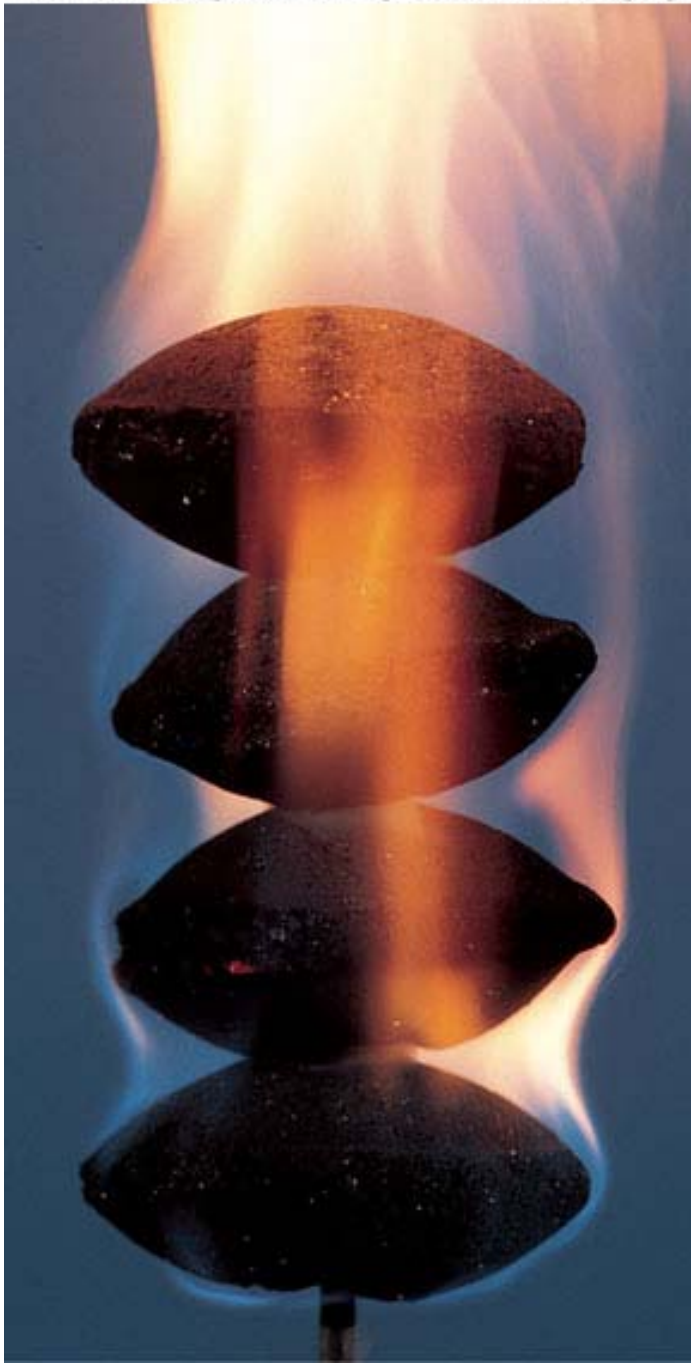
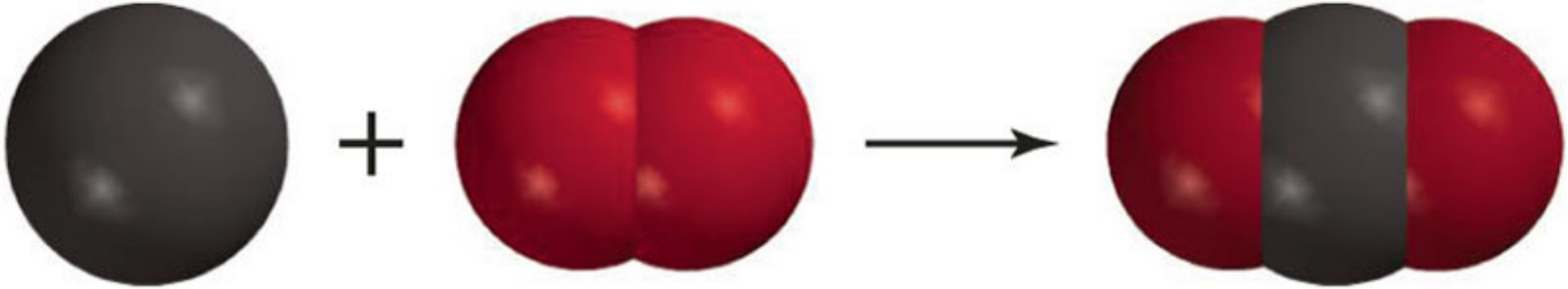
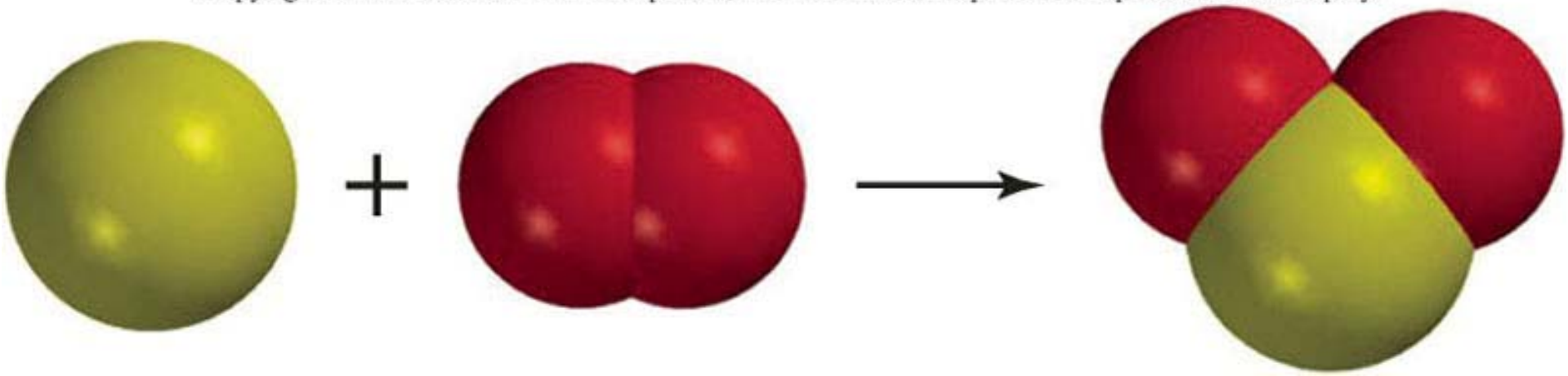


Combustion

- The rapid combination of oxygen with a substance.
- A major type of chemical reaction.
- When elemental carbon or carbon-containing compounds burn in air, oxygen combines with the carbon to form CO_2 or CO (or both).



