A comparison of gas and electric cremator emissions in the UK

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Abstract

There are 307 crematoria operating in the United Kingdom (UK), processing 472,000 cremations in 2019; over 98% of these cremations were undertaken using gas-fired cremators. Presently, there is no academic literature that addresses the carbon dioxide (CO_2) and nitrogen oxide (NO_x) emissions of cremation; regulatory bodies policies are only focused on mercury and particulate emissions. The latest models of electric cremators are being labelled as 'green cremation', this study models and compare the CO_2 and NO_x emissions of both cremators. An electric cremator produces 50-80% less CO_2 emissions than the gas cremator, the range is dependent on the number of cremations processed per day and energy tariff used, and produces 33% less NO_x emissions. As the fuel mix becomes 'greener', there will be a further 44% reduction in CO_2 emissions from the electric cremator connected to the national electricity grid between 2020 and 2050. The electric cremator has a higher initial cost than the gas cremator, however, differences in running costs are negligible. Alternative fuels, such as hydrogen blend and biogas may be feasible in reducing emissions in certain cases, however, they are not viable solutions for the UK industry. Findings from this research suggest that UK crematoria should install electric rather than gas cremators, however, existing intact gas crematoria should consider the higher financial costs of switching. UK policymakers should propose new standards on CO_2 and NO_x emissions from cremation. With the UK government's drive towards electrification of the economy, manufacturers must offer electric cremators, which could decrease the initial unit price to crematoria.

Keywords: cremation, CO_2, NO_x, gas, electric, future, cost

Declaration

I hereby confirm that the entirety of this dissertation is my work, where others work has been used, it has been referenced accordingly using CU Harvard referencing. I confirm that I have abided to the Coventry University ethics policy and that all of the work submitted corresponds with the submitted ethics documents accepted prior to the completion of this work.

I agree that this research project can be made available to other students in the School of Energy, Construction & Environment as a reference document.

Signed: BCopeland **Date:** 09/04/2021

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List of Abbreviations

GHG	Greenhouse Gas
RCP	Representation Concentration Pathways
RCT	Required Cremation Temperature
CO_2	Carbon Dioxide
NO_x	Nitrogen Oxide
SSP	Shared Socioeconomic Pathways
SCR	Selective Catalytic Reduction
BEIS	Department for Business, Energy & Industrial Strategy
DEFRA	Department for Environment, Food & Rural Affairs
CCC	Climate Change Committee

1 Introduction

1.1 Background

The UK cremation industry is becoming increasingly aware of its environmental duties and impact through initiatives such as the Environmental Stewardship Group (ESG), which is a collaboration of major stakeholders in the bereavement industry. The UK bereavement industry is worth £2.5 billion a year, and cremation accounts for 78% of all funerals (Environmental Stewardship Group 2021; The Cremation Society 2019). The UK cremation industry processes around 472,000 cremations per year across 307 crematoria [2019], the demand for cremations is relatively inelastic to price as it serves an essential service (The Cremation Society 2019). This service has been overburdened during the COVID-19 pandemic. As cremation is essential for the bereaved, the consumer choice is limited to the region in which they reside, therefore, the environmental aspects of the cremation process are not usually considered by the consumer.

The UK government has set a target to reduce greenhouse gas emissions (GHG's) to 68% below 1990 levels by 2030, this will require the electrification of major industries and decarbonisation of domestic and industrial heating (BEIS 2020i). The UK has set new legislation which aims to decarbonise the economy, such as: the banning of gas boilers in new-build homes by 2025 and a ban on new petrol and diesel cars by 2030 (BEIS 2020h). Increased renewable energy generation is integral to the decarbonisation of grid electricity, renewable generation in the UK is up to c. 40% [2020], 8% higher than in 2010 (BEIS 2020c).

Gas cremation requires the combustion of natural gas at temperatures above 800°C, which is 13 times higher than a domestic boiler, therefore, requiring a significant volume of gas to attain temperature (DFW Europe 2021; Viessmann 2021). More than 98% of UK cremators are gas-fired, in recent years a new electric cremator has been produced, which has been installed by two UK crematoria in Huntingdon and North Oxfordshire (The CDS Group 2020). Crematoria that have chosen the electric cremator during their next installation have classified the cremator as the 'green option' (Huntingdon Town Council 2020). Crematoria are run by both local authority and private organisations, 74% of local authorities have signed up to the climate emergency and therefore electric cremation could be a viable option to further reduce both carbon dioxide (CO_2) and nitrogen oxide (NO_x) emissions in the industry; as the UK strives to become net-zero by 2030 (Declare a Climate Emergency 2021).

1.2 Research Problem

DEFRA (2012) regulates the UK cremation emissions through the 'Process Guidance Notes (5/2)', however, both CO_2 and NO_x are unregulated. The available scientific literature regarding cremation emission is limited to the analysis of mercury and particulate emissions (González-Cardoso et al. 2018; Takaoka et al. 2021). There are online sources that estimate the CO_2 emissions from gas cremation is about 245kgCO_2 per cremation, however, these claims are not supported by the scientific evidence (National Geographic 2019). Currently, there is no publicly available information that provides an estimate for the CO_2 and NO_X emissions from electric cremation [March 2021].

This research project is a comparative study that focuses on gas and electric cremation emissions (CO_2 and NO_x). This study considers future projections of gas and electric energy mixes [using available government publications] and also viable alternative fuels to ensure that the future industry is sustainable. A financial cost comparison is to be undertaken using initial unit and energy consumption costs. The findings and recommendations from this innovative research will inform key stakeholder decisions and help policymakers review and reduce CO_2 and NO_x emissions in the cremation industry.

1.3 Purpose of the Research

This study investigates both gas and electric cremation emissions using a pragmatic research approach to ensure the major stakeholders and policymakers can make informed decisions.

Main Aim:

To investigate present and future carbon dioxide (CO_2) and nitrogen oxide (NO_x) emissions from gas and electric cremators under various policy and technology scenarios.

Objectives:

- Undertake a critical review of the literature.
- Examine current CO_2 and NO_x emissions from UK gas and electric cremations and review alternative fuel types.
- Investigate the carbon intensity, energy use, and CO_2 emissions of cremations using future energy projections.
- Undertake a cost comparison of gas and electric cremation.
- Provide recommendations to the cremation industry linked to fuel-type choices and UK emissions policies.

2 Literature Review

The literature review will provide context to the issue of cremation emissions by systematically reviewing the available literature and identifying gaps in our knowledge. This chapter includes content on climate change, energy use in the UK, and cremation industry emissions.

2.1 Climate Change

The IPCC (2011) defines climate change as the change in climate over a prolonged period of time, caused by either natural variability or anthropogenic activity, this is recognised by changes in averages using statistical tests. Natural cycles do cause changes in climate, identified as forcing agents, including solar irradiance, tectonic processes, Milankovitch Cycles, and El Niño Southern Oscillation (Met Office 2021). The BGS (2021) identifies natural greenhouse gases (GHG's) as a crucial factor in retaining a habitable temperature on Earth, the naturally produced GHG's absorb heat energy and reduce the amount of energy released back to space. Human activity, particularly in the post-industrial age, has increased GHG levels to unprecedented levels, particularly carbon dioxide (CO_2), as seen in Figure 1 (NOAA 2020).

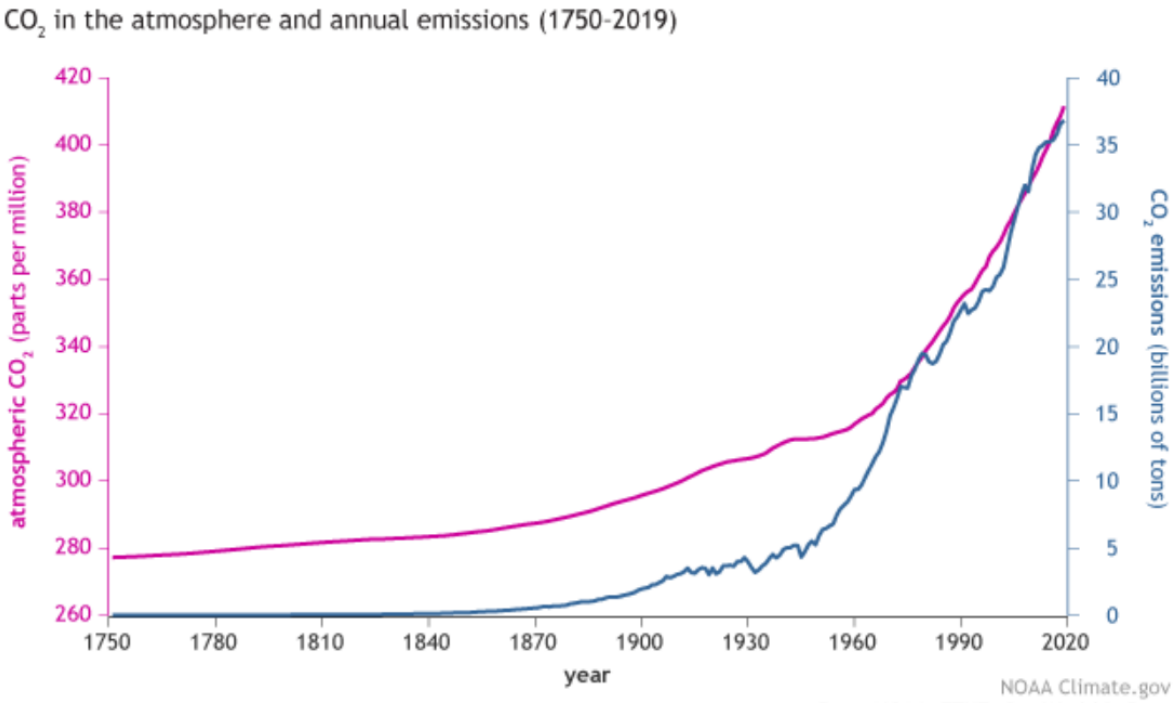


Figure 1. CO_2 levels [pink line] measured against human emissions [blue line] (NOAA 2020)

Anthropogenic activities, such as GHG emissions and land-use changes in the post-industrial age, have caused an increased frequency of extreme events and have altered

weather patterns on national and global scales (Bhattacharya 2019). The Climate Change Committee (2020) projects that the UK will see an 'inevitable' future change in climate with a 0.5°C increase in average temperature, a 10% increase in heavy precipitation, and a 50% likelihood of heatwaves each year from 2050. The UK was responsible for emitting approximately 435.2 million tonnes of CO_2 in 2019, with transport and energy being the highest emitters, therefore, the UK is jointly responsible for past and future climate change (BEIS 2020a). The UK is required to mitigate against the risk of climate change by reducing their GHG emissions at source under the 2015 Paris Agreement (UNFCCC 2015). The UK is set to host the 26th UNFCC meeting in November 2021, the meeting will highlight global climate change issues and present mitigation measures to further reduce GHG emissions (GOV.UK 2021).

The IPCC (2011) developed future climate change scenarios using Representation Concentration Pathways (RCP's), which project temperature increases based on GHG emissions and other radiative forcings (Shahbaz et al. 2020). The RCP scenarios do not consider policy development, crises (such as COVID-19) and socioeconomic factors; the Shared Socioeconomic Pathways (SSPs) do and are to be considered in the next IPCC report (Pedersen et al. 2021). Pedde et al. (2021) explored a multi-driver approach for the UK, which examines both the UK's RCP's and SSPs to create a Climate Change Impact, Adaptation and Vulnerability (CCIAV's) assessment. In 2022, the third edition of the UK climate change risk assessment is required by law to be published, this will outline the risk priority of each sector of the UK economy and also address the research gaps highlighted in the 2nd edition (Climate Change Committee 2021).

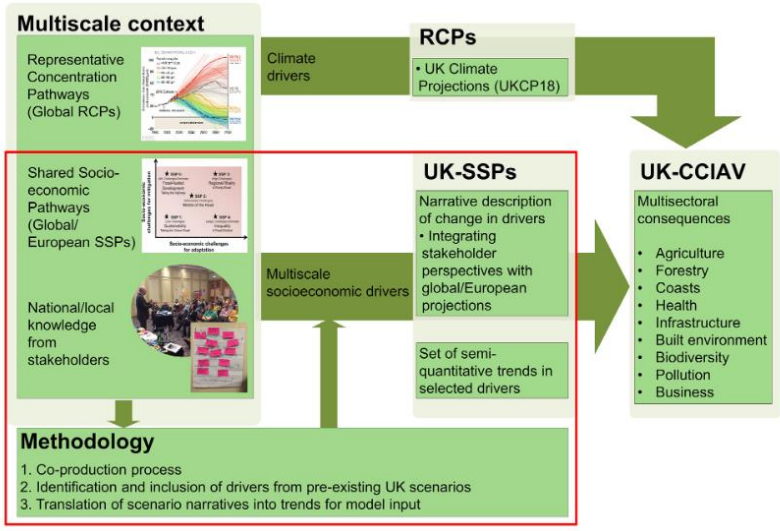


Figure 2. Assessment of CCIAV's for a UK multi-driver approach (Pedde et al. 2021)

Figure 2 combines key stakeholder knowledge and SSPs to identify the UK's key socioeconomics drivers; the UK SSPs differs from that of Europe as they also integrate national policy and research derived from stakeholder knowledge (Pedde et al. 2021). In Figure 3, the SSPs demonstrate a trade-off between mitigation and adaptation of climate change, where SSP1 (Sustainability) represents maximised mitigation, which will reduce the requirement for adaptation to climate change impacts. The SSP5 pathway (Fossil-Fuelled Development) is reliant on adaptation and technological advancement (Chen et al. 2017; Kebede et al. 2018).

Figure 3. UK Shared Socioeconomic Pathways (SSPs) concerning adaptation and mitigation challenges (Pedde et al. 2021).

2.2 Energy Use: UK

Energy consumption (absolute) in the UK continues to fall and is now comparable to that of 1970; improved efficiency, conservation technologies and economic divergence from heavy manufacturing are the main drivers (BEIS 2020d). Future energy consumption in the UK could increase in future years as energy efficiency technology stagnates, the population continues to grow and energy consumption from decentralised sources (i.e. rooftop solar panels) is not included in the energy consumption mix (Chatterton et al. 2016). Consequently, the UK must still reduce its carbon intensity within the national energy mix.

To reduce the UK's carbon intensity the government's energy strategy must continue to diverge from fossil fuels (Şahin 2021; Eurostat 2020). Kattirtzi and Winskel (2020) identified a divergence of opinions with decarbonisation through community-based provision, national

policy and infrastructure; or through a mixture of technological advancement and policy, some stakeholders believe a combination of pathways is the appropriate approach. However, an approach that identifies and mitigates short-term pollution and long-term decarbonisation would be appropriate (OECD 2020). Brexit (UK exit from European Union) brings further uncertainty to the UK energy mix over the medium-term (Adedoyin and Zakari 2020). Changes to the UK's energy system post-Brexit are uncertain, however, the UK has pledged to continue to trade gas and electricity across national boundaries due to the construction of further interconnectors between France and Norway (National Grid 2021). More importantly, private businesses and domestic households will remain the key drivers of change in the energy system with support from the local and national governments (Cairney et al. 2019). The UK has set a target of 50% renewable energy generation by 2030, this is challenging as wind and solar are intermittent sources and there is, therefore, a need for increased energy storage capacity or an increase in alternative energy sources, such as nuclear energy (Sharifzadeh, Lubiano-Walochik and Shah 2017).

2.3 UK Gas Network

To achieve net-zero emissions by 2050, the UK gas network will need to be decommissioned, however, as of 2016, 23 million UK households were supplied through the gas network, mainly for heating (Scafidi et al. 2021). The demand for natural gas in the UK is dominated by two main sectors, domestic use and transformation (conversion to electricity), which accounted for 36% and 35% respectively in 2019 (BEIS 2020b). The UK heat demand is susceptible to seasonal flexibility and alternatives to natural gas are required to supply energy for heating and hot water in the winter months. Artificial heating accounts for 37% of total GHG emissions in the UK, making it the single largest contributor (BEIS 2018). To understand the efficacy of decarbonising the UK gas network, alternatives must be explored like biogas and hydrogen. Furthermore, the decentralisation and electrification of UK heating could also be considered, which would involve electrification through heat pumps, which would require less energy than an electrical heating system (Chen et al. 2021).

2.3.1 UK Natural Gas Supply

The UK's fossil fuel consumption in 2020 was almost solely from natural gas, as coal is being phased out from energy production by 2025. Natural gas emits less CO_2 than coal per kilowatt-hour [kWh] (Table 1; BEIS 2019; Leonard, Michaelides and Michaelides 2019).

Fuel Type	$kgCO_2/kWh$
Coal	0.33
Natural Gas	0.18

Table 1. Fossil fuel carbon dioxide (CO_2) emissions per kWh (BEIS 2019)

A concern is that the UK is a net importer of gas, in 2019 the production of gas accounted for 439TWh whereas imports accounted for 518.1TWh, therefore, the life-cycle and upstream emissions of gas-fired generation are not accounted for as domestic supplies diminish (BEIS 2020c; Hammond and O'Grady 2017; Table 2). The transmission distances of gas imports have a significant impact on emissions, as gas imported from Russia is thought to emit 20 times the amount of CO_2 compared to domestic supplies, the result of higher gas leakages through piping over transmission distances (Hammond, Howard and Jones 2013).

The UK gas supply is finite and will decrease, BEIS (2020c) estimates that by 2035 natural gas production will be 55% lower than in 2018. At present, the domestic gas supply comes from the UK continental shelf, shale gas, or biomethane, although there is a moratorium on shale gas (Foxon 2013; Brock 2020). Biomethane provides little additional opportunity for the UK to increase its energy security and reduce CO_2 emissions, as there are issues of land use availability, which restrict supplies (Hammond and O'Grady 2017). The UK will need to increase its imports of natural gas, which could be secured through new Russian pipelines, although this is politically challenging and will increase life-cycle emissions. The UK is more likely to increase its importation of Liquified Natural Gas (LNG), which, due to the energy-intensive liquefication process, is more carbon-intensive [0.23-0.27$kgCO_2$/kWh] (Richards and Al Zaili 2020).

