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SAB Science Integration for Decision Making Fact Finding Interviews
EPA Office of Air and Radiation (OAR) Office of Air Quality Planning and Standards (OAQPS)
January 12, 2010

Schedule and Logistics

Meeting with OAQPS Managers	9:00 to 10:30, Conf. Rm. C500A/RTP-Bldg C
Meeting with OAQPS Scientists	12:00 to 1:30, Conf. Rm C500C/RTP-Bldg C

<u>Logistics</u>

SAB members meet for breakfast and coordination at 7:30 and leave for security screening at the OAQPS offices at 8:30.

SAB Science Integration for Decision Making Fact-Finding Meeting
Meeting with Director, Health and Environmental Impacts Division, OAQPS
Conference Room C500A
109 T.W. Alexander Drive, Durham, NC
Call-in Number for SAB subgroup: 866-299-3188, access code 343-9981 and press the # sign.
January 12, 2010, 9:00-10:30 a.m.

Draft Agenda

Purpose of Interview: to help SAB Committee members learn about OAQPS current and recent experience with science integration supporting EPA decision making so that the SAB can develop advice to support and/or strengthen Agency science integration efforts.

1. Introductions facilitated by the SAB Staff Office

2. Discussion facilitated by SAB Members
   - Practices for integrating science to support decision making
   - Consideration of public, stakeholder, external scientific, and other input in science assessment
   - Drivers and impediments to implementing past recommendations for science integration
   - Ways program receives feedback on how science is used in decision-making
   - Workforce to support science integration for decision making

3. Identification of any follow-up actions

Planned participants

EPA Office of Air Quality Planning and Standards
Ms. Lydia Wegman, Director, Health and Environmental Impacts Division
Dr. Bryan Hubbell, Senior Advisor for Science and Policy Analysis for the Health and Environmental Impacts Division

SAB Committee on Science Integration Committee Members
Dr. Rogene Henderson, Lovelace Respiratory Research Institute
Dr. Thomas Wallsten, University of Maryland

SAB Staff Office
Dr. Anthony Maciorowski, Deputy Director
Dr. Angela Nugent, Designated Federal Officer

SAB Science Integration for Decision Making Fact-Finding Meeting
Meeting with Scientists in the Office of Air Quality Planning and Standards OAQPS
Conference Room C500C
109 T.W. Alexander Drive, Durham, NC
Call-in Number for SAB subgroup: 866-299-3188, access code 343-9981 and press the # sign.
January 12, 2010, 12:00 - 1:30 p.m.

Draft Agenda

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EPA Office of Air Quality Planning and Standards
- Mr. Tyler Fox, Leader of the Air Quality Modeling Group
- Dr. David Guinnup, Leader of the Sector-Based Assessment Group
- Dr. Bryan Hubbell, Senior Advisor for Science and Policy Analysis for the Health and Environmental Impacts Division

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Available Biosketches for OAQPS Managers and Scientists

Mr. Tyler Fox

Tyler Fox leads the Air Quality Modeling Group for EPA's Office of Air Quality Planning and Standards. His group is responsible for air quality modeling support for major air regulations and polices; providing guidance to Regional, state, and local agencies on State Implementation Plans (SIP) and permit modeling for new sources; and coordinating with EPA's Office of Research and Development (ORD) and research community on model development and improvements in modeling science. He has served as group leader for the past five years and worked for the Agency's air office for a total of 10 years. His training is in economics and he has a Master's in Economics from the University of Virginia.

Dr. David Guinnup

A former Professor of Chemical Engineering at North Carolina State University, Dave Guinnup has worked for the United States Environmental Protection Agency as an environmental engineer in the Office of Air Quality Planning and Standards (OAQPS) for 21 years. He currently serves as the Leader of the Sector-Based Assessment Group, where he manages a number of exposure and risk assessment activities for the EPA’s Air Toxics Program, including the residual risk program, the National Air Toxics Assessment (or NATA), and analytical aspects of EPA’s new program, “Assessing Outdoor Air Near Schools.”

Dr. Bryan Hubbell

Bryan Hubbell is Senior Advisor for Science and Policy Analysis for the Health and Environmental Impacts Division in the Office of Air and Radiation in the U.S. Environmental Protection Agency. He has written and presented extensively on the health impacts and economic benefits and costs of air quality regulations, serving as the principal benefits analyst for many of EPA's recent regulatory analyses, and led the project team that developed the environmental Benefits Mapping and Analysis Program (BenMAP). He is currently leading the review of the secondary welfare standards for NOx and SOx. His research interests include health impact assessments methods, integrated climate and air quality assessment models, reduced form air quality modeling, selection of optimal controls to maximize net benefits of air quality regulations, and improving valuation of health and environmental changes.

Air Quality Policy in the U.S.

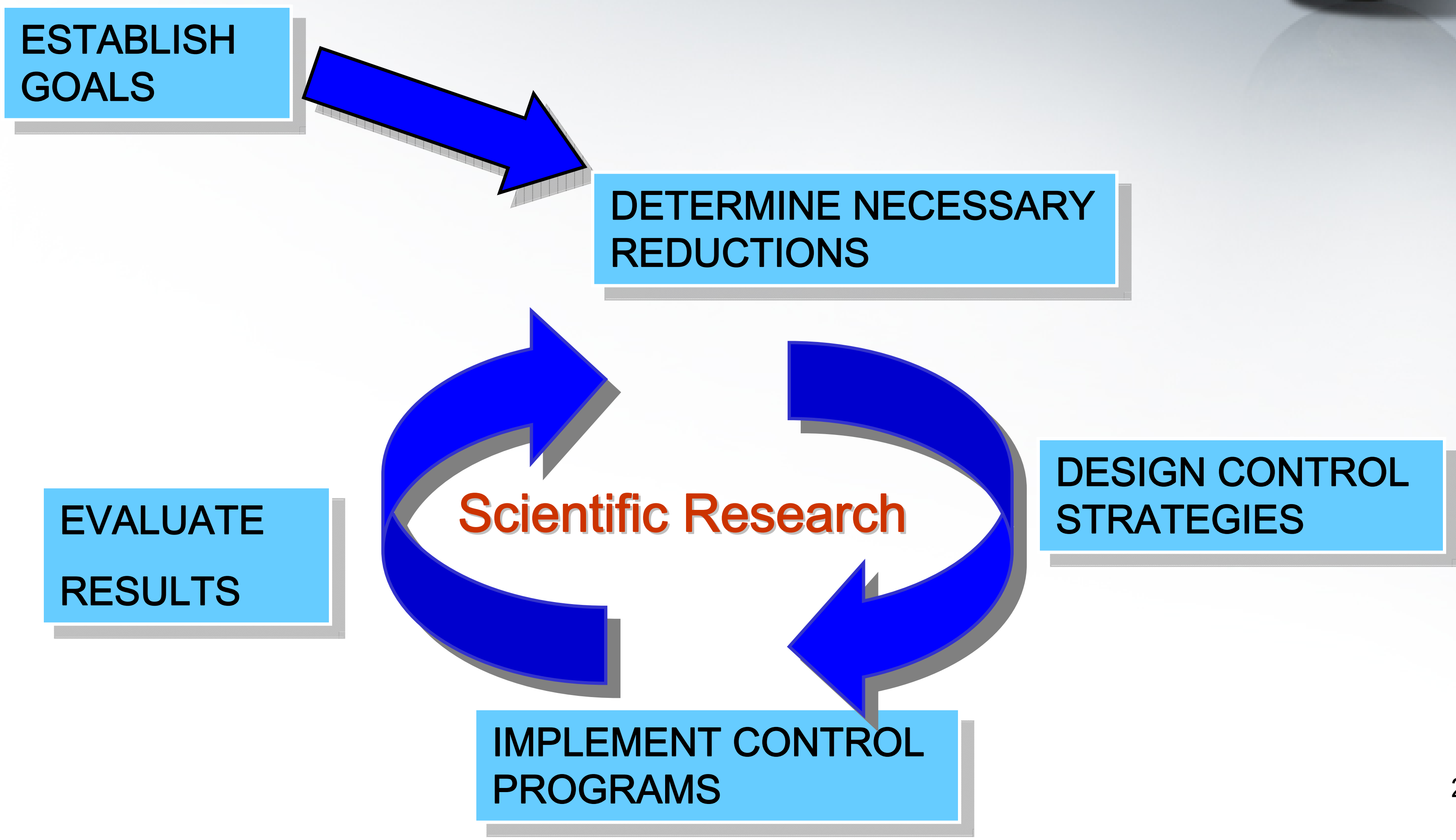
Opening Remarks for the

EnviroCities 2008 International Conference

Sources and Health Effects of Air Pollution:
Knowledge to Practice

November 11, 2008

The U.S. Air Quality Management Process



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Laws, Standards, and Regulations

- Clean Air Act (1970) and Amendments (1990)
- Standards for ubiquitous air pollutants are reviewed every 5 years: PM, Ozone, NOx, SOx, CO, Lead
- Implementation is the responsibility of the states
- National regulations to implement standards issued based on a number of factors:
  - Interstate transport
  - Mobile sources
- Technology and risk standards to address 187 air toxics established and reviewed cyclically

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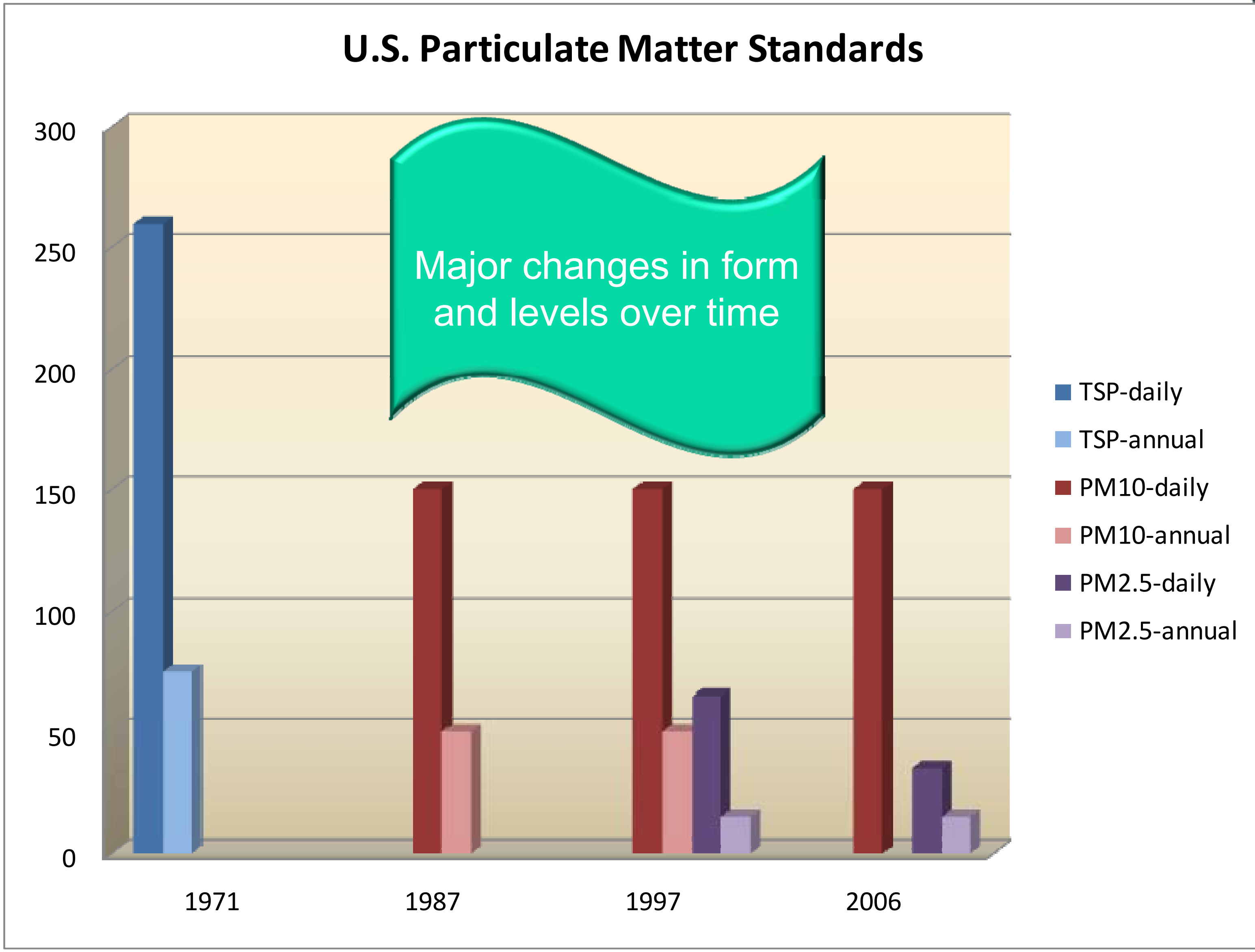
Past and Present Standards

Unchanged since 1971!

CO =	9 ppm 8-hour
	35 ppm 1-hour
NOx =	0.053 ppm annual average
SOx =	0.03 ppm annual average
	0.14 ppm daily average

Past and Present Standards



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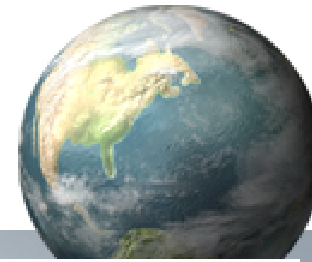
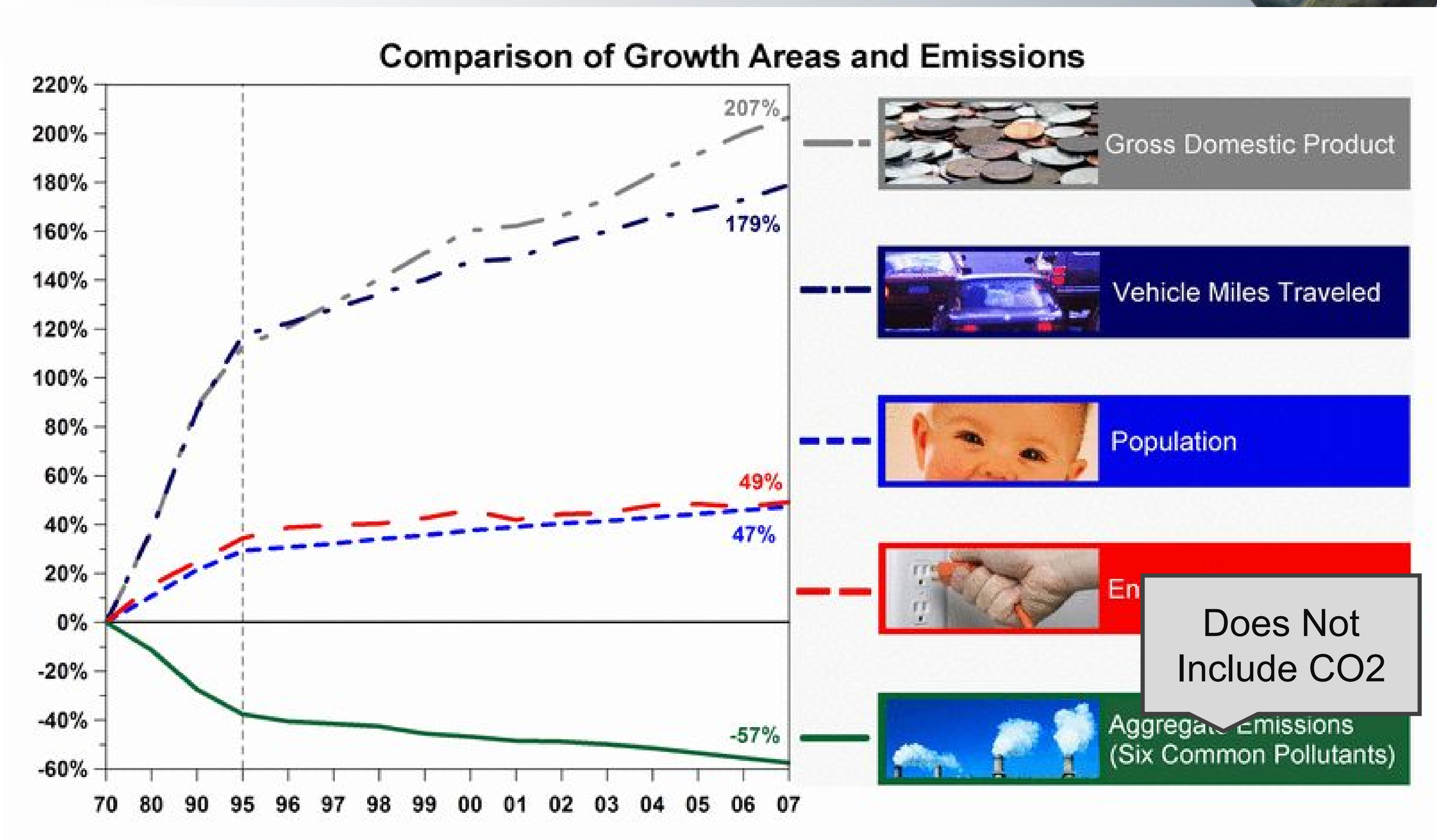
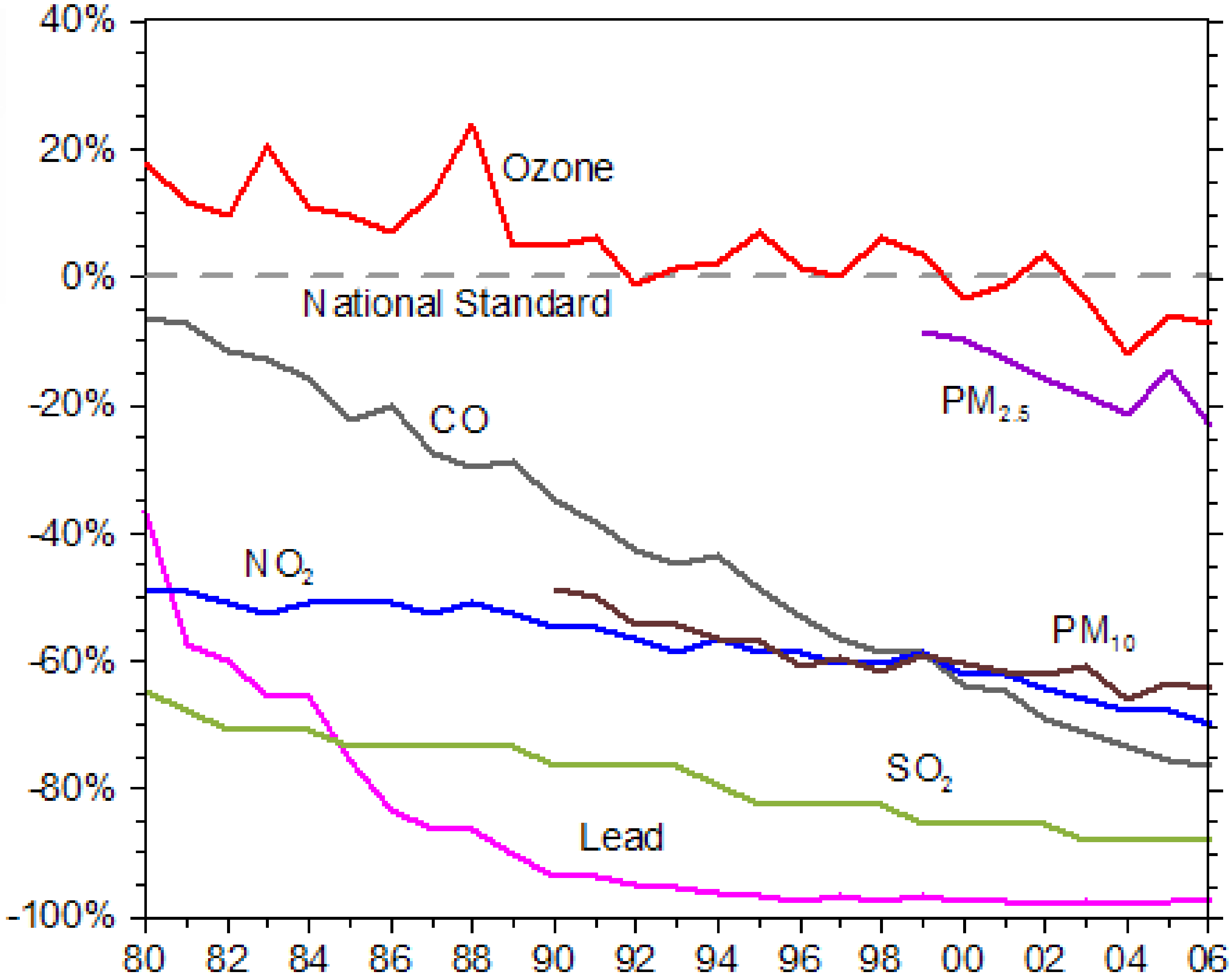
Progress in Implementation





Trends in the Levels of the Six Principle Pollutants Relative to U.S. National Standards: 1980 - 2006



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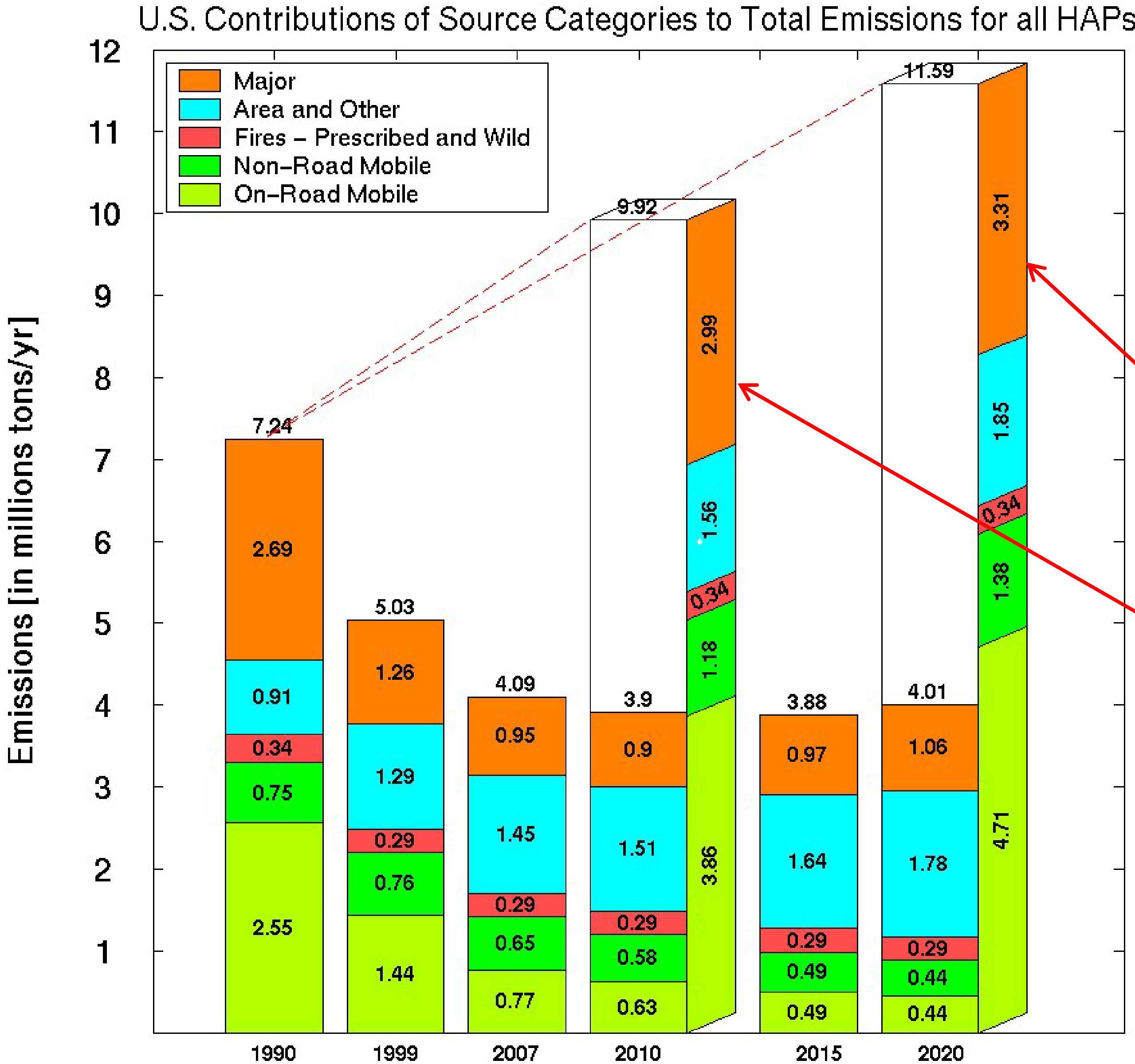
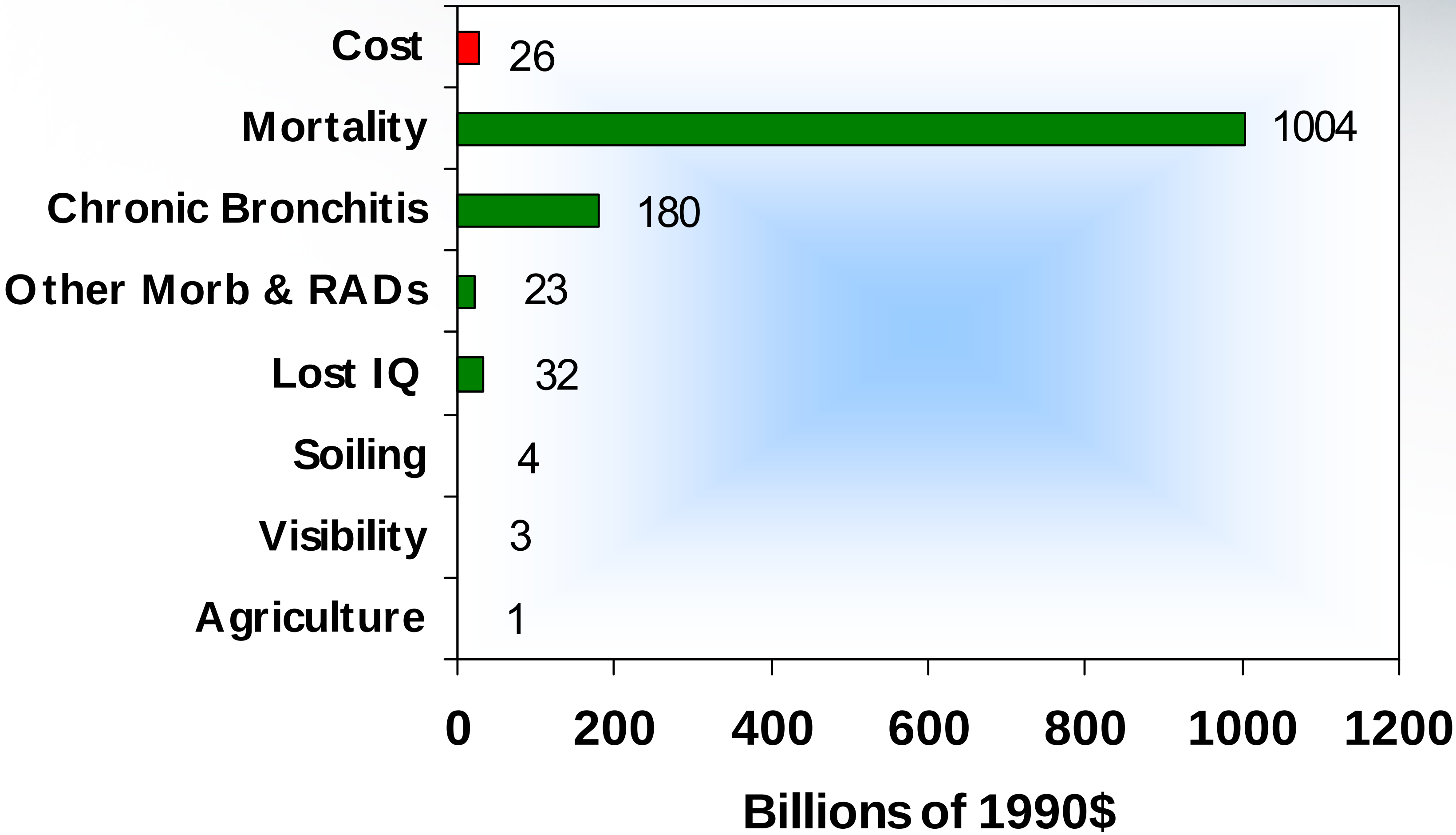
Progress in Reducing National Air Toxics Emissions from 1990 to 2007 and Beyond

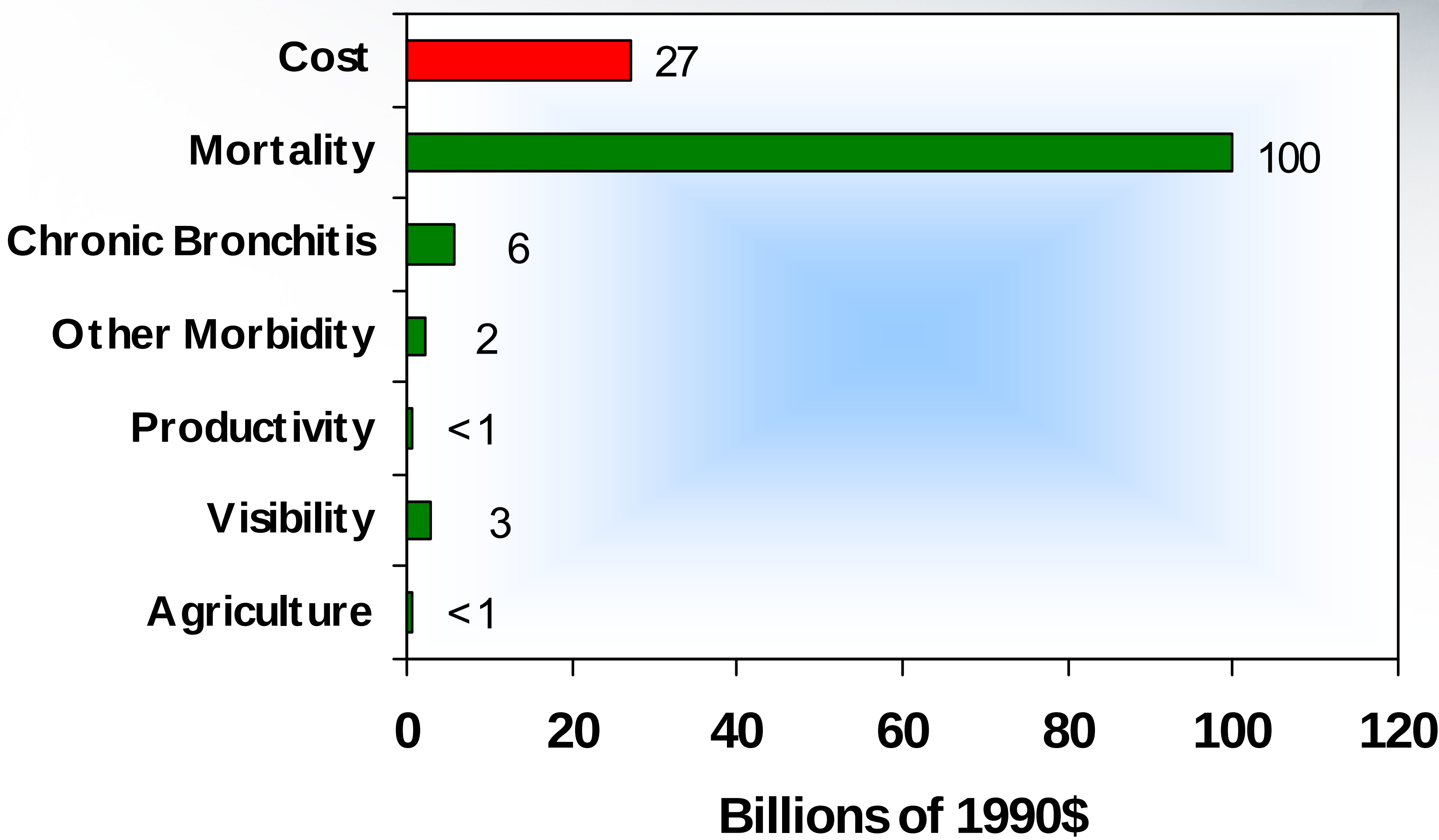


Toxics emissions were expected to get much worse without the Clean Air Act

Annual Benefits and Costs of the 1970 Clean Air Act in 1990



Projected Additional Annual Benefits and Costs of the 1990 Clean Air Act Amendments in 2010



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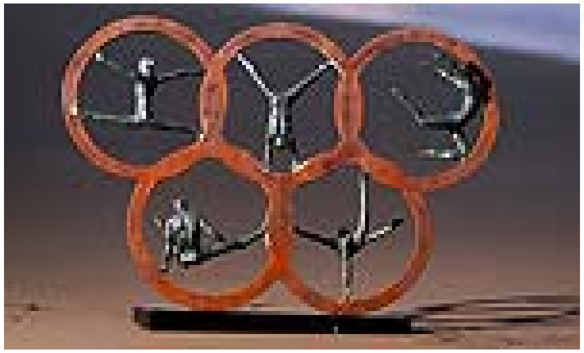
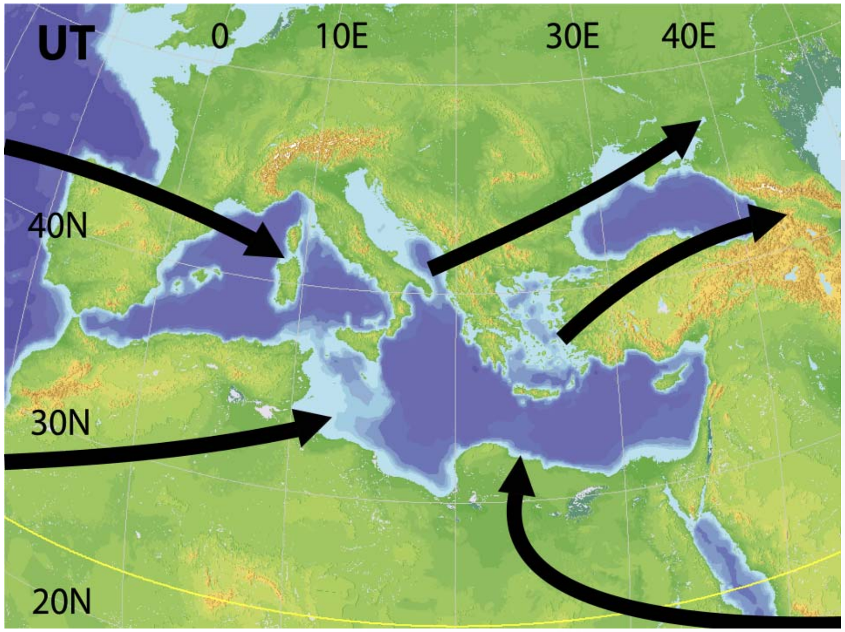
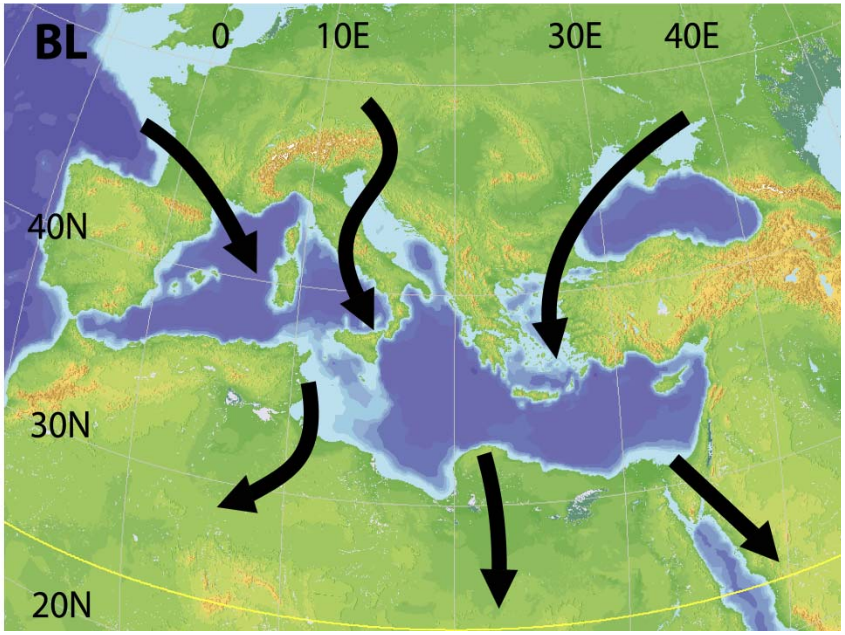
International

- Collaborating with EPA offices and other agencies on **air quality information and forecasting system** for worldwide use
- Supporting **Long-Range Transport of Air Pollution Convention**
- Cooperating with the Chinese on **regional air quality** and **long-range transport** issues, and consulted on **2008 Olympic Games**



Mediterranean: A Cross-Roads for Air Pollution





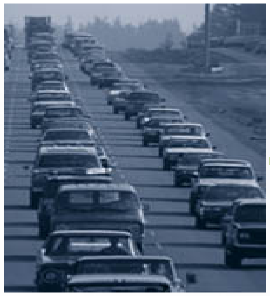
- Upper air flows bring pollution from North America and the Indian Subcontinent
- Boundary layer flows bring pollution from Europe

See Lelieveld et al.
Science 25 October 2002: 794
DOI: 10.1126/science.1075457

What's next?

