (or adaption or compensation to stressors), and the role of statistics in assessing adversity. Used airway hyper-responsiveness to SO_2 as a case study.

Health Effects Institute: Compiled and reviewed studies regarding chronic and acute toxicity guidelines for mobile source air toxicants.

Trade Organization: Evaluated studies examining low-dose exposure to BPA and effects on reproduction and development using a W approach. Discussed results in written comments and oral testimony to CalEPA in the context of whether BPA should be listed as a female reproductive toxicant under Proposition 65.

Cleaning Product Company: Evaluated toxicity of chemicals in all-natural cleaning products.

Municipality: In response to citizens' concerns, independently investigated whether there was an increased incidence of cancer in residents living near a municipal landfill. Communicated findings with city officials and residents at public meetings.

Toy Distributor: Determined whether a toxicological evaluation of a toy was sufficient for determining children's health risks. Assessed the toxicity of a chemical found in the toy, potential routes of exposure, and possible health risks.

Trade Organization: Conducted a systematic review and meta-analyses of 2,4-dichlorophenoxyacetic acid (2,4-D) and non-Hodgkin's lymphoma, gastric cancer, and prostate cancer. Participated as an observer at the IARC Monograph 113 Meeting at which 2,4-D was evaluated.

Trade Organization: Assessed whether animal, mechanistic, and epidemiology evidence is consistent with the nickel ion bioavailability model, which asserts that the carcinogenicity of nickel-containing substances is based on the bioavailability of the nickel ion at nuclear sites of target respiratory epithelial cells.

Public Agency: Evaluated the variability in water lead levels across a US city and the association between water lead levels and blood lead levels in children.

Pesticide Company: Assessed whether epidemiology, toxicology, and mechanistic evidence support chlorpyrifos being a neurobehavioral toxicant in humans at relatively low exposure levels. Evaluated evidence using recently proposed frameworks for integrating human and animal data, as well as Gradient's hypothesis-based weight-of-evidence (HBWoE) approach.

Cleaning Product Company: Evaluated the potential risks of birth defects from exposure to the chemical components of products used in floor stripping and refinishing.

Trade Organization: Conducted a critical examination of a proposal by the National Academy of Sciences that linear low-dose extrapolation should be used for non-cancer and cancer endpoints as a default because measurement error in epidemiology studies linearizes dose-response curves.

Law Firm: Reviewed specific exposure information and occupational epidemiology literature for a claim regarding a causal association between formaldehyde inhalation and acute myeloid leukemia.

Law Firm: Evaluated whether radiation should have been considered as a potential cause of an individual's mesothelioma. Analyzed both specific exposure information and toxicology and epidemiology literature on radiation and mesothelioma.

Trade Association: Using the HBWoE approach, evaluated whether epidemiology, toxicology, and mechanistic evidence supports the plausibility of formaldehyde as a human leukemogen.

Chemical Companies: Calculated a benchmark dose (BMD) for an industrial chemical using US EPA's BMD Software (BMDS). Assessed several dose-response models and evaluated the impact of using historical control data.

Trade Organization: Evaluated whether epidemiology, animal toxicity, mechanistic, and pharmacokinetic evidence indicates that toluene diisocyanate is a human carcinogen.

Trade Organization: Critically reviewed meta-analysis of respiratory cancer risk following inhalation exposure to nickel compounds. Provided comments regarding the methods, limitations, and interpretation of results throughout the conduct of this study.

Trade Organization: Conducted a pilot meta-analysis of studies bearing on the ability of very low oral exposures to BPA to affect prostate weight in rodents. Investigated the possibility of publication bias and evidence for a temporal trend in the data.

Trade Organization: Critically reviewed a draft European Union report on the state of the science regarding endocrine-disrupting chemicals. Assembled a panel of experts to determine whether the draft report constituted a complete and unbiased analysis of endocrine disruptors.

Trade Organization: Reviewed epidemiology studies assessing associations between BPA and several health effects.

Trade Association: Reviewed and prepared comments on ACGIH's proposed Threshold Limit Value for manganese. Reviewed the methodology applied by ACGIH, compared the use of published regression analyses of manganese dose-response data to benchmark dose modeling of more recent data, and identified appropriate adverse effect levels of manganese in occupational studies.

Chemical Manufacturer: Reviewed the epidemiology and mode-of-action data on acetic anhydride and cancer using a systematic WoE approach to determine whether the data are consistent with ACGIH cancer classification.

Law Firm: Evaluated epidemiology literature regarding present and future risks of cancer and non-cancer health effects in a group of individuals from inhalation exposures to trichloroethylene (TCE) and perchloroethylene (PCE).

Law Firm: Evaluated the epidemiology literature regarding cancer and non-cancer health effects of benzene, dioxin, and pentachlorophenol. Conducted a cluster analysis to determine whether individuals residing in an area with alleged exposures had increased rates of several cancers and non-cancer health effects.

Pesticide Companies: Critically reviewed epidemiology, toxicology, and mechanistic studies to assess whether exposure to atrazine in drinking water is associated with reproductive and developmental health effects.

Confidential Client: Evaluated the health effects associated with hexavalent chromium based on an assessment of the epidemiology literature. Assessed the scientific rigor of an analysis of potentially exposed individuals' survey responses.

Trade Organization: Classified, summarized, and entered relevant lead studies into the International Uniform Chemical Information Database (IUCLID) 5.2, a database for the intrinsic and hazard properties of chemical substances that companies can use to submit data under the REACH legislation in Europe.

Trade Organization: Provided written and oral testimony to the US National Toxicology Program (NTP) and its Board of Scientific Councilors regarding occupational epidemiology studies of styrene and whether styrene should be considered a human carcinogen.

Trade Organization: Developed scientifically sound approaches for incorporating human data into quantitative non-cancer risk assessment to support commentary on the ongoing US EPA revision of its dioxin assessment.

Trade Organization: Evaluated the associations between metal exposures and health outcomes using NHANES data.

Trade Organization: Conducted a WoE assessment of exposure to soluble nickel compounds and respiratory cancer risk based on animal carcinogenicity, mode-of-action, and occupational epidemiology studies.

Trade Organization: Conducted a critical review of the US EPA Toxicological Review of 1,4-Dioxane in support of "Summary Information" provided in IRIS. Proposed alternative methods to calculate the cancer slope factor and reference dose.

Law Firm: Evaluated the toxicology and epidemiology evidence regarding several pesticides and whether there was evidence for a causal association with certain birth defects.

Law Firm: Assessed recent occupational epidemiology studies of manganese and their bearing on the reference concentration (RfC).

Law Firm: Assessed whether epidemiology literature supports an association between low-level exposures to lead and IQ.

Trade Organization: Determined whether linear low-dose extrapolation should be used for non-cancer endpoints.

Law Firm: Assessed appropriateness of statistical analyses used by the Ramazzini Foundation for comparing cancer incidence rates in rats treated with MTBE and untreated rats.

Law Firm: Critically reviewed epidemiology literature of radium and osteosarcoma risk. Determined whether osteosarcoma rates were higher than expected in certain geographic regions in a southern state.

Law Firm: Critically reviewed potential health effects associated with exposure to heating oil from a basement spill.

Law Firm: Critically reviewed the epidemiology literature on the role of ionizing radiation in cancer risk in patients receiving radiation therapy, in nuclear energy facility workers, and in patients receiving Thorotrast treatments.

Chemical Company: Conducted a comprehensive review of the scientific literature on indoor dust levels of several flame retardants and an exposure assessment of each one.

Consumer Product Company: Interpreted the results of two genotoxicity screening assays in light of their sensitivity and specificity.

Toy Manufacturer: Conducted failure analyses of children's toys to determine whether proper or improper use was likely to lead to physical harm. Made recommendations regarding ways to make the toys safer.

Chemical Manufacturing Plant: Evaluated the mercury toxicology and epidemiology literature and determined whether levels in residential soil were above background and likely attributable to a nearby manufacturing plant.

Chemical Company: Conducted a critical review of neurodevelopmental toxicity studies of the flame retardant, decabromodiphenyl ether.

Petroleum Refining Company: Conducted an uncertainty analysis of the carcinogenicity of naphthalene using an HBWoE approach.

Power Plant: Critically reviewed published epidemiology studies of health effects in children residing near coal-fired power plants or coal mines. These studies examined respiratory outcomes, birth defects, and effects on physical development.

Law Firm: Analyzed health effects – including fetal, infant, and total death rates and cancer rates – and certain vital statistics in a Montana county. Compared overall health status of the county to that of the state.

Trade Organization: Evaluated and applied an uncertainty analysis focused on dioxin exposure and health effects data from key toxicology and human biomonitoring-based epidemiology studies as part of a margin-of-exposure analysis.

Law Firm: Evaluated toxicology and epidemiology evidence regarding glutaraldehyde and hydroquinone exposure and leukemia.

Trade Organization: Developed and refined a search strategy for the exposure and health effects of a chemical used in a manufacturing process using several databases, such as PubMed, Toxline, IRIS, and HSDB. Identified and screened relevant articles for inclusion in an electronic database.

Cleaning Product Company: Designed methodology for testing the presence and activity of an enzyme in a cleaning product. Determined whether this enzyme was appropriate for the product.

Wood Treatment Plant: Analyzed dioxin and PCB congeners in individuals residing near a wood treatment plant and compared them to background levels reported by NHANES. Analyzed these compounds in soil, dust, and sediment to determine whether there were elevated risks of exposure.

Small Business: Assessed whether cancer cases at a small business could be attributed to a common exposure.

Trade Association: Re-analyzed published rat testicular carcinogenicity data on MTBE using the Poly-3 statistical method to account for survival differences among treatment groups.

Pesticide Company: Analyzed US EPA's use of the lower confidence limit on the benchmark dose ($BMDL_{10}$) to determine a point of departure for the cancer risk of dimethylarsenic acid in humans.

Research Organization: Critically reviewed epidemiology literature to determine if the effects of lead and mercury on human neurological development are additive or synergistic.

Flame Retardant Company: Provided toxicological, database, and risk analysis support for product development of phosphorus-based flame retardant chemicals with low potential for health and environmental impact.

Chemical Company: Contributed to the drafting of an evidence-based argument submitted to US EPA regarding whether acetonitrile should be delisted from the US EPA's Toxic Release Inventory.

Smelter: Reviewed general and company-specific historical knowledge of human and ecological toxicity of smelter contaminants.

Manufacturer: Summarized the cancer and non-cancer effects of cobalt and nickel for a company that fabricates tungsten heavy metal alloy products.

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Zu, K; Goodman, JE; Prueitt, RL. 2019. "Evaluating Mechanistic Evidence: Beyond the IARC 10 Key Characteristic Framework for Carcinogens." Presented at the National Toxicology Program (NTP) Workshop: Converging on Cancer, Washington, DC, April 29-30.

Goodman, JE; Johnson, G; Prueitt, RL; Zu, K. 2019. "Systematically Evaluating and Integrating Evidence on Cancer in National Ambient Air Quality Standards (NAAQS) Reviews." Presented at the National Toxicology Program (NTP) Workshop: Converging on Cancer, Washington, DC, April 29-30.

Goodman, JE; Pizzurro, DM; Lemay, JC; Lewandowski, T; Zu, K. 2018. "Use of Chemical-specific Adjustment Factors in Health Risk Assessments: A Tale of Two Preservatives." Poster #175/OP02-04. Presented at EUROTOX 2018, Brussels, Belgium, September 2-5.

Prueitt, RL; Lynch, HN; Mohar, I; Goodman, JE. 2018. "Critical Evaluation of Threshold for Respiratory Effects of Toluene Diisocyanate." Poster #701/P19-27. Presented at EUROTOX 2018, Brussels, Belgium, September 2-5.

Goodman, JE; Peterson, MK; Hixon, ML; Pacheco Shubin, S. 2018. "Derivation of a Maximum Allowable Dose Level for Bisphenol A." Poster #2903/P429. Presented at the Society of Toxicology (SOT) 57th Annual Meeting, San Antonio, TX, March 11-15.

Lynch, HN; Goodman, JE; Prueitt, RL; Mohar, I. 2018. "Critical Evaluation of Thresholds for Respiratory Effects of Toluene Diisocyanate." Poster #1197/P248. Presented at the Society of Toxicology (SOT) 57th Annual Meeting, San Antonio, TX, March 11-15.

Prueitt, RL; Lynch, HN; Zu, K; Shi, L; Goodman, JE. 2018. "Evaluation of Respiratory Cancer Risk from Dermal Exposure to Toluene Diisocyanate." Poster #2820/P343. Presented at the Society of Toxicology (SOT) 57th Annual Meeting, San Antonio, TX, March 11-15.

Liu, X; Zu, K; Lam, T; Goodman, JE. 2018. "Systematic Review and Meta-analysis of Diazepam and Labor Duration." Poster #1876/P207. Presented at the Society of Toxicology (SOT) 57th Annual Meeting, San Antonio, TX, March 11-15.

Zu, K; Goodman, JE; Pizzurro, DM; Lewandowski, TA. 2018. "Use of Clinical Data to Inform Risk Assessments of Food Additives: A Case Study of Sodium Benzoate." Poster #2847/P370. Presented at the Society of Toxicology (SOT) 57th Annual Meeting, San Antonio, TX, March 11-15.

Goodman, JE; Lynch, HN; Prueitt, RL; Mohar, I. 2017. "Evaluation of ACGIH TLVs for Toluene Diisocyanate." Poster #P.178. Presented at the Society for Risk Analysis (SRA) Annual Meeting, Arlington, VA, December 10-14.

Pizzurro, DM; Zu, K; Lewandowski, TA; Goodman, JE. 2017. "Use of Pharmacokinetic Data for Adjustment Factor Derivation for Benzoate Preservatives." Presented at American College of Toxicology (ACT) 38th Annual Meeting, Palm Springs, CA, November 5-8.

Zu, K; Liu, X; Shi, L; Tao, G; Loftus, C; Lange, S; Goodman, JE. 2017. "Concentration-response of Short-term Ozone Exposure and Hospital Admissions for Asthma in Texas." Presented at the Society of Epidemiological Research 50th Annual Meeting, Seattle, WA, June 20-23.

Lynch, HN; Goodman, JE. 2017. "Risk Assessment Calls for Standard Guidelines for Exposure Characterization in Epidemiology Studies." Presented at the Society of Epidemiological Research 50th Annual Meeting, Seattle, WA, June 20-23.

Lam, T; Loftus, C; Zu, K; Kennedy, EM; Goodman, JE. 2017. "2,4-Dichlorophenoxyacetic Acid and Soft Tissue Sarcoma: Meta-analysis of the Published Literature." Presented at the Society of Epidemiological Research 50th Annual Meeting, Seattle, WA, June 20-23.

Prueitt, RL; Goodman, JE. 2017. "Mode-of-action Evaluation for Ozone-induced Respiratory Effects Through Activation of Neural Reflexes." Poster #2824/P226. Presented at the Society of Toxicology (SOT) 56th Annual Meeting, Baltimore, MD, March 12-16.

Lynch, HN; Goodman, JE; Yan, Z. 2017. "Risk Assessment Calls for Standard Guidelines for Exposure Characterization in Epidemiology Studies." Poster #1311/P534. Presented at the Society of Toxicology (SOT) 56th Annual Meeting, Baltimore, MD, March 12-16.

Zu, K; Liu, X; Goodman, JE. 2017. "Meta-analysis of Dose-response Relationships from Epidemiology Studies for Risk Assessment: A Case Study of Trans Fats and Coronary Heart Disease." Poster #1850/P424. Presented at the Society of Toxicology (SOT) 56th Annual Meeting, Baltimore, MD, March 12-16.

Lemay, JC; Zu, K; Zhang, J; Goodman, JE. 2016. "Sunscreen Safety for Kids: A Risk Assessment of a Common Preservative." Poster #MP168. Presented at the Society of Environmental Toxicology and Chemistry (SETAC) North America 37th Annual Meeting, Orlando, FL, November 6-10.