Source of Natural Gas	Percentage of Supply
UK Production (inc. biomethane)	45%
Norwegian Pipeline	31%
Russian Pipeline	<1%
LNG Imports (50% from Qatar)	21%
Other Pipelines	2%

Table 2. UK Gas Supply 2019 (BEIS 2020c)

2.3.2 UK Biogas Future

As of 2017, biogas accounted for 4% of the UK's total gas supply (Business Energy 2018). The UK gas supply is highly dependent on potentially uncertain future trade agreements, declining indigenous supply, and the requirement for the UK to reduce its natural gas

demand to comply with legally binding carbon targets; consequently, biomethane could be an important bridging fuel (Richards and Al Zaili 2020). Biofuels (BioLPG), much like LPG, can be used as an alternative fuel for transportation. The feedstock supply of BioLPG has a significant impact on life-cycle emissions, waste cooking oil has an 89% reduction in GHG's in comparison to fossil fuels, whereas rapeseed crop has a 5% increase (Acquaye et al. 2012). Adams (2018) investigates the life-cycle emissions of biomethane - a 'climate-neutral fuel' defined as biogenic. However, the entire chain of biomethane production must be considered as emissions are highly dependent on the feedstock supply. Anaerobic digestion (AD) plant matter supplied through crop yield provides a large share of the UK's biomethane production (31%); the application of fertilisers, soils emissions (nitrogen oxide), and heavy-duty vehicle use (diesel) are primary sources of life-cycle emissions in AD plants (DEFRA 2020; Adams and McManus 2019). Indirect and direct land-use change, attributed to crop-based bioenergy plants, will cause carbon leakage if not effectively mitigated through policy implementation. It has been suggested that AD plants that utilise manure and waste should be encouraged with higher subsidies (Styles, Dominguez and Chadwick 2016; Tufvesson, Lantz and Börjesson 2013; Ostwald and Henders 2014).

The future of bioenergy in the UK is dependent on policy decisions. The Renewable Heat Incentive (RHI) scheme is set to finish in March 2021 - the main catalyst for bioenergy uptake. The sustainability of bioenergy is reliant on policy-makers encouraging the use of waste feedstock, which possesses a lower carbon intensity, and an increase of injection to grid-points to incentivise new suppliers and optimise energy security (Richards and Al Zaili 2020). Hoel (2020) argues that bioenergy from any source should neither be taxed nor subsidised as the energy production of bioenergy is carbon-neutral and not carbon-negative; the subsidisation of bioenergy may indicate that the tax on fossil fuel production is too low. Hoel (2020) does not consider the use of carbon capture storage (CCS), which would require significant policy and financial support, with subsidies for high-cost infrastructure (Babin, Vaneeckhaute and Iliuta 2021; Bellamy et al 2021).

2.3.3 Hydrogen Gas

The use of hydrogen gas has focused on transport (Centre for Policy Studies 2020). There is potential for hydrogen to help decarbonise the UK's domestic and industrial heat demand, however, this will require significant investment and policy support from the UK government (Edwards, Font-Palma and Howe 2021). The UK gas network is equipped for partial hydrogen injection (20%), the process does present safety challenges although it would reduce CO_2 emissions in the gas network by an estimated four million tonnes of CO_2 per year, reducing energy system CO_2 emissions by 2.5% (Quarton and Samsatli 2020). The

utilisation of hydrogen gas in the UK energy system is in direct competition with the electrification movement, the principal competing factors are cost, public uptake and government subsidisation (Watson, Lomas and Buswell 2019). There is a requirement for global policy and standards, which determine blend limits, the sourcing of hydrogen gas, and its transportation across borders. There are also issues of economies of scale (International Energy Agency 2019). Hydrogen possesses a lower molecular weight in comparison to natural gas, therefore the pipelines would require larger diameters and increased leakage testing (Edwards, Font-Palma and Howe 2021).

There are two principal methods for producing hydrogen gas: 96% of global production is through steam methane reforming (SMR), using fossil fuels and 4% is produced through electrolysis, using a mixture of electricity and water (Energy Research Partnership 2016). To produce ‘blue hydrogen’ a combination of SMR and carbon capture storage (CCS) is required, whereas to produce ‘green hydrogen’ a combination of water and renewable electricity is needed. To reach 2050 carbon net-zero targets hydrogen production must be 10 times greater (c. 270TWh) (Committee on Climate Change 2019; Edwards, Font-Palma and Howe 2021). The future of low-carbon hydrogen is reliant on the implementation of CCS technology, as it is envisaged that 63% of hydrogen by 2050 will be produced through SMR. If SMR is the chosen source for hydrogen, the demand for natural gas will increase and, therefore, increase the upstream emissions of hydrogen gas, especially if LNG is used (Committee on Climate Change 2018; Edwards, Font-Palma and Howe 2021).

2.4 UK Electricity Network

The UK has set a decarbonisation target for UK electricity’s carbon intensity to reduce to 0.005kgCO_2/kWh, which would be a major landmark towards reaching zero-carbon grid intensity by 2050 (Sithole et al. 2016). The UK electricity generation mix in the second quarter of 2020 was led by low-carbon generation (64%), with renewable energy accounting for 46% of total generation, up by 11% from the previous year. Gas generation decreased by 29.9% from the previous year (BEIS 2020b; Table 3).

Source	2019 (TWh)	2020 (TWh)	2019 (% of mix)	2020 (% of mix)
Gas	33.3	23.2	43.8	35.4
Coal	0.45	0.4	0.6	0.6
Nuclear	13.1	11.9	17.1	18.1
Renewables	27.1	30.1	35.5	45.9
Renewable	**2019 (TWh)**	**2020 (TWh)**	**2019 (% of mix)**	**2020 (% of mix)**
Onshore wind	6.1	6.1	22.5	20.3
Offshore wind	6.0	7.8	22.1	26.0
Bioenergy	9.2	9.9	36.5	33.0
Solar	4.9	5.1	18.1	17.0
Hydro	1.0	1.1	3.7	3.7

Table 3. Electricity mix Q2 of 2019 and 2020 (BEIS 2019; BEIS 2020g)

2.4.1 Renewable Energy Generation

The governance of the UK electricity network is focused on a centralised system of generation using primary fuels, large wind farms, solar farms, and nuclear energy, which is distributed through high-voltage grids and lower-voltage to reach the consumer (Baker, Hook and Sovacool 2021). Battaglini et al. (2009) support a combination of community-based (decentralised) renewable energy schemes and the existing centrally regulated network, both co-existing to provide a cost-optimised approach to achieving net-zero carbon by 2050 (Child et al. 2019).

2.4.2 The future of low-carbon electricity

Saidi and Omri (2020) investigated whether the role of renewable and nuclear energy is substitutional or complementary, their study concluded that both energy generation technologies reduce CO_2 emissions in economically developed countries. The government must encourage more Public-Private Partnerships to increase private investment in renewable energy, which will secure long-term levelised costs of energy (Johnston et al. 2020). An effective economic policy is the feed-in-system, which encourages the generation of renewable energy through subsidisation, the subsidy is known to positively impact renewable energy generation in the UK but is subject to specific market conditions (Alolo, Azevedo and El Kalak 2020).

In terms of an economic comparison between renewable and conventional alternative energy generation, renewable energy currently presents a lower levelised cost of energy (LCOE) in the EU, USA, and China when carbon dioxide equivalent (CO_{2eq}) costs are

excluded, however, when they are included, all G20 countries will achieve lower LCOE by 2030 (Ram et al. 2018). Ram et al. (2018) added that for countries to achieve lower LCOE for renewables they would have to invest consistently over time to gradually increase the level of renewable generation, as intermittent and intense generation would interrupt the power systems. Lazard (2020) undertook an unsubsidised analysis of the global LCOE of renewable energy in comparison to conventional energy and represents the cost competitiveness of renewable energy (Lazard 2020; Figure 4).

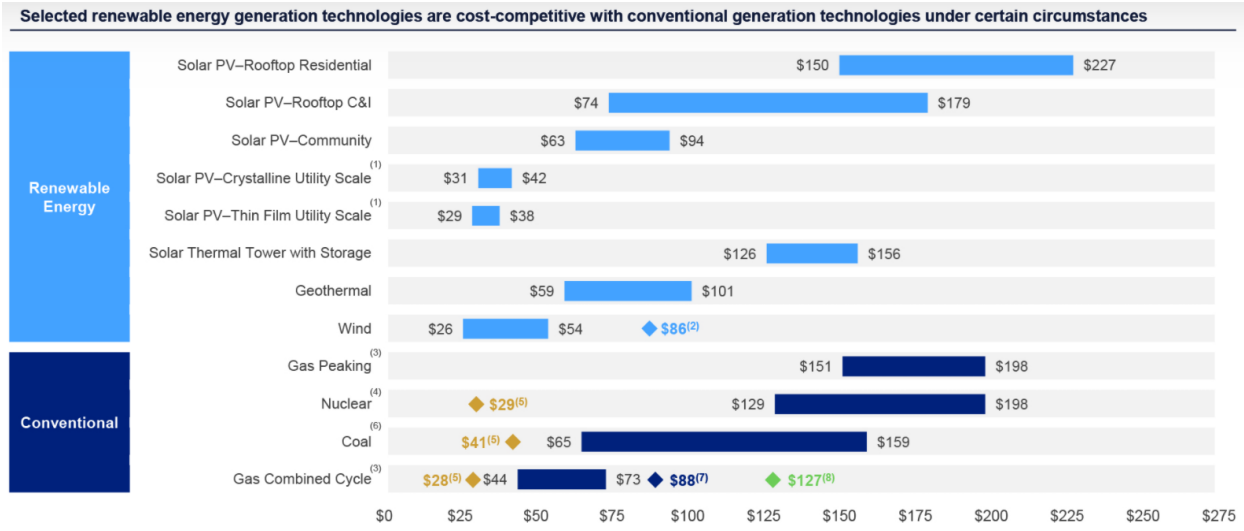


Figure 4. The levelised cost of energy for renewable energy compared to conventional sources (Lazard 2020).

Allan et al. (2020) investigated the environmental and economic impacts of offshore wind development in the UK, which is considered the future of renewables, and claimed that it is highly achievable for the UK to reach the 30GW generation target, which would reduce CO_2 emissions by between 611k and 653KMtCO_{2eq}. In 2020, the UK government pledged to increase its target of 30GW of energy from offshore wind to 40GW by 2030, which would power every home in the UK (GOV.UK 2020b). The disadvantage of wind energy is that supply does not correlate with demand and thus storage is required, therefore, a decision must be made between renewable energy curtailment or electrochemical storage. This is a possibility, CEP Energy in Australia announced [February 2021] the world's largest battery storage [1200MW], which is designed to integrate the increasing share of renewable energy (Energy Storage 2021). Storage technologies have higher life-cycle emissions of up to 30% compared to curtailment (Barnhart 2017). Curtailment is a better option for the UK, the focus should switch to increasing electrical demand as the carbon intensity decreases and a switch to electrical heating. Combustion systems that utilise additional renewable energy will be the most environmentally sound solution (Mei, Yaxu and Xuguang 2017).

With increased renewable electricity generation and policies to increase electrical demand, economies of scale will help reduce the unit cost of electricity generation and utilisation. The UK government's investment focused on renewable energy will provide a more realistic pathway to attain net-zero than green gas (Davis et al. 2020; Bachner et al. 2019).

2.5 Cremation Industry Emissions

Academic literature on emissions from cremations is limited. Work focuses on mercury and particulate matter (PM2.5) emissions from cremation but does not consider CO_2 or NO_x emissions. Defra (2012) is the regulatory body for UK cremation emissions, the PG5/2 document summarises regulations for both gas-fired and electric-fired cremators, much of the focus is on abatement systems in which 50% of UK cremations are required to be processed through abated plants. Takaoka et al. (2021) estimate that 10% of UK cremations exceed the regulated limit of mercury concentration, which demonstrates the weak uptake of emission reduction technology across the industry. González-Cardoso et al. (2018) investigated crematories in Mexico, highlighting the high levels of PM2.5 emissions that occur without abatement, however, in this study, combustion temperatures range from 482-797 °C, which is below the recommended minimum 800°C for a cremation to reduce emissions.

DEFRA (2012) determine the CO_2 emissions from gas as the principal GHG during the cremation process. The advice for operators is to reduce gas consumption through retaining and reviewing quarterly gas bills as a part of their permit; however, this is the only control technique recommended to reduce emissions and is not regulated. There are no control techniques for NO_x emissions in the existing legislation. To control NO_x emissions, an uptake in Selective Catalytic Reduction (SCR), known in the industry as DeNOx, has developed across the UK, the technology reduces NO_x emissions by 70-90% (Romero and Wang 2019). An SCR system requires the application of urea, which has probable disadvantages: ammonia slip, physical space for the system (difficult for urban crematoria), CO_2 stored in the urea, and emissions upon application (He, Chen and Xu 2017; Trevor Brown 2016).

Monitoring CO_2 and NO_x emissions from the cremation process is not required by the regulator (DEFRA), however, from a series of general publications: 245kg of CO_2 and 500g of NO_x is thought to be emitted per 75-minute cremation when gas is the combustion fuel (Promessa 2019; Champ Funeral Services 2016; Daily Echo 2019). The emissions from the combustion fuel itself must be differentiated from the emissions from the cadaver and coffin (Table 4). In the UK, 95% of combusted coffins are thought to be constructed of chipboard or medium-density fibreboard (MDF). Coffins constructed using adhesives and chipboard/MDF

have a high nitrogen content, which when combusted produce high levels of NO_x (Piekarski et al. 2017).

Source	Average Weight	Carbon Content	Total CO_2 Emissions
Cadaver	76.5kg[1]	18% of average body[2]	12.6kg
Chipboard Coffin	35kg[3]	409gCO_2e/kg[4]	14.3kg
Total	n/a	n/a	26.9kg

Table 4. Carbon emissions resultant from cadaver and coffin (Wales.GOV 2009[1]; ThoughtCo. 2019[2]; LifeArt 2019[3]; VTTResearch 2013[4])

2.6 Conclusion

The review of academic, governmental, and business literature has highlighted the UK's energy transitioning towards low-carbon alternative sources, although there is no single method to decarbonise a national energy system. However, the UK government has directed most investment and policy incentives towards renewable electricity generation.

The UK energy mix is becoming increasingly important to the cremation industry, as most cremators in the UK operate using gas combustion, which is recognised in the literature as the principal cause of emissions. European manufacturers (DFW Europe and IFZW) have developed new types of electric cremation plants that remove the requirement for a gas connection and the technology has the potential to decarbonise the cremation industry and also reduce nitrogen oxide emissions. Electric cremation must be reviewed in terms of its efficiency and carbon intensity when compared to a gas cremation plant, using different future UK energy mix scenarios.

The literature review has revealed the gaps in the analysis of CO_2 and NO_x emissions from cremation, there are evidential emissions from gas combustion, however, these need to be compared to electrical combustion emissions in the context of cremation and the UK's future energy mix.

3 Methodology

3.1 Research Model

The following chapter outlines the research design and strategy essential to fulfil the aims and objectives of this project. A justification for the research philosophy, methods, and approaches will be provided using the ‘research onion’ framework (Saunders, Lewis and Thornhill 2016; Figure 5). Prior to developing a research objective, a researcher attains a positionality and philosophy (outer layers of the onion), which provides the context to the ‘inner layers’ of the research (data collection methods). Therefore, the aims and objectives of a project are developed and influenced by the researcher's views, values and beliefs.

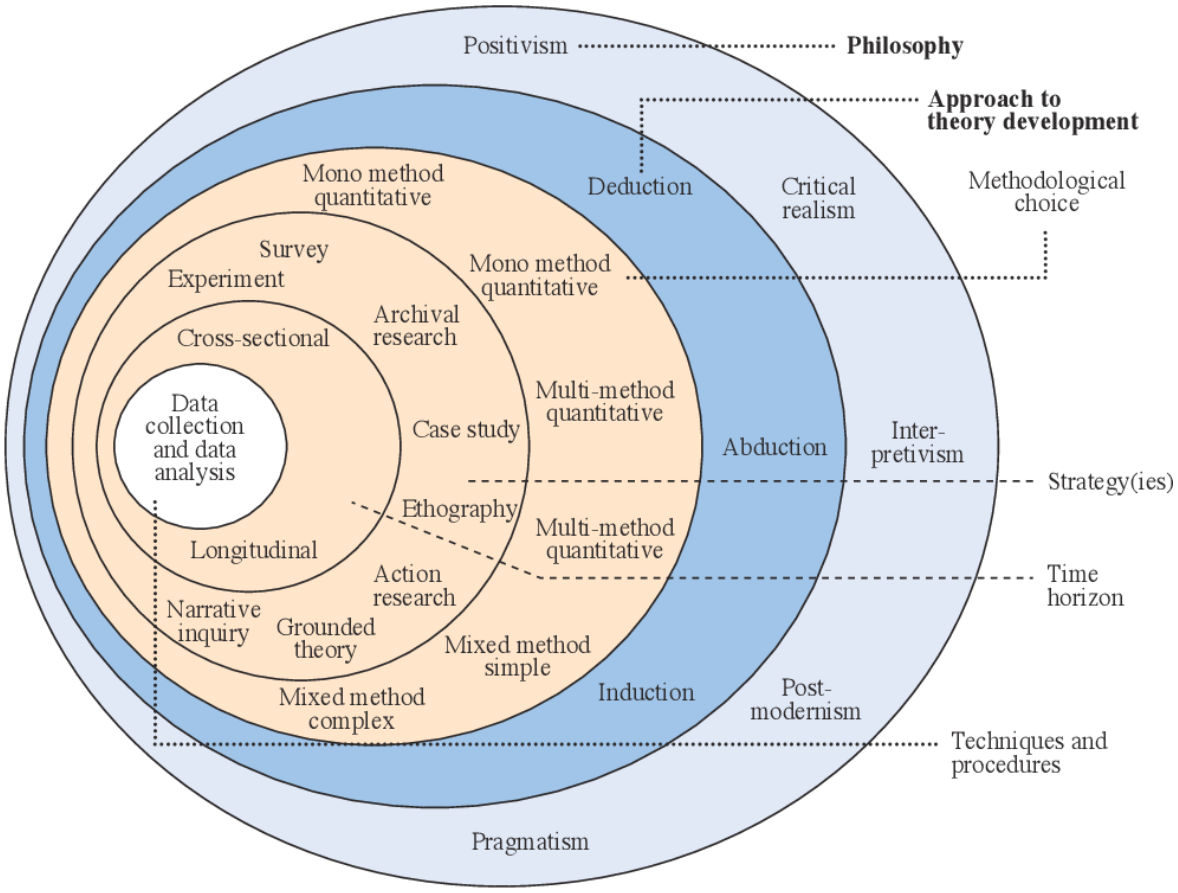


Figure 5. Research onion framework (Saunders, Lewis and Thornhill 2016).