$C(s) + O_2(g) \rightarrow CO_2(g)$



$S(s) + O_2(g) \rightarrow SO_2(g)$

Tbl.01.08

Table 1.8 Characteristics of Chemical Equations

Always Conserved
Identity of atoms in reactants = Identity of atoms in products
Number of atoms in reactants = Number of atoms in products
Mass of all reactants = Mass of all products
May Change
Number of molecules in reactants may differ from number of molecules in products
Physical states (*s*, *l*, or *g*) of reactants may differ from physical states of products

Balancing Chemical Reactions

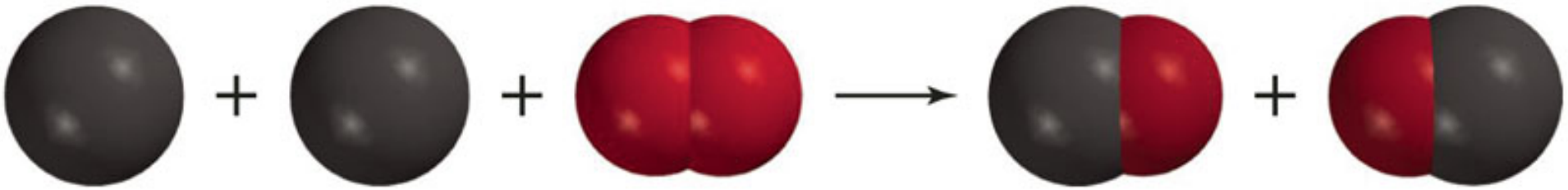
$$2\ C\ (s) + O_2\ (g) \rightarrow 2\ CO\ (g)$$

Now reactants : 2 atoms of carbon and 2 atoms of oxygen

Products : 2 atoms of carbon and 2 atoms of oxygen

Now the both the Oxygens and the Carbon match.

Fig.01.p035a



$$C + C + O_2 \rightarrow CO + CO$$

Your Turn 1.23

- Chemical Equations
  - Balance these equations and draw a representation of each using spheres. For the latter, both H_2O and NO_2 are bent molecules, with O and N, respectively, as the middle atom.

    a. $N_2 + O_2 \rightarrow NO$

    b. $N_2 + O_2 \rightarrow NO_2$

    c. $H_2 + O_2 \rightarrow H_2O$

Consider This - 1.25

A grandmother offered this advice to rid the garden of pesky caterpillars.

“Hammer some iron nails about a foot up from the base of your trees, spacing them every four to five inches.”

According to this grandmother, the iron nails convert the tree sap (a sugary substance containing carbon, hydrogen, and oxygen atoms) into ammonia (NH_3), a substance that caterpillars cannot stand.

Comment on the accuracy of grandma’s chemistry (allowing that the nails may still work, regardless of her explanation).

- A **hydrocarbon** is any chemical compound that consists only of carbon (C) and hydrogen (H).
  - They generally consist of a carbon backbone and atoms of hydrogen attached to that backbone.
- Methane (swamp/marsh gas or natural gas) is a hydrocarbon with one carbon atom and four hydrogen atoms: CH_4.
- Ethane is a hydrocarbon consisting of two carbon atoms held together with a single bond, each with three hydrogen atoms bonded: C_2H_6.
- Propane has three C atoms (C_3H_8) and so on (C_nH_{2n+2}).

- Liquid geologically-extracted **hydrocarbons** are referred to as *petroleum* (literally "rock oil") or *mineral oil*, while gaseous geologic hydrocarbons are referred to as *natural gas*.

- All are significant sources of fuel and raw materials as a feedstock for the production of organic chemicals and are commonly found in the Earth´s subsurface using the tools of petroleum geology.

- Oil reserves in sedimentary rocks are the principal source of hydrocarbons for the energy and chemicals industries.

- Hydrocarbons are of prime economic importance because they encompass the constituents of the major fossil fuels (coal, petroleum, natural gas, etc.) and biofuels, as well as plastics, waxes, solvents and oils.

http://en.wikipedia.org/wiki/Hydrocarbon

Combustion Reactions

- Hydrocarbons react with more than enough oxygen to yield carbon dioxide and water – this is **complete** combustion
  - Methane Combustion

  $CH_4 + ? O_2 \rightarrow ? CO_2 + ? H_2O$

Methane Combustion

$CH_4 + ? O_2 \rightarrow ? CO_2 + ? H_2O$

Only source of carbon is the CH_4.

How many atoms of carbon does one molecule of CH_4 contain?

ONE

SO products must contain how many atoms of carbon?

ONE

How many atoms of carbon does one molecule of CO_2 contain?

ONE

How many atoms of carbon does one molecule of H_2O contain?

NONE

$1 CH_4 + ? O_2 \rightarrow 1 CO_2 + ? H_2O$

Methane Combustion

$CH_4 + ? O_2 \rightarrow ? CO_2 + ? H_2O$

Only source of hydrogen is the CH_4.

How many atoms of hydrogen does one molecule of CH_4 contain?

FOUR

SO products must contain how many atoms of hydrogen ?

FOUR

How many atoms of hydrogen does one molecule of CO_2 contain?

NONE

How many atoms of hydrogen does one molecule of H_2O contain?

TWO

How many atoms of hydrogen does TWO molecule of H_2O contain?

FOUR

$1CH_4 + ?O_2 \rightarrow 1CO_2 + 2H_2O$

Methane Combustion

$1\ CH_4 + ?\ O_2 \rightarrow 1\ CO_2 + 2\ H_2O$

Now we balance the oxygen.

