The Silent Epidemic:
Coal and the Hidden Threat to Health

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What is Health?

Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.

World Health Organization
1948

Medical Knowledge and Evidence-Based Medicine

“There are things we know that we know … [and] there are things that we now know we don’t know. But there are also unknown unknowns. There are things we do not know we don’t know.”

Donald Rumsfeld, June, 2002

Two examples

1. An individual who lives near a coal mine develops chronic lung disease: did the mine cause COPD?

2. Hypothesis: does living near a coal mine affect health? Study by Hendryx and Ahern in a study of a cohort of West Virginians

The Hierarchy of Evidence

- Randomized controlled clinical trial (RCT) – The Gold Standard
  - Establish outcome measure
  - Enroll participants who meet criteria
  - Random assignment to treatment group or exposure – with protection of randomization process
  - Evaluation of outcome by blinded individual
  - Application of statistical test
- A Meta analysis is even better

The Hierarchy of Evidence

Start at the Bottom Rung

- Case report – clinical observation
- Case series – clinical observation
- Ecological associations – existing data
- Case control – new data
- Cohort
  - Retrospective – existing and new data
  - Prospective – new data
Why alternatives to RCT

- May not be feasible
  - Unethical – randomize to inhalation of coal dust
  - Impractical – expensive, delay study results
- Alternatives required

Evidence for Causal Relationships

- Major – strength of association
  - Consistency – replication of study
  - Biological plausibility
  - Temporality – time between exposure to disease development
  - Statistical significance
- Other: dose-response
  - Experimental evidence including animal studies, cessation effects, others

Observational Studies: can test hypothesis - yields odds ratio

- Case control studies
  - Identify cases
  - Identify matched controls
  - Retrospective analysis of exposure
  - Retrospective direction of inquiry
  - Use existing data (may be biased or flawed)

Cohort Study

- Participants identified on basis of exposure (high pollution city vs low pollution city)
- Participants evaluated at onset and periodically to determine whether disease develops (e.g., asthma)
- Expensive, time consuming but less dependent on biased observation

Hendryx and Ahern

Relations Between Health Indicators and Residential Proximity to Coal Mining in West Virginia. Am J Public Health 2008
- Sophisticated phone survey by county
- Coal Production statistics
- Excellent control for confounding variables in statistical analysis

Results Hendryx and Ahern

- As coal production increased, health status worsened and rates of cardiopulmonary disease, lung disease, cardiovascular disease, diabetes and kidney disease worsened.
- Example result for COPD: odds ratio and 95% confidence interval
  - Less than 4 million tons: 0.969 (0.596 – 1.577)
  - More than 4 million tons: 1.559 (1.069 – 2.272)
Health Effects of Electricity Generation, Various Fuels

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Deaths/cases</th>
<th>Serious Illnesses/cases</th>
<th>Minor Illnesses/cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite</td>
<td>32.6 (8.2-130)</td>
<td>208 (74.6-193)</td>
<td>17.676 (4.419-70.704)</td>
</tr>
<tr>
<td>Other Coals</td>
<td>24.5 (6.1-98)</td>
<td>225 (56.2-899)</td>
<td>31.288 (5.322-551.580)</td>
</tr>
<tr>
<td>Oil</td>
<td>18.4 (4.6-73.6)</td>
<td>103 (40.4-655.6)</td>
<td>9.551 (2.188-38.204)</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>2.8 (0.70-11.2)</td>
<td>30 (7.48-120)</td>
<td>703 (1762-813)</td>
</tr>
<tr>
<td>Biomass</td>
<td>4.6 (1.16-18.5)</td>
<td>43 (10.8-172.6)</td>
<td>2.276 (569-9.104)</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.052</td>
<td></td>
<td>0.32</td>
</tr>
</tbody>
</table>

Based on: Deaths/cases per TeraWh generated electrical power in Europe, 95% confidence intervals.

