Air Pollution – 3

- Emission Controls

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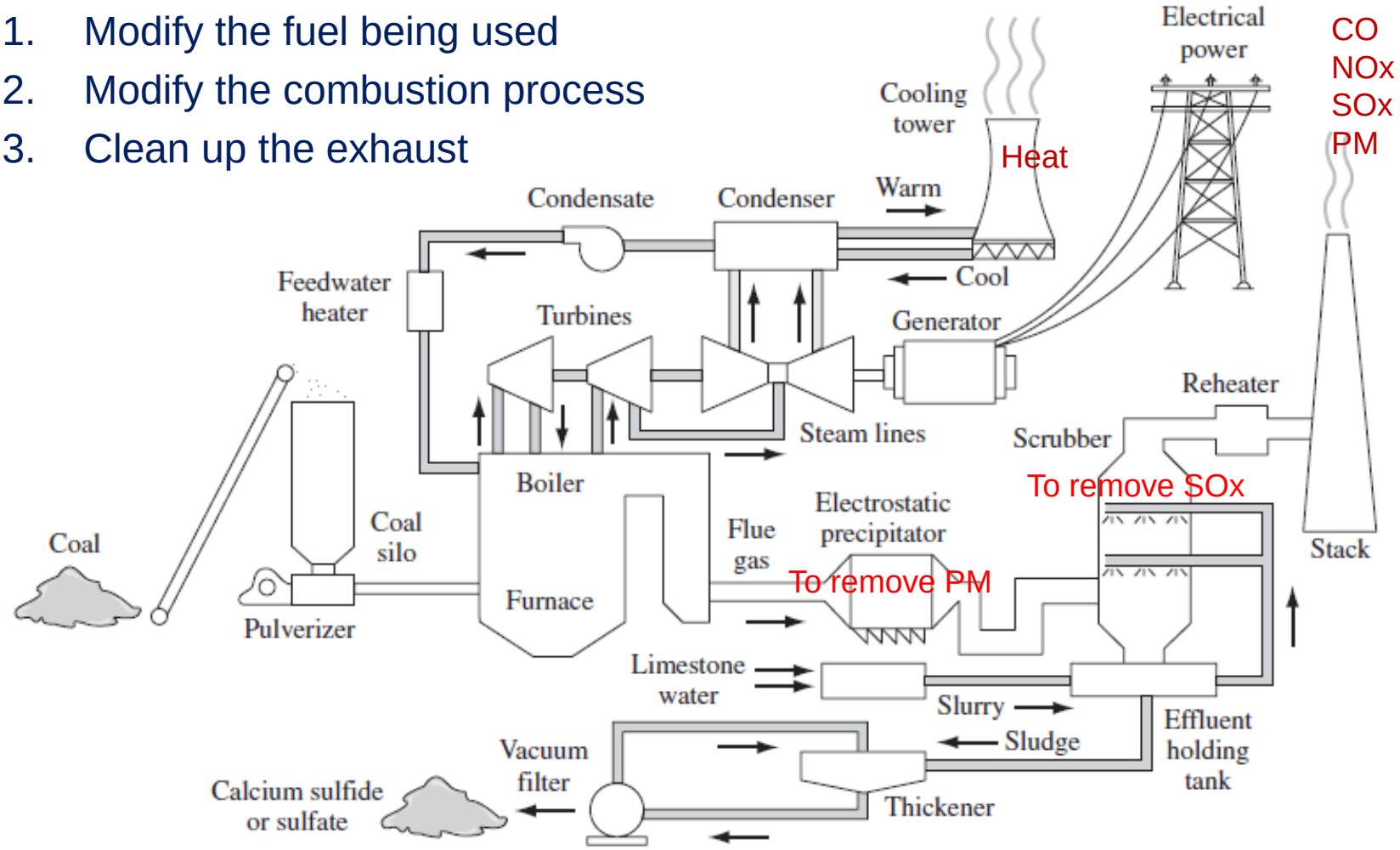
Emission Controls

- **Recall the six criteria pollutants:**
  - CO
  - NO_x
  - SO_x
  - O_3
  - Pb
  - PM

- For SO_2, NO_x, CO, O_3, PM, control emissions from:
  - Industrial sources
  - Motor vehicles

Emission Controls

- **Industrial sources: Coal fired power plants**
  - Methods of control:
    1. Modify the fuel being used
    2. Modify the combustion process
    3. Clean up the exhaust