How many atoms of oxygen on the products side?

One molecule of CO_2 contains how many atoms of oxygen?

TWO

Two molecules of H_2O contain how many atoms of oxygen?

TWO

For a total of FOUR atoms on oxygen on the products side.

One molecule of O_2 contains how many atoms of oxygen?

TWO

So how many molecules of O_2 do we need to supply ALL of the oxygen necessary for the combustion of one molecule of CH_4?

$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$

Your Turn 1.26

- Combustion Reactions
  - Write the balanced combustion reaction for the following compounds.
    a. C_3H_8 - Propane
    b. C_8H_{18} - Octane

Combustion Reactions

- When there is insufficient oxygen available the chemical reaction will not go to completion.
- Instead of forming carbon dioxide the hydrocarbon will burn to produce carbon monoxide – this is **incomplete** combustion.

Incomplete Combustion Reactions

$2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$

But if there isn't enough O_2 then the following reaction competes:

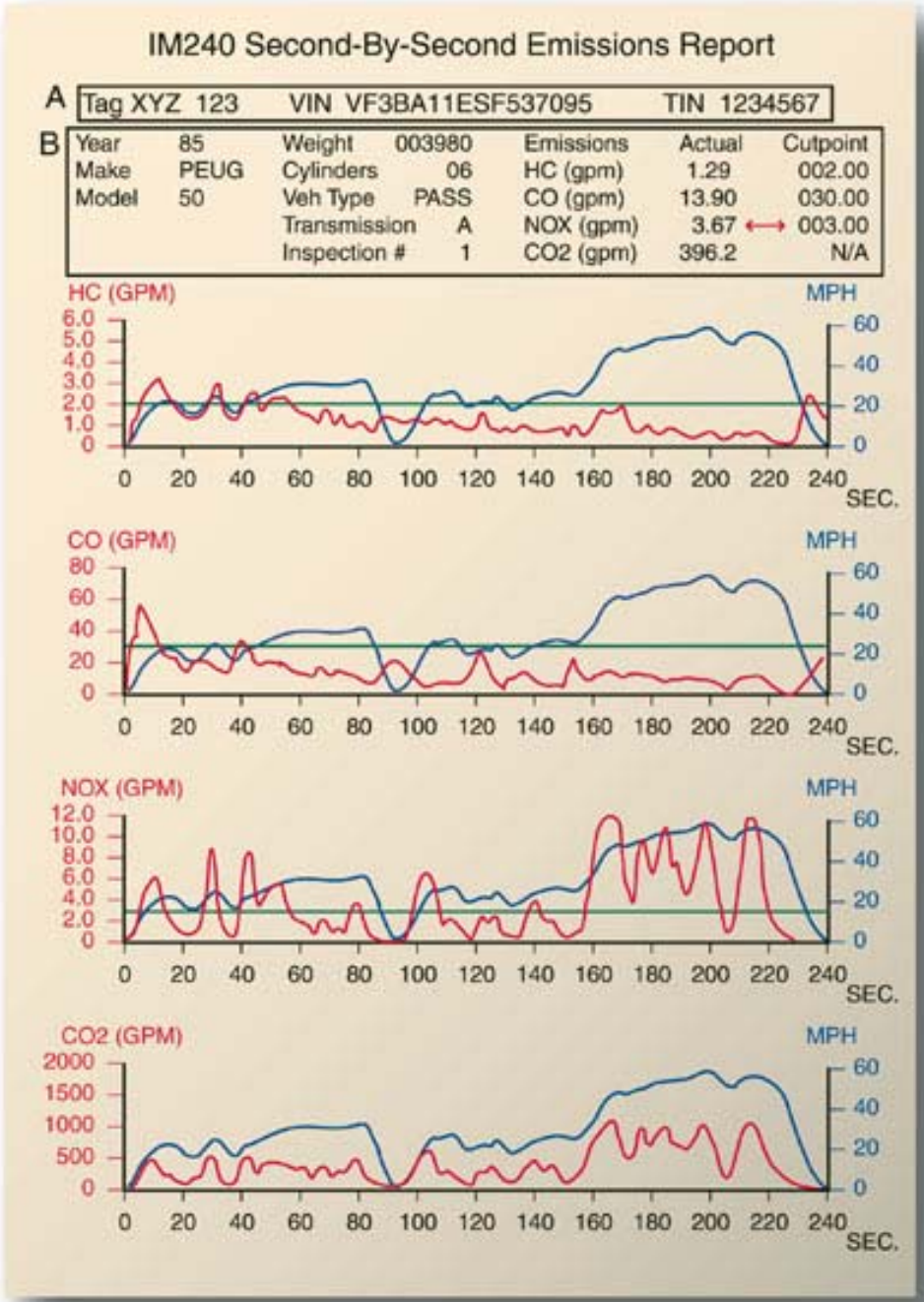
$2\ C_8H_{18} + 17\ O_2 \rightarrow 16\ CO + 18\ H_2O$