U.S. generates about 4,000 TWh per year


Coalworkers Pneumoconiosis

Diagnostic Criteria
- Chest X-Ray consistent with CWP
- Sufficient occupational exposure
- Other causes ruled out

CPW prevalence
- 1.1% if 9 or fewer years underground mining experience
- 5.4% if 25 or more years underground mining experience

Source: AS Laney & MD Attfield, Occup Environ Med, 2010

Coal Transport

- About 70% of all rail traffic is related to coal transport
- Rail accidents are much more common per ton-mile than road traffic
- Diesel locomotives emit particulates that are harmful to health
- Trucks produce particulates from diesel engines and wear and tear of roads

Hazardous Air Pollutants (HAPS) Released by Coal Combustion (from over 60)

- Oxides of sulfur
- Oxides of nitrogen
- Arsenic
- Beryllium
- Cadmium
- Chromium
- Mercury
- Nickel
- HCl
- HF
- Acrolein
- Dioxins
- Formaldehyde
- Uranium and Thorium
Coal Ash

- We burn about 1 trillion tons of coal each year.
- This produces about 100 million tons of coal combustion waste.
- As pollution control devices become more efficient as mandated by the Clean Air Act, the ash becomes more toxic.
- Ash is largely unregulated and often stored under substandard conditions.

Kingston spill, December 22, 2008

- Dam failed holding back a 84 acre area.
- 1.1 billion gallons released.
- At dozens of other sites, arsenic and other toxicants have leached into ground water.

Air Pollution Damages in 2005

406 Coal Plants: $62 billion

Source: NAS Hidden Costs of Energy, 2009

Air Pollutants

- Criteria Air Pollutants: harmful to health and environment, have National Ambient Air Quality Standards (NAAQS):
  - Carbon Monoxide
  - Lead
  - Nitrogen Dioxide
  - Particulates (10 and 2.4 micron aerodynamic diameter)
  - Ozone
  - Sulfur Dioxide
  - Mercury

People Living In Counties Where NAAQS Not Met, 2007

Source: EPA

Oxides of Nitrogen

\[ \text{NO}_x + \text{Organics} + \text{sun} = \text{Ozone} \]

Source: EPA
Sulfur Dioxide Sources

Source: EPA

Small Particles - PM$_{2.5}$

Source: EPA

Satellite Derived PM$_{2.5}$ Concentration 2001 - 2006

Source: van Donkellar et al., EHP 2010;118:847

PM and Cardiovascular Disease

- Harvard 6 Cities Study: 26% increase mortality in most versus least polluted cities
- ACS Cancer Prevention Study: each 10 μg/m$^3$ increase in PM$_{2.5}$ associated with increases of 4% in all cause and 5% cardiopulmonary mortality
- Other studies: show increases in acute myocardial infarct, defibrillator discharges, myocardial ischemia during stress test

Source: Cited by Brook et al Circulation 2004

Air Pollution and Stroke

- Korean Study: increased ischemic stroke risk with daily increases in suspended particulates and sulfur dioxide, one day lag nitrogen dioxide, and carbon monoxide, and 3 day lag for ozone
- Taiwan study: on warm days (> 20 C) positive association between PM$_{10}$, NO$_x$, SO$_x$, CO, and O$_3$ for cerebral hemorrhage and ischemic stroke admissions
- Women’s Health Initiative: an increase of 10 μg/m$^3$ in the PM$_{2.5}$ concentration was associated with a 24% increase in the risk for a cardiovascular event and an increased risk for a cerebrovascular event


PM$_{2.5}$ Pollution and Hospital Admissions, 60 Northeast Counties Medicare Data

% change in hospital admissions per 10 μg/m$^3$

ANOVA shows East significantly higher than West for all outcomes except heart failure and COPD

Source: F Dominici et al. JAMA 2006;296:1127-1134
Air Pollution and Leading Causes of Death in Americans

- Heart Disease – leading cause in US - 617,527 in 2008
  - Myocardial Infarct
  - Congestive Heart Failure
  - Fatal Arrhythmia
- Malignant neoplasms – Second leading cause in US, 566,137 deaths in 2008
  - Asthma (esp. kids)
  - Emphysema
  - Bronchitis
  - Cancer
- Stroke – Fourth leading cause in US, 133,750 deaths in 2008

Source: CDC, 2011

Anthropogenic Mercury Sources (tonnes), 2005

- Fossil fuel combustion, 878
- Metal production, 200
- Other gold production, 111
- Large scale gold production, 350
- Chlor-alkalai, 47
- Cement kilns, 189
- Incineration, 125
- Cremation, 26

Source: UNEP Global Mercury Assessment, 2008

Impact of Hg on Child Development

- Doubling of Hg concentration reduces neuro-developmental test scores by 5.7 – 15.9% of a standard deviation.
- Using conservative measures, the annual lost productivity cost due to Hg is $8.7 billion (range $2.2 – 43.8 billion)
- Of this total, $1.3 billion (range $0.1 – 6.5 billion) is attributable to coal-fired power plants
- EPA indicates that among the most highly exposed individuals in US, Hg may reduce IQ by about 7 points.


