

CO₂ IMPLICATIONS OF USING COAL DERIVED FLY ASH

Executive Summary

Whilst Environmental Product Declarations (EPD's) are now seen as the benchmark standard for comparing different materials, they do have their limitations. They tend to be company specific and it can be very difficult to access the various assumptions and underlying calculations underpinning the final value.

In reality, most people tend to identify with the carbon footprint and in this respect, the members of the UKQAA have decided to provide indicative CO₂ values for coal derived fly ash (CDFA) together with the detailed assumptions and calculations pertaining to these values which relate to loading into a truck prior to delivery to the customer.

The paper focuses on the two main sources of CDFA, namely

- “Fresh” CDFA sourced from the electro-static precipitators or bag filters from coal fired power station
- CDFA recovered from stockpiles or lagoons with an average of 20% moisture and 12% carbon

The value obtained for “fresh” CDFA sourced from the precipitators is based on information obtained on the volume of air and energy required in dense phase conveying systems to transport CDFA over a distance of some 200 metres.

In the case of stockpiled or landfilled CDFA, the information has been obtained through expert input of the energy requirements to extract 250,000 tonnes of CDFA together with information arising from pilot trials on the drying and processing of this material.

The results are as follows:

- “Fresh” CDFA sourced into a silo within 200 metres of the electro-static precipitators or bag filter:
 - **1 kg CO₂ per tonne CDFA**
- Landfilled or stockpiled ash loaded into a truck:
 - **6.5 kg CO₂ per tonne CDFA**
- Dried landfilled ash to <0.5% moisture and <30% remaining on a 45 micron mesh:
 - **67.4 kg CO₂ per tonne CDFA**
- Dried landfilled ash to <0.5% moisture; <30% remaining on a 45 micron mesh and processed to contain <5% carbon:
 - **93.7 kg CO₂ per tonne CDFA**

It should be noted that the assumptions for stockpiled or landfilled ashes may range significantly subject to the local geography and moisture contents of the stockpile. Furthermore, these figures will not remain static as a result of:

- Future developments in low carbon/renewable energy sources
- Innovations in drying and processing technologies
- Use of bio-fuels, battery power and hydrogen produced from renewable energy.

Background

The UK Government's target of reaching net zero carbon by 2050 has resulted in a need to understand the carbon footprint of different materials

Whilst Environmental Product Declarations (EPD's) to EN 15804 (previously ISO 14025) are becoming a pre-requisite for the marketing and trading of many products, they can be exceedingly complex with little transparency underpinning all the underlying assumptions and calculations.

In reality, most people only identify with the headline figure of the CO₂/kg of a product or process when looking at their impact on the environment. Whilst this should be a relatively straight forward calculation, the complexity can increase exponentially when sites are producing multiple product streams. This has resulted in significant resource being directed to consultants and auditors to monitor, measure and report and new words entering into the lexicon of day to day language such as "greenwashing".

Maintaining the confidence of the public is critical when it comes to the reporting of data and it is difficult to see how this can be achieved without revealing the details behind the calculations. It is also critical to avoid arbitrary re-allocations of CO₂ to reduce the carbon footprint of the main product – "greenwashing".

For a number of years, the French steel industry has been involved in discussions of how to reallocated some of the CO₂ resulting from the production of pig iron and the subsequent steel to the blast furnace slag. There is no underlying science underpinning the reallocation of CO₂ to the slag as the slag is only present as part of the ironmaking process to remove impurities and deleterious elements. The reallocation will have no impact on the climate or the behaviour of the steel industry and is merely a political attempt to improve the CO₂ footprint of the steel, the primary polluter.

A massive amount of resource and time has been devoted discussing whether the allocation from the iron to the slag should be by mass or economic value. As an allocation by mass would have resulted in a carbon footprint that would have made the slag unattractive to the construction industry, the "preferred" route is to allocate CO₂ based on the relative economic values of the slag and the steel. Relative prices can fluctuate significantly based on supply-demand balances so will different slags have different allocations based on quality and point in the economic cycle? Would slags sold at a negative gate price (which has happened in the past in some parts of the world) have a negative CO₂? And what happens if there is no market for the blast furnace slag. Would this be carbon storage?

The UKQAA is a strong advocate of transparency and that when it comes to the allocation of CO₂ to "by-products" or "wastes", it should only be the incremental energy that is used to transport or process the by-products or wastes that should be included within the CO₂ calculations.

