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Switching from heavy oil to LNG

Estimated savings in carbon emissions and costs

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1 Abstract and summary

This report estimates the carbon saving that could be achieved by a European industrial user of heavy fuel oil (HFO) switching to liquefied natural gas (LNG). The saving is expressed in two ways: as a physical volume (tonnes of carbon dioxide equivalent emitted); and as a monetary volume (the market value, in Euros, of those emissions as carbon credits).

The estimate can be expressed as three equations:

Carbon footprint = Energy consumption x Efficiency x Emission factor

$\text{Carbon footprint}_{LNG} - \text{Carbon footprint}_{HVO}$ = Carbon saved by switching

Carbon saved x Carbon credit price = Money saved by switching

The equations are simple. Finding sensible data for them is less so. Data sources for the footprint calculation (first equation) are reviewed in the next chapter. In the subsequent chapter, a base-case estimate of carbon and money saved by switching is presented.

2 Data for the carbon footprint

The basic equation for the carbon footprint is:

Carbon footprint = Energy consumption x Efficiency x Emission factor

This chapter reviews the data for each of the variables, for both LNG and heavy oil.

2.1 Energy consumption

For the estimate, we assume an industrial user of heavy fuel oil, who is using it to raise steam. Base-case consumption is defined in units convenient to SHV: 1,000 tonnes/year of LPG equivalent. This has been converted to energy content, at higher and lower heating values (Table 1).

Table 1: Energy value of 1,000 tonnes of LPG

	Units	HHV[1]	Source	LHV[2]	Source
LPG energy content	MJ/kg	50.152	(US Dept of Energy 2010)	46.0	(Joint Research Centre of the EU Commission, EUCAR et al. 2006: Appendix 1, p 11)
Consumption	GJ/yr	50,152	Calculation	46,000	Calculation

2.2 Efficiency (of the boiler)

Boiler efficiency is a complex topic, subject to a number of significant influences (CleaverBrooks 2010):

- *Internal boiler design* – main features are: the number of passes, burner geometry, air and fuel controls, heating surface area, pressure vessel type, radiation and convection losses, and atmospheric or condensing heat transfer.

[1] Higher heating value (gross heating value)
[2] Lower heating value (net heating value)

- *Operating parameters* – flue gas temperature in the stack, excess air and ambient air temperature.
- *Fuel type and specification* – mainly the hydrogen-to-carbon ratio, or the HHV/LHV ratio.

Typical furnaces and steam boilers used for industrial processes, according to (Towler and Sinnott 2012, Chap 3), have a efficiency of about 85%. That is, at stable, full-load operation of a properly-maintained system, the heat load exiting the heat-transfer area[3] is 85% of the higher-heating-value (HHV) of the incoming fuel. Typical furnaces and steam boilers also are atmospheric; they are not capable of operating in condensing mode. For instance, in 2007, only about 3% of all domestic heating systems in the EU were of a condensing type (VHK 2007, Vol 2, p 10). Data are not available for industrial systems, but presumably the penetration of condensing systems is not massively higher than in the domestic sector.

Switching from atmospheric to condensing design offers probably the greatest one-off potential for efficiency improvement. Theoretically, the switch can boost efficiency of a natural-gas-fired heater/boiler by 11% and an oil-fired one by 6%[4] (VHK 2007Vol 1, p 20, Section 2.14); the difference is due to differences in latent heat content. For LPG, we have estimated the efficiency boost to be 8.8%, calculated by the ratio of the LHV/HHV ratios of natural gas (90.2%) and LPG (92%)[5], as reported in (AEA 2012)

Switching from atmospheric to condensing design is such an obvious improvement that many governments have begun to mandate it for domestic boilers. Although condensing design is not known to be mandated for industrial applications, it is encouraged by governments (US Dept of Energy 2012), and investment-payback can be achieved in less than two years.

Therefore, for the base case in this comparison, we have assumed that the typical industrial user will switch not only from heavy fuel oil to LNG, but also switch from atmospheric to condensing heat transfer. The relative efficiency gain is calculated as follows, using the efficiencies noted two paragraphs above:

Improved gas-fired efficiency/ Improved oil-fired efficiency, or 1.11/1.06 = 1.047

So, for the base case, it is assumed that the switch from an atmospheric to a condensing heat exchanger will improve energy efficiency 4.7% more if this is done with LNG than if done with HFO.

No assumption is made for efficiency declines relative to length of service. Although these are widely known to occur, no reliable dataset for them has been found[6].

