Chem Factsheet

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Fossil Fuels and Carbon Footprints

To succeed in this topic, you need to:

- Be familiar with simple organic structures, especially hydrocarbons
- Be familiar with the process of combustion of hydrocarbon fuels
- Be familiar with the Greenhouse Effect

After working through this Factsheet, you will:

- Be aware of the concept of carbon footprint
- Be aware of the gases that contribute to a carbon footprint
- Know how to calculate and compare carbon footprints

Introduction

A carbon footprint measures the total greenhouse gas emissions caused directly and indirectly by a person, organisation, event or product.

Three types of carbon footprint can be measured – one that measures an organisation's overall activities, one that looks at the life cycle of a particular product or service and one that looks at a single specific event.

A carbon footprint is the total greenhouse gas (GHG) emissions caused directly and indirectly by an individual, organisation, event or product and is expressed as a carbon dioxide equivalent (CO_2e). A carbon footprint accounts for all six Kyoto GHG emissions:

- Carbon dioxide (CO_2) – 100-year GWP = 1
- Methane (CH_4) – 100-year GWP = 34
- Nitrous oxide (N_2O) – 100-year GWP = 298
- Hydrofluorocarbons (HFCs) – 100-year GWP = 1550
- Perfluorocarbons (PFCs) – 100-year GWP = 5350
- Sulphur hexafluoride (SF_6) – 100-year GWP = 22800

Carbon dioxide equivalent (CO_2e) is a unit of measurement that allows different greenhouse gases to be compared. CO_2e emissions are calculated by multiplying the emissions of each of the six greenhouse gases by its 100-year global warming potential (GWP)

Simple carbon footprint calculation

The true carbon footprint of driving a car includes not only the emissions that come out of the exhaust pipe (direct emissions), but also all the emissions that take place when oil is extracted, shipped, refined into fuel and transported to the petrol station, not to mention the substantial emissions caused by producing and maintaining the car (indirect emissions).

To illustrate a simple carbon footprint calculation, only the direct emissions from a 100-mile car journey will be considered. We will assume:

- Petrol is octane, C_8H_{18}
- The fuel consumption of the car is 40 mpg; so, the 100 mile journey consumes 2.5 gallons.
- The density of petrol is 3.31 kg / gal

$$C_8H_{18} + 12\tfrac{1}{2}O_2 \rightarrow 8CO_2 + 9H_2O$$

↓ 2.5 gal = 2.5 x 3.31
= 8.275 kg = 8275 g
= 8275/114 = 72.6 mol → x 8 → 581 mol
x 44
↑ = 25550 g = **25.6 kg**

Comparing the carbon footprints of different fuels

For the purposes of this comparison we will consider coal, methane and petrol.

For petrol, the calculation above is based on burning 8275 g of petrol. For comparison with other fuels we will consider the carbon footprint per gram and per joule of energy released.

per gram

Octane, C_8H_{18};

8275 g = 25.6 kg CO_2e so 1 g = 25600/8275 = 3.1 g CO_2e

Coal (i.e. carbon, C)

$C + O_2 \rightarrow CO_2$
12 g C gives 44 g CO_2 so 1 g C gives 44/12 = 3.7 g CO_2e

Methane, CH_4

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
16 g CH_4 gives 44 g CO_2 so 1 g CH_4 gives 44/16 = 2.75 g CO_2e

For methane, this could be considered to be a reduction, if the methane would otherwise be in the atmosphere, as methane has a GWP of 34 so 1 g of methane in the atmosphere has a CO_2e = 34 g. So, it could be argued that burning the methane to produce CO_2 is a 'saving' of 31.25 g CO_2e per gram of methane burned.

per joule of energy produced

ΔH_c C_8H_{18} = −5470 kJ mol^{-1}; ΔH_c C = −394 kJ mol^{-1}; ΔH_c CH_4 = −890 kJ mol^{-1};

Octane, C_8H_{18};

114 g gives 5470 kJ so 1 g (3.1 g CO_2e) gives 5470/114 = 48 kJ = 3.1/48 = 0.065 g CO_2e per J

Coal (i.e. carbon, C)

12 g gives 394 kJ so 1 g (3.7 g CO_2e) gives 394/12 = 32.8 kJ = 3.7/32.8 = 0.11 g CO_2e per J

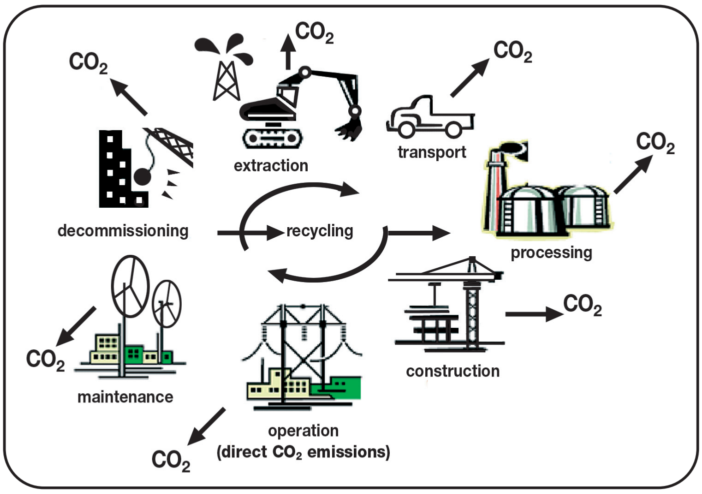
Methane, CH_4

16 g gives 890 kJ so 1 g (2.75 g CO_2e) gives 890/16 = 55.6 kJ = 2.75/55.6 = 0.049 g CO_2e per J

As mentioned above, these examples deal only with direct emissions resulting from the combustion process itself. No indirect emissions are considered.