3.1.1 Research Philosophy and Positionality

The positionality of the researcher is not an integral part of the ‘research onion’, however, all research projects involve innumerable factors that influence the study’s design. Jafar (2018) expresses that quantitative research should involve positionality as it increases context through disclosure of the research environment, which should not diminish from the overall result of the study. A review of sustainability within the bereavement industry was facilitated

by the researcher's experience after completing a one-year work placement with The CDS Group, a specialist company in cemetery and crematoria consultancy. In advance of working with The CDS Group, the researcher developed core values related to climate change and emission reduction, which instilled an interest in cremation industry emissions.

The outer layer of the research onion can be subdivided into three philosophical theories: epistemology, ontology, and axiology, and all influenced this research project. This research follows a positivist epistemology, defined as a reliance on scientific evidence to form legitimate claims and infer relationships in data (Couper 2020). The gaps in scientific research regarding cremation emissions (specifically CO_2 and NO_x emissions) required the researcher to provide scientifically evidenced recommendations, which are informed by elements of pragmatic axiology gained from industry experience. Due to the complex nature of the cremation industry, and the multiple factors that influence the performance and efficiency of cremation equipment, an element of pragmatism is required to attain meaningful results. Pragmatism is defined as the practical use of data to form knowledgeable conclusions (Kelly and Cordeiro 2020).

3.1.2 Research Approach

A hypothetico-deductive research model has been chosen, this research project will obtain and analyse data to formulate falsifiable conclusions, which are not presently available in current academic literature (Gunter 2012).

3.1.3 Research Strategy

This research study involves a multi-method quantitative strategy of primarily objective data analysis, with elements of subjective qualitative data from the bereavement industry. The importance of a multi-method strategy is to reduce scepticism as each research method possesses limitations, and therefore, subjective information provides pragmatic conclusions and recommendations, which can add weight to the quantitative data (Brewer and Hunter 1989).

The primary method utilised in this study was the request for data from various stakeholders within the industry. There are issues involved with using secondary data gathered by individuals external to the investigation, as the environment where data originates cannot be controlled or reviewed directly. The researcher must consider that the data may have been manipulated to reach a desired outcome; therefore, comparisons between multiple datasets, using the comparative case study strategy (CCSS) is an important element of analysis herein. Bartlett and Vavrus (2017) define CCSS as the critical assessment and comparison

of two or more case studies to help recognise similarities anomalies, which could then be questioned.

The results of the research must be contextualised using real-world comparators to ensure the recommendations are grounded. Upham, Dendler and Bleda (2011) conclude that public perception of emission values on food labels is heightened when real-world comparators, i.e. food emissions versus car milage, allows the public to visualise their carbon footprint.

3.1.4 Time Horizon

The study of cremation processes involves many variables that can influence energy consumption within the business, however, this study is time-constrained and, therefore, cannot provide definitive ‘cause and effect’ relationships for every variable. However, this cross-sectional study does allow the comparison of several variables. Bryman (2007) defines a cross-sectional study as a snapshot in time of different datasets to then find a relationship between variables.

3.2 Data

The philosophy and approach to research have a causal effect on the core of the research and determines data collection and analysis strategies.

3.2.1 Adaption of research

The litigious and confidential nature of the cremation industry resulted in early adaptions to the research strategy. The initial strategy was to collect CO_2 and NO_x emission data directly from the operators, however, this was not possible due to current monitoring procedures that do not involve CO_2 and NO_x data collection. Therefore, the strategy shifted to the collection of energy consumption data. Operators of crematoria are under immense pressure, due to the COVID-19 pandemic, therefore, the cooperation of cremator manufacturers was viewed as the most viable approach.

3.2.2 Data collection

The researcher's positionality allowed access to manufacturers of cremation equipment, three out of four European cremation manufacturers that were contacted took part in the study (Table 5).

Manufacturer	Contact Strategy	Cremation Machine Manufactured	Data Requested	Data Received
IFZW GmbH and Co, Germany	Contact had been made prior to this investigation regarding other matters. Contact was made through work email.	Gas and Electric	Energy consumption data from gas and electric cremators from different sites over a period of time. A written review of cremation fuel preference concerning emissions.	Average energy consumption data from gas cremators. A written review of cremation fuel preference concerning emissions.
Matthews Environmental Solutions Ltd, UK	Contact via university email.	Gas	Energy consumption data from gas cremators from different sites over a period of time. A written review of cremation fuel preference concerning emissions.	Raw energy consumption data of two gas cremators at one site. A written review of cremation fuel preference concerning emissions.
DFW Europe BV, Netherlands	Contact had been made prior to the investigation regarding other matters, contact was made through work email.	Gas and Electric	Energy consumption data from gas and electric cremators from different sites over a period of time. A written review of cremation fuel preference concerning emissions.	Average energy consumption data from gas and electric cremators. A written review of cremation fuel preference concerning emissions.

Table 5. Data collection from the manufacturers

The collection of data from various sources will allow the researcher to collate, compare data and generate averages that better reflect cremation emissions in the UK. The importance of contacting manufacturers that produce both gas and electric machinery will provide a broader insight into emissions within the cremation industry across energy types.

3.2.3 Data cleansing

The drawback of receiving data from multiple sources is data uniformity. The units of measure must be consistent, the common unit for gas consumption is meter cubed (m^3), whereas electricity consumption is measured in kilo-watt hour (kWh); consequently, gas consumption was converted to kWh using the following calculation (Table 6):

$$((n / 1.02264) \times 40) / 3.6 = \boldsymbol{N}$$

Gas consumption (m^3)	*n*
Gas consumption (kWh)	*N*
Volume correction factor	1.02264
Gas calorific value (UK average)	40
Conversion factor	3.6

Table 6. Natural gas conversion calculation (Valda Energy 2021)

3.3 Data Analysis

3.3.1 Objective Data- Energy Consumption

The first stage of data analysis is to explore the energy consumption data using descriptive statistics to calculate the annual averages, and once obtained other controls can be considered; for example, the number of cremations per day has a significant influence on the average energy consumption. The data received from the two manufacturers are lifetime averages of the cremators, which take into account energy consumption change based on cremations per day. The data will be analysed to assess the efficiency of gas and electric cremators using cremations per day. The data will then be modelled into cremations per year which will better inform the recommendations for individual crematoria, which are dependent on facility usage. The final scenario is to model the entire UK cremation industry emissions based on the cremator type and fuel type to understand the overall emissions.

The average energy consumption data scenarios can then be extrapolated into CO_2 and NO_x emissions using conversion factors produced by the UK government (GOV.UK 2020a). To

accurately model future cremator installation and emissions, the UK's future energy mix will need to be reviewed using four scenarios: 2020, 2030, 2035, and 2050. Sloarch and Stamford (2021) conducted a similar study that investigated technological options for net-zero domestic heating by 2050. This study identified decreased carbon intensity from heating between 2035 and 2050, as cremation installations have a 15-20 year lifespan, and the energy mix scenarios will provide suitable recommendations for future installations. The next stage is to use the average energy consumption data to calculate accurate cost comparisons of energy costs. Raw data is to be appended, further raw data can be provided upon request to the author via email.

3.3.2 Subjective Data- Cremation Manufacturer Reviews

As part of the data collection, cremation manufacturers have been requested to provide their views on the subject matter. All manufacturers were provided with the aim and objectives of the project to provide an accurate insight into their views on the future of cremation fuels. The three respondents operate from different countries (the UK, Netherlands, and Germany) and provide different equipment; one manufacturer provides exclusively gas and the two other manufacturers provide both gas and electric cremators. Therefore, a diverse collection of subjective data can be analysed to provide additional insight when compared to quantitative data analysis. Further stakeholders (The CDS Group, Environmental Stewardship Group, and the three European manufacturers) are to be contacted upon conclusion via a summary document which entails the findings and recommendations, these stakeholders are to provide a review that will influence the conclusions of the study.

3.4 Ethics

Coventry University accepted an ethics submission for this research prior to the investigation commencing. The ethical approval certificate is appended (Appendix A). The ethics approval confirmed that in line with policy, all data collected from participants would be password-protected. The researcher has permission to acknowledge and release data where participants have agreed to waive their anonymity (Appendix B-G).

4 Results and Discussion

This section will address the aims and objectives of the project through a series of sub-sections that:

- Compare CO_2 and NO_x emissions from gas and electric cremators.
- Model future emissions using energy mix scenarios.
- A cost comparison of energy consumption.
- Recommendations to the industry.

This research analyses data from three European cremation manufacturers. Trends in IFZW and DFW data were consistent, whereas the Matthews data showed a greater variance in gas consumption. The data excludes the gas consumption required to reach the required cremation temperature (RCT) and only includes consumption during the cremation process, therefore the Matthews data has been excluded from emissions analysis.

Average gas consumption was used from the DFW and IFZW cremators, inclusive of the RCT period. Electric cremator energy use is based on DFW data. All energy consumption data is appended.

Calculations for cremation are based upon the following assumptions in Table 7.

	Days
Total days in a year	365
Weekend days	104
Holidays	6
Cremation days	**255**

Table 7. Cremation workdays per year [2021]

4.1 Energy Consumption

Daily cremator energy consumption decreases with increased daily cremations, therefore, emissions are calculated using cremations per day. To fully understand the CO_2 and NO_x emissions from gas and electric cremators, how cremators function must be explained.

4.1.1 Gas Cremator

The gas cremator requires gas and electricity to process each cremation, at the start of the cremation day the gas cremator requires energy to reach the RCT. The gas cremation energy consumption will be highest on a Monday as the plant has been idle over the weekend, the electricity consumption during cremation is typically 15kWh/hr, whereas at rest

it is 1.75kWh/hr (DFW Europe). In between cremations, the gas cremator loses heat, thus RCT must be attained for the next process. An average gas cremation time is 1.5 hours, although this is dependent on the body type and coffin size. As the Matthews data indicates, a 'bariatric' cadaver uses on average 64.3% more gas than a 'normal' cadaver, a 'bariatric' cadaver is selected as an option by the operator if the coffin is typically over 28" wide (Matthews Environmental Ltd. 2021; Table 8).

Body Type	Gas Consumption Average (Cremator 1 and 2)
1 (Normal)	254.58kWh
2 (Bariatric)	395.90kWh

Table 8. Gas consumption based on body type (Matthews Environmental Ltd.)

4.1.2 Electric Cremator

The electric cremator retains the RCT reached in the initial installation period, with little heat loss. The energy consumption in the initial installation period is estimated to be 2500kWh over 3 days (DFW Europe), which is factored into the overall consumption. Relative energy consumption decreases with increased cremations per year, with an average electric cremation time being two hours.

4.2 Carbon Dioxide (CO_2) Emissions

Emissions resulting from the combustion of the body and coffin are also included. emissions are dependent on the size of the body and coffin, with an average of 26.9kgCO_2 (see Section 2; Table 4).

For comparative purposes, carbon intensity values are used to estimate fuel emissions (Table 9).

	2020	**2030**	**2035**	**2050**
Fuel	*kgCO_2/kWh*	*kgCO_2/kWh*	*kgCO_2/kWh*	*kgCO_2/kWh*
Natural gas (Grid)	0.184[1]	0.184	0.184	0.184
Natural gas (20% hydrogen blend)	0.184[1]	0.147	0.147	0.147
Electricity UK (Grid)	0.231[1]	0.085[2]	0.044[2]	0.005[3]
Electricity (Green Tariff)	0.000[5]	0.000	0.000	0.000

Table 9. Present and projected carbon intensity of fuel type (BEIS 2020[1]; BEIS 2018[2]; BEIS 2020[3]; ITM Power 2020[4]; Green Energy UK 2021[5])

In gas cremators, the conventional fuel mix is 96% natural gas and 4% biomethane, which has a carbon intensity of 0.184kg/kWh. However, cremators can potentially function in the future using a blend of 20% green hydrogen, which reduces carbon intensity by 20% (BEIS 2018a). The natural gas carbon intensity is likely to remain unchanged in the near term, therefore, this will not be factored into 2020 values, while a 20% hydrogen blend is likely to be the maximum permitted using existing cremation plants. Biomethane, as a singular fuel source, is unfeasible on a national scale for cremation as a large gas tank would be required and to-site gas transportation. The NO_x emissions attributed to biogas combustion and production are considered to be three times higher than natural gas, therefore the carbon equivalency value (CO_{2e}) should be considered in decision-making (Paolini et al. 2018). A biomethane mix of 4% has been considered within the natural gas carbon intensity figure (Table 9).

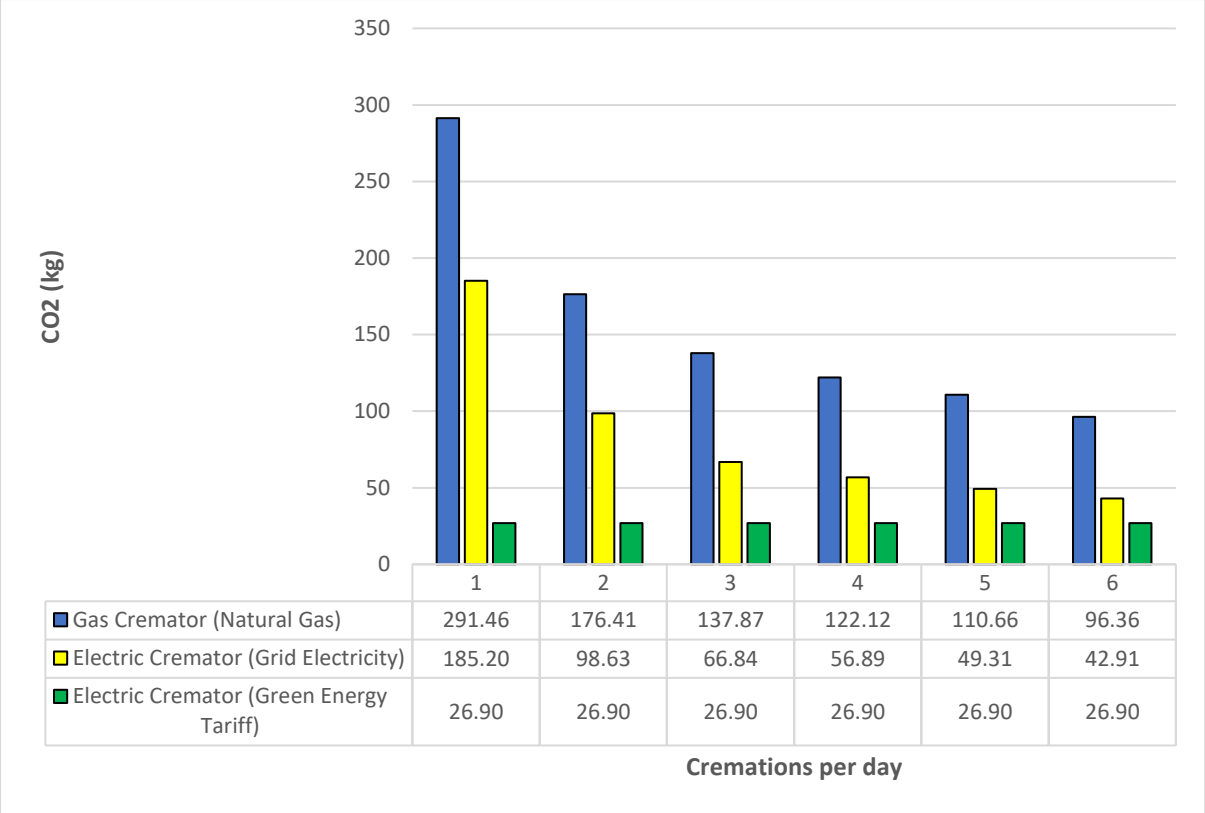
The carbon intensity of the electricity grid has halved since 2010 and is projected to fall to 0.005 kgCO_2/kWh (BEIS 2018b).

The following data is presented in three formats, and future carbon intensity is also considered:

1) CO_2 (kg) emissions for each fuel per cremation, based on cremations per day.
2) Annual CO_2 (kg) emissions for a single cremator for each fuel type.
3) Total UK emissions for each fuel type, to provide policy recommendations at a national scale.

4.3 Comparison of CO_2 emissions (2020)

The analysis of emissions, based on the cremation plant and fuel type, has been undertaken using carbon intensity values (Table 9). Figure 6 represents the amount of CO_2 (kg) emitted per cremation, including that of the body and coffin. The emissions data includes all variables of energy consumption, for gas, this includes the start-up process of the machine to reach RCT, for electric cremation this includes all energy consumption as the machine runs consistently.



	1	2	3	4	5	6
Gas Cremator (Natural Gas)	291.46	176.41	137.87	122.12	110.66	96.36
Electric Cremator (Grid Electricity)	185.20	98.63	66.84	56.89	49.31	42.91
Electric Cremator (Green Energy Tariff)	26.90	26.90	26.90	26.90	26.90	26.90

Figure 6. CO_2 (kg) emissions for each fuel type - per cremation for 2020

Conventional natural gas cremators account for over >98% of the systems currently operational in the UK (The CDS Group 2020), their CO_2 emissions are 49% higher, on average, than those of electric cremators operated on grid electricity (Figure 6). For both cremator types, the more cremations processed per day, the lower the relative CO_2 emissions per cremation. Both cremators are inefficient at one cremation per day, with CO_2 emissions decreasing by 39.5% (gas) and 46.7% (electric) after two cremations, and level-off after three cremations.

An electric cremator operating on a green energy tariff emits the same amount of CO_2 per cremation regardless of the number of cremations per day. Crematoria sourcing electricity from green energy tariffs would expect an average 80% decrease in CO_2 emissions in comparison to a conventional gas cremator, with CO_2 emissions attributed to the body and coffin only. The assertion of '100% renewable electricity' from green electricity tariffs is contested, however, there are energy companies that do generate renewable energy funded by consumer energy tariffs initiating contracts to kickstart new renewable generation, such as Ecotricity and Good Energy (Which 2019). To ensure that cremators are 100% renewable, crematoria could install solar panels or wind turbines that would offset site consumption.

