# Life-cycle energy and emissions of marine energy devices

**Like other renewable energy devices, wave energy and tidal stream energy devices offer the ability to generate power without causing carbon dioxide emissions. However, some emissions may arise during manufacturing and installation of the devices, depending on the source of power for these activities. Consequently, questions that are often asked are:**

- Over a device's entire life-cycle (manufacturing to decommissioning), how much carbon dioxide will be emitted?
- How long will it take for a device to 'pay back' the energy that was consumed, or emissions that were caused, during manufacturing and installation?

The following calculations, prepared by Black & Veatch for an imaginary wave energy device, show how answers to these questions can be estimated on a preliminary basis. They are solely for illustration and not intended to be rigorous. Also, the results should not be regarded as typical – life-cycle emissions and payback periods will vary between devices.

## Basis of estimates

The estimates are based on the observations for marine energy devices [1] that:

Emissions of carbon dioxide are broadly proportional to energy use; and therefore

The most important life-cycle stage is the manufacturing of structural materials.

A corollary of these observations is that the estimates can be made by comparing the emissions due to a device's use of structural materials with total energy production over its service life.

## Life-cycle carbon dioxide emissions

**Data**:

Carbon dioxide emissions per unit mass of steel: 1.75 tCO2/tonne steel [2]
Total mass of steel in device: 665 tonnes [3]
Carbon dioxide emissions due to steel manufacturing: 1.75 x 665 = 1160 tCO2
Average annual energy production: 2.3 GWh/year [3]
Service life: 20 years [3]
Total energy production over service life: 2.3 GWh/year * 20 year = 46 GWh

**Life cycle carbon dioxide emissions:**

$$\frac{1160\ tCO_2}{46\ GWh} = 25\ gCO_2/kWh$$

In practice, allowing for emissions in other life cycle stages, total emissions are likely to be in the range 1-2 times this amount: 25 $gCO_2$/kWh to 50 $gCO_2$/kWh.

## Energy payback period

**Assumptions and data:**

The majority of primary energy used in steel manufacturing is a fossil fuel, which is used for heating, and there is relatively little direct electricity usage.

- The fossil fuel will vary but is assumed to be coal, which has a carbon emissions factor of 0.30 tCO2/MWh [4], and the efficiency of conversion to heat 90% = 0.33×is assumed to be 90%. This gives emissions of 0.30 tCO2/MWh tCO2/MWh, the reciprocal of which is 3.0 MWh/tCO2.

- 0.33 MWh of grid electricity is consumed per tonne of steel , and the associated emissions are 0.43 tCO2/MWh [4]. This product of these gives 0.14 tCO2/tonne steel due to electricity. Assuming a generation efficiency of 35%, the primary energy input due to electricity is 0.94 MWh/tonne steel, (0.33 MWh/tonne steel / 35%).
- Given total emissions of 1.75 tCO2/tonne steel (as above), 1.61 tCO2/tonne steel is due to heat input (1.75 – 0.14 tCO2/tonne steel). The primary energy 1.61 tCO2/tonne steel = 4.82×input due to heat is therefore 3.0 MWh/tCO2 MWh/tonne steel.
- The total energy intensity of steel manufacturing is therefore 0.94 + 4.82 = 5.77 MWh/tonne steel.

**Energy used to produce the steel for the wave energy device:**
665 tonnes steel x 5.77 MWh/tonne steel = 3840 MWh = 3.84 GWh

**Energy payback period:**

$$\frac{3.84\ \text{GWh}}{2.3\ \text{GWh/year}} = 1.7\ \text{years} = 20\ \text{months}$$

Note that one could also consider that the electricity generated by the wave energy device avoids the use of primary energy conversion to electricity at an efficiency of 35%, in which case the primary energy input avoided is 2.3 GWh/year / 35% = 6.57GWh/year, which gives an energy payback period of only 7 months.

**<u>Carbon dioxide emissions payback period</u>**
Linking the life-cycle emissions and energy payback calculations together, it is possible to estimate the carbon dioxide emissions payback period. This is not the same as the energy payback period because the carbon intensities of energy consumption and displaced electricity production are different.

**Data:**

Carbon dioxide emissions due to steel manufacturing (as above): 1160 tCO2
Average annual energy production (as above): 2.3 GWh/year = 2300 MWh/year
Electricity produced by the wave energy device displaces grid electricity with emissions 0.43 tCO2/MWh.
0.43 =×Avoided emissions due to displaced electricity production = 2300 989 tCO2/year

**Carbon payback period:**

$$\frac{1160\ \text{tCO}_2}{989\ \text{tCO}_2\text{/year}} = 1.2\ \text{years} = 14\ \text{months}$$

In practice, allowing for emissions in other early life stages that are not related to manufacturing of structural materials (see above), total emissions in the first 2 years of the life of the device are likely to be in the range 1-1.5 times the steel manufacturing emissions. Consequently, the carbon payback period is likely to be in the range of 14 months to 21 months (i.e. 1 to 2 years).

**Footnotes**

[1] Source: ETSU (1999), A Brief Review of Wave Energy
[2] Source: Oxera (2004), CO2 emissions trading: How will it affect UK industry?, Appendices
[3] Source: Black & Veatch
[4] Measuring CO2 - Methodologies