Fuel Switching

√ Fuel switching

- Use a fuel with a lower sulfur content
- Mix high and low sulfur coals
  - 0.2 % coal results in ~0.4 lb-SOx/MBTU
  - 5.5 % results in ~10 lb-SOx/MBTU
  - Regulation for new sources is 1.2 lb-SOx/MBTU
- Techniques being developed to clean coal or remove sulfur prior to combustion
  - e.g., Microbial desulfurization
- Current tendency: replace coal with natural gas (shale gas)

Changes to Combustion Process

√ Changes to combustion process

- **Fluidized bed combustion**
  - Limestone (calcium carbonate) is introduced
  - Reacts with sulfur oxides to form gypsum $(CaSO_4)_{(s)}$
  - SO_2 emissions reduced by up to 90%
  - Called fluidized bed combustion because coal/limestone mixture is suspended by fast moving air injected in the bottom
  - Particles contact boiler tubes→ efficient heat transfer
  - Lower temperatures, less thermal NO_x formed

- **Low NO_x combustion**
  - NO_x formed from N in fuel, and from the combination of N_2 and O_2 at high temperatures (thermal NO_x)
  - To control thermal NOx, modify temperature and air
  - Older equipment modified for low excess air combustion. With little excess air, O_2 not available to form NO_x (15 to 50% reduction)

Treating Exhaust or Flue Gas

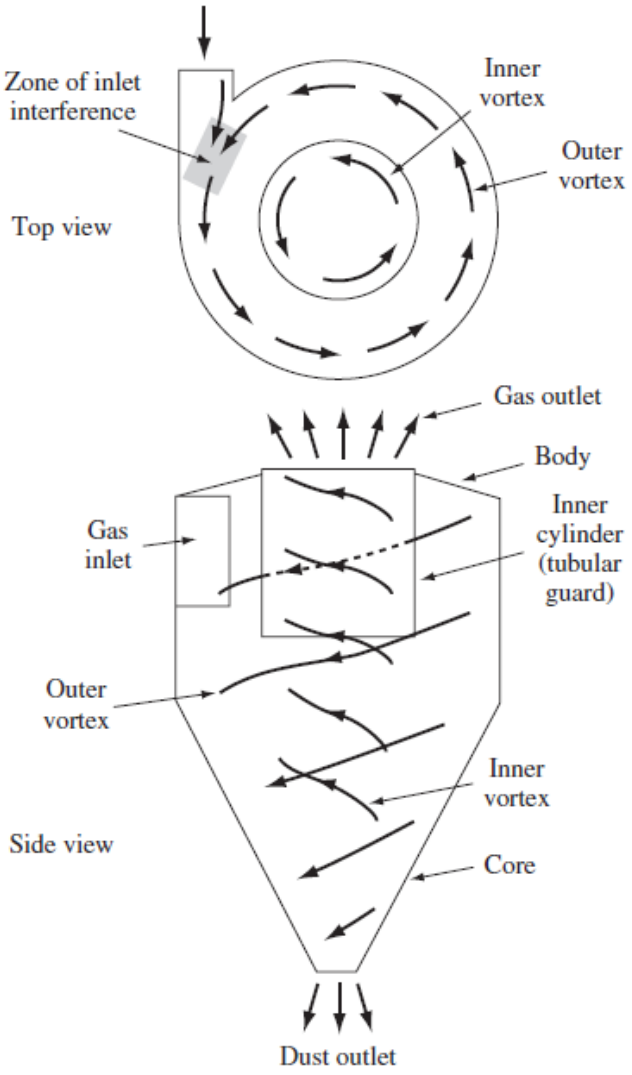
√ Treating Exhaust or Flue Gas

- Remove SO_2 using flue gas desulfurization or scrubbing
- Most US scrubbers use a wet process that produces sludge that is disposed of or thrown away
- Wet slurry of limestone ($CaCO_3$) sprayed into flue gas
- SO_2 is absorbed, $CaSO_3$ is formed and removed
- These scrubbers are about 90% efficient, but there are a number of drawbacks
  - High cost and energy consumption, high water usage and waste production, etc.