As a consequence, the purpose of this paper is to provide the detailed assumptions and calculations which provide an "indicative" CO₂/kg for CDFA which can be related back to the source and subsequent processing requirements. It should be noted that the figures can only be an "indicative benchmark" as every site will need to use data specific for that location.

There are two ways that CDFA can be sourced for use in the construction sector:

- Direct capture of “fresh ash” from the power station
- Extraction from landfill or lagoons.

Direct Capture of “Fresh” CDFA from the Power station

When pulverised coal is burned in coal fired power stations, the CDFA is captured in the electrostatic precipitators or bag filters. At this stage, the options are

- Sluice the ash to lagoons
- Send the ash to a silo where it can be mixed with water and trucked to landfill or sold as “conditioned” ash
- Send the ash to a silo for loading into a pneumatic tanker for dry load out sales.

The UKQAA defines that all the ash captured in the precipitators and sluiced to lagoons or mixed with water for landfill forms part of the power generation process. As a consequence, any energy associated with this should be allocated to power generation.

In the case of dry load out sales, if the loading of pneumatic vehicles takes place at the same silo banks used for conditioning the ash for landfill, it can be argued that the CDFA carries zero CO₂ allocation loaded into the truck.

This is not always the case so the UKQAA has decided to allocate the power to convey the CDFA from the precipitators (or bag filters) to the load out silo to the product. CDFA is mainly conveyed by dense phase systems and the manufacturers of such equipment have different air consumption requirements which are also dependent on:

- The distance to convey the ash to the silo
- Pipe diameter
- Height the ash needs to be lifted
- Material density etc.

Discussions with designers of conveying systems indicate that there is little difference in predicted air consumption over the range of 50 - 200 metres. So, to convey CDFA up to 200 metres, the assumptions and calculations are as follows:

- Distance conveyed: <200 metres
- Tonnage: 20 tonnes per hour
- Air requirement: 100 cubic feet per minute (CFM)
- Assumed a compressor will produce 4 CFM/horse power (HP)
- Energy requirement $100/4 = 25$ HP
- 1 HP = 746 watts
- 25 HP = 18.7 kW – say 1 kW per tonne of CDFA conveyed
- Assume the energy to convey the ash is 100% from coal fired power
 - https://www.parliament.uk/globalassets/documents/post/postpn_383-carbon-footprint-electricity-generation.pdf
 - Say 0.986 tonnes CO₂ per MWhr
 - = 0.986 kg CO₂ per kWhr
- **Say 1 kg per tonne of ash conveyed. (0.92 kg CO₂ per tonne to match calculation)**

As a consequence, the UKQAA recommends that without a detailed breakdown of energy consumption that can be directly allocated to the pneumatic transport of CDFA, “Fresh” CDFA should carry a CO₂ allocation of 1kg/tonne before any further processing and transportation to the customer.

Extraction from Stockpiles or Lagoons.

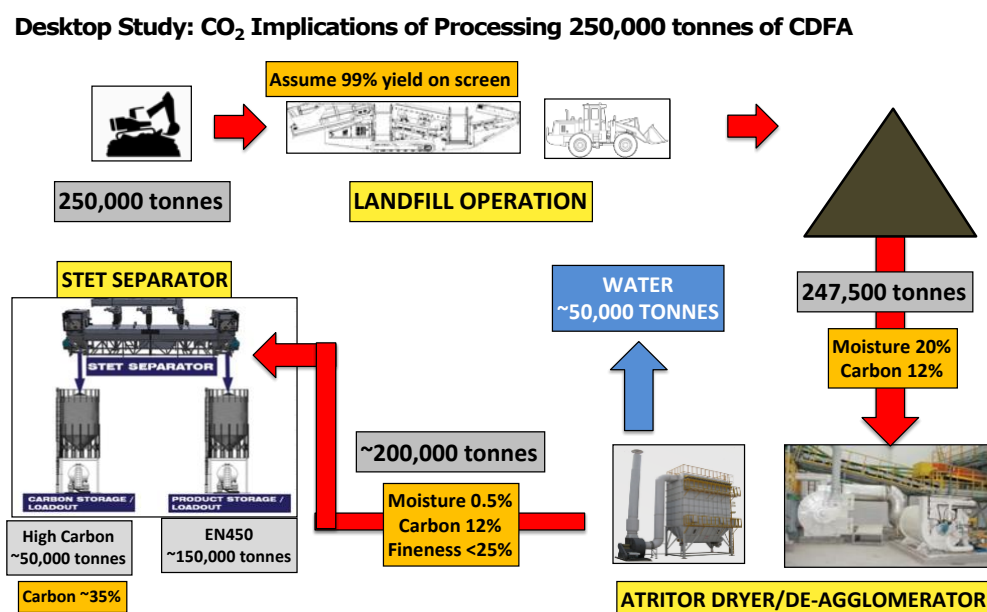
As stated above, the UKQAA assumes that any ash sourced from lagoons or legacy stockpiles carries a zero carbon footprint.

