Research into sustainable and alternative waste collection vehicle usage

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CIWM

FRITH RESOURCE MANAGEMENT

ISWA
International Solid Waste Association

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Faun Zoeller, UK

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ULEMCo Ltd, UK

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Private sector companies

ALBA W&H Smart City Pty, Singapore

Energy Vision, USA

Envac Scandinavia, Sweden

FCC, UK

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OLWG Ltd, UK

Infore Environment, China

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Suez, UK & France

Veolia, UK

Waste Management Inc, USA

Disclaimer:

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Note: the information in this report and the findings of this study were correct at the time of undertaking (September 2021 to March 2022); however, this is a rapidly developing area, that is subject to change.

Executive Summary

Climate change is the defining issue of our time. World-wide commitments are focussed on limiting global warming to 1.5°C and achieving net zero emissions of greenhouse gases (primarily carbon dioxide and methane) by 2050. Municipal waste collection, delivered by councils / municipalities and their private sector contractors, plays an important role in the potential to improve the impact of vehicles used for municipal solid waste management on carbon emissions and air quality.

Frith Resource Management (FRM) has therefore been engaged by the International Solid Waste Association (ISWA) to undertake a study on the adoption by municipalities of low emissions and alternative vehicle fuels for waste collection. It is the intention that the findings may be used to inform the decision-making processes of municipalities seeking to adopt such vehicles for their waste and recycling collection services.

The objective of this project is to understand the path towards acquisition and use of low emissions and alternative fuel vehicles, their performance, cost and the challenges faced.

The scope of the project is to gather information on the current practices of a sample of municipalities around the world in upper / middle income countries on the use of low emission and alternative vehicle fuels for waste collection. For the purposes of this project, "low emission" is less than 50g carbon dioxide/km measured at the vehicle tailpipe. The report also covers alternative fuels that may not meet this standard but are lower than petrol, diesel or liquified petroleum gas (LPG). Such fuels include, but are not limited to:

- electric
- hydrogen
- biofuels
- compressed natural gas (CNG) and liquified natural gas (LNG)
- hybrid vehicles

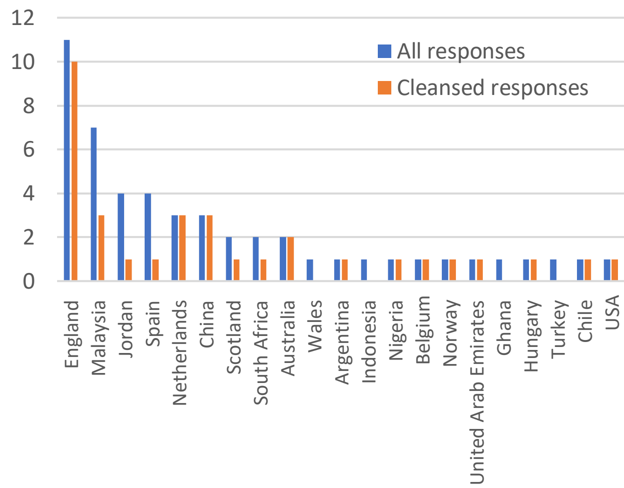
This report presents a limited snapshot of the experiences of some municipalities that have adopted alternative vehicle fuels for waste collection services, supplemented by broader discussion from waste management companies and vehicle manufacturers. It is not intended to be an exhaustive survey, nor to make recommendations for any preferred option, however the summary findings for each fuel type may be of interest to municipalities seeking to adopt, or transition to, alternative low emission fuels.

Information has been gathered through a two-stage survey:

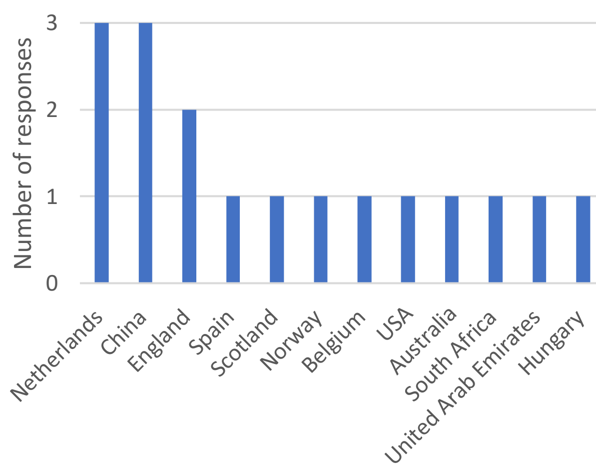
1. Stage 1 aimed to gain an understanding of the motivations for municipalities adopting or not adopting low emission and alternative vehicle fuels for waste collection. Stage 1 was undertaken by an on-line questionnaire during October and November 2021 circulated through the network of ISWA national members and the valuable contributions of NVRD and CIWM.
2. Stage 2 focused on obtaining detailed information from selected municipalities, supplemented by discussions with waste management companies and vehicle manufacturers. Stage 2 was undertaken between November 2021 and January 2022.

Stage 1 summary

The online survey in Stage 1 yielded 51 responses. Of these, 18 were from organisations that did not directly represent a municipality. These include waste management companies, research institutes, consultants and other suppliers to the waste industry. Of those 33 municipalities that responded to the survey, 17 reported that they had already introduced low emission or alternative vehicle fuels for their waste collection services, as shown below. There is a moderate to low level of adoption of low emission or alternative vehicle fuels by survey respondents, with the highest levels being in the Netherlands and China. This is only a small snapshot of each respondent country. The results may not be representative of the full international picture, and the survey results should not be considered to be statistically correct.

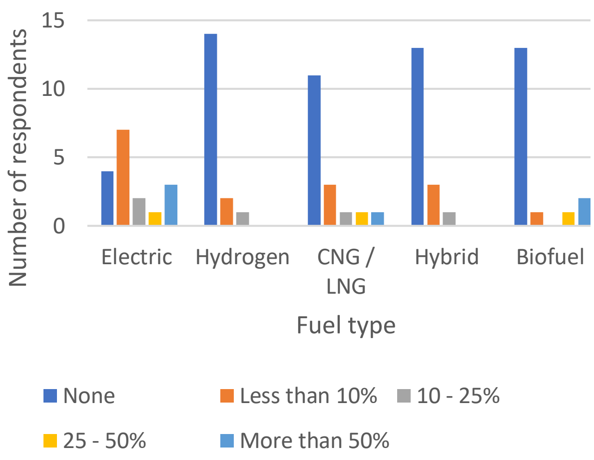


Locations of the Stage 1 survey responses

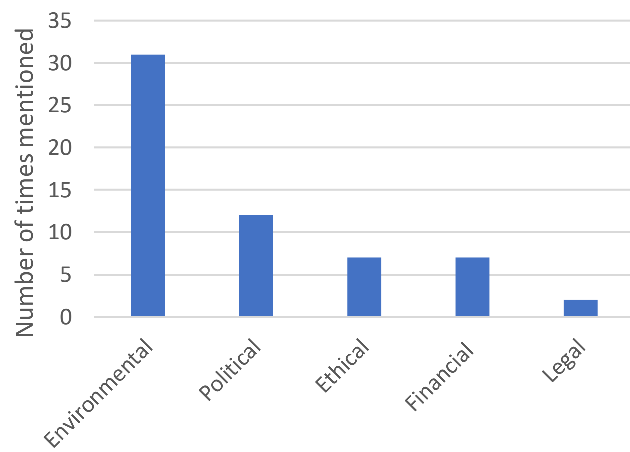


Locations of municipality respondents that have introduced alternative fuels (Stage 1: 33 respondents)

Of those responding in the Stage 1 survey, there appears to be a range of fuel types in the fleet, with most adopting a proportion of their standard diesel fleet with an alternative fuel, as shown in the chart below. The responses to this question were used to identify municipalities for detailed exploration in the second stage of the survey. The prime motivating factor for introducing alternative fuel vehicles is environmental consideration, tying in with concern around the global climate change situation.



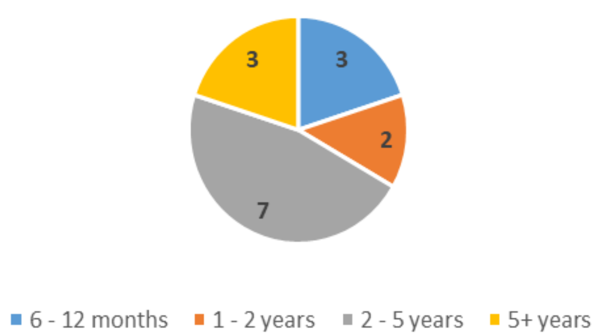
Types of fuel and proportion of municipal waste collection fleet using each fuel type (Stage 1: 17 respondents)



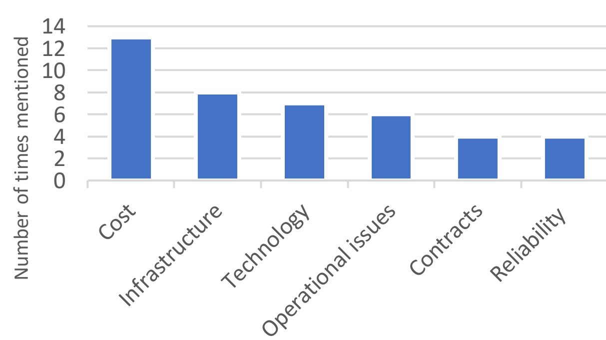
Motivations for considering using alternative vehicle fuels (Stage 1: 32 respondents)

The majority of the remaining respondents which stated they had considered the vehicles but had yet to introduce them, reported that they were likely to introduce them within a 5-year timescale, as shown below.

Of the 15 respondents that had considered alternative fuels but had not yet introduced them, the most cited reason was the availability of funding or the cost of the vehicles. This is followed by the provision of supporting infrastructure, such as for vehicle charging or refuelling, the availability of technology and operational reasons associated with the vehicles.



Timescales for introducing alternative fuels (Stage 1: 15 respondents)



Reasons for not introducing alternative fuel vehicles yet (Stage 1: 15 responses)

Stage 2 summary

A total of 26 organisations contributed to the discussion on the use of alternative fuels for waste collection for Stage 2. These included municipalities, waste management companies, vehicle manufacturers and other relevant organisations. Discussions were held by MS Teams meetings or by telephone, with some communication being carried out by email. The fuel types covered include:

- Electric
- Hydrogen (fuel cell and diesel hybrid combustion)
- Natural gas
- Hydrotreated vegetable oil (HVO)

The majority of experience offered through this study has been with electric vehicles. Eight case studies have been compiled on the experiences of the municipalities interviewed. The report identifies the following key points for each fuel type from the experiences of these municipalities, along with the views from the vehicle manufacturers and waste management companies that also contributed to this study.

Stage 2: Summary of key points for each fuel type

Fuel type	Key benefits	Key challenges
Electric	- Zero emissions - Improved driving conditions - Lower operating costs	- High vehicle capital cost - Charging infrastructure - Vehicle supply chain - Battery range - Other environmental impacts (e.g. battery production)
Hydrogen fuel cell	- Zero emissions - Increased travel range - Speed of fuelling - Vehicle life	- Hydrogen supply - High vehicle capex - Vehicle supply chain
Hydrogen / diesel hybrid combustion[1]	- Moderate capex for conversion - Ease of use	- Hydrogen supply - Conversion considerations - Limited carbon reductions
Natural gas	- Reduced emissions - Lower fuel cost - Similar performance	- High vehicle capital cost - Fuelling infrastructure
HVO	- Ease of use - Lower emissions	- Fuel supply - Fuel cost - Performance efficiency

Reduced emissions are one of the key drivers for adopting alternative fuel vehicles, while other benefits include lower operating cost and longer vehicle life. There are several themes in the key challenges: in

[1] Other hybrid combinations exist, however no other examples were forthcoming through the survey

particular, the high capital cost of alternative fuel vehicles, supply chain issues, and developing appropriate infrastructure for fuelling or charging. Each municipality has a different energy and fuel supply situation. As such there is no universal single solution; the optimum fuel will depend on the particular situation.