Bailey, LA; Kerper, LE; Goodman, JE. 2016. "Occupational Exposure Level for Manganese in Welding Fumes Based on the Best Available Science." Presented at the Manganese 2016 Conference: Manganese Health Effects on Neurodevelopment & Neurodegenerative Diseases, New York, NY, September 25-28.

Goodman, JE; Zu, K; Tao, G; Rhomberg, LR. 2016. "Evaluation of Occupational Benzene Exposure and Leukemia Mortality: A Lifetable Analysis of the Pliofilm Cohort." Presented at the Epidemiology Congress of the Americas 2016 Annual Meeting, Miami, FL, June 21-24.

Zu, K; Tao, G; Goodman, J. 2016. "Pleural plaques and lung function in the Marysville worker cohort: A re-analysis." Presented at the Epidemiology Congress of the Americas 2016 Annual Meeting, Miami, FL, June 21-24.

Lange, SS; Tao, G; Rhomberg, LR; Goodman, JE; Dourson, ML; Honeycutt, ME. 2016. "Dose Response Curves Derived from Clinical Ozone Exposures Can Inform Public Policy." Presented at the Society of Toxicology (SOT) 55th Annual Meeting, New Orleans, LA, March 13-17.

Zu, K; Lemay, JC; Zhang, J; Goodman, JE. 2016. "A Hazard and Risk Assessment of Phenoxyethanol in Children's Personal Care Products." Presented at the Society of Toxicology (SOT) 55th Annual Meeting, New Orleans, LA, March 13-17.

Prueitt, RL; Cohen, JM; Goodman, JE. 2016. "Evaluation of Atherosclerosis as a Mode of Action for the Cardiovascular Effects of Particulate Matter." Presented at the Society of Toxicology (SOT) 55th Annual Meeting, New Orleans, LA, March 13-17.

Seeley, MR; Goodman, JE. 2016. "Evaluation of Nitrogen Dioxide and Airway Hyper-responsiveness." Presented at the Society of Toxicology (SOT) 55th Annual Meeting, New Orleans, LA, March 13-17.

Zu, K; Loftus, CT; Goodman, JE. 2015. "Non-Hodgkin's Lymphoma and 2,4-dichlorophenoxyacetic Acid: A Meta-analysis." Poster No. 022. Presented at the Society for Epidemiological Research 48th Annual Meeting, Denver, Colorado, June 19, 2015.

Rhomberg, LR; Mayfield, DB; Goodman, JE; Butler, EL; Nascarella, MA; Williams, DR. 2015. "Quantitative Cancer Risk Assessment for Occupational Exposures to Asphalt Fumes During Built-up Roofing Asphalt (BURA) Operations." Presented at the INRS 2015 Occupational Health Research Conference, Nancy, France, April 8-10.

Tao, G; Zu, K; Long, CM; Goodman, JE; Valberg, PA. 2015. "Forest-fire Fine Particulate Matter and Daily Mortality in Greater Boston and New York City." *Toxicologist* 144(1):163. Abstract 763. Presented at the Society of Toxicology (SOT) 54th Annual Meeting, San Diego, CA, March 22-26.

Zu, K; Tao, G; Kerper, LE; Rhomberg, LR; Goodman, JE. 2015. "Evaluation of US EPA's Noncancer Risk Assessment of Libby Amphibole Asbestos." *Toxicologist* 144(1):164. Abstract 768. Presented at the Society of Toxicology (SOT) 54th Annual Meeting, San Diego, CA, March 22-26.

Sax, SN; Pizzurro, DM; Zu, K; Lynch, HN; Prueitt, RL; Goodman, JE. 2015. "Ozone Exposure and Systemic Biomarkers: Evaluation of Evidence of Adverse Cardiovascular Health Impacts." *Toxicologist* 144(1):166-167. Abstract 778. Presented at the Society of Toxicology (SOT) 54th Annual Meeting, San Diego, CA, March 22-26.

Prueitt, RL; Lynch, HN; Tabony, JA; Beck, NB; Goodman, JE; Rhomberg, LR 2015. "Evaluation of Study Quality Criteria Frameworks." *Toxicologist* 144(1):400. Abstract 1865. Presented at the Society of Toxicology (SOT) 54th Annual Meeting, San Diego, CA, March 22-26.

Kerper, LE; Lynch, HN; Zu, K; Tao, G; Utell, M; Goodman, JE. 2015. "A Systematic Review of Asbestos-induced Pleural Plaques and Lung Function." *Toxicologist* 144(1):401. Abstract 1869. Presented at the Society of Toxicology (SOT) 54th Annual Meeting, San Diego, CA, March 22-26.

Seeley, MR; Thakali, S; Goodman, JE. 2015. "Birth Defect Rates in High and Low Atrazine-use States." *Toxicologist* 144(1):462. Abstract 2151. Presented at the Society of Toxicology (SOT) 54th Annual Meeting, San Diego, CA, March 22-26.

Loftus, CT; Goodman, JE; Zu, K. 2015. "2,4-dichlorophenoxyacetic Acid and Non-Hodgkin's Lymphoma, Gastric Cancer, and Prostate Cancer: Meta-analyses of the Published Literature." *Toxicologist* 144(1 (Supplement)):192. Abstract 2831. Presented at the Society of Toxicology (SOT) 54th Annual Meeting, San Diego, CA, March 22-26.

Goodman, JE; Lynch, HN; Prueitt, RL; Beck, NB; Tabony, JA; Rhomberg, LR. 2014. "Evaluation of Study Quality Criteria Frameworks." Presented at the Society for Risk Analysis Annual Meeting, Denver, Colorado, December 7-10.

Sax, SN; Pizzurro, DM; Zu, K; Lynch, HN; Prueitt, RL; Goodman JE. 2014. "Weight-of-evidence Evaluation of Short-term Ozone Exposure and Cardiovascular Biomarkers." Presented at the Society for Risk Analysis Annual Meeting, Denver, Colorado, December 7-10.

Lange, SS; Rhomberg, LR; Dourson, ML, Tao G, Goodman JE, Honeycutt M. 2014. "How Dose Response Curves Derived from Clinical Ozone Exposures can Inform Public Policy." Presented at the Society for Risk Analysis Annual Meeting, Denver, Colorado, December 7-10.

Kerper, LE; Lynch, HN; Mohr, LC; Goodman, JE. 2014. "Do Asbestos-induced Pleural Plaques Cause Lung Function Deficits?" *Toxicologist* 138(1):475. Abstract 1811. Presented at the Society of Toxicology (SOT) 53rd Annual Meeting, Phoenix, AZ, March 23-27.

Prueitt, RL; Sax, SN; Lynch, HN; Lemay, JC; King, JM; Goodman, JE. 2014. "Weight-of-evidence Evaluation of Short-term Ozone Exposure and Cardiovascular Effects." *Toxicologist* 138(1):475. Abstract 1810. Presented at the Society of Toxicology (SOT) 53rd Annual Meeting, Phoenix, AZ, March 23-27.

Lemay, JC; Prueitt, RL; Hixon, ML; Goodman, JE. 2013. "Distinguishing between Risks and Hazards: A Case Study of Bisphenol A." Presented at the Society for Risk Analysis Annual Meeting, Baltimore, MD, December 810. 13p.

Sax, SN; Prueitt, RL; Goodman, JE. 2013. "Weight-of-evidence Evaluation of Short-term Ozone Exposure and Cardiovascular Effects." Presented at the Society for Risk Analysis Annual Meeting, Baltimore, MD, December 8-11.

Goodman, JE, Prueitt RL, Rhomberg, LR. 2013. "Hypothesis-based Weight-of-evidence Evaluation of the Human Carcinogenicity of Toluene Diisocyanate." Presented at the Conference on Isocyanates and Health: Past, Present and Future, April 3-4.

Seeley, MR; Goodman, JE. 2013. "Is There a Subset of Susceptible Individuals in Controlled Air Pollution Studies?" *Toxicologist* 132(1):414. Abstract No. 1945. Presented at the Society of Toxicology (SOT) 52nd Annual Meeting, San Antonio, TX, March 10-14.

Prueitt, RL; Goodman, JE; Rhomberg, LR. 2013. "Hypothesis-based Weight-of-evidence Evaluation of the Human Carcinogenicity of Toluene Diisocyanate." *Toxicologist* 132(1):415. Abstract No. 1951. Presented at the Society of Toxicology (SOT) 52nd Annual Meeting, San Antonio, TX, March 10-14.

Rhomberg, LR; Goodman, JE; Bailey, EA; Prueitt, RL. 2012. "Weight-of-evidence Frameworks, Systems, and Tools: A Survey of Existing Approaches and Notes on Best Practices." Presented at the "Putting it All Together: Recent Developments in Risk Assessment Approaches" Symposium, Society for Risk Analysis Annual Meeting, San Francisco, CA, December 11. 24p.

Sax, SN; Lau, JH; Goodman, JE. 2012. "Evaluation of the BenMAP Model for Estimating Mortality Impacts of Lower Ozone Concentrations." Presented at the 22nd Annual Conference of the International Society of Exposure Science, Seattle, WA, October 28-November 1.

Bailey, LA; Goodman, JE; Beck, BD. 2012. "Revised Reference Concentration for Manganese Oxide Based on Recent Epidemiology and Pharmacokinetic Studies." *Toxicologist* 126(1):213. Abstract No. 995. Presented at the Society of Toxicology (SOT) 51st Annual Meeting, San Francisco, CA, March 11-15.

Peterson, MK; Goodman, JE. 2012. "Infant Risk and Exposure Assessment of Bisphenol A in Polycarbonate and 'BPA-free' Plastic Bottles." *Toxicologist* 126(1):319. Abstract No. 1478. Presented at the Society of Toxicology (SOT) 51st Annual Meeting, San Francisco, CA, March 11-15.

Prueitt, RL; Goodman, JE; Bailey, LA; Rhomberg, LR. 2012. "Hypothesis-based Weight-of-evidence Evaluation of the Neurodevelopmental Effects of Chlorpyrifos." *Toxicologist* 126(1):309. Abstract No. 1430. Presented at the Society of Toxicology (SOT) 51st Annual Meeting, San Francisco, CA, March 11-15.

Seeley, MR; Goodman, JE. 2012. "Is Sulfur Dioxide a Reproductive and Developmental Toxicant?" *Toxicologist* 126(1):24. Abstract No. 119. Presented at the Society of Toxicology (SOT) 51st Annual Meeting, San Francisco, CA, March 11-15.

Bailey, LA; Goodman, JE; Rhomberg, LR. 2011. "Hypothesis-based Weight-of-evidence Evaluation of Naphthalene: Carcinogenic Hazard Assessment and Mode of Action." Presented at SETAC North America 32nd Annual Meeting, Boston, MA, November 14. 1p.

Prueitt, RL; Goodman, JE. 2011. "Evaluation of Adverse Effects on Human Lung Function Caused by Ozone." *Toxicologist* 120(Suppl. 2):491. Abstract No. 2286. Presented at the Society of Toxicology (SOT) 50th Annual Meeting, Washington, DC, March 6-11.

Peterson, MK; Bailey, LA; Dodge, DG; Goodman, JE; Valberg, PA. 2011. "A Weight-of-evidence Evaluation of Asbestos Exposure and Mesothelioma Risk among Electricians." *Toxicologist* 120(Suppl. 2):414. Abstract No. 1935. Presented at the Society of Toxicology (SOT) 50th Annual Meeting, Washington, DC, March 6-11.

Goodman, JE; Mayfield, DB; Bailey, LA; Rhomberg, LR. 2011. "Weight-of-evidence Evaluation of Formaldehyde Exposure and Leukemia Risk." *Toxicologist* 120(Suppl. 2):416. Abstract No. 1944. Presented at the Society of Toxicology (SOT) 50th Annual Meeting, Washington, DC, March 6-11.

Mattuck, RL; Seeley, MR; Reid, KR; Goodman, JE. 2011. "Human Health Risks from Exposure to 1,4-butanediol in Craft Kit Beads." *Toxicologist* 190(Suppl. 2):332. Abstract No. 1545. Presented at the Society of Toxicology (SOT) 50th Annual Meeting, Washington, DC, March 6-11.

Dodge, DG; Pollock, MC; Sax, SN; Petito Boyce, C; Goodman, JE. 2011. "Risk Characterization of the Brominated Flame Retardant Decabromodiphenyl Ethane in Indoor Dust." *Toxicologist* 120(Suppl. 2):271. Abstract No. 1268. Presented at the Society of Toxicology (SOT) 50th Annual Meeting, Washington, DC, March 6-11.

Peterson, MK; Bailey, LA; Dodge, DG; Goodman, JE; Valberg, PA. 2010. "Risk Assessment of Mesothelioma Among Electricians." Presented at the Society for Risk Analysis Annual Meeting, Salt Lake City, UT, December 5-8.

Haber, LT; Prueitt, RL; Goodman, JE; Thakali, S; Patterson, J. 2010. "Report of a Workshop: An Evaluation of Hypotheses for Determining the Carcinogenic Potential of Nickel-containing Substances." Presented at the Society for Risk Analysis Annual Meeting, Salt Lake City, Utah, December 5-8. 1p.

Goodman, JE; Kerper, LE; Petito Boyce, C; Prueitt, RL; Rhomberg, LR. 2010. "Weight of Evidence Exposures Analysis of Exposures to Dioxins and Dioxin-like Compounds and Associations with Thyroid Hormone Levels during Early Development." Presented at the Society of Toxicology (SOT) 49th Annual Meeting, Salt Lake City, UT. 1p.

Prueitt, RL; Goodman, JE; Thakali, S. 2010. "An Evaluation of Hypotheses for Determining the Carcinogenic Potential of Nickel-containing Substances." Presented at the Society of Toxicology (SOT) 49th Annual Meeting, Salt Lake City, UT. 1p.

Dodge, DG; Goodman, JE; Beck, BD. 2010. "Weight-of-evidence Analysis of Hydroquinone and Leukemia." *Toxicologist* 114(1):111-112. Abstract No. 514. Presented at the Society of Toxicology (SOT) 49th Annual Meeting, Salt Lake City, UT, March 7-11.

Thakali, S; Chandalia, JK; Seeley, M; Goodman, JE. 2010. "Meta-analysis of Nitrogen Dioxide Effects on Airway Hyper-responsiveness in Asthmatics: Effects of the Types of Airway Challenge, Exposure Methods, and Activites During Exposure." *Toxicologist* 114(1):401. Abstract No. 1886. Presented at the Society of Toxicology (SOT) 49th Annual Meeting, Salt Lake City, UT, March 7-11.

Goodman, JE; Chandalia, JK; Thakali, S; Seeley, M. 2009. "Meta-analysis of Controlled Nitrogen Dioxide Exposure Studies Assessing Airway Hyper-responsiveness in Asthmatics." Presented at the Society for Risk Analysis Annual Meeting, Baltimore, MD, December 6-9.

Goodman, JE; Rhomberg, LR; Pruiett, RL. 2009. "A Weight-of-evidence Analysis of the Human Carcinogenicity of Styrene." Presented at the Annual Meeting of the American College of Epidemiology, Silver Spring, MD, September 13-15.

Prueitt, RL; Goodman, JE; Dodge, DG; Thakali, S. 2009. "A Weight-of-evidence Evaluation of the Carcinogenicity of Soluble Nickel." *Toxicologist* 108(1):328. Abstract No. 1582. Presented at the Society of Toxicology (SOT) 48th Annual Meeting, Baltimore, MD, March 15-19.

Goodman, JE; Rhomberg, LR. 2009. "A Weight-of-evidence Approach to Evaluating Epidemiological Data on Styrene Cancer Hazards." *Toxicologist* 108(1):248. Abstract No. 1190. Presented at the Society of Toxicology (SOT) 48th Annual Meeting, Baltimore, MD, March 15-19.

Beyer, LA; Beck, BD; Goodman, JE. 2009. "Background Rates of Lymphomas/Leukemias and Leydig Cell Tumors in Sprague Dawley Rats." *Toxicologist* 108(1):421. Abstract No. 2028. Presented at the Society of Toxicology (SOT) 48th Annual Meeting, Baltimore, MD, March 15-19.