- Multipollutant approaches
- Sector based approaches
- Interactions between climate and AQ

One-Atmosphere Approach



Mobile Sources

(Cars, trucks, planes, boats, etc.)

Industrial Sources

(Power plants, refineries/ chemical plants, etc.)

Area Sources

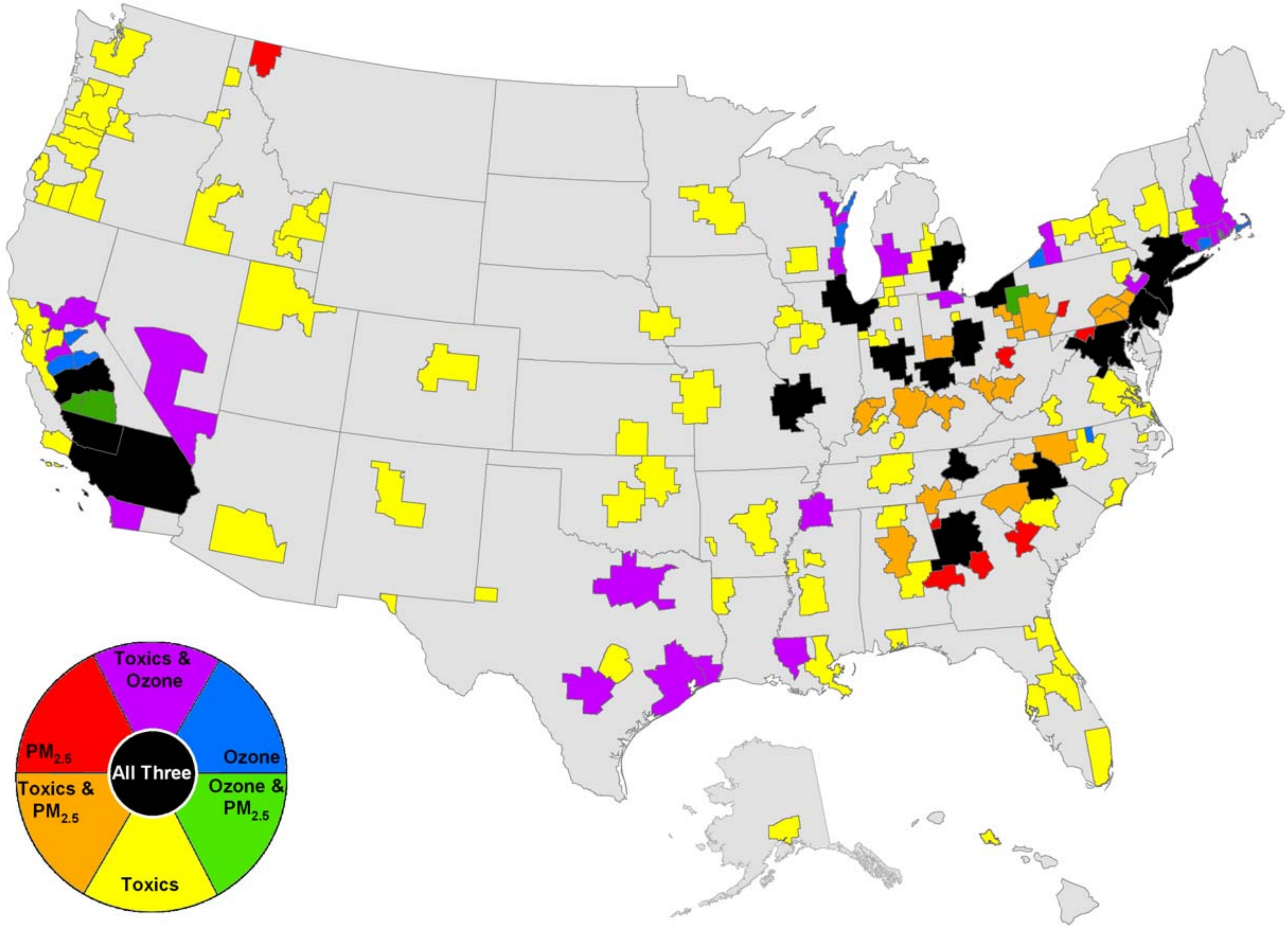
(Residential, farming commercial, biogenic, etc.)

Chemistry

Meteorology

- Ozone
- PM
- Acid Rain
- Visibility
- Air Toxics
- Atmospheric Deposition
- Climate Change

Nexus of PM, Ozone, and Toxics in the U.S.



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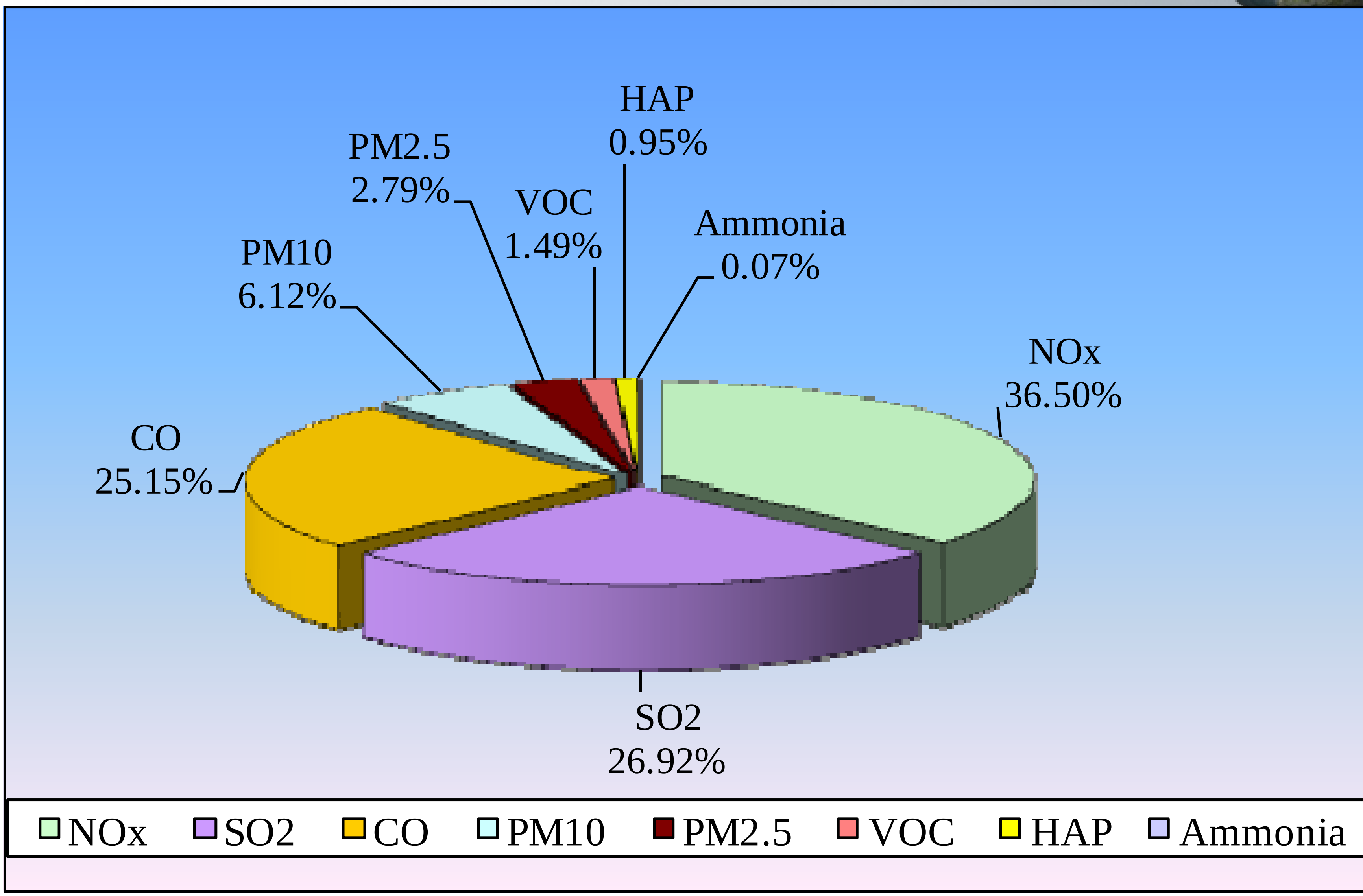
Multipollutant Emissions: Cement Manufacturing Sector



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Thank You!

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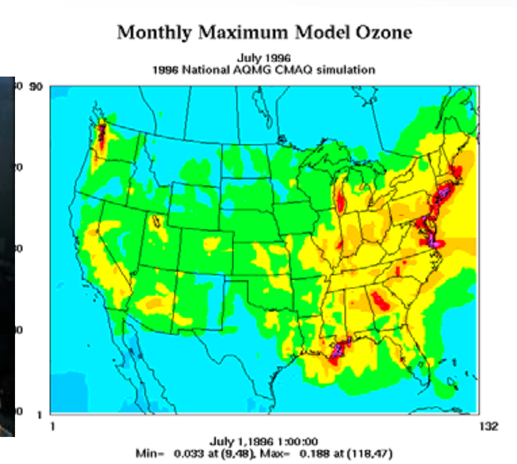
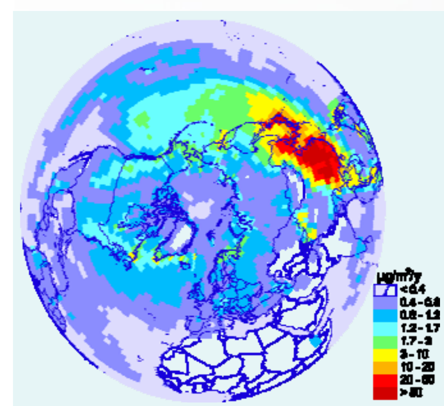
Air Pollution Control in the 21st Century

City	County	State	Regional-National-International

1920 1950 1970 1980 1990 2000





Science and Policy Analysis in the Setting of US EPA Air Quality Standards

EnviroCities 2008 International Conference

Sources and Health Effects of Air Pollution:
Knowledge to Practice

November 11, 2008

Dr. Bryan J. Hubbell
U.S. Environmental Protection Agency
Office of Air and Radiation

Disclaimer: The opinions expressed in this presentation are those of the author and do not reflect opinions or policy of the U.S. EPA

Overview

- The Role of Scientific Review
- The Role of Risk Assessment
- Health Impact and Benefit-Cost Assessments
- Risk Communication

NAAQS Scientific Review

- Workshop on science policy issues
  - Highlight significant new and emerging research
  - Ensure that the review focuses on the key policy-relevant issues and considers the most meaningful new science
- Assessment of peer-reviewed published literature
  - Focus is on new science after the last review – thousands of new studies published in last 5 years
- Integrated Science Assessment document
  - Concise evaluation, integration and synthesis of the most policy-relevant science,
  - Includes key science judgments that will be used in conducting the risk and exposure assessments.

Interactions with the Science Community

- EPA Office of Research and Development – provides STAR grants to promote policy relevant research
- Health Effects Institute – jointly funded by EPA and the auto industry – broadly seen as an independent source for policy relevant research
- International conferences – provide an opportunity for EPA to interact with a wide range of researchers from around the world.

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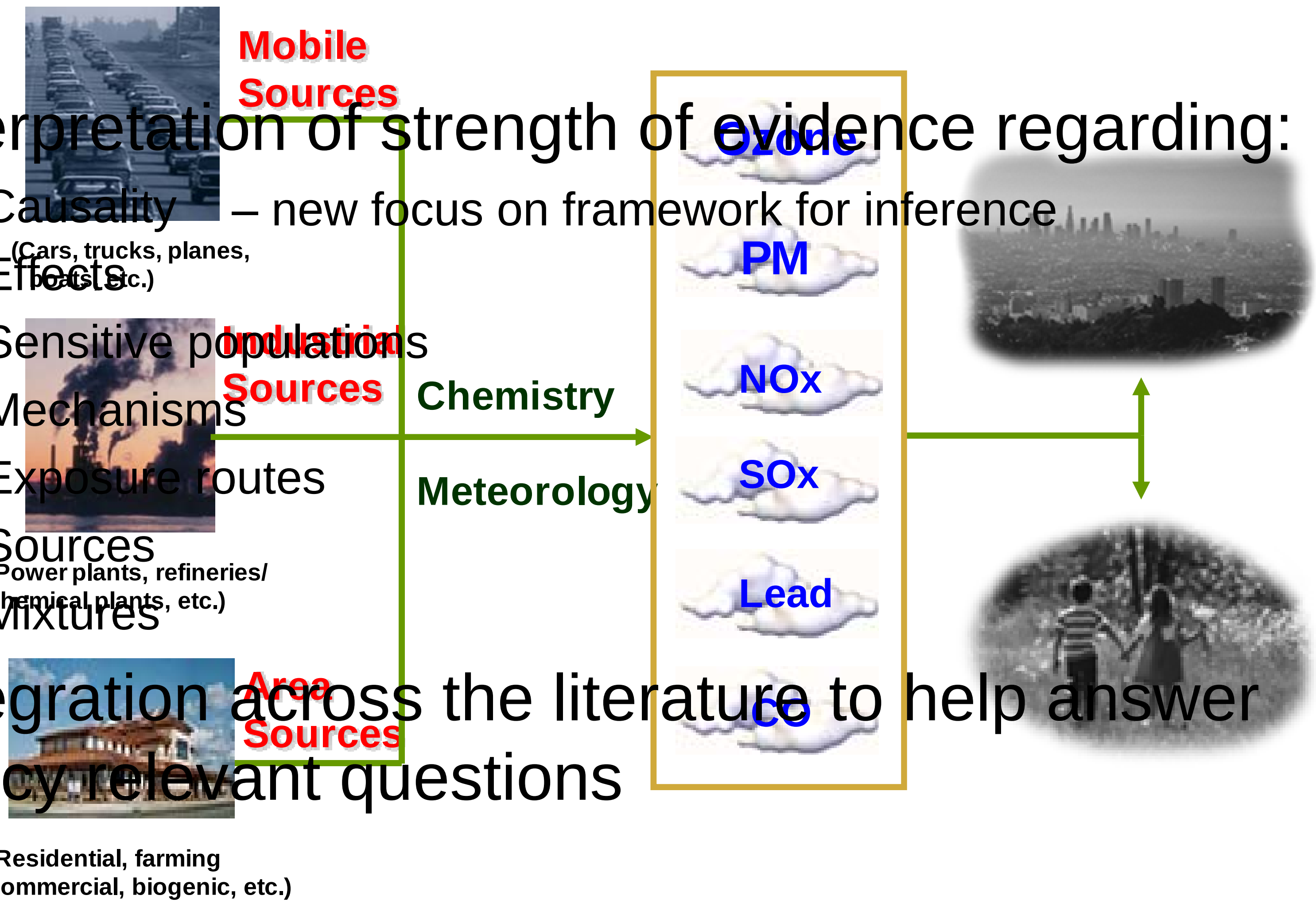
What does the science review offer?

- Understanding of sources, atmospheric chemistry
- Interpretation of strength of evidence regarding:
  - Causality – new focus on framework for inference
  - Effects
  - Sensitive populations
  - Mechanisms
  - Exposure routes
  - Sources
  - Mixtures
- Integration across the literature to help answer policy relevant questions



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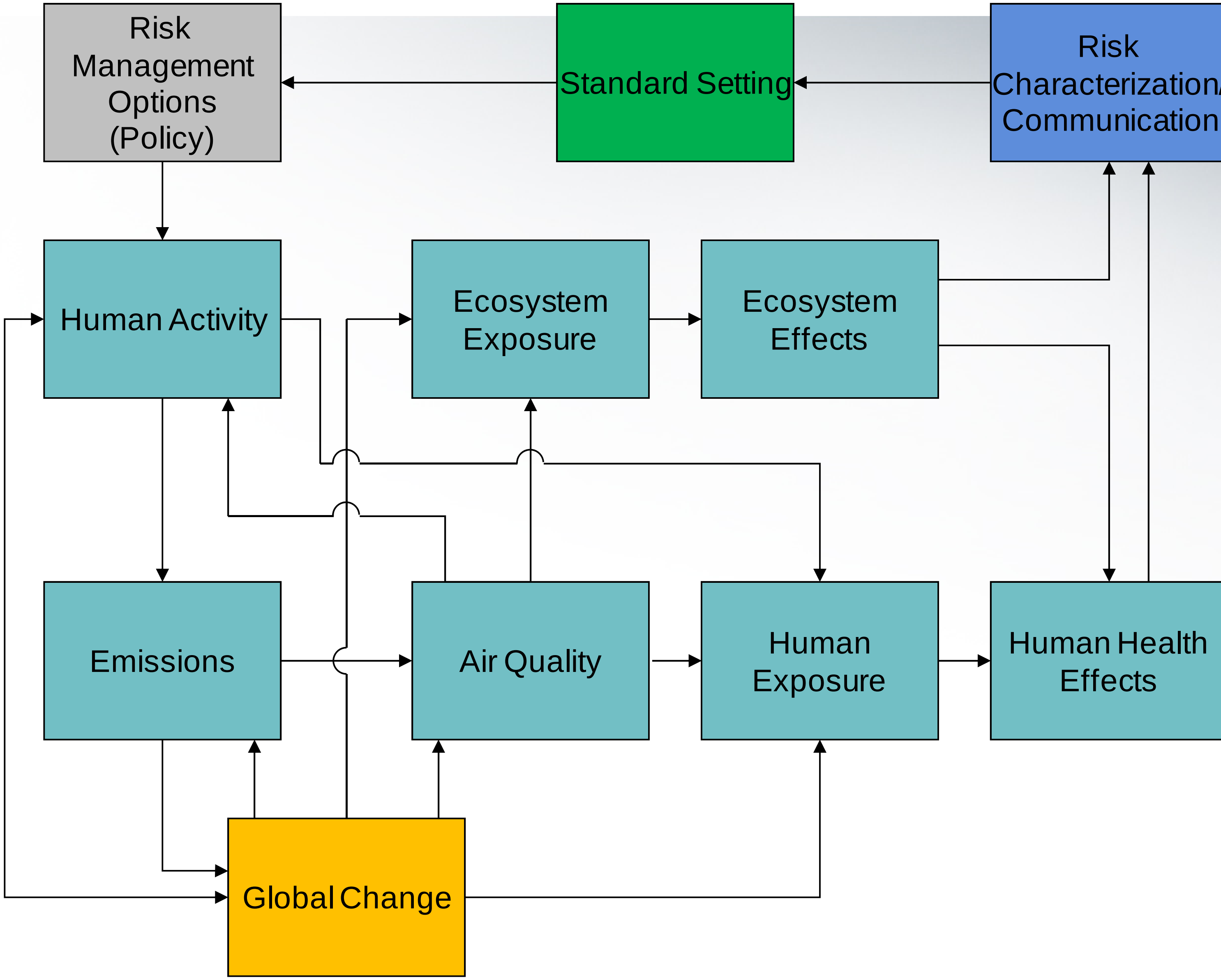
The Role of Risk Assessment

- Designed to estimate human exposures and to characterize the potential health risks that are associated with
  - current ambient pollution levels
  - ambient levels simulated to just meet the current standards
  - ambient levels simulated to just meet alternative standards that may be considered
- Careful consideration of uncertainties

Risk analysis and its components



Science and Risk Assessment in the Setting of Standards

- A policy assessment pulls the scientific evidence and risk assessment results together
- This policy assessment identifies conceptual evidence- and risk-based approaches for reaching policy judgments,
- It discusses what the science and risk/exposure assessments say about
  - the adequacy of the current standards
  - potential alternative standards

Types of Exposure Information Provided

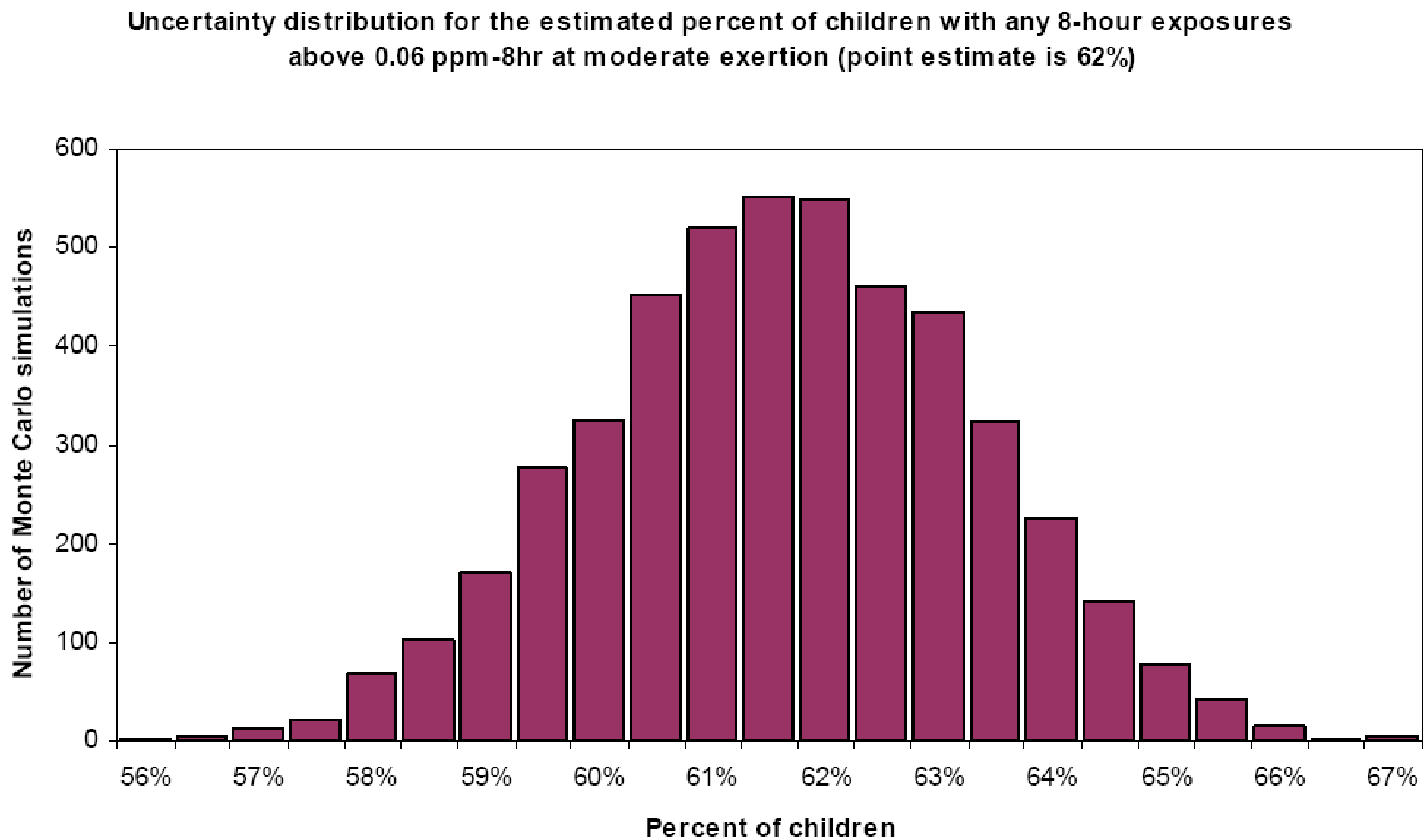


Figure 4-4. Uncertainty of percent of children with exposures above 0.06 ppm-8hr (Boston 2002 base case)

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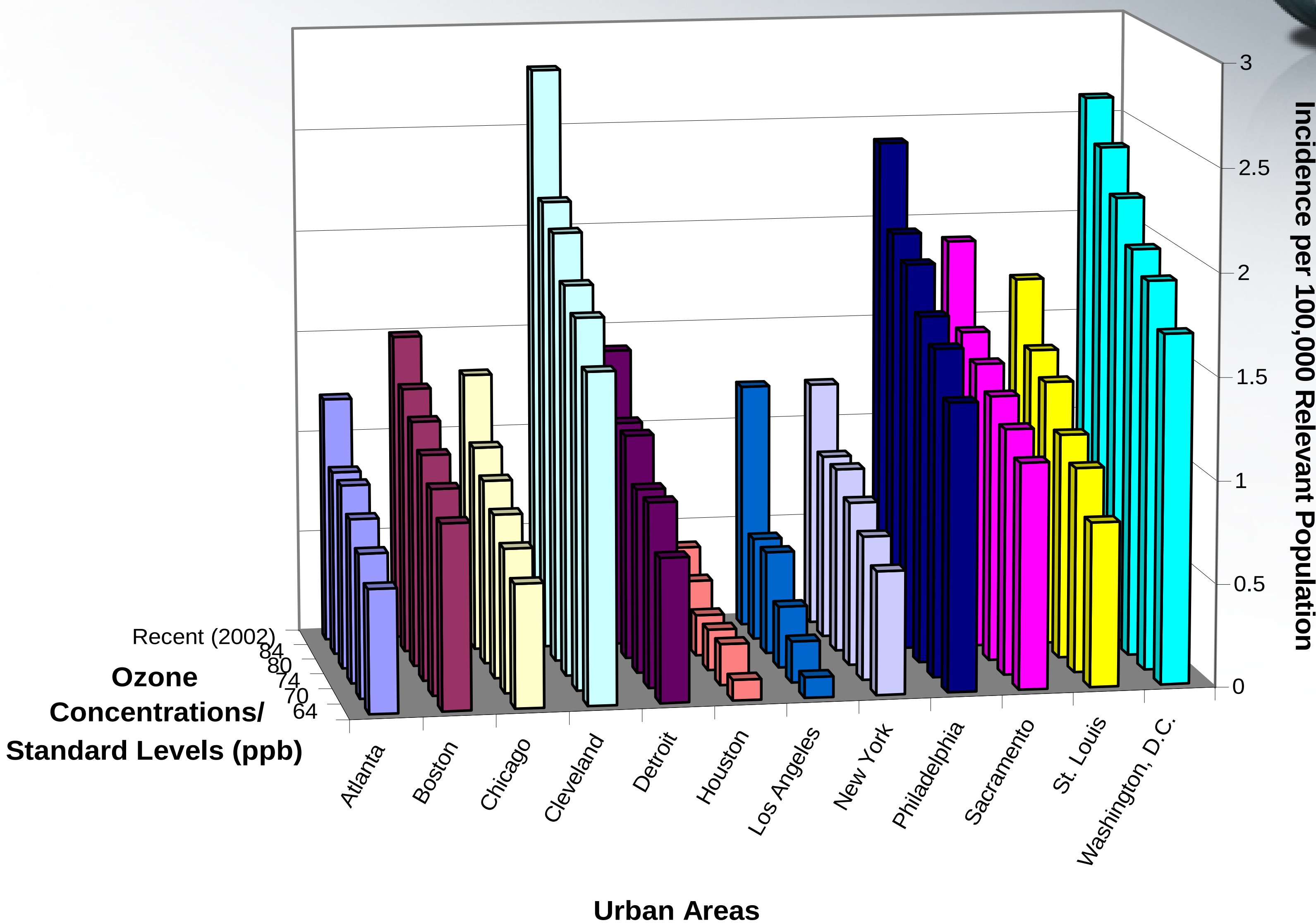
Types of Risk Information Provided



Setting the Standards

- The EPA Administrator makes the ultimate decision on the level of the standard – Cannot consider costs of implementation!
- Standards must be requisite to protect the public health with an adequate margin of safety – Standards are not risk free!
- Recent decisions:
  - PM: Maintain annual standard of 15 µg/m^3, tighten daily standard from 65 to 35 µg/m^3
  - Ozone: Tighten daily standard from 0.084 ppm to 0.075 ppm
  - Lead: Tighten quarterly average standard from 1.5 µg/m^3 to 0.15 µg/m^3
- Uncertainty in science and exposure/risk assessment remains a significant element in decisions on the standards

Health Impact and Benefit-Cost Assessments

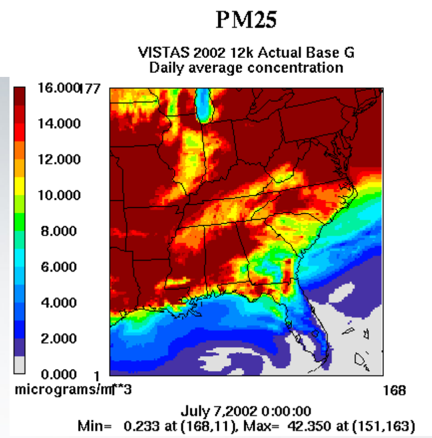
- Part of the rulemaking process
- Not used to set the level of the standard
- Useful for evaluating implementation strategies, but there are many uncertainties
- Useful for accountability assessments
- Tools are available
  - CMAQ (Community Multiscale Air Quality model)
  - CoST (Control Strategy Tool)
  - BenMAP (environmental Benefits Mapping Analysis Program)

What are we trying to answer?

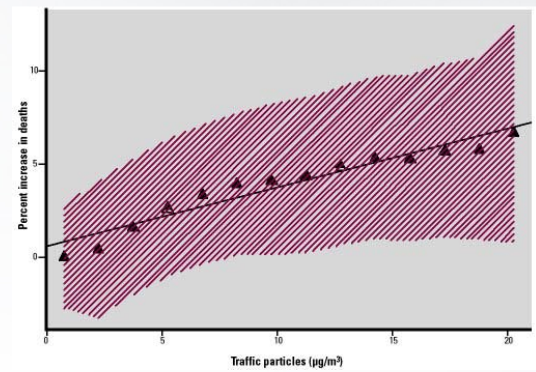
- What are the health and economic benefits of emissions controls and the associated improvements in air quality?
- What are the societal costs of emissions controls?

How do we measure air quality benefits?