[3] This does not include losses in distribution, start-up and shut-down, modulation and so on.
[4] This is a relative increase. For instance, the efficiency of the gas-fired condensing unit would be 1.11 x 85%, or 94.35%. For the oil-fired condensing unit, it would be 1.06 x 85%, or 90.1%.
[5] That is: 90.2/92 x 1.11 = 1.088, i.e an 8.8% increase.
[6] This would be an interesting area of further research.

2.3 Emission factors

Three types of emission factors are relevant to this comparison: combustion only, CO_2 only; combustion only; and well-to-stack. These have been compiled at three levels of scope (Table 2) from authoritative sources. They all are normalised by input energy (MJ of fuel), as is common in most carbon footprint comparisons of fuels.

Table 2: Emission factors for LNG and HFO, stationary combustion (g CO_2e/MJ)

	LNG		**Heavy fuel oil**		**Light fuel oil**		**LPG**	
Scope of emissions	*LHV*	*HHV*	*LHV*	*HHV*	*LHV*	*HHV*	*LHV*	*HHV*
Combustion, CO_2 only	56.11	51.03	80.6	74.7	71.82	68.23	64.67	59.50
Data sources	(Johnson 2012, p 22)	(AEA 2012)	(Joint Research Centre of the EU Commission, EUCAR et al. 2006: Appendix 1, p 11)	(US Environmental Protection Agency 2009, Cell A35)	(AEA 2012)	Ratio	(AEA 2012)	Ratio
Explanation of scope	Only carbon dioxide emitted in the fuel's combustion is included.							
Combustion, all GHGs[7]	56.31	51.21	80.9	74.98				
Data sources	Ecoinvent: Natural gas, burned in boiler condensing modulating <100kW/RER U	Calculated: LHV value x ratio of HHV/LHV from CO_2 only	Ecoinvent:Heavy fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	Calculated: LHV value x ratio of HHV/LHV from CO_2				
Explanation of scope	All 'Kyoto' greenhouse gases – carbon dioxide, methane and nitrous oxide – emitted only in the fuel's combustion are included.							
Well-to-stack, all GHGs	69.15	64.07	94.9	90.16	85.22	80.96	77.28	71.10
Data sources	(Joint Research Centre of the EU Commission, EUCAR et al. 2006: Appendix 1, p 24)	Calculated: LHV value x ratio of HHV/LHV from CO_2	Ecoinvent: Heavy fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	Calculated: LHV value x ratio of HHV/LHV from CO_2	(Joint Research Centre of the EU Commission, EUCAR et al. 2006: Appendix 1, p 16)	HHV/LHV ratio	(Johnson 2012, from supplementary material)	HHV/LHV ratio
Explanation of scope	All 'Kyoto' greenhouse gases – carbon dioxide, methane and nitrous oxide – emitted from the beginning of the supply chain (i.e. oil and gas production) are included.							

[7] 100-year GWPs, IPCC 2007

3 Savings from switching from HFO to LNG

Carbon footprints for the LNG and HFO boiler/furnace, and the differences between the two, have been calculated according to the two equations:

Carbon footprint = Energy consumption x Efficiency x Emission factor

Carbon $footprint_{LNG}$ – Carbon $footprint_{HVO}$ = Carbon saved by switching

The footprints (Table 3) are calculated as the preceding text describes, and the differences are expressed in tonnes of CO_2 as well as in two 'everyday' units that would be understood by laypeople:

- *Car-km equivalents*: this is the difference, HFO footprint minus LNG footprint, expressed in terms of the number of kilometres an average, new EU car would need to drive to emit the same amount of carbon.
- *German-homes-heated equivalents*: this is the difference, HFO footprint minus LNG footprint, expressed in terms of the number of average German homes (heated by LPG) that would emit the same amount of same amount of carbon from their heating systems.

Table 3: LNG & HFO footprints and their differences (1 kton LPG consumption eq.)

	LNG	**HFO**	**HFO-LNG**		
Scope of emissions	*t CO2e*	*t CO2e*	*t CO2e difference*	*Car-km eq.*	*German-homes-heated eq.*
Combustion, atmospheric boiler, CO_2 only	2,673	3,840	1,167	7,778,681	177

Another 'everyday' unit, of course, is money. If the industrial boiler/furnace is operating under some sort of carbon cap, such as the EU's Emissions Trading System (ETS), then cutting carbon has a value, calculated as:

Carbon saved x Carbon credit price = Money saved by switching

The value of the credits of course depends on the market price of carbon, so a default has been given, the current price of EUAs. This price x the tonnes is calculated and presented, to show the possible savings from a switch. Although a default price is given, users can enter any price.

4 References

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