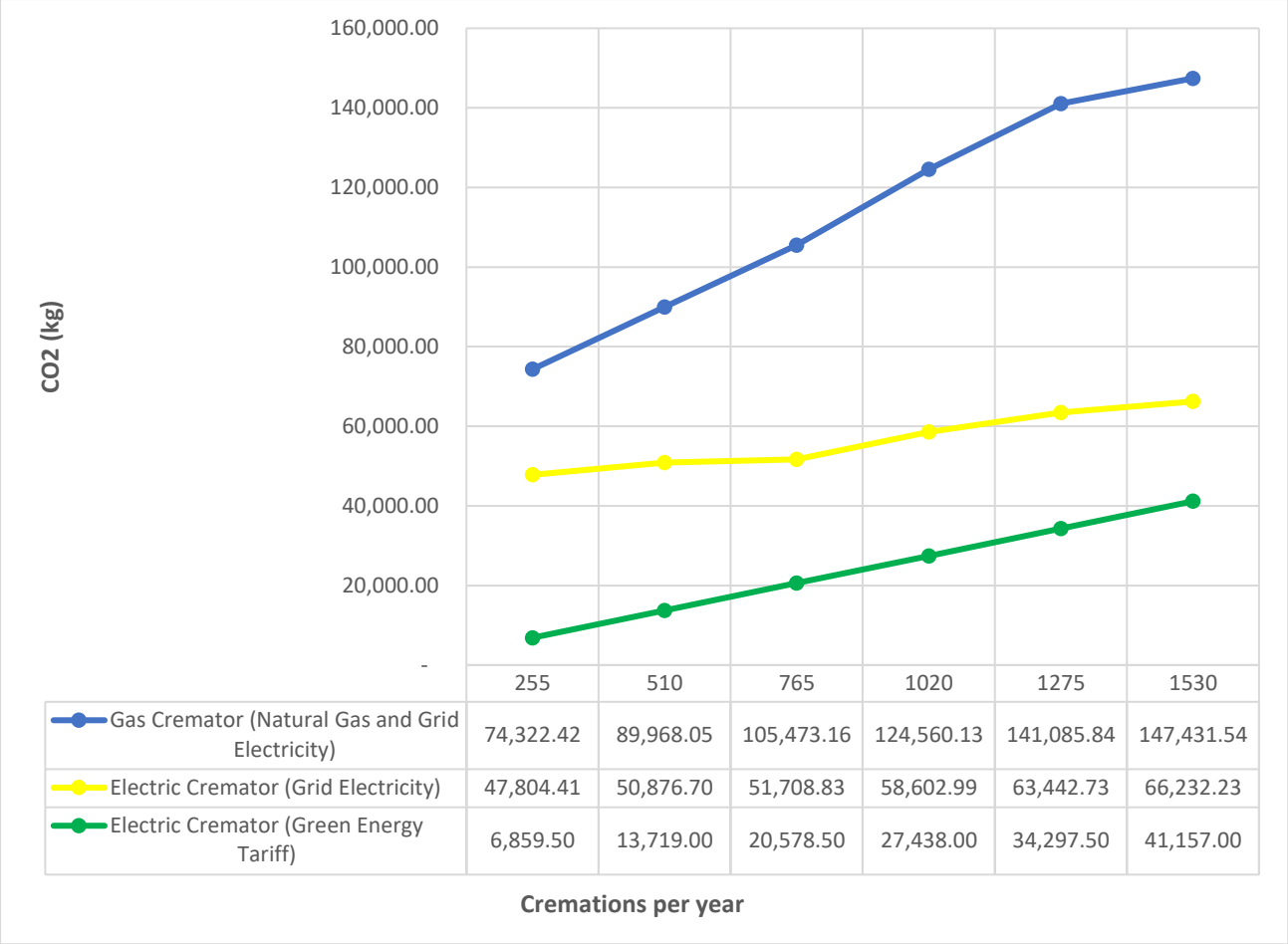
As body and coffin emissions are constant, emissions reduction should focus on fuel type (Table 10).

Main Fuel Type	Gas	Electricity	Body and Coffin
Gas Cremator CO_2 emissions (%)			
Natural Gas	74.9%	5.4%	19.7%
Electric Cremator CO_2 emissions (%)			
Grid Electricity	0.0%	58.3%	40.7%
Green Electricity	0.0%	0.0%	100.0%

Table 10. Percentage of fuel contribution to CO_2 emissions for an average cremation

Figure 7 shows annual crematorium CO_2 emissions for cremators of varying fuel types. CO_2 emissions are dependent on the number of cremations per cremator (per annum). It is assumed that 510-1,275 gas-fuelled and 510-1,020 electric are feasible per year, when cremations exceed these set values, then a second cremator is warranted. The gas cremator emissions level off after the fifth cremation, as the time period between cremations decreases, and therefore residual heat is utilised from the previous cremation.

CO_2 emissions from a gas cremator are noticeably higher [Figure 7]. The average UK cremator processes three cremations per day (Appendix M), translating to 765 cremations per year. If a gas crematorium operating three cremations per day switched to electric, CO_2 emissions drop by 50.9% (or 53,764kgCO_2). A crematorium could further reduce CO_2 emissions (by 60.2%) by using a green electricity tariff. An 80.5% reduction in CO_2 emissions could be achieved for a crematorium operating three cremations per day.



	255	510	765	1020	1275	1530
Gas Cremator (Natural Gas and Grid Electricity)	74,322.42	89,968.05	105,473.16	124,560.13	141,085.84	147,431.54
Electric Cremator (Grid Electricity)	47,804.41	50,876.70	51,708.83	58,602.99	63,442.73	66,232.23
Electric Cremator (Green Energy Tariff)	6,859.50	13,719.00	20,578.50	27,438.00	34,297.50	41,157.00

Figure 7. CO_2 (kg) emissions based on cremations per year

Figure 8 represents CO_2 emissions from the 472,302 UK cremations undertaken in 2019. The data is modelled on three cremations per cremator. In 2019, >98% of UK cremators were gas-fired, consequently, c. 65 million kgCO_2 was emitted from cremation. If the UK was to switch all-electric cremators annual emissions would fall by 51.5% or 33.5 million kgCO_2; a further 18.9 million kgCO_2 could be removed if all crematoria switched to green electricity tariffs.

CO_2 emissions reductions range between 51.5% and 80.5% depending on the electricity tariff.

The UK government has pledged to ban gas boilers from new domestic homes by 2025 (GOV.UK 2019). At present, 78% of UK homes are gas heating and 99% of cremators, consequently, the UK government could push for new crematoria to be all-electric (EDF 2019).

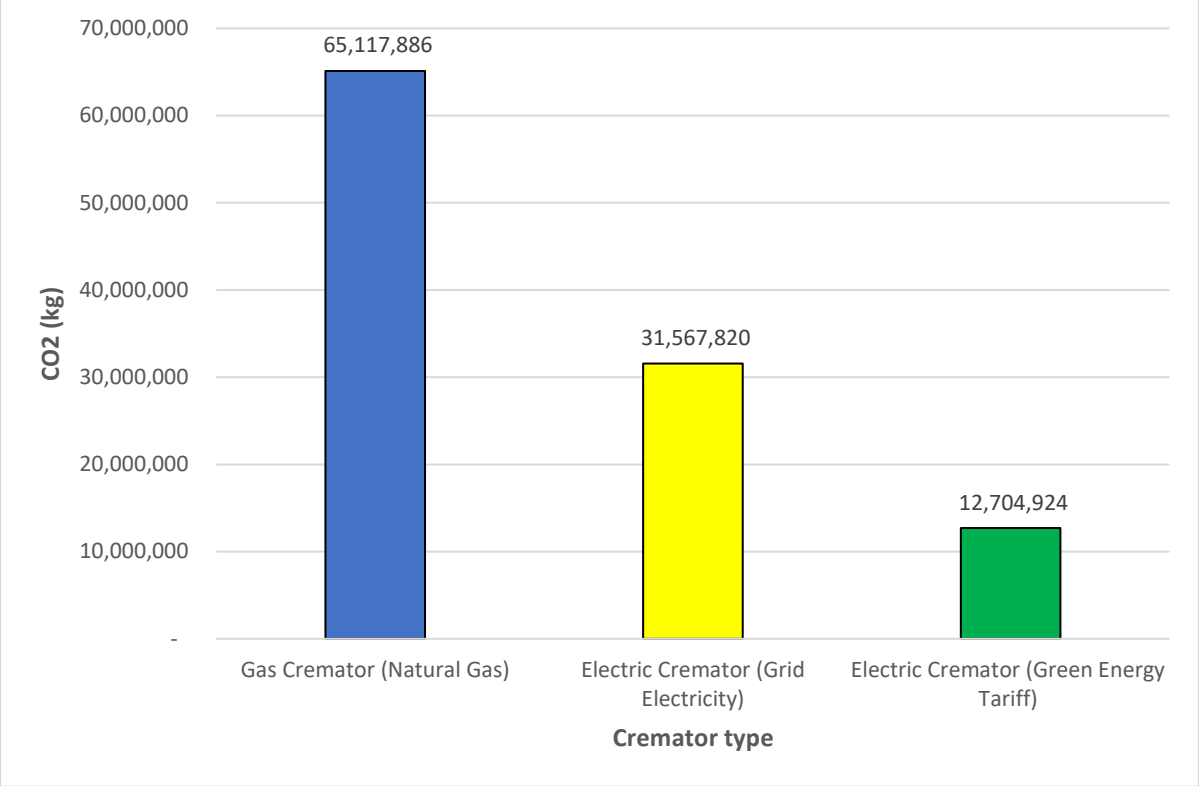


Figure 8. UK - CO_2 (kg) emissions per year - Modelled for each cremator (2019)

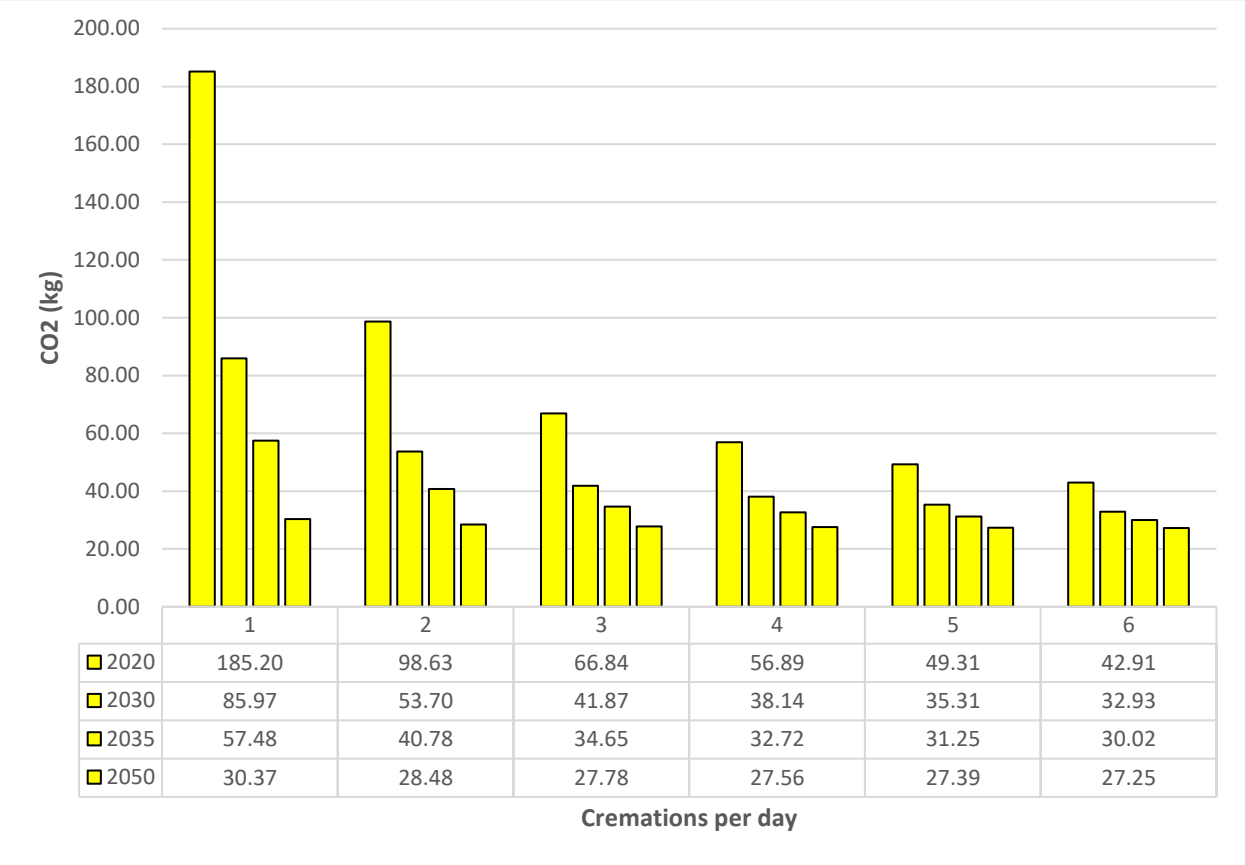
4.4 Future Projections

Energy networks are transitioning towards a net-zero carbon future, these changes will impact the carbon intensities of fuels, and this is key to future cremation emissions. The CCC (2020b) determine electrification as a key response required to reach net-zero by 2050 and highlight that low-carbon electricity is now lower-cost than fossil-fuel generated electricity. Furthermore, the UK government, with this focus on a zero-carbon economy, has also banned the sale of new petrol and diesel cars from 2030 (BEIS 2020h). Cremation plants last 15-20 years, they have fewer limitations when compared to the electrification of transport, i.e. battery life and charging points (Pereirinha et al. 2018). The European Commission (2017) estimates that in the next 10 years, all new passenger vehicles could be electrified if breakthroughs in range and infrastructure continue. The primary limitation concerning the use of an electric cremator is the extended cremation time of c. 25%. The electrification of vehicles is favoured by local governments, as procurement deals are weighted by environmental protection, the same should be true of electric cremation (European Commission 2017).

The carbon intensity of the grid electricity is projected to decrease to 44gCO_2/kWh [by 2035], with the further uptake of renewable energy and a reduction in gas generation (BEIS 2018b).

The carbon intensity from electricity in 2050 may be 5gCO_2/kWh, based on a flexible system including carbon capture, nuclear energy, and green hydrogen power (BEIS 2020f).

If a crematorium was to install an electric cremator, operating on grid electricity, they should expect, at current projections, for CO_2 emissions to decrease by 1.84% per year. The largest decline in CO_2 emissions would occur between 2020 and 2030, with emissions decreasing by 42% from c. 83kgCO_2 to c. 42kgCO_2 per cremation. The results in Figure 9 are inclusive of emissions from the body and the coffin, therefore, between 2020 and 2030 the CO_2 emissions from fuel decreased by 63% with average emissions of c. 20kgCO_2 per cremation using electricity.



	1	2	3	4	5	6
2020	185.20	98.63	66.84	56.89	49.31	42.91
2030	85.97	53.70	41.87	38.14	35.31	32.93
2035	57.48	40.78	34.65	32.72	31.25	30.02
2050	30.37	28.48	27.78	27.56	27.39	27.25

Figure 9. Future Projections - Electric Cremation (kgCO_2)

For gas cremators, the decarbonisation of the gas grid is unlikely to be achieved using biogas, due to the finite land and waste, and reduced competition between food and energy (Gustafsson and Svensson 2021). A centralised gas grid using a hydrogen blend of 20% is more feasible, higher blending ratios (>20%) would require significant changes to gas infrastructure and appliances. More recent appliances [post-1996] have been manufactured to function effectively using a 23% hydrogen mix (HyDeploy 2021). Distribution safety risks become moderately significant between blending ratios of 20-50% and require infrastructure

upgrades due to the higher potential leakage, as hydrogen is more mobile than methane (NREL 2013). Using 20% green hydrogen would reduce CO_2 emissions by 20%.

Figure 10 represents the future projections of annual national CO_2 emissions for both gas and electric cremation. The electric cremator follows the same carbon intensity projections as Figure 9, however, a gas cremator that incorporates a 20% centralised hydrogen blend from 2030 also shows reductions in carbon intensity. These scenarios are modelled on three cremations per cremator per day using the 2020 death rate. If most UK cremation plants remain gas-powered, annual emissions in 2050 would be 53,147 Tonne carbon dioxide (TCO_2), however, if all cremators were to switch to electric, on grid electricity, this figure would be 13,113 TCO_2, a 75.3% reduction.

Figure 10. UK CO_2 (T) emissions, future projections

By 2050, if all cremators were to be switched to grid electricity, CO_2 emissions from combustion fuel would be only 3.1%, and 96.9% from the body and coffin. A further reduction would require research into the carbon content of wood and increased combustion efficiency. Carbon sequestration, i.e. planting of trees could be used to further reduce CO_2 emissions from the body, paid for through crematoria taxation. The average UK cremator on a green energy tariff (765 cremations) emits c. 20 tonnes of CO_2 per year which equates to 26 acres of established forestry, or 331 tree seedlings grown for 10 years (EPA.GOV 2020).

4.5 Nitrogen Oxide (NO_x) Emissions

The measurement of NOx emissions is complex as there is not a single conversion factor available to measure NO_x from fuel use. There are three types of NO_x emissions during combustion (US EPA 1999):

1. Fuel NO_x - resulting from organically bound nitrogen in the fuel (not relevant for natural gas or electricity).
2. Prompt NO_x - resulting from excess air during combustion (negligible for cremation).
3. Thermal NO_x - resulting from high oxygen concentration, high temperatures, and high residence times in the combustion zone (relevant during cremation).

High levels of thermal NO_x are dependent on flue gas [oxygen] flow during cremation. Gas flow for a gas cremation is typically 2000mg/m^3 and 1000mg/m^3 for electric cremation; to calculate NO_x concentrations, the length of the cremation process must be considered (DFW Europe; Appendix O). The cremation process is a non-homogenous procedure with fluctuating flow values, however, an average value based on typical flow regimes exists.