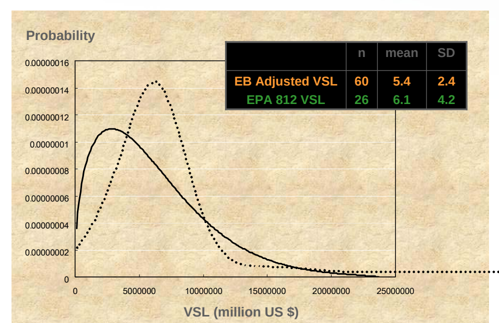
- Air quality models tell us how air quality is expected to change

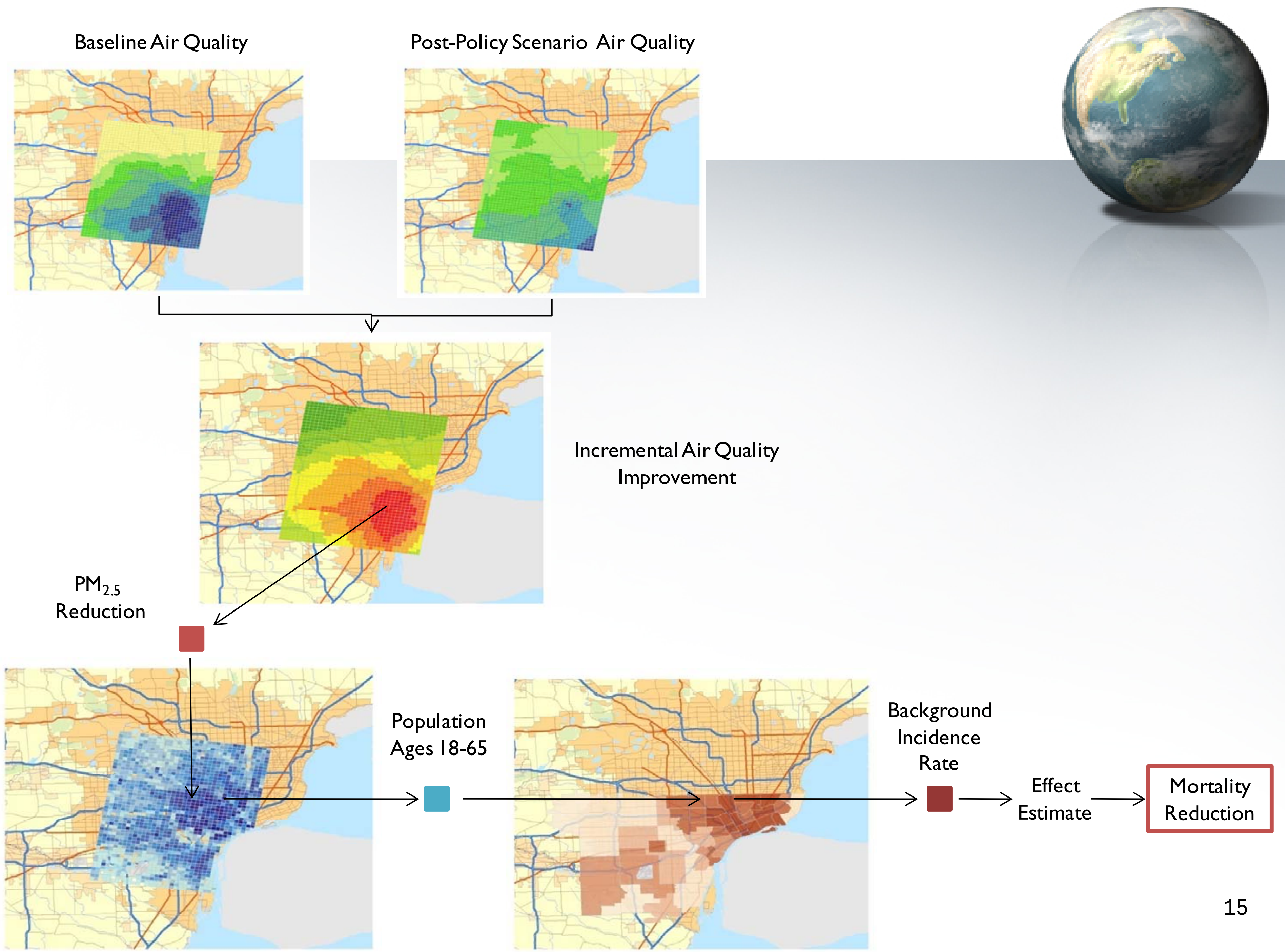


- Epidemiology studies give us concentration-response relationships to predict how health effects will change



- Economic studies tell us how much the changes in health effects are worth




Baseline Air Quality
Post-Policy Scenario Air Quality
Incremental Air Quality Improvement
PM2.5 Reduction
Population Ages 18-65
Background Incidence Rate
Effect Estimate
Mortality Reduction
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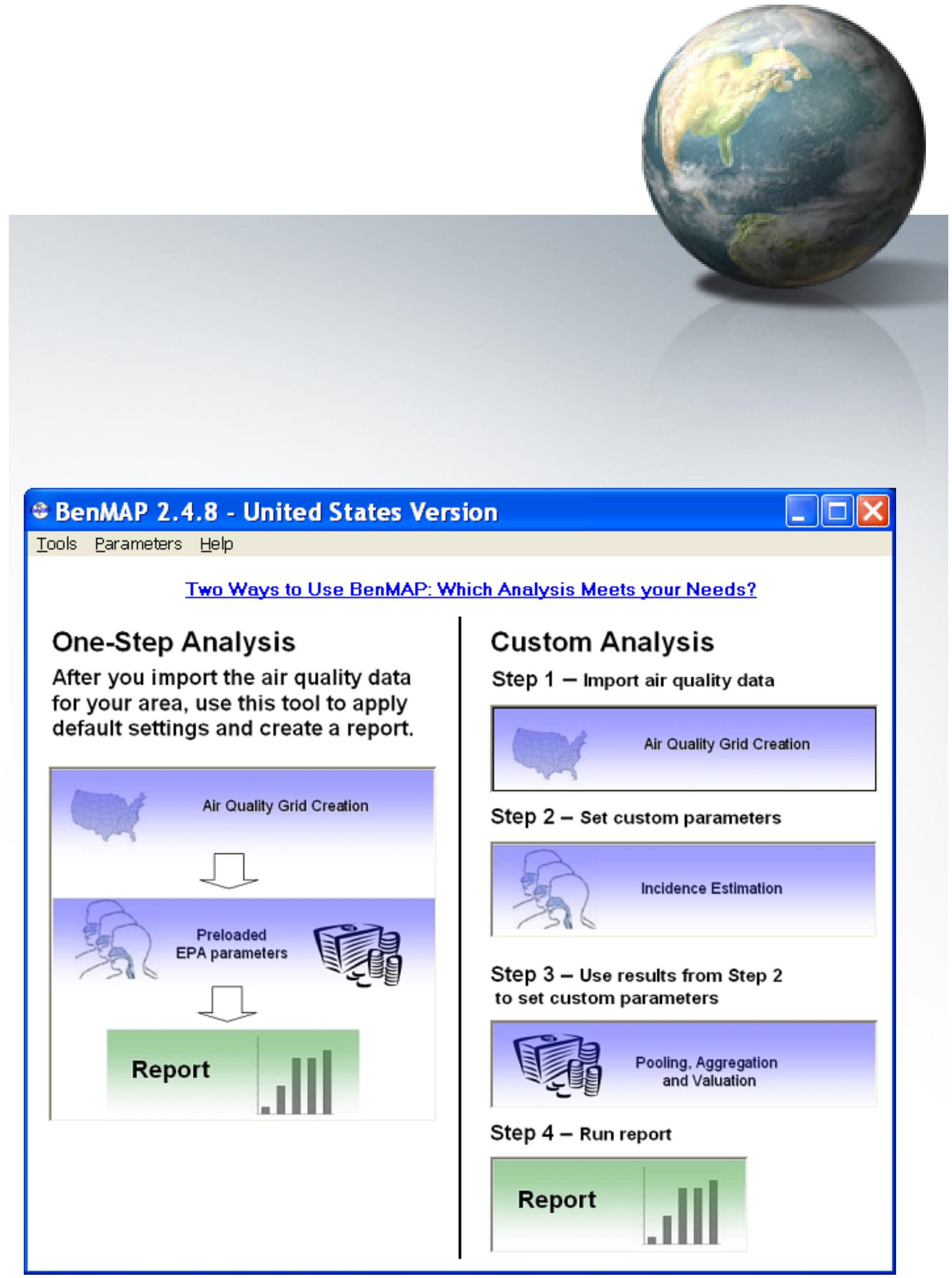
U.S. Version

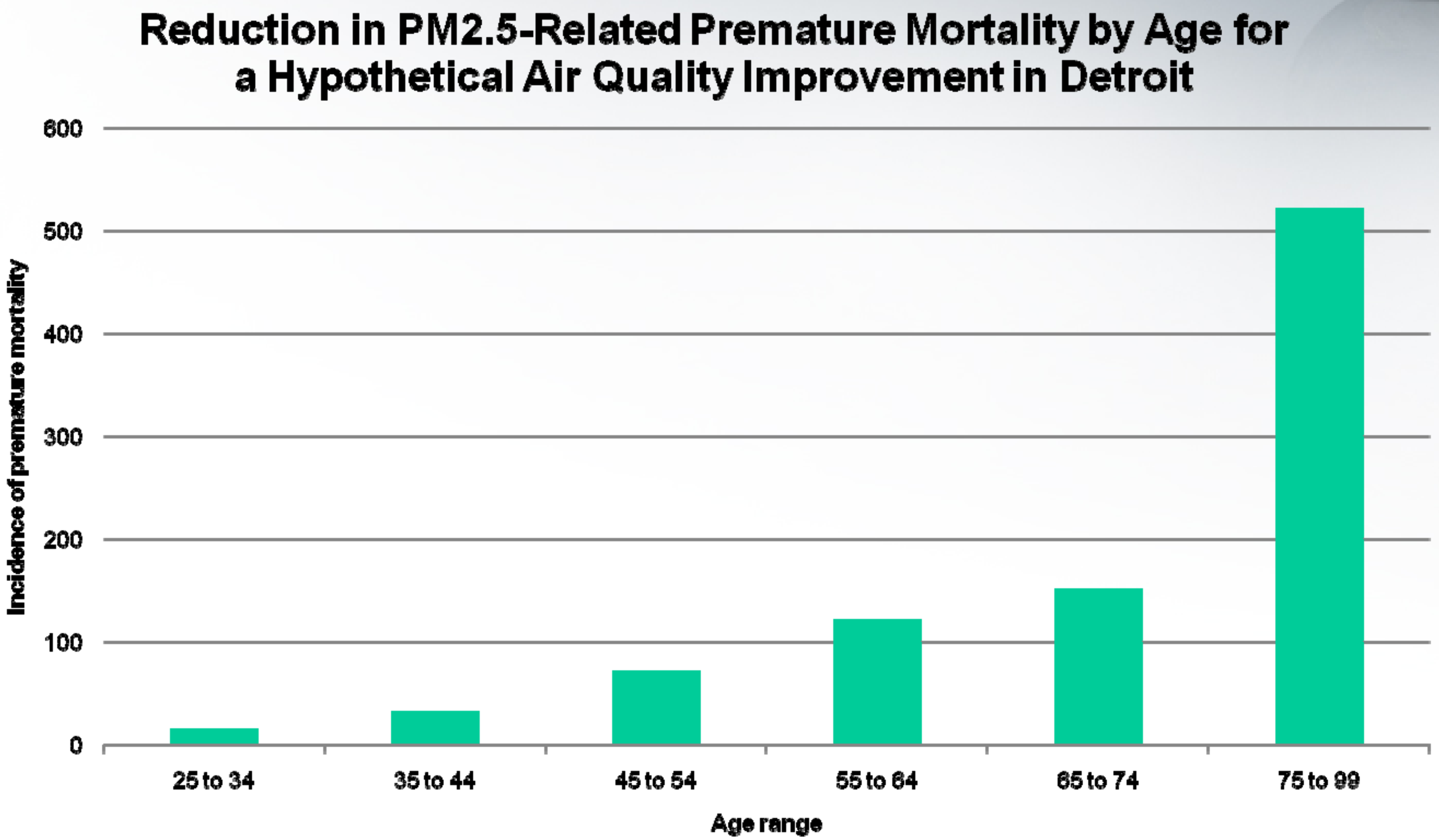
Environmental Benefits Mapping and Analysis Program



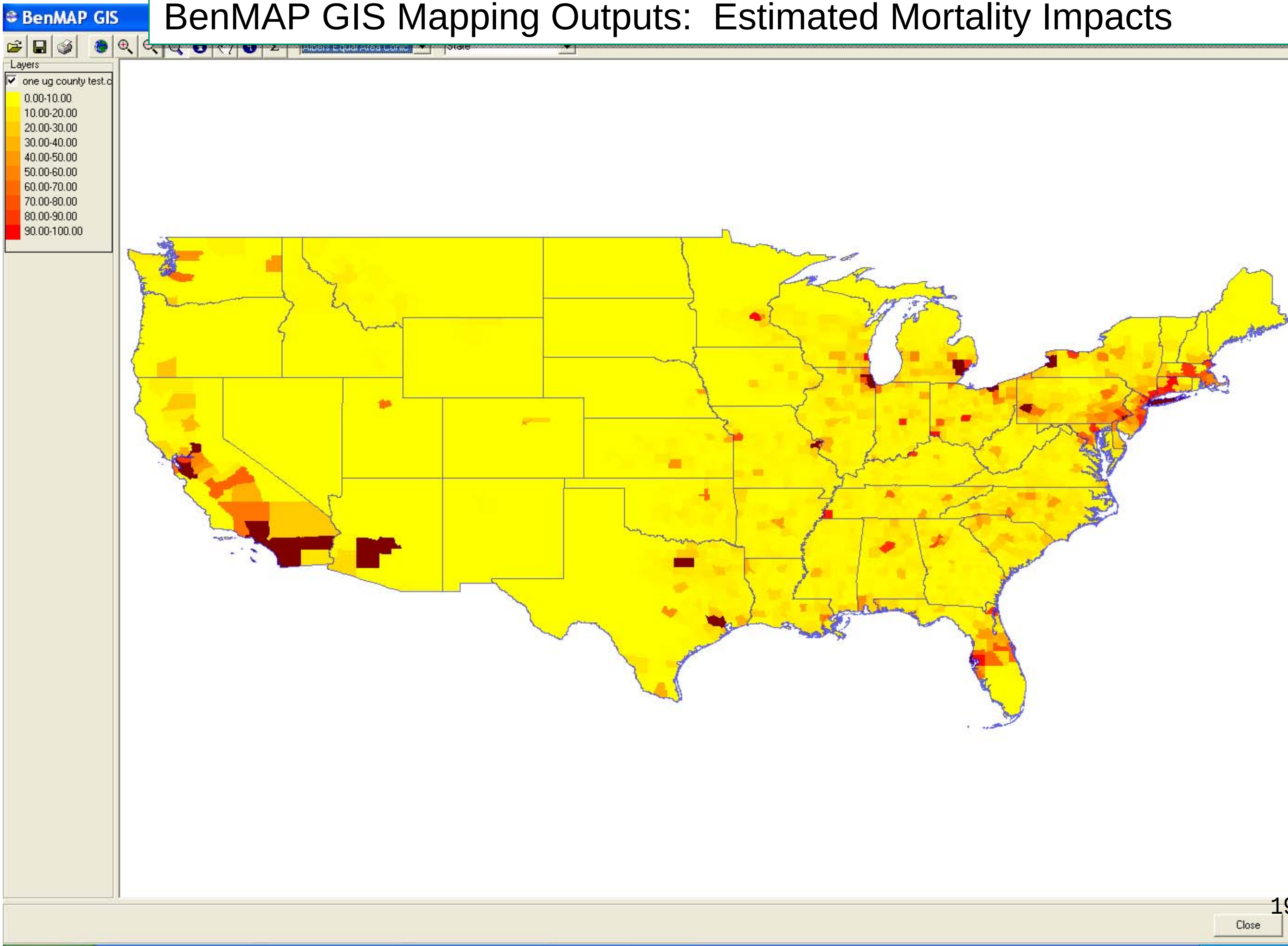
Key Features of BenMAP

- Includes all of the key inputs to a benefits analysis
- The user only has to provide modeled environmental data – or select monitored air quality data for a "what if" style analysis
- BenMAP is an integrated GIS mapping, query, and statistics tool
- Outputs results (exposure, incidence, and valuation) in a variety of formats, including spreadsheets and shape files suitable for use with standard GIS packages such as ArcView

Example BenMAP Output



BenMAP GIS Mapping Outputs: Estimated Mortality Impacts



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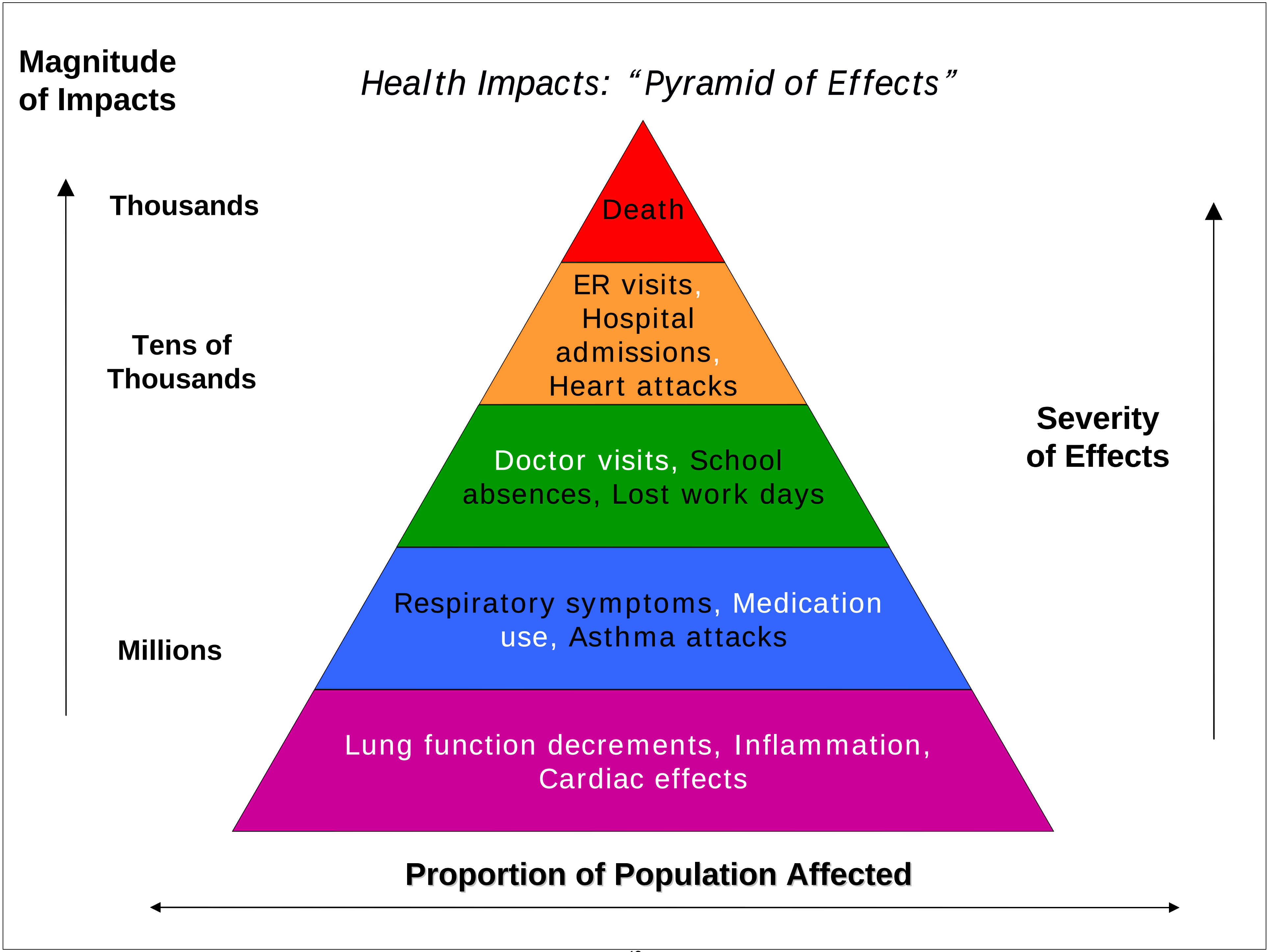
Magnitude of Impacts
Health Impacts: "Pyramid of Effects"
Thousands
Tens of Thousands
Millions
Death
ER visits, Hospital admissions, Heart attacks
Doctor visits, School absences, Lost work days
Respiratory symptoms, Medication use, Asthma attacks
Lung function decrements, Inflammation, Cardiac effects
Severity of Effects
Proportion of Population Affected

How do we value improvements in air quality?

- Avoided Costs
  - Nonfatal heart attacks
  - Hospital admissions
  - Work loss days
- Willingness to Pay
  - Premature death
  - Chronic bronchitis
  - Respiratory symptoms

Current U.S. Values for Health Effects

• Premature death:	$5.5 million
• Chronic bronchitis:	$340,000
• Heart attacks:	$66,000 - $140,000
• Hospital admissions:	$6,000 - $18,000
• ER visits:	$300
• Respiratory symptoms	$15 - $60
• Asthma attacks	$40
• Work loss days	$100
• School absences	$75

Projected Benefits of Recent Actions

- Engine and Fuel standards for nonroad diesels

By 2030

12,000 premature deaths avoided annually + many additional health impacts

Economic value of health benefits over $80 billion annually

Projected benefits are almost 40 times costs!

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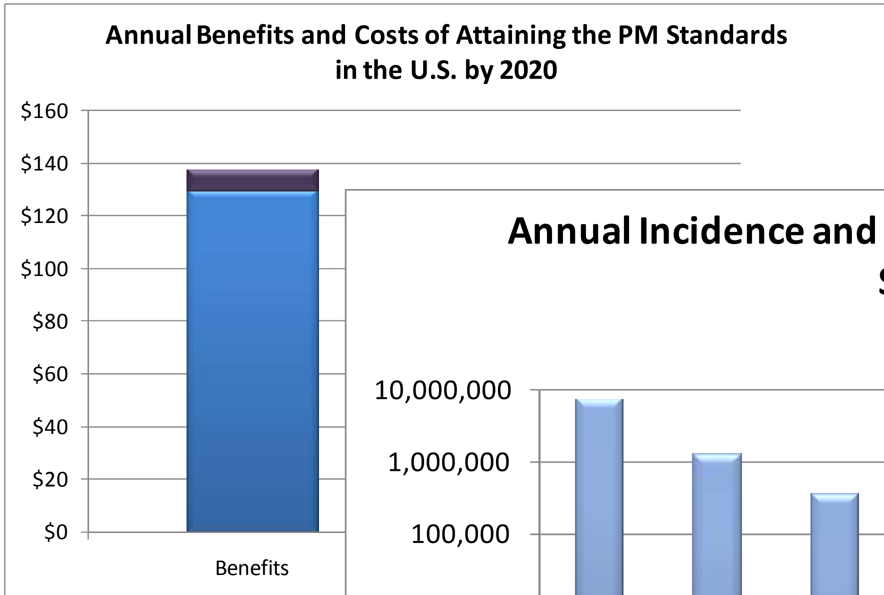
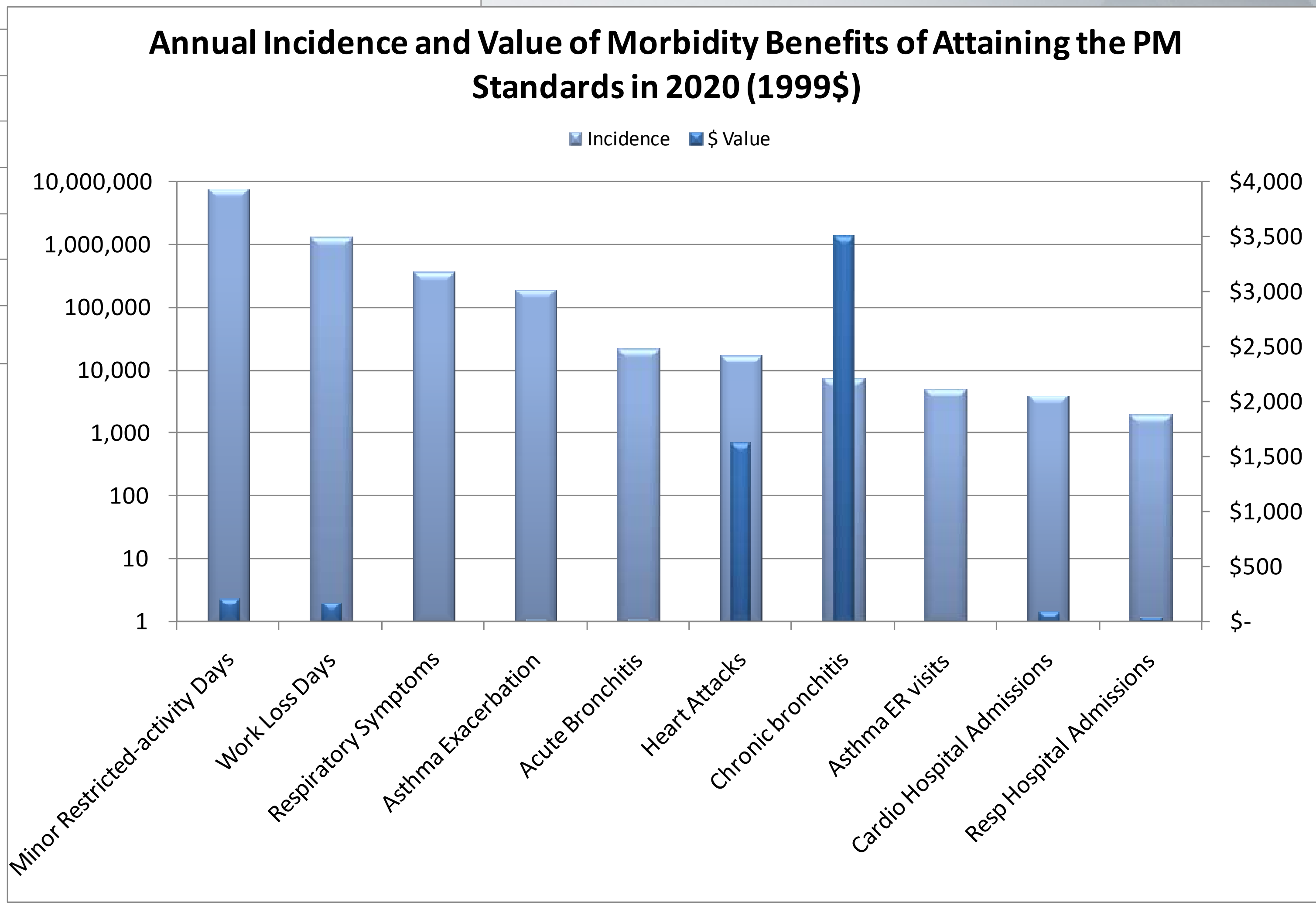
Projected Benefits of Recent Actions



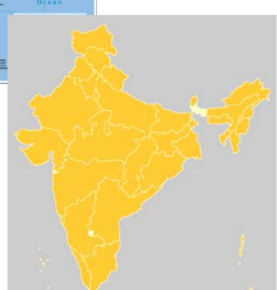


BenMAP International Projects

- China: Benefits analysis of EGU control strategy.

- South Korea: Health benefits of Seoul air quality management plan

- Latin America: Benefits of air quality improvements in Mexico City, São Paulo, Santiago



- India: Benefits analysis in Mumbai

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US-China Joint Economic Study (JES): Integrated AQ Modeling Assessment

Decision Support System

Policies ↓ ↑ Impacts

Decision-maker/ Analyst

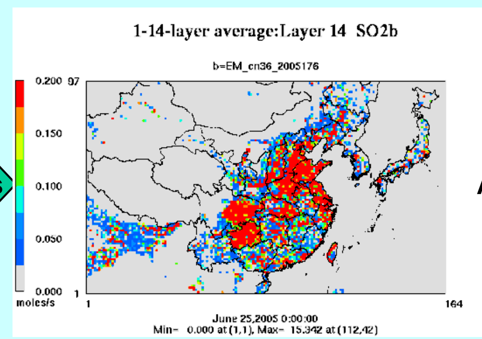
Modeling Framework

C-PAC
Cost Estimate Tool

China Pollution Abatement Cost Tool

→ Emissions →

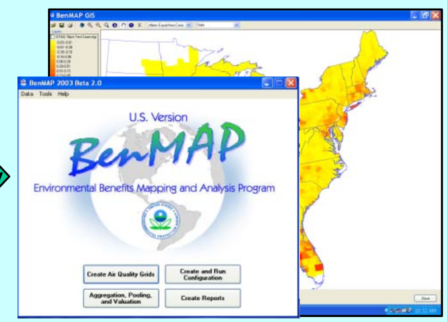
CMAQ
Air Quality Model



Community Multi-scale Air Quality Model

→ Air Quality →

BenMAP
Health Benefits Model



Benefit Mapping Tool

Cost/Benefit Analysis

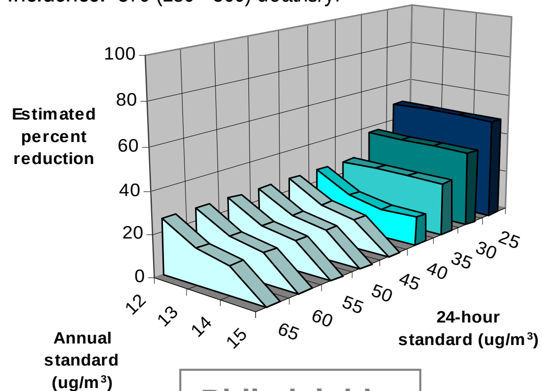
Emissions Control → **Air Quality Benefit** → **Health Benefit**

Risk communication

- Critical but often given little attention
- Often requires translation, simplification, and condensation

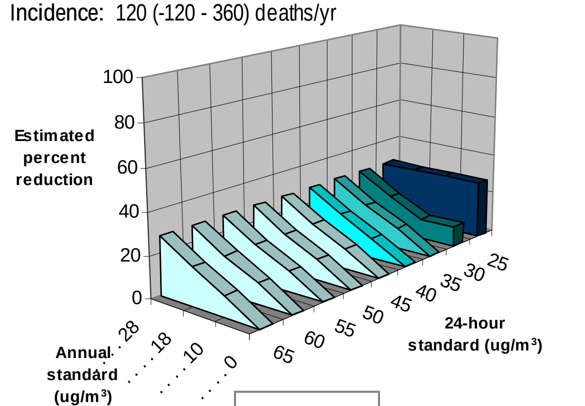
Example Results from City Specific PM Risk Analyses

Incidence Rate: 24 (12 - 37) deaths/yr/100,000
Incidence: 370 (180 - 560) deaths/yr



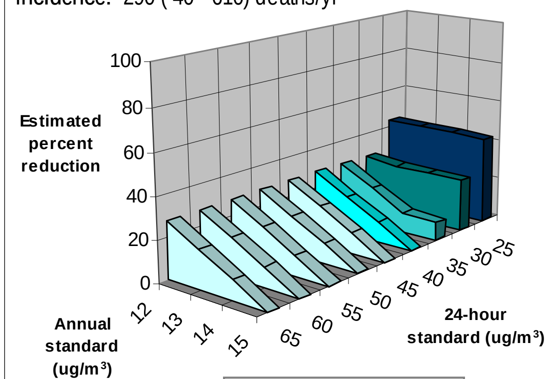
Philadelphia

Incidence Rate: 6 (-6 - 17) deaths/yr/100,000
Incidence: 120 (-120 - 360) deaths/yr



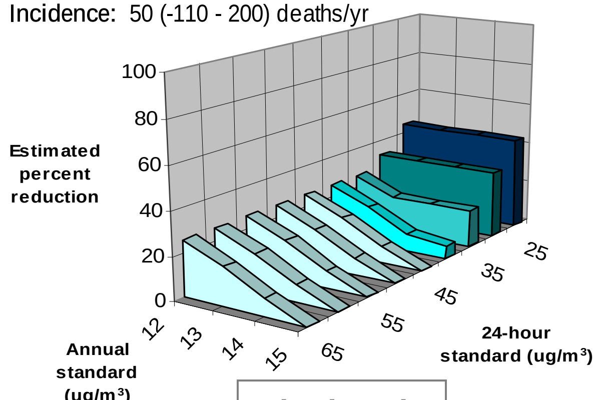
Detroit

Incidence Rate: 3 (0 -6) deaths/yr/100,000
Incidence: 290 (-40 - 610) deaths/yr



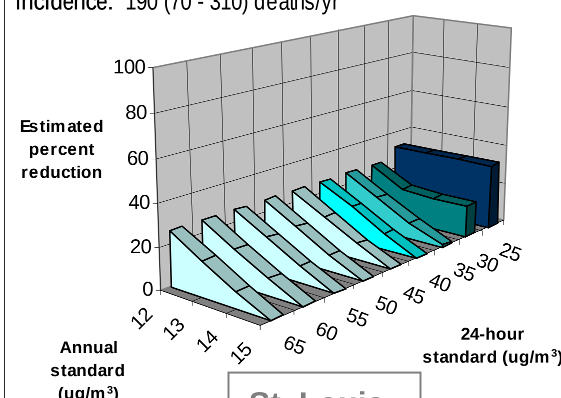
Los Angeles

Incidence Rate: 4 (-8 - 16) deaths/yr/100,000
Incidence: 50 (-110 - 200) deaths/yr



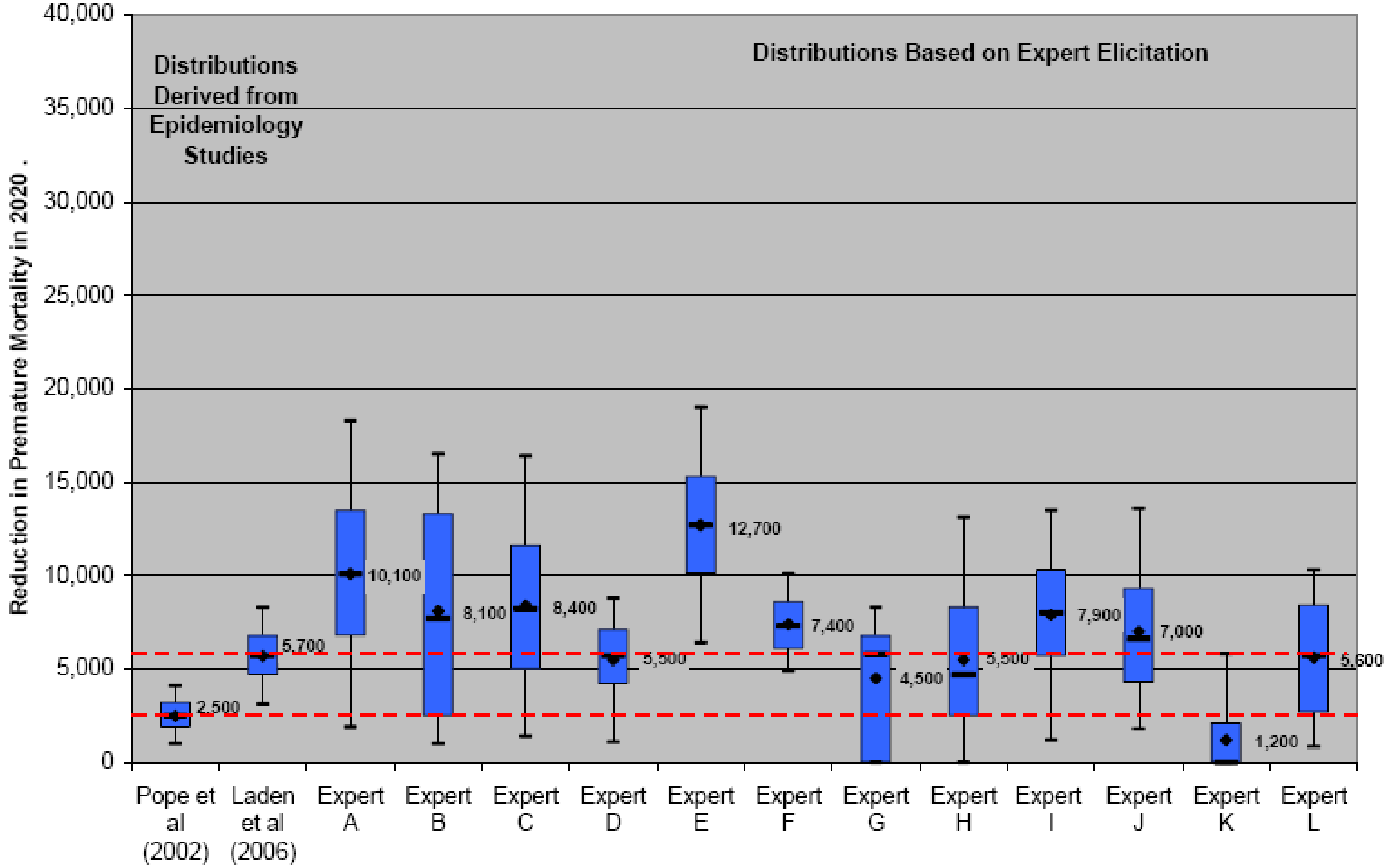
Pittsburgh

Incidence Rate: 8 (3 - 12) deaths/yr/100,000
Incidence: 190 (70 - 310) deaths/yr



St. Louis

Communication of results from the PM NAAQS benefits analysis



Note: Distributions labeled Expert A - Expert L are based on individual expert responses. The distributions labeled Pope et al. (2002) and Laden et al (2006) are based on the means and standard errors of the C-R functions from the studies. The red dotted lines enclose a range bounded by the means of the two data-derived distributions.

