# The Effects of Green Infrastructure on Air Quality
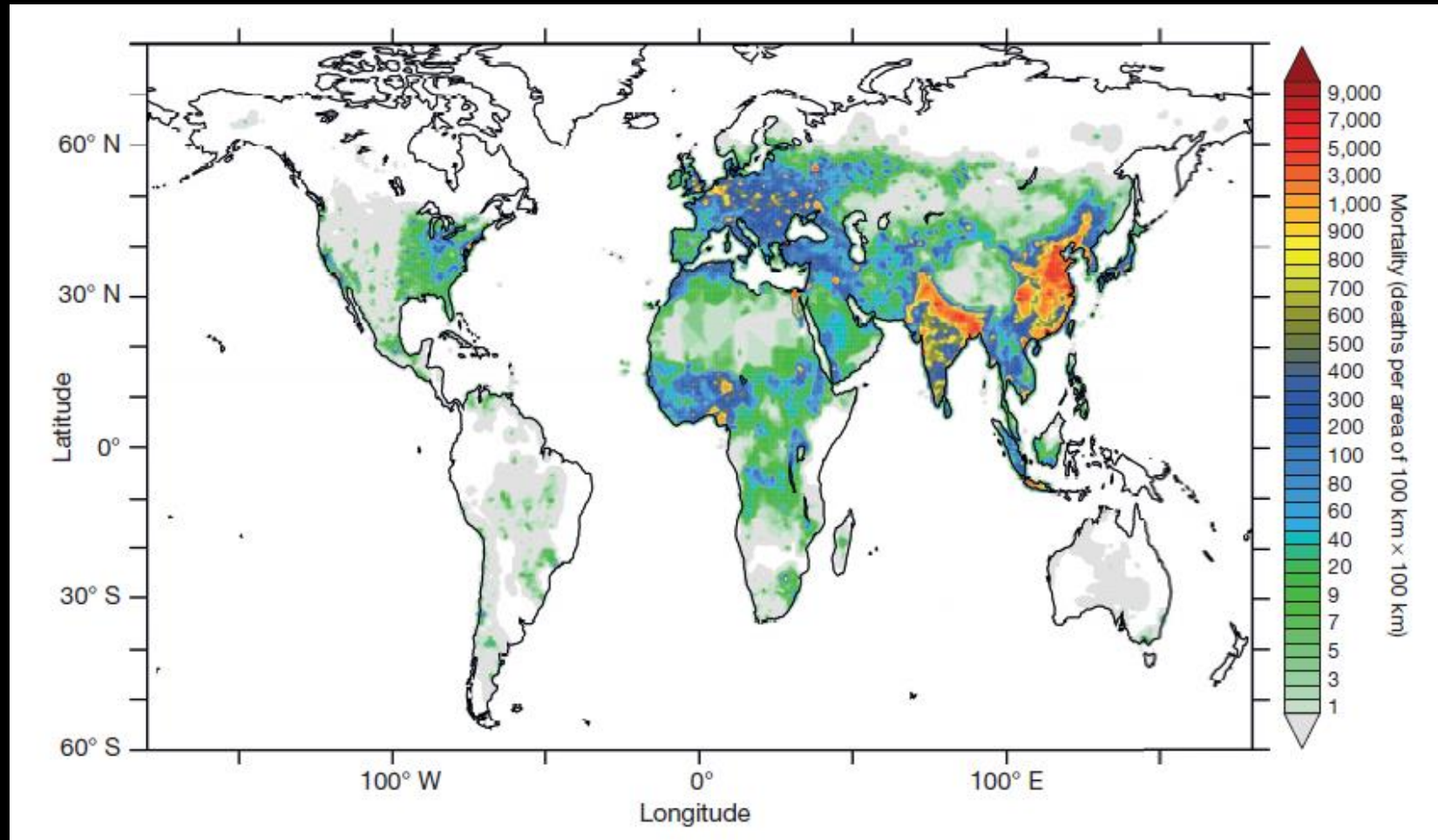
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*US Forest Service*

*Syracuse, NY, USA*

# Urbanization Issues – Air Pollution

- 3.7 million deaths from outdoor air pollution (2012)
- World's largest single environmental health risk



Air pollution mortality (2010) – Nature, 2015

# Issue

- Exposure to air pollutants is associated with:
  - increased respiratory symptoms
  - hospitalization for heart or lung diseases
  - premature death

# Air Pollutants

- Particulate matter ($PM_{10}$ $PM_{2.5}$)

- Primary Gaseous

  - Carbon monoxide (CO)

  - Nitrogen oxides ($NO_x$)

  - Sulfur dioxide ($SO_2$)

- Secondary Gaseous

  - Ozone ($O_3$)



good up high

ozone

bad nearby



HUMAN HAIR
50-70 μm
(microns) in diameter

● PM2.5
Combustion particles, organic
compounds, metals, etc.
< 2.5 μm (microns) in diameter