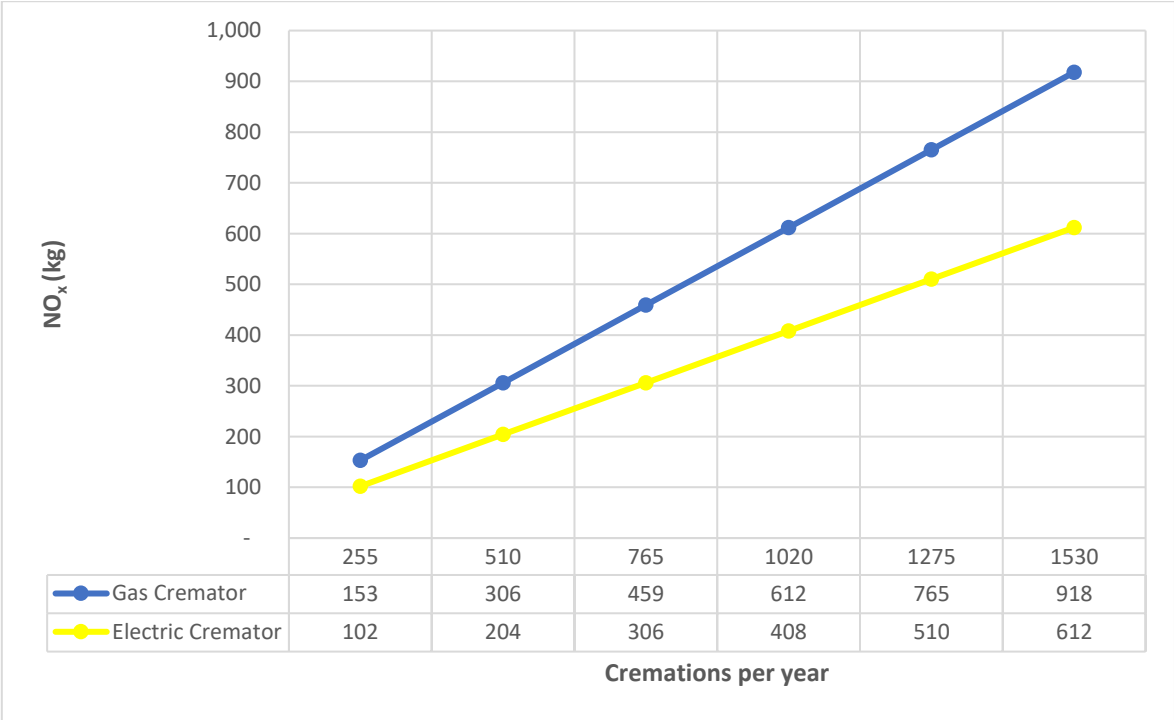


Figure 11. NO_x (kg) emissions per year (one cremator)

NO_x emissions have a considerable impact on the environment, the particulates can deplete the ozone causing an increase in ultraviolet radiation at the earth's surface (Zhang et al.

2021). The electric cremator produces a third-less NO_x than gas; furthermore, a reduced cremation time would also lower NO_x emissions (Figure 11).

There is an option for both cremator types to install selective catalytic reduction (SCR), otherwise known as $DeNO_x$, this process requires ammonia to react with the flue gases to convert the NO_x into water vapour. There are challenges associated with SCR, ammonia is considered a toxic gas and can harm the environment. The rapid application of urea-water solutions requires an on-site tank, which may not be possible with restricted urban space. Nevertheless, NO_x emissions should be zero, and SCR should be more widely considered.

Annual NO_x emissions for UK cremations would be reduced by a third if all cremators were to switch to electric, 94,460kg less emitted NO_x or 27,52,436kgCO2e, higher than annual CO_2 emissions from all cremations (EPA.GOV 2020; Table 11). If all unabated gas cremators in the UK were switched to fully abated electric cremators (SCR) in 2020, it would be the equivalent of reducing 133 million car miles, or removing 13,300 passenger cars off the road each year (GOV.UK 2015).

Cremator Type	**Annual NO_x emissions (2020 death rate)**	**Carbon Dioxide Equivalent (CO_{2e})**
Gas Cremator	283,381kg	82,747,310kg
Electric Cremator	188,921kg	55,164,874kg

Table 11. Annual NOx emissions and CO2e (EPA.GOV 2020)

4.6 Cost comparison

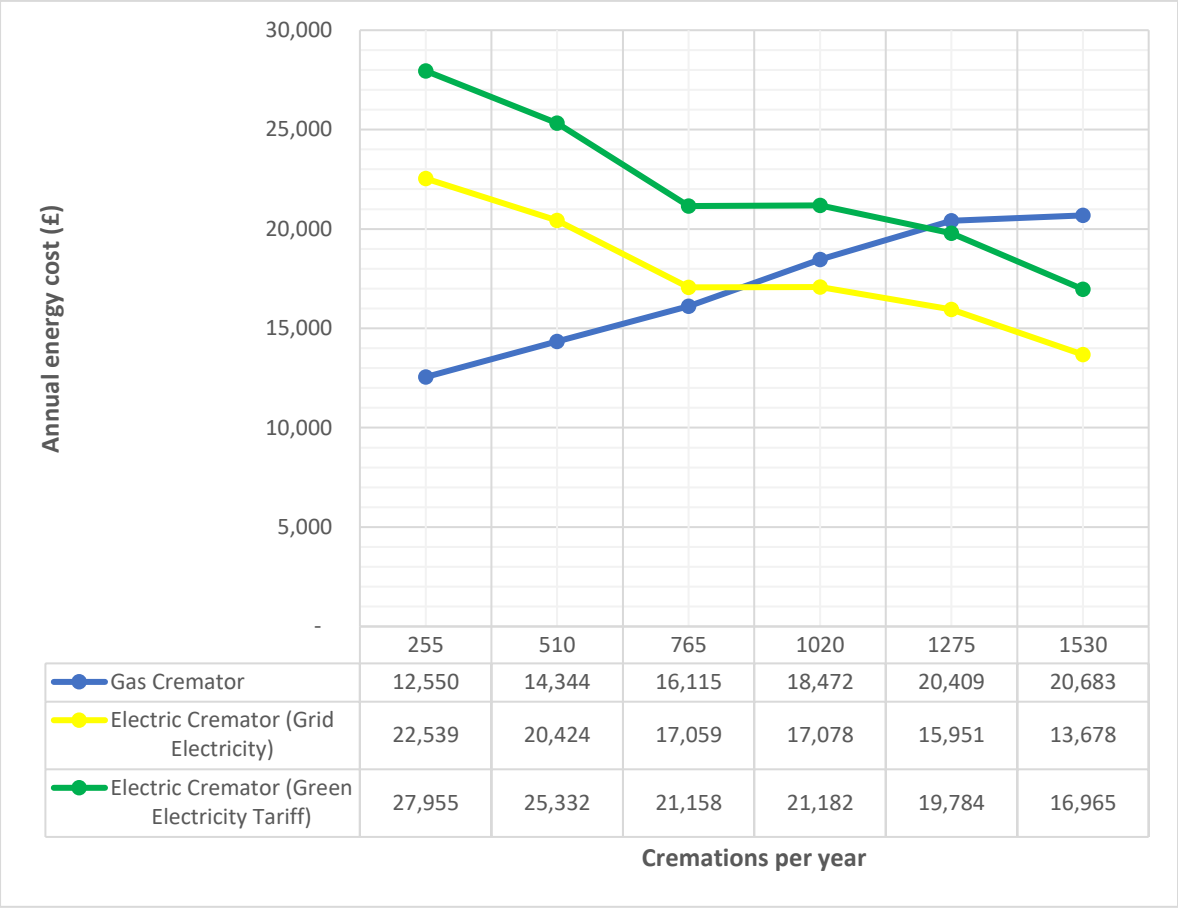
The financial cost of electrification is a critical element in the transition to lower emissions, and levelised cost is an important measure as renewables increase. Thus, it is prudent to analyse the running costs of gas and electric cremators using current business energy costs (Table 12).

Energy Type	**Cost (£)**	**Unit**
Electricity [Grid]	0.129[1]	/kWh
Electricity [100% Renewable Energy]	0.16[2]	/kWh
Natural Gas	0.03[1]	/kWh

Table 12. Cost of energies (Business Electricity Prices 2021[1], and Safe Energy Switch 2020[2])

Initial costs are important in decision making, the supply of gas cremators is higher than electric cremators, electric cremators are only available from two European suppliers [DFW Europe and IFZW] at present. The cost difference between an electric and gas cremator

differs between manufacturers as does the subsidiary equipment offered, for confidentiality purposes the unit's costs cannot be shared, however, the electric cremator has a higher average cost of c. £165,000 per unit. Figure 12 compares annual energy costs versus cremations, across various energy types, per year.



	255	510	765	1020	1275	1530
Gas Cremator	12,550	14,344	16,115	18,472	20,409	20,683
Electric Cremator (Grid Electricity)	22,539	20,424	17,059	17,078	15,951	13,678
Electric Cremator (Green Electricity Tariff)	27,955	25,332	21,158	21,182	19,784	16,965

Figure 12. Annual cost comparison of energy costs for each cremator (£)

The energy consumption costs of average grid electricity cremators and natural gas cremators, operating at 3-4 cremations per day, are negligible. The cost difference of a cremator operating on a green electricity tariff is noticeably higher, however, as the renewable electricity share increases, the price gap will decrease.

Due to the lower initial cost of a gas cremator and lower running costs (up to 867 cremation per year), gas cremators are currently the most cost-efficient option. However, other factors such as cremator maintenance must also be considered. The fluctuating temperatures of gas cremators compared to the electric cremators causes considerably more damage to the interior lining of the gas cremator. A typical gas cremator costs c. £12.00 per cremation to re-line as the re-lining is done periodically and the hearth costs c. £3000 to replace after 2000 cremations, due to the infancy of the electric cremator technology, the financial cost savings are unknown.

The UK electricity network has increased its renewable share every year, from 9.4% in 2011 to c. 45% in 2021 (GOV.UK 2021). The levelised cost of electricity (LCOE) has declined in the UK by 27% between 2013 and 2020, by 2025 it is estimated to have decreased by a further 37% (Shen et al. 2020; Carbon Brief 2020). Despite the sharp decrease in LCOE of renewables, there is a noticeable disconnect in actual energy prices, as older renewable energy plants, which rely on feed-in tariffs, currently outnumber newer wind and solar plants with lower LCOE (GTM 2020). Long-term infrastructure improvements, i.e. strategic deployment of battery technology, with government support, would decrease the wholesale consumer price of electricity (IEA 2021).

The future cost of natural gas must be considered as the national supply declines and imports of LNG increase (Devine and Russo 2019). Crematoria could become self-sustainable by using solar panels to sell electricity back to the grid at the same usage rate. The highest efficiency solar panel available is the SunPower 415Watt solar panel which costs circa £500 per panel, a 7kW system of 18 panels produces c. 10,000 kWh, therefore the typical cremator of 765 cremations requires 240 panels, costing a total of c. £120,000 (Energy Sage 2016). The ground space required for 240 solar panels (415W) is c. 5500 square feet, which would be feasible for many crematorium sites.

A larger crematorium with several cremators and less ground space may opt for wind turbines. A wind turbine producing c. 36MW/year would cost c. £70,000, the average electric cremator requires c. 135MW/year (The Renewable Energy Hub UK 2021). A typical cremator would require four turbines per cremator which is twice the cost of a solar panel system however if ground space is an issue then it may be a viable alternative, planning is more difficult to secure for wind turbines. Other techniques such as waste heat recovery units from the cremator to the chapel are feasible solutions to reducing overall energy demand, as piloted by Huntingdon Town Council (2020).

4.7 Stakeholder Engagement

Three key stakeholders (manufacturers) have provided their views on the future of the cremation industry (Appendix P). The reviews are considered essential in producing valid recommendations based on established data. The reviews highlight the key differences separating ‘greener’ electric cremators and more financially viable gas cremators.

DFW Europe states the cremation industry is increasing its environmental awareness, and lists the benefits of electric cremation, specifically lower CO_2 and NO_x emissions, which are consistent with the results in this study. Regarding cremator efficiency, IFZW considers the gas cremator to be more efficient at higher usage, which is consistent with this report,

however, emissions remain higher due to the gas exhausted during cremator initiation at the beginning of the day. They also recommend that intact gas cremators should not be removed and replaced by electric cremators. However, it has been shown herein that the electric cremator can reduce CO_2 emissions by c. 80% over the 15-year lifespan of the cremator, especially with the drive towards zero emissions by 2030, proven by the sign-up to the climate emergency scheme by 74% of local authorities (Declare a Climate Emergency 2021). Matthews Environmental Ltd. makes an important proposition regarding a dual-fuel cremator being possible which could reduce the gas consumption to reach RCT, therefore for cremators performing >5 processes per day, this may be a more energy-efficient process, however, this is not available on the market.

All three manufacturers acknowledge that a change is required in the cremation industry to make the industry cleaner and that alternative fuels, whether that be electricity or greener gas, are crucial for this transition. The views of all stakeholders are key in the development of recommendations.

4.8 Recommendations

A cremation plant needs replacing every 15-20 years and the crematorium operator must consider cost projections when making decisions. The two most important factors are cost and emissions. At purchase, an electric cremator is an estimated £165,000 (average) more expensive than gas, although the running cost differences are negligible. Choosing electric cremation would reduce CO_2 emissions by c. 50-80%, depending on the choice of electricity tariff and cremations per day; nonetheless, the carbon intensity of the electric grid is set to decline to 0.005kgCO_2/kWh by 2050. The installation of an SCR system must also be considered, notwithstanding whether the choice is electric or gas cremation. An SCR system costs an estimated £25,000 per cremation plant.

Like the transport and heating sectors, the use of hydrogen energy is in its infancy. A centralised blend of 20% hydrogen does not offer emission reductions comparable to electric cremation. The blending of biomethane into natural gas (at c. 4%) has been included in the carbon intensity of natural gas in this study, a crematorium fully operated by biomethane would require a resupplied on-site tank. It would be unfeasible for all crematoria in the UK to run solely off biomethane due to a lack of supply and infrastructure, however, it may be feasible for certain sites.

The UK industry must consider the intention of the ‘green consumer’, the adoption of sustainable processes is likely to influence choice concerning which crematoria the bereaved may choose, therefore influencing revenue (Harvard Business Review 2019). For

example, Kia promotes their approach to business operations as a relationship between humans, sustainability, and corporate social responsibility, the green consumerism market is growing as can be seen for the transport industry (Kia 2021).

4.8.1 Policy Recommendations

Disclosure of CO_2 emissions

The UK cremation industry requires monitoring and disclosure of CO_2 emissions from cremation every quarter to an independent regulatory body (DEFRA). Local authorities should consider cremation CO_2 emissions in their carbon reporting to ensure net-zero emissions are achieved.

Reporting of NO_x emissions

Currently, the minimum requirement for emissions testing of cremators does not include NO_x, the UK industry should be required to disclose NO_x emissions as in other sectors of the economy, such as transport.

4.8.2 Recommendations to UK crematoria

New Crematorium

As of February 2021, 300 of the 404 UK local authorities have declared a climate emergency, which requires net-zero emissions by 2030. Cremation emissions are a substantial proportion of a local authority's CO_2 emissions, standing at 161,182kgCO_2 per average gas cremator. The national implementation of electric cremators would remove the need for gas connections, and if the land is available, local authorities could install photo-voltaic cells and/or wind turbines, and plant trees to sequester residual emissions from the body and coffin, e.g. 26 acres of established forest to offset the residual emissions from the average cremator.

Existing Crematorium

It is recommended that the existing gas crematoria should switch to electric cremation at the point of decommissioning. This decision is dependent on the number of cremations processed per day (per cremator) and the future carbon intensity. A crematorium considering the removal of an already functioning gas cremator should review pre-existing capital costs.

Alternative Solutions

Some existing crematoria do not have the infrastructure to install high voltage electricity mains, in this case, crematoria should seek alternative ways to make their gas cremators more sustainable, such as installing SCR, alternative fuels, and offsetting.

4.8.3 Industry Recommendations

Emissions Calculator

An emissions calculator should be developed, which requires the operator to input and then publish their annual cremation emissions. This spreadsheet would project the CO_2 and NO_x emissions of the crematorium using both gas and electric cremation and calculate initial and annual costs to allow for informed decision-making.

Cremator Supply

Electric cremators are not currently manufactured in the UK, manufacturers in the UK should consider manufacturing electric cremators which could reduce costs to UK consumers such as importation and tax costs.

4.9 Limitations of the study

This research did involve limitations that became apparent in the data collection process, due to COVID-19 the bereavement industry has been overburdened, therefore the operators of crematoria were unavailable to be involved in the research. The data is reliant solely on the energy consumption data provided by three European manufacturers. The electric cremator is in emerging technology therefore the emissions projections are based on averages sourced from crematoria in the Netherlands.

Future research into this subject area should include further research into the SCR system, logistics of long-term electric cremator installations, and freedom of information requests of UK crematoria to ensure a more comprehensive review of UK emissions is undertaken.

5 Conclusion

The primary focus of this project has been to evaluate greenhouse gas emissions from both gas and electric cremation plants, with a specific focus on fuel-based emissions. The future projections of fuel carbon intensities have been modelled to provide accurate recommendations to stakeholders within the cremation industry. An outline of the key findings and recommendations are provided in this conclusion.

5.1 Findings

Finding 1: Electric cremation produces lower CO_2 and NO_x emissions than gas cremation.

This research has calculated that electric cremation produces 50-80% less CO_2 emissions than gas, this range is controlled by the energy tariff and number of cremations per day. The electric cremator reduces NO_x emissions by c. 33%, without selective catalytic reduction (SCR). An electric cremator, on a green energy tariff, with SCR installed, would reduce CO_2 emissions by c. 80% and NO_x emissions by >99%.

Finding 2: Alternative fuels, such as hydrogen blending and biogas, do not reduce CO_2 emissions to the same level as electric cremation.

Hydrogen is likely to become available in the centralised gas network at a blending rate of 20%; blended rates above 20% would increase leakage risks and are, therefore, not compatible with current infrastructure. If blended hydrogen was ‘green’ then CO_2 emissions from gas cremation would be reduced by 20%. The possibility of having all UK cremators run using 100% biogas is unfeasible due to distribution issues, notably the availability of biogas and the requirement for new on-site infrastructure.

Finding 3: CO_2 emissions from electric cremators on the National Grid will fall by 42% between 2020 and 2030.

Electrification is key to the government's plans to decarbonise the economy; the UK government has banned the installation of gas boilers in new-build homes by 2025 and the sale of petrol and diesel cars by 2030. The carbon intensity of the electricity grid is set to decrease to 0.005kgCO_2/kWh by 2050, whilst natural gas remains at c. 0.184kgCO_2/kWh with further reductions of c. 20% in CO_2 emissions possible through a green hydrogen blend.

Finding 4: Gas cremation is currently the cheapest option for cremation if initial costs are included.

The purchase and installation cost of electric cremators is on average c. £165,000 more than gas cremators, however, electric cremators are more cost-effective in terms of energy consumption, if three or more cremations are processed per day. Maintenance must also be considered when calculating overall costs. Electric cremators cause less damage to the lining and therefore are replaced less frequently, however, the financial savings are currently unknown due to the infancy of electric cremation.

5.2 Recommendations

Recommendation 1: New crematoria should install electric cremators and existing crematoria should replace gas cremators at the point of cremator decommission with electric cremators.

Regardless of the cremations per day, electric cremators will produce lower CO_2 and NO_x emissions than gas, therefore, all crematoria should review whether it is feasible to switch from existing gas cremators to electric.

Recommendation 2: Crematoria that do not have the infrastructure to install electric cremators should improve the efficiency and sustainability of their gas cremators.