Incomplete Combustion Reactions

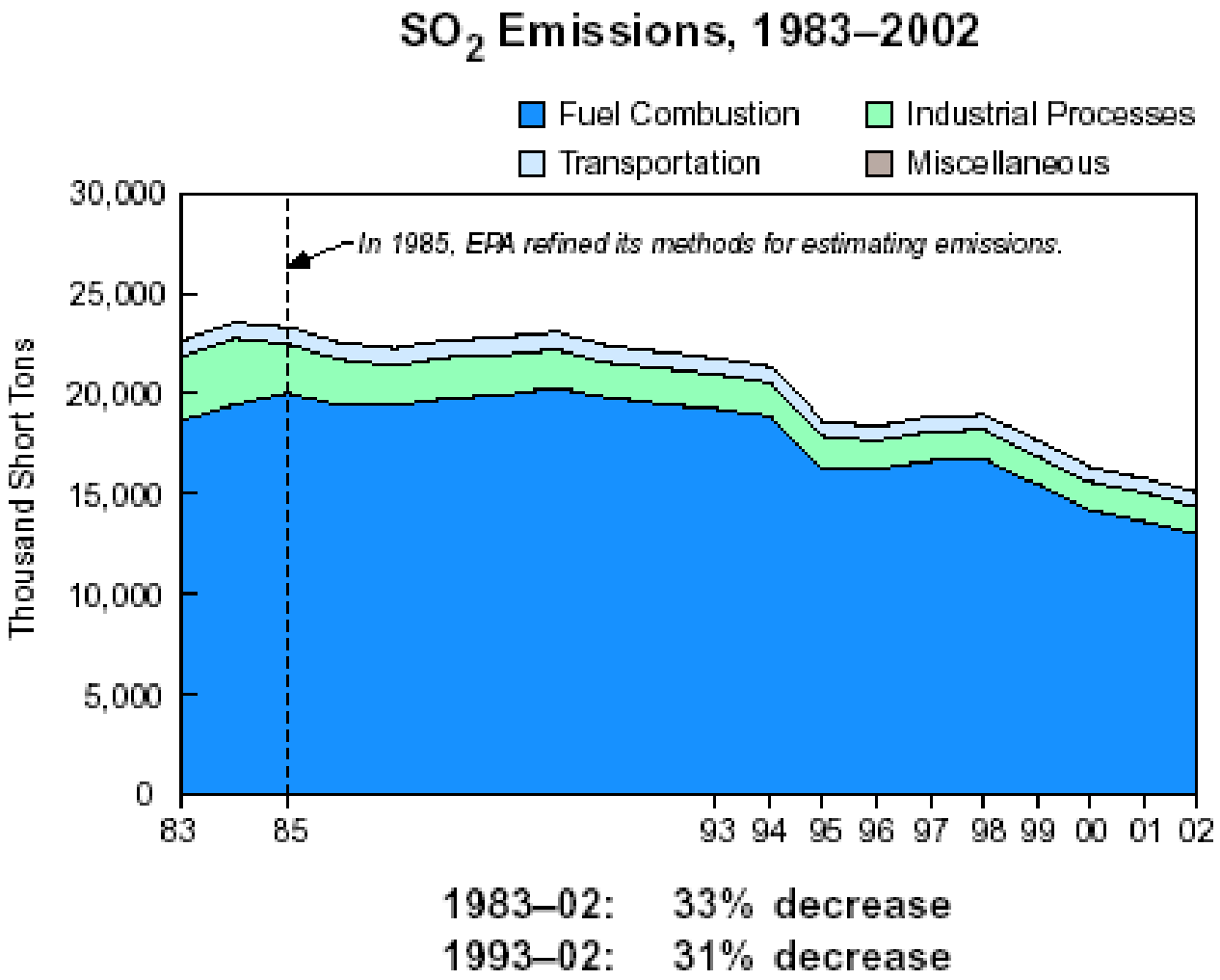
- CO is a criteria air pollutant and is monitored during auto emissions tests
- Mass monitors for CO, hydrocarbons and NO_x.
  - 310 CMR 60.02: AIR POLLUTION CONTROL FOR MOBILE SOURCES (http://vehicletest.state.ma.us/depregs.pdf)

TABLE A
Transient Loaded – Mode Emission Test Standards in Grams Per Mile

	Hydrocarbons	Carbon Monoxide	Oxides of Nitrogen
Cars			
1996 and newer	0.80	15.0	2.0
1991 – 1995	1.2	20.0	2.5
1984 – 1990	2.0	30.0	3.0



SO_2 Atmospheric Chemistry



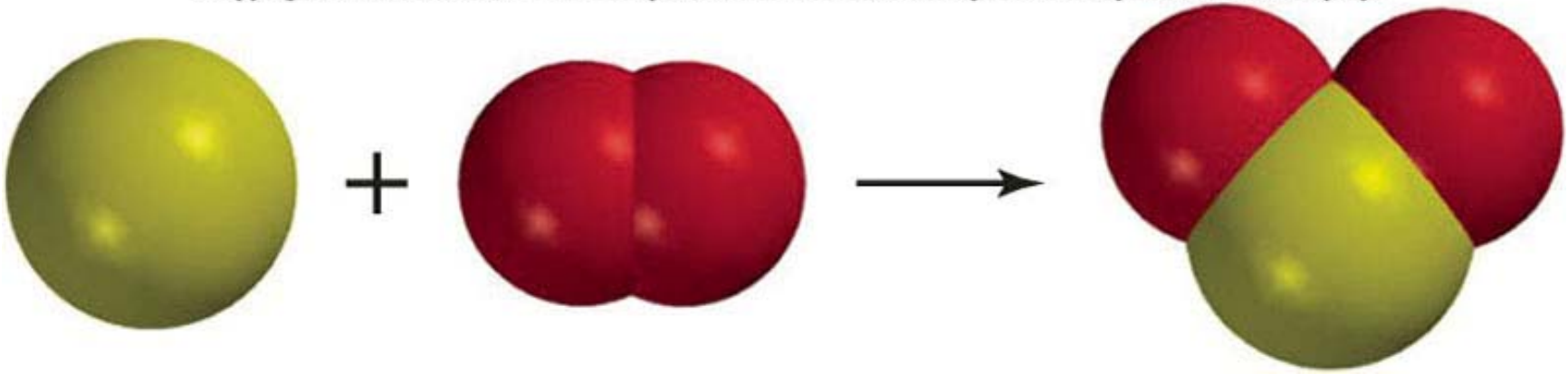
http://www.epa.gov/airtrends/sulfur2.html

SO_2 Atmospheric Chemistry

- **Coal** is a fossil fuel extracted from the ground by underground mining or strip mining.
- It is a readily combustible black or brownish-black sedimentary rock.
- It is composed primarily of **carbon** and **hydrocarbons**, along with assorted other elements, including **sulfur**.
- Coal remains an enormously important fuel and is the most common source of electricity world-wide.
- **In the United States, for example, the burning of coal generates over half the electricity consumed by the nation.**

SO_2 Atmospheric Chemistry

- Most coals contain 1 – 3 % sulfur
- When coal is burned the following reaction occurs