● PM10
Dust, pollen, mold, etc.
<10 μm (microns) in diameter
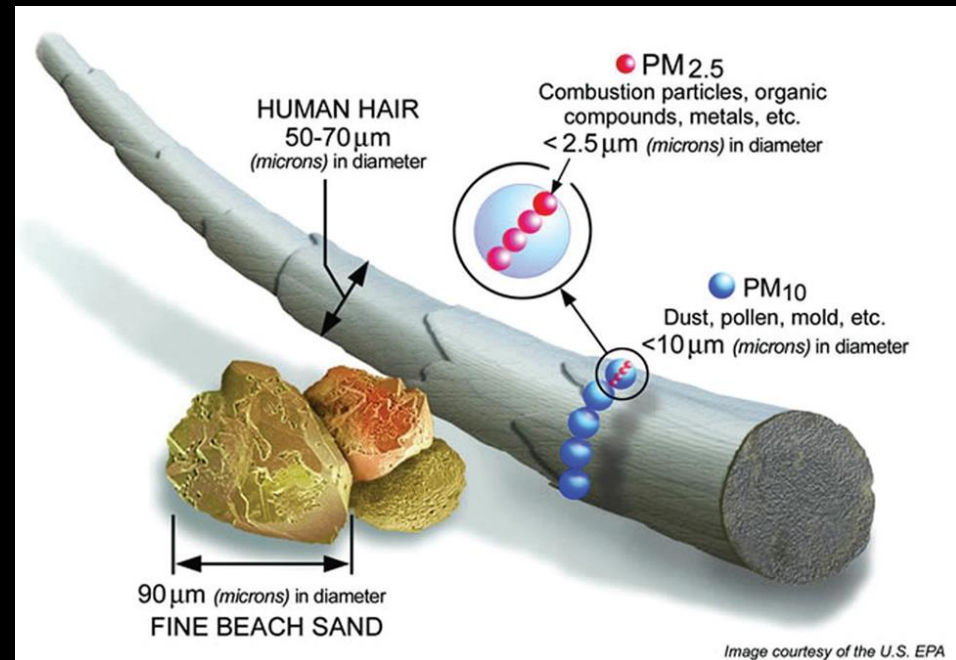
90 μm (microns) in diameter
FINE BEACH SAND