Electric cremation requires a higher electrical power connection than the gas cremator, this may not always be possible, in this case, crematoria should seek alternative ways to improve the sustainability of their gas cremators. Crematoria operating gas cremators should review the viability of on-site biogas tanks, which could provide energy for all cremations. All crematoriums operating gas cremators should consider installing an SCR system and switch to a green electricity tariff.

Recommendation 3: Financial costs of replacing an intact gas cremator must be considered in decision making.

A high initial financial outlay is involved when replacing an intact gas cremator with an electric system. However, this study highlights that the majority of UK electricity by 2050 will be from renewable sources with potentially lower levelised and absolute costs.

Recommendation 4: An emissions and cost calculator should be developed to ensure UK crematoria can make informed decisions.

The calculator should allow for comparisons between fuel types and cremation plants.

Recommendation 5: UK cremation manufacturers should consider manufacturing electric cremators.

If electric cremators were manufactured in the UK this may reduce unit costs (e.g. importation tax) and, thereby make the future purchase of electric cremators financially viable for UK crematoria.

Recommendation 6: Regulatory bodies, such as the Environment Agency (EA) and Department for Environment, Food & Rural Affairs (DEFRA), should extend industry regulation to include CO_2 and NO_x emissions.

The current process guidance notes (PG5/2: DEFRA) do not regulate CO_2 or NO_x emissions. Consequently, updated PG5 guidance notes should include new basic standards on emissions reporting and reduction.

Recommendation 7: Local authorities should request crematoria to disclose CO_2 and NO_x emissions of cremation.

Local authorities are required to produce carbon accounting reports; however, CO_2 and NO_x cremation emissions are not currently included.

5.3 Concluding remarks from the industry

Industry stakeholders had been contacted and asked to comment on a summary report (see Appendix Q and R). The stakeholders that responded include:

- DFW Europe (Electric and Gas Cremator Manufacturer)
- IFZW (Electric and Gas Cremator Manufacturer)
- The CDS Group (Bereavement Industry Consultants)
- Environmental Stewardship Group (Voluntary Public-Private Environmental Group)

The reviews provided by the industry stakeholders have shaped the final conclusions and recommendations of this study.

DFW Europe

DFW Europe acknowledges the recommendations provided in this study are both feasible and viable, however, states that the industry ethos must change if the recommendations are to be taken on board. The manufacturer also stated that the research into ‘greener’ coffins must also consider the energy required in the cremation process to combust the material notwithstanding the chemical elements of the coffin material. The manufacturer also made important remarks regarding cost comparison, as crematory equipment offered differs

between manufacturers' quotations, therefore, an average initial cost difference has now been used in this report.

IFZW

The reviewer does not agree with findings 1 and 2 and questions the efficiency of future UK power networks. The reviewer disputes finding 4 and determines electric cremation to be less expensive in the future and attributes the operation and handling of the cremator to have a large impact on energy consumption. IFZW provides important feedback regarding the inclusion of the life-cycle emissions of cremator manufacturing when considering whether to replace an intact gas cremator, this has been added to the areas which require further research. IFZW considers the emission and cost calculator to be the most important recommendation to allow stakeholders to make informed decisions.

The CDS Group

The reviewer recognises this study to be an integral and invaluable document to inform the stakeholders within the industry, however, they state that the report's findings will face a challenge from stakeholders with a commercial interest in gas cremation. Within the review, The CDS Group highlights the importance of analysing life-cycle emissions of biofuels and, additionally, the increase in thermal NO_x of biofuels due to the higher combustion temperatures. An important element of the reviewer's comments includes the issue of delaying the electrification of cremation to wait for 'green gas' solutions, biofuels have been available for many years and, therefore, prompts the question as to why these have not yet been implemented. The reviewer determines this research to be crucial for local crematoria to secure government grants to switch to electric cremators by providing scientific evidence of GHG emission reduction.

Environmental Stewardship Group (ESG)

The ESG welcomes the release of quantifiable data to concur with current understandings of cremation emissions. The consensus is that all findings and recommendations are acknowledged and agreed upon within the review. The review draws upon the government's sixth Carbon Budget concerning supply and demand, which will drive down the price of 'greener' technologies that are in their infancy. The reviewer draws upon 'Recommendation 4' regarding the benefits of including financial costs in the emissions calculator as it could improve the profitability of crematoria by subsequently reducing energy consumption. A call for investors to seek opportunity in the manufacturing of electric cremators is noted as "warranted".

Stakeholder Review Conclusion

The consensus is that this study is key to decision-making within local authorities and private corporations, but it may face challenges from companies that favour gas cremation. The stakeholders have provided important additional information regarding: financial costs, biofuels, the carbon footprint of replacing intact cremators, and future research recommendations, which have helped reshape the findings and recommendations.

5.4 Concluding Statement

This study confirms that using electric cremators reduces both CO_2 and NO_x emissions. The UK cremation industry must consider the report's findings and recommendations and play an active role in reducing greenhouse gas emissions. There are a number of areas that warrant further research:

- The effectiveness of the SCR system in cremations, the residual products, and the life-cycle emissions of this process.
- Analysis of maintenance costs of electric cremators to provide accurate lifetime cost comparisons.
- Explore other methods to offset CO_2 emissions from the body and the coffin.
- Consider coffin choices for cremation that reduce both CO_2 and NO_x emissions during the production and combustion stages, and also taking into consideration the energy required to combust the coffin material.
- The carbon footprint of manufacturing and replacing an intact gas cremator with an electric cremator; in comparison to the increased GHG emissions of operating a gas cremator to the end of its useful life.

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Appendices

Appendix A – Ethical Approval Certificate

Certificate of Ethical Approval

Applicant:	Benjamin Copeland
Project Title:	A comparison of gas and electric cremator emissions in the UK.

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Medium Risk

Date of approval:	08 Jan 2021
Project Reference Number:	P113871

Appendix B – Participant Information Sheet

Participant Information Sheet –

A comparison of gas and electric cremator emissions in the UK.

Purpose of the project:

Main Aim:

- To investigate carbon dioxide (CO2) and nitrogen oxide (NOx) emissions from conventional gas and electric cremators and evaluate alternative energy sources for cremation.

Objectives:

- Undertake a critical review of the literature.
- Measure and account for current CO_2 and NO_x emissions in the UK resultant from gas cremation and investigate the benefits and viability of alternative fuels.
- Investigate the emissions from potential electric cremators and review the benefits and viability of such cremations in the UK.
- Using real-world comparisons, review the impact to UK emissions of changing to electric-only cremators.
- Provide recommendations to the cremation industry regarding future energy types and UK emissions policies.

Why have I been chosen?

You have been chosen as a key stakeholder in the research to rightfully inform the research with regard to cremation.

Do I have to take part?

You do not have to take part in this research project and can withdraw from the project at any time prior to submission of this research project.

What will happen with the results of the study?

The results of this study will be submitted to the university and potentially released to the industry to inform with recommendations.

Further information/Key contact details of researcher and supervisor.

If you have any questions that cannot be answered by the researcher regarding this research project, please contact the research supervisor.

Researcher:

Name: Ben Copeland

Email: [redacted]

Supervisor:

Name: Adrian Wood

Email: [redacted]

Appendix C – Informed Consent Form (DFW Europe)

Informed Consent Form Template

DFW Europe

	Please tick
1. I confirm that I have read and understood the participant information sheet for the above study and have had the opportunity to ask questions.	✔
2. I understand that my participation is voluntary and that I am free to withdraw at anytime without giving a reason.	✔
3. I understand that all the information I provide will be treated in confidence	✔
4. I understand that I also have the right to change my mind about participating in the study for a short period after the study has concluded (*insert deadline here*).	✔
5. I agree to remove anonymity from the data provided and allow the researcher to reference the data.	✔
6. I agree to take part in the research project	✔

Name of participant: Sjaak Zutt (Technical Director at DFW Europe)

Signature of participant: .....

Date: 22/02/2021

Name of Researcher: Ben Copeland

Signature of researcher: BCopeland .....

Date: 22/02/2021

Appendix D – Informed Consent Form (Matthews Environmental Ltd.)

Informed Consent Form Template

Matthews Environmental Ltd.

	Please tick
1. I confirm that I have read and understood the participant information sheet for the above study and have had the opportunity to ask questions.	✔
2. I understand that my participation is voluntary and that I am free to withdraw at anytime without giving a reason.	✔
3. I understand that all the information I provide will be treated in confidence	✔
4. I understand that I also have the right to change my mind about participating in the study for a short period after the study has concluded (*insert deadline here*).	✔
5. I agree to remove anonymity from the data provided and allow the researcher to reference the data.	✔
6. I agree to take part in the research project	✔

Name of participant: Elliott Jones (Matthews Environmental Ltd.)

Signature of participant: 

Date: 22/02/2021

Name of Researcher: Ben Copeland

Signature of researcher: BCopeland .....

Date: 22/02/2021

Appendix E – Informed Consent Written Response (IFZW)

BF

Barbara Fink
Tue 23/02/2021 08:43
To: Ben Copeland
Cc: jonathan heath[redacted]

Hello Ben,
We confirm that we are happy for you to use the data and information we have provided and you may or may not quote IFZW as a source.
Any conclusions or recommendations should, however, be your own.
We hope you will understand, therefore, that we do not wish to sign the consent form.
Best regards
Barbara

BCopeland 23/02/2021

Appendix F – Informed Consent Form (The CDS Group)

Informed Consent Form Template

The CDS Group

	Please tick
1. I confirm that I have read and understood the participant information sheet for the above study and have had the opportunity to ask questions.	✔
2. I understand that my participation is voluntary and that I am free to withdraw at anytime without giving a reason.	✔
3. I understand that all the information I provide will be treated in confidence	✔
4. I understand that I also have the right to change my mind about participating in the study for a short period after the study has concluded (*insert deadline here*).	✔
5. I agree to remove anonymity from the data provided and allow the researcher to reference the data.	✔
6. I agree to take part in the research project	✔

Name of participant: Justin Smith (Director at The CDS Group)

Signature of participant: *justin smith*

Date: 09/03/2021

Name of Researcher: Ben Copeland

Signature of researcher: *BCopeland* .....

Date: 09/03/2021

Appendix G – Informed Consent Form (Environmental Stewardship Group)

Informed Consent Form Template

Environmental Stewardship Group

	Please tick
1. I confirm that I have read and understood the participant information sheet for the above study and have had the opportunity to ask questions.	✔
2. I understand that my participation is voluntary and that I am free to withdraw at anytime without giving a reason.	✔
3. I understand that all the information I provide will be treated in confidence	✔
4. I understand that I also have the right to change my mind about participating in the study for a short period after the study has concluded (*insert deadline here*).	✔
5. I agree to remove anonymity from the data provided and allow the researcher to reference the data.	✔
6. I agree to take part in the research project	✔

Name of participant: Jon Cross FloD (Group Facilitator of Environmental Stewardship Group)

Signature of participant: .....

Date: 17/03/2021

Name of Researcher: Ben Copeland

Signature of researcher: BCopeland

Date: 17/03/2021

Appendix H – Raw Data (DFW Europe)

Electric Cremator Raw Data [Electricity Consumption] (DFW Europe)

	Electric
Cremations per day	kWh
1	20
2	18
3	15
4	15
5	14
6	12

Gas Cremator Raw Data [Gas Consumption] (DFW Europe)

	Gas
Cremations per day	m^3 per cremation
1	150
2	80
3	60
4	55
5	50
6	40

Gas Cremator [Electricity Usage] (DFW Europe)

E usage/hr	12	kWh
E usage/hr	1.75	kWh
Crem Time	1.5	hr

Appendix I – Raw Data (IFZW)

Gas Usage

Monday

Average per cremation	Preheat m³	Preheat kWh	1st cremation m³	1st cremation kWh	2nd cremation m³	2nd cremation kWh	3rd cremation m³	3rd cremation kWh	4th cremation m³	4th cremation kWh	5th cremation m³	5th cremation kWh	6th cremation m³	6th cremation kWh	Total m³	Total kWh
31,89	106,5	1065	42,34	423,4	19,82	198,2	9,92	99,2	4,26	42,6	4,26	42,6	4,26	42,6	191,36	1913,6
37,42	106,5	1065	42,34	423,4	19,82	198,2	9,92	99,2	4,26	42,6	4,26	42,6	187,1	1871		
45,71	106,5	1065	42,34	423,4	19,82	198,2	9,92	99,2	4,26	42,6	182,84	1828,4				
59,53	106,5	1065	42,34	423,4	19,82	198,2	9,92	99,2	178,58	1785,8						
84,33	106,5	1065	42,34	423,4	19,82	198,2	168,66	1686,6								
148,84	106,5	1065	42,34	423,4	148,84	1488,4										

Tuesday - Friday

Average per cremation	Preheat m³	Preheat kWh	1st cremation m³	1st cremation kWh	2nd cremation m³	2nd cremation kWh	3rd cremation m³	3rd cremation kWh	4th cremation m³	4th cremation kWh	5th cremation m³	5th cremation kWh	6th cremation m³	6th cremation kWh	Total m³	Total kWh
21,76	45,7	457	42,34	423,4	19,82	198,2	9,92	99,2	4,26	42,6	4,26	42,6	4,26	42,6	130,56	1305,6
25,26	45,7	457	42,34	423,4	19,82	198,2	9,92	99,2	4,26	42,6	4,26	42,6	126,3	1263		
30,51	45,7	457	42,34	423,4	19,82	198,2	9,92	99,2	4,26	42,6	122,04	1220,4				
39,26	45,7	457	42,34	423,4	19,82	198,2	9,92	99,2	117,78	1177,8						
53,93	45,7	457	42,34	423,4	19,82	198,2	107,86	1078,6								
88,04	45,7	457	42,34	423,4	88,04	880,4										

Appendix J – Variance in Energy Consumption based on Body Type (Matthews Environmental Ltd.) [Raw Data Available Upon Request]

Cremations Per Cremator

Cremator	Total Amount of Cremations
1	550
2	506

Cremations Per Cremator (Body Type)

Body Type	Cremator 1 (Cremations)	Cremator 2 (Cremations)
Bariatric	24	16
Infant	4	0
Normal	550	490

Gas Consumption by Body Type (Cremator 1 and 2)

Body Type	Cremator 1 - Average Consumption (kWh)	Cremator 2 - Average Consumption (kWh)
Normal	243.1570558	266
Bariatric	336.8189	454.9770963

Gas Consumption by Body Type (Average)

Body Type	Gas Consumption Average (Cremator 1 and 2) [kWh]
1 (Normal)	254.58
2 (Bariatric)	395.90

Appendix K – Averages of Energy Consumption Used for Emission Analysis

Electric Cremator [Electricity Consumption] (DFW Europe) – kWh Calculations

Cremations per day	Per working year (kWh)	Per cremation (kWh)
1	177,220.00	694.98
2	160,828.00	315.35
3	134,740.00	176.13
4	134,890.00	132.25
5	126,148.00	98.94
6	108,532.00	70.94

Gas Cremator [Gas Consumption] (DFW Europe and IFZW Average) – kWh Calculations

Cremations per day	Per working year (kWh)	Per cremation (kWh)
1	346,602.91	1,359.23
2	389,542.70	763.81
3	431,716.77	564.34
4	493,408.40	483.73
5	541,143.73	424.43
6	533,408.25	348.63

Gas Cremator [Electricity Consumption] (DFW Europe) – kWh Calculations

Cremations per day	Per working year (kWh)	Per cremation (kWh)
1	16,682.63	65.42
2	20,603.25	40.40
3	24,523.88	32.06
4	28,444.50	27.89
5	32,365.13	25.38
6	36,285.75	23.72

Appendix L – Emissions Calculations [Electric and Gas Cremator]

Electric Cremator - CO_2 and NO_x emissions [Grid Electricity]

Cremations per day	CO2/year (kg)	CO2/cremation (kg)	Nox/year (kg)	Nox/cremation (kg)	CO2/year (kg) [inc..body and coffin]	CO2/cremation (kg) [inc..body and coffin]
1	40,367.31	158.30	102.00	0.4	47,226.8	185.2
2	36,580.10	71.73	204.00	0.4	50,299.1	98.6
3	30,552.73	39.94	306.00	0.4	51,131.2	66.8
4	30,587.39	29.99	408.00	0.4	58,025.4	56.9
5	28,567.63	22.41	510.00	0.4	62,865.1	49.3
6	24,497.63	16.01	612.00	0.4	65,654.6	42.9

Electric Cremator - CO_2 emissions [Green Electricity Tariff]

Cremations per day	CO2/year (kg) [inc. body and coffin]	CO2/cremation (kg) [inc. body and coffin]
1	6859.5	26.9
2	13719	26.9
3	20578.5	26.9
4	27438	26.9
5	34297.5	26.9
6	41157	26.9

Gas and Electric Cremator - NO_x emissions

Fuel	Gas	Electric
Recorded NOx emission (mg/m3)	200	200
Flue gas flow (m3/hr)	2000	1000
Cremation Time (hr)	1.5	2
Total Nox (kg)	**0.6**	**0.4**

Gas Cremator - CO_2 and NO_x emissions [Natural Gas]

Cremations per day	CO2/year (kg)	CO2/cremation (kg) [average/cremation]
1	63,608.57	249.45
2	71,488.88	140.17
3	79,228.66	103.57
4	90,550.31	88.77
5	99,310.70	77.89
6	97,891.08	63.98

Gas Cremator - CO_2 and NO_x emissions [Grid Electricity]

Cremations per day	CO2/year (kg)	CO2/cremation (kg)
1	3,854.35	15.12
2	4,760.17	9.33
3	5,666.00	7.41
4	6,571.82	6.44
5	7,477.64	5.86
6	8,383.46	5.48

Gas Cremator - Total CO_2 and NO_x emissions [Natural Gas and Grid Electricity]

Cremations per day	CO2/year (kg)	CO2/cremation (kg)	Nox/year (kg)	Nox/cremation (kg)	CO2/year (kg) [inc. body and coffin]	CO2/cremation (kg) [inc. body and coffin]
1	67,462.92	264.56	153	0.6	74,322.42	291.46
2	76,249.05	149.51	306	0.6	89,968.05	176.41
3	84,894.66	110.97	459	0.6	105,473.16	137.87
4	97,122.13	95.22	612	0.6	124,560.13	122.12
5	106,788.34	83.76	765	0.6	141,085.84	110.66
6	106,274.54	69.46	918	0.6	147,431.54	96.36

Appendix M – Average UK Crematorium Calculation (Data Extrapolated from Cremation Society 2019)

Cremators per crematorium (%)

Cremators Per Crematorium	Percentage of Crematoria	Number of Crematoria	Total
1	22.92%	70	70
2	48.17%	148	296
3	20.60%	63	190
4	5.32%	16	65
5	0.33%	1	5
6	1.33%	4	24
		Total	651

Cremations per average crematorium

Operating Crematoria	cremations (2019)	Cremations per crematoria (average)
307	472302	1538

Average Cremations Per Crematorium

Averages closest to 3 per day [765 per year]	725.783364

Appendix N – Cost Calculations (£) – Electric and Gas Cremator

Electric Cremator – Total Financial Cost of Energy (£) [Grid Electricity]

Cremations per day	Cost Per Year (£)	Cost Per Cremation (£)
1	22,538.88	88.39
2	20,424.31	40.05
3	17,058.96	22.30
4	17,078.31	16.74
5	15,950.59	12.51
6	13,678.13	8.94

Electric Cremator – Total Financial Cost of Energy (£) [Green Energy]

Cremations per day	Cost Per Year (£)	Cost Per Cremation (£)
1	27,955.20	109.63
2	25,332.48	49.67
3	21,158.40	27.66
4	21,182.40	20.77
5	19,783.68	15.52
6	16,965.12	11.09

Gas Cremator – Natural Gas Costs (£)

Cremations per day	Cost Per Year (£)	Cost Per Cremation (£)
1	10,398.09	40.78
2	11,686.28	22.91
3	12,951.50	16.93
4	14,802.25	14.51
5	16,234.31	12.73
6	16,002.25	10.46

Gas Cremator – Electricity Costs (£) [Grid Electricity]

Cremations per day	Cost Per Year (£)	Cost Per Cremation (£)
1	2,152.06	8.44
2	2,657.82	5.21
3	3,163.58	4.14
4	3,669.34	3.60
5	4,175.10	3.27
6	4,680.86	3.06

Gas Cremator – Total Costs (£) [Natural Gas and Grid Electricity]

Cremations per day	Cost Per Year (£)	Cost Per Cremation (£)
1	12,550.15	49.22
2	14,344.10	28.13
3	16,115.08	21.07
4	18,471.59	18.11
5	20,409.41	16.01
6	20,683.11	13.52

Appendix O – Nitrous Oxide Calculation – Information Source (DFW Europe)

Fri 19/02/2021 07:15

To: Ben Copeland
Cc: [redacted]

Hi Ben,

We use the following.