Goodman, JE; Bailey, LA; Beck, BD. 2008. "Recent Occupational Studies of Manganese and their Bearing on the Reference Concentration (RfC)." Presented at the Annual Meeting of the American College of Epidemiology, Tucson, AZ, September 14-16.

Aylward, LL; Goodman, JE; Charnley, G; Rhomberg, LR. 2008. "A Margin of Exposure Approach to Assessment of Non-cancer Risks of Dioxins Based on Human Exposure and Response Data." Presented at the 28th International Symposium on Halogenated Persistent Organic Pollutants, Birmingham, England, August 17-22.

Goodman, JE; Bailey, LA; Beck, BD. 2008. "Recent Studies of the Health Effects of Manganese and the Implications for the Reference Concentration (RfC)." *Toxicologist* 102. Abstract No. 1787. Presented at the Society of Toxicology (SOT) 47th Annual Meeting, Seattle, WA, March 16-20.

Dodge, DG; Haber, LT; Kopras, E; Goodman, JE; Pagan, I; Gift, JS; Rhomberg, LR. 2008 "Case Studies for the Development of a Pathophysiological Progression Model." *Toxicologist* 102(1):245. Abstract No. 1189. Presented at the Society of Toxicology (SOT) 47th Annual Meeting, Seattle, WA, March 16-20.

Beyer, LA; Slayton, TM; Goodman, JE; Greenberg, GI; Hudson, TC; Sax, SN; Beck, BD. 2008 "Evaluation of Key Information Informing the Basis of EPA's New Recommended Ozone Standard." *Toxicologist* 102. Abstract No. 1462. Presented at the Society of Toxicology (SOT) 47th Annual Meeting, Seattle, WA, March 16-20.

Pagan, I; Haber, LT; Rhomberg, LR; Goodman, JE; Dodge, DG; Foureman, GL. 2007. "Development of a Pathophysiological Progression Model for Selected Endpoints." Presented at the Society for Risk Analysis Annual Meeting, San Antonio, TX, December 9-12.

Haber, LT; Rhomberg, LR; Goodman, JE; Dodge, DG; Zhao, QJ; Pagan, I; Foureman, GL. 2007. "Considerations Regarding the Structure and Application of a Pathophysiological Progression Model." Presented at the Society for Risk Analysis Annual Meeting, San Antonio, TX, December 9-12.

Dodge, DG; Zhao, QJ; Haber, LT; Goodman, JE; Pagan, I; Foureman, GL; Rhomberg, LR. 2007. "Case Studies for the Development of a Pathophysiological Progression Model: Fatty Liver." Presented at the Society for Risk Analysis Annual Meeting, San Antonio, TX, December 9-12.

Mechanic, LE; Luke, BT; Goodman, JE; Chanock, SJ; Harris, CC. 2007. "Polymorphism Interaction Analysis (PIA): A Method for Investigating Complex Gene-gene Interactions." Presented at Approaches to Complex Pathways in Molecular Epidemiology, Santa Ana Pueblo, NM, May 30-June 2.

Goodman, JE; Gaylor, D; Beyer, LA; Rhomberg, LR; Beck, BD. 2007. "MTBE is Not Associated with a Statistically Significant Increase in Leydig Cell Tumors in Sprague-Dawley Rats." *Toxicologist* 96(1):339. Abstract No. 1637. Presented at the Society of Toxicology (SOT) 46th Annual Meeting, Charlotte, NC, March 25-29.

Rhomberg, LR; Goodman, JE; McConnell, EE; Sipes, IG; Witorsch, RJ; Slayton, TM; Yu, CJ; Lewis, AS. 2007. "An Updated Weight of the Evidence Evaluation of Reproductive and Developmental Effects of Low Doses of Bisphenol A." *Toxicologist* 96(1):427. Abstract No. 2067. Presented at the Society of Toxicology (SOT) 46th Annual Meeting, Charlotte, NC, March 25-29.

Beyer, LA; Goodman, JE; Seeley, MR; Slayton, TM; Beck, BD. 2007. "Carcinogenicity Evaluation of Methyl Tert-butyl Ether (MTBE)." *Toxicologist* 96(1):325. Abstract No. 1569. Presented at the Society of Toxicology (SOT) 46th Annual Meeting, Charlotte, NC, March 25-29.

Zanetti, KA; Kahn, MA; Bowman, ED; Goodman, JE; Chanock, S; Harris, CC. 2007. "Compromised Complement System Increases Colon Cancer Susceptibility in African-Americans." *Proc. Am. Assoc. Cancer Res.* 48.

Schoen, A; Eldan, M; Goodman, JE; Beck, BD. 2006. "DMA_V-induced Bladder Tumors: Unique Rat Susceptibility." *Toxicologist* 90(1):448. Abstract No. 2186. Presented at the Society of Toxicology (SOT) 45th Annual Meeting, San Diego, CA, March 5-9.

Goodman, JE; Harris, CC. 2005. "GST-T1, p53, and CASPASE-8 Polymorphisms and Colon Cancer Risk." Presented at the Society of Toxicology (SOT) 44th Annual Meeting, New Orleans, LA, March 6-10.

Goodman, JE; Bowman, E; Chanock, S; Harris, CC. 2004. "Arachidonate Lipoxygenase (ALOX) and Cyclooxygenase (COX) Polymorphisms and Colon Cancer Risk." *Proc. Am. Assoc. Cancer Res.* 44.

Goodman, JE; Bowman, E; Chanock, S; Harris, CC. 2004. "ALOX & COX Polymorphisms & Colon Cancer Risk: Association with ALOX-5 G-1753A & G-1700A." Center for Cancer Research Fourth Annual Fellows and Young Investigators Retreat, Williamsburg, VA, March 9-11.

Sullivan, AE; Goodman, JE; Silber, PM; Yager, JD. 2004. "Correlation Between Catechol-O-methyltransferase Genotype and Phenotype." *Toxicologist* 88.

Sullivan, AE; Goodman, JE; Yager, JD. 2003. "Catechol-O-methyltransferase (COMT) and Catechol Estrogens in Breast Cancer." Presented at the 226th National American Chemical Society Division of Toxicology Meeting, New York, NY, September 7-11.

Goodman, JE; Sullivan, AE; He, P; Silber, PM; Yager, JD. 2003. "Correlation Between Catechol-O-methyltransferase Genotype and Phenotype." AACR Molecular and Genetic Epidemiology of Cancer Conference Proceedings, Waikoloa, HI, January 18-23.

Goodman, JE; He, P; Yager, JD. 2002. "COMT Polymorphism and Catechol Estrogen Methylation in Breast Epithelial Cell Lines." *Proc. Am. Assoc. Cancer Res.* 45.

Goodman, JE; He, P; Yager, JD. 2001. "Kinetics of High and Low Activity Human Catechol-O-methyltransferase Activity for Catechol Estrogen Methylation." *Proc. Am. Assoc. Cancer Res.* 42.

Lavigne, JA; Goodman, JE; Fonong, T; Odwin-DeCosta, S; He, P; Yager, JD. 2001. "The Effects of Catechol-O-methyltransferase Inhibition on Catechol Estrogen Levels and Oxidative DNA Damage in MCF-7 Cells." *Proc. Am. Assoc. Cancer Res.* 42.

Goodman, JE; Lavigne, JA; Hengstler, JG; Helzlsouer, KJ; Yager, JD. 2000. "Catechol-O-methyltransferase Polymorphism Not Associated with Ovarian Cancer." *Proc. Am. Assoc. Cancer Res.* 41.

Chen, JQ; Delannoy, M; Goodman, JE; Lavigne, JA; Odwin, SE; He, P; Yager, JD. 2000. "Enhanced Transcript Levels of Mitochondrial Genes, Respiratory Chain Activity, Bcl-2 Levels and Glutathione Distribution by Ethinyl Estradiol in Female Rat Hepatocytes." *Proc. Am. Assoc. Cancer Res.* 41.

Invited Lectures, Testimony, and Other Presentations

"A Case for Good Epidemiology Practice Guidelines for Regulatory Risk Assessment." Presented at the Environmental Epidemiology Committee Webinar, September 23, 2021.

"Food Safety." Presented at Gradient's Trends 75 Webinar, June 19, 2019.

"Evaluating Adverse Drug Effects in Pharmacoepidemiology Studies." Presented at Gradient's Trends 71 Webinar, February 28, 2018.

"Study Quality and Evidence Integration in the IRIS Process." Presented at the National Academies of Science, Engineering, and Medicine Review of Advances Made to the IRIS Process Workshop, Washington, DC, February 1, 2018.

"Challenges for the Agrochemical Industry." Presented at the International Society of Exposure Science (ISES) Annual Conference, Research Triangle Park, NC, October 17, 2017.

"National Ambient Air Quality Standards." Presented at the Institute for Humane Studies and the Mercatus Center Risk Analysis Seminar, Portland, OR, June 27, 2016.

"Why Epidemiologists Need Toxicologists (and Vice Versa)." Presented at the CropLife America & RISE 2016 Spring Conference, Arlington, VA, April 14, 2016.

"Systematic Review." Presented at the Asphalt Institute Spring Meeting, Nashville, TN, April 13, 2016.

"An Introduction to Meta-analysis." Presented at the Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, April 5, 2016.

"Evaluation of Scoring Approaches and Consideration of an Independent Approach." Presented at the 40th Annual Winter Meeting of Toxicology Forum, Washington, DC, February 10, 2016.

"Extrapolation of Controlled Human Study Results to the US Population." Presented at the Society for Risk Analysis Annual Meeting, December 6-9, 2015.

"How a Sensitivity Analysis of Raw Data Would Strengthen EPA's Chlorpyrifos Risk Assessment." Presented at the Society for Risk Analysis Annual Meeting, December 6-9, 2015.

"The Future of Toxicology." Presented at the SPI Food Packaging Summit, November 10, 2015.

"Evaluation of Evidence EPA Cites in Support of the Ozone National Ambient Air Quality Standards for Ozone Proposed Rule." Presented at the 2015 Env-vision Conference, May 12-14, 2015.

"The Scientific Evidence Does Not Support the Administrator's Proposed Conclusion that the Primary Ozone NAAQS Should Be Between 0.065 and 0.070 ppm." Testimony at the US Environmental Protection Agency (EPA) Public Hearing on the Proposed Updates to the National Ambient Air Quality Standards (NAAQS) for Ground-level Ozone, Washington, DC, January 29, 2015.

"Risk-of-bias Analysis: Case Study of Pleural Plaques and Lung Function." Presented at the Society for Risk Analysis Annual Meeting, December 7-10, 2014.

"Is a Stricter Ozone NAAQS Supported by the Science?" Presented at the Association of Battery Recyclers 2014 Fall Meeting, October 16, 2014.

"NexGen: Are We There Yet?" Presented at the 2014 Health Effects Institute Annual Conference, May 6, 2014.

"Hypotheses and Weight-of-evidence Frameworks." Presented at the 53rd Annual Society of Toxicology Meeting, March 23, 2014.

"When an Association Indicates Causation." Presented at the 53rd Annual Society of Toxicology Meeting, March 23, 2014.

"Rethinking Meta-analysis: Applications for Air Pollution Data and Beyond." Presented at the Society for Risk Analysis Annual Meeting, December 8-11, 2013.

"Incorporation of Weight-of-evidence Best Practices in the National Ambient Air Quality Standards Review Process." Presented at the Society for Risk Analysis Annual Meeting, December 8-11, 2013.

"Bradford Hill Viewpoints and Hypothesis-based Weight of Evidence." Presented at the Society for Risk Analysis Annual Meeting, December 8-11, 2013.

"Rethinking Meta-analysis: Applications for Air Pollution Data and Beyond." Presented at the Harvard Systematic Review Symposium, October 3-4, 2013.

"A Hypothesis-based Weight-of-evidence Approach to Evaluate the Human Carcinogenicity of Isocyanates." Presented at the Isocyanates & Health Conference, April 3, 2013.

"Using Epidemiology to Analyze Neurodevelopmental Toxicity Across Species." Presented at the 52nd Annual Society of Toxicology Meeting, March 14, 2013.

"Designing Case-control Studies." Presented at the New York Medical College School of Health Science & Practice, February 21, 2013.

"Designing Cohort Studies." Presented at the New York Medical College School of Health Science & Practice, February 11, 2013.

"Systemic Reviews and Meta-analysis." Presented in the Use of Expert Elicitation to Inform Decisionmaking Workshop, Society for Risk Analysis 2012 Annual Meeting, San Francisco, CA, December 2012.

"Survival Analysis & Meta-analysis." Presented at the New York Medical College School of Health Sciences & Practice, November 8, 2012.

"Overview of the Controversy Surrounding Bisphenol A Toxicity." Presented at the Biological Relevance and Health Concerns of Genotoxicity Conference, Newark, DE, October 24, 2012.

"Biological & Statistical Interaction." Presented at the New York Medical College School of Health Sciences & Practice, October 11, 2012.

Testimony regarding "EPA's Assessment of Health Benefits Associated with $PM_{2.5}$ Reductions for the Final Mercury and Air Toxics Standards." Presented to the Subcommittee on Energy and Power, United States Congressional Committee on Energy and Commerce American Energy Initiative Hearing, Washington, DC, February 8, 2012.

"Synthesizing Evidence: An Introduction to Systematic Reviews, Meta-analysis, and Expert Elicitation." Presented at the Society for Risk Analysis 2011 Annual Meeting, Charleston, SC, December 2011.

"Why Meta-analyses and Systematic Reviews Come to Different Conclusions About Formaldehyde and Leukemia." Presented at the Society for Risk Analysis 2011 Annual Meeting, Charleston, SC, December 2011.

"The Weight of Evidence Regarding Bisphenol A and Human Health." Presented at the Society for Risk Analysis New England Chapter Meeting, Harvard School of Public Health, Boston, MA, December 2011.

Testimony regarding Air Quality and Children's Health. Presented to the Subcommittee on Clean Air and Nuclear Safety and the Subcommittee on Children's Health and Environmental Responsibility, United States Senate Committee on Environment and Public Works Hearing, Washington, DC, June 8, 2011.

"On Babies, Bottles, and Bisphenol A." Presented at the Defense Research Institute Toxic Torts and Environmental Law Seminar, New Orleans, LA, February 2011.

"Bisphenol A and Human Health: What Does the Science Show?" Presented at the Policy of BPA Event, American Enterprise Institute, Washington, DC, June 2010.

"Human Health Risk Assessment." Presented at the Massachusetts Maritime Academy, Buzzards Bay, MA, May 2010.

"The Science Behind the Reconsideration of the Ozone NAAQS." Presented as part of the webinar, How Will EPA's New Ozone Standards Affect Your Community? April 2010.

"Weight-of-evidence Analysis of Reproductive and Developmental Health Effects of Bisphenol A." Presented at the Nypro Bisphenol A Information Event, Clinton, MA, March 2010.

"Everyday Exposures to Bisphenol A Do Not Cause Adverse Health Effects in Humans." Presented at the Harvard Extension School, Environmental Management Program, Cambridge, MA, March 2010.

"New Developments in Exploratory Research on 'Estrogenicity' – Progress Toward Validation of New Endpoints and Testing Methods." Presented at the Society of the Plastics Industry's Food, Drug, and Cosmetic Packaging Materials Committee Winter Conference, Atlanta, GA, December 2009.

"Avoiding Potential Long-term Liability through Risk Assessment for Material Selection." Presented at the 21st Annual Product Liability Conference, University of Wisconsin-Madison, Madison, WI, September 2009.

"Epidemiology and Risk Assessment." Presented at the Annual Meeting of the American College of Epidemiology, Silver Spring, MD, September 2009.

"Risk Assessment Techniques for Materials Selection." Presented as part of the Strategies for Substance Replacement in Products Webinar, May 2009.