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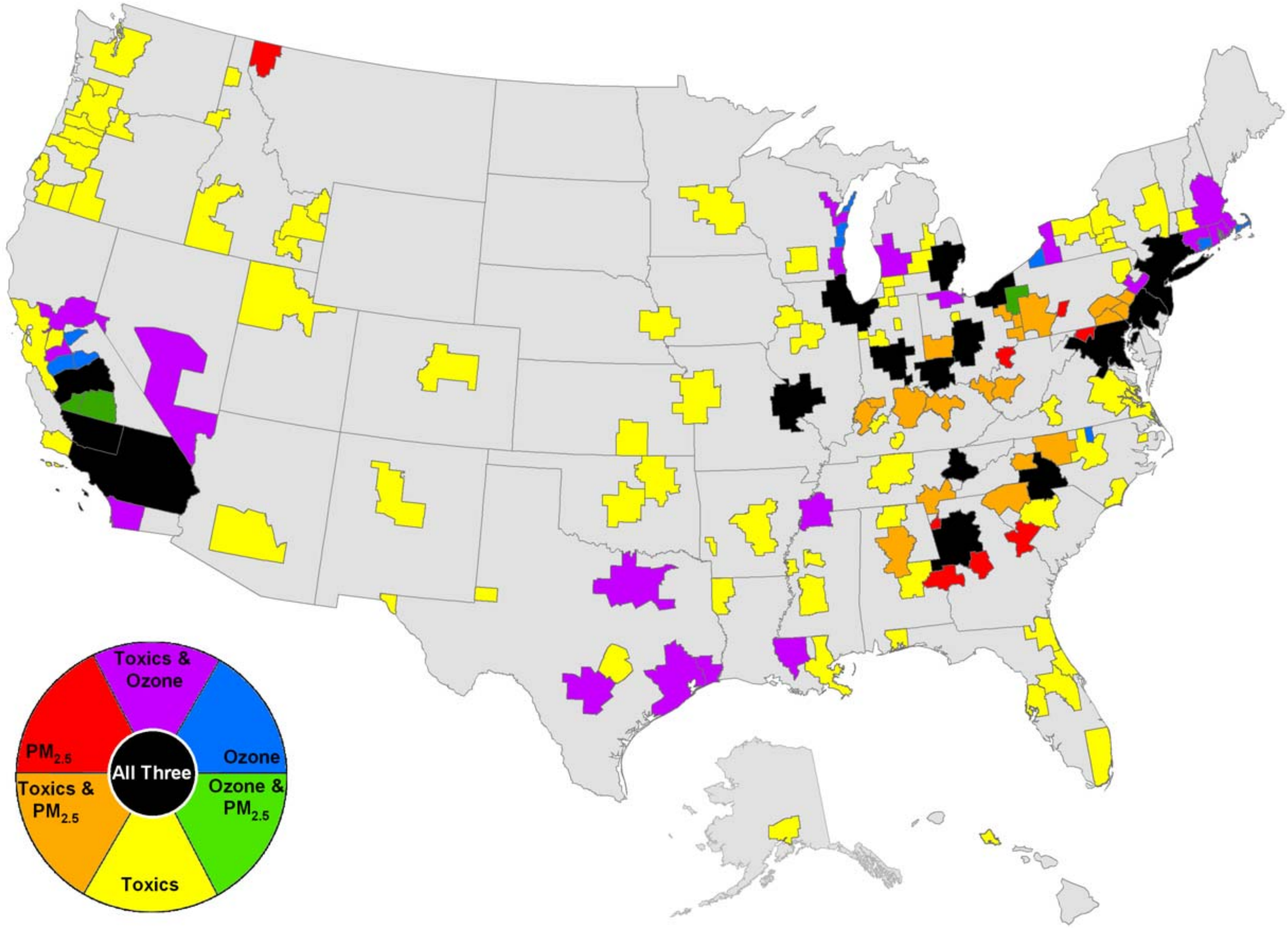
Nexus of PM, Ozone, and Toxics in the U.S.

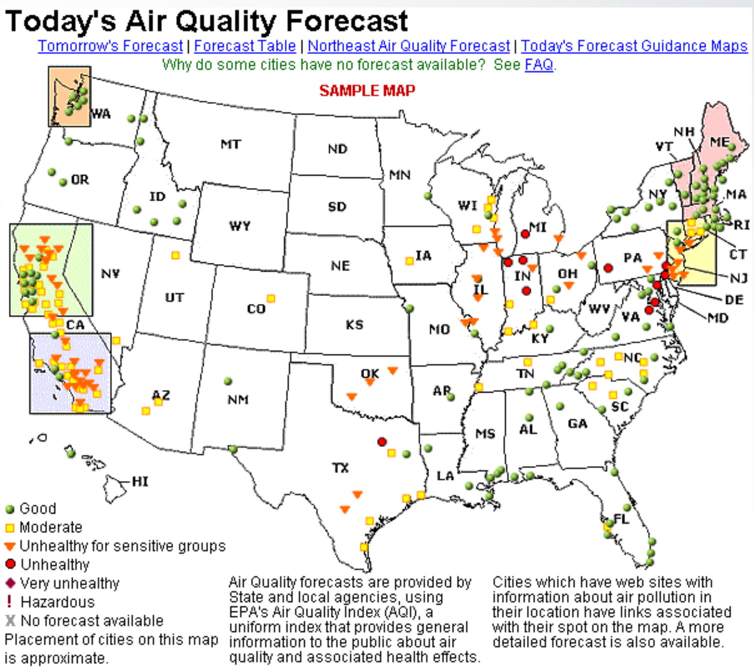


30

Air Quality Index

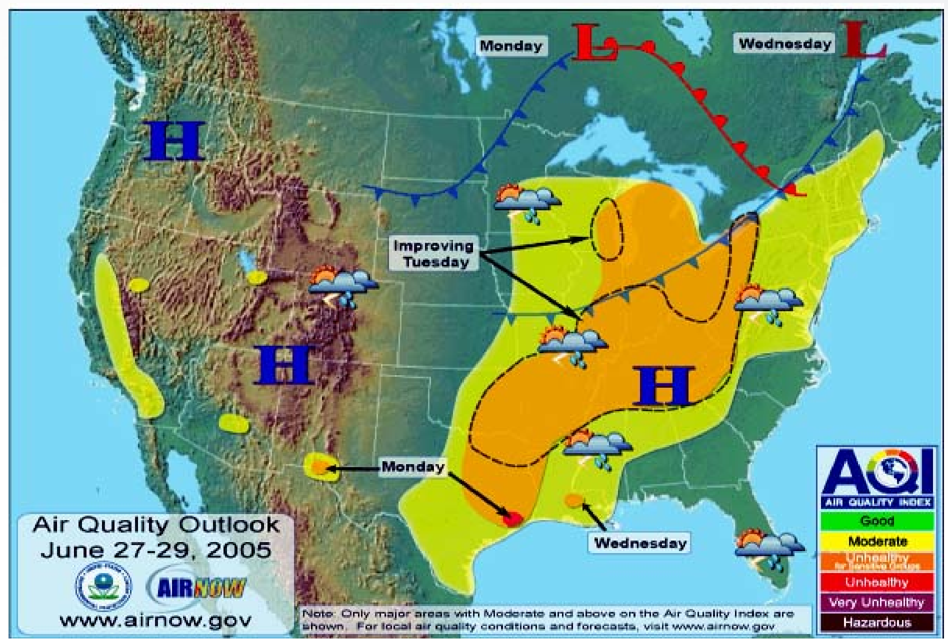
Descriptors	Cautionary Statement
Good 0 – 50	No message
Moderate 51 – 100	Unusually sensitive individuals
Unhealthy for Sensitive Groups 101 - 150	Identifiable groups at risk - different groups for different pollutants
Unhealthy 151 - 200	General public at risk; sensitive groups at greater risk
Very Unhealthy 201 - 300	General public at greater risk; sensitive groups at greatest risk

Air Quality Forecasting



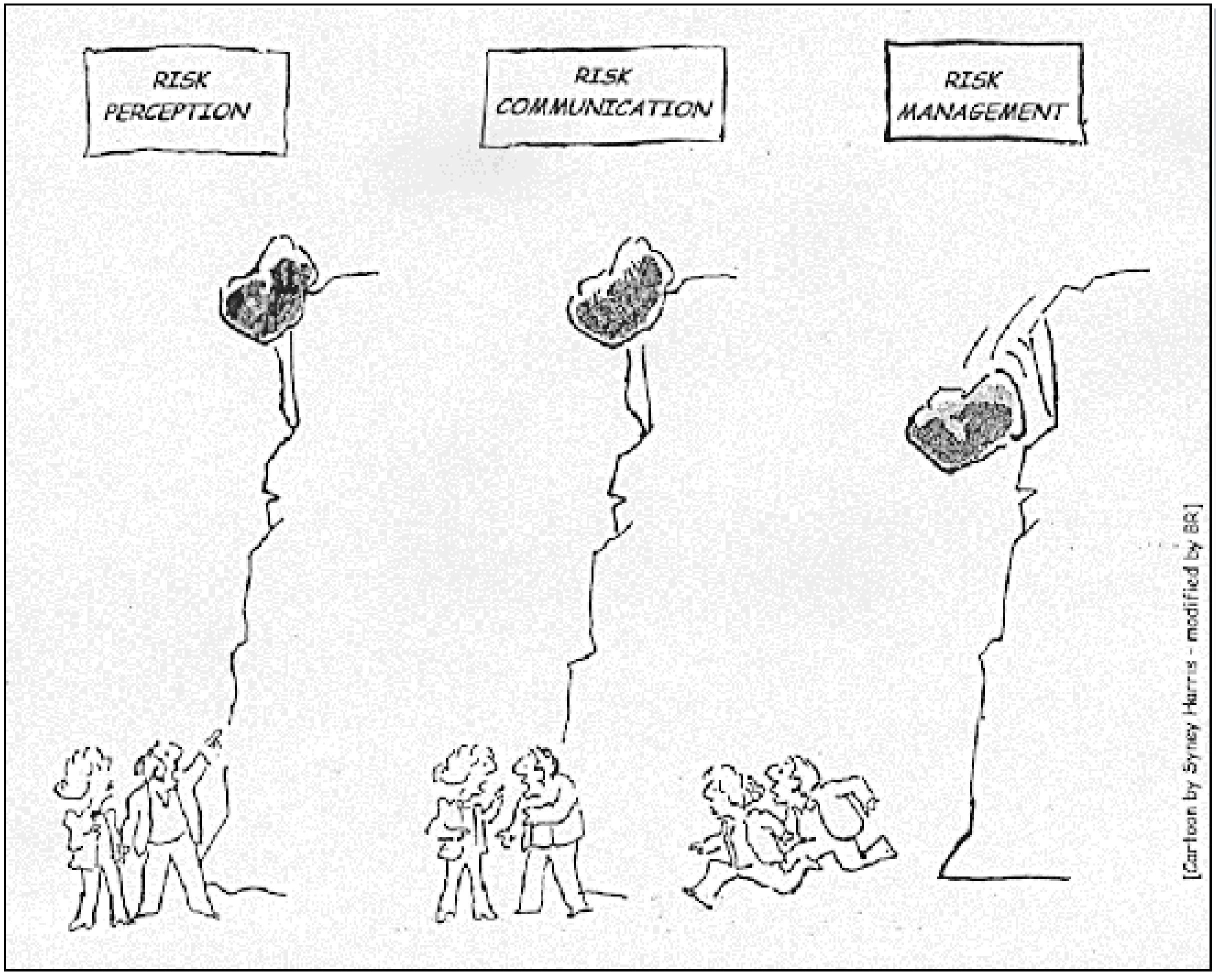
Daily

U.S. EPA AIRNOW www.epa.gov/airnow



Two-Day Outlook

Risk communication



- Without good, clear communication, risk analysis will not lead to reduced risk!

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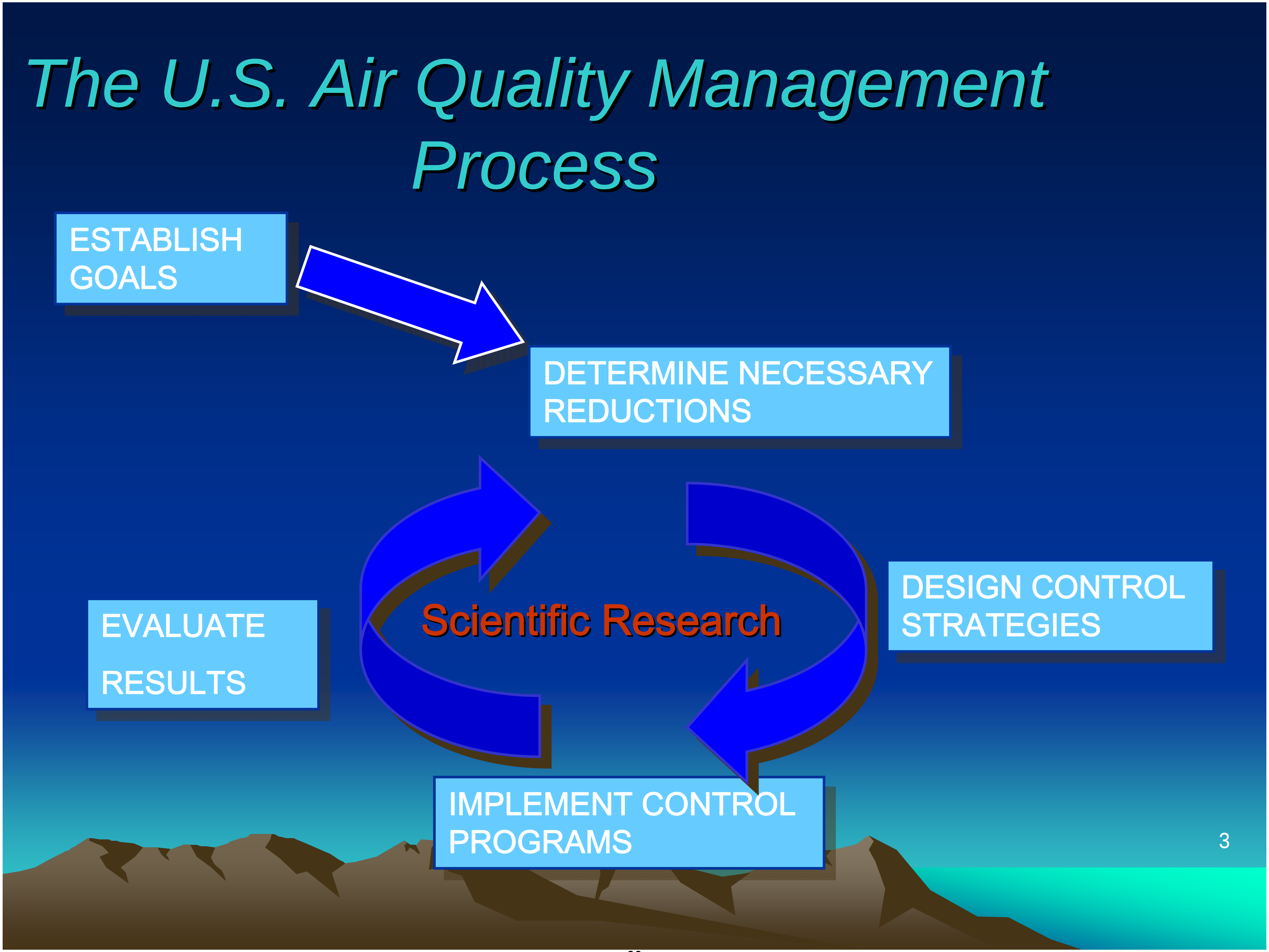
Thank you!

Dollars and Deaths: Cost-Benefit Calculations and Air Pollution Regulations

Dr. Bryan J. Hubbell
Office of Air and Radiation
U.S. EPA

Overview

- Quick air policy overview
- Benefit-cost analysis at EPA
- How EPA conducts a benefits analysis
- Interactions between science and policy
- Bringing uncertainty into the analysis
- What about climate?


The U.S. Air Quality Management Process
ESTABLISH GOALS
DETERMINE NECESSARY REDUCTIONS
DESIGN CONTROL STRATEGIES
IMPLEMENT CONTROL PROGRAMS
EVALUATE RESULTS
Scientific Research
3

Laws, Standards, and Regulations

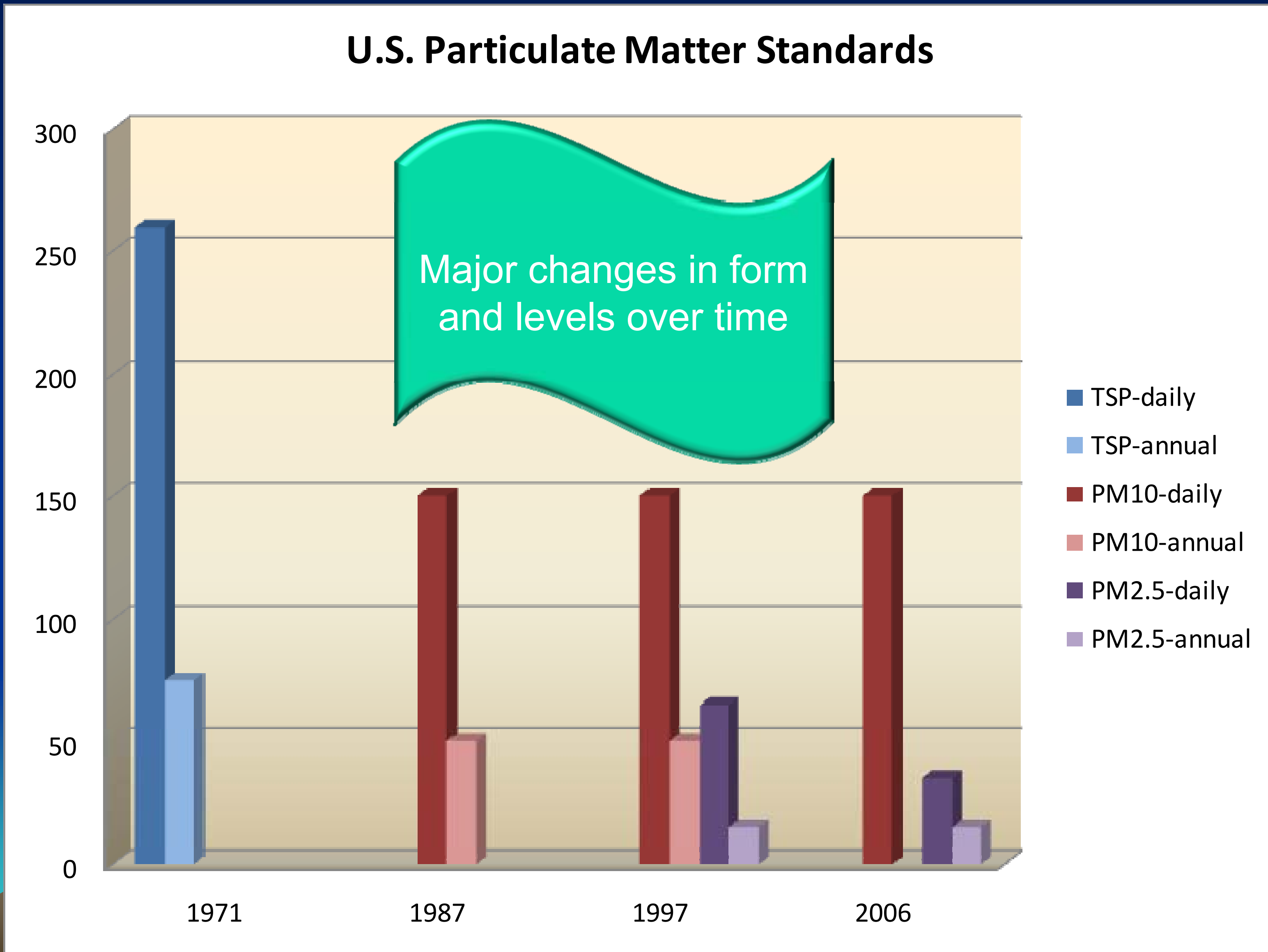
- Clean Air Act (1970) and Amendments (1990)
- Standards for ubiquitous air pollutants are reviewed every 5 years: PM, Ozone, NOx, SOx, CO, Lead
- Implementation is the responsibility of the states
- National regulations to implement standards issued based on a number of factors:
  - Interstate transport
  - Mobile sources
- Technology and risk standards to address 187 air toxics established and reviewed cyclically

Past and Present Standards

Unchanged since 1971!

CO =	9 ppm 8-hour
	35 ppm 1-hour
NOx =	0.053 ppm annual average
SOx =	0.03 ppm annual average
	0.14 ppm daily average

Past and Present Standards



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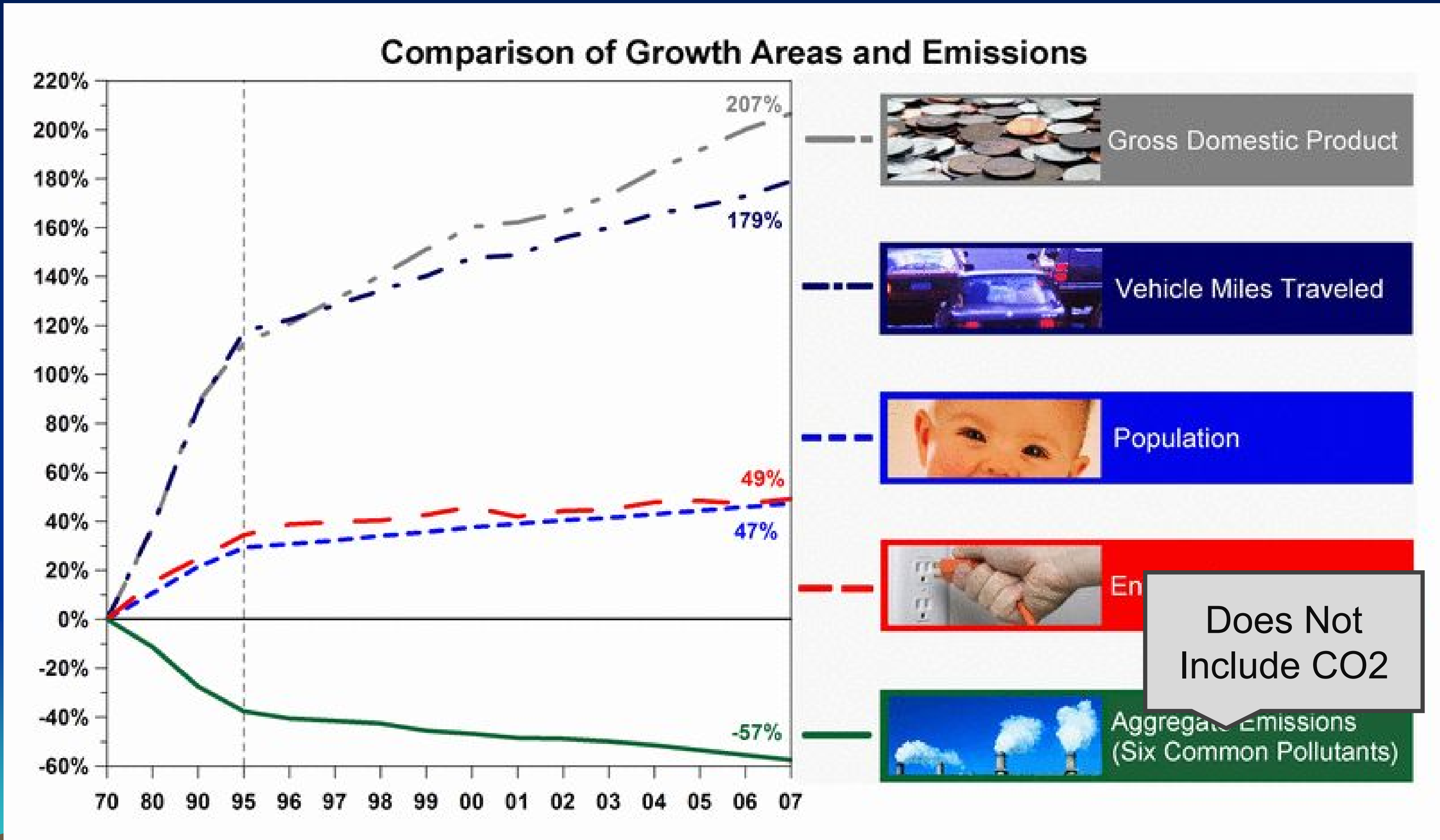
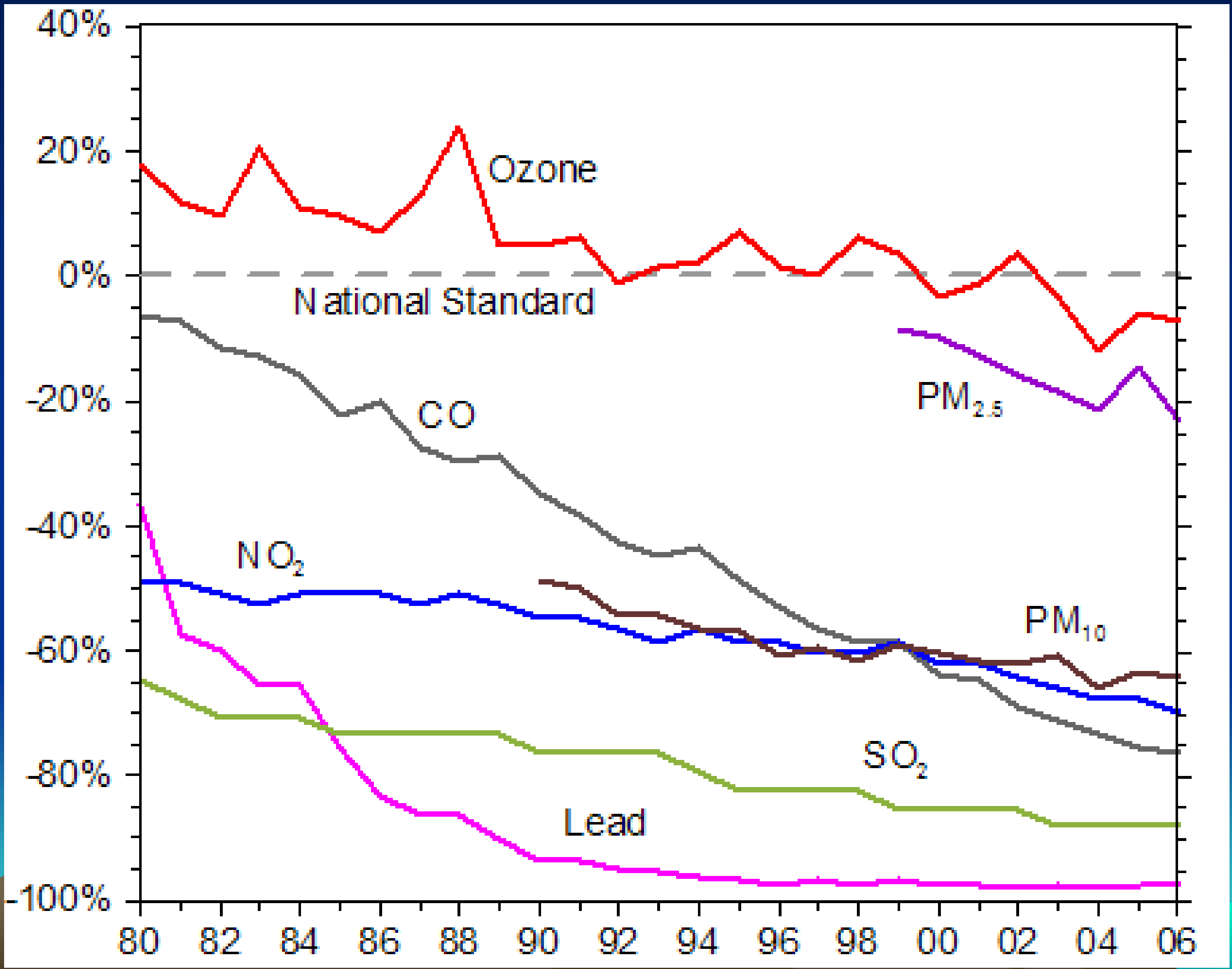
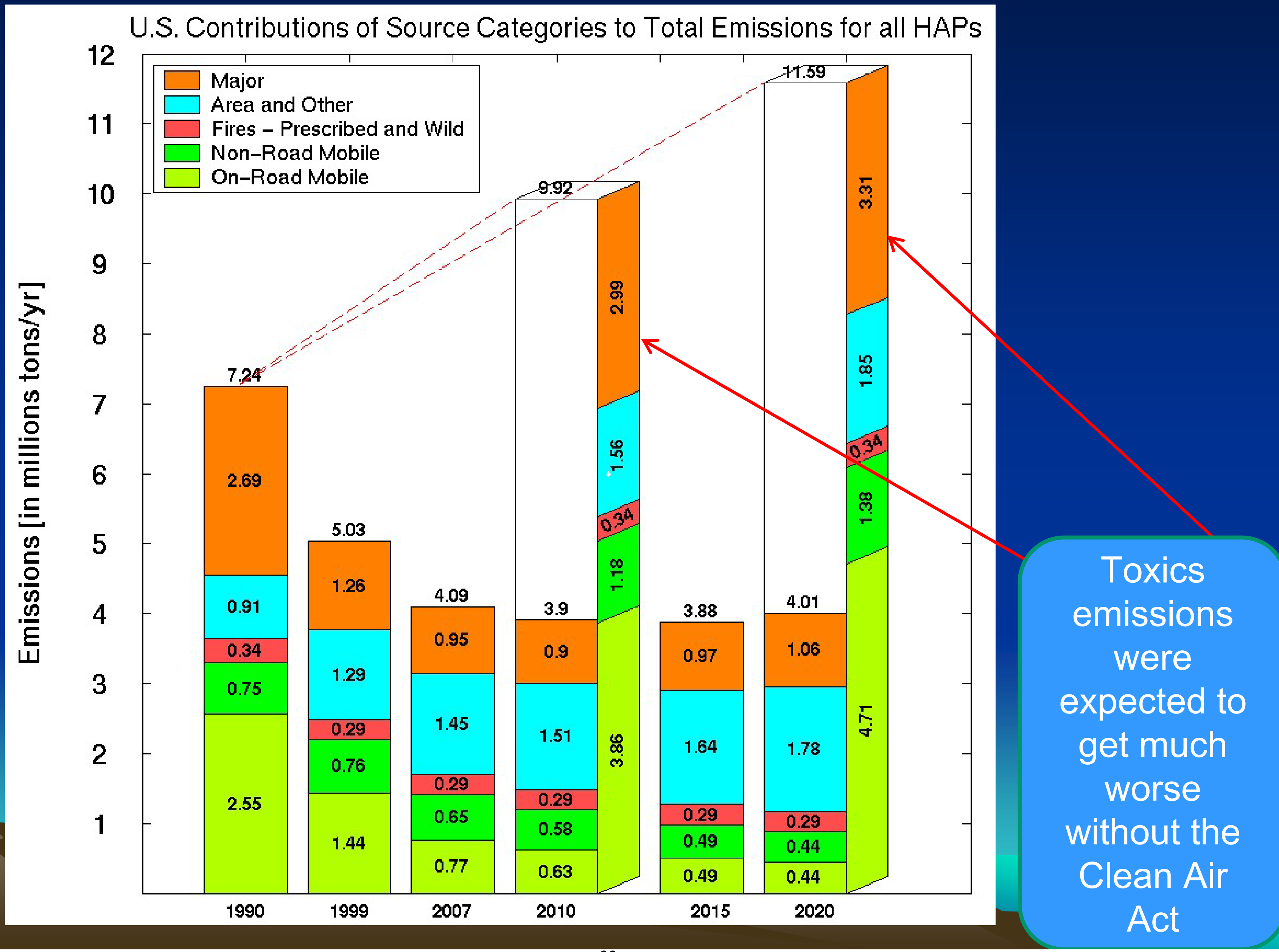
Progress in Implementation



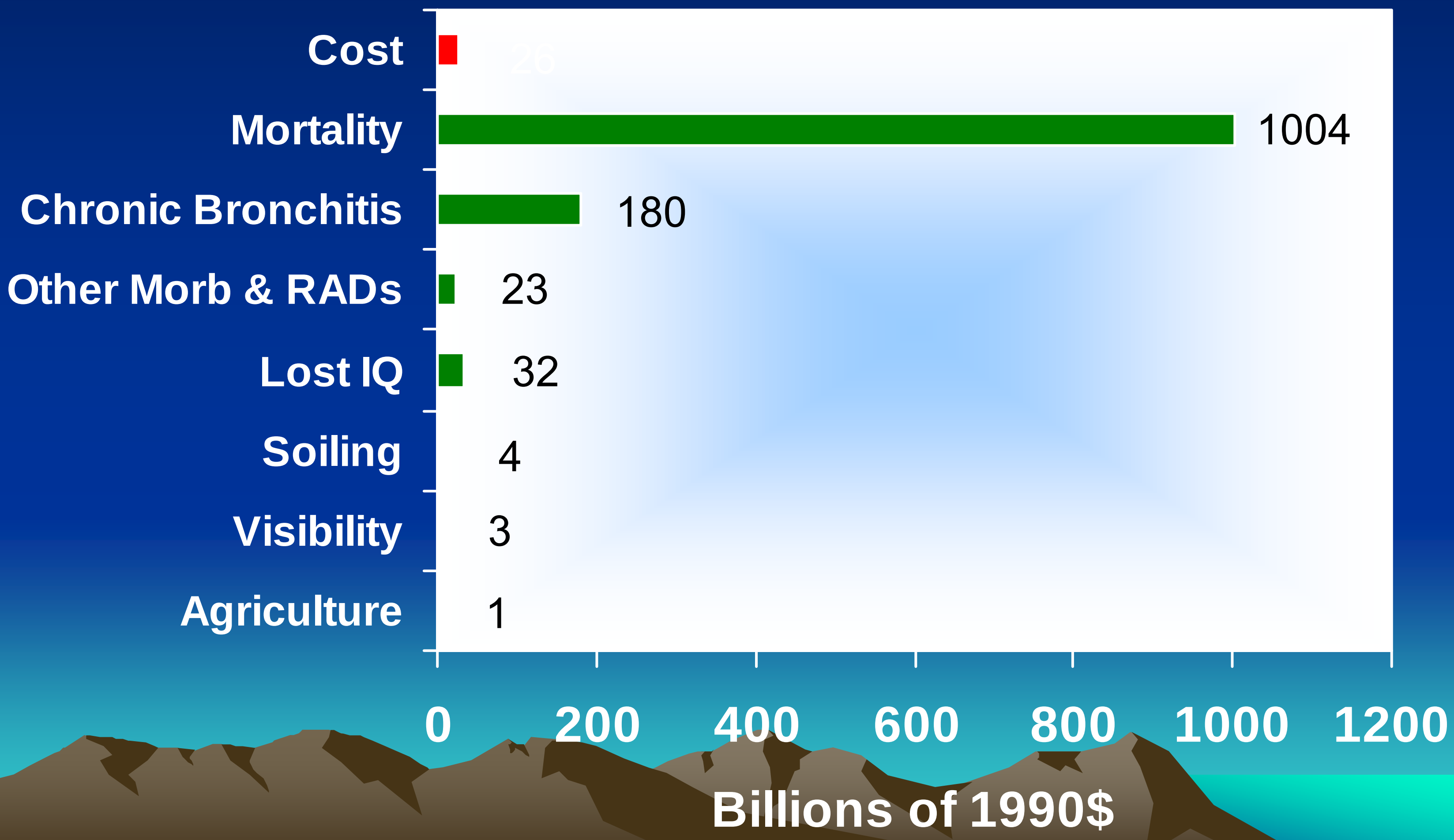
Trends in the Levels of the Six Principle Pollutants Relative to U.S. National Standards: 1980 - 2006



Progress in Reducing National Air Toxics Emissions from 1990 to 2007 and Beyond



Annual Benefits and Costs of the 1970 Clean Air Act in 1990



Projected Additional Annual Benefits and Costs of the 1990 Clean Air Act Amendments in 2010

11

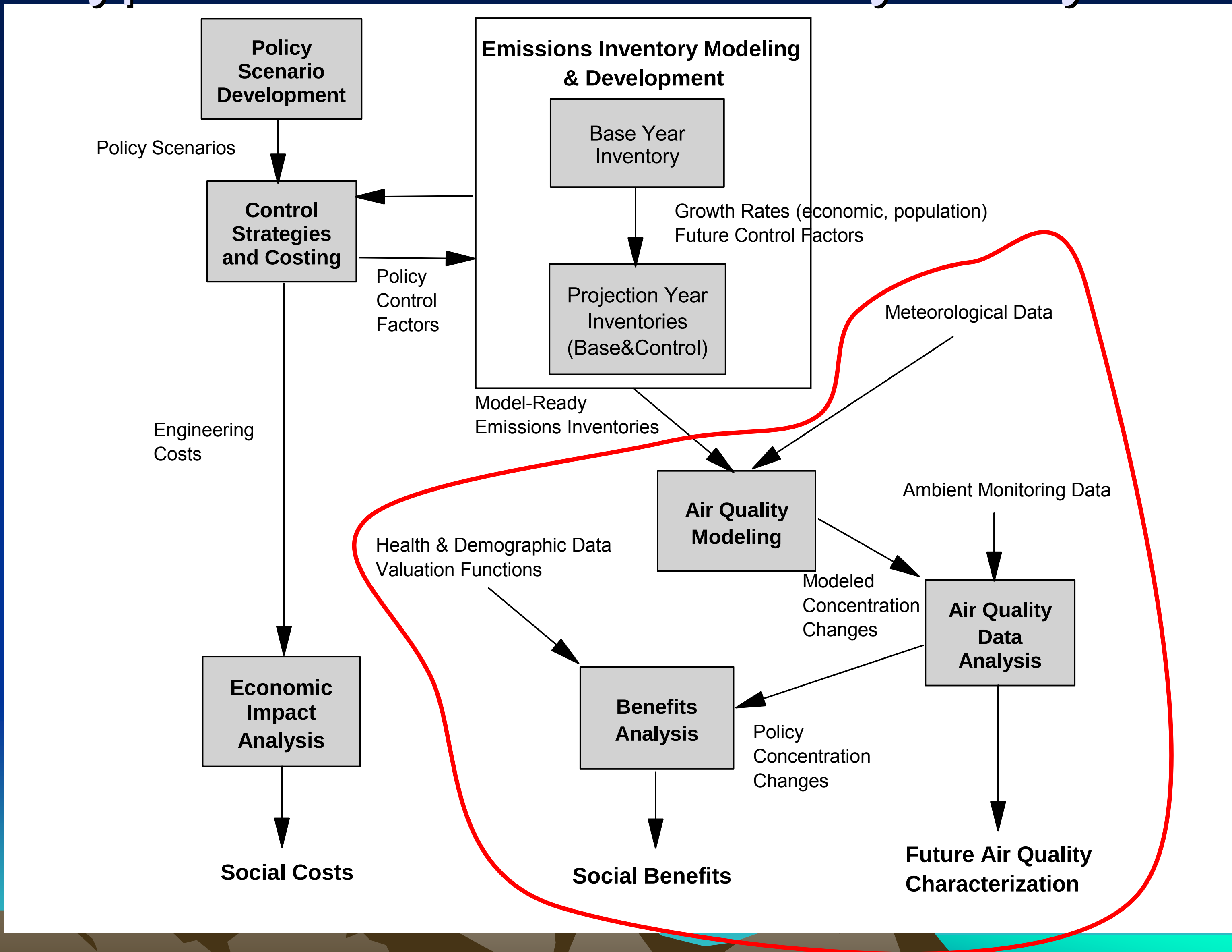
Health Impact and Benefit-Cost Assessments

- Part of the rulemaking process
- Not used to set the level of the standard
- Useful for evaluating implementation strategies, but there are many uncertainties
- Useful for accountability assessments
- Tools are available
  - CMAQ (Community Multiscale Air Quality model)
  - CoST (Control Strategy Tool)
  - BenMAP (environmental Benefits Mapping Analysis Program)

What are we trying to answer?

