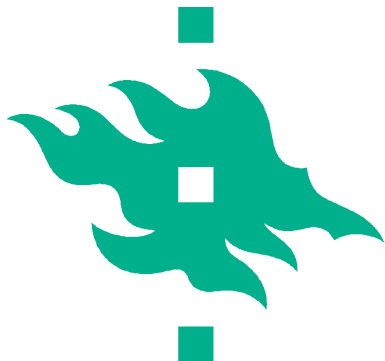


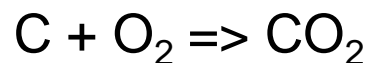
Greenhouse gas emissions from direct combustion of various fuels (e.g. grain dryer)

- The most significant greenhouse gas from direct combustion is carbon dioxide (CO₂)
- Large number of other compounds are also formed
- Their effect on global warming is described with the carbon dioxide equivalent (CO₂eq, CO₂e, CDE)
 - CO₂eq describes the amount of CO₂ units that has similar global warming potential (GWP) than one unit of the substance concerned
 - Methane (CH₄) 24,5 CO₂eq
 - Nitrous oxide (N₂O) 320 CO₂eq

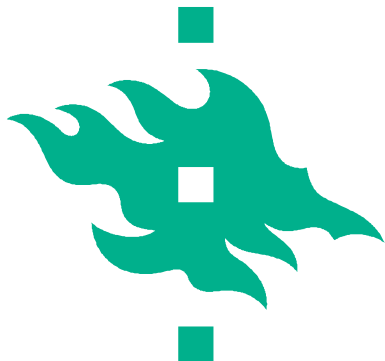


Direct CO₂ emissions

- CO₂ is formed always when burning fuel that contains carbon
- The carbon in the fuel combines with the oxygen from the air:



- The amount of CO₂ can be calculated by the atomic masses of carbon and oxygen and the carbon content of the fuel

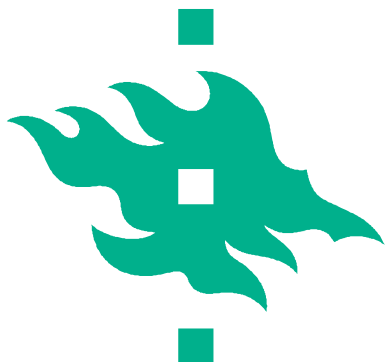


Direct CO₂ emissions

- Atomic mass of carbon is 12u and oxygen 16u

$$\text{CO}_2 = 12\text{u} + 2 \times 16\text{u} = 44\text{u}$$

- Burning 1 kg of carbon produces $44/12 \approx 3,67$ kg of CO₂ in complete combustion
- **The CO₂ emission of combustion is $3,67 \times c_C \times m_{\text{fuel}}$**
 c_C = fuel carbon content (mass basis)



Direct CO₂ emissions

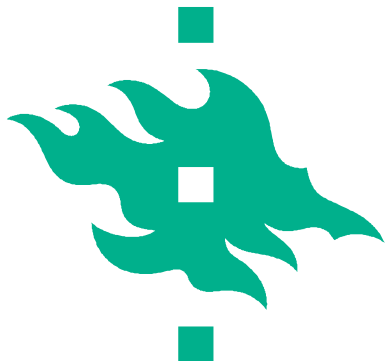
Example: carbon content of diesel fuel is 85,7 %. CO₂ emission from burning 1 kg of diesel fuel is:

$$m_{\text{CO}_2} = 3,67 \times c_{\text{C}} \times m_{\text{fuel}}$$

$$m_{\text{CO}_2} = 3,67 \times 0,857 \times 1 \text{ kg} = 3,15 \text{ kg} / 1 \text{ kg fuel}$$

Density of diesel fuel is 0,84 kg/l

$$m_{\text{CO}_2} = 3,15 \text{ kg} \times 0,84 = 2,64 \text{ kg} / 1 \text{ l fuel}$$



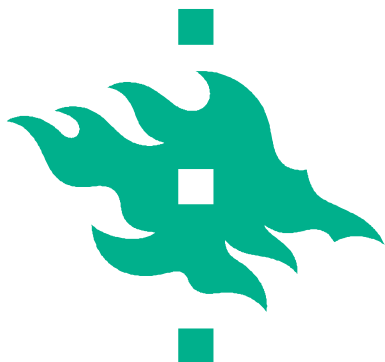
Direct CO₂ emissions

- CO₂ emission is usually expressed in g/MJ or t/TJ
- CO₂ emission g/MJ of fuel = $3,67 \times c_C / H_a$
 c_C = fuel carbon content (mass basis)
 H_a = lower heating value of the fuel

Example: carbon content of diesel fuel is 85,7 % and lower heating value $H_a = 42,7$ MJ/kg. CO₂ emission is:

$$3,67 \times c_C / H_a$$

$$3,67 \times 0,857 / 42,7 \text{ MJ/kg} = 0,0736 \text{ kg/MJ} = 73,6 \text{ g/MJ}$$