Worldwide Mercury Deposition

Source: UNEP Global Atmospheric Mercury Assessment, 2008

Simulated Mercury Emission From East Asia

Source: UNEP Global Atmospheric Mercury Assessment, 2008
Bioaccumulation of Mercury


Mercury in Alaskan Fish

“Most species of Alaska fish – including all five wild Alaska salmon species – contained very low mercury levels that are not of health concern.”

“Of 359 women of childbearing age from 51 Alaskan communities tested as a part of Alaska’s [2002 – 2006 monitoring program] none had hair mercury levels of clinical or public health concern as a result of eating Alaska fish.”

Source: Alaska Dept. of Health and Social Services, Oct 15, 2007

Climate Change is a Health Issue, Not Just an Environmental Issue

- Climate change is real and caused by human activity
- Climate change is bad for us and our community
- We need to act now to protect those who are vulnerable
- Taking action creates a win-win situation: solutions to climate impacts also improve health

Clean Air Act

- Signed in 1970
  - Established EPA
  - EPA mission: to protect human health and the environment
  - Established NAAQS
- Amended in 1990
  - Established Acid Rain Program
  - Gave EPA authority to regulate sources
    - Point sources
    - Mobile sources
Effects of CAA on Emissions

Source: EPA

Annual Health Effects Avoided: Clean Air Act as Amended

<table>
<thead>
<tr>
<th>Health Effect</th>
<th>Pollutant(s)</th>
<th>Year 2010</th>
<th>Year 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult mortality</td>
<td>PM</td>
<td>160,000</td>
<td>230,000</td>
</tr>
<tr>
<td>Ozone mortality</td>
<td>Ozone</td>
<td>6,300</td>
<td>7,100</td>
</tr>
<tr>
<td>Chronic bronchitis</td>
<td>PM</td>
<td>54,000</td>
<td>75,000</td>
</tr>
<tr>
<td>Acute bronchitis</td>
<td>PM</td>
<td>130,000</td>
<td>180,000</td>
</tr>
<tr>
<td>Acute myocardial infarction</td>
<td>PM</td>
<td>110,000</td>
<td>230,000</td>
</tr>
<tr>
<td>Asthma exacerbation</td>
<td>PM, Ozone</td>
<td>1,700,000</td>
<td>2,400,000</td>
</tr>
<tr>
<td>Hospital admission</td>
<td>PM, Ozone</td>
<td>86,000</td>
<td>135,000</td>
</tr>
<tr>
<td>Lost days at work</td>
<td>PM</td>
<td>13,000,000</td>
<td>17,000,000</td>
</tr>
</tbody>
</table>

Source: EPA

Predicted Temperature Changes, Three Different Models

Source: IGCC Fourth Assessment Rpt Chap 10

Coal and Global Warming


Source: Energy Information Admin.
Percent Yield Impact of Climate Change on Four Crops


Medical Professionalism

- devotion to medical service
- public profession of values
- and negotiation or engagement with the public to establish social priorities
  - 90% of physicians rate community participation, political involvement, and collective advocacy as being very important
  - 43% rate reduction of air pollution as being very important


Professionalism and the Environment

“Physicians have information and expertise about environmental change that can contribute to its slowing or prevention. Work to prevent global environmental change is consistent with the social responsibility of physicians and other health professionals.”

Political action may be required and should not contraindicate action.