"Investigation of Potential Cancer Clusters in Northampton, MA." Presented at the John F. Kennedy School, Northampton, MA, September 2008.

"Did Chemicals in Your Product Cause John Doe's Disease? The Toxicologist Speaks." Presented at the 20th Annual Product Liability Conference, University of Wisconsin-Madison, Madison, WI, September 2008.

"Investigation of Potential Disease Clusters in Northampton, MA: Progress Update." Presented at the Robert K. Finn Ryan Road School, Northampton, MA, October 2007.

"Investigation of Potential Disease Clusters in Northampton, MA." Presented at the Robert K. Finn Ryan Road School, Northampton, MA, May 2007.

"Single Nucleotide Polymorphisms (SNPs), Inflammation and Colon Cancer." Presented at the Cancer Prevention Fellowship Program Seminar Series, NCI, Rockville, MD, February 2004.

"The Epidemiology of Inflammation and Colon Cancer." Presented at the Laboratory of Human Carcinogenesis Meeting, NCI, Bethesda, MD, December 2003.

"Macrophage Migration Inhibitory Factor (MIF) in Inflammatory Bowel Diseases." Presented at the Laboratory of Human Carcinogenesis International Workshop, Bethesda, MD, September 2003.

"Chronic Inflammation and Colon Cancer Risk." Presented at the Cancer Prevention Fellowship Program Seminar Series, NCI, Rockville, MD, June 2003.

ATTACHMENT A

CV of Dr. Anne E. Smith

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Anne E. Smith
Curriculum Vitae

Education

Stanford University
PhD, Economics (with PhD minor in Department of Engineering-Economic Systems, Stanford Engineering School), 1984

Stanford University
MA, Economics, 1981

Duke University
BA Economics, *summa cum laude*, 1977
Phi Beta Kappa

Professional Experience

Current **A. E. Smith Expert Consulting, LLC**
Owner, Independent Consultant

NERA Economic Consulting
2011-2021 Managing Director and Co-Head of Global Environmental Group

Charles River Associates
1998-2011 Vice President and leader of the Climate & Sustainability Group

Decision Focus Incorporated (later DFI-Aeronomics)
1984-1998 Principal, Vice President, and leader of the Environmental Policy Practice; Member of DFI Board of Directors from 1997-1998.

SRI International
1981-1982 Research Analyst in Decision Analysis Group

U.S. Environmental Protection Agency
1977-1979 Economist in Economic Analysis Division of the Office of Policy Planning and Evaluation

Service on Advisory Committees & Professional Organizations

Congressionally Mandated Committee to Conduct a Review of the Continued Analysis of Supplemental Treatment of Low-Activity Waste at the Hanford Nuclear Reservation, National Academy of Sciences, 2021-present.

Chartered Science Advisory Board, U.S. Environmental Protection Agency, 2018-2021. (Served as lead reviewer for the Chartered Board's reviews of several SAB committee reports, including the SAB review of EPA's development plans for a computable general equilibrium model, SAGE, and of the SAB review of EPA's draft update of its Economic Analysis Guidelines.)

EPA Science Advisory Board Ad Hoc Committee to conduct a review of EPA's *Reduced Form Tools Evaluation* report, U.S. Environmental Protection Agency, 2020.

Congressionally Mandated Committee on Supplemental Treatment of Low-Activity Waste at the Hanford Nuclear Reservation, National Academy of Sciences, 2017-2020.

Best Reviewer Award for 2017 from *Risk Analysis* (the professional journal of the Society for Risk Analysis).

Board of Directors, Society for Benefit-Cost Analysis, 2013-2014.

Panel of Experts on "Lessons Learned from the European Union's Emissions Trading Scheme and the Kyoto Protocol's Clean Development Mechanism," U.S. General Accountability Office, 2008. (Report: GAO-09-151, released November 2008).

Congressionally Mandated Committee on Management of Certain Radioactive Waste Streams Stored in Tanks at Three Department of Energy Sites, National Academy of Sciences, 2005-2006.

Committee on Risk-Based Approaches for Transuranic and High-Level Radioactive Waste, National Academy of Sciences, 2003–2005.

National Coal Council, member, 2001–2011.

Committee on the Characterization of Remote-Handled Transuranic Waste for the Waste Isolation Pilot Plant, National Academy of Sciences, 2001–2002.

Programmatic Review of EPA's $PM_{2.5}$ Research Program, Subcommittee on Risk Management, Board of Scientific Counselors, U.S. Environmental Protection Agency, 1999.

Technical Expert to Committee on Idaho National Engineering and Environmental Laboratory High-Level Waste Alternative Treatments, Board on Radioactive Waste Management, National Academy of Sciences, 1998.

Committee to Evaluate Science, Engineering, and Health Basis of DOE's Environmental Management Program, Subcommittee on Priority Setting, Timing and Staging, National Academy of Sciences, 1995–2002.

Panel on DOE’s Environmental Restoration Priority-setting System, National Academy of Sciences, 1992–1993.

Dialogue on Global Climate Change and National Energy Policy, Keystone Foundation, Keystone, CO, 1989–1990.

Working Group on Assessment of the Impact of Pollutants on the Marine Environment, Group of Experts on Scientific Aspects of Marine Pollution (GESAMP), United Nations, Bangkok, Thailand, 1984.

Working Group on Biological Aspects of Thermal Pollution of the Marine Environment, GESAMP, United Nations, Rome, Italy, 1983.

Ad-hoc Committee on Cost-Benefit Analysis, United Nations Economic Commission for Europe, Geneva, Switzerland, 1982.

Testimony in Judicial and Regulatory Proceedings

Expert declaration on climate benefits of a new transmission line in support of opposition to Plaintiffs’ motion for preliminary injunction on behalf of American Transmission Company LLC, ITC Midwest LLC, and Dairyland Power Cooperative *National Wildlife Refuge Ass’n et al. v. U.S. Army Corps of Engineers et al.*, Case Nos. 3:21-cv-00096-wmc and 3:21-cv-000306-wmc (Western District of Wisconsin). Declaration dated October 18, 2021.

Expert declaration on estimation of federal social cost of carbon, analytic uncertainties, and potential energy cost damages to consumers; on behalf of the State of Louisiana Attorney General’s office in the State of Louisiana, by and through its Attorney General Jeff Landry, *et al.* v. Joseph R. Biden, Jr., in his official capacity as President of the United States, *et al.*, Case No. 2:32-cv-1074-JDC-KK (Western District of Louisiana). Declaration filed July 23, 2021.

Expert witness on emissions impacts of a new transmission line on behalf of American Transmission Company, LLC, ITC Midwest LLC, and Dairyland Power Cooperative in their joint application before the Wisconsin Public Service Commission for authority to construct and operate a new 345 kV transmission line. Docket No. 5-CE-146. Rebuttal testimony filed May 28, 2019; surrebuttal testimony filed June 11, 2019.

Expert witness power plant emissions health risk estimates, benefit-cost issues, and economic value of delayed compliance in in remedy phase of Natural Resources Defense Council, Inc. Sierra Club, Inc., and Respiratory Health Association v. Illinois Power Resources Generating, LLC, Case No. 1-13-cv-01181 (Central District of Illinois Peoria Division). Written report filed March 21, 2018; deposition testimony June 20, 2018; written supplemental report filed April 5, 2019; written supplemental rebuttal report filed April 20, 2019, deposition testimony April 24, 2019.

Expert witness on climate damages and market damages due to excessive Renewable Identification Numbers (RINs) under the U.S. Renewable Fuels Standard in United States of

America v. NGL Crude Logistics, LLC (f/k/a Gavilon, LLC), Case No. 2:16-cv-1038-LRR (N.D. Iowa, E.D.). Written report filed December 22, 2017; deposition testimony April 19, 2018.

Expert witness on Social Cost of Carbon before the Office of Administrative Hearings for the Minnesota Public Utilities Commission in the Matter of the Further Investigation into Environmental and Socioeconomic Costs Under Minnesota Statute § 216B.2422, Subdivision 3. MPUC Docket No. E-999/CI-14-643. Direct testimony and expert report filed June 1, 2015; rebuttal testimony filed August 12, 2015; surrebuttal testimony filed September 10, 2015; cross-examination at hearing September 25, 2015. Further testimony before Commissioners at PUC hearing July 21, 2017.

Expert witness on job and employment impact analysis methods in Murray Energy Corporation *et al.* v. Gina McCarthy, Case No. 5:14-cv-00039 (N.D.W.Va.) Written report filed April 25, 2016; deposition testimony June 3, 2016; summary judgment in favor of client October 17, 2016.

Expert witness on present value of economic benefits to a company from delayed compliance in Puget Soundkeeper Alliance v. Rainier Petroleum Corporation, Case No. 2:14-cv-00829-JLR, U.S. District Court for the Western District of Washington at Seattle. Written rebuttal report filed August 17, 2015; case settled before trial.

Expert witness on business damages associated with opacity exceedances and alleged PM violations in Sierra Club v. Energy Future Holdings Corp. et al., Case No. 6:12-cv-108 (W.D.Tex.), U.S. District Court for the Western District of Texas, Waco Division. Written expert report filed June 13, 2013; declaration filed October 10, 2013; trial February 24-26, 2014.

Expert witness on business damages associated with opacity exceedances in Sierra Club v. Energy Future Holdings Corp. et al., Case No. 5:10-cv-156 (E.D.Tex.), U.S. District Court for the Eastern District of Texas, Texarkana Division. Written expert report filed May 21, 2013; rebuttal report filed June 20, 2013; case settled before trial.

Expert witness on emissions-related damages estimates in United States of America v. Westvaco Corporation, Civil Action No. MJG 00-CV-2602, U.S. District Court for the District of Maryland. Written expert report filed February 21, 2012; deposition March 22, 2012; trial testimony January 17, 2013.

Expert witness on impacts of sectoral CO_2 emissions limits on cost of electricity generation in the State, and associated macroeconomic and revenue impacts to the State, State of New Mexico Environment Improvement Board, EIB 11-16(R), in the matter of Proposed Repeal of Regulation 20.2.100 NMAC – "Greenhouse Gas Reduction Program." Written expert report filed October 7, 2011; testimony and cross examination December 13, 2011.

Expert witness on cost to utilities and associated state macroeconomic and state revenue impacts of multi-state GHG cap-and-trade policy, State of New Mexico Environment Improvement Board, EIB 11-15(R), in the matter of Proposed Repeal of Regulation 20.2.350 NMAC – "Greenhouse Gas Cap and Trade Provisions." Written expert report filed September 15, 2011; testimony and cross examination November 8, 2011.

Expert witness in international arbitration on business damages of a disrupted business venture associated with emissions reduction investments on a national natural gas utility system; under the auspices of the Permanent Court of Arbitration, Case No. 2009-18. Expert report on markets for Kyoto Protocol compliance instruments filed June 29, 2010; expert report on business damages and discount rates filed December 8, 2010; cross examination on September 2, 2011.

Expert witness on present value of economic benefits to a company from delayed compliance in PennEnvironment and Sierra Club v. GenOn Northeast Management Company, Civil Action No. 07-00475, U.S. District Court for Western District of Pennsylvania. Expert report finalized May 6, 2011, not filed prior to case settlement.

Expert witness on costs and risks of coal plant closure policy, Public Utilities Commission of the State of Colorado, Docket No. 10M-245E, in the matter of the Commission consideration of Public Service Company of Colorado Plan in compliance with House Bill 10-1365, "Clean Air – Clean Jobs Act." Written answer testimony filed September 17, 2010; written cross-answer testimony filed October 8, 2010; written supplemental answer testimony filed November 9, 2010; written supplemental cross-answer testimony filed November 15, 2010. Cross-examinations on October 28, 2010 and November 19, 2010.

Expert witness on cost and economic impacts, State of New Mexico Environment Improvement Board, EIB 10-04(R), in the matter of Proposed Regulation 20.2.350 NMAC – "Greenhouse Gas Cap and Trade Provisions." Written expert report filed August 16, 2010; testimony and cross examination September 29, 2010.

Expert witness on cost-benefit analysis in State of North Carolina *ex. rel*. Roy Cooper, Attorney General (Plaintiff) v. Tennessee Valley Authority (Defendant), Case No. 1:06-CV-20, U.S. District Court for the Western District of North Carolina, Asheville Division. Written expert report filed February 27, 2007; deposition June 19, 2007; testified July 29, 2008.

Expert witness on utility company compliance costs and emissions impact of an alternative emissions control approach to the proposed mercury control policy for the State of Illinois, (in the matter of proposed new Ill. Adm. Code 225, *Illinois Pollution Control Board Hearings on the matter of Control of Emissions from Large Combustion Sources (Mercury)*). Written testimony filed July 28, 2006; cross examination at IPCB hearings on August 14-17, 2006 (Chicago IL).

Expert witness on estimating economic benefits of visibility improvements, *State of Washington Pollution Control Hearings Board*, expert report filed December 1998 (summary judgment in favor of client before testimony occurred).

Testimony in Congressional Hearings

"EPA's Final Clean Power Plan" *U.S. House of Representatives Committee on Science, Space, and Technology*, November 18, 2015.

"Impacts of U.S. Environmental Protection Agency Regulations" *U.S. House of Representatives Committee on Oversight and Government Reform*, February 26, 2015.

"Discussion Draft of 'Energy Consumers Relief Act of 2013' " *U.S. House of Representatives Committee on Energy and Commerce, Subcommittee on Energy and Power*, April 12, 2013.

"The American Energy Initiative – A Focus on EPA's New Proposal to Tighten National Standards for Fine Particulate Matter in the Ambient Air" *U.S. House of Representatives Committee on Energy and Commerce, Subcommittee on Energy and Power*, June 28, 2012.

"The American Energy Initiative – A Focus on What EPA's Utility MACT Rule Will Cost U.S. Consumers" *U.S. House of Representatives Committee on Energy and Commerce and Subcommittee on Energy and Power*, February 8, 2012.

"Innovative Practices to Create Jobs and Reduce Pollution" *U.S. Senate Committee on Environment and Public Works, Subcommittee on Green Jobs and the New Economy*, October 13, 2011.

"Quality Science for Quality Air" *U.S. House of Representatives Committee on Science, Space, and Technology, Subcommittee on Energy and the Environment*, October 4, 2011.

"Auctioning under Cap and Trade: Design, Participation and Distribution of Revenues" *U.S. Senate Committee on Finance*, May 7, 2009.

"Legislative Hearing Regarding the American Clean Energy and Security Act" *U.S. House of Representatives Committee on Energy and Commerce and Subcommittee on Energy and Environment*, April 24, 2009.

"America's Climate Security Act of 2007, S.2191" *Legislative Hearing of the Senate Committee on Environment and Public Works*, November 8, 2007.

"Counting the Change: Accounting for the Fiscal Impacts of Controlling Carbon Emissions" *House Committee on the Budget*, November 1, 2007.

"Lessons Learned from Existing Cap and Trade Programs" *House Committee on Energy and Commerce, Subcommittee on Energy and Air Quality,* March 29, 2007.

"Energy Market and Economic Impacts of a Proposal to Reduce Greenhouse Gas Intensity with a Cap and Trade System," *U.S. Senate Committee on Energy and Natural Resources,* January 24, 2007.

"Science and Risk Assessment behind the EPA's Proposed Revisions to the Particulate Matter Air Quality Standards," *U.S. Senate Environment and Public Works Committee*, July 19, 2006.

"Economic Impacts of Various Proposals to Reduce Domestic Greenhouse Gas Emissions," *U.S. Senate Committee on Energy and Natural Resources,* September 20, 2005.

"The Proposed Regional Haze Regulation and its Relationship to the Work of the Grand Canyon Visibility Transport Commission," *U.S. Senate Committee on Energy and Natural Resources, Subcommittee on Forests and Public Land Management*, October 1997.

"Scientific Foundations for U.S. EPA's Proposed New National Ambient Air Quality Standard for $PM_{2.5}$," *U.S. Senate Committee on Environment and Public Works, Subcommittee on Clean Air, Wetlands, Private Property, and Nuclear Safety,* February 1997.