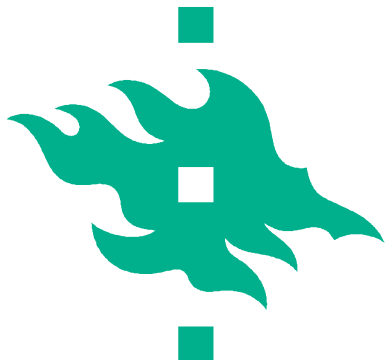


Calculated CO₂ emissions from different fuels

Fuel	Carbon content [%]	H _a [MJ/kg]	CO ₂ emission [g/MJ]
Diesel fuel	85,7	42,7	73,6
Natural gas*	75	50	55,0
Rapeseed oil	78,2	37,3	76,9
Wood (chips)	50 (48-52)	19 (dry matter)	96,5

* Natural gas imported to Finland is 98% methane. It has carbon content of 75% (C=12u, H=4x1u, CH₄=16u, 12/16=75%)

<http://www.maakaasu.fi/kirjat/maakaasukasikirja/maakaasun-koostumus-ja-ominaisuudet>

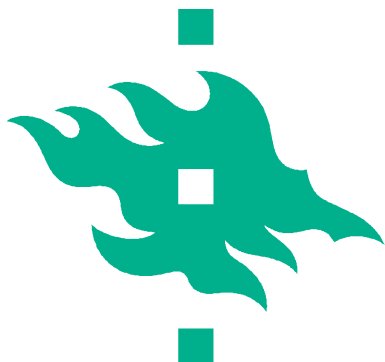


Official Finnish figures

Fuel	H _a [MJ/kg]	CO ₂ emission [g/MJ]
Diesel fuel	42,8	73,0
Light fuel oil	42,4	74,1
Natural gas	36,0 [MJ/m ³]	56,1
Liquid biofuels	40	77,4
Wood (chips)*	10,4	109,6

* Heating value of wood is expressed in wet basis, moisture ~ 40%

http://www.stat.fi/til/khki/2003/khki_2003_2005-09-12_luo_002.html



CO₂ emission per litre of liquid fuel

- Liquid fuels are sold in litres

Example: diesel fuel

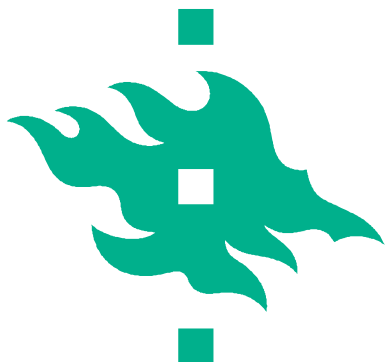
Density = 0,84 kg/l

Ha = 42,7 MJ/kg

= 0,84 kg/l x 42,7 MJ/kg = 35,868 MJ/l

Volume of 1 MJ = 1 / 35,868 MJ/l = 0,02788 l/MJ

CO₂ emission = 73 g/MJ / 0,02788 l/MJ = 2640 g/l = 2,64 kg/l



CO₂ emission per m³ (of wood chips)

- Wood chips are sold in cubic meters

Example: wood chips

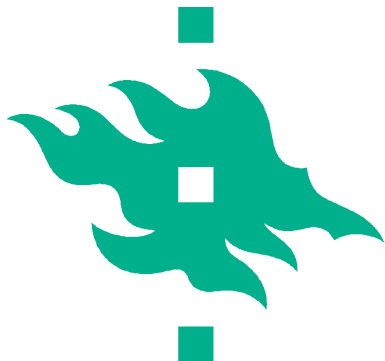
Density = 300 kg/m³ (250-350 kg/m³)

Ha = 10,4 MJ/kg

= 300 kg/m³ x 10,4 MJ/kg = 3120 MJ/m³

Volume of 1 MJ = 1 / 3120 MJ/l = 0,000321 m³/MJ

CO₂ emission = 109,6 g/MJ / 0,000321 m³/MJ = 324 kg/m³



Other GHG from combustion

- In internal combustion engines also methane and nitrous oxide are formed
 - Figures of $0,004 \text{ g NH}_4 / \text{MJ}_{\text{fuel}}$ and $0,031 \text{ g N}_2\text{O} / \text{MJ}_{\text{fuel}}$ are suggested (Mäkinen et al 2006)
 - Concentrations in exhaust gases for $\text{NH}_4 \sim 5 - 15 \text{ ppm}$ and $\text{N}_2\text{O} \sim 1 - 3 \text{ ppm}$
- Other GHG from combustion in furnaces?
 - Controlling the combustion is much easier than in engines
 - Continuous combustion
 - Steady conditions



This material has been produced in ENPOS project. ENPOS is acronym for *Energy Positive Farm*.

The project partners are

- University of Helsinki, department of Agricultural Sciences – Agrotechnology
- MTT Agrifood Research Finland - Agricultural Engineering
- Estonian University of Life Sciences

Project home page is at <http://enpos.weebly.com/>

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This publication reflects the authors views and the Managing Authority cannot be held liable for the information published by the project partners.

ENPOS Energy Positive Farm



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