IMPACT 3 …ON TECHNOLOGY: Thermochemical aspects of fuels and foods

The thermochemical properties of fuels and foods are commonly discussed in terms of their *specific enthalpy*, the enthalpy of combustion divided by the molar mass, or their *enthalpy density*, the enthalpy of combustion divided by the molar volume. Specific enthalpies are typically reported in kilojoules per gram and enthalpy densities in kilojoules per litre (i.e. kilojoules per cubic decimetre).

Table 1 lists the specific enthalpies and enthalpy densities of several fuels. The most suitable fuels may be those with high specific enthalpies, as the advantage of a high molar enthalpy of combustion may be eliminated if a large mass of fuel is to be transported. Thus, H_2 gas compares very well with more traditional fuels such as methane (natural gas), iso-octane (a component of gasoline), and methanol. However, H_2 gas has a very low enthalpy density, so the advantage of a high specific enthalpy is undermined by the large volume of fuel to be transported and stored.

To assess the factors that optimize the heat output of carbon-based fuels, consider the combustion of 1 mol $CH_4(g)$, the main constituent of natural gas. The combustion of 1 mol $CH_4(g)$ releases 890 kJ of energy as heat. Now consider the combustion of 1 mol $CH_3OH(g)$:

$$CH_3OH(g) + \tfrac{3}{2}O_2(g) \rightarrow CO_2(g) + 2\,H_2O(l) \quad \Delta H^{\ominus} = -764\,kJ$$
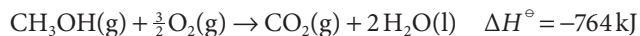
This reaction is also exothermic, but only 764 kJ of energy is released as heat per mole of methanol molecules. The replacement of a C–H bond by a C–O bond renders the carbon in methanol more highly oxidized than the carbon in methane, so it is reasonable to expect that less energy is released to complete the oxidation of carbon to CO_2 in methanol.

A typical 18–20 year old human requires a daily input of about 9–12 MJ. If the entire consumption were in the form of glucose (**1**; which has a specific enthalpy of 16 kJ g^{-1}), that would require the consumption of 560–750 g of glucose. In fact, digestible carbohydrates have a slightly higher specific enthalpy (17 kJ g^{-1}) than glucose itself, so a carbohydrate diet is slightly less daunting than a pure glucose diet, as well as being more appropriate in the form of fibre, the indigestible cellulose that helps move digestion products through the intestine.
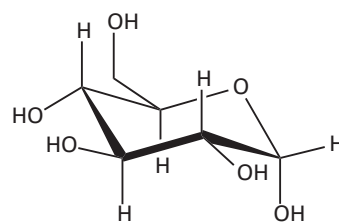
1 α-D-Glucose

Fats are long-chain esters like tristearin (beef fat). The enthalpy of combustion of a fat at around 38 kJ g^{-1} is much greater than that of carbohydrates and only slightly less than that of the hydrocarbon oils used as fuel (48 kJ g^{-1}). Fats are commonly used as an energy store, to be used only when the more readily accessible carbohydrates have fallen into short supply. In Arctic species, the stored fat also acts as a layer of insulation; in desert species (such as the camel), the fat is also a source of water, one of its oxidation products.

Proteins are also used as a source of energy, but their components, the amino acids, are often too valuable to squander in this way, and are used to construct other proteins instead. When proteins are oxidized (to urea, $CO(NH_2)_2$), the equivalent specific enthalpy is comparable to that of carbohydrates.

The energy released as heat by the oxidation of foods needs to be discarded in order to maintain body temperature within its typical range of 35.6–37.8 °C. A variety of mechanisms contribute to this aspect of homeostasis, the ability of an organism to counteract environmental changes with physiological responses. The general uniformity of temperature throughout the body is maintained largely by the flow of blood. When heat needs to be dissipated rapidly, warm blood is allowed to flow through the capillaries of the skin, so producing flushing. Radiation is one means of discarding heat; another is evaporation, where energy as heat is used to cause the endothermic vaporization of water. Evaporation removes about 2.4 kJ per gram of water perspired. When vigorous exercise promotes sweating (through the influence of heat selectors on the hypothalamus), 1–2 dm^3 of perspired water can be produced per hour, corresponding to a heat loss of 2.4–5.0 MJ h^{-1}.

Table 1 Thermochemical properties of some fuels

Fuel	Combustion equation	$\Delta_c H^{\ominus}/(kJ\,mol^{-1})$	Specific enthalpy/(kJ g^{-1})	Enthalpy density/(kJ dm^{-3})
Hydrogen	$H_2(g) + \tfrac{1}{2}\,O_2(g) \rightarrow H_2O(l)$	−286	142	13
Methane	$CH_4(g) + 2\,O_2(g) \rightarrow CO_2(g) + 2\,H_2O(l)$	−890	55	40
Octane	$C_8H_{18}(l) + \tfrac{25}{2}\,O_2(g) \rightarrow 8\,CO_2(g) + 9\,H_2O(l)$	−5471	48	3.8×10^4
Methanol	$CH_3OH(l) + \tfrac{3}{2}\,O_2(g) \rightarrow CO_2(g) + 2\,H_2O(l)$	−726	23	1.8×10^4