Image courtesy of the U.S. EPA

# Green Infrastructure Effects

T

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# Temperature / Air Effects

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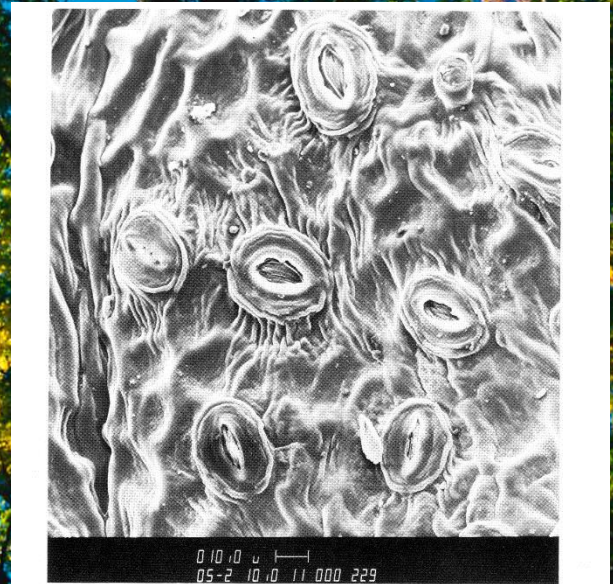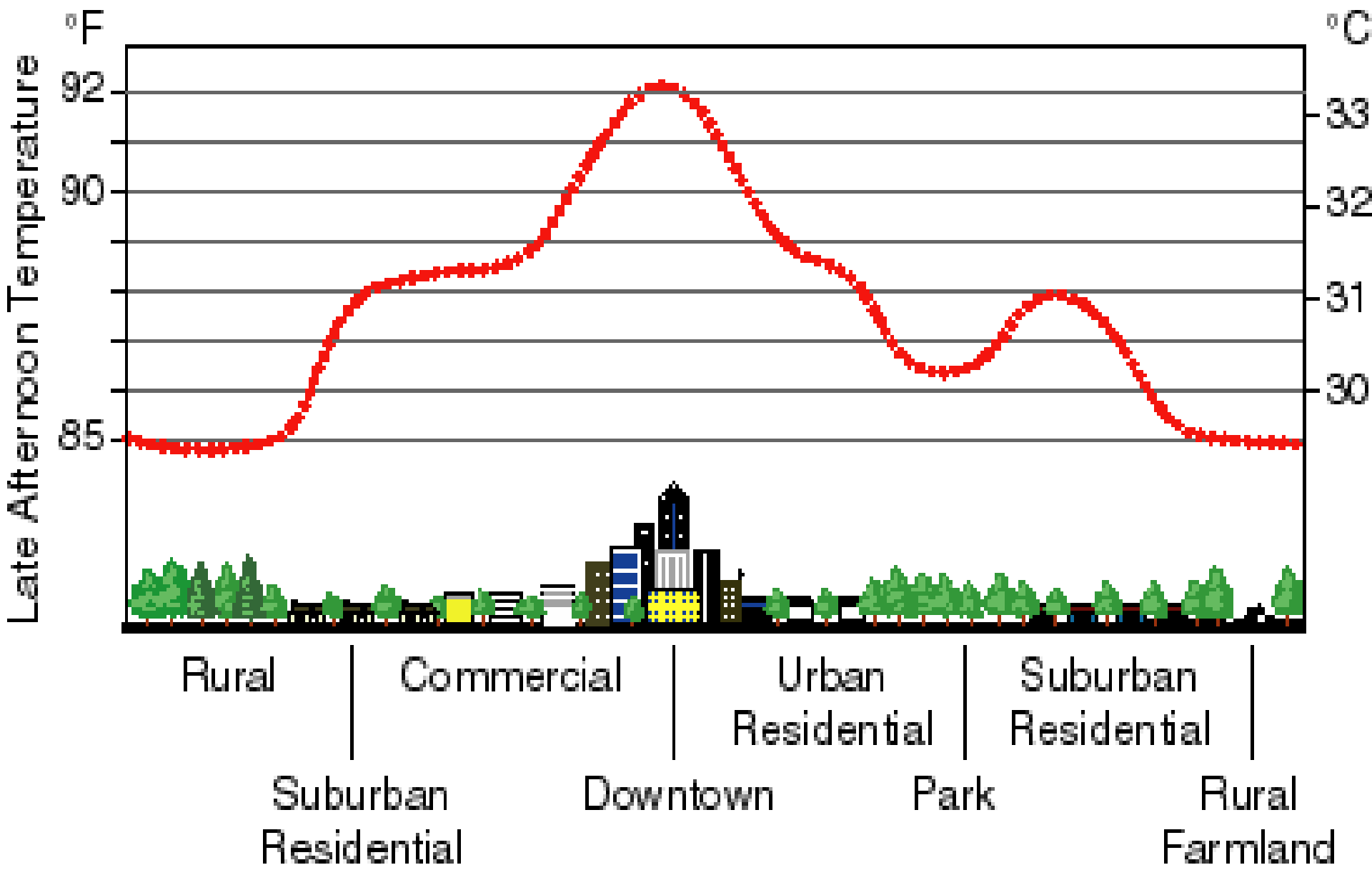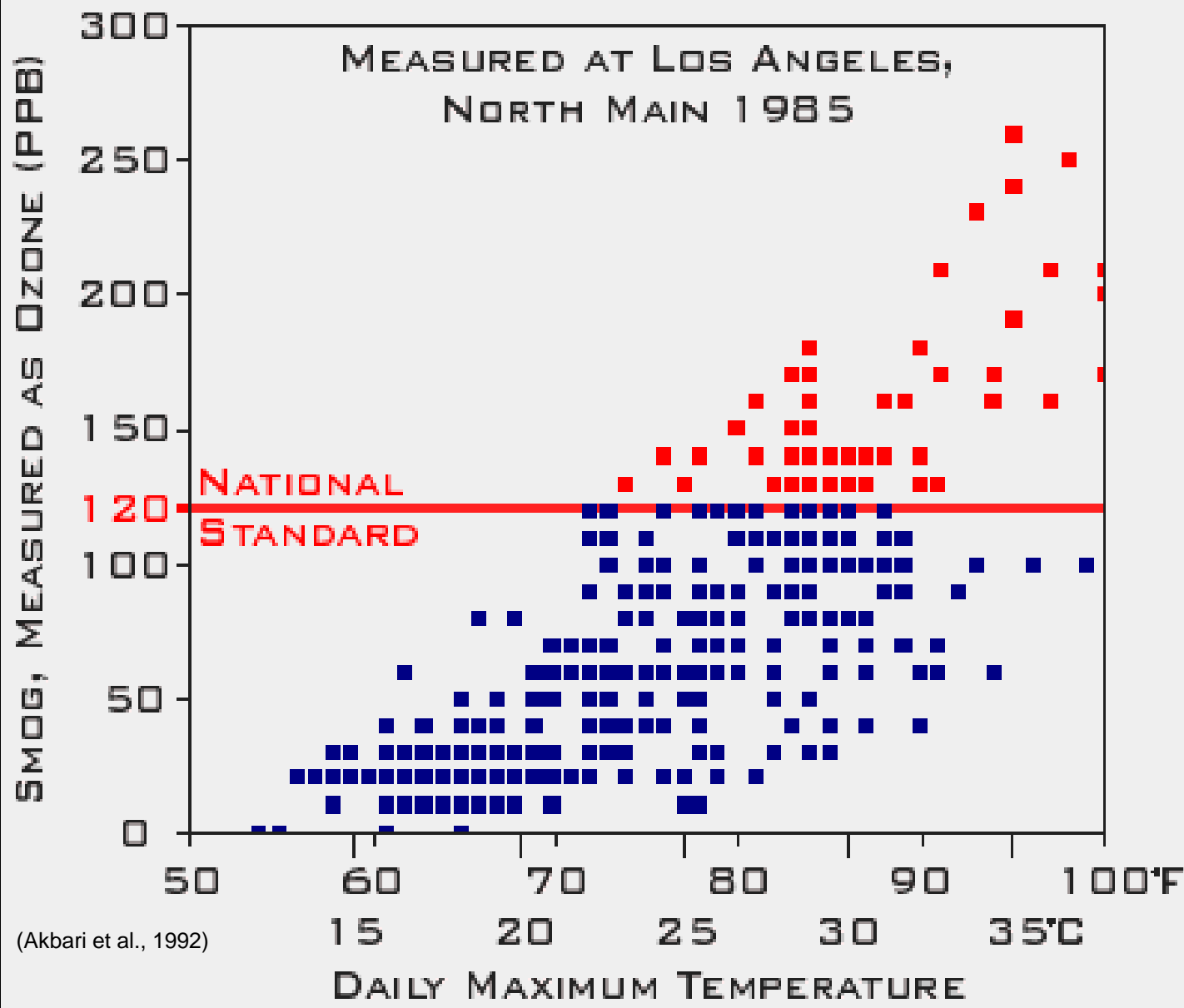**Figure 5-6.** Scanning electron microscope micrograph of the abaxial surface of a 3-week-old London plane leaf showing stomates. Scale, 10 $\mu$m.