PM Removal

√ Cyclones

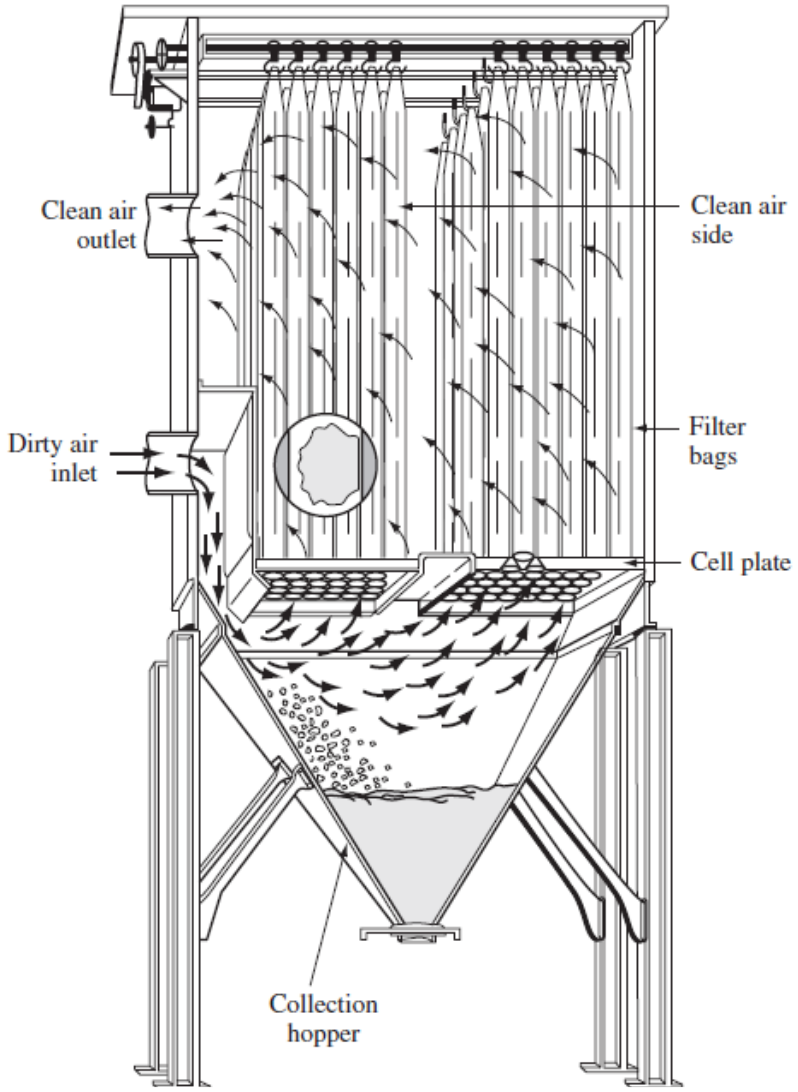
- Gas and particles enter and must spin through chamber
- Large particles are carried to walls by centrifugal force (collide and slide down)
- Very efficient for larger particles (90% for > 5 μm)
- Not effective for smaller particles
- Relatively inexpensive and maintenance free



PM Removal

√ Baghouses

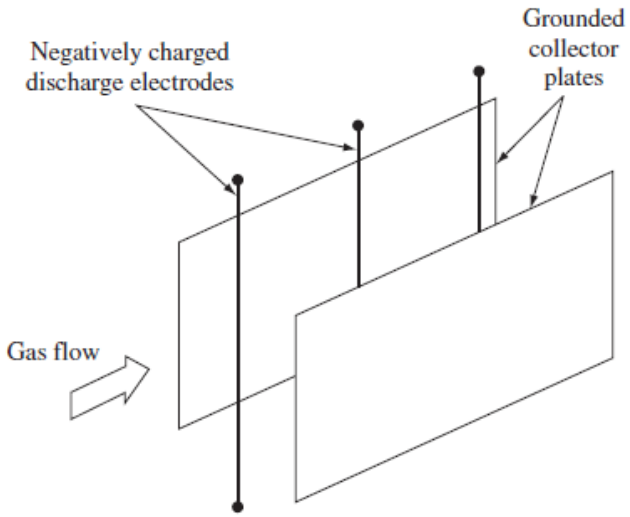
- Particles forced through fabric filter bags
- Fabric itself filters some, but the layer of dust on the bag does most of the filtering
- Very effective for particles of 1 μm, capable of collecting some 0.01 μm particles



PM Removal

√ Electrostatic precipitator

- Use a very strong electric field (100,000 V) to ionize air/gas
- The ionized gas or air acquires a negative charge that attaches to particles passing by. The particles are then charged and become susceptible to the electric field, and are collected on grounded plates
- Very effective, even for submicron particles
- Little pressure drop, but expensive to operate and maintain



Motor Vehicles

√ Motor vehicles

- Over 1 billion cars worldwide (since 2010)
  - Consume over 1 billion gallons of fuel each year
  - Produce more than half of CO and 1/3 of NO_x

