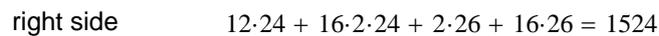
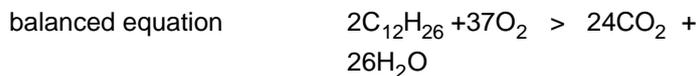


Chemical formulaeHydrogen

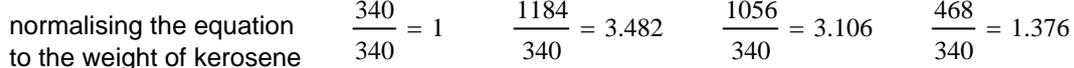
$$4 + 32 > 36$$



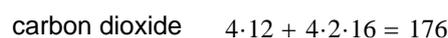
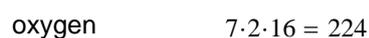
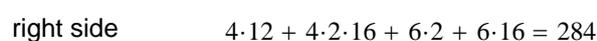
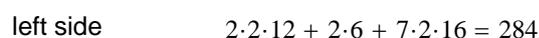
so that

1 ton of hydrogen burns in 8 tons of oxygen, producing 9 tons of water (vapour).Kerosene

these results can be in any consistent weight units, kg, lb, g, ton or tonne



so that

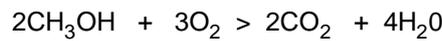
1 ton of kerosene burns using 3.48 tons of oxygen, producing 3.11 tons of CO₂ and 1.38 tons of water (vapour)Methane (fossil gas)

	water	$6 \cdot 2 + 6 \cdot 16 = 108$		
normalising the equation to the weight of methane	$\frac{60}{60} = 1$	$\frac{224}{60} = 3.733$	$\frac{176}{60} = 2.933$	$\frac{108}{60} = 1.800$

so that

1 ton of methane burns in 3.73 tons of oxygen, producing 2.93 tons of carbon dioxide and 1.8 tons of water (vapour)

Methyl alcohol (methanol)



comprising



Molecular Weights

left side $2 \cdot (12 + 3 + 16 + 1) + 3 \cdot 2 \cdot 16 = 160$

right side $2 \cdot (12 + 2 \cdot 16) + 4 \cdot (2 + 16) = 160$

methanol $2 \cdot (12 + 3 + 16 + 1) = 64$

oxygen $3 \cdot 2 \cdot 16 = 96$

carbon dioxide $2 \cdot (12 + 2 \cdot 16) = 88$

water $4 \cdot (2 + 16) = 72$

normalising the equation to the weight of methanol	$\frac{64}{64} = 1$	$\frac{96}{64} = 1.500$	$\frac{88}{64} = 1.375$	$\frac{72}{64} = 1.125$
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so that

1 ton of methanol burns in 1.5 tons of oxygen, producing 1.38 tons of carbon dioxide and 1.1 tons of water (vapour).
 Actually 1 3/8 tons carbon dioxide and 1 1/8 tons water vapour.

SAF Synthesised Aircraft Fuel, aka Sustainable Aircraft Fuel

- 1 SAF fuel is 50% kerosene (from fossil oil) and 50% synthetic.
- 2 The synthesised part is derived from compost waste or grown biological material. There is unlikely to be enough compost waste to generate synthetic fuel for the airline industry, let alone for buses that are already doing this, and all the other transport methods that would like to do it.
- 3 It is claimed to be beneficial because for the biological part, carbon absorbed in growing can be burnt as fuel.
- 4 Grown biological material displaces land either from jungle or food growth.
- 5 The synthesised half is apparently identical to fossil kerosene, so produces the same amount of carbon dioxide.

Conclusion: Even if burning fuel from grown bio matter or compost waste is regarded as acceptable, SAF will only cut carbon emissions by 50%. For carbon dioxide emissions from SAF, refer to paragraph for kerosene.

So far, these calcs take no account of the calorific value of each compound. 1 ton of each compound would not produce the same amount of energy.