Cassel and McCally. Ann Int Med 1990;112:467-463

The Earth’s Annual Global Energy Balance


Radiative Forcing of Climate, 1750 - 2005

Greenhouse Gases, 0 - 2005

The Keeling Curve

\[ C + O_2 = CO_2 \]

\[^{13}C\text{ Ratio and CO}_2\text{ Sources}\]

Carbon exists in two isotopic forms: \(^{12}C\) (99%) and \(^{13}C\) (1%). Different steps in photosynthesis favor one isotopic form of carbon over the other. This enables scientists to deduce the origin of CO\(_2\) in the air. Increasing deviations from the \(^{13}C/^{12}C\) ratio in a standard link atmospheric CO\(_2\) to burning fossil fuels.

**Heat Waves**

- **Definition:** Maximum daily temperature exceeds the average daily maximum by 5 Centigrade for 5 days or more relative to 1961 – 1990 data.
- Heat waves have been more common in the second half of the century.
- Earth policy institute estimates 52,000 died in 2003 European heat wave.


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**2003 European Heat Wave June - August**

Image created from Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite.

About 52,000 deaths Associated with the Heat wave

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**NASA North America Land Data Assimilation System, July 2011 Data**

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**Vulnerability to Delta Flooding 8.7 Million Displaced by 2050**

Source: IPCC, Working Group II, 2007

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**Infectious Diseases Dengue**

- **Vector:** A. aegypti
- **Caused by:** flavivirus
- **4 – 7 days after infection**
  - Retrobulbar pain
  - Petechial bleeds
  - Severe bone pain
  - Extravasation of plasma – organ failure and death

**Dengue**

- 1.5 billion live where there is 50% risk
- By 2085 predicted to rise to 5-6 billion

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**Infectious Disease Malaria**

- **Cause:** P. vivax, P. falciparum, P. malariae, P. ovale
- **2 – 3 million deaths per year**
- **Children at greatest risk**
- **Greatest impacts in marginal areas**

- **Cyclic fevers**
- **Pulmonary edema**
- **Blackwater fever due to hemolysis**
- **Coma, death**

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### Diarrheal and Water-Borne Cholera

- Cholera, *V. cholerae*
- Consumption of contaminated food or water
- Abrupt onset abdominal pain, cramps, severe diarrhea, vomiting, dehydration
- 50% mortality if untreated
- Rehydration therapy reduces death rate to 1%
- I.V. fluids and antibiotics need for severe illnesses

### Carbon Capture and Storage

Carbon dioxide capture and storage is “a process consisting of the separation of CO₂ from industrial and energy-related sources, transport to a storage location, and long-term isolation from the atmosphere.”

Source: Intergovernmental Panel on Climate Change

### Carbon Capture and Sequestration: May Consume 40% of Electrical Output

- **Post-combustion capture (coal, natural gas combined cycle)**
  - Organic solvent (e.g., monoethanolamine) combines with CO₂—typically 3-15% flue gas
  - Oxygen (90 – 95%) used instead of air for combustion, flue gas compressed and dried
- **Pre-combustion capture**
  - Fuel mixed with steam and air or oxygen, resulting gas high in CO and H₂ — treatment repeated, yields H₂ and CO₂, CO₂ captured, H₂ burned


### Comparison of Long-Lived Global Warming Gases

<table>
<thead>
<tr>
<th>Gas</th>
<th>Atmospheric Lifetime (years)</th>
<th>Concentration in Atmosphere (2005)</th>
<th>20 year OWP</th>
<th>100 year OWP</th>
<th>900 year OWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>very long, see below</td>
<td>379 ± 0.65 ppm</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Methane</td>
<td>12</td>
<td>1.774 ± 1.8 pgg</td>
<td>72</td>
<td>24</td>
<td>7.6</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>114</td>
<td>319 ± 0.12 pgg</td>
<td>289</td>
<td>298</td>
<td>153</td>
</tr>
</tbody>
</table>

Source: Lockwood, Coal: The Black Threat to Health
Adapted from IPCC Reports
Climate Change and Health

Worldwide Natural Disasters 1900 - 2008

- Global warming is likely to cause an increase in the number of natural disasters
- Disasters in the graph met one or more of the following criteria
  - 10 or more people killed
  - 100 people affected
  - Declaration of state of emergency
  - International aid requested

Source: Center for Research on Epidemiology of Natural Disasters

Natural Disaster Frequency

Natural Disaster Frequency, Cont.

Natural Disaster Frequency, Cont.
Natural Disaster Frequency, Concluded