- Many advances made in the 70's
  - Legislation required a 90% reduction in emissions
  - Oil embargo of 1973 resulted in a delay in standards (afraid of reduced fuel economy)

- **Standards are enforced on a 'fleet average' for each car manufacturer.**

- Similarly, we can meet these standards by changing:
  1. Fuels
  2. Combustion process
  3. Treating exhaust gas

Fuel Switching

√ Switching fuel

- Sulfur is in diesel fuels, and there are efforts to reduce the S content (e.g., mix with biodiesel in Brazil)
- Motivation to switch fuels → identify future fuel source

√ Fuel alcohols

- Higher octane rating – more power
- Complete combustion – less HC and CO
- Lower flame temperature – less NO_x

However,

- Higher emissions of formaldehyde
- Lower volatility – hard cold starts
- Burns without a flame (add colorants)
- Lower energy content
- Huge water footprint (high water requirements and water pollution by fertilizers during crop agriculture) and food prices

Fuel Switching

√ Fuel Alcohols

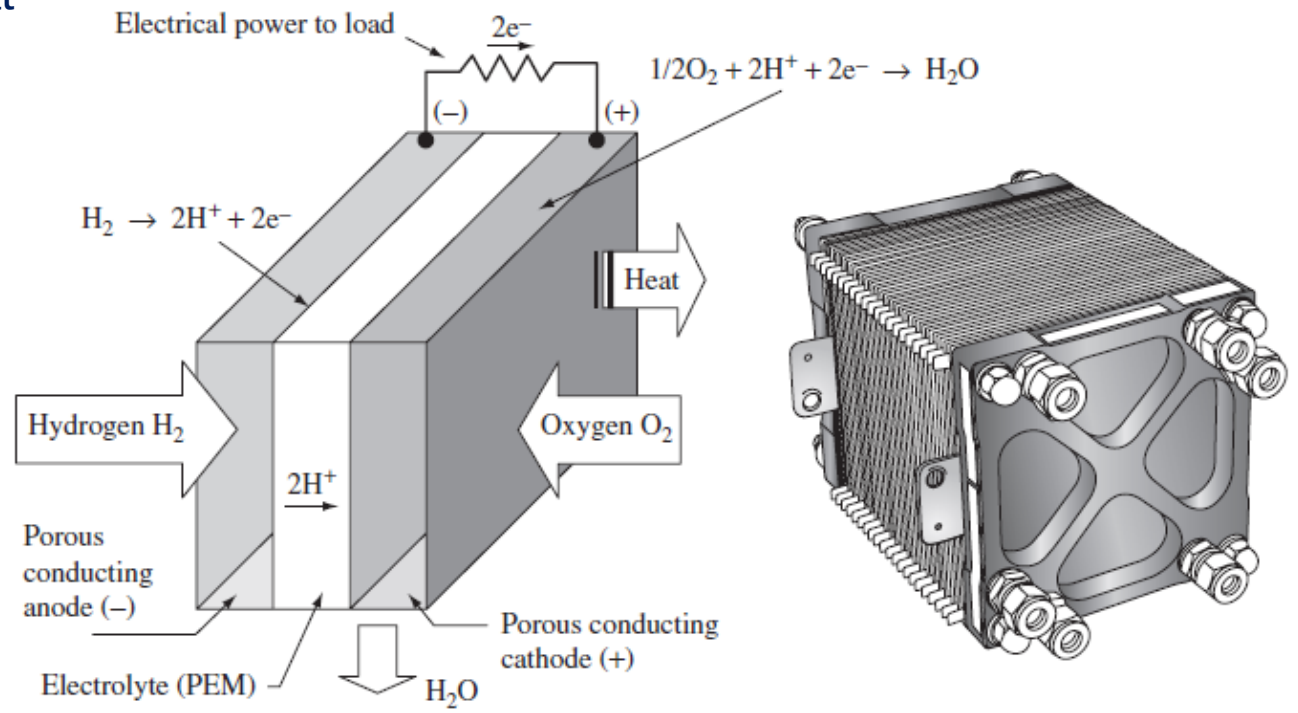
- Some mixtures are used:
  - Ethanol blends
  - Methanol blends (85% methanol)