As a consequence, the CO₂ footprint of stockpiled CDFA is dependent on the incremental energy to extract the ash from the stockpile together with any further processing required. Key considerations include:

- Location of the deposit and ease of access
- The moisture level of the CDFA within the deposit
- The level of processing required
 - Does the CDFA require de-agglomeration or grinding to improve fineness?
 - Does the CDFA require to be dried and, if so, are there sources of waste heat?
 - Is there a requirement for carbon removal?
- Availability of ‘green energy’
 - Renewable electricity generation
 - Drying gas such as hydrogen fuelled burners
 - Electric motors and battery power, hydrogen and bio fuels for operating plant

The following ‘desk top’ study assumes a CDFA moisture content of 20% and an LOI of 12%. The subsequent calculations have then been based on discussions that have taken place in the UK with contractors who manage stockpiled CDFA and technology providers – Atritor and STET – who were involved in pilot scale tests to process stockpiled CDFA to supply material for testing by Dundee University.

The process flow used for the basis of the calculations is illustrated below:



Landfill Stockpile Extraction

The landfill operation is assumed to require bulldozers, shovels, screens, dumper trucks and water bowsers. With single use deposits of CDFA, the yields are expected to be high once organic material is scraped off the top layer which is why a recovery figure of 99% is used.

It is recognised that every stockpile of CDFA will have its own idiosyncrasies and the fuel consumption will be site and plant dependent. Whilst these factors will impact on CO₂ emissions, of greater interest will be how plant operators foresee the future energy sources for powering their plant. Fuel cells? Bio-fuels? Hydrogen gas?

If renewable energy or hydrogen is used to power the plant and machinery, then the CO₂/tonne of CDFA extracted would fall to close to zero.

Key assumptions for landfill extraction are provided in Appendix A1 and are based on fuel oil. The figures included in the Appendix have been based on feedback from a contractor specialising in operating with CDFA stockpiles.

Drying and De-agglomeration

Drying and de-agglomeration is by far the most intensive use of energy: both in the form of electrical energy for processing and de-agglomeration and the gas used for drying. This might not be required if the CDFA is used as a secondary aggregate though for use as an SCM, the stockpiled CDFA needs to be dried, de-agglomerated and possibly subjected to carbon removal.

For the purposes of the case study, it is assumed that the CDFA has a moisture content of 20% and that it will be dried using town gas as the energy source.

The ability to utilise waste heat from other processes or the partial or indeed total replacement of the town gas with hydrogen will have a significant impact on the CO₂ allocated to the drying. In the case of the electrical power, rather than assume 100% renewable energy, the model has assumed the current UK emission factor: 0.21107 kg CO₂/kWh (www.electricityinfo.org). This value will fall as the UK continues its move towards 100% green energy.

Key assumptions and outputs provided in Appendix A2 were based on the Atritor pilot plant testing with assumptions made for the power requirements for the balance of plant to feed the Atritor mill and to convey the resulting product. New drying technologies are being developed (Coomtech) and these may result in significant energy savings in future.

Carbon Removal

The desk top study has been based on the feedback from pilot scale tests using the STET tribo-electric carbon removal technology. STET carbon removal technology has a long history of use for CDFA and there is a very good understanding of the power requirements for running a separator including feed, filters and conveying systems (balance of plant).

Whilst the STET tribo-electric carbon removal process uses relatively little energy in its own right, the 'yield' of final product does have a significant impact if the CO₂ generated over the whole recovery process is fully allocated to the final product. The yield is very much a function of the carbon content of the feed ash and the target level for the final product. The higher the level of feed carbon and the lower the desired level of carbon in the final product, the lower the yield, ceteris paribus.

In the case study, the feed level of carbon is assumed to be 12% and the final product target is <5%. Pilot plant testing indicated a yield of 75% is achievable based on the dried samples received by STET from Atritor. It might be possible to raise these yields to closer to 80% in a full scale plant.