This study has identified a number of areas where further work may be of use to municipalities seeking to adopt alternative fuel vehicles:

- *End of life vehicle management* – what happens to the vehicles at the end of their frontline service: resale / reuse, decommissioning, retrofit, recycling of components
- *Life cycle analysis* – the full environmental impacts associated with the vehicle manufacture, supporting infrastructure, fuel / power generation, vehicle use and end of life
- *Supply chain capacity* – an assessment of the capacity of the vehicle supply market to meet potential demand, particularly taking into account lead times.

In summary, this report gives an insight into the experiences of municipalities operating alternative fuel vehicles for waste collection. The findings may be of interest to others seeking to adopt such fuels.

Note: the information in this report and the findings of this study were correct at the time of undertaking (September 2021 to March 2022); however, this is a rapidly developing area, that is subject to change.

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Acronyms used in the report

Acronym	Meaning
ACEA	European Automobile Manufacturers Association
BEV	battery electric vehicle
CO_2	carbon dioxide
CCUS	carbon capture, utilisation and storage
CNG	compressed natural gas
FAME	Fatty Acid Methyl Ester
FRM	Frith Resource Management
HVO	Hydrotreated / hydrogenated vegetable oil
ISWA	International Solid Waste Association
LNG	liquified natural gas
LPG	liquified petroleum gas
NOx	nitrogen oxides
SOx	sulphur oxides
OEM	original equipment manufacturer
RCV	refuse collection vehicles
RNG	Renewable Natural Gas (or biomethane or biogas)
WTW	well to wheel

1 Introduction

1.1 Background

Climate change is the defining issue of our time. World-wide commitments are focussed on limiting global warming to 1.5°C and achieving net zero emissions of greenhouse gases (primarily carbon dioxide (CO_2) and methane) by 2050.

The way forward is widely recognised to require input across all sectors; with road transport being a significant contributor, accounting for over 17% of global carbon emissions[2]. Decarbonisation of the sector is therefore critical to ensure the world stays on track to limit global warming. There is a mass of support driving the transition to zero emission vehicles, with markets representing two billion people. Automakers representing more than a quarter of car sales globally, are committed to working towards 100% of all vehicle sales being zero emission by 2040 or earlier. For example, in December 2020, Europe's trucks manufacturers, following research with the Belgium Potsdam Institute for Climate Impact Research, concluded that all new trucks sold needed to be fossil free by 2040 to reach carbon neutrality by 2050. The ACEA (European Automobile Manufacturers Association) stated that it would be possible to meet this target if the right charging/refuelling infrastructure is built and the necessary policy framework is in place, including comprehensive CO_2 pricing to drive the transition[3].

COP26, UN Climate Change Conference, further highlighted the global climate emergency and brought the crisis to the wider attention of people around the world. The "greening" of the transportation sector was supported by agreements signed at the conference, which marked a global shift to 100% zero emissions vehicle adoption[4]. Over 30 nations, 11 car manufacturers and tens of organisations signed a declaration committing to working together towards all sales of new cars and vans being zero emissions by 2040[5]. A new Memorandum of Understanding[6] was signed by 15 countries (Austria, Canada, Chile, Denmark, Finland, Luxembourg, Netherlands, New Zealand, Norway, Scotland, Switzerland, Turkey, United Kingdom, Uruguay and Wales) to work together toward 100% zero-emission new truck and bus sales by 2040. An interim goal has been set by these countries to of 30% zero-emission new vehicle sales by 2030. Following this, the UK made the commitment to phase out new, non-zero emission heavy goods vehicles (HGV) weighing 26 tonnes and under by 2035, and all new HGVs sold in the UK to be zero emission by 2040 (10 November 2021, COP26)[7].

The transportation commitments being made are an important part of the overall global transition towards a low carbon economy. The European Commission's "Low Emission mobility strategy"[8] sets the guiding principles for member states on how to prepare for this future. The key points of the strategy are:

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[2] Landmark agreements at COP26 signify global shift to 100% zero emission vehicle adoption in 2030s | Climate Group (theclimategroup.org) (Accessed 19/01/2022)

[3] All new trucks sold must be fossil free by 2040, agree truck makers and climate researchers - ACEA - European Automobile Manufacturers' Association (Accessed 24/11/2021)

[4] https://www.theclimategroup.org/our-work/press/landmark-agreements-cop26-signify-global-shift-100-zero-emission-vehicle-adoption

[5] Top five climate commitments made at COP26 - Energy Saving Trust

[6] 15 countries agree to work toward 100% ZEV truck and bus sales by 2040 - Green Car Congress (Accessed 24/11/2021)

[7] CILT; UK confirms pledge for zero-emission HGVs by 2040 - Distance Learning College Nov 12, 2021 (Accessed 24/11/2021)

[8] A European Strategy for low-emission mobility (europa.eu) (accessed 19/01/2022)

- Increasing the efficiency of the transport system
- Speeding up the deployment of low emission alternative energy for transport such as the use of biofuels, electricity, hydrogen, renewable synthetic fuels, and removing barriers to the electrification of transport
- Moving towards zero-emission vehicles

Councils / municipalities and their private sector contractors are playing an important role in the delivery of this strategy, particularly in their improvement of the collection and transportation fleet for municipal solid waste management. These vehicles play a vital role in the global activity to reduce emissions from their activities[9] and to help achieve local, national, and global climate change goals, reach carbon neutrality and improve air quality in cities.

Much work has already been carried out on the use of alternative fuels for municipal waste collection activities, including (but not limited to): Energy Vision's topical report, "The Refuse Revolution"[10] focussing on the USA; Eunomia's "Ditching Diesel" report[11] which explores the costs and benefits of electric refuse collection vehicles; research on prototype electric refuse trucks and other alternative fuels by TNO in the Netherlands[12]; and various publications by the Zemo Partnership[13].

1.2 Project objectives

The objective of this project is to understand the path towards acquisition and use of low emissions and alternative fuel vehicles, their performance, cost and the challenges faced. It is intended that the findings of the work may be used to inform the decision-making processes of municipalities seeking to adopt such vehicles for their waste and recycling collection services.

1.3 Project scope

The scope of the project is to gather information on the current practices around the world in upper / middle income countries on the use of low emission and alternative vehicle fuels for waste collection. For the purposes of this project, "low emission" is less than 50g CO_2/km measured at the vehicle tailpipe, but the research also covers alternative fuels that may not meet this standard but are lower than petrol, diesel or liquified petroleum gas (LPG). Such fuels include, but are not limited to: electric, hydrogen, biofuels, compressed natural gas (CNG) and liquified natural gas (LNG) or hybrid vehicles.

Information has been gathered through a two-stage survey:

1. The Stage 1 survey focused on an on-line questionnaire aimed at gathering information on the motivations for municipalities adopting or not adopting low emission and alternative vehicle fuels for waste collection. The responses from the Stage 1 survey were also used to inform the selection of municipalities for detailed case studies in Stage 2.

[9] ISWA Project ToR Sustainable Collection and Transportation Technologies, June 2021
[10] The_Refuse_Revolution.pdf (energy-vision.org) (Accessed 06/01/22)
[11] Ditching Diesel - A Cost-Benefit Analysis of Electric RCVs (eunomia.co.uk) (Accessed 21/02/22)
[12] Sustainable Vehicles | TNO (Accessed 21/02/22)
[13] Publications & Resources | Fuels | Zemo Partnership (Accessed 21/02/22)

2. Stage 2 focused on obtaining more detailed information from carefully selected municipalities, to ensure a good global spread and the full range of vehicle fuel types were captured, to provide real-life operational information and experiences.

A Word version of the Stage 1 questionnaire can be found in Appendix A; sample questions for Stage 2 can be found in Appendix B, while recognising that information gathered during the second stage was carried out in a flexible manner depending on the municipality situation.

This report presents a snapshot of the situation in some countries. It is by no means an exhaustive market study, nor are the findings intended to be representative of the global position. The subject matter is a fast-moving area that is continually developing in both the technological solutions and the size of the market. The experiences of municipalities gathered through this study have been supplemented by opinions and information provided by waste management companies and vehicle manufacturers where appropriate. It should be noted that other municipalities and companies may have different experiences; the commentary is based on responses received through this project. Throughout this report there are references to news items and publications by others, as relevant to the topic. However, the scope of the study does not include a literature review.

The scope of this study is not to compare different fuels or to make recommendations for any preferred option, as this will be specific to the local situation. Similarly, no assessment is made for the future market capacity or direction in relation to alternative fuels for waste collection vehicles globally, regionally, or locally. Environmental and sustainability issues are discussed in the report as relevant to the issues raised; however, a life cycle analysis of the different vehicle fuel types is out of scope of this current study.

The discussion and points raised are based on the views and experiences of those organisations which contributed to the report through virtual and telephone discussions, or by email.

2 Overview of different fuel types

This report covers a number of alternatives to diesel that are currently in use for waste collection vehicles (also referred to refuse collection vehicles, or RCV). More detail on the use of the fuels is given in subsequent sections of the report. There are different hybrid versions possible, but these are the main vehicle types covered by this report, based on the experiences of those municipalities and private sector companies with contributed to the report.

2.1 Electric

When sustainable transport is considered, an electric vehicle is often the first solution that comes to mind. Electric vehicles are powered by an electric motor rather than a combustion engine. The motor can be powered directly by a battery (typically lithium-ion), sometimes referred to as a battery electric vehicle (BEV) or by hydrogen in a fuel cell. The latter is covered as part of the discussion on hydrogen below.

Electric vehicles emit no carbon, nitrogen oxides (NOx), sulphur oxides (SOx) or particulates at the point of use. However, a full life cycle assessment of electric vehicles needs to take into account how the electricity is generated. Clearly, renewable electricity will perform better than that generated from fossil fuels. In addition, the carbon impacts associated with the manufacture of the vehicle can be higher than a diesel equivalent, largely due to the energy and resources required to manufacture the battery. However, the US Environmental Protection Agency reports that the lifetime greenhouse gas emissions of an electric vehicle are typically lower than a diesel equivalent, even when the vehicle manufacture is considered[14].

Figure 1: Electric RCV charging (photo courtesy of Rotterdam City Council, Netherlands)

A battery electric vehicle is charged by either mains or stored electric power. The charging process can be lengthy (typically overnight) for a full charge, with rapid charging being used to top up during the day. Sufficient power supply is needed, which may require substation infrastructure to be developed close to the vehicle depot, as well as charging points.

2.2 Hydrogen

Hydrogen is the simplest element and is found in abundance on Earth, bound in water and natural gas, amongst other naturally occurring compounds. Hydrogen can be produced in a number of ways, most common are[15]:

- Steam methane reformation - reacting hot steam with natural gas to release hydrogen

[14] Electric Vehicle Myths | US EPA (Accessed 14/02/22)
[15] UK Hydrogen Strategy (publishing.service.gov.uk) (Accessed 31/01/22)

- Electrolysis - passing electricity through water to produce oxygen and hydrogen

Electrolysis to produce hydrogen can be low carbon if the electricity used is renewable, termed "green hydrogen". Steam methane reformation is energy and carbon intensive, often termed "grey hydrogen"; the carbon impact can be reduced (or even neutralised) if the carbon emitted is captured and stored, or re-used (carbon capture, utilisation, and storage, (CCUS)). The carbon accounting over this "blue hydrogen" (with CCUS) does not include the fugitive methane emissions associated with the extraction, pumping and transportation of the natural gas used in the process. There are other colour classifications of hydrogen, but these are the most common.