Source: boiseguardian.com

Fuel Cells

√ Fuel Cells

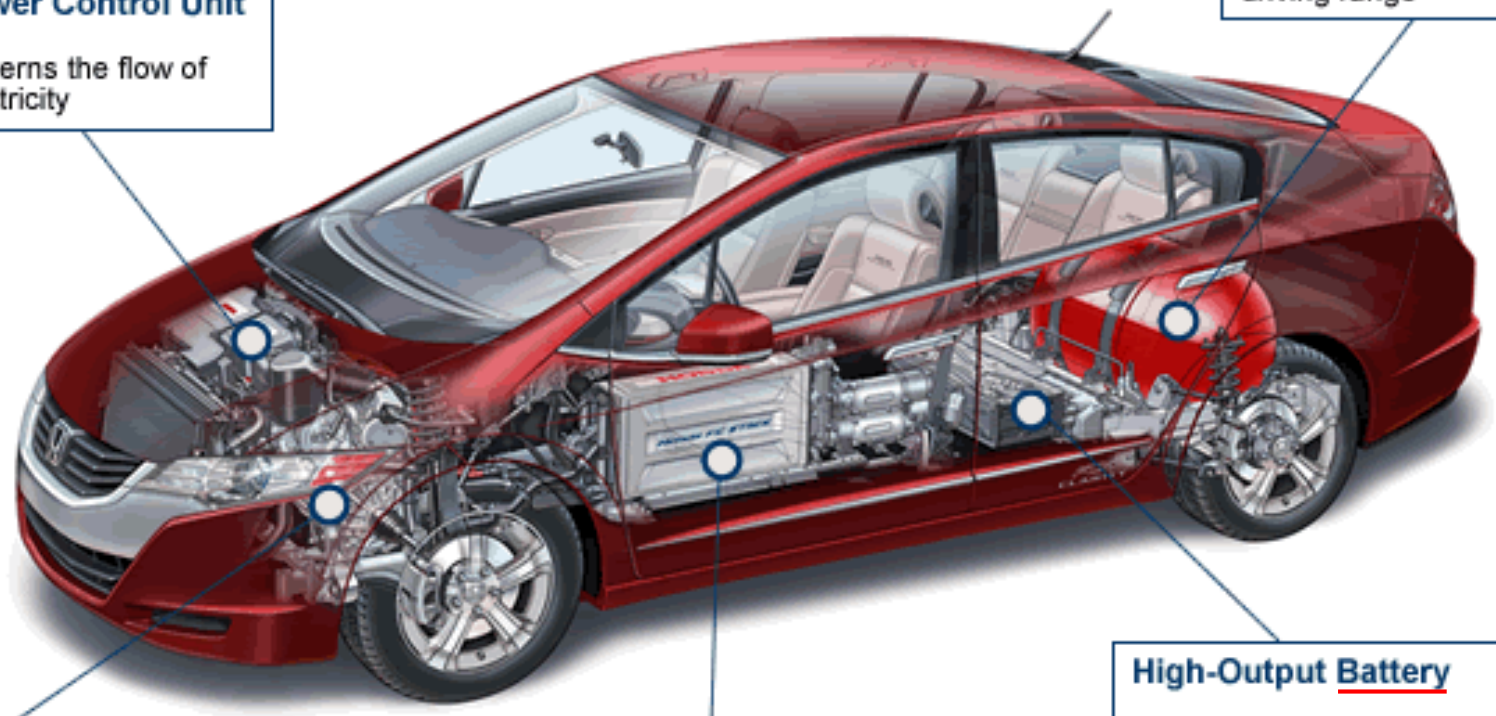
- In principle, fuel cells do not run out/require recharging
- It will produce energy in the form of electricity and heat as long as fuel is supplied.
- Consists of two electrodes placed around an electrolyte
- O_2 passes over one electrode and H_2 over the other, generating electricity, water, and heat



(a) A single cell

(b) A fuel-cell stack

Fuel Cells



Hydrogen Storage Tank

Stores hydrogen gas compressed at extremely high pressure to increase driving range

Power Control Unit

Governs the flow of electricity

Electric Motor

Propels the vehicle much more quietly, smoothly, and efficiently than an internal combustion engine and requires less maintenance

Fuel Cell Stack

Converts hydrogen gas and oxygen into electricity to power the electric motor

High-Output Battery

Stores energy generated from regenerative braking and provides supplemental power to the electric motor

Vehicle image courtesy of American Honda Motor Co., Inc.

