(Ultrafine) particles: Sources, exposure and health effects

Gabriel Bekö
Natural sources

Anthropogenic outdoor sources
Particle size

Smallest particle: 2 nm (0.002 μm or 10\(^{-9}\) m)
Largest particle: 100 μm (10\(^{-4}\) m)

Coarse >2.5μm
Fine 0.1 - 2.5μm
Ultrafines (nanoparticles) <0.1μm (100 nm)

PM2.5 <2.5μm
PM10 <10μm
The Globen Arena, Stockholm (100 µm)
Head of pin needle (1 nm)
Epidemiological studies – ambient particles

- Short term effect studies – hospitalisation for respiratory and heart disease, aggravation of asthma, respiratory symptoms, impaired lung function

- Long term effect studies: Increase in mortality for each 10µg/m³ increase in PM2.5 (Pope et al., 2002)
Loss in statistical life expectancy (months) that can be attributed to anthropogenic contributions to PM2.5
Unvented burning of biomass and mortality

1 600 000 deaths/year

800 000 deaths/year
Unvented biomass burning – Developing countries

Chinese Burden of Disease from Top 10 Risk Factors
Plus Selected Other Risk Factors

- Alcohol
- Blood pressure
- Tobacco
- Underweight
- Occupational hazards (5 kinds)
- Indoor smoke from solid fuels
- Overweight
- Road traffic accidents
- Low fruit & vegetables
- Cholesterol
- Unsafe water/sanitation
- Urban outdoor air pollution
- Lead (Pb) pollution
- Physical inactivity
- Unsafe sex
- Climate change

380,000 premature deaths per year
Pneumonia in children: 21,000
COPD in women: 342,000
Lung cancer in women: 18,000

252,000 premature deaths per year
Ultra-fine particles (nanoparticles)

Able to reach the smaller airways of the lower respiratory tract

Large surface area per unit mass

Toxic and carcinogenic substances

- polycyclic aromatic hydrocarbons (PAHs)
- metals
Sources of airborne particles

- ambient particles infiltrated indoors
- particles emitted indoors
- particles formed indoors through reactions of gas-phase precursors emitted both indoors and outdoors
particle **number** concentration                        particle **mass** concentration

particles/cm³ OR µg/m³

20 oranges / bowl   4.000.000 poppy seeds / bowl
2 kg / bowl          2 kg / bowl
0.4 m²               12.5 m²

Mixed bowl: 90% of the weight will be oranges (2kg vs 0.2 kg)
99.99% of the number will be poppy (20 vs 400.000)
Measurements in 56 Copenhagen homes

Area under the curve = integrated exposure

Nights, unoccupied periods
Indoor sources explain about 65% of the total daily residential exposure.
Contribution of background and indoor sources to integrated exposure (GeoMean)

Daily integrated exposure (cm$^{-3}$ h/d)

- **Copenhagen**
  - Outdoor
  - Indoor

- **Beijing**
  - Outdoor
  - Indoor

- **California**
  - Outdoor
  - Indoor

*Mullen et al. 2011*
Contribution of peaks/events

Home No.

Daily Integrated Exposure (cm$^3$ h/d)
Lung function and systemic effects

Health endpoints:
- Microvascular function
- Lung function (spirometer)
- Biomarkers (blood - hemoglobin, white blood cells, ... urine, saliva)

- Association between residential exposure and lung function, markers of inflammation and diabetes

- When stratified, association confirmed for candle related exposure, not for cooking related exposure
Personal monitor + GPS (59 persons)

Concentration x Time

### Median PN concentration (#/cm³)

- **Home**: 12.5 (52.2%)
- **Active transport**: 0 (0.5%)
- **Passive transport**: 0.8 (3.2%)
- **Other indoor - building**: 9.6 (40.1%)
- **Other outdoor**: 0.85 (3.5%)

### Average time spent (h/d)

- **Home**: 12.5 (52.2%)
- **Active transport**: 9.6 (40.1%)
- **Passive transport**: 0.5 (1.9%)
- **Other indoor - buildings**: 0
- **Other outdoor**: 0
Where do we get most of it from?

~50% of total exposure occurs in the home

<table>
<thead>
<tr>
<th>Location</th>
<th>Median contrib. to total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>In the home</strong></td>
<td></td>
</tr>
<tr>
<td>Away from home</td>
<td><strong>50</strong></td>
</tr>
<tr>
<td>Active transport</td>
<td><strong>1.8</strong></td>
</tr>
<tr>
<td>Passive transport</td>
<td><strong>5.4</strong></td>
</tr>
<tr>
<td>Other indoor - buildings</td>
<td><strong>41.5</strong></td>
</tr>
<tr>
<td>Other outdoor</td>
<td><strong>3.3</strong></td>
</tr>
<tr>
<td><strong>All indoors – buildings</strong></td>
<td><strong>90.6</strong></td>
</tr>
<tr>
<td><strong>All indoors incl. passive trans.</strong></td>
<td><strong>95.4</strong></td>
</tr>
<tr>
<td><strong>All outdoors</strong></td>
<td><strong>4.6</strong></td>
</tr>
</tbody>
</table>
Lung function and systemic effects