Key assumptions for carbon removal are provided in Appendix A3 and are based on STET's extensive experience of designing, building and operating carbon removal plants.

There are alternative technologies such as carbon burn out processes and these can have very high yields as there is no by-product apart from the CO₂ gas released into the atmosphere. However, unless there is carbon capture technology installed, every tonne of carbon removed through burn out technology results in some 4 tonnes of CO₂ gas released into the atmosphere not including any CO₂ related to the electrical power to run the processing plant. Indicative values are provided in Appendix A4 though it is beyond the scope of this report to produce a detailed model for carbon burn out.

Results from the Desk top Study

The table below summarises the estimates for the CO₂ generated during the various stages of landfill extraction and subsequent processing with the carbon footprint allocated to the final product.

	Ash Tonnes	Yield	Tonnes CO2	Split	kg CO2/t	kg CO2/t product
Landfill Extraction	250,000	99.0%	1,620	12%	6.5	10.8
Drying	247,500	80.5%	11,815	84%	59.3	79.1
Processing	199,238	75.0%	568	4%	3.8	3.8
Final EN450 Product	149,428		14,002	100%	93.7	93.7
Hi Carbon	49,809		All energy consumed allocated to product			

With reference to the desk top study and based on CDFA with a moisture content of 20% and 12% LOI:-

- Stockpiled CDFA extracted and loaded onto a truck would have a CO₂ allocation of $(1,620/247.5) = 6.5 \text{ kg CO}_2/\text{t}$
- Dried Stockpiled CDFA loaded into a pneumatic truck would have a CO₂ allocation of $(1,620 + 11,815)/199,238 = 67.4 \text{ kg CO}_2/\text{t}$
- Dried Stockpiled CDFA produced to an EN450 B/N specification would have a CO₂ allocation of **93.7 kg CO₂/t** with all energy allocated to the final product
 - This is based on a 75% yield for electro-static separation of the carbon though recent trials suggest the yields might be closer to 80% for a 12% LOI

The above values can be reduced by:

- Use of renewable energy for power
- Use of bio-fuel, hydrogen or waste heat for drying
- Reducing the moisture content of the CDFA through windrows and covered storage
 - A small reduction in the moisture content of the wet feed material has a significant impact on the thermal energy required to dry the material. Atritor calculate that a 5% reduction in feed moisture content from 20% to 15% would reduce the thermal energy requirement and associated CO₂ by approximately 25%.
- Use of bio-fuel, electric motors or hydrogen for landfill operations
- Innovations in technology (ref Coomtech)

Electricity requirement

Processing 20 t/hr

Per mill:

Dryer	Motor (kWh)	Operating (kWh)
Mill	250	200
Rotary V	1.5	1.5
Screws	1.5	1.5
Fan	200	140
Total operating kWh per mill		343

Total kWh = 343 kWh

Total kWh on dry feed basis = total kWh / dry solids out
= 343 / 16
= 21.4 kWh/t

UK electrical emission factor = 0.21107 kgCO₂/kWh

CO₂ (kg/t) = total kWh on dry feed basis x UK electrical emission factor
= 21.4 x 0.21107
= 4.52 kg/t

Total CO₂ from drying

Total CO₂ from drying = gas requirement CO₂ + electricity requirement CO₂
= 54.8 + 4.52
= 59.32 kg/t

APPENDIX A3: Processing: 199,238 tonnes processed 75% yield

Separation plant 13.5 kWh/t

UK electrical emission factor = 0.21107 kgCO₂/kWh

CO₂ (kg/t) = (total kWh/t x UK electrical emission factor) / yield percentage
= (13.5 * 0.21107) / 0.75
= 3.80 kg/t

APPENDIX A4: Carbon Burn Out Assumptions

Burn out 12% LOI to 2%	
LOI In	12 %
LOI Out	2 %
Ash Feed	20 TPH
Kg Carbon Burned	2000 kg/hr
Kg CO ₂	7,333 kg/hr
Ash Product	18 TPH
CO ₂ Produced by Burn	407 kg Co ₂ /T
If Dried first from 20% to 5% Moisture using gas:	
CO ₂ per T drying gas	41
Total CO ₂ kg/T	449 kg CO ₂ /T

Note the above figures for burn out represent only the CO₂ produced chemically during the burn out process, and additional CO₂ would have to be attributed to the electrical energy consumed by the process equipment.