- What are the health and economic benefits of emissions controls and the associated improvements in air quality?
- What are the societal costs of emissions controls?

Typical Elements of a Policy Analysis

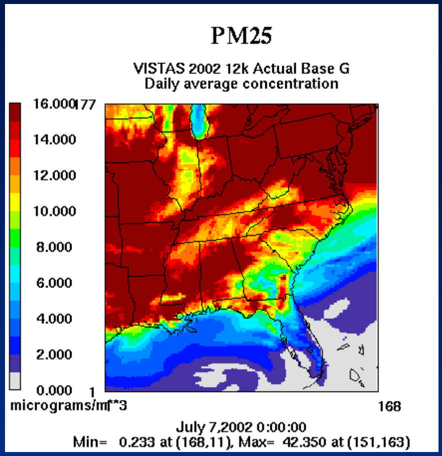


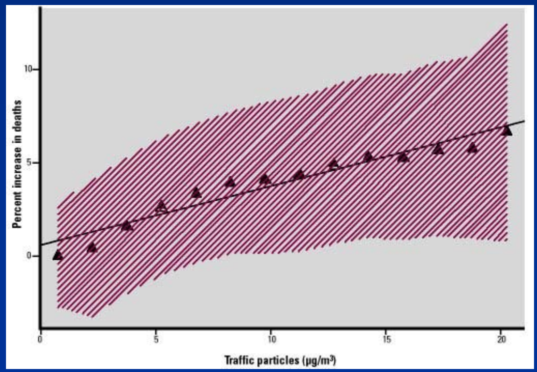
What Are the Benefits of Reduced Air Pollution?

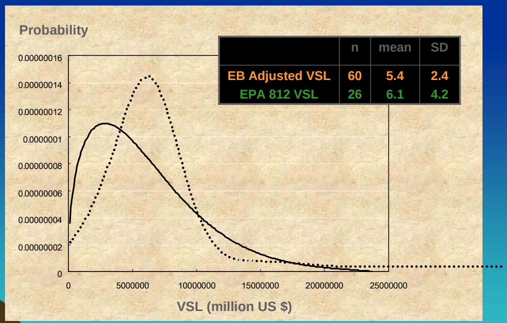
- Health
  - Reduced risk of premature death
  - Reduced risk of chronic illness, for example chronic bronchitis
  - Reduced risk of hospitalization
  - Reduced risk of respiratory illnesses and symptoms
  - Reduced sick days
  - Increased productivity for outdoor workers
- Welfare
  - Visibility improvements
  - Improved agricultural and forest yields
  - Reduced damage to structures
  - Reduced cleaning costs
  - Reduced ecosystem damages

How do we measure these benefits?

- Air quality models tell us how air quality is expected to change
- Epidemiology studies give us concentration-response relationships to predict how health effects will change
- Economic studies tell us how much the changes in health and welfare effects are worth







Statistical Lives and Cases

- **What is a Statistical Life?**
  - A statistical life is a convenient short-hand concept for describing the effect of small changes in the risk of premature death for a large population of potentially exposed people.
  - For example, if the risk of dying is 1 in 10,000, then there will be one statistical life lost for every 10,000 people exposed to the risk.
- Generally, epidemiology studies let us predict changes in statistical lives or cases associated with air pollution

Valuing Statistical Lives and Cases

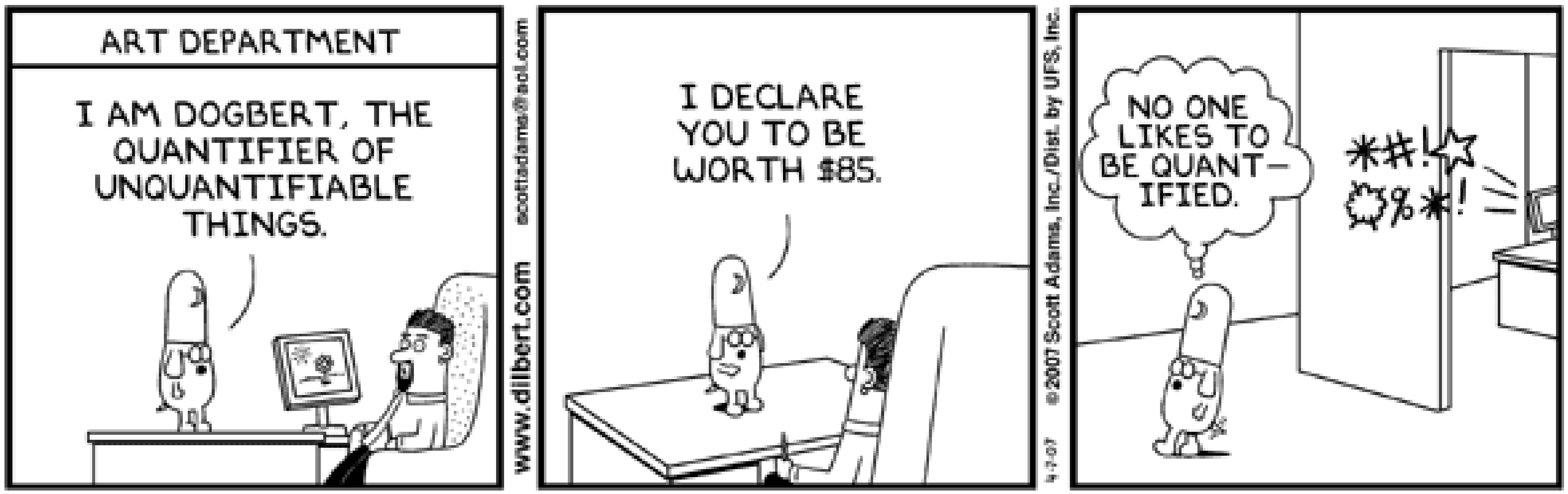
- For a particular health effect, the value of a statistical case is "built" by dividing the *value* of a small risk change by the actual change in risk:

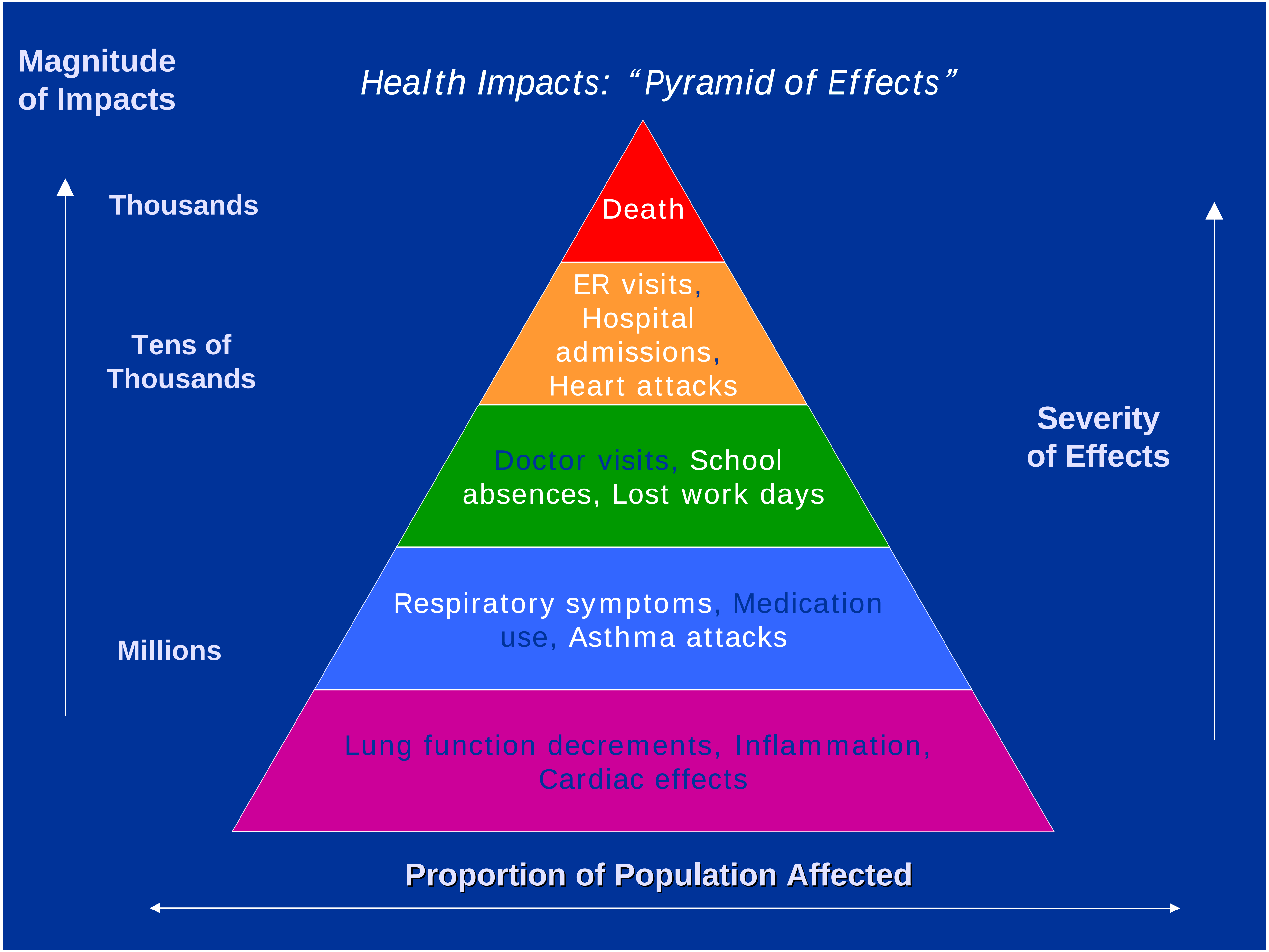
  VSC=value of risk change/risk change

- In the case of risk of death, this is known as the value of a statistical life, or VSL. Here's an example: Suppose a policy reduces the risk of dying by 1 in 10,000, and people are willing to pay $100 for this risk reduction. Then the VSL for this particular risk reduction is $1 million, as shown below: VSL = $100÷1/10,000 = $1,000,000

Valuing Statistical Lives and Cases

- The VSL is NOT the value of the life of a specific person




Magnitude of Impacts
Health Impacts: "Pyramid of Effects"
Thousands
Tens of Thousands
Millions
Death
ER visits, Hospital admissions, Heart attacks
Doctor visits, School absences, Lost work days
Respiratory symptoms, Medication use, Asthma attacks
Lung function decrements, Inflammation, Cardiac effects
Severity of Effects
Proportion of Population Affected

Emerging Public Health Impacts

- Low birth weight
- Decreased lung development
- Cancer
- Doctor visits
- New incidence of asthma
- Mercury and lead cardiac impacts in children and adults

- Not quantified due to
  - Lack of appropriate baseline incidence rates
  - Not enough weight of evidence
  - Not easily monetized or characterized in terms of public health significance

How do we value improvements in air quality?

- Avoided Costs
  - Nonfatal heart attacks
  - Hospital admissions
  - Work loss days
  - Household cleaning expenditures
- Willingness to Pay
  - Premature death
  - Chronic bronchitis
  - Respiratory symptoms
  - Visibility

Cost of illness

- Captures the direct dollar savings to society of reducing a health effect
- Ignores the value to individuals of reduced pain and suffering
- Generally a lower bound when no WTP estimates are available

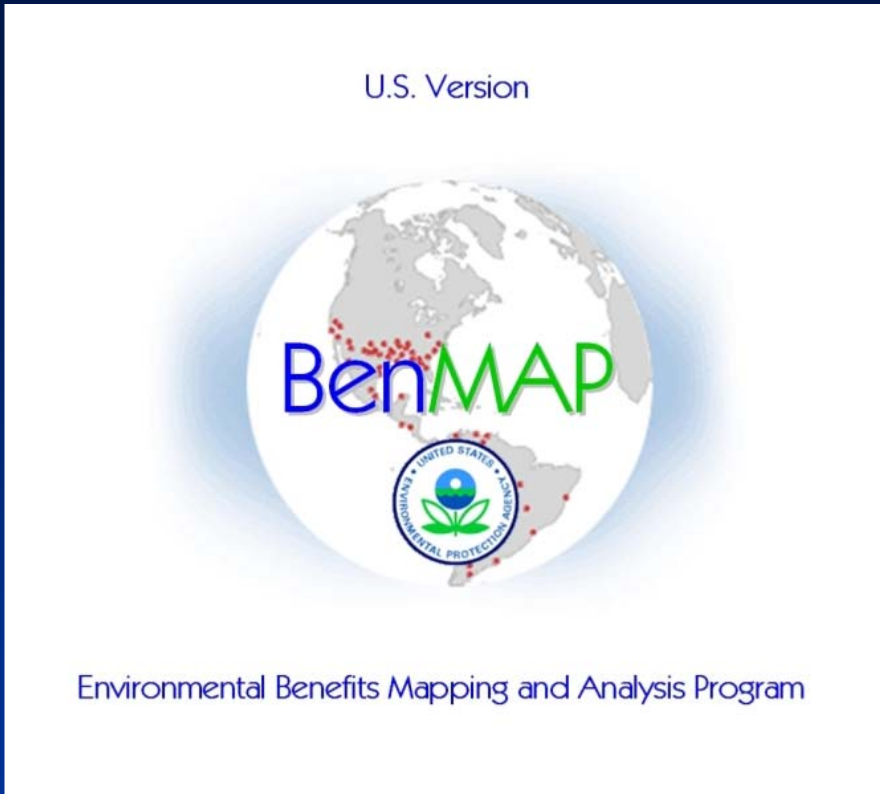
Willingness to Pay

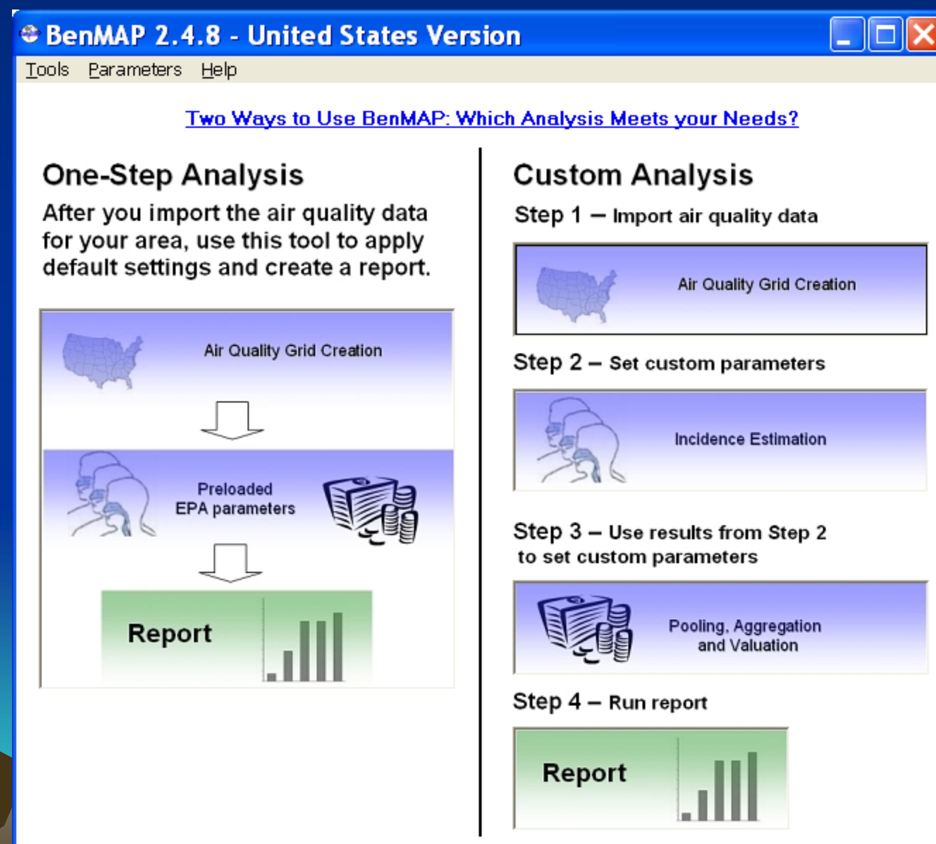
- Measures the complete value of avoiding a health outcome
- Relies on either revealed or stated preferences for risk reductions
  - Revealed preferences from labor market studies provide values for fatal risk reductions
  - Stated preferences from "contingent valuation" studies provide values for chronic illnesses and acute respiratory effects
- Generally more uncertain than COI

Current values for health effects

• Premature death:	$7.4 million
• Chronic bronchitis:	$340,000
• Heart attacks:	$66,000 - $140,000
• Hospital admissions:	$6,000 - $18,000
• ER visits:	$300
• Respiratory symptoms	$15 - $60
• Asthma attacks	$40
• Work loss days	$100
• School absences	$75

Putting It All Together: BenMAP

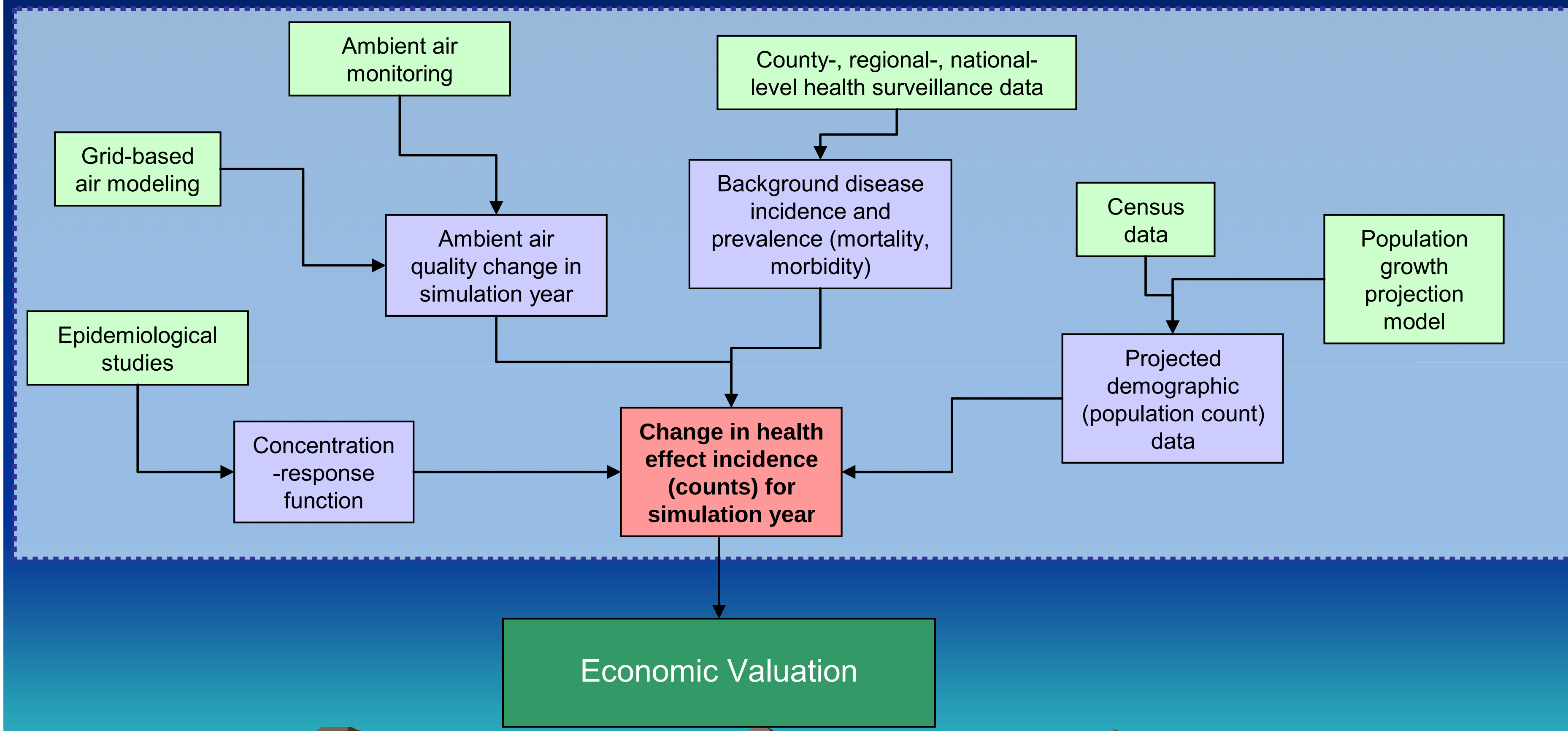

U.S. Version
BenMAP
Environmental Benefits Mapping and Analysis Program

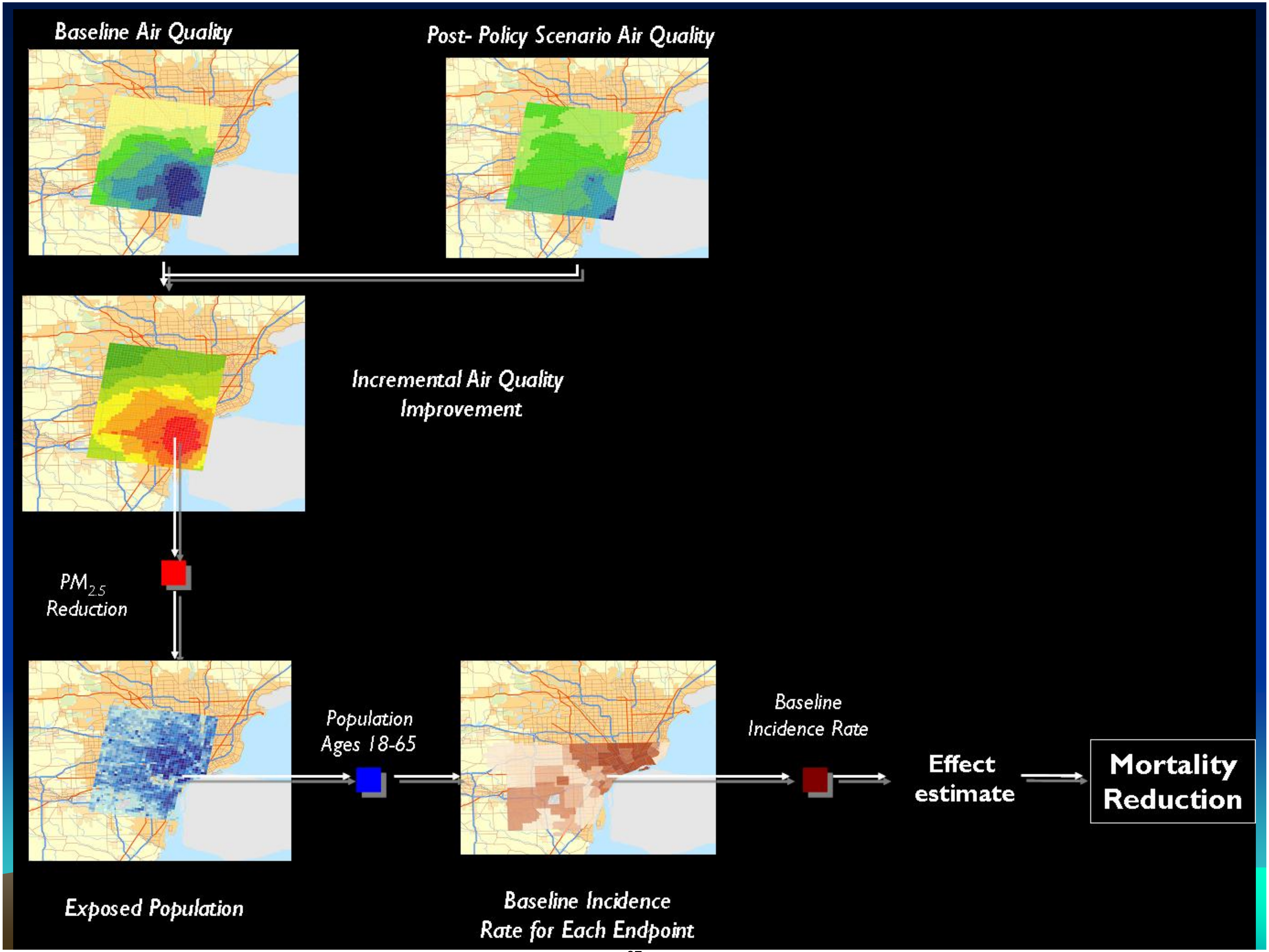

BenMAP 2.4.8 - United States Version
Tools Parameters Help
Two Ways to Use BenMAP: Which Analysis Meets your Needs?
One-Step Analysis
After you import the air quality data for your area, use this tool to apply default settings and create a report.
Air Quality Grid Creation
Preloaded EPA parameters
Report
Custom Analysis
Step 1 – Import air quality data
Air Quality Grid Creation
Step 2 – Set custom parameters
Incidence Estimation
Step 3 – Use results from Step 2 to set custom parameters
Pooling, Aggregation and Valuation
Step 4 – Run report
Report

Key Features of BenMAP

- Includes all of the key inputs to a benefits analysis
- The user only has to provide modeled environmental data – or select monitored air quality data for a “what if” style analysis
- BenMAP is an integrated GIS mapping, query, and statistics tool
- Outputs results (exposure, incidence, and valuation) in a variety of formats, including spreadsheets and shape files suitable for use with standard GIS packages such as ArcView

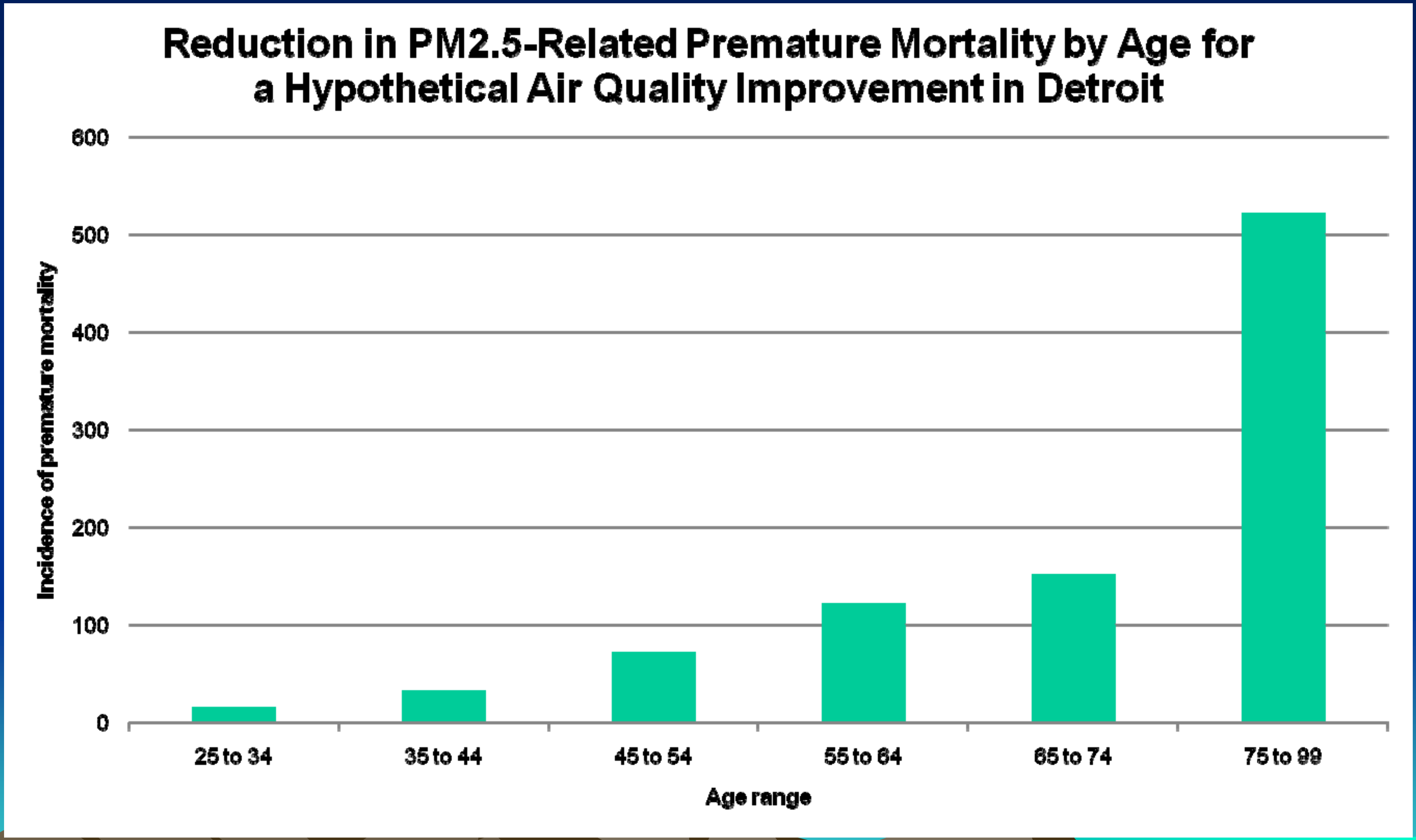
BenMAP Health Benefits Assessment Framework



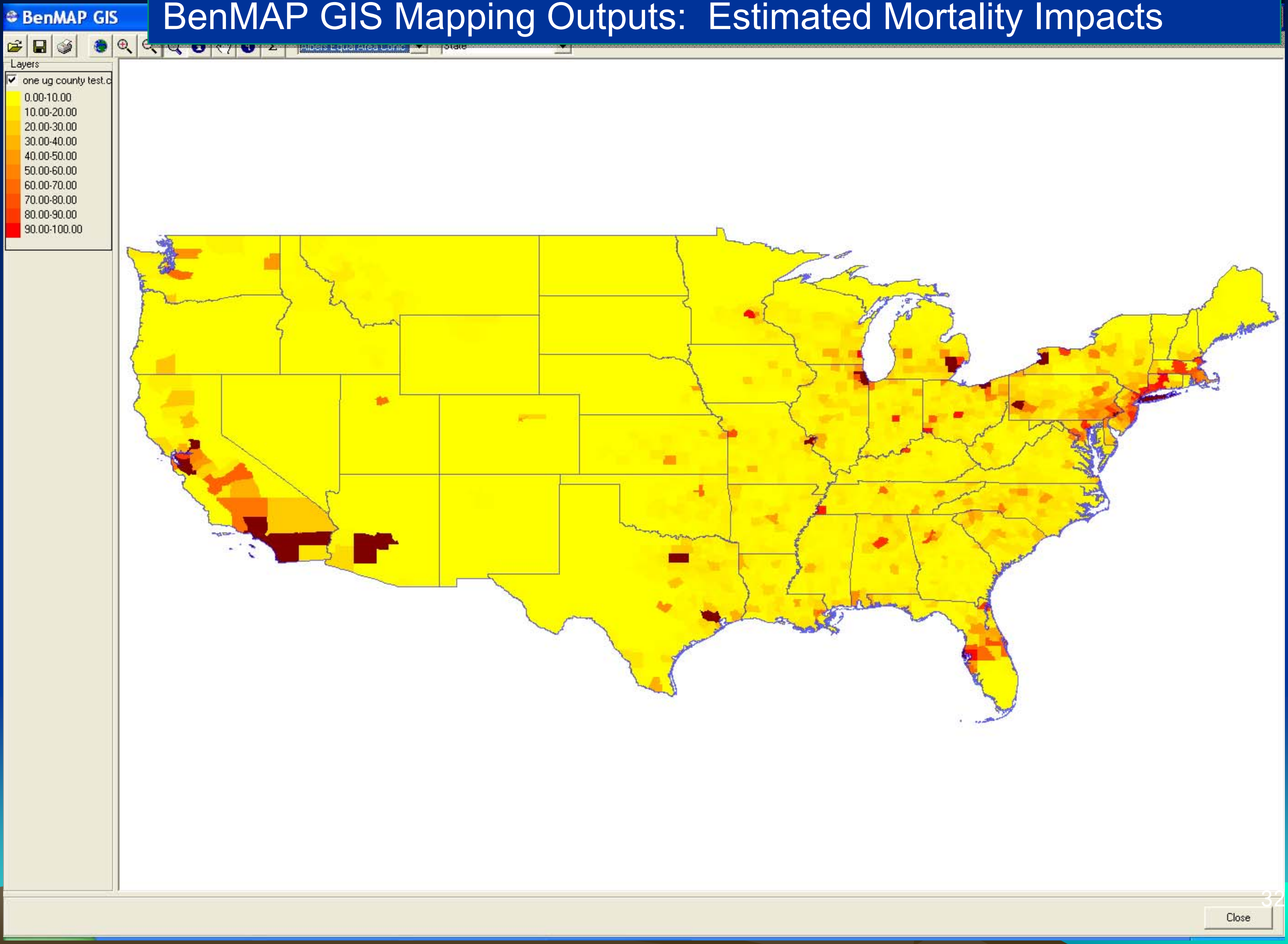


Baseline Air Quality
Post- Policy Scenario Air Quality
Incremental Air Quality Improvement
$PM_{2.5}$ Reduction
Population Ages 18-65
Baseline Incidence Rate
Effect estimate
Mortality Reduction
Exposed Population
Baseline Incidence Rate for Each Endpoint

Example BenMAP Output



BenMAP GIS Mapping Outputs: Estimated Mortality Impacts



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Projected Benefits of Recent Actions

- Engine and Fuel standards for nonroad diesels

By 2030

12,000 premature deaths avoided annually + many additional health impacts

Economic value of health benefits over $80 billion annually

Projected benefits are almost 40 times costs!