Examples of Past Analysis and Research Projects

Benefit-Cost and Integrated Assessments

Utility Air Regulatory Group—Prepared a study of history of benefit-cost analyses in EPA regulatory impact analyses, benefit-cost practice and theory, and the role of co-benefits in the context of RIA objectives.

Electric Power Research Institute—Prepared an integrated assessment methodology for assessing the costs and benefits of controlling mercury from U.S. power plants. Applied the methodology to contrast the relative merits of controlling mercury emissions through cap-and-trade or MACT standards.

Southern Appalachian Mountains Initiative—Led a team of expert economists and sociologists to advise SAMI's multi-stakeholder group on the state of the art in valuing changes in air quality-related values and provided guidance for SAMI to plan a comprehensive socioeconomic impact assessment of alternative emissions management options for the southeastern region of the United States. Valuation techniques covered included ecosystem-related changes, visibility, recreation, health, materials, agro-forestry, lifestyle changes, and reliability. Also provided guidance on options and techniques for assessing economic impacts and distributional impacts.

U.S. Environmental Protection Agency—Developed multi-criteria decision support tool for evaluation of strategies for anticipatory adaptation to climate change. Applications developed for sea level rise, water resources, and agriculture. Led case study applications in Egypt and New York.

Grand Canyon Visibility Transport Commission—Led the development of the GCVTC's integrated assessment model, its associated database of emissions control measures, and projected baseline of visibility conditions in the southwestern region of the United States; also applied a 15-region REMI model of the western United States to assess the macroeconomic impacts of alternative visibility management strategies generated through use of the integrated assessment system.

U.S. Environmental Protection Agency—Documentation of integrated assessment model, the Policy Evaluation Framework (PEF), and evaluation of alternative climate policy timing strategies using PEF.

Nuclear Electric, plc, U.K.—Led development of Gemini-UK model of UK greenhouse gas emissions and greenhouse gas control options. Used model to assess value of future nuclear generation in achieving UK carbon dioxide emission targets.

National Acid Precipitation Assessment Program (NAPAP)—Supported the Director of NAPAP (a 10-year interagency research program in the Executive Office of the President) in coordinating its final integrated assessment of the benefits and costs of options for controlling acid precipitation in the U.S. Worked with expert teams in each externality area to condense their best available scientific information into estimates of changes under alternative emissions scenarios, including both quantitative and qualitative assessments.

Social Cost of Carbon and Other Climate Impact Analyses

Dorsey & Whitney, LLP—In context of a Minnesota Public Utilities Commission proceeding on the externality value of carbon dioxide emissions, prepared evaluation of analytical framing assumptions used in estimating the Federal Social Cost of Carbon (SCC). Using the same three integrated assessment models (PAGE, FUND, DICE), provided quantitative estimates of how much the Federal SCC would be altered by variations in the selected framing assumptions. Results were incorporated into an expert report and testimony in contested case hearing; Commission adopted its final choice of Minnesota's current CO_2 adders from integrated assessment model runs produced by our project team.

American Council for Capital Formation—Prepared technical comments on EPA's social cost of methane (SCM) estimates and evaluation of sensitivity of SCM estimates to key uncertainties in the estimation process. Demonstrated how sensitivity reverses EPA's finding of positive on net benefits in its August 2014 RIA for proposed emissions standards for new and modified sources in the oil and gas sector.

Texas Commission on Environmental Quality—Written comments on the benefit and cost comparisons of the proposed Clean Power Plan, with re-evaluation of the way in which costs and benefits were presented in the regulatory impact analysis. Included assessment of the timing of the benefits associated with the social cost of carbon (SCC).

Utility Air Regulatory Group—Prepared a white paper describing the multiple sources of uncertainty when estimating the SCC and the extent to which the Federal Government's SCC values have addressed those uncertainties. Submitted to OMB on the Federal government's SCC values with UARG's comments.

American Petroleum Institute—Prepared a study reviewing the theoretical and empirical bases for the "damage functions" in climate change integrated assessment models used to derive estimates of the social cost of carbon (SCC). Submitted to OMB docket on the Federal government's SCC values with API's comments.

Electric Power Research Institute—Review of literature on infectious disease risks from changing climate and development of plan for integrated assessment framework to address the risk.

Electric Power Research Institute—Developed model of heat-related illness risks and mitigation risk management.

Electric Power Research Institute—Participated in a group of experts advancing the state of knowledge regarding appropriate ways of estimating societal value associated with ecosystem impacts of global climate change.

U.S. Environmental Protection Agency—Interdisciplinary review and critique of considerations for valuing ecosystem-related impacts of climate change.

U.S. Environmental Protection Agency—Documentation of EPA's climate change integrated assessment model (IAM), the Policy Evaluation Framework (PEF), and evaluation of alternative climate policy strategies using this integrated assessment model.

Modeling of Energy Market and Economic Impacts

Climate Leadership Council. Analyzed the relative macroeconomic and energy market impacts of two alternative Federal policy options for reducing carbon emissions economy-wide, including a market-based approach and an approach founded on more common regulatory measures for each key emitting source.

Confidential client. Directed an assessment of the global energy market impacts and associated U.S. macroeconomic impacts of a change in corporate income taxes affecting the natural gas and sectors of the U.S. The analysis prepared an integrated set of scenarios by linking NERA's Global Petroleum Model (GPM), Global Natural Gas Model (GNGM) and macroeconomic N_{ew}ERA model (including its bottom-up electricity sector).

Confidential utility client. Applied electricity sector modeling under multiple future scenarios to develop estimate of range and variance in projected CO_2 permit prices and ERC prices under the Clean Power Plan (CPP) for a specific state, to help company develop business strategies. Scenarios included different scopes for interstate trading, levels of natural gas prices, energy load growth, and generation technology costs.

Six trade associations of large industrial electricity users—Co-led integrated modeling of alternative Federal Plan proposals for implementation of the Clean Power Plan (CPP). Projected ranges in projected electricity rates by state and Henry Hub natural gas prices as result of differing implementations. Analysis also included assessment of leakage prevention measures. Report submitted to CPP Federal Plan Docket.

American Coalition for Clean Coal Electricity—Co-led integrated modeling analyses of the costs, electricity sector impacts, and fuel price impacts of EPA's proposed and final Clean Power Plan rules, including state-specific electricity rate impacts.

National Association of Manufacturers—Co-led project to estimate costs of compliance with a tightened ozone NAAQS and applied an integrated model of the U.S. electricity sector and macroeconomy to estimate the resulting economic impacts of the compliance spending. Results projected for each U.S. state individually.

U.S. Chamber of Commerce—Written report on methods for estimating and characterizing employment impacts of regulations, with a review and evaluation of methods used by EPA. Report recommended use of integrated economy-wide modeling, leading to a 2015-2016 review of the issue by an EPA Science Advisory Board panel on economy-wide modeling.

National Association of Manufacturers—Led development of method for using an integrated model of the U.S. energy economy to assess macroeconomic impacts of Federal debt levels under two carbon tax policies whose revenues would be used for both debt reduction and income tax rate reductions. Work involved adaption of the N_{ew}ERA computable general equilibrium model to account for impact of debt level on interest rates. Estimated the national, regional, and state economic impacts of the carbon tax policies.

American Coalition for Clean Coal Electricity—Prepared an analysis of the macroeconomic impacts of the combined compliance costs of four regulations affecting the U.S. electric generating sector: the Cross-State Air Pollution Rule (CSAPR), the proposed utility MACT rule, the proposed Section 316(b) cooling water intake rule, and the anticipated coal ash handling rule.

Multiple clients over multiple years—From 2003-2009, analyzed the costs and economic impacts of most of the climate bills then being proposed to cap U.S. greenhouse gas emissions using a model that integrated a detailed electricity sector model with a computable general equilibrium model of the rest of the economy, MRN-NEEM. Analyses have included estimates of impacts to society at large, and to value of assets owned by individual companies. Also projected carbon allowance prices and demand for carbon credits/offsets.

Edison Electric Institute, EPRI, other industry organizations, and private corporations—Developed an integrated modeling framework for assessing costs and economic impacts of multi-pollutant emissions trading policies in the U.S. Framework incorporates a bottom-up, unit-level model of U.S. electricity sector with a top-down macroeconomic model of the U.S. economy at large. Submitted formal comments on cost and impact analyses of the Clean Air Mercury Rule (CAMR), and the Clean Air Interstate Rule (CAIR).

U.S. Environmental Protection Agency—Developed engineering-based model (GEMINI-US) integrating environmental and energy-economy feedbacks, for use in evaluating a range of regulatory options to control greenhouse gases; this effort involved a detailed analysis of energy subsidy impacts. Model was a key participant in Stanford University's Energy Modeling Forum 12 (the first of the EMFs focused on climate policy impacts) and in EMF 13.

Criteria Pollutant Health Risk and Benefits Analyses

Electric Power Research Institute (EPRI)—Prepared review and weight-of-evidence summary of relative risks from all published epidemiological papers on chronic, long-term exposure mortality risk in the U.S. from ambient $PM_{2.5}$. Reviewed how EPA's BenMAP model can be enhanced to serve better function as a risk analysis support tool. Evaluated BenMAP-based calculations of $PM_{2.5}$ NAAQS benefits in context of EPA rationale for NAAQS decision and provided quantitative estimates with greater internal consistency. Demonstrated method for conducting quantitative uncertainty analysis of BenMAP-based risk estimates. Developed historical review of use of uncertainty analysis in $PM_{2.5}$ risk analyses by EPA. Results, with quantitative sensitivity analyses, reported in a suite of peer-reviewed articles in the journal of the Society for Risk Analysis.

Texas Commission on Environmental Quality—Using original individual response data from clinical studies of lung function responses to ozone exposure, re-estimated the exposure-response function used in EPA's ozone health risk analysis to explore uncertainty about model specification in EPA's risk estimates under alternative ozone NAAQS levels.

Virginia Department of Environmental Quality—Under subcontract to the Virginia Polytechnic Institute, prepared an assessment of the potential for double-counting of $PM_{2.5}$ and ozone cobenefits in EPA's regulatory impact analysis of the proposed Clean Power Plan. Analysis was mandated by a Joint Resolution of the Virginia legislature.

American Petroleum Institute—Developed probabilistic simulation method to quantify statistical uncertainty around EPA's point estimates of frequency of lung function decrements to the general population under alternative ozone NAAQS levels. Submitted to EPA's docket on the proposed ozone NAAQS with API's comments.

Gibson Dunn and Crutcher—Prepared an expert report on uncertainties in the application of BenMAP to the estimation of health impacts from $PM_{2.5}$ and on techniques for estimating willingness to pay for changes in mortality risk (VSL and VSLY evidence). Analysis used in expert testimony in a New Source Review lawsuit.

Utility Air Regulatory Group—Review and technical critiques of EPA's risk analyses for ozone health effects associated with the 2014-2015 ozone NAAQS rulemaking proceedings, including sensitivity analyses of EPA's health impacts estimates using the BenMAP model. Demonstrated quantitative unreliability of EPA's estimates of respiratory mortality from long-term exposure to ambient ozone, given evidence of effects threshold in the original epidemiological analysis.

Texas Commission on Environmental Quality—Served on steering committee for a major public workshop hosted by TCEQ to engage a group of nationally-recognized science, legal, and policy experts in a discussion of the nexus between scientific evidence and policy judgment for the 2015 ozone NAAQS decision.

Utility Air Regulatory Group—Performed a review of environmental benefits estimates for all major EPA air-related rulemakings since 1997, and of EPA's regulatory impact analysis practices dating back to the 1980s that identified the emergence and expansion of EPA's reliance on $PM_{2.5}$ co-benefits in non-PM rulemakings, such as ozone. Prepared a report identifying areas for improvement in EPA's regulatory impact analyses and for improving the credibility of EPA's $PM_{2.5}$ health risk calculations.

Utility Air Regulatory Group—Reviewed and technically critiqued health effects literature for ambient $PM_{2.5}$, with focus on potential errors in the statistical inferences being used as the basis for risk and benefits estimates associated with the proposed PM NAAQS. Supported UARG with expert testimony on risks in public hearings and before the EPA Science Advisory Committee (CASAC). Also made technical presentations to senior EPA staff in a non-public setting on risk assessment methodology.

U.S. Environmental Protection Agency—Performed risk assessment of the health effects of ambient carbon monoxide, using physiological modeling and decision analysis, in support of the National Ambient Air Quality Standards-setting process.

Other Environmental Risk and Benefits Analyses

[Confidential Client]—Categorized environmental and ecosystem impacts of wildfires. Reviewed and summarized methods for estimating carbon emissions due to wildfires and estimates of wildfire emissions trends in U.S. Analysis of data from existing carbon cycling modeling studies to evaluate wildfire carbon emissions in context of total carbon sequestered in biomass and soils in U.S.

Utility Air Regulatory Group—Replicated EPA survey methodology for identifying societally acceptable urban visibility levels and demonstrated lack of robustness of results of the methodology to alternative survey framing. Published results in peer-reviewed journal.

EPRI—Managed the design and implementation of a full-scale contingent valuation survey to estimate willingness to pay (WTP) for improvement in regional haze conditions in scenic vistas in the Eastern U.S. The survey explored the sensitivity of stated willingness to pay to different questionnaire formats. Results were found to be sensitive to alternative ways of reminding respondents of their personal budgets. Published results in peer-reviewed journal.

U.S. Department of Energy—Served on a large, multi-company team to produce a DOE Report to Congress assessing the occupational safety and health risks to public and workers from legacy wastes across the U.S. nuclear weapons complex. Led the team's data review for the Fernald facility.

Electric Power Research Institute—Developed and applied tools for evaluating risks and cleanup options for contaminated sites, including PCBs, manufactured gas plant wastes, chemical spills, and tank leaks. Included full scale risk analysis tools, and a site screening and prioritization system patterned after the EPA's CERCLA Hazard Ranking System, but with modifications considered appropriate to better map scores to actual site risk.

Nuclear Electric, plc, U.K.—Reviewed and critiqued existing and on-going efforts to value the externalities of different electricity fuel cycles. Prepared a research plan in this area for the client to address data gaps in valuing environmental externalities of power.

National Acid Precipitation Assessment Program—Managed Integrated Assessment of the NAPAP program, coordinating analysis activities of researchers in emissions, atmospheric modeling, and effects assessment. Prepared materials impact assessment sections of IA.

Electric Power Research Institute—Developed analysis tool for assessing and managing risks of leaks from underground storage tanks and piping. Analyses produced to support comments on alternative EPA regulatory options addressing leaking underground storage tanks. Tool also applied to assist power companies make tank management decisions.

Stanford University—Developed laboratory worker protocol for air toxics health risk management plan, including statistical design for ambient monitoring program.

Business Strategy and Asset Risk Management Engagements

Promontory Point Resources—Prepared a statutorily-required assessment of the need for a new non-hazardous waste regional landfill in the State of Utah. Report included a detailed estimation of the extent of the market across multiple states that would be more cost-effectively served by a new landfill at the proposed location, for alternative types of waste streams.

[Confidential Power Sector Company]—Performed decision analysis for a company on whether to invest in upgrade or close a large coal-fired generating unit in the company's portfolio, accounting for uncertainties in future natural gas prices, coal costs, energy and capacity prices, and climate policy risks.

Edison Electric Institute—Researched drivers of past energy transitions in electricity sector to evaluate the prospect for continuation of a full transition to natural gas and other low-carbon generation in absence of carbon emissions regulatory drivers. Results discussed in plenary session of EEI CEOs' Leadership Convention in June 2017.

[Confidential Power Sector Company]—Performed decision analysis for a company to optimize its decisions on whether to invest in newly-required pollution controls or replace some or all of its coal-fired generating units with natural gas units.

[Confidential Power Sector Company]—Reviewed reasonableness of an assessment of financial rating risk under the proposed Clean Power Plan to reduce utility CO_2 emissions.