There may also be the potential in the future for the generation of hydrogen from waste processes, thus "closing the loop" if used in waste fleets. For example, the UK Government has recently pledged £5m to develop a technology to produce hydrogen from biomass and waste, which has the added benefit of removing CO_2 from the atmosphere in the process[16].

Hydrogen is already used extensively in industry, and is seen as versatile, highly combustible, and perhaps the ultimate fuel in some sectors. However, it can be expensive to produce. Costs will vary across the world, but in the USA the CNBC[17] reported recently that making hydrogen from natural gas costs US$1.50 per kg, whereas green hydrogen costs more than three times this. The whole process of producing hydrogen, compressing it and then converting it into energy can also be inefficient.

Hydrogen can be used in vehicles for transportation in two ways:

- Direct combustion, as a replacement for fossil fuels – hydrogen cannot be used in standard diesel engines, vehicle modification or conversion is required
- Hydrogen fuel cells – to power an electric motor by electrical energy generated through an electrochemical reaction between hydrogen, oxygen from the air in an electrolyte

At the point of use in the vehicle, hydrogen produces water and heat, with no carbon emissions.

The use of hydrogen fuel cells is often referred to as a "range extender" for electric vehicles. Other than the need to re-fuel with hydrogen rather than using stored electrical energy, a fuel cell vehicle works much like a battery electric vehicle.

2.3 Natural gas

Natural gas is a fossil energy source formed over millions of years, deep beneath the earth's surface. The main component of natural gas is methane, with other hydrocarbon alkanes. Natural gas is extracted from the ground, or from beneath the seabed, and processed to remove water and non-hydrocarbon compounds.

Natural gas is not a new fuel. Natural gas has long been used as a domestic heating and cooking fuel, and for industrial uses. Its use as a vehicle fuel is well-established. As a vehicle fuel, natural gas is compressed for ease of use and transportation, as either Liquified Natural Gas (LNG) or Compressed Natural Gas (CNG). The difference between the two comes down to the energy density – there is

[16] Hydrogen BECCS Innovation Programme - GOV.UK (www.gov.uk) (Accessed 14/02/22)
[17] What is green hydrogen vs. blue hydrogen and why it matters (cnbc.com) (Accessed 31/01/22)

more energy per given volume in LNG than CNG. This study focuses on CNG, as LNG is more commonly used in long distance haulage applications.

Figure 2: Side loader natural gas RCV (photo courtesy of City of Toronto Council, Canada)

The use of natural gas in vehicles is similar to diesel; it is mixed with air in an internal combustion engine. CNG can be taken straight from the gas main, compressed and dispensed to the vehicle; there may be no need for tanker transportation.

Although a fossil fuel, natural gas is purported to be a cleaner fuel than diesel, as it is free of lead, benzene, and sulphur. It has reduced exhaust emissions with lower carbon, NOx, SOx and particulates. The non-corrosive nature of natural gas reduces maintenance and wear on the engine. CNG is also understood to be more fuel efficient than diesel at the point of use, with a lower fuel price[18].

Natural gas is abundant in the earth's reserves, however, there will be fugitive emissions and leakage of methane from the extraction, processing, and transportation stages. Methane can also be made from biological degradation of waste. This Renewable Natural Gas (RNG), or biomethane or biogas, has the same properties as a vehicle fuel as CNG, and is being used to close the loop in waste management to fuel waste collection fleets.

2.4 Hydrogenated / Hydrotreated Vegetable Oil

Hydrogenated (or hydrotreated) vegetable oil (HVO) is a biofuel with a similar chemical composition to diesel and therefore can be used as a direct replacement for diesel in newer engines (reportedly suitable for Euro 5 and Euro 6). The HVO is used as a "drop in fuel", no vehicle modifications are necessary, meaning the vehicle can continue to run on diesel in the event of supply problems. Different blends of HVO are available depending on supply; HVO100 being 100% biofuel, HVO20 being 20% biofuel and 80% fossil diesel. HVO100 is the focus of this study.

HVO100 is a renewable, non-fossil fuel, typically derived from fuel crops and waste vegetable fats and oils. Neste[19] describes the production process as: "*impurities are removed from the raw materials which are then hydrotreated at a high temperature. The outcome is a colourless and odourless fuel of an even quality that has an identical chemical composition with fossil diesel.*"

HVO offers the benefits of lower emissions, being a cleaner burning fuel than diesel. HVO100 gives a 90% reduction in CO_2 (greenhouse gas) emissions. Claims regarding NOx and particulates emissions

[18] 10 reasons why CNG is the new diesel | Fleet Europe (Accessed 08/02/22)
[19] www.neste.com (Accessed 19/01/22)

vary, with some quoting zero emissions and others quoting reductions[20]. It is also renewable, a non-fossil fuel.

HVO can withstand the cold and have a long shelf life of 10 years, meaning that stock rotation and degradation in storage is less of an issue. If the HVO is of the approved fuel standard[21], there should be no impact on vehicle warranties.

HVO differs from first generation biodiesel, also known as Fatty Acid Methyl Ester (or FAME), produced by the esterification of vegetable oils and fats, in the raw materials used in its manufacture as well as the process. HVO is more stable and cleaner burning than FAME biodiesel. FAME biodiesel has not been included in this report.

[20] For example, Nationwide Fuels (www.nationwidefuels.co.uk (Accessed 19/01/22) quotes 27% reduction in NOx and 84% reduction in particulates, while Orange Gas (https://orangegas.nl/ Accessed 19/01/22) quotes zero emissions for NOx, SOx and particulates

[21] In Europe EN15940 covers Paraffinic Diesel Fuel Specifications

3 Overview of current situation

3.1 Introduction

This section of the report provides an overview of the current situation based on the results of the on-line stage 1 survey.

The online survey was distributed across different countries through the network of ISWA national members, alongside valuable contribution from NVRD and CIWM. The Stage 1 survey yielded a total of 51 responses, as shown in Figure 3. The spread of responses across the world demonstrates the coverage achieved by the survey approach. This was dictated, to a certain degree, by the level circulation of the survey. However, it is also likely to be indicative of the level of interest in alternative fuel waste collection vehicles in each of the countries. **Due to the nature of the survey, the results presented cannot be considered to be statistically representative of the entire international position but give a snapshot of the situation for those municipalities that responded to the survey.**

The aim of the survey was to collect the views from municipalities / councils responsible for waste collection. Of the 51 responses, 18 were from respondents that were considered to not directly represent a municipality. These include waste management companies, research institutes, consultants and other suppliers to the waste industry.

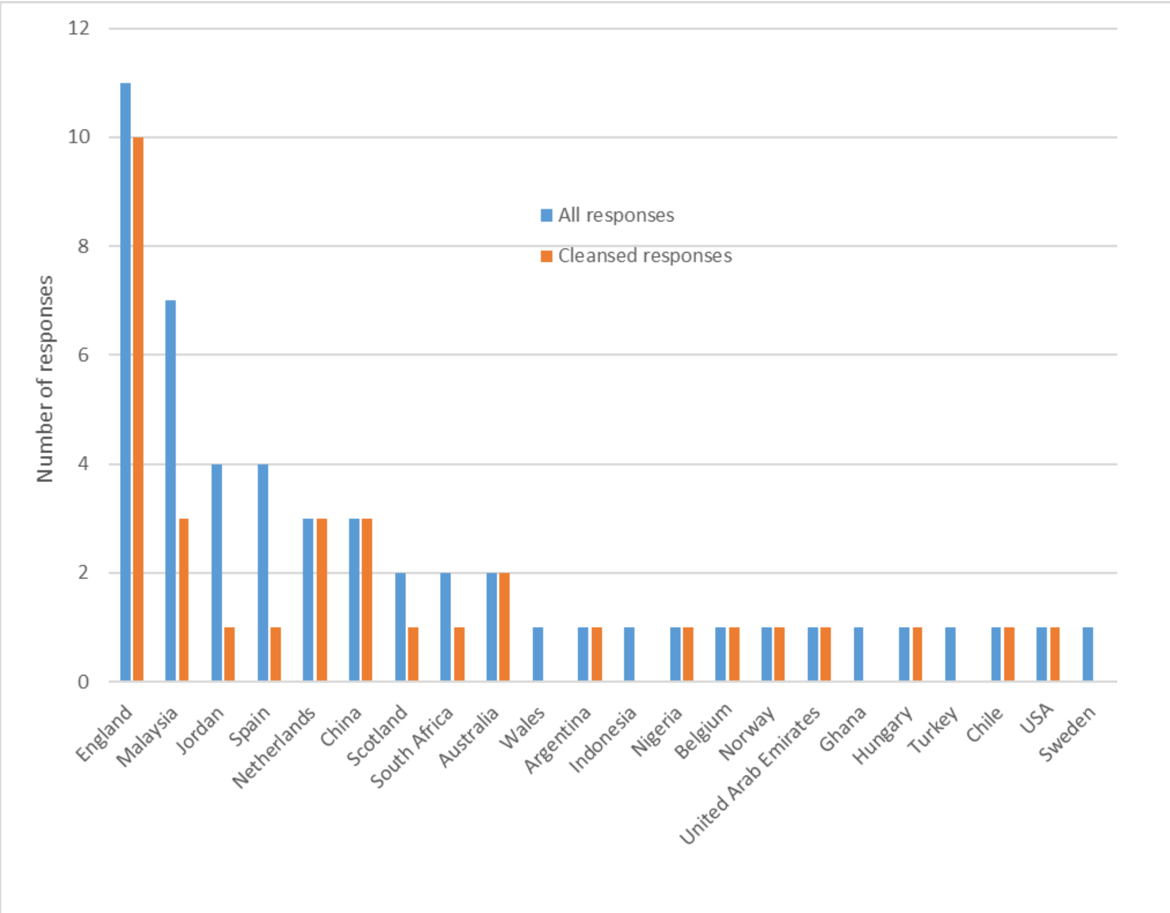

Figure 3: Locations of the Stage 1 survey responses

3.2 Adoption of alternative fuels

Of those 33 municipalities that responded to the survey, 17 reported that they had already introduced low emission or alternative vehicle fuels for their waste collection services. The location of those municipalities that have introduced such vehicles is summarised in Figure 4.