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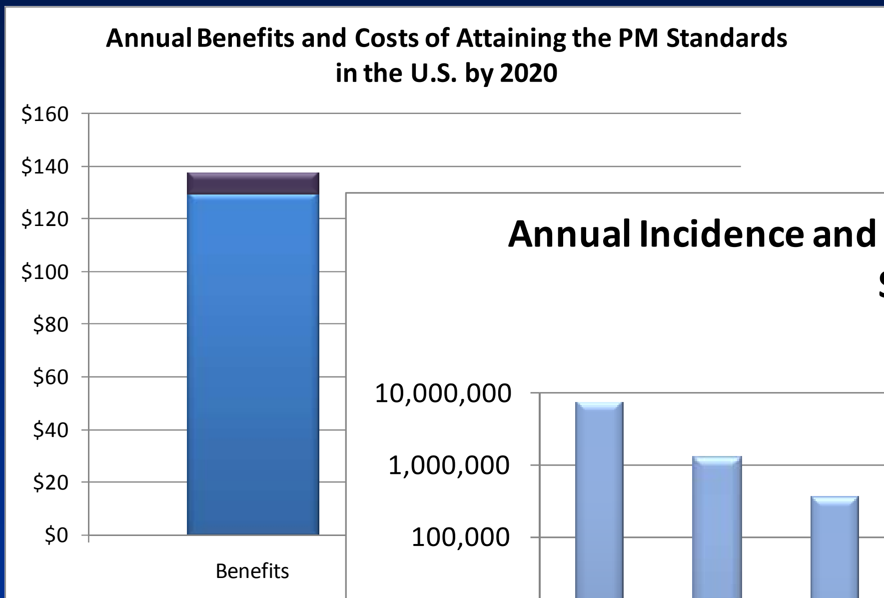
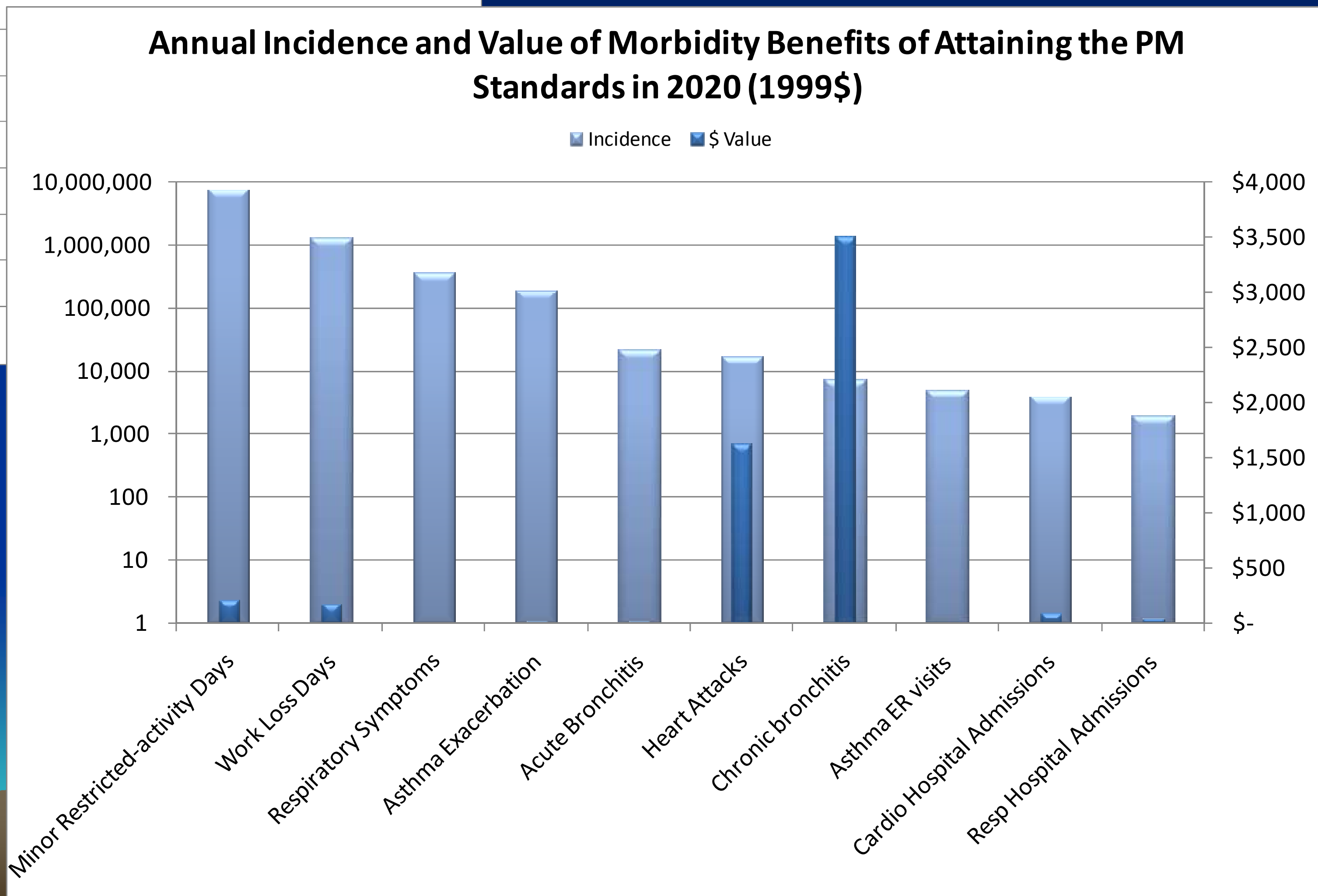
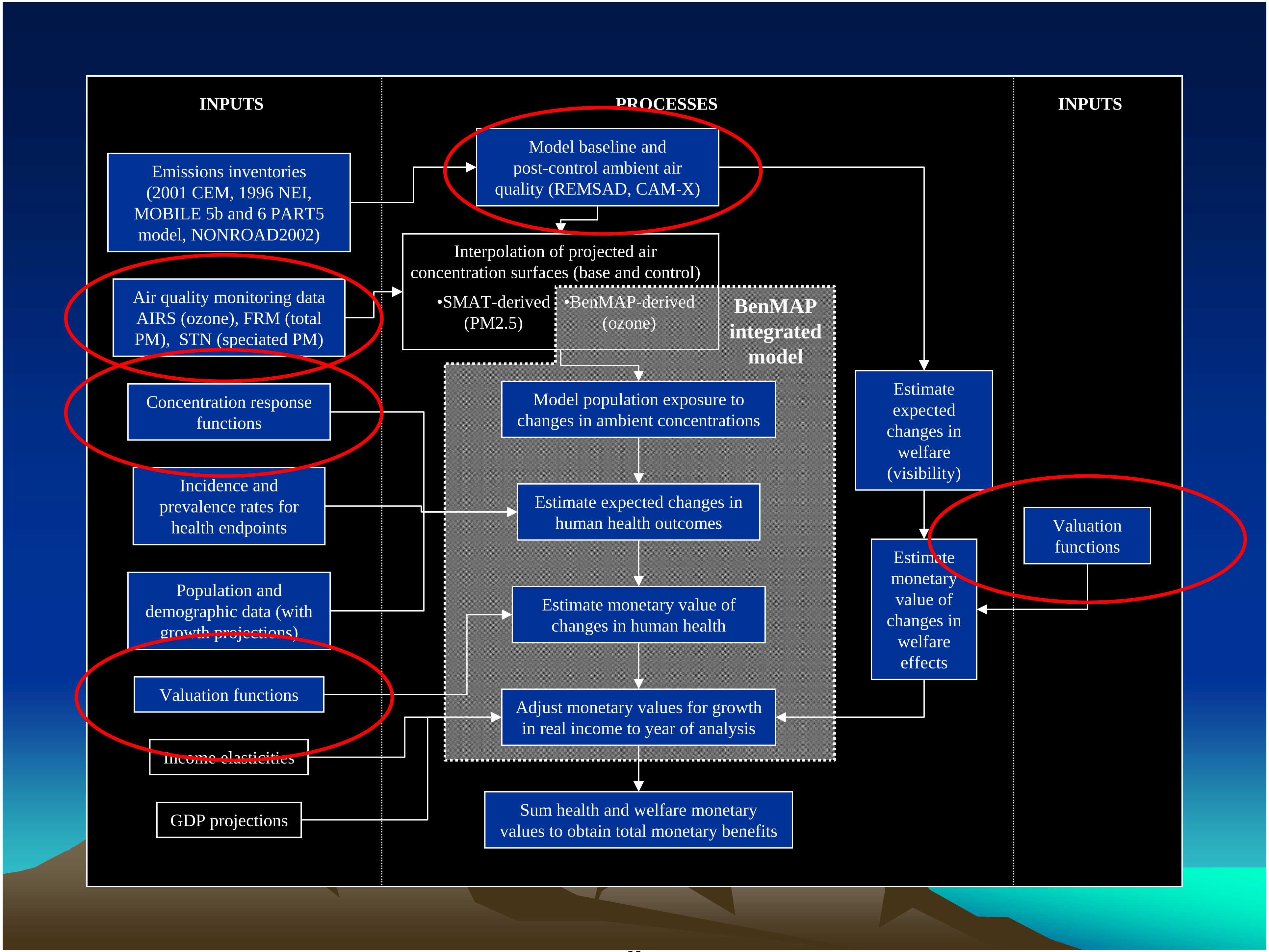
Projected Benefits of Recent Actions

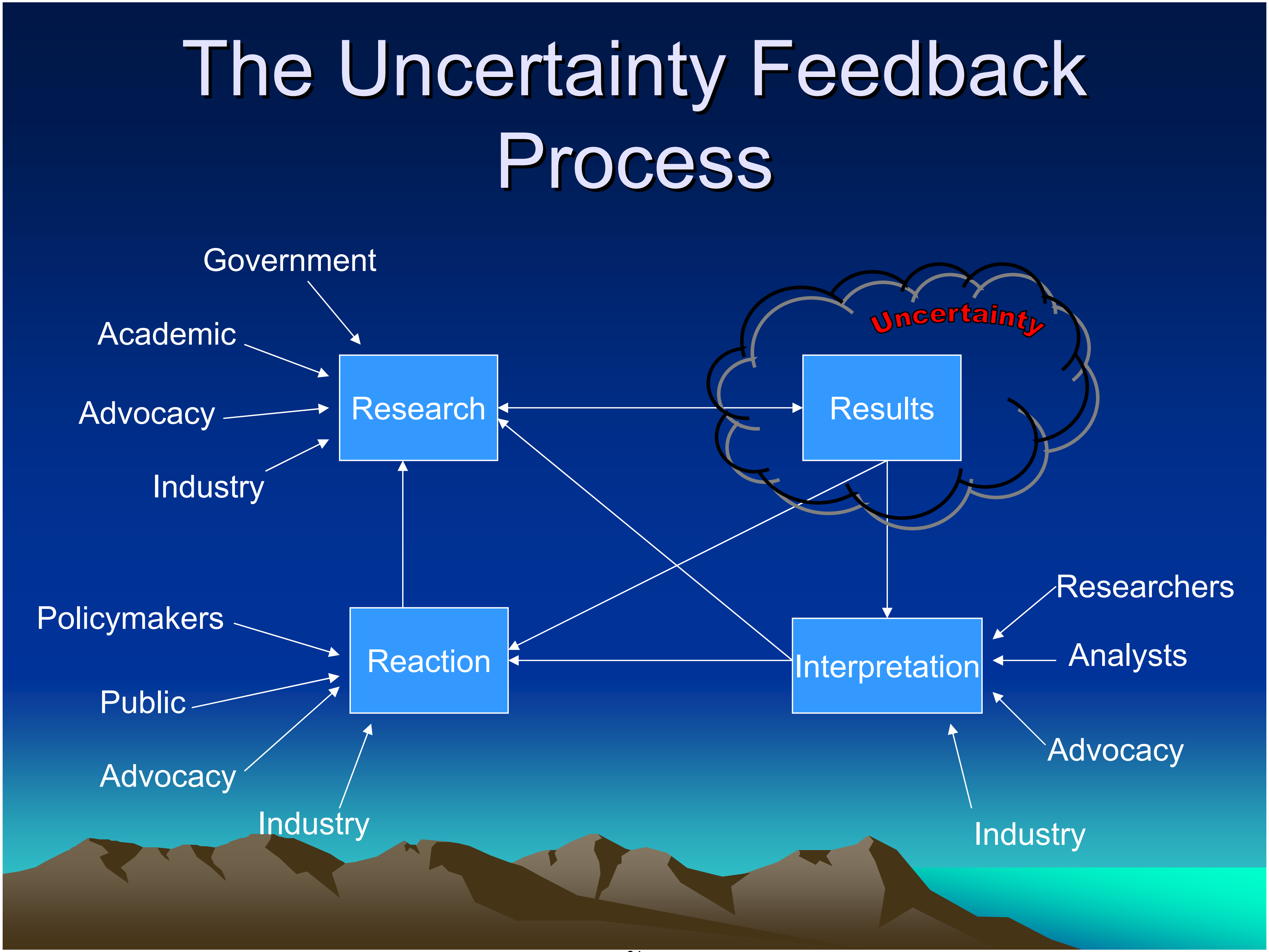




Where Does Science Play a Role?

- At each step in the policy analysis process, different scientific disciplines are needed to provide essential inputs
- The validity of the final analysis rests heavily on the validity of the science used to provide the key inputs


INPUTS
PROCESSES
INPUTS
Emissions inventories (2001 CEM, 1996 NEI, MOBILE 5b and 6 PART5 model, NONROAD2002)
Model baseline and post-control ambient air quality (REMSAD, CAM-X)
Interpolation of projected air concentration surfaces (base and control)
•SMAT-derived (PM2.5)
•BenMAP-derived (ozone)
BenMAP integrated model
Air quality monitoring data AIRS (ozone), FRM (total PM), STN (speciated PM)
Concentration response functions
Model population exposure to changes in ambient concentrations
Estimate expected changes in welfare (visibility)
Incidence and prevalence rates for health endpoints
Estimate expected changes in human health outcomes
Valuation functions
Estimate monetary value of changes in welfare effects
Population and demographic data (with growth projections)
Estimate monetary value of changes in human health
Valuation functions
Adjust monetary values for growth in real income to year of analysis
Income elasticities
GDP projections
Sum health and welfare monetary values to obtain total monetary benefits


The Uncertainty Feedback Process
Government
Academic
Advocacy
Industry
Research
Uncertainty
Results
Policymakers
Public
Advocacy
Industry
Reaction
Interpretation
Researchers
Analysts
Advocacy
Industry

So what does uncertainty mean?

In that about which I am most confident, you are not interested

About that in which I am most interested, you are not confident

Scientist

Policymakers

Examples of Feedback in Action

- Epidemiology:
  - The case of fine particulate matter and premature death
  - Ozone and mortality: the endless do loop
- Economics: The case of the “Senior Death Discount”

Particulate Matter

- Research
  - Particulate Matter and Premature Death
- Results
  - By the early 1990's: Limited number of statistical studies showing a link between fine particulate matter and premature death, little supporting clinical or toxicological data
- Interpretation
  - EPA set new PM2.5 standards in 1997.
  - EPA estimated the new standards would result in 15,000 fewer deaths from PM2.5 in 2010.
- Reactions
  - Claims of "junk science" from industry and conservative stakeholders, demands for release of research data
  - Support for more protective standards from ALA and environmental groups, and hundreds of articles in the press and academic journals

Case Example: Particulate Matter (continued) – Outcomes part 1

- General Accounting Office Report: Use of Precautionary Assumptions in Health Risk Assessments and Benefits Estimates
  - Found that EPA had not generally adopted precautionary assumptions in estimating benefits of NAAQS
- HEI Reanalysis costing ~ $2 million
  - Affirmed findings of original studies
  - Suggested areas for additional research
- Extension of Freedom of Information Act
  - Requires agencies to "ensure that all data produced under a [Federal] award will be made available to the public through procedures established under the FOIA."
  - Still causing concerns within scientific community over confidentiality of subject data and proprietary data
- Appropriations bill language requesting NAS study of benefits analysis methods
  - NAS study completed in 2002
  - Confirmed that EPA's approach is generally reasonable
  - Recommended enhanced treatment of uncertainty, including that surrounding the PM-mortality relationship
  - Suggested using "expert judgment" to help characterize uncertainty

Case Example: Particulate Matter (continued) – Outcomes part 2

- Hundreds of new studies examining the relationship between PM and health effects, sponsored by EPA, HEI, industry, and state agencies.
- Full scale expert elicitation conducted by EPA to characterize uncertainty in the PM mortality relationship
- Scientific foundation for PM health effects upheld – 20 of 22 CASAC members supported tighter daily and annual PM standards
- As a result, new, even tighter daily standard set in 2006 -- However, the decision to tighten the daily but not the annual standard was based on interpreting the evidence and did not use the quantitative risk analysis because it was determined that it was “too uncertain”.

1997 O3 NAAQS

Initial meta-analysis based on 9 studies, primary range included meta-analysis mean and zero. No consideration of O3 mortality in O3 risk assessment.

1998 NOx SIP Call

Revised pooled mean estimate based on 4 US studies, primary range included zero.

July 1999: 1st SAB Advice Received

Advised that current ozone studies had not adequately addressed concerns about double-counting with PM2.5 mortality effects.

1999/2000 Final Tier 2 Rule/HD Engines/ Section 812 Prospective Report

Ozone mortality removed from primary estimate due to SAB concerns about double counting with PM2.5. Supplemental pooled mean estimate based on 4 US studies included in appendix. Range with zero not included.

Sept 2001: 2nd SAB Advice Received

Advised EPA to evaluate new Thurston and Ito 2001 analysis and “incorporate any plausible damage function for mortality based on ozone.”

March 2004: 3rd SAB Advice Received

“Supports EPA’s plans for meta-analyses for ozone mortality and the Agency's plans to consider adding it to base case analysis, subsequent to review of the results of those analyses.”

May 2004 Nonroad Rule

Followed same approach as Tier 2

March 2005 CAIR

Followed same approach as Tier 2, with exception of using refined 3 study pooled approach

EPA funds 4 ozone mortality studies which are peer-reviewed and published in June 2005

September 2005 O3 Implementation

Benefits analysis white paper recognizes the additional scientific support for ozone mortality and includes ozone mortality in the main analysis

Feb 2006: Final O3 CD published

Includes review of many new ozone mortality studies, including the NMMAPS multicity analysis and the 3 recent ozone mortality meta-analyses. Concludes there is strong epidemiological basis for ozone mortality effect.

August 2006: NRC project begun

Project Title: Estimating Mortality Risk Reduction Benefits from Decreasing Tropospheric Ozone Exposure

October 2006: 4th SAB Advice Received

CASAC concurs with agency risk analysis incorporating non-zero mean mortality impacts (zero only considered as part of distributions derived from std errors), finding “…**premature total non-accidental and cardiorespiratory mortality** for inclusion in the quantitative risk assessment to be appropriate.”

Jan 2007: Final O3 Risk Assessment

Includes many estimates of ozone-related mortality impacts, including estimates based on the NMMAPS analysis and other single and multi-city ozone-mortality studies. Uncertainty represented only by statistical confidence intervals derived from the epidemiological studies. No zero mean effect reported.

March 2008: O3 NAAQS Final RIA

Interim approach under development

Spring 2008: NAS Report Completed

The "Senior Death Discount"

- Analytical issue: Most of the premature mortality associated with air pollution occurs in the elderly population, yet the value placed on reductions in premature mortality (the value of a statistical life or VSL) is based on working age adults.
- Research: How does the value of reductions in mortality risk (the value of a statistical life) vary with age?
- Results: Mixed, with some limited evidence from the UK and Canada suggesting individuals over the age of 65 have a VSL around a third lower than individuals aged 40. Research in the U.S. did not seem to support this relationship.

- Interpretation
  - EPA's Science Advisory Board suggested that if adjustments to VSL for age are made they should be based on age specific willingness to pay for mortality risk reductions. Other stakeholder groups suggested that additional adjustments could be made by using the value of life years gained rather than premature deaths avoided.
  - EPA included a sensitivity analysis in an appendix to the RIA for the Heavy Duty Engines rule in 1999 showing the impact of different assumptions about the relationship between age and VSL. In the Clear Skies analysis of 2001, EPA constructed an "alternative estimate" of benefits that, among other assumptions, reduced the VSL for individuals over 65 by 35 percent. The alternative estimate was only 10 percent of the magnitude of the base estimate

- Reaction
  - Because of the large difference between the base and alternative estimates, environmental groups became aware of the assumptions being used in the alternative analysis
  - The term “Senior Death Discount” was coined and public outcry over the practice became pronounced.
  - Dozens of articles in major newspapers and journals were published criticizing the use of lower VSL for older individuals.

- Outcomes
  - In early May, 2003, the EPA administrator announced EPA would not use age-adjusted values in decision making
  - On May 30, 2003, OMB issued a memo directing federal agencies to cease using age-adjusted VSL values in regulatory analysis
  - In July 2003, an amendment to a house appropriations bill was passed that forbid EPA from using different values of VSL for different age groups (sponsored by Rep Allen and Waxman)
  - In November 2003, an amendment to a senate appropriations bill was passed with similar provisions (sponsored by Sens Durbin, Snowe, Jeffords, Boxer, Lautenberg, Cantwell, and Lieberman)
  - Research continues into the relationship between age and VSL
  - The most recent SAB advice is for EPA to use the same VSL for all ages, and to avoid using the VSLY approach

So How Do We Improve the Process?

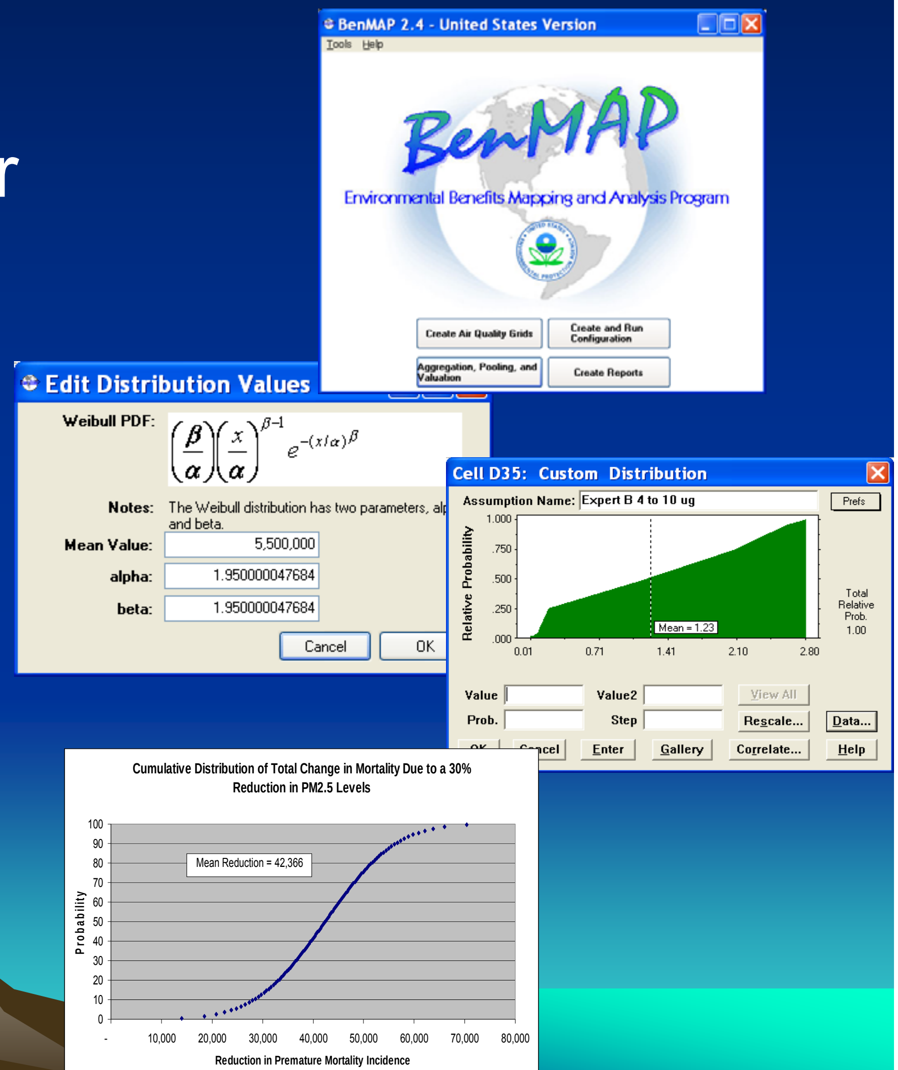
- Clear from the two examples that we need a better understanding of uncertainty in the translation of scientific results into policy analysis
  - Uncertainty ≠ Doubt
  - Sound Science ≠ Consensus
  - Uncertainty should not be manufactured, just communicated
- Also need better communication with stakeholder groups to explain our choices of assumptions
- Moving forward in both areas through tool development

Cost-Benefit Analysis with Uncertainty

- NAS panel recommended moving probabalistic analysis into main body of RIAs
- OMB's new guidelines require probabilistic analysis for rules costing more than $1 billion
- Integrated uncertainty assessment requires propogation of uncertainty along the entire pathway of analysis
- Several methods are available for integrating uncertainty
- Our current focus has been on using Monte Carlo approach
- Investigating a number of complementary approaches, including
  - Bayesian model averaging
  - Bayesian meta-analysis
  - Sensitivity analysis
  - Response surface analysis
  - Expert elicitation/judgement

BenMAP Uncertainty Characterization

- BenMAP can propagate uncertainty from a number of sources using standard distributions or custom distributions (such as those obtained from expert elicitations)
- BenMAP provides central tendency estimates as well as percentiles of distributions for input and output distributions



Benefits Analysis Uncertainty Presentation: PM NAAQS RIA (1)

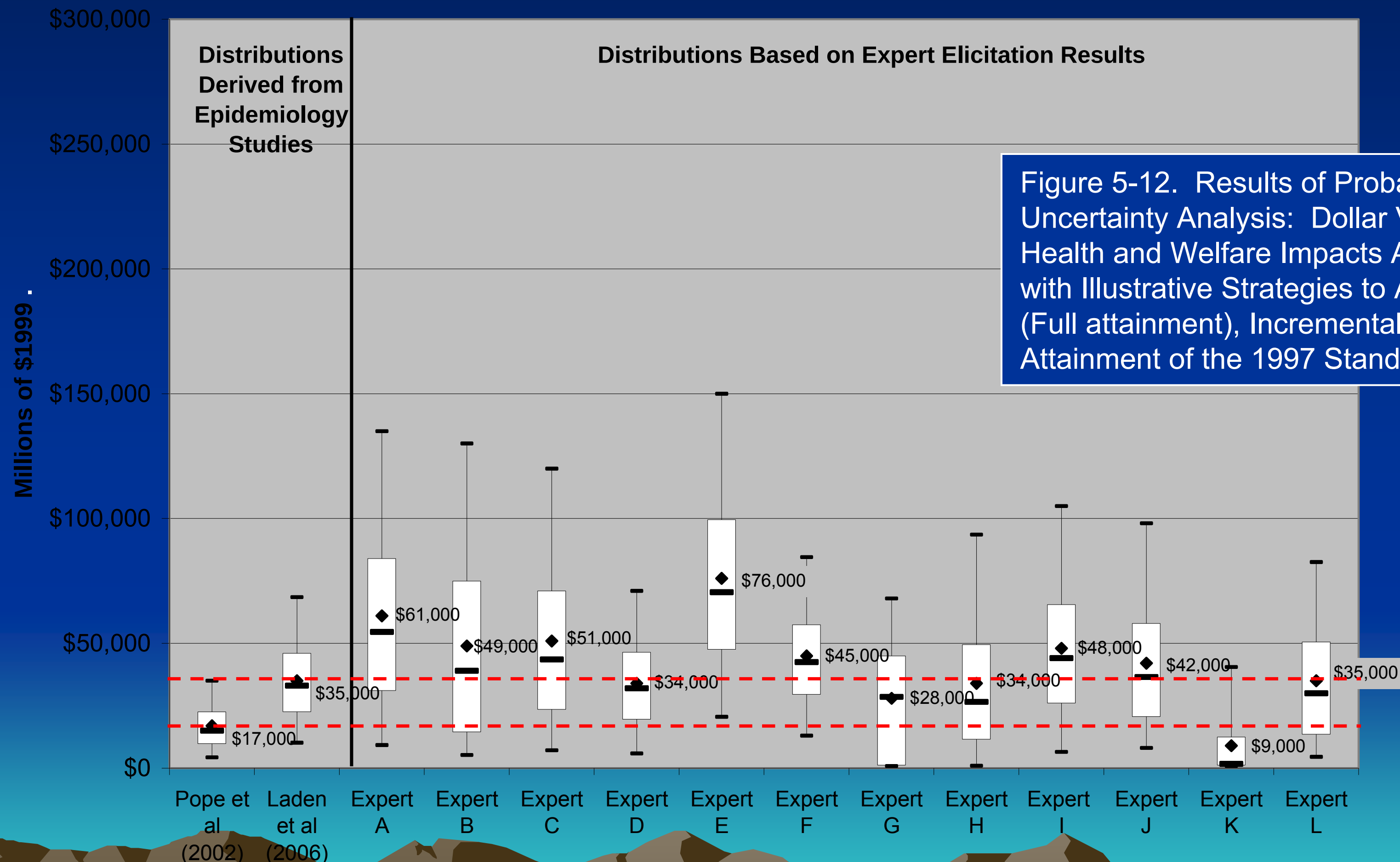
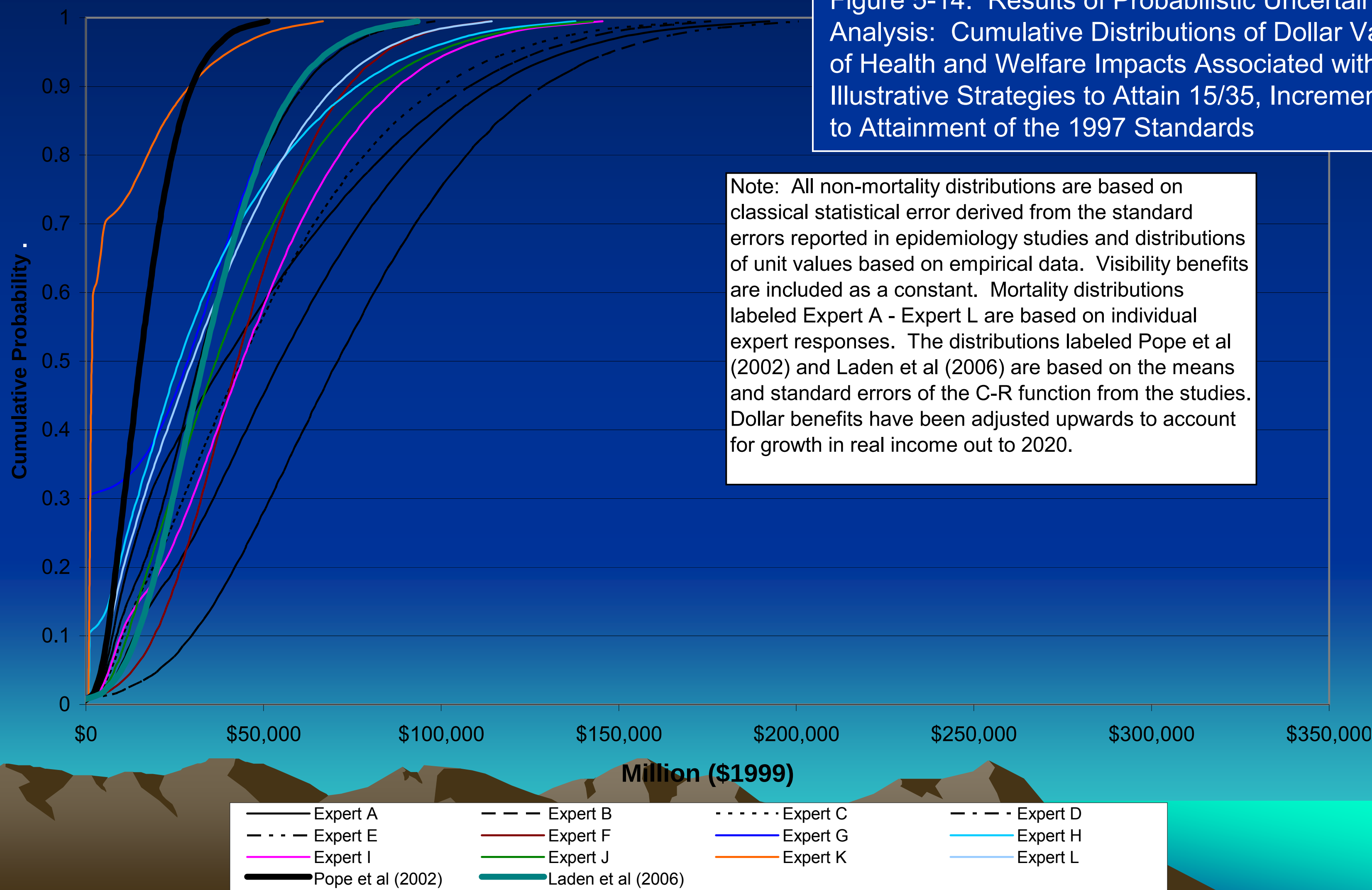


Figure 5-12. Results of Probabilistic Uncertainty Analysis: Dollar Value of Health and Welfare Impacts Associated with Illustrative Strategies to Attain 15/35 (Full attainment), Incremental to Attainment of the 1997 Standards

Note: All non-mortality distributions are based on classical statistical error derived from the standard errors reported in epidemiology studies and distributions of unit values based on empirical data. Visibility benefits are included as a constant. Mortality distributions labeled Expert A - Expert L are based on individual expert responses. The mortality distributions labeled Pope et al. (2002) and Laden et al (2006) are based on the means and standard errors of the C-R functions from the studies. Dollar benefits have been adjusted upwards to account for growth in real income out to 2020.The red dotted lines enclose a range bounded by the means of the two data-derived distributions.