[Confidential private equity firm]—For an equity firm considering a fund investing in carbon offsets, characterized the range of alternative US carbon policy outcomes and the associated financial risks of the investment.

Ameren Missouri—Developed a probabilistic method for the company's integrated resource plan of 2008. Worked with stakeholders to incorporate their comments and issues; wrote requests for approval of approach to the Missouri Public Service Commission; conducted expert elicitations of Ameren subject matter experts; and applied an integrated model of the U.S. to generate inputs of future market conditions for the probabilistic set of scenarios regarding future natural gas prices, carbon prices, and other key inputs that became the foundation of the company's final IRP analysis. Was engaged to also support the company's 2011 IRP, using the same technical approach that was developed for 2008.

[Confidential Diversified Energy Company]—Assessed the sensitivity of profitability of the individual business operations across the varied operations of a large, diversified energy company to alternative future gas price and climate policies. This effort enabled an integrated and internally consistent view of overall corporate risks and opportunities associated with carbon.

Southern Company—Supported senior executives of the company in the planning and development of its May 2005 report to shareholders on climate policy business risk assessment. Activities included the modeling of climate policy scenarios, integration of results into internal corporate analyses, and conducting multi-day workshops for the Board of Directors.

[Confidential Power Companies]—Real-options analysis applied to develop a corporation's emissions trading compliance strategies, accounting for regulatory and market uncertainties. An application to NO_x identified ways to reduce company's compliance costs by over $60 million.

Petro-Canada—Prepared a company-wide assessment of the firm's business strategy and recommended adjustments considering potential new developments in air quality and climate change policy. Developed probabilistic decision analyses for specific asset development projects, which were presented to the firm's CEO and executive team.

U.S. Department of Agriculture, Food Safety and Inspection Service. Worked closely with USDA staff to develop a risk ranking system to support a risk-based procedure for allocating Department resources for sampling for contaminants across the entire US food supply.

Cooperative Research Network of National Rural Electric Cooperative Association—Prepared report explaining business opportunities and strategies for cooperative utilities as participants in upcoming NO_x emissions trading programs.

Comision Federal de Electricidad, Mexico—Developed alternatives for addressing air quality concerns in Mexico through integrated national energy strategy.

Publications

"A Simulation-Based Assessment of Alternative Explanations for Apparent Confounding in 'PM Decomposition' Studies" (with W. Chang, G. Glasgow and B. Ramkrishnan), *Environmental Modeling & Assessment*, Vol. 27, August 2022, pp. 665-692.

"A Simulation-Based Assessment of the Ability to Detect Thresholds in Chronic Risk Concentration-Response Functions in the Presence of Exposure Measurement Error" (with G. Glasgow and B. Ramkrishnan), *PLoS ONE*, Vol 17(3), March 2022, pp. 1-17.

"Using Uncertainty Analysis to Improve Consistency in Regulatory Assessments of Criteria Pollutant Standards" *Risk Analysis*, Vol. 40(3), March 2020, pp. 442-449.

"Setting Air Quality Standards for $PM_{2.5}$: A Role for Subjective Uncertainty in NAAQS Quantitative Risk Assessments?" *Risk Analysis*, Vol. 38(11), November 2018, pp. 2318-2339.

"Integrated Uncertainty Analysis for Ambient Pollutant Health Risk Assessment: A Case Study of Ozone Mortality Risk" (with Garrett Glasgow), *Risk Analysis*, Vol. 38(1), January 2018, pp. 163-176.

"Uncertainty in the Estimated Risk of Lung Function Decrements Owing to Ozone Exposure," (with Garrett Glasgow), *Journal of Exposure Science and Environmental Epidemiology*, Vol. 27(5), September 2017, pp.535-538.

"Consumer's Guide to Regulatory Impact Analysis: Ten Tips for Being an Informed Policymaker" (with Susan Dudley and others), *Journal of Benefit-Cost Analysis* Vol. 8(2), Summer, 2017, pp. 187-204.

"Inconsistencies in Risk Analyses for Ambient Air Pollutant Regulations," *Risk Analysis*, Vol. 36(9), September 2016, pp. 1737-1744. (Received Best Paper Award for 2016 from Society for Risk Analysis.)

"Author Synthesis and Response" *Risk Analysis* (Special Issue on Air Pollution Health Risks) Vol. 36(9), September 2016, pp. 1780-1782.

"Response to Commentary by Fann *et al.* on "Enhancing the Characterization of Epistemic Uncertainties in $PM_{2.5}$ Risk Analyses," *Risk Analysis*, Vol. 35(3), March 2015, pp. 381-384.

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"Cap and Trade, Market Regulation, and Economic Factors in Climate Change." *Global Climate Change Law and Regulations: Planning for a Carbon-Constrained Regulatory Environment*, a Rocky Mountains Minerals Law Foundation Special Institute, New Orleans, LA, January 22-23, 2015.

"An Evaluation of the Robustness of the Visual Air Quality 'Preference Study' Method," *Journal of the Air and Waste Management Association*, Vol. 63(4), April 2013, pp. 405-417.

"Climate Engineering – Alternative Perspective," Chapter 1.2 in *Smart Solutions to Climate Change – Comparing Costs and Benefits*, Bjorn Lomborg (ed.), Cambridge University Press, 2010.

"Evaluation of Health Effects of Ambient Ozone," (with Roger O. McClellan, Mark W. Frampton, and others), *Inhalation Toxicology*, Vol. 21(S2), September 2009, pp. 1-36.

"R&D Policy," (with W. David Montgomery and Lee Lane), Chapter 1.5 in *A Taxing Debate: Climate Policy Beyond Copenhagen*, Ian Marsh (ed.), Growth No. 61, CEDA – the Committee of Economic Development of Australia, August 2009

"Macroeconomic Analysis of American Clean Energy and Security Act of 2009," (with Robert Baron, Scott Bloomberg and others), *USAEE Dialogue*, Vol. 17(2), August 2009, pp. 12-16.

"A Top-Down Bottom-up Modeling Approach to Climate Change Policy Analysis," (with Sugandha D. Tuladhar, Mei Yuan, and others), *Energy Economics*, Vol. 31(S2), July 2009, pp. S223-S234.

"A Statement on the Appropriate Role for Research and Development in Climate Policy," (with Kenneth J. Arrow, Linda R. Cohen and others), *Economists' Voice,* February 2009, pp. 1-4.

"Price, Quantity, and Technology Strategies for Climate Change Policy," (with W. David Montgomery), Chapter 27 in *Human Induced Climate Change: An Interdisciplinary Assessment,* M. Schlesinger *et al.* (eds.), Cambridge University Press, 2007.

"Methods and Results from a New Survey of Values for Eastern Regional Haze Improvements," (with Michael A. Kemp, Timothy H. Savage, and Catherine L. Taylor), *Journal of the Air and Waste Management Association*, Vol. 55, November 2005, pp. 1767-1779.

"Not All Problems Have Been Solved in Emissions Trading." *Natural Gas*, John Wiley & Sons, Inc., December 2001, pp. 15–20.

"An Empirical Mechanistic Framework for Heat Related Illness," (with Nathan Chan, Mark Stacey, and others), *Climate Research*, Vol. 16, January 2001, pp. 133–143.

"Global Climate Change and the Precautionary Principle," (with W. David Montgomery), *Human and Ecological Risk Assessment*, Vol. 6, No. 3, 2000, pp. 399–412.

"Analysis of the Reduction of Carbon Emissions through Tradable Permits or Technology Standards in a CGE Framework," (with E. Balistreri, P. Bernstein, and others), *AERE/Harvard Workshop on Market-Based Instruments for Environmental Protection*, Cambridge, MA, July 18–20, 1999.

"An Integrated Assessment Framework for Climate Change and Infectious Diseases," (with N. Chan, K. Ebi, and others), *Environmental Health Perspectives*, Vol. 107, No. 5, May 1999.

"Preserving Flexibility in the Kyoto Protocol." *Journal of the Forum for Environmental Law, Science, Engineering, and Finance*, August 1998.

"Making Appropriate Comparisons of Estimated and Actual Costs of SO_2 Emissions Reductions under Title IV," Paper 98-TP49.01, *Air and Waste Management Association Conference*, San Diego, CA (June 14–18, 1998).

"The Costs of Reducing Utility SO_2 Emissions—Not as Low as You Might Think," (with Jeremy Platt and Denny Ellerman), Massachusetts Institute of Technology, Center for Energy and Environmental Policy Research, WP-98010, August 1998; a shorter version of the paper was published in *Public Utilities Fortnightly*, May 15, 1998.

"Statistical Shell Game," *EEI's Electric Perspectives*, May-June 1997, pp. 38–52.

How Statistics Can Mislead PM Policy, (with Nathan Y. Chan). Decision Focus Incorporated white paper. March 10, 1997.

"The Real Particulate Matter Culprit: EPA's Flawed Assumptions," Commentary, *Inside EPA's Risk Policy Report*, Vol. 3, No. 2, February 21, 1997, pp. 35–38.

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"Energy Modeling with Environmental Constraints." *Nuclear Energy in the 21st Century—An Environmental Bonus?* Proceedings of the International Conference of the British Nuclear Energy Society, Bath, U.K., April 14–15, 1994.

"Integrated Environmental/Energy Policy Analysis for the U.K," (with Stephen M. Haas), *Global Climate Change: Science, Policy, and Mitigation Strategies*, C. Mathai and G. Stensland, eds., Air and Waste Management Association, 1994.

"A Multi-Attribute Approach to Choosing Adaptation Strategies," (with H. Quan Chu), *Global Climate Change: Science, Policy, and Mitigation Strategies*, C.V. Mathai and G. Stensland (eds.), Air and Waste Management Association, 1994.

"The Effect of Daytime Running Lights on Crashes between Two Vehicles in Saskatchewan: A Study of a Government Fleet," (with G. Sparks, R. Neudorf, and others), *Accident Analysis and Prevention*, Vol. 25, No. 5, 1993, pp. 619–625.

"Issues in Implementing Tradable Allowances for Greenhouse Gas Emissions." Paper 91–169.4, *Proceedings of the Air & Waste Management Association Conference*, Vancouver, BC, June 1991.

"Environmental Policy Assessment in the 1990s," (with J. D. Scheraga), *Forum for Social Economics,* Autumn 1990.

"A Probabilistic Model for Assessing Damages of Acid Deposition to Painted Surfaces." *Acid Rain: Scientific and Technical Advances*, Selper Ltd., London, 1987.

"TANKS: A Software Tool for Managing the Risks of Underground Storage Tanks." *Managing Environmental Risks*, Air Pollution Control Association, Washington, D.C., 1987.

Development of Decision Analysis Methodology for Health Risk Assessment – An Illustrative Application to Alternative Air Quality Standards for Carbon Monoxide, (with P. McNamee and M. W. Merkhofer). SRI International Report prepared for U.S. Environmental Protection Agency under Contract 68-02-3575, 1983.

"The Costs and Benefits of Sulphur Oxide Control," (with R. Barnes and G. Parkinson), *Journal of the Air Pollution Control Association*, 1983.

Current Memberships in Professional Societies

Air and Waste Management Association (AWMA)
Association of Environmental and Resource Economists (AERE)
Institute for Operations Research and the Management Sciences (INFORMS)
International Association for Energy Economics (IAEE)
Society for Benefit-Cost Analysis (SBCA)
Society for Risk Analysis (SRA)
United States Association for Energy Economics (USAEE)

ATTACHMENT B

Copy of EPA State and Local Environment and Energy Program, "CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool: How COBRA Works" slide presentation, March 2021. Available at: https://www.epa.gov/sites/default/files/2021-03/documents/how_cobra_works_mar2021_508.pdf.

Estimating the Co-Benefits of Clean Energy Policies

State and Local
Energy and Environment Program

CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool: **How COBRA Works**

Air Quality | Human Health | Societal Benefits

United States
Environmental Protection
Agency

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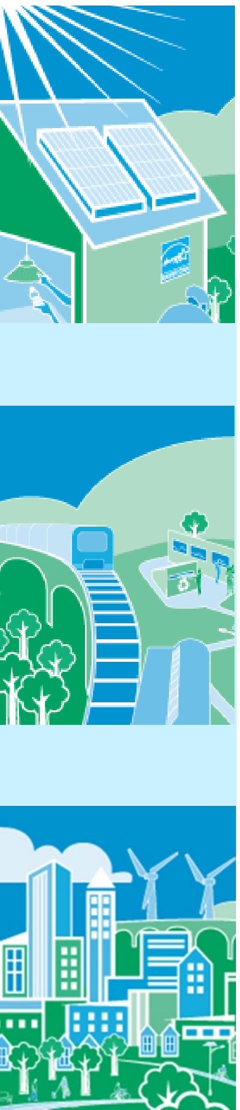
March 2021

What is COBRA?

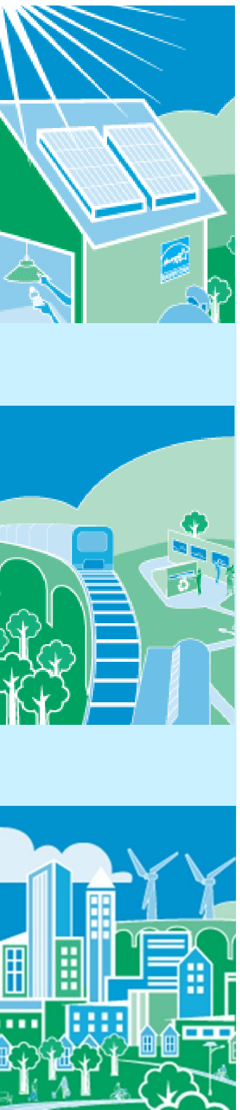


- The CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool is a peer reviewed screening tool that inexpensively and quickly estimates the air quality, human health, and associated economic impacts of various state- and county-level emission reduction scenarios.
  - The model estimates and maps the health effects and related economic value of the effects by county for state, region, U.S.

- COBRA is based on rigorous methods used by EPA health benefits assessments and adapted for use as a screening model.

- COBRA enables users to obtain a first order approximation of costs and benefits of different emission scenarios that can be used to narrow a long set of promising options to a smaller list which can be evaluated using more sophisticated air quality models.

How Does COBRA Work?



Users enter emissions change(s) and discount rate for 2016, 2023 or 2028

- $PM_{2.5}$, SO_2, NO_x, NH_3, VOCs

COBRA:

Quantifies Changes in Air Quality

- Uses a simple air quality model, the Source Receptor (S-R) Matrix, to estimate effects of changes on ambient particulate matter.

Calculates Change in Health Outcomes

- Uses "canned" concentration response functions to link the changes in particulate matter to epidemiological studies[1]

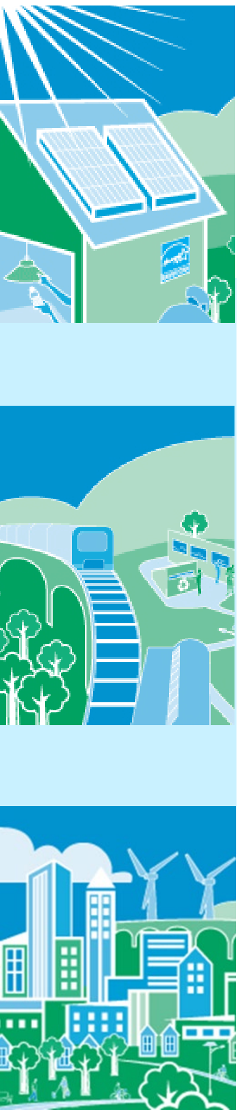
Calculates Monetary Value

- Uses "canned" values based on willingness-to-pay, cost of illnesses , value of a statistical life and direct medical costs.

Outputs = Tables and maps of illnesses and deaths avoided and the related economic value.

[1] COBRA excludes benefits beyond particulate matter-related ones and may be conservative in that respect.

