The Confluence of Air Quality, Health and Climate Change: A Challenge to Air Scientists…and Everyone Else

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Excess O3 in 2050

Frontiers in Air Quality Science
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Congratulations – 21 years young!

- Multidisciplined perspective
- Creative science staff
- High level of productivity
- Impact publications
- High relevancy
- Internationally respected
- Targeted outreach
Fire has a Long History

Emphysema in Argentinian mummy

CT scan of a Peruvian mummy
1306 - **King Edward I** banned the burning of sea coal in London under penalty of death.

1661 - **John Evelyn** (*Fumifugium*)

“London’s inhabitants breathe nothing but an impure and thick mist, accompanied with a fuliginous and filthy vapor,...corruption the lungs and disordering the entire habit of their bodies…”
… to the right and left, was the same interminable perspective of brick towers, never ceasing in their *black vomit*, blasting all things living or inanimate, shutting out the face of day, and closing in on all these horrors with a dense dark cloud.”

The Old Curiosity Shop, April, 1840. Charles Dickens (1812-1870) p. 326…
Then Came Disasters in **Donora** and London

**Week of Oct 25, 1948...**

- 20 people died; 7000 (50%) population affected
- Those with pre-existent pulmonary and cardiac disease were most affected

Source: D. Davis, *When Smoke Ran Like Water*,
Then Came Disasters in Donora and London

Not only did thousands succumb quickly, but survivors who got sick and recovered had shorter life spans.
Fire Brought Global Economic Growth
Output / Person (Year 1 to 2003)

Manchester, England, 1840

Early Industrial Revolution
1760 to 1860

Today
Smoky Skies Also Meant Prosperity...

1950s

Eisenhower's Highways

The birth of suburbia

New York City – 1966

Los Angeles – 1970

1972
The Tide Began to Turn with Legislation

- **UK**
  - Clean Air Act (1956)
  - National Survey (1961) – monitoring network
  - Enhanced Urban Network (1992)

- **USA**
  - The Air Pollution Control Act (1955)
  - Clean Air Act (1967)
  - Clean Air Act Amendment (1970)
    - Established EPA
    - NAAQS and HAPs
  - CAA Amendment (1990) – Major Refinements
Clean Air Act Amendments of 1970

• Established *National Ambient Air Quality Standards (NAAQS)* for most common pollutants (Criteria Air Pollutants).

• Assessment of NAAQS adequacy every 5 years

• NAAQS would be health based – cost not a factor

• **Criteria pollutants for which there are NAAQS**
  – Photochemical oxidants
  – Particulate matter (TSP – now PM$_{2.5}$ and PM$_{10}$)
  – Nitrogen oxides (now NO$_2$)
  – Sulfur dioxide
  – Carbon monoxide
  – Hydrocarbons (no longer exists)
  – Lead
  – [CO$_2$]… CAA authorization 111(d)
Translating the Science into Regulation

Pyramid of Health Effects for NAAQS

- Death
- Hospital Admissions
- Doctor visits
- Asthma attacks, medication use, symptoms
- Lung function changes, immune cell responses, heart rate or heart rate variability responses

Severity of Effects

Population Impacted

At Risk

Atmospheric Sciences

NAAQS Review Process

- Peer-reviewed scientific studies
- Workshop on science policy issues
- Integrated Review Plan: timeline and key policy-relevant issues and scientific questions
- CASAC, meeting and public comment
- Integrated Science Assessment: concise evaluation and synthesis of most policy-relevant studies
- Policy Assessment: multi-stakeholder analysis of policy options based on integration and interpretation of information in the IIA and TEA

Current PM NAAQS Review Documents

Integrated Review Plan
Draft – Sep 2008
Final – Feb 2009

Integrated Review Plan
Final – Oct 2007

Integrated Science Assessment
Draft – Sep 2008
Final – Feb 2009

Risk/Exposure Assessment
Preparatory Planning Documents - Feb 2009
Draft – Sep 2009
Final – Dec 2009

Policy Assessment
Draft Final – 2010
Revolutionary Integration of Health Data

Data Value: Human studies supported by toxicology
The PM Issue of the ’70s/80s was Acid Aerosols

- Visibility impairment was caused by fine particles formed precursors transported over 100's of miles
- Acid aerosols damaged forests
- Acid ($\text{H}_2\text{SO}_4$) was thought to be a major pulmonary irritant

- Smoke reduction & lower sulfur coal and oil
- Acid aerosols didn’t have that much effect on breathing mechanics and the epidemiology didn’t find much PM effect
- Ozone seemed to be problem loomed

PM Problem was thought... Solved!
1980-1990: The Era of Oxidant Air Pollution

Ozone Reduces Lung Function

Asthma

Healthy Lungs

Inflammation

Atlanta
In 1997, the PM Epidemiology Was Compelling...
(but with many uncertainties)
Air pollution particles are blamed for deaths

By H. JOSEF HEBERT
Associated Press

WASHINGTON — Dust, soot and tiny particles in polluted air over the nation’s major cities cause tens of thousands of premature heart and lung-related deaths each year, an environmental group said Wednesday.