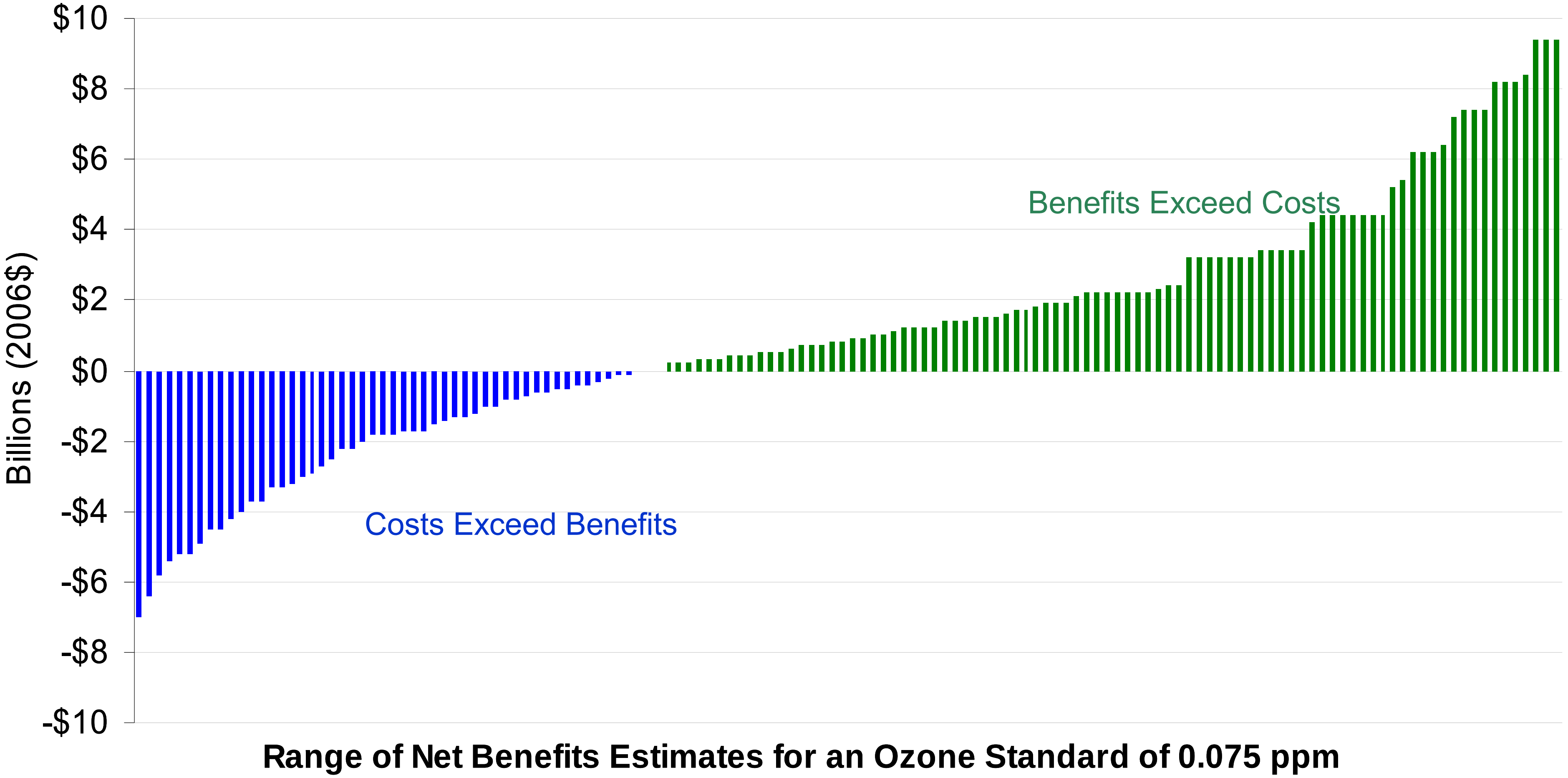
Benefits Analysis Uncertainty Presentation: PM NAAQS RIA (2)

Figure 5-14. Results of Probabilistic Uncertainty Analysis: Cumulative Distributions of Dollar Value of Health and Welfare Impacts Associated with Illustrative Strategies to Attain 15/35, Incremental to Attainment of the 1997 Standards



Note: All non-mortality distributions are based on classical statistical error derived from the standard errors reported in epidemiology studies and distributions of unit values based on empirical data. Visibility benefits are included as a constant. Mortality distributions labeled Expert A - Expert L are based on individual expert responses. The distributions labeled Pope et al (2002) and Laden et al (2006) are based on the means and standard errors of the C-R function from the studies. Dollar benefits have been adjusted upwards to account for growth in real income out to 2020.

Comparing Benefits with Costs



What About Climate?

- Climate analysis is even more complicated
  - Current techniques are limited to aggregate impacts -- generally global or regional $/ton of CO_2 ("Social Cost of Carbon")
  - Significant omitted categories and large data gaps
  - Hard to deal with highly uncertain events with large impacts, e.g. collapse of ice shelves
  - Not clear how to treat global vs domestic impacts
- Important issue of how to treat intergenerational benefits – should they be discounted?

Useful Websites

- EPA Air Benefit Cost Group
  - https://www.epa.gov/ttn/ecas/
- BenMAP
  - https://www.epa.gov/air/benmap/
- The Costs and Benefits of the Clean Air Act: 1990 to 2010
  - http://www.epa.gov/air/sect812/
- The Nonroad Diesel Regulatory Impact Analysis
  - http://www.epa.gov/nonroad/
- EPA Science Advisory Board
  - http://www.epa.gov/sab
- Health Effects Institute
  - http://www.healtheffects.org
- General Accounting Office Report on Use of Precautionary Assumptions in Health Risk Assessments and Benefits Estimates
  - http://www.gao.gov/docdblite/summary.php?accno=164183&rptno=GAO-01-55
- Harvard Center for Risk Analysis
  - http://www.hcra.harvard.edu/
- Office of Management and Budget Office of Information and Regulatory Affairs
  - www.whitehouse.gov/omb/inforeg/

Science Needs in OAQPS Air Pollution Policy Development

Bryan Hubbell, U.S. EPA
Office of Air and Radiation

Overview

- What are the research needs to support current and future reviews of the NAAQS?
  - What role does scientific information play in NAAQS decisions?
  - What are key policy–relevant questions that could be informed by advances in the scientific evidence?
- What are the research needs to support current and future policies for air toxics?

Note: This presentation is focused on health based research needs – however, there is an increasing need for research to support the secondary NAAQS – for example we are currently working to set an ecologically based secondary standard to protect against the effects of NOx and SOx deposition.

2

NAAQS: Clean Air Act Section 109 Requires Overarching Questions to be Addressed

- In light of newly available information, are current *primary* standards *requisite* to protect public health with an *adequate margin of safety*?

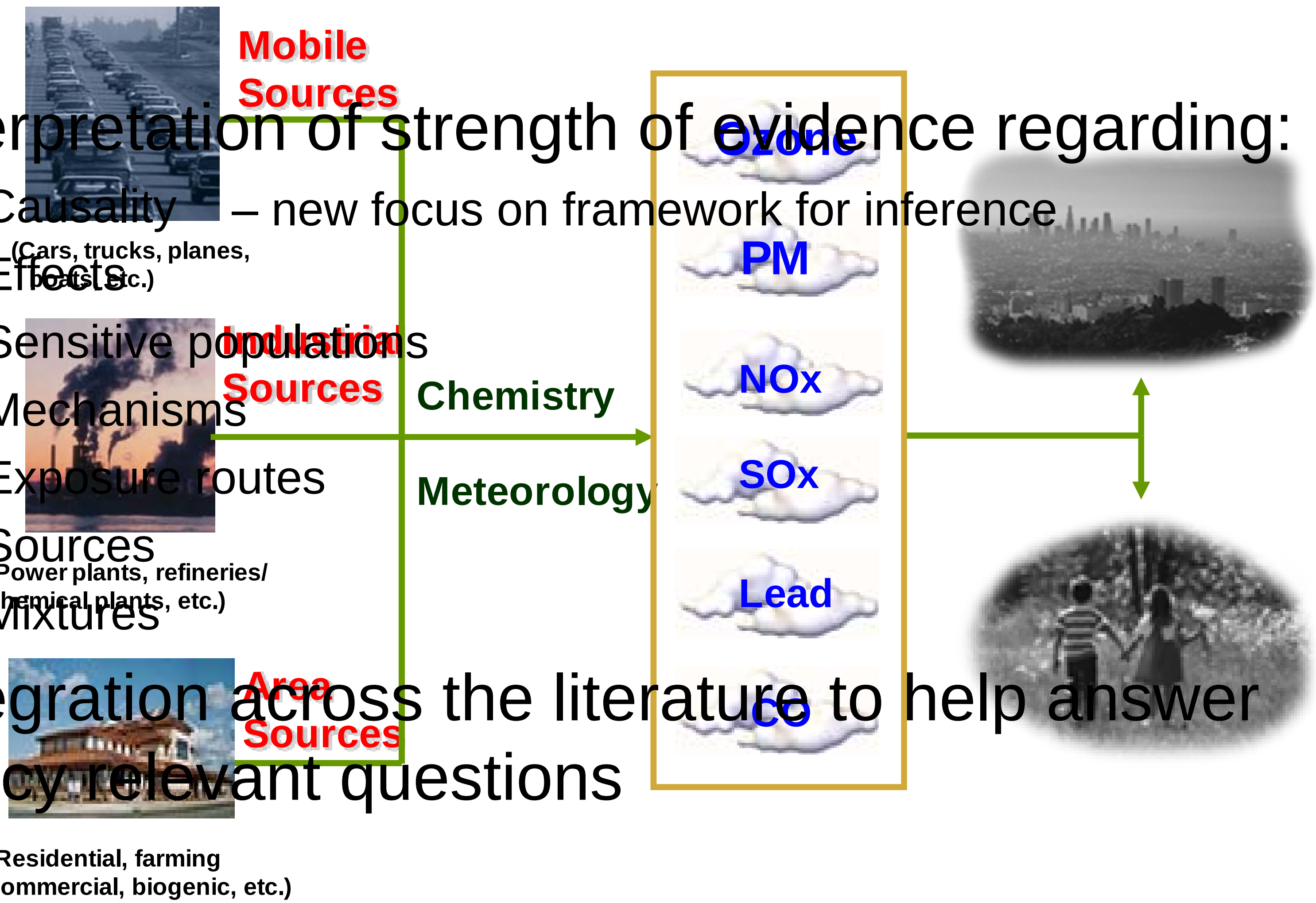
  In light of newly available information, are current *secondary* standards *requisite* to protect public welfare from any known or anticipated adverse effects?
- If not, what revisions are appropriate in terms of:
  - Indicator(s),
  - Averaging time(s),
  - Level(s), and
  - Form(s)

Current NAAQS Process: Key Steps

- <u>Planning:</u>
  - Receive early input from experts, including CASAC
  - Focus efforts on key policy-relevant issues and science that informs our understanding of these issues
  - NCEA/OAQPS create one Integrated Review Plan (IRP) early in process
- <u>Integrated Science Assessment (ISA)</u>
  - Replace voluminous Criteria Document with more concise synthesis of most policy-relevant science accompanied by extensive Annexes
  - Develop continuous survey/evaluation of new science; create state-of-the-art electronic databases to catalog new studies - HERO
- <u>Risk/Exposure Assessment (REA)</u>
  - Create more concise document in parallel with development of ISA
  - Emphasize key results, observations and uncertainties
- <u>Policy Assessment (PA)/Rulemaking</u>
  - Develop policy assessment which will present staff conclusions on adequacy of current NAAQS and, when appropriate, consideration of potential alternative NAAQS
- Consider CASAC recommendations and public comments throughout development of assessment documents as well as on proposed rule

What does the science review offer?

- Understanding of sources, atmospheric chemistry
- Interpretation of strength of evidence regarding:
    - Causality – new focus on framework for inference
    - Effects
    - Sensitive populations
    - Mechanisms
    - Exposure routes
    - Sources
    - Mixtures
- Integration across the literature to help answer policy relevant questions



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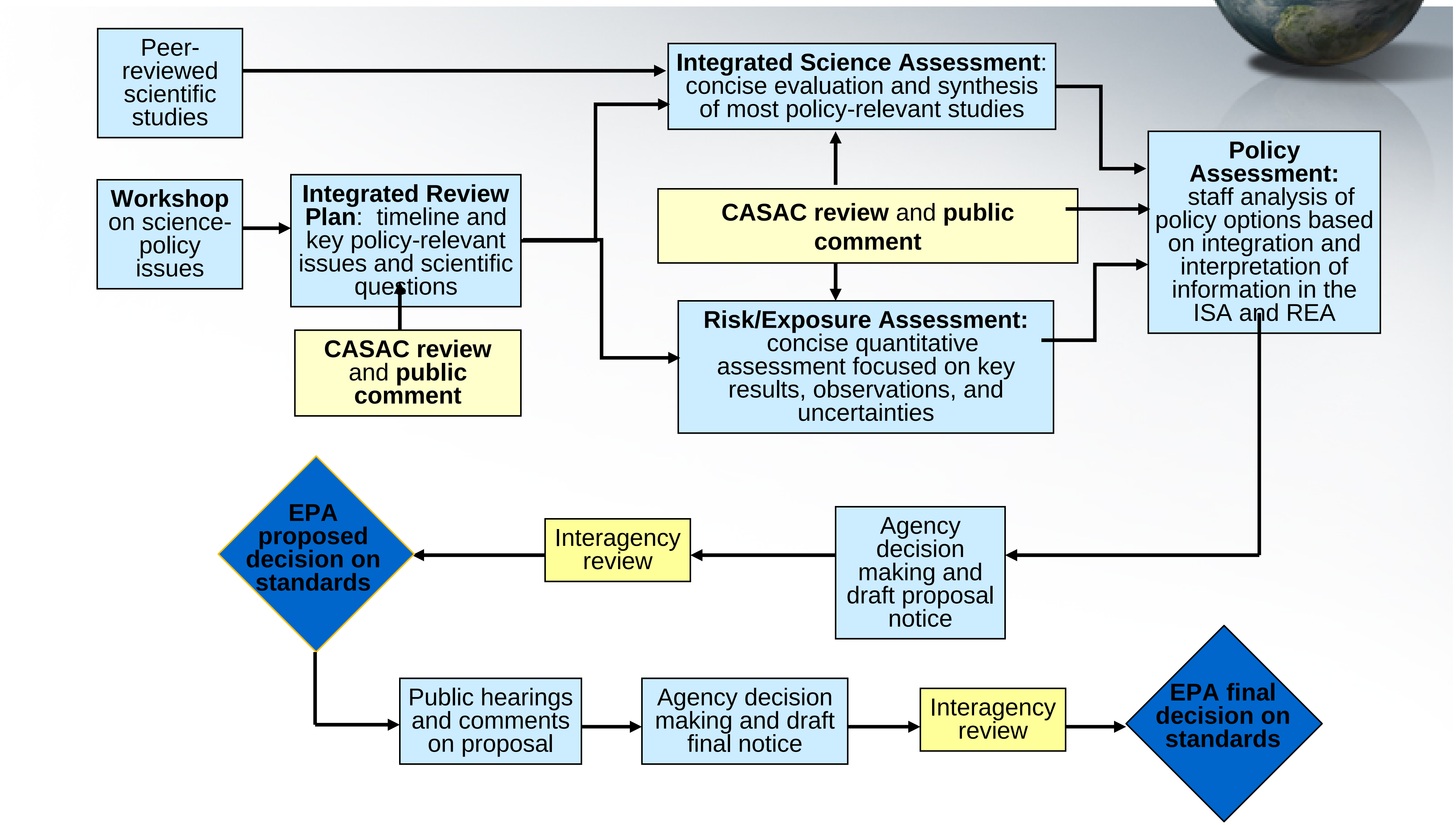
The Role of Risk Assessment

- Designed to estimate human exposures and to characterize the potential health risks that are associated with
  - current ambient pollution levels
  - ambient levels simulated to just meet the current standards
  - ambient levels simulated to just meet alternative standards that may be considered
- Careful consideration of uncertainties

More on the Policy Assessment Document....

- A policy assessment pulls the scientific evidence and risk assessment results together
- This policy assessment identifies conceptual evidence- and risk-based approaches for reaching policy judgments,
- It discusses what the science and risk/exposure assessments say about
  - the adequacy of the current standards
  - potential alternative standards

NAAQS Review Process



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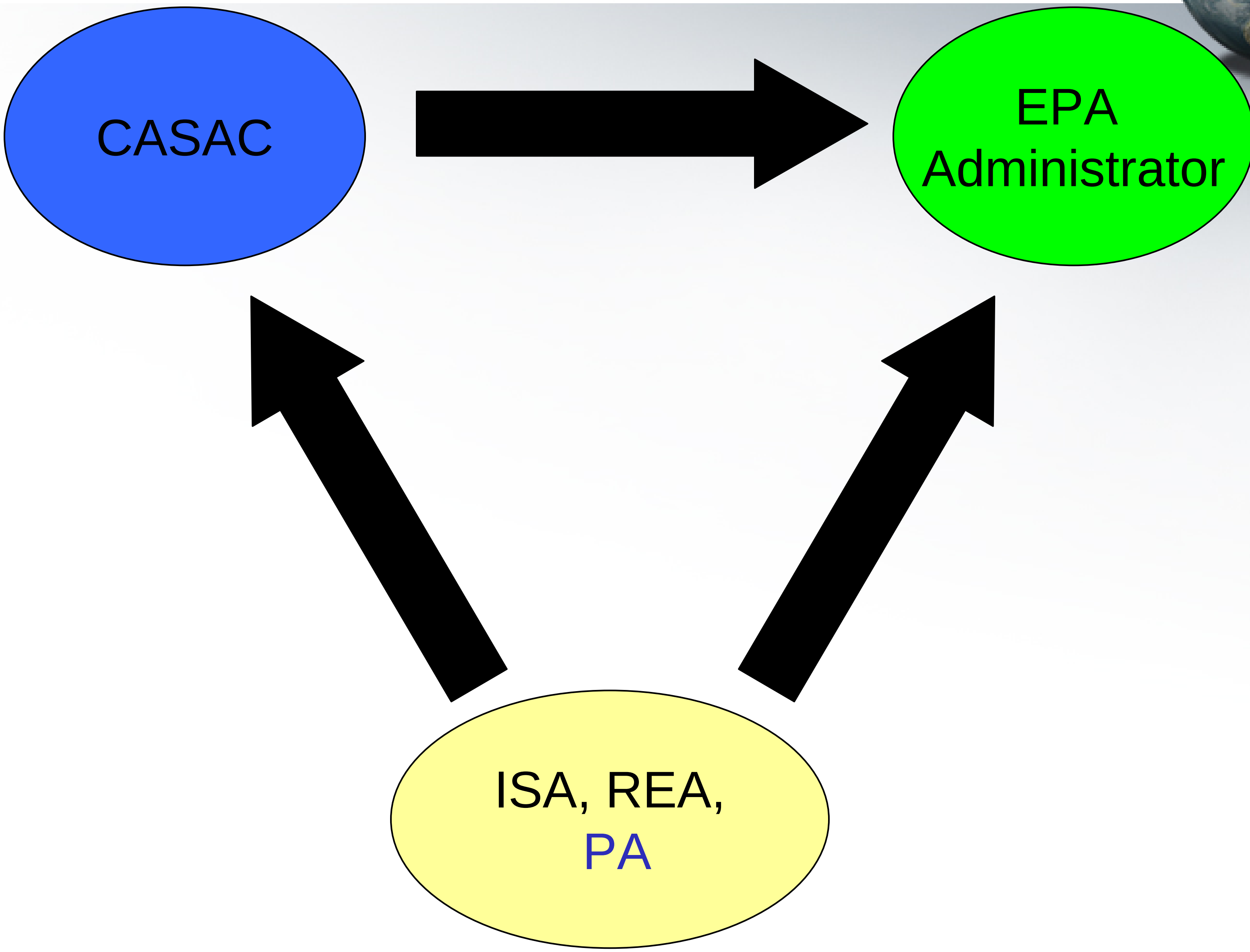

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Statutory Requirements for NAAQS

- ***Primary (health-based) Standards*** . . .

  in the "judgment of the Administrator" are "requisite" to protect public health with an "adequate margin of safety"

  - "Requisite" – sufficient but not more than necessary
  - "Adequate margin of safety" – intended to address uncertainties associated with inconclusive evidence, and to provide a reasonable degree of protection against hazards that research has not yet identified

  - ★ In addressing the margin of safety requirement, EPA has consistently based its judgments on the science, taking into consideration:
    - Nature of health effects
    - Size of populations at risk and degree of exposure
    - Degree of scientific uncertainty that such effects will occur
  - ★ Public health protection intended for:
    - Adverse health effects, not all identifiable effects
    - At-risk population groups

Recent NAAQS Decisions

- 2006: PM
  - Revised primary 24-hour $PM_{2.5}$ standard to provide additional public health protection – 35 µg/m^3; Retained primary annual $PM_{2.5}$ standard of 15 µg/m^3
  - Retained primary 24-hour PM_{10} standard to provide protection from exposures to thoracic coarse particles; Revoked primary annual PM_{10} standard
  - Revised secondary standards to be identical to primary standards
  - Court remanded primary annual $PM_{2.5}$ and $PM_{2.5}$ secondary standards; Court affirmed PM_{10} decisions; primary 24-hour $PM_{2.5}$ standard not challenged
- 2008: Ozone
  - Revised level of primary and secondary standards from 0.084 ppm to 0.075 ppm
  - Currently reconsidering 2006 decisions
- 2008: Lead
  - Revised level from 1.5 µg/m^3 to 0.15 µg/m^3 to provide increased public health protection especially for children
  - Revised form in terms of a maximum (not-to-be-exceeded) rolling three-month average evaluated over a three-year period, as compared to previous averaging time of calendar quarter

What are the missing pieces?

- Uncertainty in science and exposure/risk assessment remains a significant element in decisions on the standards
- Where to stop? – with apparently non-threshold pollutants, critical to understand impacts at lower concentrations. Additional clinical studies can be useful here.
- Are we regulating the right things? – more studies on PM composition and sources
- Are we protecting at-risk populations? Expanded interest in factors that determine susceptibility and vulnerability, e.g. genetic markers.
- Is the suite of standards protective? Given the variety of mixtures to which populations are exposed, are single pollutant standards adequately protective in a multipollutant environment – which mixtures are more toxic, e.g. near roadway, ports, industrial centers, etc.
- Are we adequately capturing exposure? How well do central site monitor based health studies capture important exposures to different pollutants?
- Weight of evidence? Are there enough studies to give us confidence in the robustness of findings?
- How confident are we? Given current causality paradigm, what are the missing elements that would increase the confidence that pollutants are causally associated with health risks, and that those associations exist at levels below the current standards?

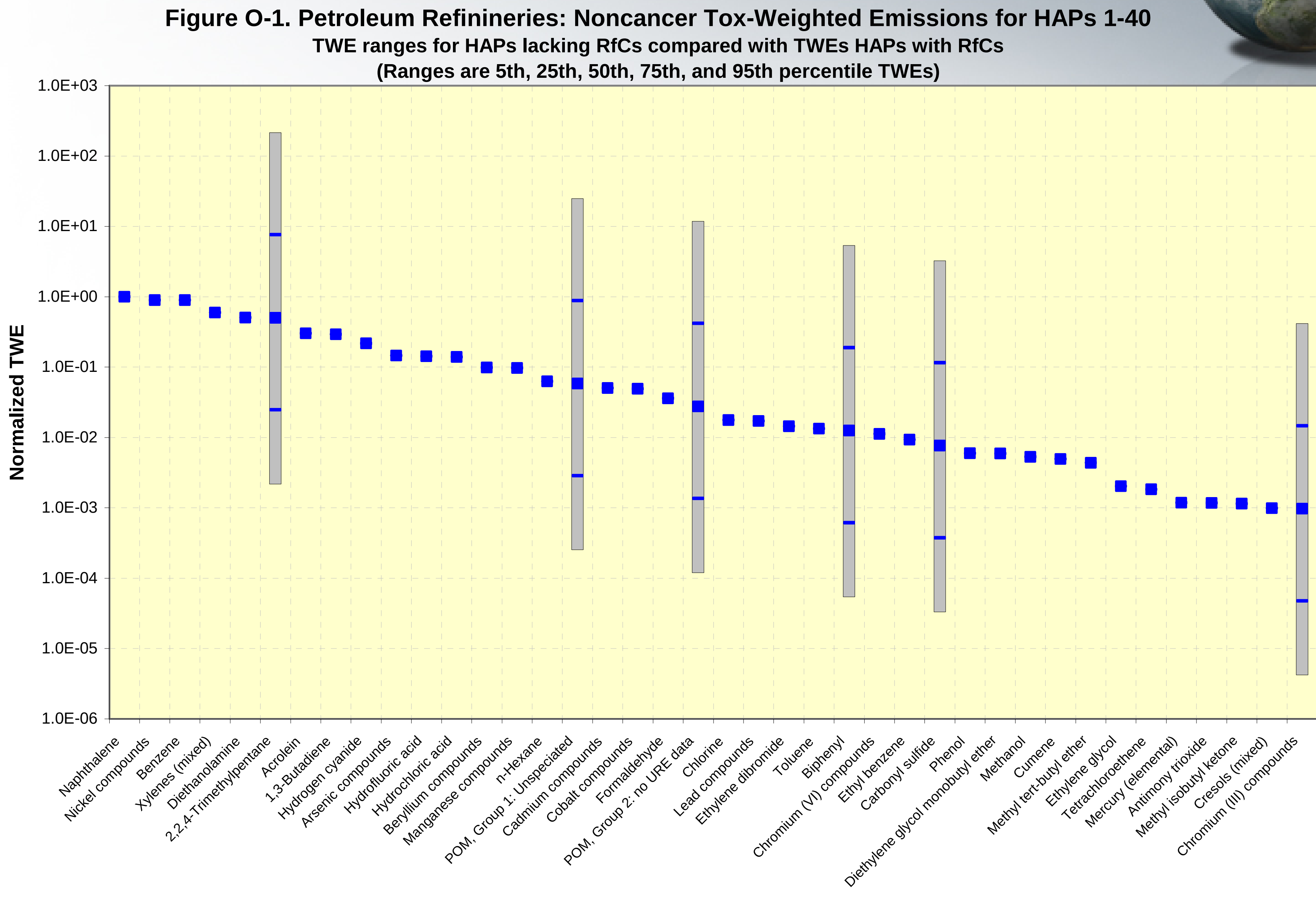
Some specific ideas for ORD research

- Additional clinical research into the effects of exposures to low levels of criteria pollutants, including low levels within an overall mixture of pollutants
- Animal studies examining toxicity of different mixtures of pollutants, and focusing on interactions between pollutants within the mixture
- Toxicology studies examining genetic markers that can identify susceptible subpopulations
- Studies of exposures to mixtures representing different exposure profiles, e.g. central site monitors, near-roadway, ports, high industry – some focus on the proportion of daily or annual exposure to each mixture would be useful

What are the needs for air toxics policies?

- Linkages between animal studies and human outcomes (e.g. work by Dan Axelrad)
- Extrapolations between pollutants (e.g. work by Vernon Benigus on toluene)
- Interpreting exposures above the RfC – need for dose-response relationships
- Assessment of new chemicals – should the HAPs list be expanded?
  - Are there simple tests to characterize potential toxicity or risk?
- Assessment of toxicity to children
  - What is the applicability of age specific adjustment factors for carcinogens?
- Assessment of acute toxicity – is this a concern? Can we extrapolate acute toxicity effects from animals to humans?
- Confirming non-carcinogenicity of suspected non-carcinogenic substances, e.g. hydrochloric acid

Supplemental Uncertainty Analysis - HAPs lacking dose-response values



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- Is this type of analysis useful in prioritizing research on individual air toxics?
- Are there suggestions on how OAQPS can improve these screens to be more useful to ORD?

Policy Monitor

Regulation and Progress under the 1990 Clean Air Act Amendments

Bryan J. Hubbell*, Richard V. Crume*, Dale M. Evarts*, and Jeff M. Cohen†

Introduction

Air quality in the United States has improved dramatically in the past two decades as a result of aggressive air quality management programs, advanced research into the health and environmental effects of air pollution, and the development of new pollution control technologies (Bachmann 2007). The legal authority for federal air pollution control programs is derived from the Clean Air Act (CAA) and its amendments. The CAA of 1970[1] was the first major legislation granting far-reaching powers to the federal government to regulate air pollution sources and establish ambient air quality standards (*Clean Air Act* 1970). It established national ambient air quality standards (NAAQS) to protect public health in polluted areas, New Source Performance Standards (NSPS) to limit air pollution emissions from stationary (industrial) sources, National Emission Standards for Hazardous Air Pollutants to reduce emissions of particularly toxic air pollutants (air toxics), and a mobile source pollution control program. To allow states some autonomy in addressing their unique circumstances, state agencies were given flexibility in defining how the NAAQS would be achieved.

The CAA Amendments of 1977 established a New Source Review (NSR) program for areas of the United States not attaining the levels of the NAAQS (*Clean Air Act Amendments* 1977). This program mandated stringent controls on new industrial sources and required

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[1]Technically, the CAA of 1970 was actually a set of far-reaching amendments to the Clean Air Act of 1963. However, given the scope and importance of the 1970 CAA amendments, it is generally considered to be the genesis of modern air quality policy.

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emissions from new sources to be offset by emission reductions from other industries in the nonattainment area. Similarly, a Prevention of Significant Deterioration (PSD) program was established for areas attaining the NAAQS, with the goal of preventing these areas from slipping into nonattainment status.

Experience with the 1977 Amendments revealed various gaps and deficiencies. The 1990 Amendments to the CAA addressed these concerns and put in place a number of innovative approaches to controlling pollution, which have resulted in lower air pollution emissions despite increased industrial production and automobile use (*Clean Air Act Amendments* 1990). These new programs included Maximum Achievable Control Technology (MACT) for stationary sources of air toxics, an acid rain program, and an expansion of permitting authority. Other provisions addressed modifications to the attainment and nonattainment provisions, greater enforcement authority, and more research on air pollution monitoring, characterization, and control. In addition to several highly effective CAA regulatory programs, voluntary initiatives have also contributed to improved air quality, as have international efforts aimed at reducing the transport of air pollution to the United States from overseas.

This article describes the 1990 CAA Amendments (CAAA), regulations issued by EPA following their passage, progress made in air quality management over the last twenty years, and the likely future direction for U.S. air quality management programs at the federal level. We provide a full account of regulations issued from 1990 to 2009, including those implementing new provisions under the CAAA of 1990 as well as those implementing provisions under the original CAA. The next section provides a description of the 1990 CAAA. This is followed by sections discussing the progress that EPA has made in establishing regulations to meet the requirements of the CAA and its amendments since 1990. The final section offers some conclusions and discusses key issues and trends that are likely to shape air quality management in the United States in the future.

The 1990 Clean Air Act Amendments

In crafting the 1990 CAAA, Congress sought to address three major environmental threats—acid rain, urban air pollution, and toxic air pollutants. There was also considerable interest in improving the nation's air pollution permit program and increasing compliance with regulations through a strengthened enforcement program. The CAAA contained several innovative approaches, including market-based initiatives, performance-based standards, and emissions banking and trading provisions. This section summarizes the major provisions of the 1990 CAAA and the most significant changes made to the original CAA. The discussion is organized by CAAA title.[2]

Title I (Provisions for Attainment and Maintenance of National Ambient Air Quality Standards)

Title I of the CAAA addresses how states and the federal government should act to reduce emissions of pollutants that affect ambient air quality, and provides the basis for setting,

[2]The 1990 CAAA altered the structure of the titles of the original 1970 CAA. In this discussion, we reference the titles as laid out in the 1990 CAAA.

attaining, and maintaining NAAQS.[3] It establishes time lines for attainment and the level of progress that states and the federal government are expected to make as they work toward eventual attainment of the standards.

The role of the primary NAAQS was established in the original Clean Air Act, Section 109:

> National primary ambient air quality standards . . . shall be ambient air quality standards the attainment and maintenance of which in the judgment of the Administrator, based on such criteria and allowing an adequate margin of safety, are requisite to protect the public health.

In other words, the primary NAAQS are set based on an assessment of what the current science says about what level of ambient air pollution will protect public health with an adequate margin of safety. In and of themselves, the NAAQS do not result in a lowering of emissions or improvement in air quality. Rather, NAAQS establish the nation's goals for clean air, reflecting the scientific record at the time of each review of the NAAQS.

In addition to the primary health-based NAAQS, EPA also sets secondary NAAQS to protect the public welfare from the adverse effects of ambient air pollution, including: (1) effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility, climate, economic values, and personal comfort and well-being; (2) damage to and deterioration of property; and (3) hazards to transportation.

While the 1990 CAAA maintained much of the CAA's Title I, it also established new provisions for the protection of visibility in and near national parks and other areas. Additionally, changes to Title I were made to provide different time lines and control requirements for ozone, particulate matter (PM), and carbon monoxide (CO) nonattainment areas that depend on the severity of the pollution problem. Finally, the 1990 CAAA required the federal government to implement regulations on several classes of mobile sources and consumer products in order to reduce emissions from these sources and assist states in attaining the NAAQS.

Title II (Provisions Relating to Mobile Sources)

Title II of the CAAA provides for the control of emissions from mobile sources through the setting of engine and fuel standards. This title covers all mobile sources of emissions, including onroad and offroad vehicles, recreational vehicles, airplanes and trains, marine vessels, and small engines (e.g., lawnmowers).

The 1990 CAAA addressed mobile sources in several ways. Tighter emissions standards were established for both automobiles and trucks, and manufacturers were required to reduce emissions from gasoline evaporation during refueling. Fuel quality has also been controlled by reducing gasoline volatility and the sulfur content of diesel fuel, requiring cleaner (reformulated) gasoline for cities with serious ozone problems, and specifying higher levels of alcohol-based oxygenated fuels to be produced and sold during the winter months in areas exceeding the federal CO standard.

[3]NAAQS consist of four parts: (1) the indicator, or pollutant of concern; (2) the level of the standard; (3) the standard's averaging time (e.g., annual, daily, or hourly); and (4) the form of the standard (i.e., the particular air quality statistic used to measure whether an area is meeting the standard; for example, the 98th percentile of daily average concentrations).