Changes to Combustion Process

√ Changing the Combustion Process

- Internal combustion engines:
  - Four stroke engine
  - Most vehicles have 4, 6, or 8 cylinders
- Design details of the cylinder and compression affect hydrocarbon emissions, efficiency of combustion, power.
- From stoichiometry, we can determine how much air is needed for the complete combustion of gasoline
- When there is more fuel than this stoichiometric ratio, the mixture is rich.
  - High CO & HC emissions from incomplete combustion
- If more air is provided, the mixture is lean.
  - More NO_x may form
- Before catalytic converts, cars ran slightly rich

Ideal Air to Fuel (A/F) Ratio

- Determine the ratio of air to fuel (by mass) required for complete combustion of gasoline

Air

$$C_7H_{13} + 10.25O_2 + 38.54N_2 \rightarrow 7CO_2 + 6.5H_2O + 38.54N_2$$

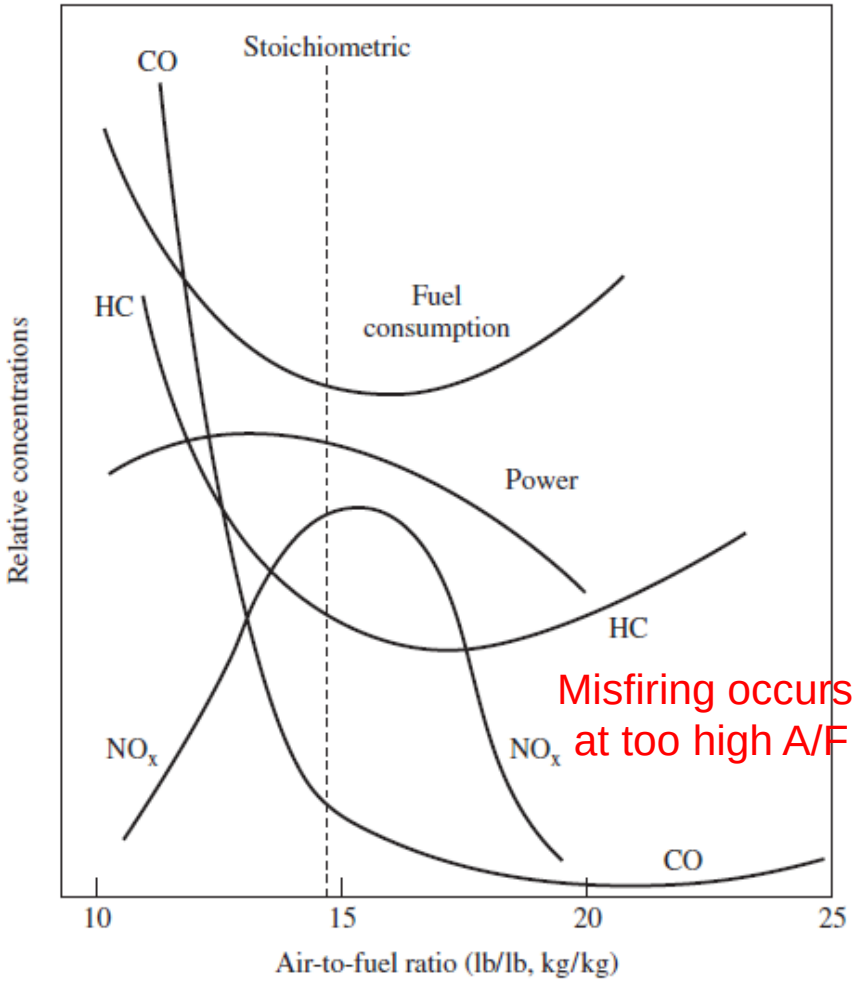
Find the masses of each constituent:

- 1 mol C_7H_{13} = 7 x 12 + 13 x 1 = 97 g
- 10.25 mol O_2 = 10.25 x 2 x 16 = 328 g
- 38.54 mol N_2 = 38.54 x 2 x 14 = 1079 g

$$\frac{Air}{Fuel} = \frac{328+1079}{97} = 14.5 \frac{g\ \text{air}}{g\ \text{fuel}} or \frac{lb\ \text{air}}{lb\ \text{fuel}}$$

Ideal Air to Fuel (A/F) Ratio

- Max efficiency slightly above $(A/F)_{stoich}$
- Diesel engines require more air (15 – 100 A/F)
- High A/F →
  - Low NO_x
  - Low CO
  - High HC
- Cars run at high NO_x region