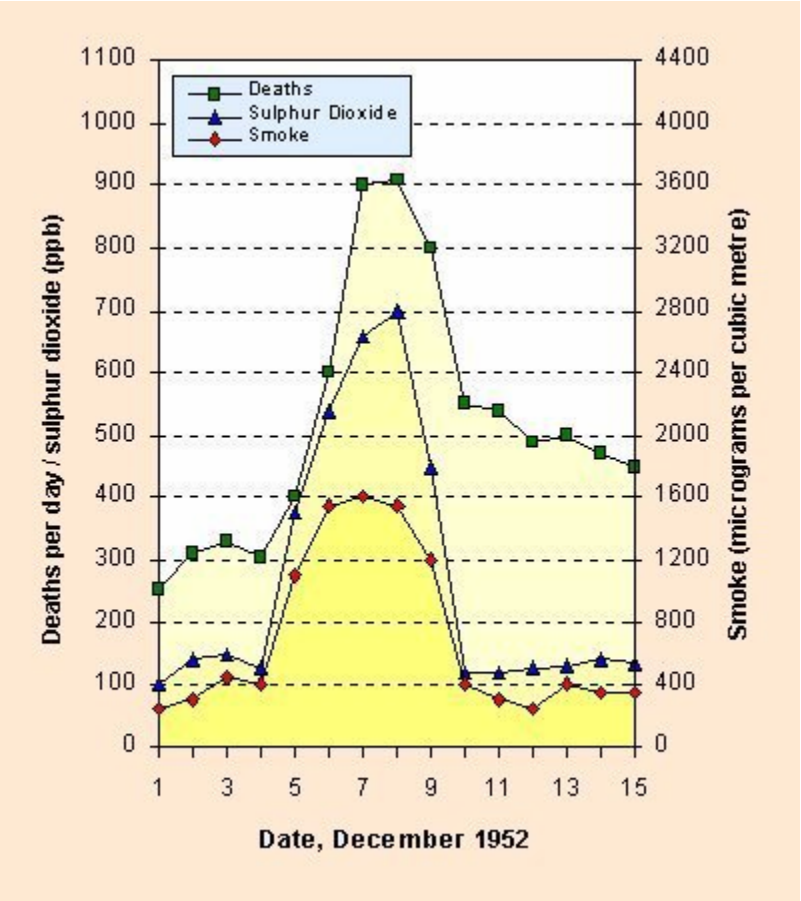
$S\ (s) + O_2\ (g) \rightarrow SO_2\ (g)$

The London Smog Disaster of 1952

http://www.portfolio.mvm.ed.ac.uk/studentwebs/session4/27/greatsmog52.htm

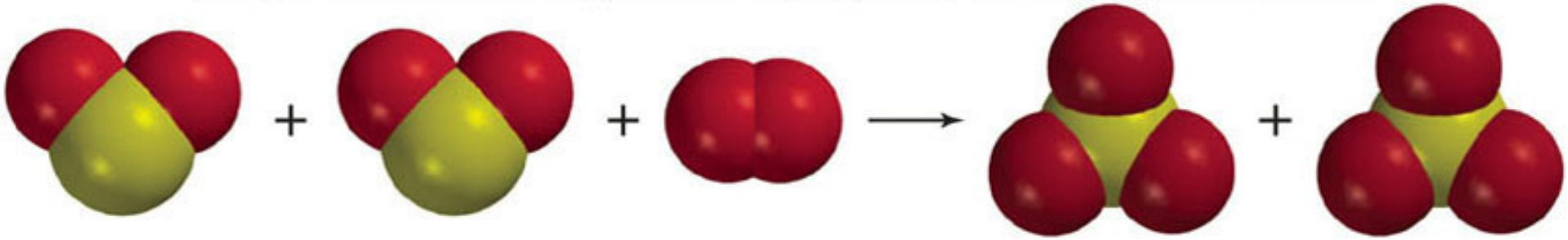
During the four days between the 4 and 8 December 1952 smoke measurements taken at the National Gallery in London suggest that the PM 10 concentration reached 14mg/m^3 which was 56 times the level normally experienced at the time and the levels of sulfur dioxide in the air increased by 7 fold peaking at around 700ppb.

Research has shown that the adverse effects of the smog were not as much due to the original pollutants- the soot and sulfur dioxide- as to the acidity of the air. Breathing in acid aerosol irritated the bronchial tubes, which produced large amounts of mucus and became inflamed. While nobody measured the acidity at the time, the pH was probably at least as low as 2.



SO_2 Atmospheric Chemistry

- Once emitted, SO_2 can react further with oxygen to form sulfur trioxide:



$$2SO_2 + O_2 \rightarrow 2SO_3$$

SO_2 Atmospheric Chemistry

- **Aerosols** – consist of particles, both liquid and solid, that stay suspended in air rather than settle out.
  - Smoke
  - Fog
  - Smog
- Within wet aerosols SO_3 reacts with water