# Sketch of an Urban Heat-Island Profile



°F | °C

Late Afternoon Temperature

92
90
85

33
32
31
30

Rural — Suburban Residential — Commercial — Downtown — Urban Residential — Park — Suburban Residential — Rural Farmland

MEASURED AT LOS ANGELES, NORTH MAIN 1985

(Akbari et al., 1992)

Reduce temperatures ➡ reduce emissions, alter chemistry

# Boundary Layer Height

# Temperature / Air Effects

## Removal

E

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MOLECULES OF GASEOUS
AIR POLLUTANT

WET
LEAF

DRY
LEAF

BOUNDARY
LAYER

STOMA

$H_2O$ LAYER

UPPER
EPIDERMIS

PALISADE

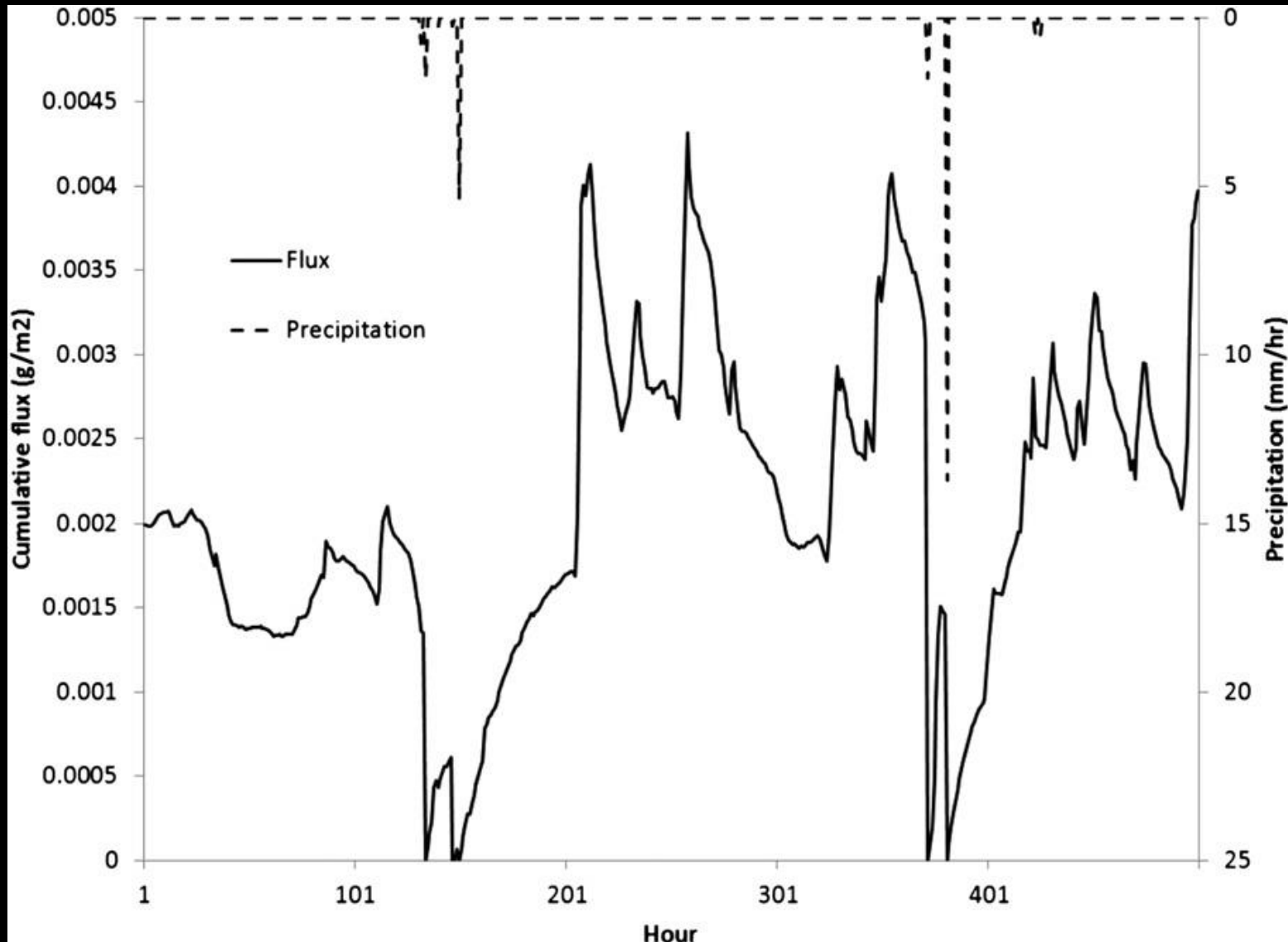MESOPHYLL
CELLS

SPONGY

LOWER
EPIDERMIS
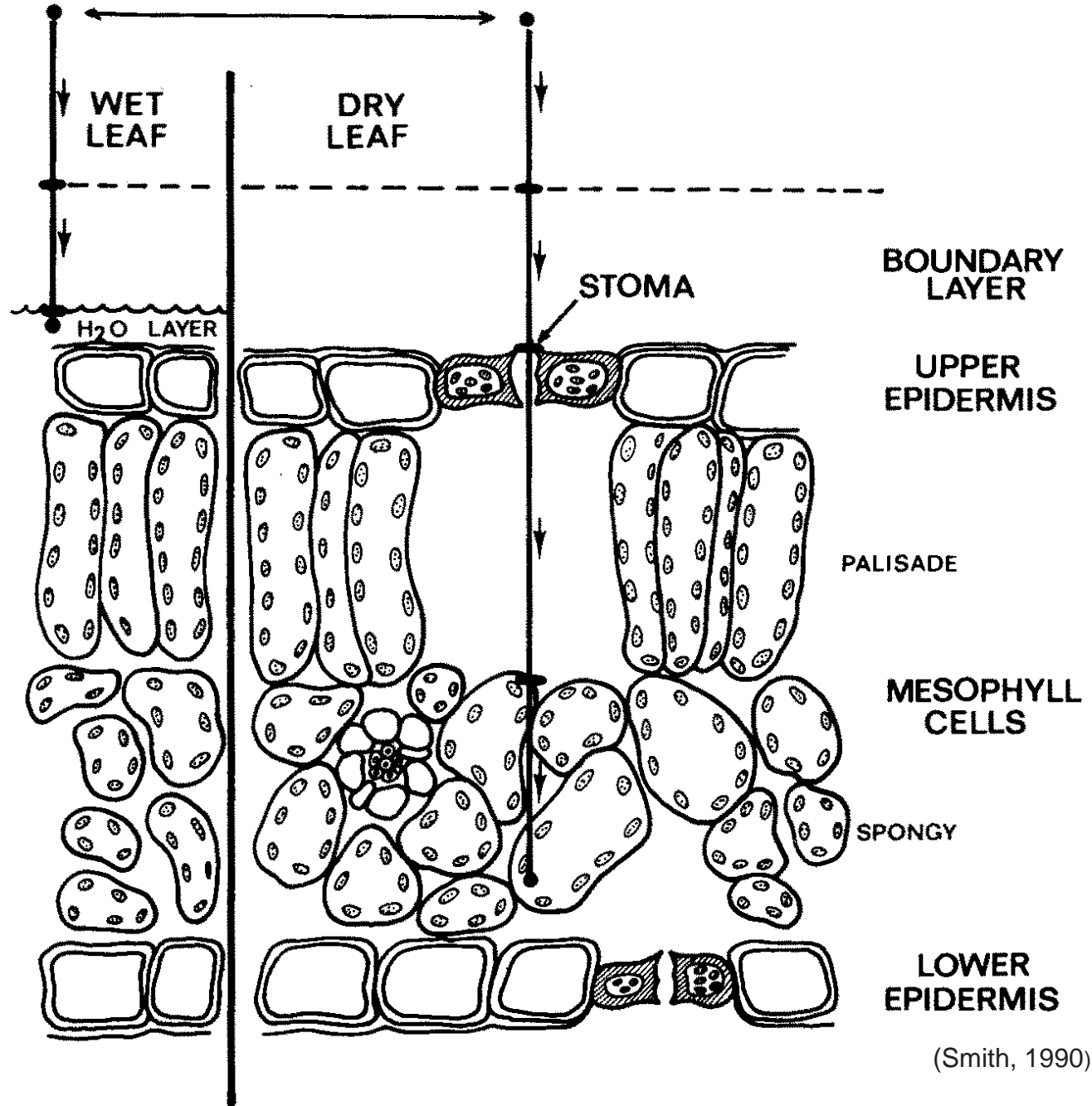
(Smith, 1990)