Treating Exhaust or Flue Gas

√ Treating the Exhaust

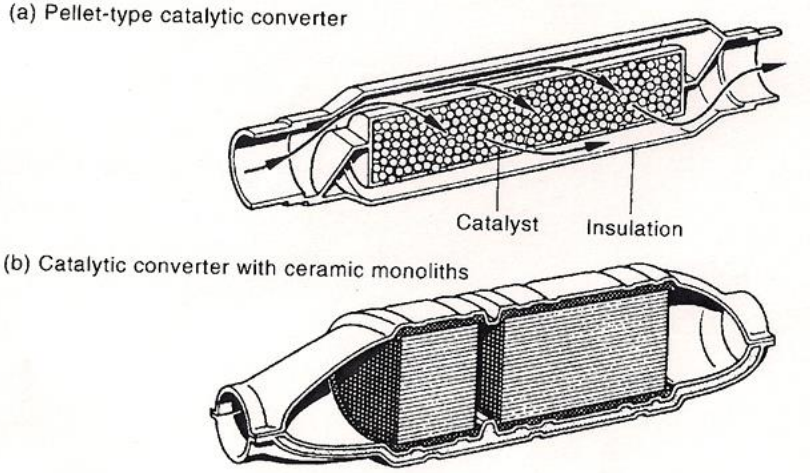
- To reduce NO_x, send exhaust gas back through combustion chamber
  - It absorbs heat, reduces temperature, thereby reducing NO_x

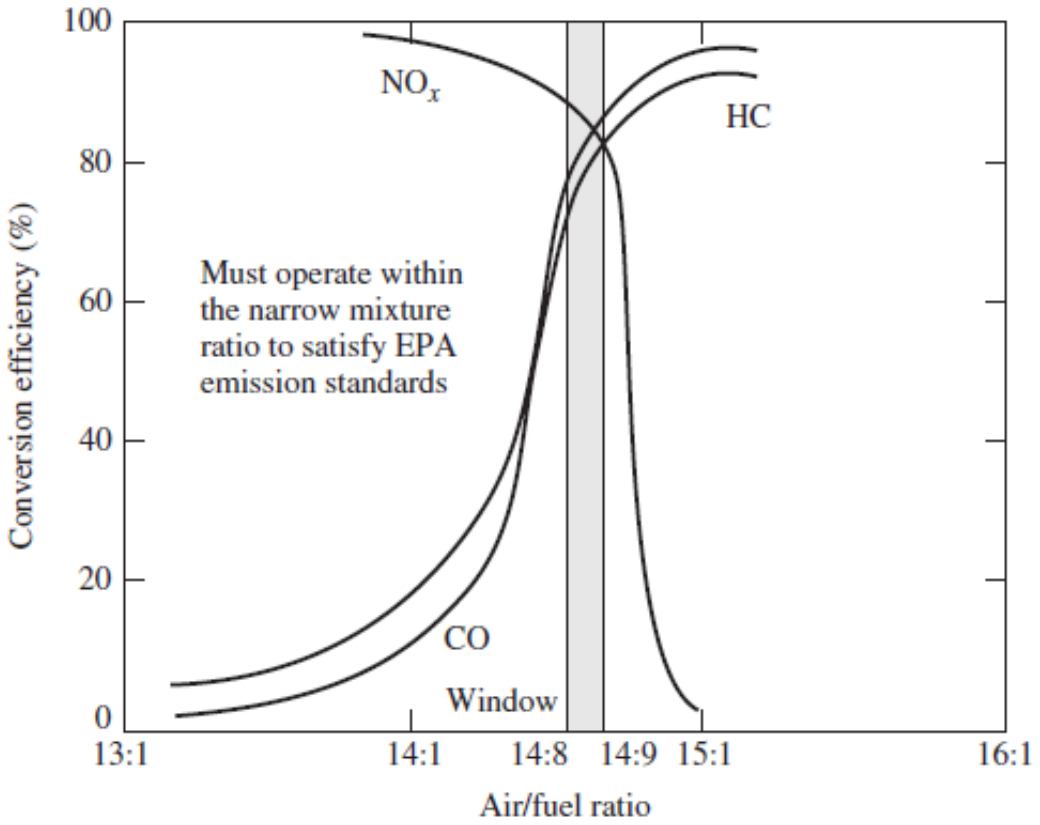
- Catalytic converter – a three way catalyst
  - Oxidizes hydrocarbons
  - Converts CO to CO_2
  - Reduces NO_2 to N_2
  - Can only operate in narrow range of air to fuel ratio, and results in more controls on fuel injection