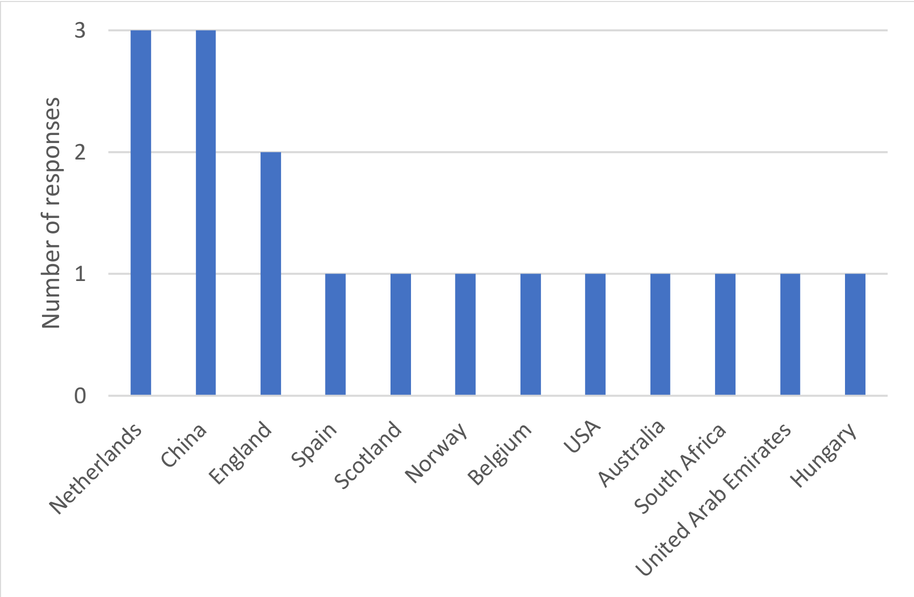

Figure 4: Locations of municipality respondents that have introduced alternative fuels (33 respondents)

Figure 4 shows that there is a moderate to low level of adoption of low emission or alternative vehicle fuels by survey respondents, with the highest levels being in the Netherlands and China. As explained, this may not be representative of the full international picture.

While approximately half the municipalities that responded to the survey have introduced low emission or alternative vehicle fuels, all responding municipalities, except for one, are considering them or have considered them. It is likely that this reflects those responding to the survey already having an interest in this area.

The respondent, based in England, which has not yet considered introducing low emission or alternative fuel vehicles stated that they expect to consider it in the next 1-2 years, and cited reasons of funding, availability of technology, track record or reliability, lack of supporting infrastructure, operational concerns, and contractual constraints for not yet considering it. In addition, the respondent considers that the current uncertainties in the waste industry regarding national policy and funding make it difficult to make any long-term decisions. Given the reasons cited, and FRM's knowledge of the municipality, it is likely that alternative fuels have been considered at a high level, although not in detail.

Figure 5 shows the types of alternative fuel and its proportion of the waste collection fleet from those responding to the survey, excluding diesel vehicles. Of those responding, there appears to be a range of fuel types in the fleet, with most adopting a proportion of their standard diesel fleet with an alternative fuel. Six respondents have more than 50% of their fleet on alternative (non-diesel) fuel, these being electric, biofuel and CNG or LNG. The responses to this question were used to identify municipalities for detailed exploration in the second stage of the survey.

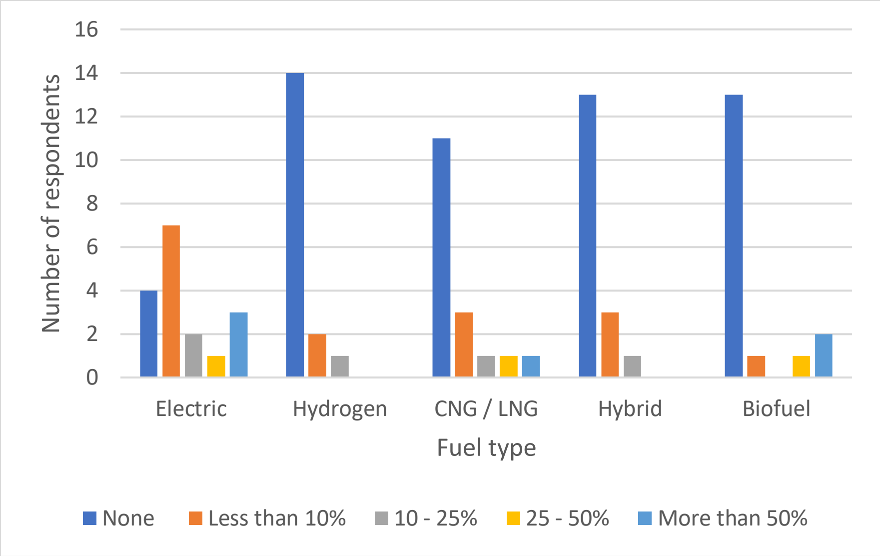

Figure 5: Types of fuel and proportion of the municipal waste collection fleet using each fuel type (17 respondents)

3.3 Motivations for considering alternative fuels

Of those that have considered introducing low emission and alternative fuel vehicles (or have already introduced them), the motivating factors cited are summarised in Figure 6. The factor mentioned by 31 of the 32 municipalities is environmental considerations. This ties in with the global crisis on climate change and the associated pledges summarised in Section 1.1 of this report. Additional commentary from the survey relates to aims to reduce carbon and greenhouse gas emissions, net zero carbon targets, and reduction in air pollution.

Political drivers were also cited as an important motivating factor, with some the respondents mentioning ambitions and local political pledges to move away from fossil fuelled vehicles. Ethical, legal, and financial drivers were mentioned by fewer municipalities. The financial motivations are interesting, given that generally the capital cost of low emissions and alternative fuel vehicles are higher than their fossil fuel equivalent but are offset by the lower operating costs, resulting in a total cost over the life of the vehicles often reported to be similar.

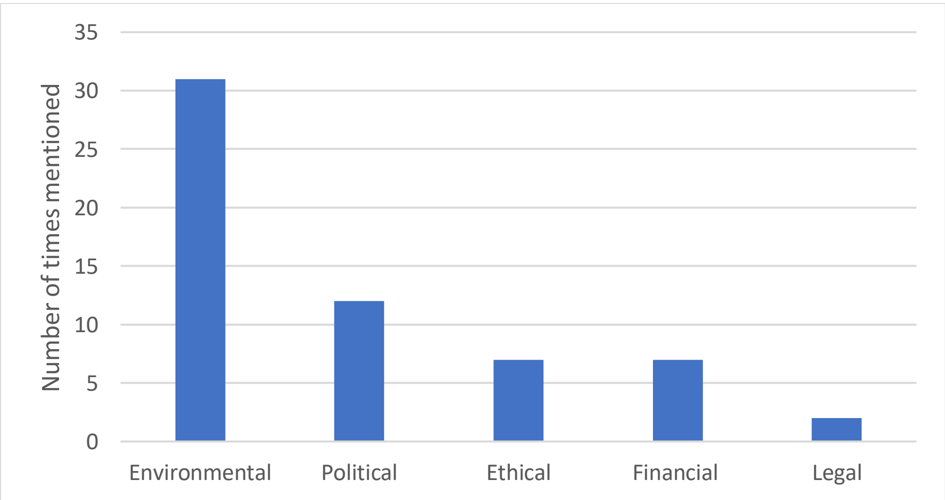

Figure 6: Motivations for considering using alternative vehicle fuels (32 respondents)

Most of the remaining respondents which stated they had considered the vehicles but had yet to introduce them, reported that they were likely to introduce them within a 5-year timescale, as shown in Figure 7.

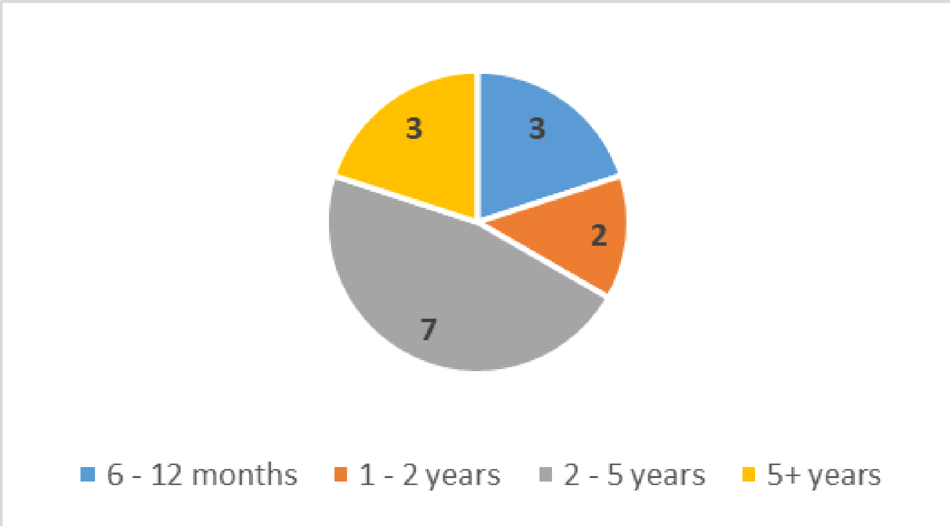

Figure 7: Timescales for introducing alternative fuels (15 respondents)

3.4 Barriers & challenges to introducing alternative fuels

Of the 15 respondents that had considered alternative fuels but had not yet introduced them, overwhelmingly the most cited reason was the availability of funding or the cost of the vehicles, as shown in Figure 8. The provision of supporting infrastructure, such as for vehicle charging or refuelling, the availability of technology and operational reasons associated with the vehicles were also key challenges. Others gave contractual constraints or the reliability or track record of alternative fuelled vehicles. Several respondents expanded on their answers, with three saying that the battery life and travel range of electric vehicles does not support their largely rural or large municipalities. In the last few years of an outsourced contract, one respondent stated it is actively looking at different technologies for its next waste collection contract, while another reported that it had tried putting pressure on its contractor, but the cost has been prohibitive to change.

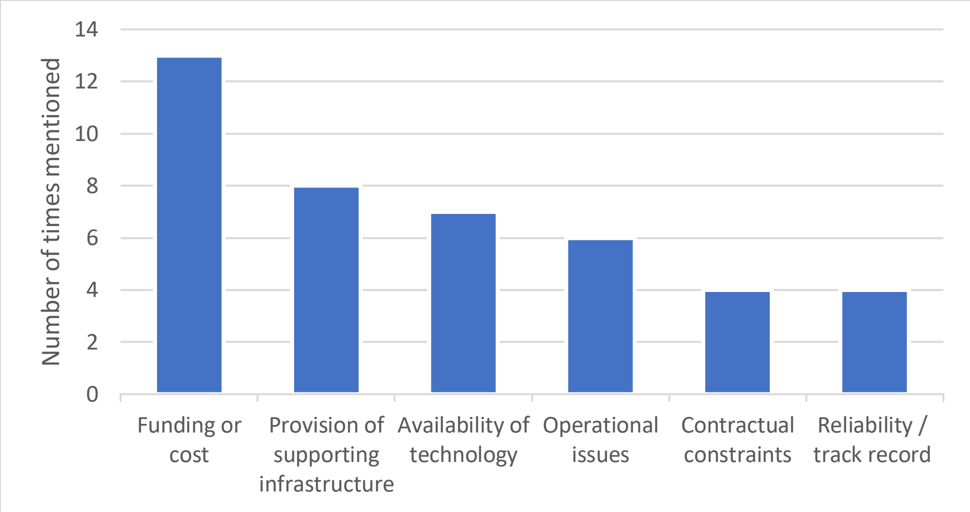

Figure 8: Reasons for not introducing alternative fuel vehicles yet (15 responses)

The challenges and barriers overcome by those municipalities that have already introduced alternative fuel waste collection vehicles mirror those of the municipalities that have yet to introduce such vehicles, as summarised in Figure 9. The main challenge, with only two of the 17 respondents not citing it, was funding or cost of the vehicles, the capital cost of the vehicles which, as already seen in Figure 8, is a major hurdle – while only one respondent mentioned their reliance on subsidies to overcome this challenge, this is likely to be more widespread.

The availability of technology was mentioned as a significant challenge, to find the right vehicle for the job. This is coupled by the obstacles of maintenance and repair, such as the availability of spare parts and the capacity at the workshops / garages to handle the vehicles. The lead time for both new alternative fuel vehicles and vehicle conversions also posed a challenge for some. Electric vehicles are also likely to require some changes to routes due to reduced payload and vehicle travel range.