**Figure 5-3.** Scanning electron microscope micrograph of the adaxial surface of an 8-week-old London plane leaf. Spore, pollen, carbonaceous, angular, and aggregate particles are visible. Scale, 10 $\mu$m.
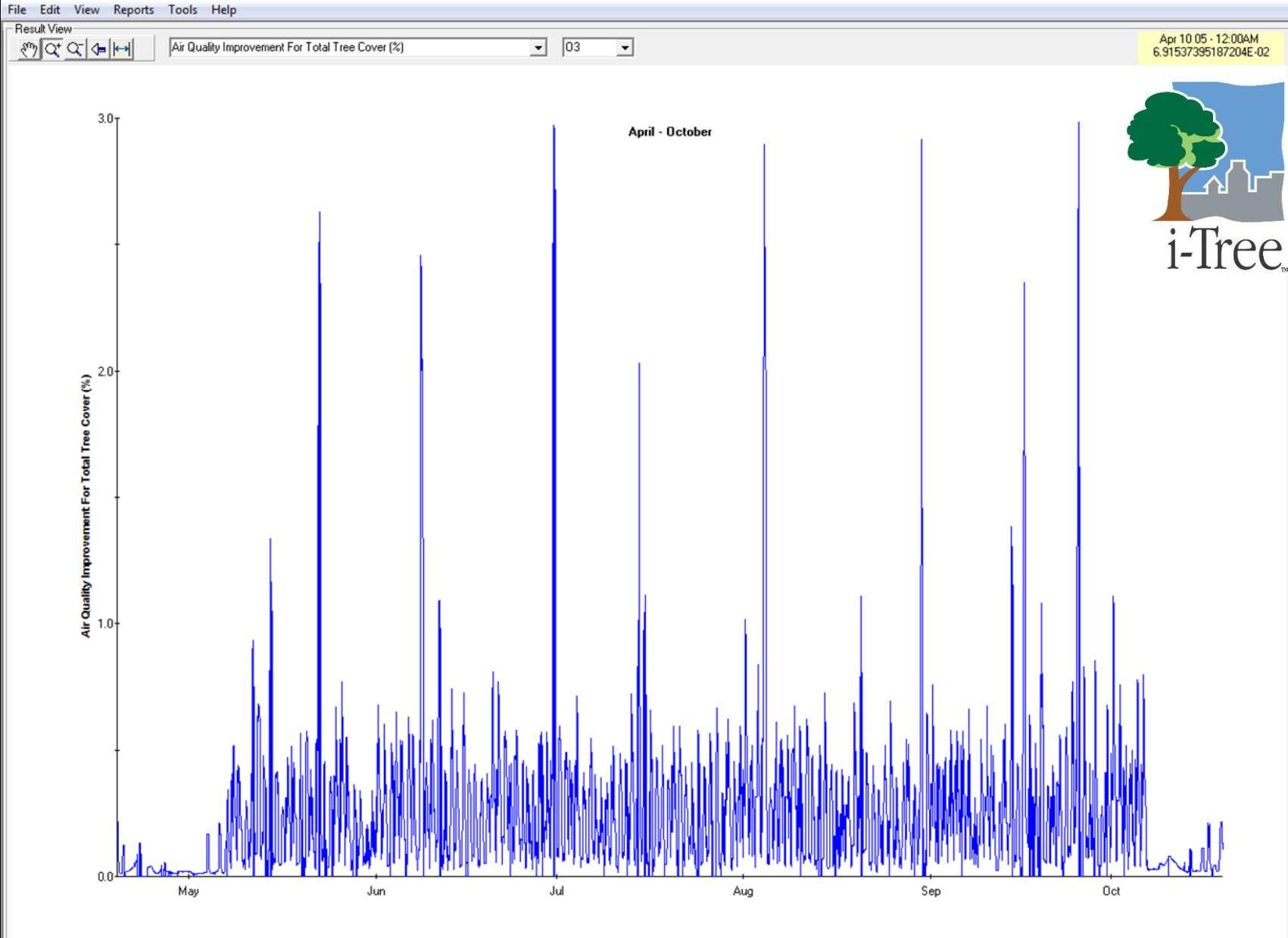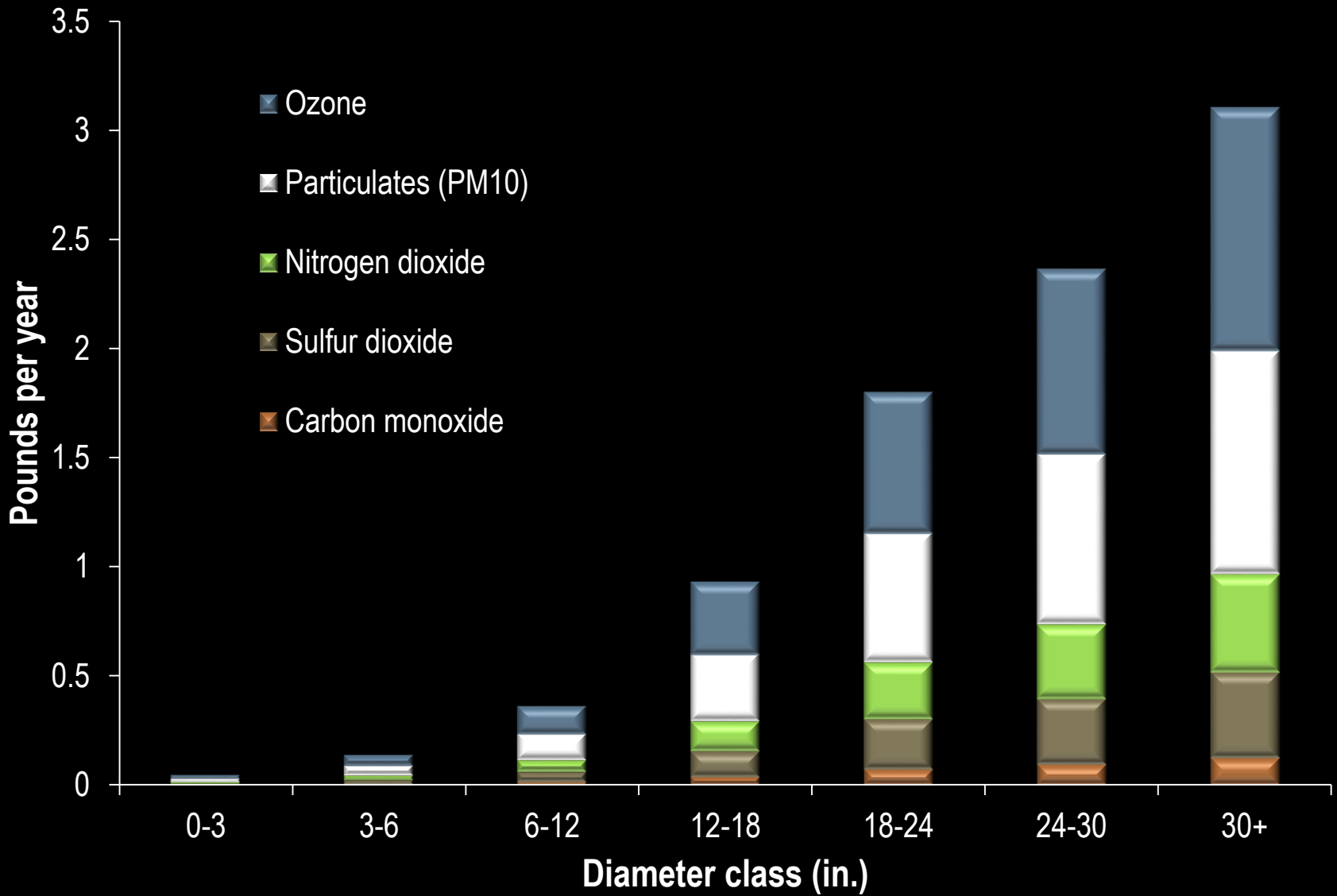
(Smith, 1990)