CO2 is clear so good.

For NOx:
The NOx emission in a gas and an electric cremator is about the same 200mg/m3.
The flue gas flow from and electric cremator is about 50% of that from an gas cremator.
Therefore the NOx emission from an electric cremator is 50% lower.

In numbers:
DFW Electric:
NOx emission from a DFW Electric is about 200 mg/m3. The flue gas flow is about 1000 m3/hr. Cremation time is about 100 min which makes 200*(1000/1000)*(100/60)=333g/cremation

DFW 6000:
NOx emission in our gas cremator is about 200mg/m3. The flue gas flow is about 2000m3/hr. Cremation time is about 90 min which makes 200*(2000/1000)*(90/60)=600g/cremation.

NOx reduction per cremation is about 270g. Mainly due to the lower flue gas flow in the electric cremators.

We're waiting for an emission report from our gas cremator in the UK to have a one to one comparison. We expect this early March.

Met vriendelijke groet, kind regards,

Sjaak Zutt
Technical Manager

DFW EUROPE

Appendix P – Cremation manufacturer Review – Pre-Assessment (Reviewer Comments in Italics)

DFW Europe [Gas and Electric Cremator Manufacturers] (09/03/2021)

"What we all see is that we have to change the way we work, how we live and how we move from one place to the other. If we don't change our habits our children, grandchildren and the children of our grandchildren have a problem for living in a good and healthy world.
That is why it is important to make an improvement in the way we work in the crematoria. Not only in the UK but all over the world.
We as a cremator supplier take our responsibility in that by building efficient (Bio) Gas, (Bio) Diesel, Hydrogen and Electric cremators.
In the past cremation times where more important than the energy consumption of a cremator.
The more energy you use the quicker the cremation can be done.
From this moment on we have to think that over and must be aware that the environmental impact should be the most important issue.
The DFW Electric gives a balanced, stable and predictable cremation time which is important for the planning of a crematorium.
At this moment we prove with emission reports and practical energy consumption figures that the DFW Electric is the Greener alternative in the Cremator industry.
We are convinced that the maintenance costs of the DFW Electric will be lower than the maintenance costs of a gas cremator over a period of 20 years.
Here are the reasons why.

- *At 100% green energy no use of fossil fuel and 50% CO2 reduction.*
- *The necessary energy for the cremation process comes from the energy in the coffin and the body because it always works as a very hot gas cremator.*
- *Very efficient use of energy during cremation and even cremation times below 110 minutes.*
- *Due to the very high temperature of the floor in the electric cremator cancerous cells have less negative impact on the cremation time compared to a gas cremator.*
- *Less moisture in the cremator installation due to the lack of gas burners so less change on corrosion in the filter system.*
- *Lower flue gas volume due to the lack of gas burners*
- *No emissions from the gas burners.*
- *50% NOx reduction compared to gas fired cremators due to the lower flue gas volume rate and less heat peaks.*
- *Elements are mounted in the brickwork so no contact with flue gasses which guarantees a long lifespan of the elements.*
- *Elements can easily be exchanged from the front and the back of the cremator.*
- *Long lasting heat resistant brickwork.*
- *Brickwork is always on temperature so the heat variation in the Electric cremator brickwork is lower than the brickwork in a gas cremator which gives a better lifespan of the brickwork.*
- *Brickwork repair time and costs are not higher to the repair costs in a gas cremator.*
- *Ultra-Silent*
- *Always ready for cremation because it acts like a very hot gas cremator stored with thermal energy.*
- *Once every 3000 cremations brickwork control and start up from cold to operation temperature.*
- *The emissions meets the PG 5 emission demands.*
- *And last but not least the Electric cremator has a very low energy consumption of 15kWh per hour at 3 cremations a day. If you do more cremations per day the energy consumption will be lower. This energy consumption is including filtration system."*

IFZW [Gas and Electric Cremator Manufacturers] (24/01/2021)

"Some general remarks about the comparison of gas and electric cremators:

In order to reach its operational temperature, every cremator needs energy and time, depending how much residual heat is still present in the brickwork from the previous usage period.

A modern cremator concept provides equipment which prevents the brickwork from cooling out overnight. Electric cremators are dependent in this. Gas cremators today are usually equipped as well, but this is not true for all suppliers. It is important not to compare apples with pears for this consideration.

The gas consumption table that I sent you previously shows values from cremators in use, not all of which have all possible equipment installed. They are average values from relatively good energy-efficient installations that we completed in the past 8 years.

The condition of the cremator plays an important part here as well – door seals, general wear and tear, careful parameterisation of the cremation system depending on its condition (regular servicing is important). Gas and electric cremators differ in their waste gas loss.

An electric cremator, almost completely sealed, has only a small waste gas loss. The electrical energy remains almost completely in the brickwork.

A gas cremator loses a significant heat volume during pre-heat via the flues, but the pre-heat takes a relatively short time.

Both cremators lose energy through the cremator casing. Even with good thermal insulation, this amounts to approximately 9-15 kWh per hour when the cremator is at operating temperature.

The frequently heard statement that the electric cremator does not lose any energy is simply incorrect or at least taken out of context. Rather, long pre-heat periods cause heat loss through the casing for a long period of time.

These times are shorter for the gas cremator (the same applies for oil, liquid gas, etc.) but the loss per hour is higher.

The decisive factor is therefore the duration of the plant's idle time between usage periods.

When operated continuously, both cremator concepts run without external energy, fed by the calorific value of the charge.

The advantages of the respective heating types are determined by the usage concepts.

If the cremator is used regularly for a small amount of cremations, the electric cremator will be the better concept.

For a medium load, both concepts are equally valid.

For continuous operation, the gas cremator will usually have a better energy balance. It must be taken into account here that the cremation times are shorter for a gas cremator than for an electric cremator.

Consumption kWh figures per cremation for a gas cremator are very similar to the consumption per operating hour. For electric cremators, the cremation times are usually longer, so that approximately 50% deviation need to be calculated. The energy consumption of a cremation system during operation is, depending on the size, approximately 18-30 kWh just for the operation of waste gas coolers, cooling pumps, waste gas fans and air fans, etc., the PLC systems are very similar too.

The electrical energy needed to heat the cremator can be seen as equivalent to the energy content of the gas consumption. The supposed higher energy volume for gas cremators is not loaded with external energy losses. For electric cremators, on the other hand, there is the question of the provenience of the electrical energy (coal or gas power plants, solar, wind or nuclear?). If comprehensive green electrical energy is available, the electric cremator will have the better balance.

In summary, there is no doubt about the sustainability of electric concepts.

But there is no need for haste; rather the technology should be developed whenever it is suited to the operational concept of the Client. Intact gas cremators should not be ripped out for this purpose. Concrete figures do not reflect a clear truth, at least not in the way they would be interpreted by the readers. The electric cremator technology is old; the references are usually not yet equipped with modern cremator concepts. We don't unfortunately at the moment have any long-term consumption data for the first new installations yet."

Matthews Environmental Ltd. [Gas Cremator Manufacturers] (27/01/2021)

"On the subject of Electric cremators these are nothing new. Several exist on other countries and historically there were a small number in the UK. These were subsequently removed and replaced by gas cremators as they were grossly inefficient and generally not fit for purpose. One of our competitors has recently developed a new electric cremator and I understand a few to have been installed. I would question the data they present on these however, as I understand it to be questionably favourable. There are significant considerations in relation to electric cremator beyond simply the perceived positive impact on emissions:

1. *A cremator is lined with refractory material which stores energy. Generally the process consists of preheating the machine to temperature prior to commencement of cremations. An electric cremator takes so long to preheat they are basically left on 24/7. Not a huge problem subject to the balance of energy consumption as a comparison to preheating a gas cremator at the start of a day.*
2. *When a coffin is charged, it will naturally ignite due to the heat energy in the chamber. The gas burner is not actually used. The gas is basically a secondary (auxiliary fuel). The coffin and the body is the primary fuel. Air is injected into the chamber to promote combustion and only towards the tail end of the cremation is the burner utilised. Meanwhile, the secondary combustion chamber where the combustibles in the exhaust gas stream are treated, the burner modulates to maintain the required temperature.*
3. *The tail end of a cremation is problematic with an electric cremator. A gas machine is designed such that the burner fires directly at the torso. It is a concentration of energy in that area which is hardest to burn. With an electric cremator you do not have that direct effect hence the latter end of a cremation is extended. One of the primary interests of a crematorium is a fast process. An average cremation would typically be circa 90 minutes. This is generally not achievable in an electric cremator. This problem is exacerbated by cancerous cells which are incredibly tough to burn even with the direct attack of a gas burner. More of an issue without.*
4. *A cremator typically lasts upwards of 20 years however within that period, work to the internal refractory material will be required. An electric cremator utilises elements embedded within the refractory hence this refractory reline work becomes more costly and complex.*
5. *Cost – currently a DFW electric cremator costs close to double the cost of a regular gas cremator.*
6. *Infrastructure – same issue as with electric cars. Even now it can be an issue to find an adequate electric supply into a crematorium for the current spec. of abated cremation systems. The use of an electric cremator will of course require a considerable increase in that capacity.*

Ultimately these electric cremators will become more common, as with everything else, turning to electric is the magical cure to all our problems. Personally I believe that considerable development is still required although it's not to say that this won't happen.

Not sure on the relevance to your paper but my own view on the matter is based on two recommendations which I would love to explore more:

1. *At present, a fully electric cremator is not feasible nor fit for purpose. My suggestion would be a dual fuel machine in the interim. The gas burners can be used for fast preheat, or alternatively if it suits, leave the thing on 24/7 utilising the electric elements. Once the secondary chamber is up to temperature, the temperature can be maintained as required using the electric elements. Meanwhile, in the main chamber, the cremation time can be kept acceptable by using the gas burner to the latter end of the process.*
2. *Looking longer term the cremation industry needs a major kick in the backside. The vast majority of crematoria are buildings of varying age, never designed for the amount of equipment required to fit in them these days, and often surrounded by an ancient graveyard. The whole crematorium facility needs a fresh concept. Some private companies are stepping in the right direction with new build sites but they need a step further. A facility needs to be built specifically for an electric cremator. If the electricity can be generated on site utilising renewable sources (wind, solar etc.) incorporated into the facility design then the overall impact of the electric cremator is reduced. Further, there is a large proportion of wasted energy from the process which is generally unfeasible to make use of. Many sites have hot water heat recovery exchanges from the cooling circuit which feed into the site central heating boiler but generally they struggle to use even as much as 100kw of the circa 400kw of energy expelled by the cooling circuit."*

Appendix Q – Summary Report for Stakeholders

Stakeholder Response Report

Introduction to research:

The available scientific literature regarding cremation emissions is limited to the analysis of mercury and particulate emissions (González-Cardoso et al. 2018; Takaoka et al. 2021). There are online sources that estimate the CO_2 emissions from gas cremation is about 245kgCO_2 per cremation, however, these claims are not supported by the scientific evidence (National Geographic 2019). Currently there is no publicly available information that provides an estimate for the CO_2 and NO_X emissions from electric cremation [March 2021].

This research project is a comparative study that focuses on gas and electric cremation emissions (CO_2 and NO_x). This study must consider future projections of gas and electric energy mixes [using available government publications] and also viable alternative fuels to ensure that the future industry is sustainable. A financial cost comparison is to be undertaken using initial unit and energy consumption costs. The findings and recommendations from this innovative research will help key stakeholder decisions and policymakers review and reduce CO_2 and NO_x emissions in the cremation industry.

Aims and Objectives:

Main Aim:

To investigate present and future carbon dioxide (CO_2) and nitrogen oxide (NO_x) emissions from gas and electric cremators under various policy and technology scenarios

Objectives:

- *Undertake a critical review of the literature.*
- *Examine current CO_2 and NO_x emissions from UK gas and electric cremations and review alternative fuel types.*
- *Investigate the carbon intensity, energy-use and CO_2 emissions of cremations using future energy projections.*
- *Undertake a cost comparison of gas and electric cremation.*
- *Provide recommendations to the cremation industry linked to fuel-type choices and UK emissions policies.*

Conclusion:

The draft conclusion (Page 2 to 4) presents the principal findings and recommendations of the overall study, prior to the full publication, the researcher requires responses to the conclusion from industry stakeholders.

Responses could include:

- *Are the findings agreed upon, do they align with current understanding?*
- *Are the recommendations feasible and viable?*
- *Will the recommendations make changes to the industry?*
- *Do you envisage this report to address gaps in industry knowledge?*
- *Recommendations for further research?*

Responses can be sent to the researcher in the form of an email or via a document. All stakeholders contacted for a response have signed an "informed consent form", therefore university ethics will be followed.

Draft Conclusion

The primary focus of this project has been to evaluate the emissions from both gas and electric cremation plants, with specific focus on fuel emissions. The future projections of fuel carbon intensities have been modelled to provide accurate recommendations to key stakeholders within the cremation industry. An outline of the key findings and recommendations are provided:

Findings:

Finding 1: Electric cremation produces lower CO_2 and NO_x emissions than gas cremation, thus addresses gaps in the literature and industry knowledge.

This research has calculated that electric cremation produces 50-80% less CO_2 emissions than gas, range is influenced by the energy tariff and number of cremations per day. The electric cremator reduces NO_x emissions by c. 33% without selective catalytic reduction (SCR). An electric cremator on a green energy tariff with SCR installed would reduce CO_2 emissions by c. 80% and NO_x emissions by >99%.

Finding 2: Alternative fuels, such as hydrogen blending and biogas, do not reduce CO_2 emissions to the same level as electric cremation, thus addresses our current understanding regarding the viability of alternative fuels.

Hydrogen is likely to become available in the centralised gas network at a blending rate of 20%, blending rates beyond 20% increase leakage risks and would, therefore, not be compatible with current infrastructure. If hydrogen within the blend was 'green' then CO_2 emissions from gas cremation would be reduced by 20%. Biogas accounts for c. 4% of gas in the centralised grid, the possibility of having all UK cremators run using 100% biogas is unfeasible due to distribution issues, the availability and the requirement for new on-site infrastructure.

Finding 3: CO_2 emissions from electric cremators on the National Grid will fall by 42% between 2020 and 2030, providing future projections for the cremation industry.

Electrification of the UK is key to the government plans to decarbonise the economy, the UK government has banned the installation of gas boilers in new-build homes by 2025 and the sale of petrol and diesel cars by 2030. The carbon intensity of the electricity grid is set to decrease to only 0.005kgCO_2/kWh by 2050, whilst natural gas remains at c. 0.184kgCO_2/kWh with a possibility to further reduce CO_2 emissions by 20% through a green hydrogen blend.

Finding 4: Gas cremation is currently the cheapest option for cremation if initial costs are included, therefore provides a comprehensive review of cremation energy consumption costs.

The purchase and installation cost of an electric cremators is [redacted] more than gas cremators, however, electric cremators are more cost-effective in terms of energy consumption, if three or more cremations are processed per day. Maintenance must also be considered when evaluating overall costs. Electric cremators cause less damage to the lining of the cremators due to less fluctuation of high temperatures, and therefore are replaced less frequently, the financial savings are currently unknown due to infancy of electric cremation.

Recommendations:

Recommendation 1: New crematoria should install electric cremators and existing crematoria should replace gas cremators at the point of decommission to an electric cremator.

Regardless of the cremations per day, electric cremators will produce lower CO_2 and NO_x emissions to gas, therefore, all crematoria should review whether it is feasible to switch from existing gas cremators to electric.

Recommendation 2: Crematoria which do not have the infrastructure to install electric cremators should improve the efficiency and sustainability of their gas cremators.

Electric cremation requires a higher electrical power connection than the gas cremator, this may not always be possible or feasible, in this case crematoria should seek alternative ways to improve the sustainability of gas cremators. Crematoria operating gas cremators should review the viability of on-site biogas tanks, which could provide energy for all on-site cremations. All crematoriums operating gas cremators should consider installing an SCR system and switch to a green electricity tariff.

Recommendation 3: Financial costs of replacing an intact gas cremator must be considered in decision making.

A high initial financial cost is involved in replacing intact gas cremators with electric which should be considered. However, this study highlights that the majority of UK electricity by 2050 will be from renewable sources with potentially lower levelised and absolute cost. Consequently, crematoria should consider governmental targets, net-zero carbon targets and green consumerism.

Recommendation 4: An emissions and cost calculator should be developed to ensure UK crematoria can make informed choices.

The calculator should be cremation plant specific; as notably differences exist between fuel types and cremation plants.