Health endpoints:
- Microvascular function
- Lung function (spirometer)
- Biomarkers (blood - hemoglobin, white blood cells, ... urine, saliva)
- Association between exposure outside the home (but not in the home) and microvascular function and markers of inflammation
- Traffic-generated ultrafine particles may have adverse health effects while ultrafine particles from indoor sources may have less effects
Indoor Sources of Chemicals

- Occupants & Pets
- Cooking & Heating
- Smoking (tobacco)
- Building materials
- Paint, floor and wall coverings
- Furnishings
- Consumer products
- Pesticides
- Mold/Fungi
- Chemistry
Chemicals since 1970

World Chemical Production

Commercial chemicals:
- ~143,000 in Europe
- ~100,000 in USA
- ~30,000 produced in amount > 1 ton/year

Over 80,000 new chemicals since WWII

Egeghy, US EPA, 2010
Is the indoor environment healthier today than it was 60 years ago?
Indoor exposures to a number of known or suspected carcinogens have decreased

- Benzene, Formaldehyde, Asbestos, Env. tobacco smoke, Radon

- Chloroform, Naftalene, Polybrominated biphenyls

**Heavy metals:**
- Lead, Mercury, Cadmium

**Gases**
- CO, SO$_2$, NOx

**Pesticides**
- Mirex, Propoxur, Chlorpyrifos, Chlordane...DDT
Swiss Paul Hermann Müller received the Nobel prize for medicine for discovery of DDT – efficient against insects.

- 3000 children die daily from malaria, 2 mil/yr
- 500 million acute malaria cases annually

- Indoor residual spraying of DDT can reduce malaria transmission by up to 90%
- Potential effects: Endocrine disruption, genotoxicity, metabolite DDE prevents androgens from expressing their biological effects

Sept 15, 2006: WHO officially recommends indoor residual spraying of DDT for control of malaria
Exposures to oxidation products have increased

Indoor levels of unsaturated organic compounds, especially terpenoids, have increased:

- 1950: <20% of homes used air fresheners
- 2007: 70% of homes used air fresheners

USA “Air freshener” sales

<table>
<thead>
<tr>
<th>Year</th>
<th>Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>$0.9 billion</td>
</tr>
<tr>
<td>2005</td>
<td>$1.5 billion</td>
</tr>
</tbody>
</table>

- Outdoor ozone levels have increased
- Air exchange rates have decreased (more time for gas phase chemistry)
More EDCs - Endocrine Disrupting Chemicals

- Chemicals that can mimic hormones
Indoor exposure to endocrine disruptors

Endocrine disruptors found in humans have been linked to:

- Immune dysfunction  *Miuashita et al. 2011*
- Neurobehavioral disorders  *Swan et al., 2010*
- Infertility  *Meeker&Stepleton 2010*
- Obesity-diabetes  *Carwile&Michels 2011*

Low dose effects have been observed for a number of “indoor” chemicals, including certain:

- Plisticizers
- Flame retardants
- Pesticides
- Detergents
- Surfactants

*not all chemicals in these use categories have hormonal activity*
Chemicals in the blood and urine from known sources

- Benzene, toluene, xylene isomers, ethylbenzene, styrene
- Perchloroethylene
- p-Dichlorobenzene
- Chlordane, dieldrin, mirex, DDT/DDE
- PCBs
- PBDEs
- Nicotine
- Perfluorinated surfactants (e.g., PFOS, PFOA)

- Naphthalene, fluorene, phenanthrene, pyrene, other PAHs
- Benzophenone
- Pentachlorophenol
- Nonylphenol, o-phenylphenol
- Bisphenol A (BPA)
- p-Dichlorobenzene
- Parabens
- Phthalates
- 2,4-D, chlorpyrifos, cis-permethrin
Flame retardants!

Chicago Tribune – May 2012

- Deceptive practices revealed – parallels with tobacco industry
  

- Laws requiring flame retardants in furniture promoted with false data

- “…your home is filled with toxic flame retardants that serve no higher purpose than enriching three companies” (NY Times, 19 máj, 2012)

When are they efficacious?

How much is enough?

Are they safe/toxic?

Alternatives exist – e.g. aluminum oxides
Phthalates

- Developmental and reproductive toxicants:
  - genital development
  - semen quality
  - children’s neurodevelopment
  - thyroid function
  - onset of puberty in females
  - obesity, diabetes

- Prenatal exposure:
  - influence on child’s mental, psychomotor and behavioral development
  - risk of developing eczema in early childhood
  - increased risk of asthma, wheeze and respiratory infections
Long-term effects???

