Hydrocarbon Combustion, NO_x and Air Pollution

Hydrocarbon Combustion

The simplest combustion of a hydrocarbon is the burning of methane CH_4 in the presence of abundant oxygen O_2 to produce carbon dioxide CO_2 and water H_2O. The reaction to produce 1 mol of CO_2 is

$$CH_4 + 2\,O_2 \Rightarrow CO_2 + 2\,H_2O + 892\,\text{kJ}$$

If oxygen is scarce, carbon monoxide CO is produced rather than CO_2:

$$CH_4 + \tfrac{3}{2}\,O_2 \Rightarrow CO + 2\,H_2O + 598\,\text{kJ}$$

Note that the carbon monoxide can be burned to carbon dioxide to recover the missing energy:

$$CO + \tfrac{1}{2}\,O_2 \Rightarrow CO_2 + 294\,\text{kJ}$$

Gasoline is largely octane C_8H_{18} and is burned with oxygen as follows:

$$2\,C_8H_{18} + 25\,O_2 \Rightarrow 16\,CO_2 + 18\,H_2O + 10944\,\text{kJ}$$

For each mole of CO_2 produced this equation can be written as:

$$\tfrac{1}{8}\,C_8H_{18} + \tfrac{25}{16}\,O_2 \Rightarrow CO_2 + \tfrac{9}{8}\,H_2O + 684\,\text{kJ}$$

Finally, in our brain and elsewhere we burn glucose $C_6H_{12}O_6$:

$$C_6H_{12}O_6 + 6\,O_2 \Rightarrow 6\,CO_2 + 6\,H_2O + 2802\,\text{kJ}$$

For each mole of CO_2 produced the equation can be written as:

$$\tfrac{1}{6}\,C_6H_{12}O_6 + O_2 \Rightarrow CO_2 + H_2O + 467\,\text{kJ}$$

Vehicles powered by gasoline or diesel must use oxygen from the atmosphere that contains 78% nitrogen. So, certain nitrogen reactions also happen in an internal combustion engine:

$$N_2 + 2\,O_2 \Rightarrow 2\,NO_2 \quad \text{and} \quad N_2 + O_2 \Rightarrow 2\,NO$$

These nitrogen oxides (abbreviated NO_x) can lead to ozone and acid rain in the lower atmosphere where we live. This happens via a variety of other more complicated reactions that are summarized by the following:

hydrocarbons (H_nC_{2n+2}) + nitrogen oxides (NO, NO_2) + light => ozone (O_3)
(photochemical smog)
nitrogen monoxide (NO) + oxygen (O_2) + UV radiation => NO_2 + O_3
(orange eye- and lung-irritating smog)
nitrogen oxides + water => acid rain
(acidification of lakes, corrosion of metals, and weathering of stone buildings and statues)

Hydrocarbon combustion also can produce carbon monoxide (CO) which prevents blood transport of oxygen.

Volkswagen's cheating on its emission controls cause its diesel cars to produce far more nitrogen oxides than claimed.

Sulfur in coal burned by power plants becomes sulfur dioxide which also becomes acid rain:
sulphur dioxide + water => acid rain
(acidification of lakes, corrosion of metals, and weathering of stone buildings and statues)

Nitrogen Dioxide Toxicity

Nitrogen dioxide is a reddish-brown gas with an irritating odor. It is a deadly poison as explained in the following paragraph from the Merck Index of Chemicals.

> One of the most insidious gases. Inflammation of lungs may cause only slight pain or pass unnoticed, but the resulting edema several days later may cause death.

At a concentration of 100 ppm (parts per million), it is dangerous for even a short exposure, and 200 ppm may be fatal. Luckily, it is so nasty looking in such high concentrations that people quickly get away from it.

This reaction proceeds vigorously when concentrated nitric acid (HNO_3) is used to clean copper:

$$2\,HNO_3(aq) + Cu(s) \Rightarrow Cu^{++}(aq) + 2\,OH^-(aq) + 2NO_2(g)$$

Ozone

In the upper atmosphere, ozone helps protect animals from much of the ultra-violet radiation of the sun. Certain man-made chemicals (chlorofluorocarbons) were once released in such large quantities that the ozone layer in the atmosphere was beginning to weaken. International cooperation to use other chemicals for refrigerants and propellants appears to have controlled this danger.

In the lower atmosphere, ozone is an eye and lung irritant and can cause pulmonary edema and chronic respiratory disease.

Hydrogen Combustion

We have already seen an example of hydrogen combustion in our explosion where the reaction was

$$2\,H_2 + O_2 \Rightarrow 2\,H_2O + 572\,kJ \quad .$$

This shows that burning hydrogen has an exhaust that is just water vapor! Unfortunately, it is actually a bit more complicated. Since we still must use air to obtain the oxygen, there will be some nitrogen oxides produced. Careful engineering, however, can probably greatly minimize those. Another problem is that hydrogen must be obtained from either water or from hydrocarbons. Oil companies would like to provide hydrogen from oil which would still involve the production of some carbon dioxide, but hydrogen can also be produced cleanly from water using solar electricity and electrolysis.

Some people are concerned about the hydrogen combustion in a car accident. Burning hydrogen is invisible, but rapidly rises above an accident whereas spilled gasoline burns on the ground where the accident victims might be located. There will only be a hydrogen explosion if the hydrogen gas has ample time to mix with oxygen in the proper proportions before being ignited by a spark.

An old news video “Hindenburg Disaster: Real Zeppelin Explosion Footage (1937) | British Pathé” (https://www.youtube.com/watch?v=CgWHbpMVQ1U) is instructive.
Also, “Why Did the Hindenburg Burn?” (https://www.youtube.com/watch?v=K5x7EOiQ1y0).