# Resuspension of Particles



Nowak, D.J., S. Hirabayshi, A. Bodine and R. Hoehn. 2013. Modeled PM2.5 removal by trees in ten U.S. cities and associated health effects. Environmental Pollution. 178: 395-402.

# Percent Air Quality Improvement

Pollution Removal Per Tree

# U.S. Air Pollution Removal and Health Effects

- 651,000 tonnes/year ($4.7 billion/year)

- U.S. Impact, reduction in incidences of:
  - ~580 deaths / year
  - ~580 emergency room visits / year
  - ~330,000 asthma exacerbations / year
  - ~485,000 acute respiratory symptoms / year

i-Tree

Nowak, D.J. S. Hirabayashi, E. Ellis and E.J. Greenfield. 2014. Tree and forest effects on air quality and human health in the United States. Environmental Pollution 193:119-129

Temperature / Air Effects

Removal

Emissions

E

# Volatile Organic Compounds: VOCs

- Natural Plant Compounds

    - essential oils (odor or essence of species)

    - toxic to insects and fungal pathogens

    - insect aggregation and disaggregation pheromones

    - plant allelopathy

- Common Types

    - isoprene (light and temperature dependent)

    - monoterpenes (temperature dependent)

# High Isoprene Emitting Genera

(>70 ug C / g leaf wt at 30°C and full sunlight)

*Casuarina* (beefwood)

*Eucalyptus* (eucalyptus)

*Liquidambar* (sweetgum)

*Nyssa* (black gum)

*Platanus* (sycamore)

*Populus* (poplar)

*Quercus* (oak)

*Robinia* (black locust)

*Salix* (willow)

# Maintenance Emissions

Temperature / Air Effects

Removal

Emissions

Energy Conservation

Winter Winds

N

Coniferous windbreaks protect house from cold winter winds.

Trees close to house on east and west protect against summer sun.

Trees on south side should be deciduous to permit winter sun while shielding the summer sun.

Avoid dense trees in the direction of summer winds that block desired cooling breezes.

Summer Winds

(Akbari et al., 1992)

Trees absorb CO$_2$ directly

Trees produce oxygen

Burning fossil fuel produces CO$_2$

Trees reduce CO$_2$ by curbing energy use

(Akbari et al., 1992)

# Air Temperature and Power Use



(Akbari et al., 1992)
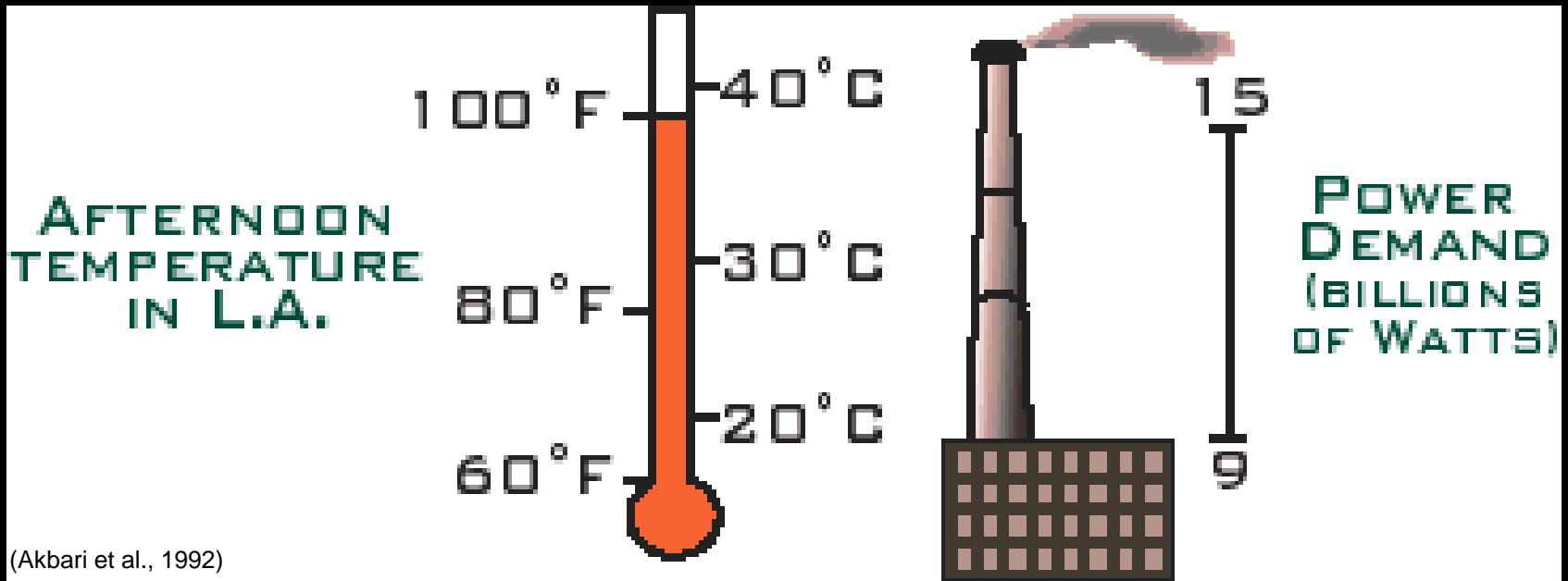
# Utility Emissions