Human Health Effects in COBRA



- COBRA estimates the number of health incidences avoided AND the related economic value for the following:
  - Adult Mortality,
  - Infant Mortality,
  - Non-fatal Heart Attacks,
  - Respiratory Hospital Admissions,
  - Cardiovascular-related Hospital Admissions,
  - Acute Bronchitis,
  - Upper Respiratory Symptoms,
  - Lower Respiratory Symptoms,
  - Asthma Exacerbations (attacks, shortness of breath, & wheezing),
  - Asthma Emergency Room visits,
  - Minor Restricted Activity Days,
  - Work Loss Days

Economic Values of Effects in 2023: Unit Values

Health Incident Avoided	Economic Value (2017$)	
	3% discount rate	7% discount rate
Adult Mortality	$9,748,682	$8,682,996
Infant Mortality	$10,866,012	$10,866,012
Non-Fatal Heart Attacks	$39,174 – $309,825	$37,038 - $297,494
Hospital Admissions	$17,655 - $47,581	$17,655 - $47,581
Asthma ER Visits	$457 - $547	$457 - $547
Acute Bronchitis	$550	$550
Respiratory Symptoms	$24 - $38	$24 - $38
Asthma Exacerbations	$66	$66
Minor Restricted Activity Days	$78	$78
Work Loss Days	$178	$178

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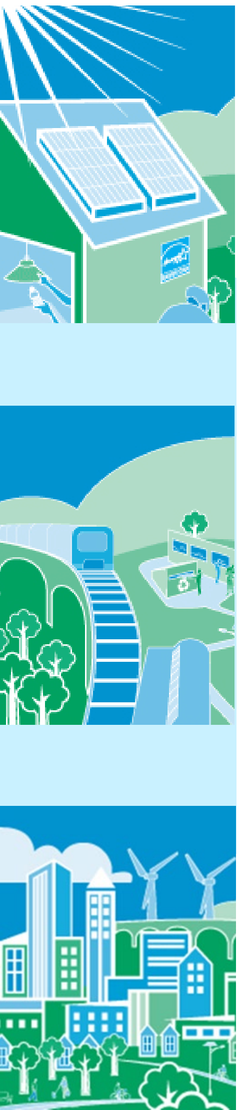
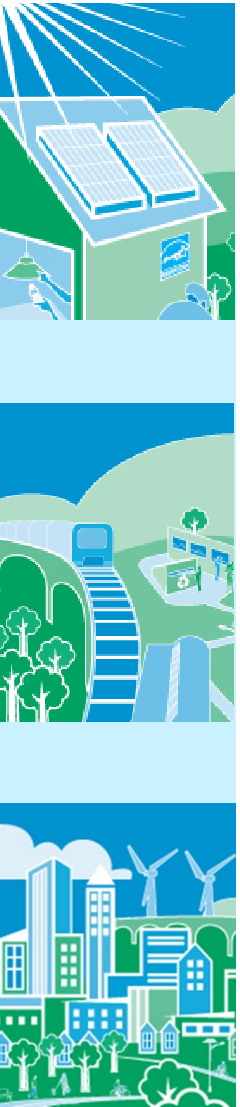
Economic Values of Effects: Sources



Health Incident Avoided	Source of Value
Adult Mortality	VSL*
Infant Mortality	VSL*
Non-Fatal Heart Attacks	Cost of Illness (COI) = Direct medical costs, opportunity cost (OC)
Hospital Admissions	COI = Hospital charges, OC
Asthma ER Visits	COI = Costs to the hospital
Acute Bronchitis	WTP = Coughing and chest tightness (CT) or restricted activity day
Respiratory Symptoms	WTP = Symptoms such as coughing, head/sinus congestion, eye irritation, CT, coughing up phlegm, and/or wheeze
Asthma Exacerbations	WTP = Bad asthma day
Minor Restricted Activity Days	WTP = Combination of coughing, throat congestion, and sinusitis
Work Loss Days	WTP = Median annual earnings divided by (5 × 52)

For more background on the VSL, see:
https://www.epa.gov/environmental-economics/mortality-risk-valuation

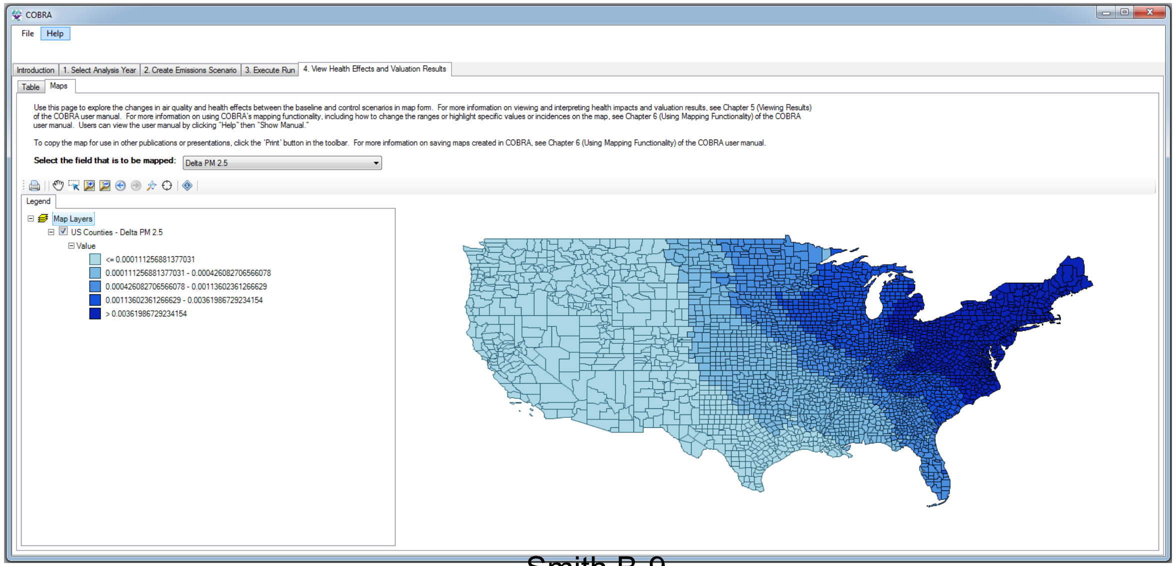
Strengths of COBRA



- Enriches discussion of co-benefits and supports a balanced decision-making process that considers both the potential costs and benefits of policy choices.
- Easy-to-Use screening tool
  - Requires minimal inputs
  - Includes "canned" equations and approaches generally consistent with EPA practices
  - Detailed User's Guide describes all assumptions and equations
- Flexible for User
  - Can enter data for a single county, statewide, group of counties, outside of state, and/or group of states
  - Can enter reductions in absolute terms or as percentage change
  - Can import custom databases on emissions, population, and disease incidence, which allows the user to vary time timeframe for analysis
  - Can import custom equations (C-R functions, economic values)
  - Can save scenarios to reuse or modify later

Strengths of COBRA

- Inexpensive (free!) compared to rigorous air quality models
  - Results from COBRA approach have fared well in informal comparisons;
  - Enables analysts to narrow a list of options at no/low cost and then devote resources to analyzing only those options with the best prospects using more expensive air quality models.
- Quick to generate results
- Mapping of results facilitates visualization of impacts
  - Provides very localized health effects and valuations: county level



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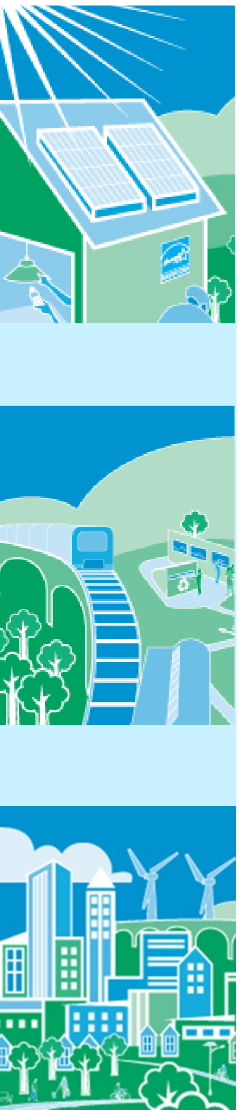
Limitations of COBRA



- EPA is a free, screening tool not a highly sophisticated model.
  - Air Quality (AQ) model is "quick and dirty"
    - COBRA is best used as screening tool, followed up with comprehensive AQ analysis and health impact assessment
  - Does not address cap issues
  - Relies upon inputs generated elsewhere
    - Assumptions about statewide % reductions may be an oversimplification

- While there are limitations that users should understand, technical peer reviewers found COBRA to be "a valuable model that produces a screening tool that can contribute to policy analysis and public dialogue."

How can I learn more?

Visit Our Website to find all of the documentation for COBRA and to download the model:

https://www.epa.gov/cobra

Contact EPA:

Emma Zinsmeister

EPA State and Local Energy and Environment Program

(202) 343-9043

Zinsmeister.Emma@epa.gov

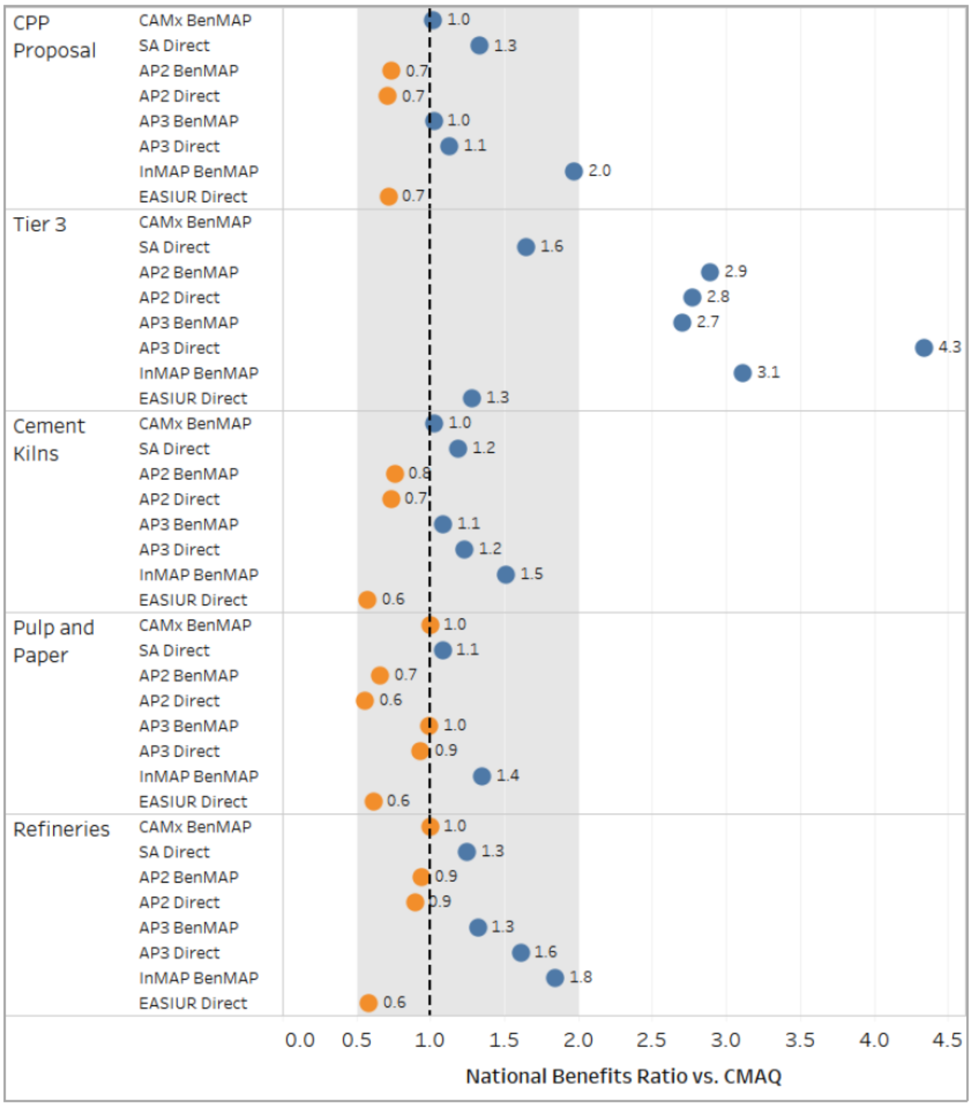
State and Local
Energy and Environment Program

ATTACHMENT C

Copies of Exhibit ES-4 and Exhibit 3-4 from IEc, "Evaluating Reduced-Form Tools for Estimating Air Quality Benefits," Final Report, October 31, 2019. Available at: https://www.epa.gov/sites/default/files/2020-09/documents/adapted_rft_report_10.31.19.pdf.

Copy of IEc, Exhibit ES-4

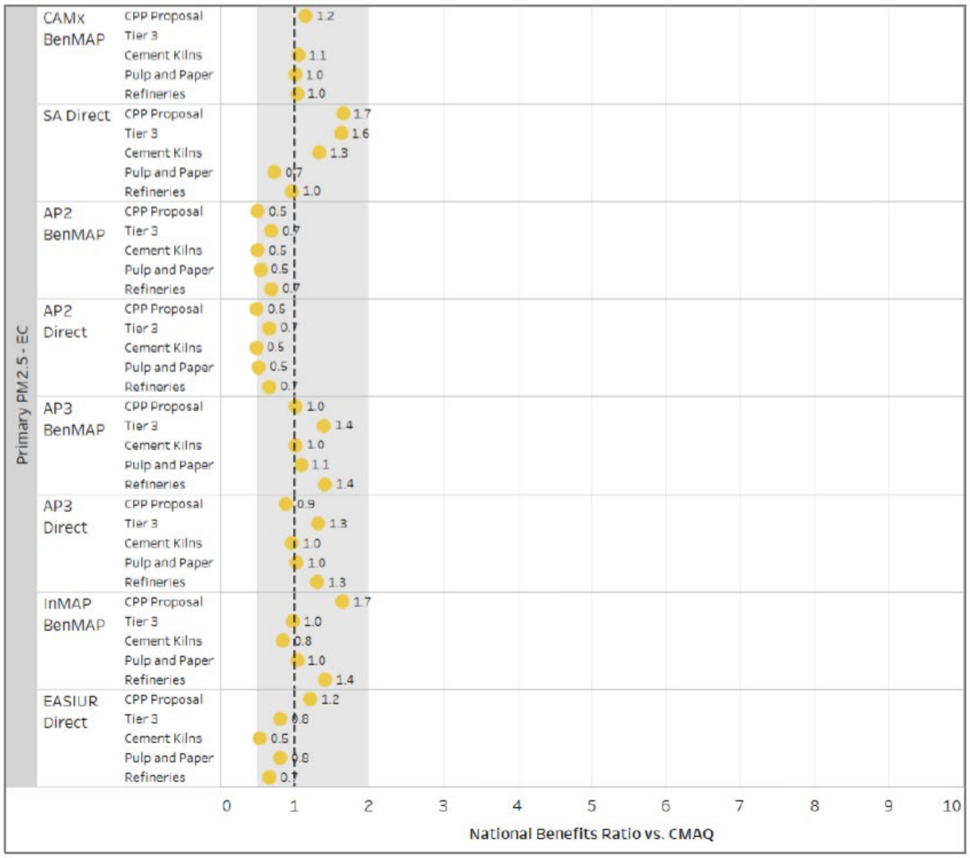
EXHIBIT ES-4. RATIO OF NATIONAL AVOIDED PREMATURE MORTALITY BENEFITS ESTIMATES COMPARED AGAINST CMAQ ESTIMATES, BY POLICY SCENARIO. ORANGE DOTS REPRESENT RATIOS LESS THAN 1 AND BLUE DOTS RATIOS GREATER THAN 1.