Recommendation 5: UK cremation manufacturers should consider manufacturing electric cremators.

If electric cremators were manufactured in the UK this may reduce costs (e.g. importation tax) and, thereby making electric cremator purchases more financially viable for UK crematoria.

Recommendation 6: Regulatory bodies - such as the Environment Agency (EA) and Department for Environment, Food & Rural Affairs (DEFRA), should extend industry regulation to include CO_2 and NO_x emissions.

The current process guidance notes (PG5/2: DEFRA) does not regulate CO_2 or NO_x emissions and whether a crematorium is attempting to reduce emissions. Consequently, updated PG5 guidance notes should include new basic standards on emissions reporting and reduction.

Recommendation 7: Local authorities should request crematoria to disclose CO_2 and NO_x emissions of cremation.

Local authorities are required to produce carbon accounting reports, however, CO_2 and NO_x cremation emissions are not currently included.

Concluding remarks from the industry based on conclusions:

……..

Concluding Statement:

The results of this study confirm using electric cremators reduces both CO_2 and NO_x emissions. The UK cremation industry must consider the findings and recommendations of this report and play a more active role in reducing greenhouse gas emissions. There are numbers of areas that warrant further research:

- *The effectiveness of the SCR system in cremations; the residual products and the life-cycle emissions of this process.*
- *Analysis of maintenance costs of electric cremators in order to provide accurate life-time cost comparisons.*
- *Appropriate methods to offset CO_2 emissions from the body and the coffin.*
- *Coffin choices for cremation that reduce both NO_x and CO_2 emissions during the production and combustion stages.*

Appendix R - Stakeholder Responses [Post-Assessment] (Reviewer Comments in Italics)

DFW Europe Review:

DFW Europe supplies a file in which is noted down the CO_2 emissions of an electric cremator. That is the Excel file with source notes to the information

1) Are the findings agreed upon, do they align with current understanding?

Not yet. See our remarks

2) Are the recommendations feasible and viable?

Yes, the recommendations are feasible and viable.

3) Will the recommendations make changes to the industry?

Not this recommendations alone. It needs more to change the mindset of the industry. In the past cremation times where more important than the energy consumption of a cremator. The more energy you use the quicker the cremation can be done. From this moment on we have to think that over and must be aware that the environmental impact should be the most important issue.

4) Do you envisage this report to address gaps in industry knowledge?

This report helps to get awareness in the industry

5) Recommendations for further research?

A study has to be done for coffin choices as you also said at the end. When a coffin gives less energy to the cremation process. This energy has to be put in by electrical elements or a gas burner. So how green is a green coffin in a cremator?

This price range is not correct. It depends probably on the supplier. But our DFW 6000 costs around GBP [redacted]. The DFW Electric Single End GBP [redacted]. So what source did you use? That gives a price difference of GBP [redacted]. Our prices are including a lot of standard options whit a value of GBP [redacted] which we know are necessary. We know that not all our competitors build there quotation the same way.

You should point out the new type of electric cremators. The first electric cremators where more expensive in maintenance.

IFZW Review:

Many thanks for your summary.
We have the following comments:

Your findings 1 and 2 are not correct in this generality - we have already discussed this. In your finding 3 you say yourself that it may be the case possibly in the future. As long as electricity generation also uses fossil energy, findings 1 and 2 remain in dispute, especially since the efficiency of the power stations and networks is not taken into consideration. We therefore consider these statements to be incorrect.

Finding 4 is not positively, but mostly, correct – this should be qualified in favour of the electric cremators as this will probably change when the new technology finds its market on a greater scale.
We would therefore recommend to attenuate this finding somewhat – in the final instance the handling and the utilisation of the plant have a large influence that needs to be taken into consideration. This would lend more credibility to the issue and make it more factually correct.

Your recommendations, on the other hand, are quite useful, especially if they remain recommendations.

Recommendation 1
Correct, since one should turn to the new technologies, this is especially feasible for new builds. Since the electric cremators may have different waste gas volumes, the downstream components for waste gas cooling and abatement should also be looked at. The lifespan should therefore always relate to the whole cremation line.

Recommendation 2
Correct, this also applies when the cremation equipment has not yet reached the end of its life. The cremator control has a large influence on the energy efficiency and many plants have potential for improvement here during their current period of usage.

Recommendation 3
Correct, even if we cannot really comment on financial aspects.
From an ecological point of view it is certainly never a reasonable decision to replace an intact gas cremator. The CO2 footprint of the production of a new plant, from the raw materials production via the transport routes and processing is currently very very large, especially since many parts of the world still work with a very high CO2 output.
We are certain, therefore, that the useful life of an existing plant should always be exploited fully.

Recommendation 4
This, from our perspective, is the most important decision basis of all.
Especially in connection with your finding 3, it is essential to map the decision processes over at least 2 decades and to check today's facts and assumptions every year. There is a lot of backlog demand on this issue, unfortunately lobbyists are usually better equipped to do this than independent scientists.

Recommendation 5
We think that this, too, is very important.
The alternative technology must not be blocked (politically) or slept through (manufacturers).

Recommendation 6
Certainly correct and important for CO2.
For NOx the issue is doubtful, the percentage that is caused by the gas burners has already been taken into consideration with a clear focus and CO2.
The NOx resulting from the coffin + content cannot be easily prevented. Often one is at the expense of the other.
For NOx it is important not to force any unsuitable waste gas cleaning technologies; these have CO2-footprints and pose other new pollutant risks as well. For small occasionally used plants such as crematoria this is the

clean and better way. These plants should not be compared with large-scale plants for waste treatment or energy generation in this regard.

Recommendation 7
Also important and correct.
Data from practical use can be collected here without relevant difficulty. From our experience, we expect it will be clearly seen then how much difference there is even within the product groups gas or electric cremators.
In the final instance, the fuel is only a complementary factor for the CO2 balance of a crematorium. Plant composition, operator habits and plant condition have a far greater influence here.
We hope that this input is helpful for you. We are looking forward to hearing from you further and to reading your final research report, we are particularly interested to know what becomes of it. It is clear that humanity needs to make changes. The sum total of the contributions will make a difference – that is our hope at least.

Environmental Stewardship Group Review:

Mr Jon Cross FIoD

[redacted]

FTAO

Mr Benjamin Copeland

[redacted]

Dear Ben,

In my capacity of the Facilitator for the Environmental Stewardship Group, which is leading the bereavement sector to sustainability, I have great pleasure in responding to your review request in relation to the cremation activities within the sector.

Firstly, an extremely important document for the sector, balanced, well thought through and absolutely on point for the current major debates and activity in relation to the environmental impact challenges we are currently facing.

In recent weeks the Environmental Stewardship Group have been gathering feedback from owner operators of crematoria in the UK as part of a 6month intensive consultation to assess where the sector is currently positioned and what are its plans for the future. It will come as no surprise that at every opportunity "information" is raised as the key requirement, however, and more pertinent in relation to this document is the repeated request for "quantifiable research backed by evidence".

Following the release of the sixth carbon budget by the Committee of Climate Change and the change in target dates for emission reductions being advanced by 15 years, serious considerations are being made in relation to capital assets such as cremators.

Having clearly established that fossil fuel will be significantly reduced during that period and the electrification of the UK via renewable resources will become the 'norm' there is even more importance on the contents, findings and recommendations presented.

Taking your findings in order: -

Finding 1: Electric cremation produces lower CO2 and NOx emissions than gas cremation, thus addresses gaps in the literature and industry knowledge.

This finding and its supporting research provides further evidence to the sector of the extent to which the current processes of cremation impact negatively everyday on the environment, and whilst there

may be arguments for alternative solutions the electrification of this process is immediately available and can make a significantly positive impact if adopted.

Finding 2: Alternative fuels, such as hydrogen blending and biogas, do not reduce CO2 emissions to the same level as electric cremation, thus addresses our current understanding regarding the viability of alternative fuels.

The explanation of your finding helps to bring further clarity to an ongoing debate about alternative fuels being the "solution" in retaining gas cremators which at a 2020 review accounted for over 90% of the UK cremators. Once again the clarity in this finding is refreshing and provides quantifiable information on which to provide answers to claims and counter claims being made on capital assets with significant cost implications.

Finding 3: CO2 emissions from electric cremators on the National Grid will fall by 42% between 2020 and 2030, providing future projections for the cremation industry.

As the uptake of the electrification changes in the UK gathers pace, each sub element of this will benefit, the electrification of cremators for the sector is a great step forward and will create additional benefits in terms of emission reductions, costs, capital savings and social and economic benefits all of which create compelling arguments for early adoption.

Finding 4: Gas cremation is currently the cheapest option for cremation if initial costs are included, therefore provides a comprehensive review of cremation energy consumption costs.

Your analysis is both fair and honest in its conclusion, it also points clearly to a number of points made by the Government which are also reflected in the 6th Carbon budget, where clear indicators of the law of supply and demand lead to significant reductions in price. The substantial reduction of the cost of solar panels in the last 10 years and projected cost reductions in green energy outline very clearly that as green energy supplies increase, costs will fall and the increase in volume of electric cremators sought will have the same effect over a period of time.

Therefore, it is safe to say that your findings certainly align with current understandings and from my experience provide an important stage in improving the sectors understanding and knowledge of this critical subject.

Moving on to your recommendations: -

Recommendation 1: New crematoria should install electric cremators and existing crematoria should replace gas cremators at the point of decommission to an electric cremator. Regardless of the cremations per day, electric cremators will produce lower CO2 and NOx emissions to gas, therefore, all crematoria should review whether it is feasible to switch from existing gas cremators to electric.

Given that the sector and its activities produce well in excess of 250,000 m tonnes of CO2 each year and the low hanging fruit within the UK carbon emissions has already been dealt with, the

bereavement sector has to step up to the plate to deliver its share of reductions. It is extremely hard to make an argument against your recommendation even taking into consideration initial higher costs.

Recommendation 2: Crematoria which do not have the infrastructure to install electric cremators should improve the efficiency and sustainability of their gas cremators. Electric cremation requires a higher electrical power connection than the gas cremator, this may not always be possible or feasible, in this case crematoria should seek alternative ways to improve the sustainability of gas cremators. Crematoria operating gas cremators should review the viability of on-site biogas tanks, which could provide energy for all on-site cremations. All crematoriums operating gas cremators should consider installing an SCR system and switch to a green electricity tariff.

As with any major shift in infrastructure there are a number of challenges which can be overcome in the passage of time. In the interim the options for mitigating negative environmental impacts should be explored and supported by a suitably robust net zero plan. The plan will provide clarity in the methods employed in addressing the sustainability whilst ensuring that it remains ready to make the switch over as soon as conditions allow.

Recommendation 3: Financial costs of replacing an intact gas cremator must be considered in decision making. A high initial financial cost is involved in replacing intact gas cremators with electric which should be considered. However, this study highlights that the majority of UK electricity by 2050 will be from renewable sources with potentially lower levelised and absolute cost. Consequently, crematoria should consider governmental targets, net-zero carbon targets and green consumerism.

Your recommendation is valid in so much that any major capital items with a life expectancy of more than 15 years in 2035 will have to be either carbon neutral or be supported by a net zero plan to offset what emissions may be created which should indeed by at a minimum level to begin with. If we refer to the Government's 10 point plan for the Green Revolution you will see an initial investment of £14bn which will attract a further £46bn to support this activity, point 10 identified a number of funding opportunities which may support to a certain extent costs incurred. However if realistic deadlines were legislated for reflecting that of domestic boiler changes, a roadmap could be created to support supply and demand and more certainty in cost projections.

Recommendation 4: An emissions and cost calculator should be developed to ensure UK crematoria can make informed choices. The calculator should be cremation plant specific; as notably differences exist between fuel types and cremation plants.

The calculation that has been advised to take place on a quarterly basis goes in part to meeting this aspiration if found in the DEFRA Process guidance note 5/2 (12) section 4.34, where it requires crematoria to calculate gas use x conversion factor on their website to give a KgCO2e figure. In reality this is not embedded into normal practises, but your recommendation to put a cost element to this would make a significant difference to the understanding of costs that could be saved and managed productively for the operator.

Recommendation 5: UK cremation manufacturers should consider manufacturing electric cremators. If electric cremators were manufactured in the UK this may reduce costs (e.g.

importation tax) and, thereby making electric cremator purchases more financially viable for UK crematoria.

A timely reminder that as an engineering nation we are guilty of not recognising that the climate emergency is the biggest challenge, but also the biggest opportunity in our lifetime. There are only a handful of electric cremators manufacturers in the world, with the closest being in Holland and Germany. Given the potential clearly presented in this paper, there will be more than enough demand for electric cremators to warrant investment now, and meet investors requirements for Environmental, Social and Governance requirements to be met.

Recommendation 6: Regulatory bodies - such as the Environment Agency (EA) and Department for Environment, Food & Rural Affairs (DEFRA), should extend industry regulation to include CO2 and NOx emissions. The current process guidance notes (PG5/2: DEFRA) does not regulate CO2 or NOx emissions and whether a crematorium is attempting to reduce emissions. Consequently, updated PG5 guidance notes should include new basic standards on emissions reporting and reduction.

The bereavement sector has a number of governmental department interfaces for legislation, guidance, advice and support, unfortunately not always linked up. At the launch of the Environmental Stewardship Group, we benefitted from a keynote speech from the Director of Regulated Industry from the Environment Agency where he advised us that Emission were going to be a major focus going forwards. The reference to modern approaches made by Sir James Bevan the CEO of the Agency indicates that this type of approach to meeting requirements is exactly what is required. Indeed, this topic is due for discussion at a round table event on the 6th April 2021 with all government departments linked to the sector. A perfect example of the validity of your recommendation.

Recommendation 7: Local authorities should request crematoria to disclose CO2 and NOx emissions of cremation. Local authorities are required to produce carbon accounting reports, however, CO2 and NOx cremation emissions are not currently included.

Once again, a very valid recommendation that will help crematoria operators to gain the knowledge and measurements from which to manage their facilities in a pro-active way leading to greater environmental benefits. In a sector which is self-policed and does not benefit from a central regulation point such a recommendation enables a clear path to meeting targets discussed and aspired to.

In conclusion the recommendations are not only valid and eminently possible they provide a series of opportunities to make a step change for the sector, the benefits of this project are significant for the sector, timely and will be well received.

Concluding Statement:

The results of this study confirm using electric cremators reduces both CO2 and NOx emissions. The UK cremation industry must consider the findings and recommendations of this report and play a more active role in reducing greenhouse gas emissions.

I honestly believe the case made in this report provides a balanced and fair review of the situation, it also provides a wealth of clarity on a subject that has been toyed with for a number of years due to the lack of quantifiable data and reasoned argument to support it.

There are numbers of areas that warrant further research:

- **The effectiveness of the SCR system in cremations; the residual products and the life-cycle emissions of this process.**
- **Analysis of maintenance costs of electric cremators in order to provide accurate life-time cost comparisons.**
- **Appropriate methods to offset CO2 emissions from the body and the coffin.**
- **Coffin choices for cremation that reduce both NOx and CO2 emissions during the production and combustion stages.**

Agreed that all of the above areas do require further research as they will further support the "greening" of the sector in a measured way. It must be noted however that challenges from the Coffin manufacturing industry will be substantial and intense, but absolutely necessary to help close the gap on where the sectors emissions need to be.

Thank you for sharing this with me, once again please let me reiterate that it is both timely and on point for what the sector needs right now. I hope that you will be able to consider sharing this at an Environmental Stewardship Group event in the future.

Kind regards,

Jon X

Jon Cross FIoD

ESG Group Facilitator

The CDS Group Review:

First, it should be noted that the outcomes of this report will be one of the most invaluable and informed documents for the cremation industry, it will help to make advised decisions on progressing operators' green agendas and carbon crisis targets to achieve zero carbon emissions within their industry by 2030.

The importance of this dissertation in this sector of the bereavement industry should not be underestimated.

Findings and response;

The findings within this dissertation might be open to challenge by some private companies who have commercial interest in prolonging the use of natural gas cremation. The carbon crisis is current and immediate and prolonging the production of carbon merely to satisfy commercial needs is something that the end users need to address. This report hopefully will go some way to achieving an understanding and insight as to how the problem can be addressed.

The evidence presented appears conclusive with reductions of carbon of up to 80% and NOx by 99%. These figures are damming of the current practice, but would have to be very strongly re-enforced with data to ensure that any challenge can be proportionately defended.

The commercial costs of replacement of gas with electric whilst significantly higher should be supported by whole life costs benefits notwithstanding the green value. The authors evidence suggests that despite the higher capital cost there is some anecdotal evidence to show that operationally costs might be lower.

Evidence of maintenance and long-term operational costs are clearly difficult to determine due to the lack of time that modern electric cremation technology has been in the market.

However, there are two considerations:

That the market should be educated to weight the benefits of the green agenda and offsetting of carbon and NOx against the capital cost of the equipment.

That the cost of the use of green gas alternatives is even further from the market knowledge.

Indeed, the dissertations' consideration of alternative fuels would suggest that the gas cremation "wait and see" philosophy for alternative green gas fuel options that could be used with minor modifications to the current gas cremation technology may according to the author, be flawed.

This issue with alternative green gas fuel needs to be explored further. A whole life production model as a result of manufacturing green gas (BioLPG) alternatives in terms of not just cost, but also production of carbon and NOx in the manufacturing process needs to be considered.

Further, it is known that BioLPG burns at higher temperatures and the production of thermal NOx is significantly higher than with electric cremation, again this should be emphasised.

The use of hydrogen gas mixes should also be evaluated in depth to determine the likely role out times, the cost of hydrogen production and the feasibility of using it as a blended product in the gas cremation sector.

The recommendations of the author are balanced and fair and whilst it would seem prudent to arbitrarily instruct the decommissioning of natural gas cremation in favour of green electric alternatives, it is clearly a political and financially driven agenda.

However, some authorities are already considering the removal of gas cremators despite them having long term operational capability simply to achieve their carbon targets.

There are also some government grants provided for the substitution of gas cremation for green electric alternatives, providing that net carbon emissions can be reduced and demonstrated. This report will certainly assist some authorities in providing an evidential based argument to assist to their application for carbon reduction funding.

Consumer ignorance and lip service is a major issue in the industry. This report may help to educate the industry through highlighting the level of negative contribution the sector is making towards hitting targets for decarbonisation and the importance of the decisions needed going forward.

The problems and negative impacts are easy to identify, and solutions and positive benefits are readily achievable, this report should clearly set these actions out, but it will be a report that has so much significance in the industry and for the betterment of public health on a national level that it should be developed further.

Justin Smith

Business Development Director CDS Group