$$H_2O + SO_3 \rightarrow H_2SO_4$$

- H_2SO_4 is sulfuric acid

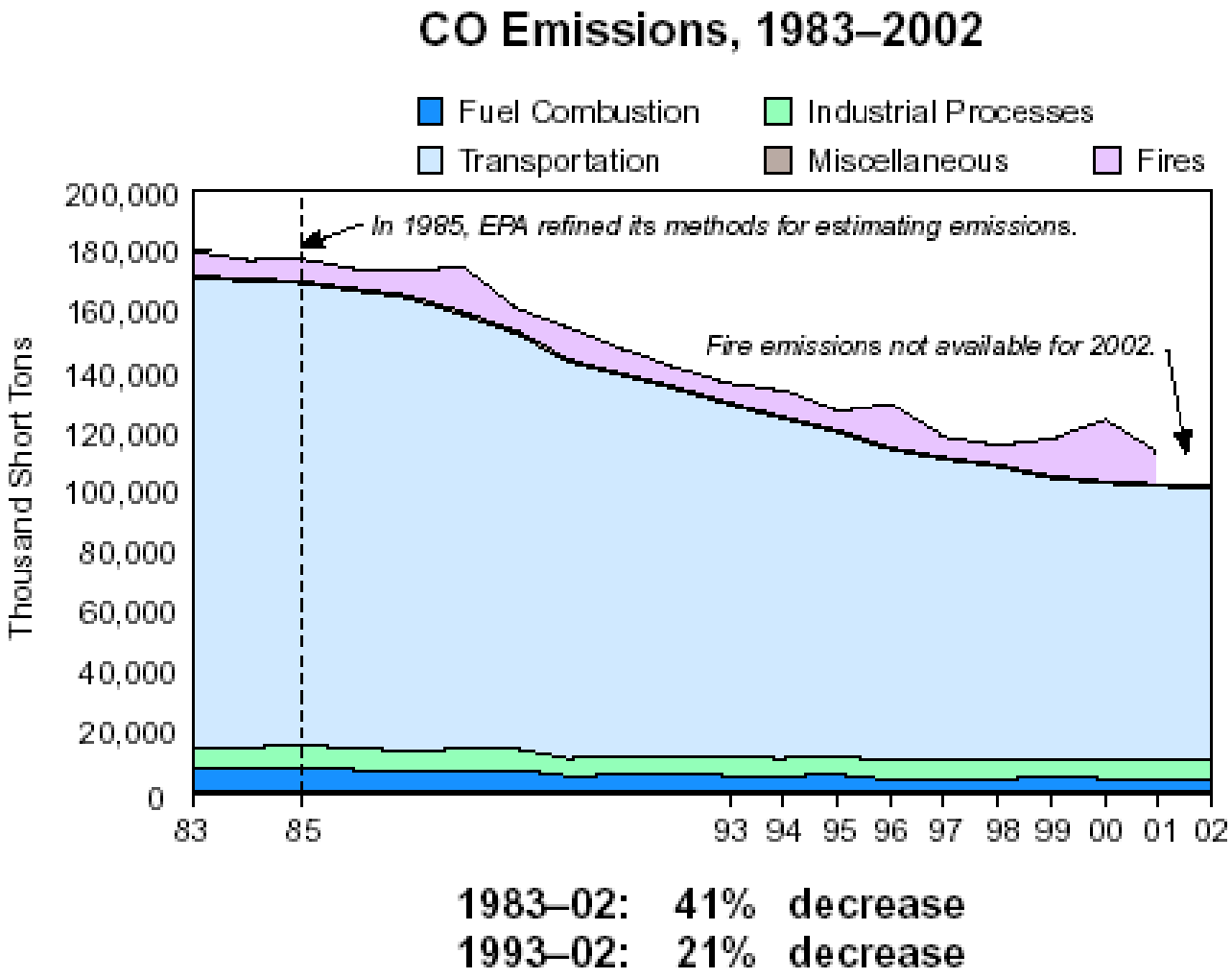
Your Turn 1.29

- SO_2 from the mining industry – Burning coal is not the only source of SO_2. The smelting of ores to produce metals is another source. For example, silver and copper metal can be produced from their sulfide ores. Write balanced chemical equations for the following statement.
  - Copper sulfide (CuS) is heated with oxygen gas to produce copper metal and sulfur dioxide.

Auto Emissions

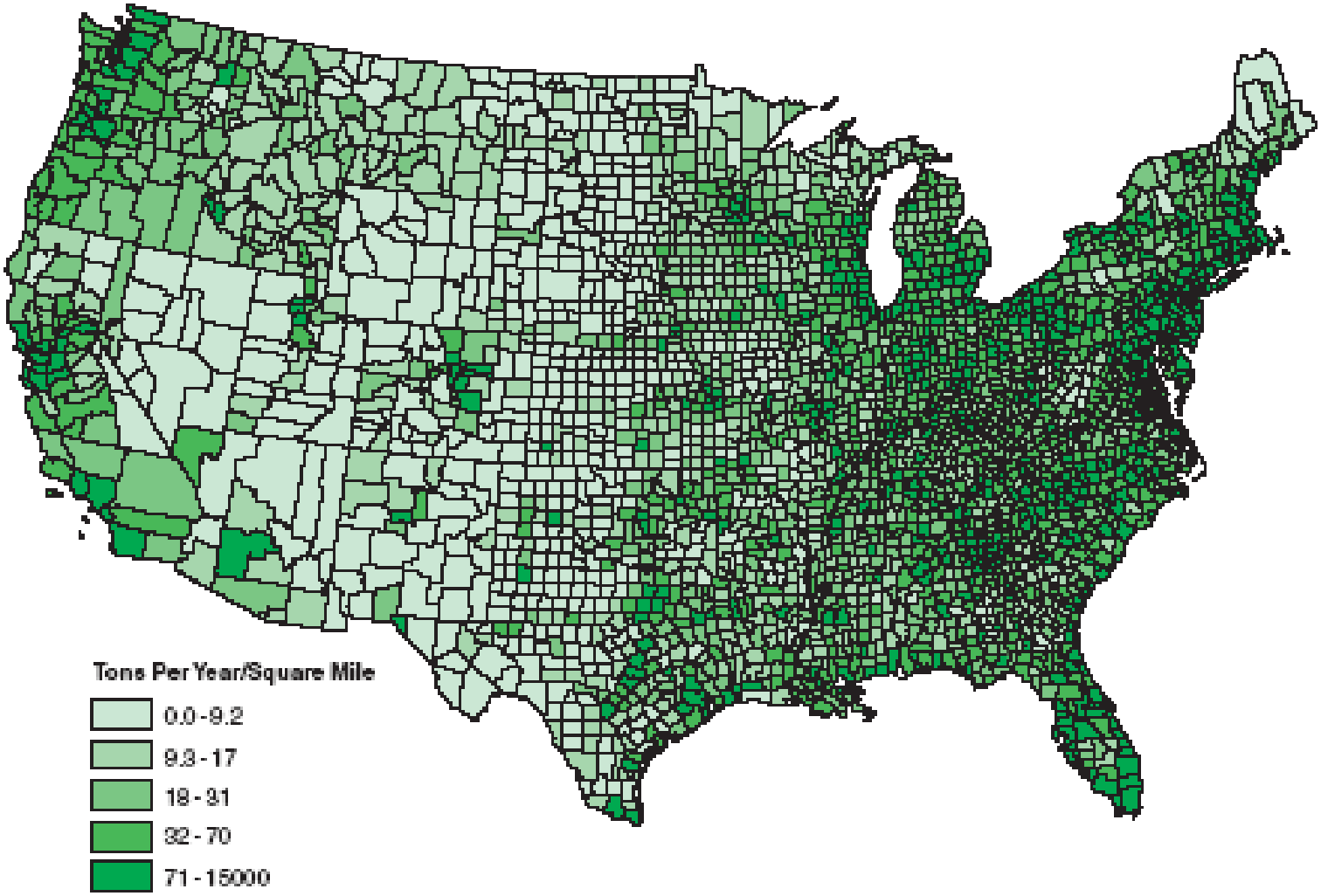
- CO (carbon monoxide)
  - Cars account for about 60% of all CO emissions nationwide
- VOCs (volatile organic compounds)
  - Volatile – a compound that readily passes into the vapor phase.
  - Organic compound – a compound that contains mainly carbon and hydrogen
  - VOCs – the vapors of incompletely burned gasoline molecules or fragments of these molecules
- NOx – the oxides of nitrogen
- Lead – if the additive tetraethyl lead is used in the gasoline to reduce “knocking”