| Emission | lbs per: | |
|---|---|---|
| | MMBtu | MWh |
| $NO_x$ | 0.1657 | 1.1216 |
| $SO_2$ | 0.4552 | 3.0811 |
| $CO_2$ | 179.7 | 1216.2 |
| $CH_4$ | 0.0225 | 0.0240 |
| $N_2O$ | 0.0022 | 0.0181 |
| $PM_{10}$ | 0.0019 | 0.4940 |
| $PM_{2.5}$ | 0.0014 | 0.3820 |
| CO | 0.0393 | 1.3270 |
| VOC | 0.0054 | 0.0575 |

# U.S. Building Energy Conservation



- 38.8 million MWh avoided annually

- 246 million MMBTU avoided annually

- Energy savings = $7.8 billion / year

- Avoided emissions = $3.9 billion / year

- 7.2% reduction in residential energy use

Nowak, D.J., N. Appleton, E. Ellis, E. Greenfield. 2017. Residential building energy conservation and avoided power plant emissions by urban and community trees in the United States. Urban Forestry and Urban Greening. 21: 158–165

**T**emperature reduction

**R**emoval

**E**missions

**E**nergy Conservation

# Los Angeles Basin Study

- Air quality impacts of increased urban tree cover may be locally positive or negative with respect to ozone

- Net basin-wide effect of increased urban tree cover is a decrease in ozone concentrations if the additional trees are low VOC emitters

Taha, 1996

# Northeastern United States

- Increased urban tree cover:
  - Reduced $O_3$ in urban areas (-1 ppb daytime)
  - Increased $O_3$ regionally (0.3 ppb)
  - Increased $O_3$ at night (loss of $NO_x$ scavenging of $O_3$)
- Physical effects (pollution removal, air temperature, wind speed, boundary layer height) are important
- Tree VOC emissions had no detectable effect on $O_3$



Nowak, Civerolo, Rao, Sistla and Luley, 2000
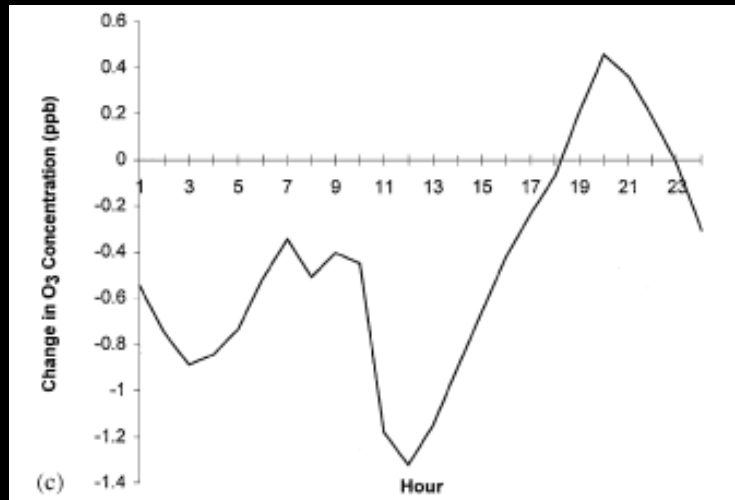
# Species Selection is Important

- Large leaf area; fine / small leaves
- High transpiration
- Textured / waxy leaves
- Low VOC
- Evergreen
- Suggested species:
  - Red maple
  - Northern hackberry
  - American beech
  - White ash
  - European larch
  - Tulip tree
  - Norway spruce
  - White pine
  - Black cherry
  - Basswood
  - Eastern hemlock
  - American elm

# Design is Important

# Management Recommendations

- Increase / sustain healthy trees & tree cover
- Sustain large, healthy trees
- Plant long-lived species
- Use low maintenance, urban adapted species
- Consider projected climate change
  - Temperature, precipitation, insects, diseases
- Minimize fossil fuel use
- Plant trees to cool air temperatures
  - Provide trees ample water
- Maximize use of low VOC species
- Plant evergreens
- Plant trees in energy conservation location and use wood for energy or products

Questions?

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