Title III (Air Toxics)

Title III of the CAAA addresses emissions of hazardous air pollutants (HAPs). The 1990 CAAA included a deliberate reshaping of the air toxics program. Specifically, it required EPA to publish a list of source categories responsible for emissions of 189 air toxics and to issue MACT standards for each category.[4] Under these provisions, a distinction is made between *major sources*, which emit at least 10 tons per year of any air toxics or 25 tons per year of any combination of these pollutants, and *area sources*, which do not meet the emissions thresholds for major sources. Examples of area sources are auto body shops and dry cleaners, sources that individually may not emit much air pollution, but taken together represent a significant fraction of nationwide emissions.

MACT standards for new sources are based on the application of emissions control technology that is equivalent to the best-controlled similar sources found anywhere in the United States, although in establishing the required level of control EPA is allowed to take into consideration costs, other environmental impacts, and energy requirements. For existing sources, the standards are based on the average of the best performing 12 percent of existing sources. To control emissions from area sources, EPA may elect to establish standards based on generally available control technologies or operating practices. While MACT standards are technology-based, EPA must examine health risk levels at regulated facilities after eight years and tighten the standards for any facilities if necessary to reduce unacceptable residual risk.

Title IV (Acid Deposition Control)

Under the new Title IV, the 1990 CAAA establishes an Acid Rain Program (ARP) to control emissions of sulfur dioxide (SO_2) and nitrogen oxides (NOx) from electricity generating utilities. The goal of the program is to decrease deposition of SO_2 and NOx from the atmosphere that leads to acidification of sensitive water bodies in the eastern United States.

The 1990 CAAA marked another significant departure from earlier air quality policy by including a market-based approach (i.e., a cap-and-trade program) to address acid rain impacts on ecosystems. This cap-and-trade program achieves broad, regional emissions reductions by setting a mandatory cap, or maximum limit, on the aggregate emissions of all affected sources. The government distributes emissions allowances (either freely or by sale) that total no more than the cap and may be traded (purchased and sold), creating a market for allowances and establishing a price. The cap ensures that the emissions reduction goal is achieved while also providing flexibility to sources and predictability for the allowance trading market. Cap-and-trade works best on a regional or larger scale to address emissions from multiple sources that exhibit a range of control costs. Such programs can be designed to work with local air pollution control efforts, as demonstrated by the recent use of regional cap-and-trade programs to support attainment of NAAQS. Experience implementing the regional cap-and-trade programs for reducing acid rain demonstrates that by placing an economic value on reducing emissions, cap-and-trade rewards innovation and early reductions and

[4]The air toxics list was subsequently reduced to 188 when one contaminant was determined to be nontoxic.

can make significant environmental improvements economically feasible (Chestnut and Mills 2005).[5]

Title V (Permits)

Title V of the 1990 CAAA establishes a new permitting authority. Previously, a new facility's pollution control requirements were often scattered among numerous and sometimes conflicting state and federal regulations. The CAAA attempted to simplify this process, ensure compliance with all applicable requirements, and facilitate enforcement by incorporating all of a source's permit obligations into a single permitting document (called a Title V Permit).

Other Changes

The 1990 CAAA also included new provisions for: (1) continuing the phase out of stratospheric ozone-depleting substances (Title VI) and (2) strengthening enforcement authorities and penalties for noncompliance (Title VII).

Progress in Air Quality Management

This section provides an account of most of the major rules and regulations that EPA has issued since the enactment of the 1990 CAAA.[6] These regulations have led to significant improvements in U.S. air quality and have helped EPA to develop a better understanding of the complex factors underlying air pollution science and emissions control programs. The first part of the discussion focuses on Titles I–III of the CAAA. This is followed by a description of regional control programs, which addresses both Title I and Title IV programs, and a discussion of international cooperation on stratospheric ozone protection and U.S. efforts to reduce ozone-depleting substances under Title VI of the CAAA.

Setting and Attaining the NAAQS (Title I)

There are currently six pollutants—collectively referred to as the "criteria" pollutants—for which NAAQS have been established: CO, lead, NOx, ozone, PM, and sulfur oxides (SOx). The NAAQS for these pollutants are reviewed on a five-year cycle, a process that includes a review of the science reported in an Integrated Science Assessment, a risk and exposure analysis, and a policy assessment document. In general, the secondary NAAQS reviews occur on the same schedule as the primary NAAQS. Costs and feasibility of implementation may not be considered in setting NAAQS.[7]

[5] More information on the ARP is provided in the next section.
[6] Note that we focus on when rules or actions were first issued and in most cases do not discuss legal actions that may have followed.
[7] For an excellent historical review of the NAAQS and their implementation in the United States, see *Will the Circle Be Unbroken: A History of the U.S. National Ambient Air Quality Standards* (Bachmann 2007).

Setting and Reviewing the NAAQS

EPA has reviewed (or is in the process of reviewing) each of the NAAQS at least once since 1990.[8] The primary NAAQS, set to protect public health with an adequate margin of safety, have tended to receive the most attention and review. Even so, the primary NAAQS for CO, NO_2 (a surrogate measurement for all oxides of nitrogen, designated as NOx), and SO_2 (a surrogate measurement for all oxides of sulfur, designated as SOx) have not been revised since first set in 1971. The last review of the SO_2 and NO_2 primary standards was completed in 1996, when a decision was made to retain the existing standards. The NO_2 and SO_2 primary standards are currently being reviewed again and are expected to be completed in 2010. The last review of the CO standards was completed in 1994 and no change was made to the standard at that time. The CO standard is currently being reviewed, a process that is expected to be completed in 2011.

The primary standard for lead was unchanged for thirty years, from 1978 until 2008. In 2008, a review of the primary lead standard was completed, and EPA decided to lower the standard by an order of magnitude, from 1.5 micrograms per cubic meter ($\mu g/m^3$) to 0.15 $\mu g/m^3$.

The primary NAAQS for PM and ozone are generally considered to be the two most important health standards, given the relatively large number of areas with elevated levels of these pollutants and the serious health effects associated with exposure. The primary NAAQS for ozone have been reviewed twice since 1990. In 1997, the previous one-hour standard was maintained, but an additional standard was set for eight-hour daily maximum ozone concentrations at a level of 0.08 parts per million (ppm). This eight-hour standard was revised again in 2008, with the revised standard set slightly lower, at 0.075 ppm. EPA is reconsidering this decision, with a new rule due to be finalized in 2011.

The PM standards have also been reviewed twice since 1990. In 1997, EPA defined a new indicator for PM mass, $PM_{2.5}$, which refers to particles less than or equal to 2.5 microns (μm) in diameter. Two standards for $PM_{2.5}$ were set: an annual standard equal to 15 $\mu g/m^3$ and a daily standard equal to 65 $\mu g/m^3$. The level of the PM_{10} standard (a standard for particles less than 10 μm in diameter that was established prior to the 1990 CAAA) was retained in 1997, although the form of the PM_{10} standard was revised. The PM standards were reviewed again in 2006. At that time, EPA decided to (1) retain the PM_{10} daily standard; (2) revoke the annual PM10 standard; (3) lower the level of the daily $PM_{2.5}$ standard from 65 $\mu g/m^3$ to 35 $\mu g/m^3$; and (4) retain the annual standard of 15 $\mu g/m^3$ for $PM_{2.5}$. EPA is currently reviewing the PM standards and is scheduled to complete the review in 2011.

EPA is currently reviewing the secondary standards for NOx and SOx and expects to complete this review in 2012. This is the first time that EPA is reviewing the secondary standards for NOx and SOx together, reflecting the interactions between these pollutants in determining the ecological effects associated with nitrogen and sulfur. This review may result in joint standards.

[8]The current levels of the NAAQS, including when these levels were originally set and reviewed, are presented in the online supplementary materials for this article.

Actions Taken to Attain NAAQS

The setting of NAAQS triggers a set of actions by EPA and the states aimed at attaining the NAAQS. These actions include: (1) the designation of areas as "nonattainment," which indicates an area either failing to attain the level of the standard or contributing to another area failing to attain the standard; (2) the submission of a State Implementation Plan (SIP); and (3) the promulgation of rules and guidance to achieve reductions in emissions from sources in nonattainment areas. Because of the variable nature of controls that can be adopted to attain the NAAQS, it is not possible to provide specific estimates of the emissions reductions that will result from the attainment of the NAAQS. EPA provides some projections based on the application of least-cost controls in nonattainment areas as part of the Regulatory Impact Analyses that accompany NAAQS, but actual controls applied in nonattainment areas may differ substantially from these projections.

EPA is required to issue final designations for nonattainment areas no later than three years after finalizing new or revised standards, and states are required to submit non-attainment SIPs three years after finalizing designations. EPA issued a final rule on implementation of the 1997 ozone standards in 2005, which addressed how states should treat reasonably available control technology (RACT) and reasonably available control measures (RACM), reasonable further progress (RFP), modeling and attainment demonstrations, and NSR in the development of their SIPs. EPA issued a final rule for preparing SIPs for the $PM_{2.5}$ standards in 2007.[9]

EPA also issues NSR and PSD regulations that apply to sources that are located within designated nonattainment areas. These regulations work together with NSPS for stationary sources to ensure that emissions reductions and prevention lead toward attainment of the NAAQS. In 2003 EPA issued a rule covering PSD and Nonattainment NSR regarding equipment replacement and maintenance, and in 2004 EPA issued a rule addressing approval and promulgation of PSD implementation plans.

The primary purpose of the NSPS is to attain and maintain ambient air quality by ensuring that the best-demonstrated emissions control technologies are installed as the industrial infrastructure is modernized. Final NSPS (and revisions and amendments) have been issued for a wide variety of source categories since 1990 (see Table 1).

In addition to the NSR, PSD, and NSPS provisions, the 1990 CAAA also established a program for controlling volatile organic compounds (VOC) emissions from consumer and commercial products to reduce the contribution of these emissions to nonattainment of the ozone NAAQS.[10] EPA issued VOC standards for architectural coatings and automobile refinish coatings in 1998. Under these rules, manufacturers and importers must limit the VOC content of subject coatings to the VOC content levels indicated by the standards. The architectural coatings rule is somewhat unique in that it offers an economic incentive by providing manufacturers and importers with an alternative compliance mechanism under which they can choose to pay a fee of $2,500 per ton of VOC in excess of the standard in lieu of meeting the VOC content limits for their coating products.

[9]The review here does not cover those actions that EPA takes to clarify requirements under the NAAQS, or guidance for aspects of implementation and monitoring requirements. However, these actions can have significant implications for states as they prepare their SIPs.

[10]VOC emissions, along with NOx emissions, are important precursors to ozone formation in urban areas.

Table 1 Final new source performance standards issued since 1990

Year	Final NSPS Source Category
1995	Municipal Waste Combustors (revisions)
1996	Municipal Solid Waste Landfills
1997	Medical Waste Incinerators
	Municipal Waste Combustors (amendments)
	Phosphate Fertilizer Industry (revisions)
1998	New Fossil-Fuel Fired Steam Generating Units (revisions)
1999	Amendment to Electric ARC Furnace NSPS
2004	Industrial-Commercial-Institutional Steam Generating Units
2005	Commercial and Industrial Solid Waste Incineration Units
2006	Electric Utility Steam Generating Units
	Large Municipal Waste Combustors (amendments)
	Stationary Compression Ignition Internal Combustion Engines
2007	Equipment Leaks of Volatile Organic Compounds (VOC) in the Synthetic Organic Chemicals Manufacturing Industry and Petroleum Refineries
	Electric Utility, Industrial-Commercial-Institutional, and Small Industrial-Commercial-Institutional Steam Generating Units (reconsideration)
	Stationary Spark Ignition Internal Combustion Engines
	Other Solid Waste Incinerators (reconsideration)
2008	Petroleum Refineries
2009	Nonmetallic Minerals Processing Plants (e.g., Quarrying and Mining)
	Stationary Combustion Turbines

Source: Federal Register.

EPA has also established a number of regional programs to address emissions that may affect attainment of NAAQS in downwind states. These programs, which evolved from the ARP mandated under Title IV of the 1990 CAAA, are addressed in the discussion of regional control programs.

Motor Vehicles and Fuel Standards (Title II)

The federal government has the primary responsibility for regulating emissions from mobile sources. As discussed in the previous section, Title II of the CAA governs mobile source emissions. These provisions were modified under the 1990 CAAA, resulting in the set of mobile source regulations that have been issued over the past two decades, including adjustments to the tailpipe standards for cars and light trucks, establishment of cold start standards, clean fuels regulations, PM standards for buses, regulation of mobile source air toxics, banning of lead in gasoline, and standards for nonroad engines.

One of the most important developments in recent air quality management is the focus on regulating direct vehicle emissions in conjunction with fuels. A number of regulations have been developed in the last two decades to reduce substantially the emissions from mobile sources through a combination of improved emissions control devices and changes in the sulfur content of fuels. Lowering sulfur levels in gasoline and diesel fuel directly reduces PM emissions and enables manufacturers to install emissions control devices which would otherwise be contaminated by the sulfur in the fuels. The suite of vehicle and fuel standards enacted by EPA covers a wide range of mobile sources, including light- and heavy-duty gasoline engines, onroad and nonroad diesel vehicles, and a number of additional mobile source categories, including small recreational vehicles, locomotives, marine engines, and lawn and garden equipment. Because the fuels and engines used by onroad and nonroad mobile sources differ, separate regulations were issued to address each combination of fuels and engines.

An important element of mobile source regulations is the timing of expected implementation. Because mobile source standards generally apply to new vehicles (there are separate mobile source programs to address retrofits), it can take decades to fully realize the reductions in emissions from the total fleet of mobile sources. Fuel standards can be implemented more quickly, but the full benefit of these fuel changes will not be realized until the entire vehicle fleet is equipped with the new emissions control technologies. For most of the standards enacted by EPA, full implementation is expected to occur by 2030 or later.

A summary of individual mobile source rules and the year they were issued is provided below.[11]

Light Duty Vehicles (1999). These rules set new tailpipe standards at an average of 0.07 grams of NOx per mile for all classes of passenger vehicles beginning in 2004 (phased in through 2009 for heavier trucks). This includes all light-duty trucks, as well as the largest sport utility vehicles. In addition, in order to improve the effectiveness of NOx control devices, a complementary fuel sulfur program was established that reduced sulfur content by up to 90 percent by capping nationwide average sulfur levels in gasoline at 30 ppm starting in 2007.[12]

Onroad Heavy-Duty Engines (2000). This rule set standards for engines of heavy-duty vehicles (e.g., trucks and buses) based on the use of high-efficiency catalytic exhaust emissions control devices. In order to preserve the effectiveness of the control devices, which is adversely affected by sulfur in fuel, the rule also reduced the levels of sulfur in on-road diesel fuel by 97 percent relative to pre-2007 engines.

The rule sets a PM emissions standard for new heavy-duty engines to take full effect for diesels in the 2007 model year. The NOx and nonmethane hydrocarbons (NMHC) standards are phased in between 2004 and 2007. The rule also requires heavy-duty gasoline engines to meet the standards with full compliance by 2009.[13]

Recreational Vehicles (2002). This rule provided emissions standards for a variety of nonroad vehicles, including industrial nonroad vehicles (e.g., forklifts, electric generators, and airport baggage transport vehicles), recreational vehicles (e.g., snowmobiles and all terrain vehicles), and recreational boats (Regulatory Announcement: Emission Standards for New Non-Road Engines 2002). The rule set standards for NOx, NMHC, and CO, with the standards varying by type of engine.

The emissions standards are projected to result in an overall 72 percent reduction in hydrocarbon (HC) emissions from recreational vehicle engines, an 80 percent reduction in NOx emissions, and a 56 percent reduction in CO emissions by 2020.

[11]EPA has also issued regulations dealing with other aspects of mobile source emissions. These are summarized in the online supplementary materials for this article. A complete listing of mobile source regulations is available online (*Federal Register Notices for Mobile Sources (Title II)—Proposed and Final Preambles and Rules* 1991–2000).

[12]The rule is available online (*Tier 2 Vehicle and Gasoline Sulfur Program, Final Rule* 2007).

[13]The rule is available online (*Clean Diesel Trucks, Buses, and Fuel: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements* 2007).

Nonroad Diesel (2004). Over 650,000 pieces of nonroad diesel equipment are sold in the United States per year, and there are about 6 million pieces of nonroad diesel equipment currently in use, accounting for 58 percent of diesel PM and 25 percent of NOx from mobile sources nationwide (Clean Air Nonroad Diesel Rule—Facts & Figures http://www.epa.gov/nonroad-diesel/2004fr/420f04037.htm). The Clean Air Nonroad Diesel rule reduced the sulfur content of nonroad diesel fuel from an uncontrolled level of approximately 3,400 ppm to 500 ppm beginning in 2007 and then to 15 ppm (in 2010 for land-based nonroad diesel fuel and in 2012 for fuel used in locomotives and marine vessels)—a 99 percent reduction. The rule is expected to cut emissions levels from construction, agricultural, and industrial diesel-powered equipment by over 90 percent when fully implemented.[14]

Mobile Source Air Toxics (2007). The Mobile Source Air Toxics (MSAT) rule is a combined fuel and engines rule. It requires that, beginning in 2011, refiners meet an annual average gasoline benzene content standard of 0.62 percent by volume on all their gasoline nationwide. Refiners must also meet a maximum average benzene standard of 1.3 percent by volume beginning in 2012, although they can meet this standard through banking, averaging, and trading.

In addition to the fuel standards, the MSAT rule sets NMHC exhaust emissions standards for passenger vehicles and trucks up to 8,500 pounds, and it sets more stringent evaporative emissions standards for new passenger vehicles (*Control of Hazardous Air Pollutants from Mobile Sources: Final Rule to Reduce Mobile Source Air Toxics* 2007). The new evaporative emissions standards are equivalent to California's standards and will be phased in between 2010 and 2013 for the lighter vehicles, and between 2012 and 2015 for the heavier vehicles.

Locomotive and Large Marine Engines (2008). This rule sets emissions standards for NOx and PM for new and rebuilt locomotive and large marine engines (*Emissions Standards for Locomotives and Marine Compression-Ignition Engines* 2008). The rule is phased in for different tiers of engines produced during different time periods. The most stringent standards (Tier 4) will be in place for engines produced in 2015 and beyond. When fully implemented, the standards are expected to result in a 90 percent reduction in PM emissions and an 80 percent reduction in NOx emissions from these sources, compared with an uncontrolled baseline in 2030.

Nonroad Small Spark Ignition Engines, Equipment, and Vessels (2008). This rule sets new standards for emissions of HC, NOx, and CO for small engines such as lawn and garden equipment, utility vehicles, generators, and a variety of other construction, farm, and industrial equipment (*Emission Standards for New Nonroad Spark-Ignition Engines, Equipment, and Vessels* 2008). The rule also sets standards for engines used in marine vessels, including outboard engines, personal watercraft, and sterndrive/inboard engines. The specific standards vary by engine and vehicle type. When fully implemented, the standards for nonmarine sources are expected to decrease combined HC and NOx exhaust emissions by 35 percent and reduce evaporative emissions by 45 percent, compared with an uncontrolled baseline in 2030. The standards for marine spark ignition engines are expected to decrease combined HC and NOx exhaust emissions by 70 percent and CO exhaust emissions by 50 percent. The standards will also result in a 60 percent reduction in combined HC and NOx emissions from

[14]Details of the rule are available online (*Clean Air Nonroad Diesel—Tier 4, Final Rule* 2004).

outboard and personal watercraft engines. The standards will reduce evaporative emissions from marine sources by about 70 percent.

Addressing the Air Toxics Problem (Title III)

Air toxics rules account for a large portion of EPA's air program rulemaking activities over the past two decades. EPA has implemented key air toxics provisions of the 1990 CAAA by issuing 96 MACT standards that apply to 174 industrial source categories.[15] While each standard has a unique time line for implementation, EPA estimates that these regulatory actions will ultimately result in a nationwide reduction of about 1.7 million tons of HAPs per year (http://www.epa.gov/ttn/atw/allabout.html). However, significant work remains to fully address the legislative requirements for HAPs under the 1990 CAAA.

One requirement where some work remains involves the need to issue standards for stationary area source categories identified for regulation due to their toxic emissions and potential health risks in urban areas. The 1990 CAAA requires EPA to identify at least 30 air toxics that pose the greatest potential health threat in urban areas (EPA has identified 33) and to regulate the area source categories that represent 90 percent of these emissions. To date EPA has identified 70 area source categories, of which 54 have been regulated. Standards for the remaining categories are under development.

Because EPA had fallen behind in meeting its area source obligations, a court order was issued to ensure that reasonable progress was being made (*Sierra Club v. Johnson* 2006). To comply with the court order, EPA must issue 10 rules every six months, beginning in December 2006. By the end of 2009, all but three of the 70 area source rules will be completed. While negotiations continue on the deadlines for industrial boilers, commercial/institutional boilers, and sewage sludge incineration, these remaining rules are expected to be promulgated in 2011.

Another area where work remains is review of the Residual Risk and Technology Rules (RTR) that are mandated eight years after an MACT standard is issued. The 1990 CAAA requires a comprehensive assessment of exposures and risks associated with emissions from MACT-regulated source categories and the development of revised standards if significant health risks remain or if improved control technologies are available.[16]

Evolution of Regional Control Programs

In recognition of the continuing environmental damages associated with acid deposition, Title IV of the 1990 CAAA included provisions to achieve deep reductions in SO_2 and NOx emissions. By adding Title IV to the CAA and establishing the ARP to reduce emissions of SO_2 and NOx from electric generating units (EGU), the CAAA changed the very nature of air pollution regulations through the introduction of market-based emissions reductions programs. These programs have been successful in reducing SO_2 and NOx emissions in a

[15]A complete list of MACT standards is available online (*National Emission Standards for Hazardous Air Pollutants* 2009).
[16]The RTRs completed to date are listed online (*Risk and Technology Review* 2009).

highly cost-effective manner (Chestnut and Mills 2005), resulting in substantial air quality, health, and environmental benefits.[17]

Based on the success of the ARP, EPA has issued other market-based regulations (i.e., the NO_x Budget Trading Program, trading programs under CAIR—the Clean Air Interstate Rule) to reduce regional emissions of SO_2 and NOx, to both reduce acid deposition and attain the $PM_{2.5}$ and ozone NAAQS. In addition, EPA has established the regional haze program to improve visibility in national parks and wilderness areas. These regulations affect sources throughout the United States and are expected to have large environmental and health benefits relative to their costs (Chestnut and Mills 2005).

The four major regional emissions reduction programs—the ARP, the NO_x Budget Trading Program, CAIR, and the Regional Haze Rule (now known as the Clean Air Visibility Rule)—are discussed in more detail below.

The ARP

Unlike most programs, the ARP was established directly by Title IV of the CAAA and did not require specific regulations. Instead, Congress directly set the cap on SO_2 emissions and established a trading program that is managed by EPA. The ARP began in 1995, and the SO_2 cap-and-trade program currently affects over 3,500 U.S. EGU. The ARP also established a rate-based NOx control program that affects a subset of approximately 1,000 coal-fired EGU.[18]

The cap-and-trade program for SO_2 emissions was the first federal regulation of its kind. It allocates a fixed number of allowances to utilities (most based on historic fuel consumption and some by auction) and then allows utilities to buy and sell allowances to cover their SO_2 emissions. Utilities can choose to reduce emissions below their allocated number of allowances and sell the extra allowances to generate revenues, or they can buy extra allowances on the market if the cost of reducing their emissions is higher than the market allowance price. The program allows sources to bank allowances for use in future years, thereby encouraging early reductions by utilities with highly cost-effective reduction opportunities.

The ARP set a long-term cap on SO_2 emissions from EGU at 8.95 million tons, to be reached by 2010. This represents a reduction in SO_2 emissions of 6.7 million tons (42 percent) relative to SO_2 emissions in 1990. The NOx provisions of the ARP set rate limits to achieve a 2 million ton reduction in NOx relative to projected 2000 emissions levels without the ARP in place. The program allowed for limited flexibility in meeting the NOx standards, using averaging of rates across groups of units.

The ARP used a two-phase approach to achieve the final emissions levels for NOx and SO_2. The first phase of the SO_2 program applied primarily to the largest coal-fired EGU from 1995–1999, and the second phase began in 2000, expanding coverage to smaller units and tightening the SO_2 cap on covered sources. The first phase of the NOx program also applied primarily to larger coal-fired units during 1996–1999, and was expanded to cover smaller sources starting in 2000.

[17] See the Clean Air Markets web site for details on programs' effectiveness: http://www.epa.gov/airmarkets/index.html.

[18] Additional details on the ARP and its accomplishments can be found in the Acid Rain and Related Programs 2007 Progress Report, available online (Acid Rain and Related Programs: 2007 Progress Report 2009).

The NOx Budget Trading Program

In the mid-1990s, EPA recognized that many areas in the eastern United States were having difficulty attaining the ozone NAAQS due to pollution transport from sources in upwind states. In response, EPA established the Ozone Transport Assessment Group (OTAG), a partnership between EPA, thirty-seven eastern states and the District of Columbia, industry representatives, and environmental groups, to assess regional air quality problems and develop consensus solutions.

In 1998, based on an improved understanding of ozone transport issues, and under the authority of Title I of the CAAA, EPA issued a call for state implementation plans (SIPs) to reduce emissions of NOx, a precursor to ozone formation. This rule, known as the NO_x SIP Call, applied to twenty eastern states and required the states to meet NOx emissions budgets. However, states were allowed to choose the control strategies to meet those budgets. The NO_x SIP Call offered states the option of participating in a regional NOx Budget Trading Program covering NOx emissions from EGU and large industrial boilers and turbines, which would allow states to achieve over 90 percent of the NO_x SIP Call reductions in a highly cost-effective way. EPA administered the trading program, and states shared responsibility with EPA by allocating allowances, inspecting and auditing sources, and enforcing the program.[19] The date for compliance with the rule varied by state, from 2003 to 2007. The NO_x Budget Trading Program was discontinued beginning with the 2009 ozone season, when EPA began administering the NOx ozone season trading program under CAIR. EPA offered states the option of including their NO_x SIP Call trading sources in the CAIR trading program.

CAIR

In 1997, EPA set significantly tighter standards for ozone and PM, creating new challenges for many urban areas due to the contribution of upwind sources to downwind nonattainment with the ozone and PM NAAQS. To address this issue, EPA developed a new set of regulations based on the successful ARP and NOx Budget Trading Program. This set of regulations, known as CAIR, was issued in 2005 under the authority of Title I of the CAAA, and is expected to significantly improve air quality in many eastern urban nonattainment areas.

CAIR creates three separate trading programs: an annual NOx program, an ozone season NOx program (complementing the existing NOx Budget Trading Program), and an annual SO_2 program (which reduces SO_2 emissions below the existing ARP cap). Similar to the NOx SIP Call, CAIR gives eastern states the flexibility either to submit a specific set of control strategies that meets their NOx and SO_2 budgets, or to participate in federally administered regional cap-and-trade programs for NOx and SO_2. All states have opted to participate in the regional cap-and-trade program.

Starting in 2009 and 2010, CAIR establishes regional caps on annual NOx and SO_2 emissions and on summertime NOx emissions in the eastern United States. Annual SO_2 emissions for affected eastern states are capped at 3.7 million tons in 2010 and 2.6 million tons in 2015. Annual NOx emissions for affected eastern states are capped at 1.5 million tons in 2009 and

[19]Details on the NO_x Budget Trading Program and its accomplishments can be found in the program's latest progress report (NOx Budget Trading Program: Compliance and Environmental Results 2008).

1.3 million tons in 2015. By 2015, this represents a reduction in EGU SO_2 of over 43 percent, and a reduction in EGU NOx of over 41 percent.

Recently, there has been some uncertainty regarding the implementation of CAIR. On July 11, 2008, the U.S. Court of Appeals for the DC Circuit issued a ruling voiding CAIR. However, on December 23, 2008, the Court allowed implementation of CAIR to continue while EPA considered alternatives.[20] According to EPA, "development and finalization of a replacement rule could take about two years."[21]

The Regional Haze and Clean Air Visibility Rules

Section 169A of the CAA sets forth a national goal for visibility, which is the "prevention of any future, and the remedying of any existing, impairment of visibility in Class I areas (national parks and wilderness areas offered special protection under the CAA) which impairment results from man-made air pollution." In 1999, EPA issued the Regional Haze Rule, which required states to submit plans to implement strategies to achieve the national goal.

The Regional Haze Rule requires states to set "reasonable progress goals," which are interim visibility improvement goals aimed at returning visibility in Class I areas to natural conditions, or those visibility conditions that existed before man-made air pollution. These goals are set to improve visibility on the haziest days and to ensure that visibility does not worsen on the best (cleanest) visibility days. While specific controls are not identified by the Regional Haze Rule, it does require states to develop enforceable strategies to meet the progress goals that address air pollution from all types of sources that emit visibility-impairing pollutants.

The Regional Haze Rule also requires states to submit plans identifying best-available retrofit technologies (BART) that can be applied to existing sources, the emissions reductions that would be achieved by applying BART, and the limits on individual sources that would be required under BART. In 2005, EPA amended the Regional Haze Rule, and the rule became known as the Clean Air Visibility Rule (CAVR). The amendments included guidelines for states to use in determining which facilities must install controls to meet the BART requirements. BART addresses SO_2, NOx, and PM emissions from twenty-six sectors, including EGU.

In 2006, EPA issued an additional rule, Revisions to Provisions Governing Alternative to Source-Specific Best Available Retrofit Technology (BART) Determinations, which allowed states to implement programs in lieu of BART provided the alternative program was demonstrated to achieve greater progress than case-specific BART. This rule allowed western states to submit plans that implemented the recommendations of the Grand Canyon Visibility Transport Commission within the framework of, and meeting the requirements of, the Regional Haze Rule (Report of the Grand Canyon Visibility Transport Commission to the United States Environmental Protection Agency 1996). The recommendations included a program to reduce SO_2 emissions to 1990 levels by the year 2040 via interim milestones requirements or declining caps.[22]

[20]Details on the CAIR rule and subsequent regulatory actions are available online (*Clean Air Interstate Rule* 2009).
[21]See http://www.epa.gov/air/interstateairquality/.
[22]More details on rules and other actions related to EPA's regional haze program are available online (*Visibility* 2009).

Stratospheric Ozone Protection

In 1987, twenty-seven countries, including the United States, signed the Montreal Protocol on Substances That Deplete the Ozone Layer (Montreal Protocol on Substances That Deplete the Ozone Layer 1987). Today, 191 countries have ratified the protocol, committing to production targets that continue to evolve with new science and emergence of alternative technologies. By the time Congress passed the 1990 CAAA, U.S. scientists, government agencies, businesses, and environmental organizations had taken a leading role in identifying the urgency of stratospheric ozone depletion and mobilized the international response. Consistent with this leadership, Title VI of the CAAA went beyond merely codifying the Montreal Protocol into U.S. law to provide a regulatory framework for aggressive and comprehensive reductions in ozone-depleting substances. This framework includes phaseout of the key ozone-depleting substances (ODS) by 2000, with limited exceptions for production for critical uses (e.g., medical devices); phaseout of hydrochlorofluorocarbons (HCFCs) by 2020; market-based trading permitting transfer of production and import allowances; and requirements for recycling of equipment and alternatives to ODS. The detailed elements of this framework are presented in Table 3 in the online supplementary materials for this article.

In 1990, stratospheric ozone depletion had become one of the most recognized threats to the global environment. Twenty years later, due to the success of the Montreal Protocol and strong domestic legislation, worldwide emissions of ozone-depleting substances have begun to stabilize, large increases in ground-level UV radiation have been prevented, and the ozone layer is projected to return to pre-1980 levels sometime between 2060 and 2075 (Scientific Assessment of Ozone Depletion, GORMP Report No. 50 2007).

Conclusions

Air pollution regulations in the United States are many, covering most sectors of our economy. Clean Air Act regulations have improved and will continue to improve public health and environmental quality. From 1970 to 2007, air regulations reduced emissions of the six principal criteria pollutants while U.S. gross domestic product increased by over 200 percent (National Air Quality: Status and Trends through 2007, 2008). The most recent regulations (since 2000), including the diesel regulations and CAIR, by themselves are expected to result in over 40,000 premature deaths avoided annually at full implementation and over $280 billion in annual monetized benefits from health and environmental improvements (Nonroad Diesel Rule RIA 2004, CAIR RIA, 2005). The Office of Management and Budget (OMB) prepares a report to Congress each year on the costs and benefits of all federal regulations. These reports have consistently found EPA air regulations to account for the largest share of both costs and benefits across all federal regulations. In the 2008 report, OMB reports annual benefits of air programs to be between $70 billion and $573 billion,[23] and annual costs to be between $26 billion and $29 billion (*Office of Management and Budget* 2009), a clear indication that air regulations provide large net benefits to society.

[23]This range is based partly on OMB assumptions about uncertainty concerning the value of mortality risk reductions.

CAA authorities and programs are chiefly one-pollutant programs, and criteria pollutant emissions programs are separate from programs addressing air toxics emissions. However, many industries emit multiple pollutants; for instance, coal-fired boilers used in many industries and the power sector emit SO_2, NOx, PM, CO, and mercury, as well as CO_2. Because of rising cost curves for controlling pollution from multiple facilities, EPA and other regulators are increasingly turning to multipollutant approaches, which focus attention on an entire source (i.e., multiple processes and emissions points rather than individual processes and emissions). From an engineering perspective, these approaches employ control technologies and methods that optimize control of multiple pollutants for the least possible cost. In addition, these approaches can reduce the regulatory burden for the regulated industry, improve compliance with control requirements, and ultimately lead to more timely and cost-effective improvements in air and environmental quality.

There are benefits of reducing air pollution that go beyond the obvious public health and welfare benefits. More attention is being paid to understanding and addressing the sources and emissions of greenhouse gases. Because sources of traditional air pollutants are also often sources of greenhouse gases, efforts to optimize control through the multipollutant approaches described above could be integrated with analysis that describes (qualitatively and quantitatively) and optimizes the cobenefits of these approaches for both climate and air quality. A major challenge is addressing the differences in the scale and timing of benefits related to reductions in air pollution (which are local and regional in scale and immediate) and reductions in greenhouse gases (which are global in scale and long-term).

Air quality management in the United States has evolved significantly over the past two decades as a result of advances in our understanding of the complexities of sources, emissions, transport, and effects of air pollution, as well as how to cost-effectively improve air quality. This evolutionary process continues as new science emerges and new ways of approaching the management and control of air pollution are developed. As EPA moves forward in addressing the environmental challenges of the next few decades, including climate change, attaining more health-protective NAAQS, and addressing multipollutant problems in heavily populated urban areas, it does so with the benefit of four decades of regulatory experience, including twenty years of experience in implementing innovative rules and regulations under the 1990 CAAA.

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Abstract

The management of air quality in the United States has evolved into a sophisticated array of rules, strategies, and initiatives since the landmark Clean Air Act (CAA) legislation of 1970 and the subsequent creation of the U.S. Environmental Protection Agency (EPA). In particular, the CAA Amendments of 1990 introduced several new programs that have substantially reshaped the nation's approach to air pollution control. This article describes the 1990 CAA Amendments, regulations issued by EPA following their passage, progress made in air quality management in the nearly twenty years since their enactment, and the likely future direction of U.S. air quality management programs at the federal level. (*JEL*: Q52, Q53, Q58)