Provision of supporting infrastructure was also a problem, and half the respondents experienced operational issues as a result of introducing the vehicles. Electric vehicles require charging infrastructure to be established, and the availability of fuelling stations for other fuels, such as biofuel and hydrogen, may not be as developed in some areas as others. Additional funding may be required to support further alternative vehicle expansion. One respondent, with hybrid hydrogen waste collection vehicles reported that fuelling stations have been unreliable, which is limiting the further conversion of the municipality's fleet.

One respondent mentioned driver education being an issue and has overcome this by having a selected group of drivers who are engaged with the developments, while another reinforced the importance of operator involvement in the whole vehicle transition process.

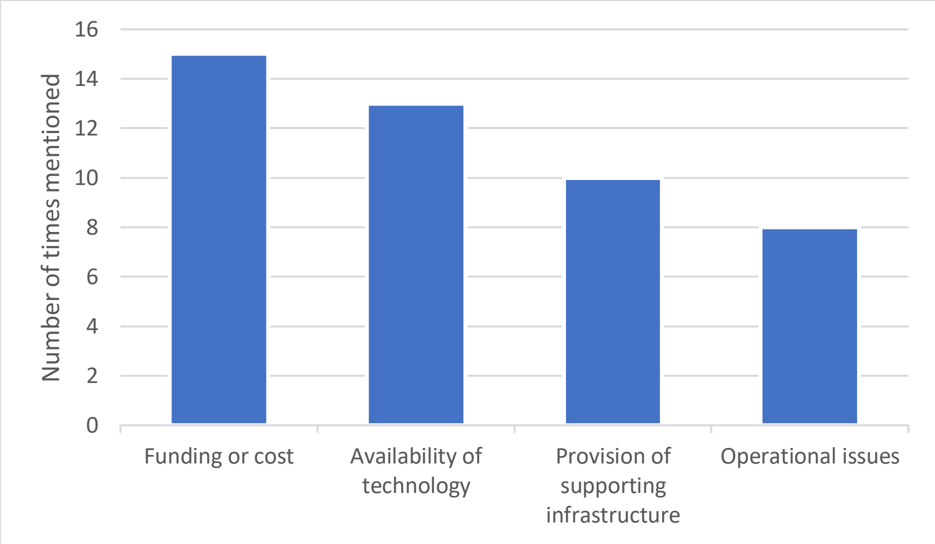

Figure 9: Challenges encountered where alternative fuels have been introduced (17 respondents)

3.5 Other factors

In general, the survey respondents reported reduced carbon emissions, less pollution and better air quality through introducing alternative fuels for their waste collection vehicles, coupled with lower operating costs through reduced fuel consumption (assumed to mean less diesel) for the same (or similar) levels of operational performance. Improved working conditions through lower noise levels were also mentioned, alongside the creation of a positive public image, as the vehicles have been welcomed by the communities. The demonstration of the benefits through vehicle / fuel trials is leading to municipalities creating demand from contractors where waste collection services are outsourced.

The positive "spill-over effect" of introducing alternative fuels was mentioned in relation to hydrogen through the municipality's use stimulating the regional hydrogen economy, with businesses developing and education / training starting to join up. Municipalities are sharing their experiences with others to allow them to learn and adapt.

Learning from their experiences, some municipalities reported that they would have planned the process better, thinking holistically. Rather than just focus on vehicle conversions, to consider the implications of the supporting fuelling / charging infrastructure, or to consider hybrid solutions rather than a single fuel type for all vehicles. Others would have liked to move quicker, while recognising the limitations of funding.

These factors are explored in more detail in the following sections of the report.

4 Experiences with electric vehicles

4.1 Introduction

There is a reasonable amount of operational experience with the use of battery electric vehicles for waste collection, and there is a large amount of interest from the market in this area with various trials in place to supplement the wider operational experience. In addition to the examples covered in more detail in this report, recent press has covered trials of electric vehicles in South Australia[22], Monaco[23], Nottingham, UK[24]. Larger electric refuse fleets are in operation in Säo Paulo, Brazil[25], Copenhagen, Denmark[26], and Manchester, UK[27], amongst others.

The view from waste management companies reported through this study is that municipalities are keen to explore electric vehicles and are pushing for their use in waste collection contracts. This is also reflected by vehicle manufacturers. For example, GeesinkNorba commented in this study that products are changing away from diesel towards electric. The company still has many of its early electric hybrid RCVs in operation today, for example, those introduced to contracts in Turkey in 2013[28], and is expanding its sales in northern Europe[29].

The points raised on the use of electric vehicles for waste collection in this report have been obtained through discussion with a number of municipalities, waste management companies and vehicle manufacturers across the world. The discussion in this section relates to battery electric vehicles (BEV) rather than hydrogen fuel cell electric vehicles, which are covered in Section 5.2, however some points are similar for both vehicle fuel types. The greater level of content for this section on electric vehicles compared to other vehicle fuel types reflects the experience in this area of those organisations contributing to this report.

Case studies for the experience of municipalities on the use of electric vehicles for waste collection are provided in Appendix C:

- New York – USA
- Rotterdam – Netherlands
- Shenzhen – China
- Westminster – UK

[22] Electric waste collection truck put through its paces - Inside Waste (Accessed 21/02/22)
[23] Four dump trucks in Monaco are now 100% electric (monaco-hebdo.com) (Accessed 25/02/22)
[24] First all-electric RCVs go into service | The Truck Expert (Accessed 21/02/22)
[25] BYD Inks Deal for 200 Electric Refuse Trucks in Indaiatuba, Brazil - CleanTechnica (Accessed 21/02/22)
[26] Copenhagen aims for all-electric waste trucks by 2025 - Industry Europe (Accessed 21/02/22)
[27] UK's largest fleet of electric waste vehicles | Biffa (Accessed 21/02/22)
[28] “First hybrid plug-in units arrive in Turkey”, Timothy Byrne, Recycling Waste World, July 2013
[29] New fleet of vehicles for Urbaser in Denmark | Geesinknorba (Accessed 21/02/22)

Suez UK on electric vehicles for refuse collection

Suez is a leading waste management company in the UK, providing waste collection and treatment services to municipalities and commercial customers. Suez UK has a company-wide commitment to electric vehicles; all company cars are electric, and they are working with clients to manage the transition from fossil fuels. Suez UK has been running trials on electric vehicles across the UK, using different makes and models to gather operational data on payloads and distances.

The company is "warming clients up" to the increased capital costs and is seeing a definite interest with vehicles being introduced during the contract term, or specified at the outset.

Suez acknowledges that routing needs to be considered: more vehicles may be required than for diesel due to reduced operational efficiency, and rural areas may not be suitable for the battery range available. Some changes to collection schedules are likely in the UK as a result of the Environment Act and the requirement for separate collections; coinciding this with a fleet change may be beneficial to residents.

Longer term, Suez UK believes that hydrogen will come to the fore for waste collection as the technology and infrastructure develops. However, the investment in electric infrastructure and substations may mean that municipalities stay with electric vehicles if the performance is sufficient.

"There will be less disruption for residents if Electric Vehicles are introduced along with a service change"

Discussion between FRM and Suez UK, December 2021

4.2 Benefits

The key benefits of using battery electric vehicles for waste collection as identified through this study are zero emissions, improved driving conditions and lower operating costs.

Zero emissions

One of the prime reasons for adopting electric waste collection vehicles is to reduce emissions, sought by climate / carbon strategies and / or local air quality drivers. Fundamentally, electric vehicles produce zero emissions at the tailpipe. The application of electric vehicles in urban and city centre environments is a positive step to improving both local air quality and carbon emissions. This is an advantage for both the operators of the service and the local community.

As set out in Section 2.1, the overall environmental impact of using electric vehicles will depend on the origin of the electric power used to charge the vehicles and how this is generated; the use of renewable power is a positive step away from fossil fuels. Westminster City Council in the UK is looking to close the loop by using electricity generated from waste treatment at the energy from waste plant to power the waste collection fleet.

Westminster City Council, London, UK

Westminster City Council has introduced electric refuse collection vehicles and street cleaners. It was found that these zero emissions (at the tailpipe) vehicles have over 90% less carbon impact than diesel vehicles. However, they came with a high upfront capital cost and a requirement for additional training for staff.

Westminster City Council have committed to converting their diesel fleet of 226 vehicles to electric by 2030.

Further detail can be found in Appendix C.

Improved driving conditions

All four case study municipalities which contributed to the study with their experiences of electric waste collection vehicles commented that the vehicles were liked by the workforce and gave improved operator working conditions. The main reason cited is universal to electric vehicles for all applications: reduced noise and vibration. This leads to improved safety and ability to communicate between the crew members. There are some operational concerns over the range of the battery, which has adversely affected the drivers' views. This is discussed in Section 4.3.

One leading UK waste management company did note that while there has "only been positive views from the public", some householders have said they didn't hear the vehicle coming so didn't put their bins out for collection! Dutch vehicle manufacturer, VDL, commented that the quiet operation of the vehicles could lead to an extended window of waste collection, which in many places cannot be carried out during the night due to noise limits.

While the driving experience is different to the diesel equivalent, following adjustment to the new vehicles by the drivers, the lack of gearbox coupled with good acceleration and responsiveness is appreciated. However, US waste management company, WM Inc, considers that electric vehicles are not yet commercially viable for waste collection in the US, given the long distances and large vehicles used. The company cites a range of operational problems, including downtime, driver acceptability and driving experience. This may not be echoed by others in the US, such as the Department of Sanitation in New York.

New York City, USA

Since September 2000, the Department of Sanitation in New York has been trialling an electric refuse vehicle, with a further seven are due to arrive by the end of 2022. Crews have had a good experience with the vehicle due to its high torque, responsive nature and ability to carry the required payload. The vehicle is also much quieter which is positive from a safety aspect. Electric vehicle costs are higher than their diesel equivalent, but charging infrastructure carries the biggest expense with capex ranging between US$35,000 - $40,000.

Further detail can be found in Appendix C.

There has been some concern over reduced payload in electric vehicles due to the weight of the battery. However, VDL Translift claims that the new generation of batteries weigh 600kg less with double the power capacity, in New York the vehicles were rigorously tested to make sure they can carry the payload they need to, and Rotterdam's experience is that the newer vehicles have no difference in payload to the diesel equivalent (noting that the older models could carry 1tonne less payload).

VDL Translift on electric vehicles

VDL is a Dutch group of companies with €5Bn turnover and 16,000 employees, offering a broad technology range, including manufacturing industries. VDL is a large family-owned company and seeks long term developments. The focus is on sustainability, noise reduction, pollution, fossil fuel reduction and carbon, leading to a "liveable city". VDL is one of the front runners in the Netherlands on alternative fuels for waste collection, having been involved in large pilot projects.

The company's experience on electric buses is now being used to provide learned experience for trucks, including waste collection, which use the same driveline. VDL's view is that public transport is about 5 years ahead of waste transport in terms of electric vehicles.

VDL produced its first prototype electric vehicle for waste collection in 2018 with a DAF chassis, expanded in 2020 to trials with four RCVs, subsidised through a research grant. The vehicle is now in series production, with 20 waste vehicles in operation in Holland. VDL and DAF are working in partnership to extend further into Europe, in particular, Switzerland and Scandinavia.

One particular hurdle was the time taken for European homologation (approvals), which took longer than expected, 1.5-2years.