Treating Exhaust or Flue Gas

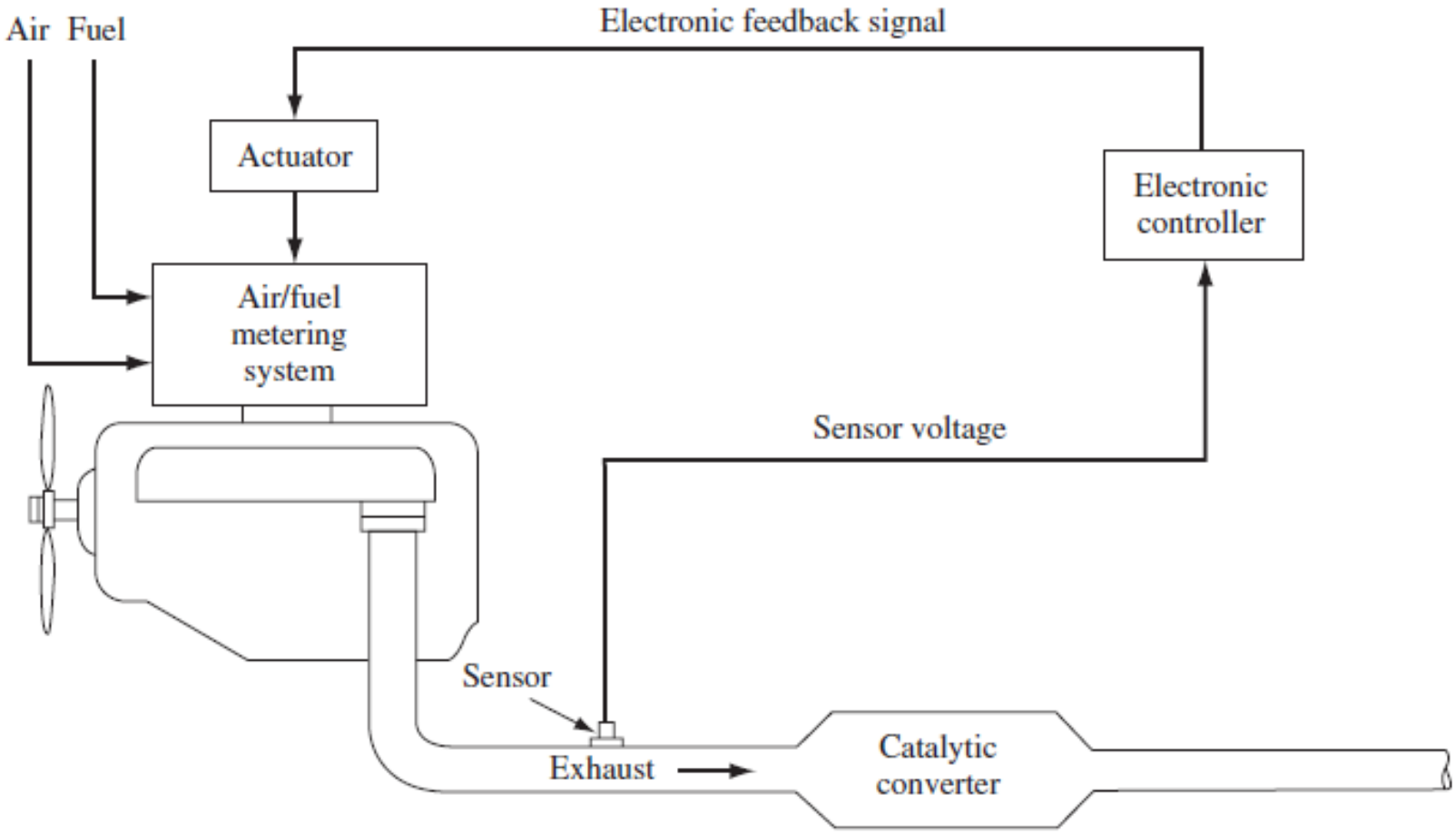
- Platimum-palladium-rhodium catalyst

$$NO + CO + HC \rightarrow N_2 + CO_2 + H_2O$$





Treating Exhaust or Flue Gas



More Emission Controls

- Another large source of HC: evaporative emissions
  - From the gas tank, especially when refueling
  - From the carburetor, especially when engine is hot

- Many minor engine modifications have been made

- Diesel engines
  - Injects fuel directly into cylinder (no carburetor)
  - Higher compression ratios
  - Run on leaner mixtures (more fuel efficient)
  - NO_x and soot are problematic

- Electric cars
  - Cars themselves would be zero emission
  - Power plants could be strategically located (remote emissions)
  - Battery technology is problematic.