- There are numerous chemicals in our indoor air that weren't there two generations ago.
- We know why they are there:
  - Flexible plastics
  - Reduce the risk of fire
  - Kill pests
  - Minimize mold
  - Make paint spread better
  - ...
- They have become part of us.

Surprisingly, the long term consequences are unknown!!!
We need toxicology data

- 3300 commercial chemicals produced or imported into the U.S. at levels > 1 million lbs/year (high production chemicals)
- No toxicity data for ~ 40% of the high production chemicals
- Full toxicity data available for only ~ 25% of the chemicals in consumer products
- The world needs to break its pattern of first producing new technologies and chemicals and then trying to evaluate their impacts after the fact. Minimizing risks from new chemicals and technologies is one of the top 10 emerging environmental issues that could have a major impact on human well-being and the planet

UN report, Feb. 2012
Exposure pathways

Inhalation, dermal absorption, dust ingestion as estimated from levels measured in dust from homes and daycare centers

Total daily intake based on metabolites measured in urine

Other pathways: food ingestion, mouthing, skin contact ...
Why DEP and DnBP?

- DEP is used as a solvent/carrier in many personal care products
- DnBP is used as a plasticizer for PVC and as a solvent/plasticizer in products such as nail polish

Latex paint doped with DEP & DnBP
Breathing arrangements
When the movies inspire science…

Dr. No

General van Dyke

Alien??
Subjects in chamber during “dermal only” pathway experiments.
Net MEP & MnBP in urine vs. time

Subject 3, MEP

amount excreted (MEP) [µg]

Time [h]

- hood
- no hood
Available research indicates that climate change may make existing indoor environmental problems worse and introduce new problems: moisture, materials, lower ventilation, changed behaviors.
Effect of energy renovation on ventilation

Min. ACH requirement: 0.5 h\(^{-1}\)

<table>
<thead>
<tr>
<th>ACH &lt; 0.5 h(^{-1})</th>
<th>ACH &gt; 0.5 h(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original building (N=43)</td>
<td>Renovated building (N=44)</td>
</tr>
<tr>
<td>37 %</td>
<td>63 %</td>
</tr>
<tr>
<td>59 %</td>
<td>41 %</td>
</tr>
</tbody>
</table>

Mean: 0.79 h\(^{-1}\)  0.48 h\(^{-1}\)
Climate change and indoor climate

Climate Change, Indoor Environments and Health

**Scenarios**
- Increased extreme heat and cold events
- Increased extreme precipitation events
- Increased sea levels
- Increased outdoor particles and ozone
- Increased fires and dust storms
- Increased outdoor pollen levels

**Impacts on buildings**
- Change of heating and cooling loads
- Increase energy consumption
- Power Outages
- Flooding and water damage
- Water systems (drainage, sewage, supply)
- Durability, insulation, and resistance of materials to salt
- Increase in ozone, and particulate pollutants
- Increase indoor allergen loads

**Impacts on Health**
- Increase mortality
- Thermal stress
- Infectious respiratory disease transmission
- Mold-related illness
- Water-borne diseases
- Vector/animal borne disease
- SBS, Respiratory illness, and others
- Allergic respiratory illness
Hypothesis: CO$_2$ in the atmosphere will double before the end of the century
Broecker (2000) has likened our release of greenhouse gases to the atmosphere to poking an angry beast with a stick! We’re not sure what will happen, but chances are it won’t be good.
Anticipate diverse & escalating disturbances

Napríklad:

• **Water** – Hundreds of millions of people exposed to increased water stress

• **Ecosystems** – Significant extinctions around the globe

• **Food** – Complex, localized impacts on small holders, subsistence farmers and fishers

• **Coasts** – Increased damage from floods and storms

• **Health** – Increased burden from malnutrition, diarrheal, cardiorespiratory, and infectious diseases

Source: IPCC, *Climate Change 2007 — Climate Change Impacts, Adaptation and Vulnerability*
Mitigation? Stabilize atmospheric CO$_2$ levels

- Aggressive measures required to stabilize at 450 ppm CO$_2$
- Still may not suffice to prevent serious environmental damage.

**Preindustrial:** 280ppm
**Today:** 400 ppm

Emission rates:
- **today:** 9GtC/r 2100, **Business as Usual:** 20GtC/r 2100, **WRE450:** 3GtC/r

Need 3x decrease from today
Need 7x decrease from BaU

*GtC – billion tons
Per-capita fossil-C emission targets

Per capita fossil C emissions from fuel use (2010):

- Global: 3.2 kgC/d
- USA: 13 kgC/d
- Denmark: 6.2 kgC/d
- Lithuania: 3.0 kgC/d

We don't need bigger cars or fancier clothes. We need self-respect, identity, community, love, variety, beauty, challenge, and a purpose in living that is greater than material accumulation. The ads tell us that bigger cars and fancier clothes will bring us those nonmaterial benefits, but of course the ads lie. By selling us things that promise to fill our inner emptiness but ultimately don't, they set us up to want more, and more, and more. You can never get enough of what you don't really need.”