VDL considers that battery electric vehicles are well-suited to cities which don't incur long travel distances, but range is an issue that needs to be addressed. The view is that one of the biggest challenges is the "human factor", it needs to be acknowledged that change will be needed in routing and driving style, and the changes need to be managed.

"Driveline of the future is electric – battery or hydrogen fuel cell"

Discussion between FRM and VDL Translift, January 2022

Lower operating costs

While the capital cost of the vehicles (see Section 4.3) is significantly greater than the diesel equivalent, the operating costs are much lower. This includes the cost of fuel (or electric) and maintenance. Westminster City Council, UK, and Shenzhen, China, (see case studies) are expecting similar total overall costs for electric and diesel over the life of the vehicles. Figures quoted in this study are that power costs are expected to be 25-35% of diesel costs for the equivalent service delivery. Despite the expected lower total overall costs expressed by others in this study, ALBA W&H Smart City Pty in Singapore considers that balance is unlikely to occur in the first (current) generation of RCV as the vehicle capital cost and supporting infrastructure is significant, however longer term the costs should be lower.

Shenzen, China

In Shenzen, 7tonne electric vehicles are used for food and mixed general waste collection. The crews have found them easier to drive and had less noise and vibration. The operating cost is 25% of the diesel equivalent and if driven well, there are no additional maintenance costs. There are challenges around the range of the vehicles, with larger vehicles having a range of 200km before requiring charging, and 130km for smaller ones.

There are plans to convert the entire waste collection fleet to electric over the next 3-5 years.

Further detail can be found in Appendix C.

The body and lift mechanism will experience similar levels of wear as for diesel RCVs, but it is expected that the chassis will have less wear due to the smoother drive, with overall maintenance costs lower as there are fewer moving parts and no fuel filter to block. Rotterdam City Council in the Netherlands is expecting a longer vehicle life for this reason. New expertise for maintenance and servicing is needed for electric vehicles. This was an issue also highlighted for hydrogen fuel cell vehicles (see Section 5.2).

Rotterdam City Council, Netherlands

As of 2021, Rotterdam uses two electric rear loading vehicles and one electric vehicle fitted with a crane (used for emptying underground waste containers). No additional training was required for the crew and they reported good experiences with the vehicles. However, it was found that the electric vehicles had a much lower range than their diesel equivalents and due to a lack of battery capacity, they're not able to complete a full shift.

Going forwards, Rotterdam hopes to replace the remaining diesel vehicles with electric vehicles once they have reached end of their life.

Further detail can be found in Appendix C.

Figure 10: Electric RCV in Wales, UK (photo courtesy of Dennis Eagle)

The lifespan of the battery may be the limiting factor, as highlighted by several parties in this study, with the battery expecting to degrade as it ages. Dennis Eagle expects the batteries for its new eCollect vehicle to last 8-10 years, which it expects should be sufficient to achieve sufficient payback. Vehicle manufacturers are providing guarantees on their battery life; it is understood that Scania[30] guarantees 80% of battery capacity on a distance limited promise, and Dennis Eagle provides a 3-year warranty.

[30] From information provided by a Scania client, ALBA H&M Smart City Pty

One consideration to be made to the operating costs for electric vehicles is that the cost of repair in the event of an accident can be very high if the battery is damaged. US waste management company, WM Inc, suggested the replacement of the battery pack is in the region of US$150k. In addition, recovery of electric vehicles if they break down is difficult as they cannot be towed and need to be transferred to low-loader to be moved.

Dennis Eagle on the new eCollect electric RCV

Dennis Eagle launched its eCollect RCV in 2018, with the first products going to customers in 2020. In 2022, it is likely that around 200 eCollect vehicles will be produced – still a small percentage of overall output but this is expected to take precedence over the next 5-10 years. Orders are concentrated in UK and Ireland, supply to Europe will be through Dennis Eagle's sister companies soon. Lead times vary, generally around 26-28 weeks, depending on production schedules, with eCollect electric vehicles only requiring a few more weeks to build than diesel.

The eCollect was designed with a view to delivering *"what a diesel RCV does for the majority of customers"*, which is around 65-100km per day over a single shift, with fairly hilly terrain. Operational experience suggests this has been achieved with the eCollect. It is possible to do 150km per day, or to operate double shifts, but most vehicles are single shift and recharged overnight.

Dennis Eagle expects batteries to last 8-10 years of front-line service, over which time the vehicle can achieve a proper payback for investment. Generally, the power cost is 25-30% of diesel fuel for the equivalent power delivery.

"Dennis Eagle is focusing on electric, but watching hydrogen developments"

Discussion between FRM and Dennis Eagle, January 2022

4.3 Challenges

The main challenges associated with the use of electric vehicles for waste collection that have been highlighted through this study are capital cost, charging network, supply chain, battery range and broader environmental concerns.

Capital cost

As with many of the alternative fuel vehicles, the capital cost of an electric RCV is significantly higher than for the diesel equivalent. One of the main challenges of adopting electric vehicles is the willingness or appetite of municipalities to invest in higher capital cost alternative fuel vehicles. UK waste management contractor, Suez, commented that it is "warming clients up" to the increased capital cost of the vehicles, while a Dutch vehicle manufacturer providing to the European market considers that there is a difference between countries on how investment is evaluated. In Spain and Italy, it is reported that the initial vehicle capital cost is of prime importance, while in the Netherlands it is the total cost of ownership that is considered. As discussed above for the main benefits of electric vehicles, the operating costs are reported to be lower than diesel.

Information provided through this study on the relative capital costs for electric RCVs varies from twice as much as an equivalent diesel vehicle to up to 3.5 times. This information has been provided anecdotally by municipalities, waste management contractors and vehicle manufacturers. There may be regional and country differences in the relative capital costs, information provided by the Department of Sanitation in New York suggests that the relative cost increase for an electric vehicle in the US is lower than in Europe. This may not be widespread, as capital costs may also depend on the number of vehicles ordered. While it might be expected that the vehicle capital cost will reduce as supply and demand increase, it has been noted that the battery is expensive, so an electric vehicle is always likely to be more expensive than diesel.

Figure 11: Electric RCV (photo courtesy of GeesinkNorba)

Some municipalities adopting electric vehicles are doing so with the assistance of grant funding to demonstrate the operational performance of the vehicles. New York is hoping that funding will be available for the gradual expansion of its electric fleet.

Conversions of standard diesel RCVs to electric are also expensive and time-consuming, according to manufacturer GeesinkNorba. However, special conversions are being replaced by OEM (original equipment manufacturer) vehicles and the company reported that prices are falling every few months, aided by sales increases from high subsidies / grants for non-fossil fuel vehicles. Conversely, UK company Refuse Vehicle Solutions estimates that an electric conversion will save up to £100,000 when compared to purchasing a new vehicle direct from a manufacturer[31].

There are also capital cost implications for establishing charging infrastructure for the vehicles (see below).

Charging network

Establishing sufficient vehicle charging infrastructure is key to the delivery of services using electric vehicles. In many of the cases discussed in this study, the capacity of the network local to the depot to ensuring sufficient charging provision was identified as a key issue, particularly for older depots. The view of UK waste management contractor, FCC, is that most local authorities have sufficient grid capacity for one or two vehicles before further infrastructure is required. Westminster City Council in the UK commented that ensuring the charging infrastructure is viable before committing to electric vehicles would be advisable, while the Department of Sanitation in New York wished it had considered the network capacity at an earlier stage. Meanwhile in Shenzhen, China, has a city-wide approach to electric vehicles, the charging network is well-developed with public charging facilities that the municipal vehicles can use.

[31] RVS provides first fully electrified RCV conversion in Wales - LAPV (Accessed 17/02/22)

Power supply has been a barrier to the expansion of the electric fleet in Rotterdam, which is expecting to incur significant capital costs for the development of charging capacity. In the meantime, the municipality is using battery storage to charge vehicles; surplus electricity at the depot is stored until it is required.

The capital costs associated with the charging infrastructure will depend on the upgrades necessary, including whether new substation(s) are required. Figures provided range up to €millions but this will be specific to the particular situation so have not been quoted here to avoid misleading. Charging infrastructure can also be supported by renewable energy. For example, South Cambridgeshire District Council, UK, has recently announced its intention to develop a solar farm to power its electric RCV fleet[32]. The timeframe for delivering infrastructure needs to be incorporated into the whole programme. This can be a lengthy process as it will involve the network provider, procurement and civils work.

Supply chain

Related to the high vehicle capital cost, to a certain degree, are the issues around the vehicle supply chain, in particular, the limited number of providers and long lead times. This does not appear to be limited by geography, but widespread amongst those organisations contributing to this study.

The lead times for all vehicle types have been increased by the impacts of the Covid-19 pandemic, but in many cases the lead times experienced by municipalities and waste management companies are longer for electric vehicles. In particular, the current shortage of semiconductor material is exacerbating the long lead times for some components.

As noted by waste management companies, the mobilisation period for municipal contracts is often tight – even for standard RCVs the lead time is currently around 12 months in many places, which does not align with the mobilisation period. This is highlighted by ALBA W&H Smart City Pty in relation to the Singapore market (see highlight text below). The company needed to provide 14 electric RCVs in a 4-5month mobilisation period – given the lengthy lead time, the company has sourced diesel vehicles which would then become part of the back-up / spare fleet when the electric vehicles arrive.

The long lead time is partly due to a limited market and low production numbers, but this should improve as vehicle manufacturers shift their production away from diesel over the coming years. For example, Mercedes is planning production of its new eEconic electric RCV later in 2022 for supply into Europe, and Dennis Eagle is expecting the production rate of its eCollect to increase over the coming years. Interestingly, Dutch vehicle manufacturer, VDL, reports that its lead time for electric vehicles is half that for diesel, which gives a boost to the transition from fossil fuel, and Dennis Eagle quoted lead times of 26-28 weeks, both of which differ from customers' experiences.

Until the supply of vehicles catches up with potential demand, vehicle manufacturers will continue to prioritise certain markets. Future waste management services will have non-fossil fuels mandated, which will drive demand and supply. From those organisations contributing to this report, we have been made aware that the market in Singapore and Australia is not well-provided

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[32] South Cambridgeshire ramps up electric RCV plans - letsrecycle.com (Accessed 28/02/22)

for in terms of electric vehicles at present. It is expected that other regions are likely to be similarly affected.

ALBA W&H Smart City Pty on the introduction of electric vehicles in Woodlands, Singapore

ALBA is a German waste management company operating in areas of Europe and Asia. The company has three major contracts in Singapore, one which has recently commenced in the Woodlands area of the country, which set a mandate for at least 14 electric vehicles (11 for refuse and 3 for recycling), approximately 25% of the fleet. Previously, the electric RCV market in Singapore was limited to the BYD T9 model, which ALBA had concerns over the battery capacity and the ability of the vehicle to deliver the operation. Vehicle manufacturer Scania is now supplying electric RCVs to the market in Singapore, which will have the capacity to cover two full rounds. The vehicles are expected to arrive late 2022.

The population density of the area is high, lending itself well to a battery electric vehicle operation. However, waste can only be collected between the hours of 07:00 and 19:00 and a typical RCV needs to travel 150-200km to accommodate the distance to the start of the round and two trips to tip loads at the energy from waste plant, so battery capacity is of particular importance. In addition, there are further energy demands from the body of the vehicle, which is estimated to take up 40% of the supply through bin lifting and compressing.