Carbon footprint for domestic electricity

All electricity generation processes generate carbon dioxide and other greenhouse gases. To compare the impacts of these different processes, the total amounts of CO_2 emitted during a system's life must be calculated. Emissions can be both direct – from operation of the power plant, and indirect – from other non-operational phases of the life cycle. Fossil fuelled technologies (coal, oil, gas) have the largest carbon footprints, because they burn these fuels during operation. Non-fossil fuel based technologies such as wind, solar, hydro, biomass, wave/tidal and nuclear are often referred to as 'low carbon' or 'carbon neutral' because they do not emit CO_2 during their operation. However, they are not 'zero carbon' forms of generation since CO_2 emissions do arise in other phases of their life cycle such as during extraction, construction, maintenance and decommissioning.



Carbon footprints are calculated using a method called life cycle assessment (LCA). This method analyses the environmental impacts of a process through all the stages of its lifecycle for the whole production chain, from exploration and extraction of raw materials to processing, transport and final use.

Conventional coal-fired power stations have the highest emissions - of the order of >1,000 gCO_2e / kWh. Lower emissions can be achieved using newer, gasification plants (<800 gCO_2e / kWh), but these are not as widespread as proven combustion technologies.

Oil now accounts for only a very small proportion of the electricity generated in the UK. It is primarily used as a back-up fuel to cover peak electricity demand periods.

The average carbon footprint of oil-fired electricity generation plants in the UK is ~650 gCO_2e / kWh.

Current gas-powered electricity generation has a carbon footprint around half that of coal (~500 gCO_2e / kWh). Like coal fired plants, gas plants could co-fire biomass to reduce carbon emissions in the future.

Low carbon technologies, such as wood chip/pellets, nuclear, wind, tidal, hydro and solar all have considerably lower footprints; typically, less than 100 g CO_2e / kWh. Most emissions occur during 'non-operational phases. e.g. for nuclear power, as no combustion is involved in power generation, 35% of the emissions come during decommissioning and 40% during uranium extraction, with the total footprint amounting to only about 5 g CO_2e / kWh.

Task

Use a personal footprint calculator (such as that found at http://footprint.wwf.org.uk/) to calculate your personal footprint and investigate how it could be reduced.

Questions

1. Determine the direct carbon footprint per passenger on an aircraft journey of 2000 km if:

- The fuel is assumed to be a 14-carbon alkane
- The fuel burns completely
- The aircraft carries 200 passengers
- The aircraft burns 3.13 kg per km travelled.

2. Determine the annual indirect carbon footprint created by regular television viewing in the UK (ignore the production of the TV). A family watch an average of 1.5 hours of television a day all year round (1 kWh has a carbon footprint of 352 g CO_2e). The television requires 200 W of power to operate.

3. Electrolysis of water is carried out using a voltage of 12 V and a current of 1.5 A. At this current, hydrogen is produced at about 680 cm^3 hr^{-1} at RTP. Using information contained in (2) regarding carbon footprint of electricity, determine the carbon footprint of hydrogen produced by electrolysis in g CO_2e per kJ. The enthalpy change of combustion of hydrogen is −242 kJ mol^{-1} and the molar volume of a gas at RTP is 24.8 dm^3

Answers

1.
- Mass of fuel burned = 3.13 × 2000 = 6260 kg
- Equation for combustion: $C_{14}H_{30} + 21.5O_2 \rightarrow 14CO_2 + 15H_2O$
- Moles of fuel burned = 6260000/198.44 = 31550 mol
- Moles of CO_2 produced = 31550 × 14 = 441640 mol
- Mass of CO_2 produced = 441640 × 44.01 = 19440 kg
- CO_2 production per passenger = 19440/200 = **97.2 kg**

2.
- Hours of viewing = 1.5 × 365 = 547.5 hours
- kWh used = 547.5 × 0.2 = 109.5 kWh
- Carbon footprint = 109.5 × 0.352 = **38.5 kg CO_2e**

3.
- Moles of hydrogen produced per hour = 680/24800 = 0.0274 mol
- Energy produced by combustion = 0.0274 × 242 = 6.635 kJ
- Power usage = 12 x 1.5 × 1 = 18 Wh = 0.018 kWh
- Indirect CO_2 production = 0.018 × 352 = 6.4 g
- Carbon footprint = 6.4/6.635 = **0.96 g CO_2e per kJ**

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