The Natural Resources Defense Council released the findings in a study on air pollution in 239 cities across the U.S.

The NRDC study projected that as many as 64,000 premature deaths from cardiopulmonary causes “may be attributed to particulate air pollution each year,” or about 6.5 percent of the nearly 1 million such deaths annually. Such pollution also has been linked to increased childhood asthma cases and health problems for the elderly.

“People face a risk of prema-
Effects Beyond the Lung

- Capillary beds of lungs; gas exchange occurs
- Pulmonary circulation
- Left heart pump
- Right heart pump
- Systemic circulation
- Capillary beds of all body tissues except lungs; gas exchange occurs

Oxygen-poor blood | Oxygen-rich blood
Coherent Evidence that PM affects the Cardiovascular System

ECG Abnormalities and death in fly ash exposed hypertensive rats

772 MI patients

![Graph showing odds ratio (OR) and 95% confidence intervals (CIs) for the association between MI and 24-hour average concentrations of PM$_{2.5}$, with OR = 1.69 (1.13-2.34) for a 20 μg/m$^3$ increment in 24-hour PM$_{2.5}$.

Peters et al., 2001

OR = 1.69 (1.13-2.34) for a 20 μg/m$^3$ increment in 24-hour PM$_{2.5}$

Liao et al., 2000

Coherent Evidence that PM affects the Cardiovascular System

Watkinson et al., 1998

ECG Abnormalities and death in fly ash exposed hypertensive rats
Potential PM Effects on the Pulmonary-CV System

Ambient PM

- Pulmonary Reflexes
  - Autonomic Nervous System
    - Conduction/Repolarization
      - Heart Rate
        - Cardiac Dysfunction

- Pulmonary Inflammation
  - Systemic Inflammation (oxidant burden)
    - Platelet Activation
      - Clotting Factors
    - Viscosity
      - Thrombosis
    - Atherosclerosis
  - Endothelial Cell Dysfunction
  - Plaque Rupture

Impaired Cardiac Function
- Sudden Cardiac Death or Failure

Chronic

- Cardiac Rhythm
  - Conduction/Repolarization
  - Heart Rate
- Autonomic Nervous System
  - Cardiac Dysfunction
Last Decade of Research Provided Impetus / Groundwork for:

- Importance of raising awareness among health care providers
- Providing specific recommendations for clinical practice:

“The overall evidence is consistent with a causal relationship between PM$_{2.5}$ exposure and cardiovascular morbidity and mortality.”

We can see the change
US Benefits Achieved with Pollution Reduction since 1970

• One of the most successful public health programs in American history with a return of more than $30 in benefits for every dollar invested in pollution (PM) reductions.

• In 2010 alone, reductions in fine particle and ozone pollution under the Clean Air Act prevented:
  - 160,000 cases of premature mortality
  - 130,000 heart attacks and 86,000 hospital visits
  - 13 million lost work days
  - 1.7 million asthma attacks

• Life expectancy improvements - ~7 mos over 10 years

• Reduction in acid deposition in lakes, streams & forests

• Improved visibility

Information gathered from Clean Air Act where you live: http://www.epa.gov/cleanairactbenefits/whereyoulive/
Emission Reductions Drove those Successes...
What’s lies ahead?

Many Issues Remain Unresolved and New Emerging Issues Appear Even More Complex
Yet Number of People Living in Areas with Pollutant Concentrations Above the NAAQS as of 2006

- CO: 0.7
- Lead: 0.2
- NO$_2$: 0.0
- Ozone (1-hr): 33.0
- Ozone (8-hr): 77.3
- PM$_{10}$: 14.7
- PM$_{2.5}$ (annual and daily): 66.9
- SO$_2$ (annual and daily): 0.3
- Any NAAQS: 106.5

Millions of People
Public Health Burden of PM$_{2.5}$

Percentage of PM$_{2.5}$ related deaths due to 2005 air quality levels by county

Summary of National PM$_{2.5}$ impacts due to 2005 air quality (Fann et al 2011)

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excess mortalities (adults)$^A$</td>
<td>130 to 320,000</td>
</tr>
<tr>
<td>Percentage of all deaths due to PM$_{2.5}$$^B$</td>
<td>5.4%</td>
</tr>
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Impacts among Children

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>ER visits for asthma (&lt;18 yr)</td>
<td>110,000</td>
</tr>
<tr>
<td>Acute bronchitis (age 8-12)</td>
<td>200,000</td>
</tr>
<tr>
<td>Exacerbation of asthma (age 6-18)</td>
<td>2,500,000</td>
</tr>
</tbody>
</table>

$^A$ Range reflects use of alternate PM mortality estimates

$^B$ Population-weighted value using Krewski et al. (2009) PM mortality estimates
We Now Must Face the Multipollutant Reality - Air Quality