ALBA is expecting future contracts to have a greater requirement for electric vehicles, and the long lead time from the supply chain is a key issue accompanied by a short 4-5month contract mobilisation period. The company manages this through procuring standard diesel RCVs for the start of the contract, which will then be used as back-up vehicles when the electric vehicles are delivered.

Lead time and limited market supply are key issues in Singapore

Discussion between FRM and ALBA, February 2022

Battery range

Concerns over the distance / travel range is not a new challenge with electric vehicles, however the battery technology is constantly advancing, and the achievable range has improved over early prototypes. Dennis Eagle's eCollect vehicle has been "*designed with a view to delivering what a diesel RCV does for the majority of customers*", even in challenging terrains. Operational experience from the company suggests that this has been achieved, however the vehicle is new to the market.

From municipality experience, small area, dense city centre applications have seen no impact on the vehicle distances covered by electric RCVs. However, the view is that a whole fleet of electric RCVs may not be appropriate for all municipalities unless a greater number of vehicles are deployed with routes being changed, or multiple depots available (to reduce the distance to the start of the round or tipping point). This is particularly the challenge with large rural municipalities.

Experiences on battery life do seem to vary amongst those contributing to this study. It may be that the expectations are different, but factors such as vehicle type, terrain, collection round specifics and driving style will also be considerations. For example, in Rotterdam, Netherlands, the experience is that the electric vehicles are only managing to deliver part of one shift in a two-shift operation due to insufficient vehicle range, which inevitably leads to routing implications. This is similar in the City of Casey in Australia. ALBA W&H Smart City Pty in Singapore reported that it originally intended to adopt twice the number of vehicles required to deliver the service with electric vehicles due to concerns over battery range until newer technology came to the market. Elsewhere, Westminster and New York have seen no problems with covering the required distance. New York's experience is that there is just under half charge left on the battery at the end of the shift (so in theory the vehicle could be sufficiently charged in just 2 hours). UK waste contractor, Suez, recognises that collection rounds may need to change due to the reduced range of electric vehicles, but if this can be incorporated alongside other service changes, it minimises the impact on householders.

City of Casey, Australia

The waste collection service is outsourced to WM which has been trialling electric RCVs with mixed success. Retrofit electric vehicles have struggled to deliver the service which involved a drive to the start of the round from the depot. Trials have also been carried out with a vehicle 18months old; again this struggled to collect the required number of bins, only achieving half the amount on a full charge. Casey has also been using three vehicles for bulky waste collection; this service has a more flexibility in when collections take place, however the Council reported that the contractor is not getting full utilisation from the vehicles and the bulky waste service is supplemented by diesel vehicles.

The Council is hoping to trial a new 23t electric RCV in 2022, but states that manufacturers are not targeting the Australian market at present.

Figure 12: Mack electric RCV (photo courtesy of Department of Sanitation, New York, USA)

The lifting and compression mechanism of the vehicles require significant charge. Figures indicated through this study are that up to 40% of the vehicle charge is needed to operate the body of a RCV, although some models can store energy from braking. Some residual charge is required on the vehicle at the end of the collection round to be able to tip, so judgement is needed on when to return to the depot to recharge. Training is required to adjust the driving style for optimal use of the battery.

Related to battery range is the charging time required. Typically, slow charging is delivered overnight, however rapid charging to c.80% battery capacity can be achieved in a shorter time (typically 2-4hours) with fast chargers to enable battery top-ups between shifts. Mercedes quotes the charging time from 20% battery capacity to 80% as 1.5hours on fast charge for its new eEconic being released in the European market in 2022, which further demonstrates the developments in battery technology.

Broader environmental concerns

While the vehicle emissions at the tailpipe are zero, there are concerns regarding the wider environmental impact associated with electric vehicles. Clearly, the method of generating electricity comes into the overall life cycle impacts, however the impacts associated with the battery production and end of life have yet to be fully determined. This argument also applies to hydrogen fuel cell vehicles (see Section 5.2).

From a recent webinar on the life cycle impacts of electric vehicle batteries[33], this is an area of interest and development, with potential short term availability problems of raw materials – nickel, lithium, and graphite - and embedded carbon in the battery supply chain due to the energy intensive extraction and refining of these materials. The lithium-ion battery market is dynamic and continued advancement means that the life cycle analysis is subject to change.

During this study, several waste management companies expressed concern over the impacts of electric vehicle manufacture, particularly the battery. The use of rare earth, precious metals and other critical materials requires mining and the associated social and ethical issues surrounding this. Management of the battery at the end of its life needs to be addressed. There is much activity around developing battery recycling technologies at present, for example, Veolia is opening its first battery recycling facility in the UK in 2024[34], and Stelco plans to recycle batteries at its facility in Ontario, Canada in 2023[35]. UK waste management company, Grundon, is taking a firm stance on both these issues, "*only adopting the best technology that is fully recyclable".* However, in the last six months the company has committed to converting two of its diesel RCVs to electric to service commercial waste collections in city centre areas[36].

An additional question arises over the resale potential of electric RCVs at the end of their frontline life in developed countries. Currently, many diesel RCVs find a second life in developing countries, however, many countries do not have the electrical infrastructure to support an electric fleet.

4.4 Electric vehicle summary

There is a reasonable amount of experience across the globe in the use of battery electric vehicles for waste collection. It is clear that the battery technology is evolving constantly, giving increased range and better operational performance. Given the development in battery technology, one consideration may be to lease the battery to reduce the risk of obsolescence.

As with many other alternative fuel vehicles, capital costs are high, but expected to reduce as supply increases. This remains a key barrier, alongside the suitability of the local infrastructure to provide sufficient power to charge a fleet of electric vehicles. The capital costs associated with power and charging infrastructure can be significant, particularly for older depots. Despite high capital costs, the operating costs of electric vehicles is low, giving a favourable total overall cost compared to diesel. Supply chain issues and long lead times remain an issue for all vehicle types covered in this study.

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[33] Webinar: Insights into EV battery life cycle analysis, Zemo Partnership, 27/10/21

[34] Veolia announces its first electric vehicle battery recycling plant in UK (circularonline.co.uk) (Accessed 15/02/22)

[35] Stelco plans to recycle electric vehicle batteries at Ontario plant | Driving (Accessed 17/02/22)

[36] Grundon commits £600,000 to electric collection vehicles after successful trials - LAPV (Accessed 21/02/22)

5 Experiences with hydrogen vehicles

5.1 Introduction

The use of hydrogen as a fuel for road transport, including waste collection is being championed by governments in Europe. Investments in infrastructure are taking place, largely around "hydrogen clusters". Many of the vehicles and much of the supporting infrastructure is being subsidised by grant funding or wider subsidies, which is helping to drive demand.

The hydrogen fuel cell market appears to be dominated by Hyzon Motors. Hyzon develops fuel cells and is joining forces with vehicle manufacturers such as GeesinkNorba in Europe[37] and Superior Pak in Australia[38], plus other partnerships for the supply of hydrogen.

Hydrogen produces no carbon at the point of use, but the generation of the hydrogen can be an energy intensive process, depending on how it is produced. Although it is outside the scope of this current study, reference is made to the "well to wheel" (WTW) energy study undertaken by the Zemo Partnership on hydrogen as a road freight vehicle fuel[39]. The report summarises the carbon and energy benefits of different hydrogen fuel vehicles (fuel cell and combustion engine) compared to battery electric vehicles and fossil fuels. The conclusions are that hydrogen vehicles perform better than diesel vehicles for WTW greenhouse gas emissions, but that the WTW energy efficiency of hydrogen vehicles is lower than for battery electric and diesel vehicles. The greenhouse gas emissions are dominated by the hydrogen production supply chain - the report quotes:

"The difference is most pronounced for heavy duty vehicles. In the case of HGVs, fuel cell electric vehicle trucks are in the order of four to six times less energy efficient than battery electric vehicle on a WTW basis. Irrespective of the low carbon hydrogen supply pathway, the hydrogen production process is energy intensive thereby influencing WTW energy efficiency. This finding highlights the importance of accounting for energy consumption along with WTW GHG emissions and ensuring an energy efficient transition to net zero GHG emissions."

As with all fuels, the environmental benefits of using hydrogen will depend on how the fuel is produced.

5.2 Hydrogen fuel cell

The use of hydrogen for waste collection is being explored through the HECTOR project[40] (**H**ydrog**e**n Waste **C**ollec**t**ion Vehicles in N**o**rth West Eu**r**ope) which is testing seven fuel cell RCVs across seven pilot areas. Two of these pilot municipalities contributed to the detailed case studies for this project, Groningen, in the Netherlands, and Aberdeen, in the UK[41] (see Appendix C).

The use of hydrogen in fuel cells to power electric motors is a fast-moving area of development at present. There are several municipalities operating vehicles retrofitted with hydrogen fuel cells,

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[37] Geesinknorba & Hyzon Motors join to deliver Hydrogen-Powered RCVs | Geesinknorba (Accessed 10/02/22)
[38] Hyzon Motors signs MoU with Superior Pak for up to 20 hydrogen-powered refuse collection vehicles - Green Car Congress (Accessed 10/02/22)
[39] https://www.zemo.org.uk/assets/reports/Zemo_Hydrogen_Vehicle_Well-to-Wheel_GHG_and_Energy_Study_2021.pdf (Accessed 10/02/22)
[40] HECTOR - Hydrogen waste collection vehicles in North West Europe | Interreg NWE (nweurope.eu) (Accessed 31/01/22)
[41] Hydrogen on trial: Fuel cell RCVs and the future (openaccessgovernment.org) (Accessed 01/02/22)

while vehicle manufacturers are starting to enter the market with OEM fuel cell vehicles. One recent example of this is St Helens Council in the UK[42], which has recently taken delivery of a hydrogen fuel cell RCV supplied by Faun Zoeller. Aberdeen City Council has recently received its first hydrogen fuel cell RCV from GeesinkNorba[43] to complement its hydrogen-diesel dual fuel vehicles, while Glasgow City Council, also in the UK, is also investing in this technology[44], with what is expected to be the largest fleet of hydrogen-powered waste collection vehicles in the world.

Faun Zoeller UK on hydrogen fuel cell RCVs

Faun Zoeller UK (FZUK) specialises in the manufacture of vehicles for the waste management industry. FZUK is pioneering hydrogen fuel cell RCVs in Europe from the company's production plant in Germany. The company has recently received orders for over 100 fuel cell vehicles.

FZUK is "fuel agnostic", promoting the right fuel for the job, with the message that hydrogen is not needed for smaller vehicles which are better with electric power, but for larger vehicles covering longer distances, electric batteries may not have sufficient range. The decisions on fuel type should be data driven.

FZUK's view is that "the vehicle is the easy bit" – the challenge is managing the change from fossil diesel to hydrogen. Engagement and collaboration are key to adopting new alternative fuel vehicles. FZUK is working collaboratively with St Helens Council in the UK to develop training, awareness raising, and change management to demystify the myths of hydrogen. St Helens Council has recently taken delivery of a Faun Zoeller hydrogen fuel cell RCV.

The company prides itself on its customer support to ease the transition to alternative fuels, with a dedicated customer experience and training centre at its UK headquarters.

FZUK says that the challenge is the hydrogen refuelling infrastructure, which needs to be developing. The company is collaborating with industry and the UK hydrogen hubs on supply issues.

"A softly, softly, gradual approach is needed to manage the change from diesel, through engagement and collaboration"

Discussion between FRM and Faun Zoeller UK, December 2021

The main benefits and challenges of hydrogen fuel cell vehicles identified through this study are set out below. This is based on information gathered mainly from the Netherlands and the views of vehicle providers.