CO Atmospheric Chemistry



http://www.epa.gov/airtrends/carbon2.html

CO Atmospheric Chemistry



Density map of 2001 CO emissions, by county.

http://www.epa.gov/airtrends/carbon2.html

CO Atmospheric Chemistry

- Reduction in CO emissions
  - Catalytic converters – devices installed in the exhaust stream to reduce emissions
    - Catalyst – a chemical substance that participates in a chemical reaction and influences its speed without undergoing permanent change

$$2CO + O_2 \xrightarrow[converter]{catalytic} 2CO_2$$

$$2NO \xrightarrow[converter]{catalytic} N_2 + O_2$$

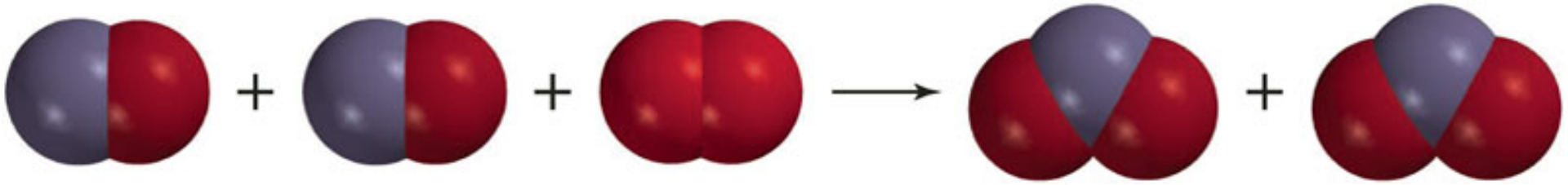
NO_x Atmospheric Chemistry

- Under very high temperature conditions, the normally stable nitrogen and oxygen in the air will react to form nitrogen monoxide

$N_2 + O_2 \rightarrow NO + NO$

NO_x Atmospheric Chemistry

- Nitrogen monoxide is very reactive and will react with oxygen to create nitrogen dioxide



$NO + NO + O_2 \rightarrow NO_2 + NO_2$

NO_x Atmospheric Chemistry

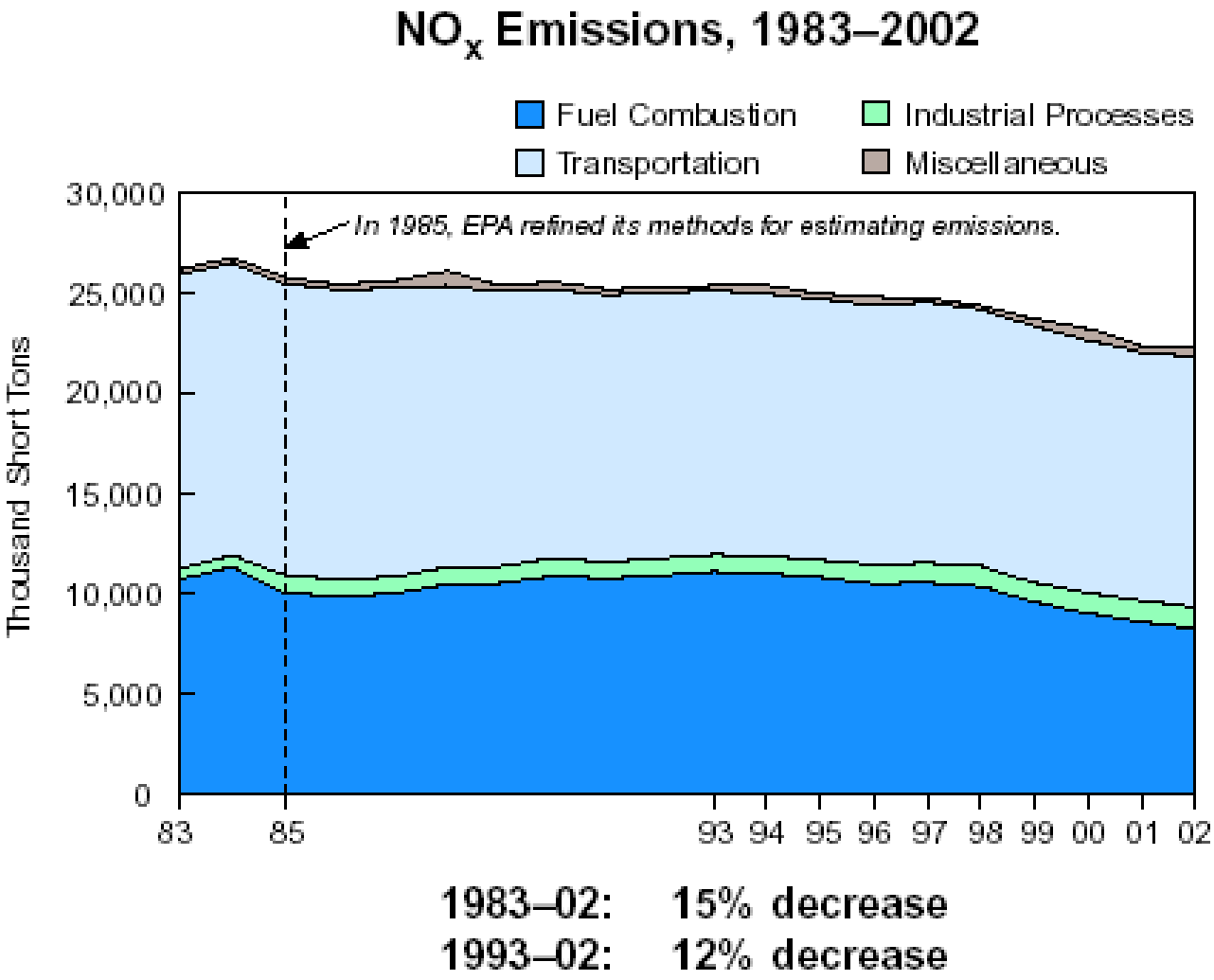
- The reaction between NO and O_2 is not the only source of NO_2 in the atmosphere.
- Complicated chain of reactions involving VOCs (which are prevalent in polluted air and are also being released by auto emissions) and hydroxyl radicals (•OH)