Copy of IEc, Exhibit 3-4, (panel 1 of 3)

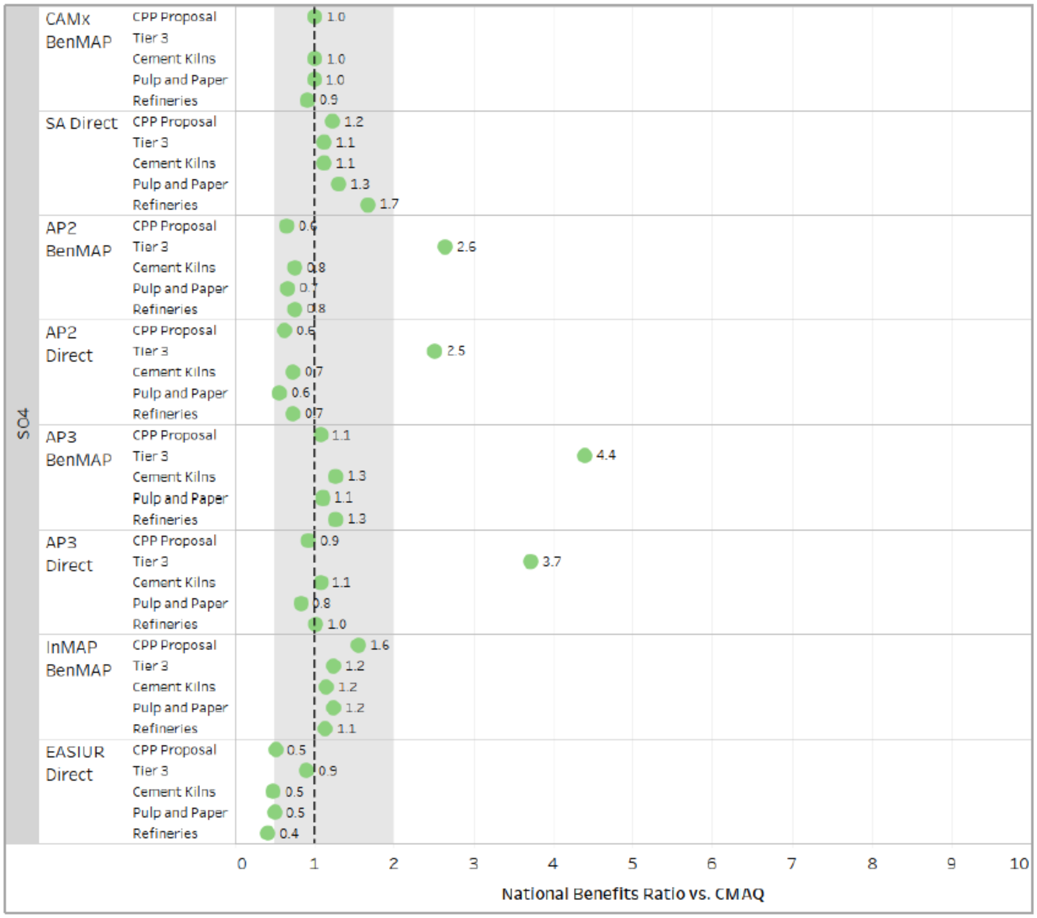
EXHIBIT 3-4. RATIO OF REDUCED-FORM TO FULL-FORM NATIONAL AVOIDED PREMATURE MORTALITY BENEFITS BY $PM_{2.5}$ SPECIES FOR EACH MODEL AND POLICY SCENARIO

PRIMARY $PM_{2.5}$ (EC ONLY):



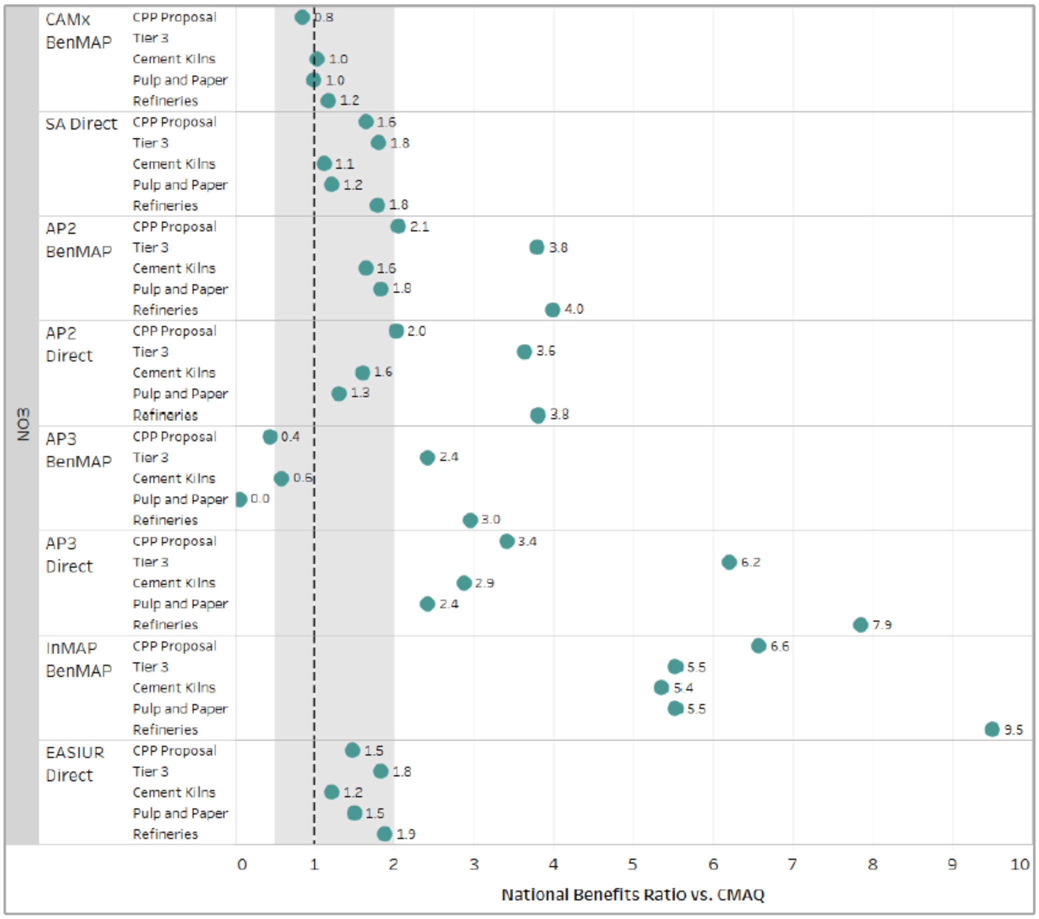
Copy of IEc, Exhibit 3-4, cont'd (panel 2 of 3)

SULFATE:



Copy of IEc, Exhibit 3-4, cont'd (panel 3 of 3.

NITRATE[21]:



ATTACHMENT D

Copy of spreadsheet named “BE Application Portfolio Benefits.xlsx.” (provided as SCE Response to Data Request Cal. Advocates-SCE-001, Q.7, Attachment).

	B	C	D	E	F	G	H
1	**act Analysis**						
2	**Source->**	**BE Application**	**BE Application**	**BE Application**	**BE Application**	**EE Workpaper**	**EE Workpaper**
3							
4	**Program**	**Customer/ Location Type**	**Measure**	**Quantity**	**Units**	**Tons per Unit**	**EUL**
8		Non-Equity	Ductless Mini-Split Heat Pump (SEER 18, HSPF 9.8)	33,458	per System	2	15
9		Non-Equity	Heat Pump HVAC Central SEER>=18 and HSPF>=9.7	14,339	per System	3.5	15
10		Non-Equity	Heat Pump Water Heater, >45 to ≤55 Gal, UEF=3.09	89,549	per System	N/A	10
11	**BE Ready Home - Total**	**All**	**All**	**199,080**	**per System**		
12							
13	BE Business	Equity	Commercial SEER-rated package heat pump 1 stage, < 65 kBtu/h SEER15 HSPF8.2	13,907	per System	3.6	15
14		Equity	Commercial SEER-rated split heat pumps, < 65 kBtu/h SEER15 HSPF8.7	271	per System	3.6	15
15		Equity	Commercial IEER-rated package heat pump, 65 to 134 kBtu/h IEER15.0 COP3.4	1,400	per System	8.9	15
16		Equity	Commercial IEER-rated package heat pump, 135 to 239 kBtu/h IEER15.5 COP3.2	1,400	per System	15	15
17		Equity	Commercial IEER-rated package heat pump, 240 to 760 kBtu/h IEER13.0 COP3.2	525	per System	29.4	15
18		Non-Equity	Commercial SEER-rated package heat pump 1 stage, < 65 kBtu/h SEER15 HSPF8.2	25,048	per System	3.6	15
19		Non-Equity	Commercial SEER-rated split heat pumps, < 65 kBtu/h SEER15 HSPF8.7	489	per System	3.6	15
20		Non-Equity	Commercial IEER-rated package heat pump, 65 to 134 kBtu/h IEER15.0 COP3.4	2,522	per System	8.9	15
21		Non-Equity	Commercial IEER-rated package heat pump, 135 to 239 kBtu/h IEER15.5 COP3.2	2,522	per System	15	15
22		Non-Equity	Commercial IEER-rated package heat pump, 240 to 760 kBtu/h IEER13.0 COP3.2	946	per System	29.4	15
23	**BE Business - Total**	**All**	**All**	**49,031**	**per System**		
24							
25	BE Ready Catalina	Equity	Heat Pump Water Heater, >45 to ≤55 Gal, UEF=3.09	1259	per System	N/A	10
26		Equity	Heat Pump HVAC Central SEER>=18 and HSPF>=9.7	126	per System	3.5	15
27		Equity	Ductless Mini-Split Heat Pump (SEER 18, HSPF 9.8)	504	per System	2	15
28		Equity	Electric Range with Induction Cooktop	378	per System	N/A	10
29		Equity	Heat Pump Clothes Dryer, Standard Size, Vented, Any Voltage Replacing Gas Clothes	165	per System	N/A	10
30	**BE Ready Catalina - Total**	**All**	**All**	**2,432**	**per System**		
31							
32	**BE Application Total**	**All**	**All**	**250,543**	**per System**		
33							

Impact Analysis

I	J	K	L	M	N	O	P
EE Workpaper	**Calculation or EE Workpaper**	**Calculation**	**Calculation**	**EE Workpaper**	**Calculation or EE Workpaper**	**Calculation**	**Calculation**
		Incremental kWh Sales				**Therms Reduction**	
Annual kWh per Ton	**Annual kWh per System**	**Annual kWh per Measure**	**Lifecycle kWh per Measure**	**Annual Therms per Ton**	**Annual Therms per System**	**Annual Therms per Measure**	**Lifecyle Therms per Measure**
323	646	21,604,993	324,074,899	134	268	8,981,802	134,727,030
430	1,505	21,575,216	323,628,238	80	279	4,000,875	60,013,127
N/A	1,470	131,636,873	1,316,368,728	N/A	201	17,999,328	179,993,275
		253,507,770	**2,847,116,551**				**542,755,305**
89	320	4,450,660	66,759,904	29	106	1,476,434	22,146,513
84	302	81,920	1,228,797	29	106	28,799	431,978
120	1,066	1,492,359	22,385,378	22	196	274,591	4,118,863
129	1,935	2,710,018	40,650,276	22	327	458,070	6,871,043
124	3,644	1,913,638	28,704,568	20	588	308,663	4,629,948
89	320	8,016,175	120,242,628	29	106	2,659,236	39,888,537
84	302	147,547	2,213,211	29	106	51,870	778,044
120	1,066	2,687,917	40,318,762	22	196	494,571	7,418,568
129	1,935	4,881,070	73,216,044	22	327	825,038	12,375,577
124	3,644	3,446,692	51,700,385	20	588	555,940	8,339,095
		29,827,997	**447,419,951**				**106,998,165**
N/A	1,470	1,851,171	18,511,710	N/A	201	253,119	2,531,193
430	1,505	189,481	2,842,209	80	279	35,137	527,055
323	646	325,272	4,879,082	134	268	135,225	2,028,371
N/A	207	78,277	782,772	N/A	14	5,420	54,204
N/A	270	44,663	446,631	N/A	13	2,098	20,978
		2,488,864	**27,462,403**				**5,161,802**
		285,824,631					**654,915,271**

Q	R	S	T	U	V	W	X	Y
EE Workpaper (E2E)	**Calculation or EE Workpaper (E2E)**	**Calculation**	**EE Fuel Sub Calculator**	**Calculation or EE Fuel Sub Calculator**	**Calculation**	**Research (see column AC)**	**Calculation**	**Calculation**
kW			**mmBTU**			**Bill Savings**		
kW per Ton	**kW per System**	**kW per Measure**	**Lifecycle mmBTU per ton**	**Lifecycle mmBTU per System**	**Lifecycle mmBTU per Measure**	**Annual Bill Savings per System**	**Lifecycle Bill Savings per System**	**Lifecyle Bill Savings per Measure**
0.138	0.276	9,234	185	371	12,412,511	$350.33	$5,255	$ 175,816,299
0.113	0.396	5,671	98	345	4,942,582	$350.33	$5,255	$ 75,349,842
N/A	-0.134	(12,000)	N/A	150	13,437,020	$64.04	$640	$ 57,343,328
		4,123			**44,589,883**			**$ 446,253,521**
0.04	0.14	1,907	40	144	1,996,250	$ 128	$1,633	$ 22,712,037
0.04	0.14	37	40	144	39,178	$ 132	$1,683	$ 456,665
0.03	0.28	399	26	235	328,777	$ 138	$1,709	$ 2,392,523
0.07	1.10	1,533	24	359	502,163	$ 199	$2,418	$ 3,385,677
0.08	2.24	1,178	27	799	419,512	$ 323	$3,893	$ 2,044,121
0.04	0.14	3,436	40	144	3,595,487	$ 128	$1,633	$ 40,907,114
0.04	0.14	67	40	144	70,564	$ 132	$1,683	$ 822,508
0.03	0.28	718	26	235	592,168	$ 138	$1,709	$ 4,309,223
0.07	1.10	2,762	24	359	904,455	$ 199	$2,418	$ 6,098,011
0.08	2.24	2,122	27	799	755,592	$ 323	$3,893	$ 3,681,707
		14,159			**9,204,147**			**$ 57,862,685**
N/A	-0.134	(169)	N/A	150	188,961	$ 207.64	$2,076	$ 2,614,766
0.113	0.40	50	98	345	43,407	$ 387.66	$5,815	$ 732,267
0.138	0.28	139	185	371	186,876	$ 387.66	$5,815	$ 2,929,069
N/A	0.003	1	N/A	12	4,654	$ (28.56)	-$286	$ (107,898)
N/A	0.042	7	N/A	4	678	$ (66.08)	-$661	$ (109,355)
		28			**424,575**			**$ 6,058,849**
		18,310			**54,218,605**			**$ 510,175,054**

Z	AA
EE Workpaper Details	
EE Workpaper	**Measure Code (EE Workpaper)**
SWHC044-02 Ductless HVAC Residential	AC-21563
SWHC045-01 Heat Pump HVAC, Residential, Fuel Sub	SWHC045D
SWWH025-03_Res HP Water Heater - FS	WH-21496
SWHC046A	AC-21548
SWHC046E	AC-21538
SWHC046N	AC-21533
SWHC046J	AC-21543
SWHC046L	AC-21545
SWHC046A	AC-21548
SWHC046E	AC-21538
SWHC046N	AC-21533
SWHC046J	AC-21543
SWHC046L	AC-21545
SWWH025-03_Res HP Water Heater - FS	WH-21496
SWHC045-01 Heat Pump HVAC, Residential, Fuel Sub	AC-21563
SWHC044-02 Ductless HVAC Residential	AC-21563
SWAP013-01	AP-21489
SWAP014-01	SWAP014D

BE Ready Home Bill Savings:

Residential Building Electrification in California - Consumer economics, greenhouse gases and grid impacts, (April 2019)						
Climate Zone	Utility	Vintage	Home Type	Equipment	Annual Bill Savings	Units
CZ10	SCE	90	SFH	wh	$ 59.49	2018$

BE Ready Catalina Bill Savings: See "BE Ready Catalina_Bill Savings" Excel file fo

BE Business Bill Savings: See "SCE BE Bill Savings V2_Business" Excel file for mo