- Transport
- Dispersion
- Transformation
- Infiltration

Exposure

- Anthropogenic
- Natural
- Primary
- Secondary
The Berkeley Earth Surface Temperature Study (BEST), 7/2012

Arctic sea ice: 2012 record low was 18% smaller than previous record, nearly 50% below average

Incoming Data is Mounting…
Climate Models Predict More Summertime Ozone with Global Change – **Climate Penalty**

Model Prediction for year 2050 relative to 2000 using constant emissions

- **Increased ozone**
- **Decreased ozone**
Potential Public Health Impacts of Climate Change

**DIRECT**
- Temp. rise
- Sea level rise
- Changes in Precipitation

**INDIRECT**

- Heat
  - Heat stress, cardiovascular failure
- Severe Weather
  - Injuries, fatalities
- Air Pollution
  - Asthma, cardiovascular disease
- Allergies
  - Resp allergies, poison ivy
- Vector-Borne Diseases
  - Malaria, dengue, hantavirus, encephalitis, Rift Valley fever
- Water-Borne Diseases
  - Cholera, cryptosporidiosis, campylobacter, leptospirosis
- Water and Food Supply
  - Malnutrition, diarrhea, harmful algal blooms
- Mental Health
  - Anxiety, post-traumatic stress, depression, despair
- Environmental Refugees
  - Forced migration, civil conflict
Cookstoves and Ambient BC

- UN Foundation Global Alliance for Clean Cookstoves
- 3M lung related deaths per year worldwide (mostly women)
- Combustion smokes as well as ambient PM have impacts on pregnancy outcomes

- Black Carbon is a major short term climate forcer
- Is BC the culprit or indicator?
Climate Change: Inequity of Health Impacts

Emissions of greenhouse gases:

Estimated mortality attributed to climate change:

There is a sense of urgency... If we don't move to address energy and climate as two sides of the same coin we will lose out.  

*Time*, April 23, 2009

Lisa Jackson  
EPA Administrator

Out of the Headlines

Global population soars...  
1 Billion in 1804  
2 billion in 1927  
6 billion in 2000  
7 billion in 2011  
10-15 billion in 3000

People need ...  
Safe food, shelter, clean water, and clean air  
But the key is cheap, “sustainable” energy
Energy is essential for economic and social development

Global population divided into income groups:
- Primary energy
- Developed (GDP>$12,000)
- Emerging (GDP<$12,000)
- Developing (GDP<$5,000)
- Poorest (GDP<$1,500)

Shifting the development profile to a "low poverty" world means energy needs double by 2050.

Shifting the development profile further to a "developed" world means energy needs triple by 2050.

By 2050, world population could rise to ~ 9 billion.¹

Source: WBCSD adaptation of IEA 2003
An Example of the Challenge Before Us

• David Douglas of Sun Microsystems
  – In 15 years the global pop. increases 1B
  – Give each a 60W light bulb
    • 0.7 oz. = 20K metric tons = 15K Priuses
    • Turned on = 60K megawatts
    • Use 4hrs / day == 10K megawatts
  – Power needed: 20 500 megwatt coal fired(?) power plants

Just to turn the lights on!!
The times they are a changin’
US Legal Approach to GHGs

- 2007 Supreme Court ruled in Mass v. EPA that GHGs are covered by the CAA
  - Vehicle emissions impact health and welfare
- 2012 Supreme Court ruled favorably on the EPA Endangerment Finding 2009
  - Light duty vehicle rule
  - New Source Review – new power plants
- 2014 Proposed Clean Power Rule
  - 30% reduction in C by 2030
  - States have most of the authority
The Energy Landscape is Changing!!!

Solutions or temporary fixes?
Preparing for Our Health Science Future
Some of My General Perspectives

We need to find “solutions” using the tools we already have - just more creatively!!

• Gone are the days of “the sky is falling”
• “Systems” approaches are essential
• What about sustainability?
  ❖ How do we make the right decisions?
• Human Factors
  ❖ Susceptibility – health; genetic; epigenetic; SES
  ❖ A role for human (social) behavior?
• Climate - prepare or adapt?
  ❖ Do we merely slow the decline?
  ❖ What are the impacts of our responses?
Toxicology of the Future

• 21st Century tox
  – Pathways
• Appropriate models
• Susceptibility
  – Frailty
  – Genetic / epigenetic
  – Target repair
  – Homeostasis
• Realistic scenarios
  – Exposures
  – Challenge the DR

“Never, ever, think outside the box”
Epidemiology of the Future

- Moving toward “causality”
- Enhanced statistical designs
  - Multipollutant models in time and space
  - Improved exposure estimates
  - Public health tracking – esp. w/ climate change
  - Susceptibility – short term vs chronic
  - Utilizing social media

- Dealing with moving targets
  - AQ in a changing energy landscape

- Accountability – are we better off?
  - Finding benefits amongst disbenefits

- The “Global Context”
  - Genes in society – nature vs nuture
Putting the Health of Our Planet and Life on It in Perspective

Photo of the Earth taken from Mars by Curiosity, Aug 2012

you are here