$$VOC + \bullet OH \rightarrow A$$

$$A + O_2 \rightarrow A'$$

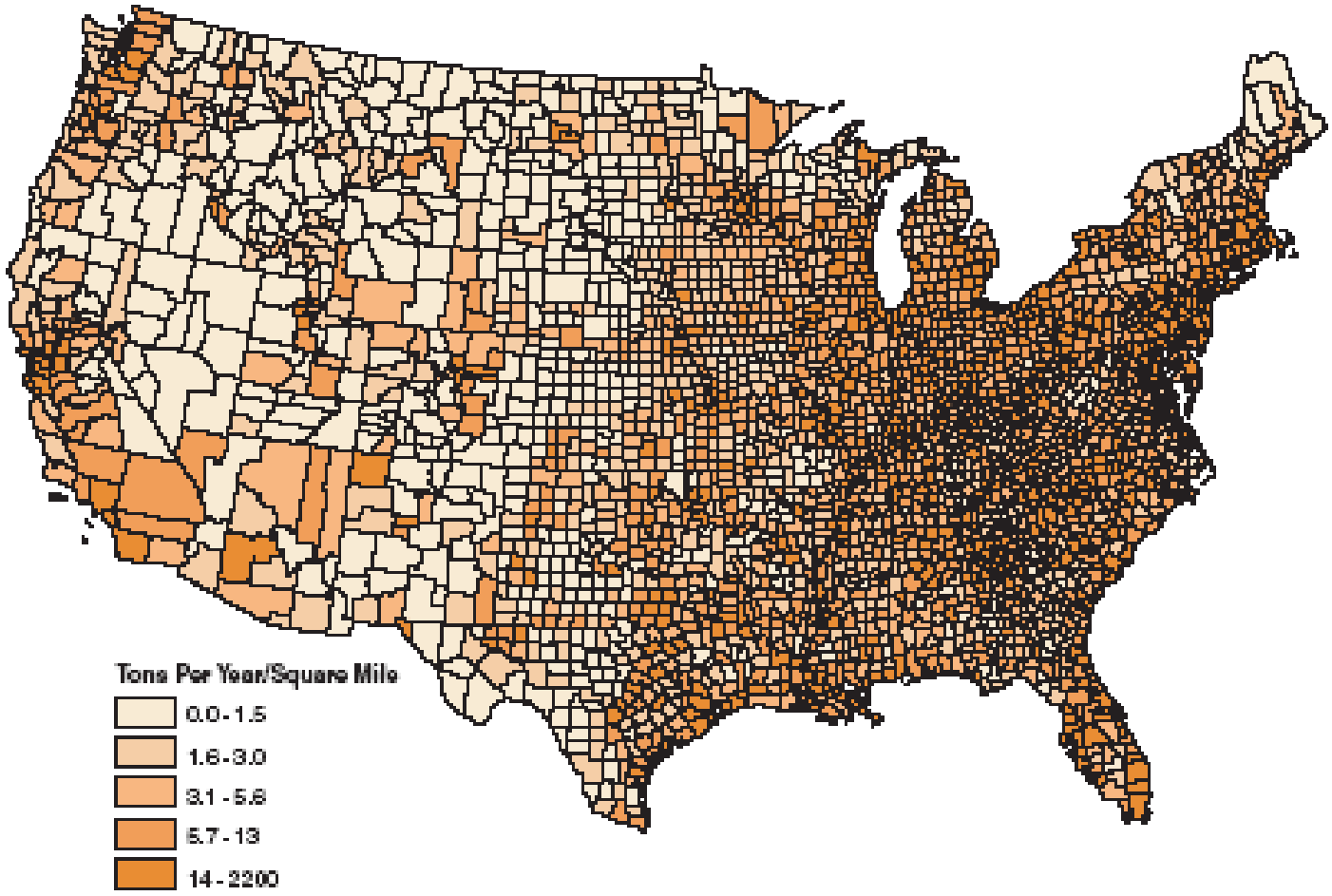
$$A' + NO \rightarrow A'' + NO_2$$

NO_x Atmospheric Chemistry



http://www.epa.gov/airtrends/nitrogen2.html

NO_x Atmospheric Chemistry



Density map of 2001 NO2 emissions, by county.

http://www.epa.gov/airtrends/nitrogen2.html

Ozone: Secondary Pollutant

- **Ozone** (O_3) is an allotrope of oxygen.
- Ozone is a highly corrosive, poisonous substance and a common pollutant. It has a sharp, pungent odor.
- It is present in low concentrations throughout the Earth's atmosphere.
- It is also formed from O_2 by electrical discharges such as lightning, and by action of high energy electromagnetic radiation.
- Some kinds of electrical equipment generate levels of ozone that a human can easily smell.
  - This is especially true of devices using high voltages, such as television sets and photocopiers.
  - Electric motors using brushes can generate ozone from repeated sparking inside the unit.
  - Large motors, such as those used by elevators or hydraulic pumps, will generate more ozone than smaller motors.