Calorific values and densities of compounds

Net Calorific Value

Hydrogen gas	120.0 MJ/kg	10.8 MJ/m ³	at 0C 1bar
Kerosene liquid	43.0 MJ/kg	35.3 MJ/l	at 15C
Methane gas	50.0 MJ/kg	35.8 MJ/m ³	at 0C 1bar
Methanol liquid	19.9 MJ/kg	15.6 MJ/l	at 15C

Density at atmospheric pressure

Hydrogen gas	0.090 kg/m ³	at 0C 1bar
Kerosene liquid	0.821 kg/l	at 15C
Methane gas	0.716 kg/m ³	at 0C 1bar
Methanol liquid	0.791 kg/l	at 15C

Hydrogen gas	1 tonne of Hydrogen contains 120000MJ and has a volume of	1000/0.090 = 11111 m ³
Kerosene liquid	1 tonne of Kerosene contains 43000 MJ and has a volume of	1000/(0.821x1000) = 1.218 m ³
Methane gas	1 tonne of Methane contains 50000 MJ and has a volume of	1000/0.716 = 1397 m ³
Methanol liquid	1 tonne of Methanol contains 19900 MJ and has a volume of	1000/(0.791x1000) = 1.264 m ³

Hydrogen storage

Some gases can be stored at high density by liquifying them, eg butane and propane. To liquify hydrogen requires cryogenic temperature or massive pressure. Hydrogen liquifies at atmospheric pressure at -253C, or 20Kelvin.

One flight from the UK to the US on (say) an A340, uses 80 tons of kerosene. (Assume 1 ton ~ 1 tonne). 80 tons of kerosene contains 80 x 43000 MJ energy = 3.44 E6 MJ.

In hydrogen this would need $\frac{3440000\text{MJ}}{120000 \frac{\text{MJ}}{\text{ton}}}$ of hydrogen = 28.6 ton hydrogen.

The volume of 28.6 tons of hydrogen at atmospheric pressure and temperature is $\frac{28.6 \cdot \text{tonne} \cdot 1000 \cdot \frac{\text{kg}}{\text{tonne}}}{0.09 \frac{\text{kg}}{\text{m}^3}} = 317,778\text{m}^3$

If hydrogen is stored at (say) 20bar pressure as gas, the volume of this is $\frac{317778\text{m}^3}{20\text{bar}} = 15890\text{m}^3$

80 tons of kerosene has a volume of $\frac{80\text{tonnes}}{0.821 \frac{\text{tonnes}}{\text{m}^3}} = 97.4 \text{m}^3$

And $\frac{15890}{97.4} = 163$ times as much volume in the aircraft as the volume of kerosene.

If the hydrogen is liquified (-253C at atmospheric pressure) it has a density of 71kg/m³.

So the volume of liquified hydrogen for this single flight would have a volume of $\frac{28.6\text{tonnes}}{71 \frac{\text{kg}}{\text{m}^3}} = 403\text{m}^3$

This is $\frac{403}{97.4} = 4.1$ times as much volume in the aircraft as the volume of kerosene.

Trees for carbon offset

A newly planted small tree (whip, about 2 feet tall) is generally considered to take 30 years to reach maturity. In this time it should weigh about 1 tonne.

Live wood consists of about 50% water and 50% carbon.

The ratio of carbon to carbon dioxide by weight is $\frac{12 + 2 \cdot 16}{12} = 3.67$

so the weight of carbon dioxide absorbed by this tree is about $3.67 \cdot 0.5 \text{ tonne} = 1.84 \text{ tonne}$

Comparing this to a single flight UK to US, it would need $\frac{80 \text{ tonne} \cdot 3.11 \cdot 1.9}{1.84 \text{ tonne}} = 257$ trees to offset this flight.

Note that 1 tonne kerosene gives 3.11 tonnes CO_2 (above) and this must be factored by 1.9 for the effect of high altitude emissions.

And it will take 30 years for 257 trees to reach maturity.

Personally, I would be very happy for the airlines to use planting trees to offset aircraft carbon dioxide emissions, provided that they shut down their operations for 30 years while the trees have a chance to grow.

The (2020 values) commercial jet fuel market uses 106 billion gallons annually, 106,000,000,000 gallons (assume US gallons).

1 US gallon = 3.785 litres. kerosene is 0.821 kg/litre.

106,000,000,000 US gallons = $106,000,000,000 \cdot 3.785 \cdot 0.821 / 1000 / 1000,000 = 329.4$ million tonnes of kerosene, and as shown above this will produce $329.4 \text{E}6 \cdot 3.11$ tonnes of $\text{CO}_2 = 1024$ million tonnes of carbon dioxide annually.

By 2050, this is set to increase to 230 billion gallons of kerosene, annually. 2223 million tonnes of CO_2 .

$$\frac{106000000000}{1000000} \cdot 3.785 \cdot \frac{0.821}{1000} = 3.2939 \times 10^2$$

$$\frac{106000000000}{1000000} \cdot 3.785 \cdot \frac{0.821}{1000} \cdot 3.11 = 1.0244 \times 10^3$$

$$\frac{230}{106} = 2.170 \quad 1.0244 \times 10^3 \cdot 2.17 = 2223$$