A case study of the experience of Groningen municipality's use of hydrogen fuel cell vehicles for waste collection in the Netherlands is provided in Appendix C. Groningen has a municipality-wide approach to the use of hydrogen as a vehicle fuel, using green hydrogen generated from solar power. This fits in with the strategic plans for the region.

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[42] St. Helens invests in OEM hydrogen fuel cell RCV - LAPV (Accessed 01/02/22)
[43] Aberdeen City Council adds UK's first hydrogen fuel cell waste truck to its vehicle fleet - LAPV (Accessed 01/02/22)
[44] Glasgow's council pledges £10.5m for hydrogen-powered bin lorries | Glasgow Times (Accessed 01/02/22)

City of Groningen, Netherlands

As of 2021, Groningen has three fuel cell refuse vehicles, there are plans to increase this number to twelve in 2022. The vehicles are fuelled by green hydrogen, which is produced using renewable electricity from Groningen's own solar field. Hydrogen fuel cell vehicles have a longer range than electric vehicles and refuelling is very quick at less than 10 minutes per vehicle, however, the capital cost of these vehicles is 2-3 times more than the diesel equivalent.

Further detail can be found in Appendix C.

5.2.1 Benefits

The main benefits of hydrogen fuel cell vehicles for waste collection are zero emissions, travel range, speed of fuelling and vehicle life.

Zero emissions

The main benefit of a hydrogen fuel cell powered vehicle is that it has zero emissions at the point of use – zero carbon, NOx, SOx and particulates – giving benefits for air quality and carbon emissions. As with all fuels, the total emissions will depend on how the hydrogen is produced. The different production methods for hydrogen are summarised in Section 2.2. Green hydrogen can be generated using power from renewable fuels, such as solar or wind. This is the approach being taken by the City of Groningen municipality in the Netherlands.

Increased travel range

Hydrogen fuel cell vehicles have an increased range compared to an electric vehicle, but the views are that the travel range is less than for diesel. The electric battery technology has evolved significantly over the last few years, particularly with regards to the potential travel range or distance, and continues to do so.

The longer travel range makes hydrogen fuel cells more suitable for waste collection in more rural (non-urban) municipalities where the range of a battery electric vehicle may not have been deemed appropriate.

It has been raised that there will be a trade-off between hydrogen tank storage on board the vehicle and its payload. However, it has been mentioned that the typical hydrogen usage for a fuel cell RCV is around 5-10kg per day; with GeesinkNorba reporting that a hydrogen fuel cell vehicle weighs only 200kg more than the diesel equivalent, this may be less of an issue.

Speed of fuelling

Fuelling a hydrogen fuel cell vehicle is much quicker than charging an electric vehicle, which takes (at the least) a few hours to reach sufficient battery capacity to service a waste collection route. Experience reported through this study is that hydrogen fuelling times are similar to diesel.

Figure 13: Hydrogen fuel cell RCV refuelling (photo courtesy of City of Groningen, Netherlands - photographer Martin Vonk)

Vehicle life

It is generally accepted that the life expectancy of an electric vehicle is longer than for a diesel engine. As set out in Section 4 this is due to the reduced wear from fewer moving parts – this also applies to hydrogen fuel cell vehicles. One vehicle manufacturer reported that the lack of an internal combustion engine means that parts can be more easily replaced, which makes it more durable and lowers the total cost of ownership. The City of Groningen municipality in the Netherlands is expecting a vehicle life of 15 years for its hydrogen fuel cell vehicles, with a refurbishment of the battery pack and hydrogen cells after 6-7 years.

5.2.2 Challenges

The main challenges of hydrogen fuel cell vehicles reported through this study relate to the supply of hydrogen, vehicle capital cost and vehicle supply chain.

Hydrogen supply

The supply of hydrogen is a main challenge for the use of hydrogen fuel cell vehicles and is considered to be a long way from commercial supply in most places. There is much development in this area, for example, recently the UK Government launched a new programme[45] to help develop innovative technologies to produce hydrogen, a clean energy source, from sustainable biomass and waste which aims to drive supply.

Hydrogen needs to be stored at pressure (typically 350Bar or 700Bar), so needs to be produced close to the point of use as transit is expensive. Even where hydrogen is produced locally, one waste management contractor in the UK has reported the difficulties of engaging with the site operator to secure supply. Hydrogen is odourless, colourless, and highly flammable. Safety issues around the storage and use of hydrogen will need to be addressed with appropriate modifications to depot infrastructure.

Investment is needed in hydrogen fuelling stations – those municipalities using hydrogen that contributed to this study have either developed their own fuelling stations or have access to public fuelling stations provided commercially. If this can be addressed, the fuelling infrastructure at a municipality level may be simpler than for electric vehicles, as no substation is required.

The cost of hydrogen reported in this study varies, with some saying it is only marginally more expensive than diesel for equivalent performance (see Section 5.3.2), others a similar equivalent pump price, and another (anecdotally) suggesting nine times the diesel equivalent price. This suggests that hydrogen supply cost and logistics vary significantly.

Vehicle capital cost

The capital cost of the vehicles remains a key challenge for municipalities seeking to adopt hydrogen fuel cell waste collection vehicles. Figures quoted range from double to quadruple the cost of a diesel equivalent, with investment largely being reliant on grant funding.

[45] Government launches new scheme for technologies producing hydrogen from biomass - GOV.UK (www.gov.uk) (Accessed 08/02/22)

Despite the higher capital cost, the total cost of ownership is reported to be lower than diesel, as summarised by Faun Zoeller UK (expressed in GB£): *"For every £1 spent on a diesel vehicle, it delivers 28p worth of travel; for every £1 spent on a hydrogen vehicle, it delivers 76p worth of travel."* Of course, this cost comparison is dependent on the cost of the hydrogen fuel.

Vehicle supply chain

Hydrogen fuel cell RCVs are not widely manufactured, although this is a rapidly changing market. The vehicles in use by the City of Groningen municipality were converted from electric RCVs. The lead time reported in this study varies upwards from 1.5years which is a significant issue for fleet management.

In addition, the safety and maintenance aspects of using hydrogen have been raised as an issue, particularly for training of vehicle mechanics. In the areas of the Netherlands where the use of hydrogen is a strategic direction for energy, such training is now being incorporated into college courses.

5.3 Hydrogen combustion

The use of hydrogen as a diesel replacement in a combustion engine for road transport is in its infancy and is a developing area. In the car market, companies including JCB and Toyota are investing in hydrogen combustion vehicle research. At present there are no vehicles that use solely hydrogen as a combustion fuel in the RCV market. This study identified few examples in practice for waste collection, those being centred around converting existing RCVs to use hydrogen in a dual fuel arrangement at a diesel substitution rate of 30-40%. The commentary relates to experiences in the UK.

Figure 14: Hydrogen fuelling station (photo courtesy of Aberdeen City Council)

A case study of the experience of Aberdeen City Council's use of hydrogen combustion vehicles for waste collection in the UK is provided in Appendix C. Aberdeen has undertaken conversions of diesel vehicles to dual fuel with hydrogen and is also testing a hydrogen fuel cell RCV through the HECTOR project. Green hydrogen is generated by electrolysis of renewable electricity from the grid.

Aberdeen City Council, UK

Aberdeen has begun the process of converting its diesel refuse vehicles into hydrogen-diesel combustion hybrids. No operational issues have been reported and the cost is much lower than purchasing hydrogen fuel cell vehicles, however the emissions savings are limited to the amount of diesel displaced. A challenge faced with these conversion vehicles is the placement of the hydrogen fuel tanks, which is determined by the size of the vehicle and chassis length.

Going forwards, Aberdeen is planning for the whole fleet to be using alternative fuels.

Further detail can be found in Appendix C.

ULEMCo on the conversion of diesel RCVs to dual fuel with hydrogen

ULEMCo is a UK company that specialises in hydrogen solutions for transport. The company has worked with a number of UK local authorities (municipalities) to convert diesel RCVs to dual fuel, under the H2ICED brand name. ULEMCo has over 100 vehicles on the road, with 50 of these being RCVs.

The main selling points that ULEMCo uses for the vehicle conversions are:

- Gives the same user experience as for diesel
- Relatively modest capital costs (c.30-50k)
- Direct carbon emission reductions related to hydrogen substitution rate

The hydrogen mix is capped at 50%, for RCVs the hydrogen mix is 30-40%. The hydrogen is used at the most efficient point in the drive cycle, so the actual consumption is determined by driver behaviour and style. Hydrogen tanks for RCVs are 2.2m long and have a capacity of 5-10kg, which is the equivalent of 16.5-33litres of diesel. The tanks are fitted below the chassis or behind the cab. The additional weight has not affected the payload.

The conversions are undertaken by overlaying the diesel engine. As the vehicles are modified post-registration, there are no approvals / homologation required. It is reported that the original vehicle warranty is not affected, and ULEMCo also provides its own warranty. The hydrogen tanks have a 15year life, and in theory could be retrofitted to another vehicle.

ULEMCo works around the hydrogen clusters in the UK. Scotland is a big focus market, with conversions completed for Glasgow and Aberdeen City Councils on their municipal fleet (waste and cleansing). Hydrogen is now available at 12 public fuelling stations across the UK.

The company also installs hydrogen fuel cells to electric vehicles for range extension and is developing solutions to fit fuel cells in heavy goods vehicles and zero emission hydrogen combustion for 7.5t vehicles through engine replacement.

"Retrofit is not bound by the asset replacement cycle"

Discussion between FRM and ULEMCo Ltd, January 2022

5.3.1 Benefits

The main benefits of hydrogen combustion reported through this study relate to moderate capital cost for conversion and ease of use.

Moderate capital cost for conversion

One of the key benefits associated with hydrogen combustion is the relatively low capital cost associated with the conversion to dual fuel, which is indicated by ULEMCo to be in the region of £30-£50k per vehicle in the UK market. The conversion process is relatively simple, Aberdeen City Council in the UK reported that the vehicle was only out of action for a week while the conversion took place.

Information provided by ULEMCo shows that the moderate cost of a dual fuel conversion can be weighed up against the carbon savings of a full conversion to hydrogen fuel cell: for the cost of one fuel cell conversion with zero emissions, a municipality could convert 7 standard diesel vehicles to dual fuel (diesel / hydrogen) each saving up to 40% of the carbon emissions.

The conversion of RCVs to dual fuel can be undertaken on new or existing vehicles, so the move away from fossil diesel does not necessarily need to link to fleet replacement cycles. That said, the conversion process does not affect the emissions classification of the vehicle, so conversion of newer vehicles should be preferred to future-proof against obsolescence. ULEMCo, the conversion company that contributed to this study, reports that there is no impact on warranties from the original vehicle manufacturer.

Ease of use

Of particular note is the ease of use for the workforce. There are limited experiences in this area of fuel development, however it is reported that there is no noticeable difference in the vehicle operation or driving conditions compared with diesel. This reduces the training needs for drivers and eases the transition of the vehicles into the fleet for everyday operation. This was a particular issue of importance for Aberdeen City Council which has a relatively large fleet (in UK terms) and a high turnover of staff.

One vehicle manufacturer reported that hydrogen combustion vehicles should be quieter than a diesel engine as there is no "engine knock" from uneven combustion of fuel. Other operating benefits mentioned include lower AdBlue exhaust fluid requirement and less frequent changing of fuel filters.

While arrangements and infrastructure are needed for the refuelling of two fuel types, the dual fuel vehicles can run solely on diesel if necessary. The fuelling arrangements are understood to be similar to diesel, with the exception of being noisier!

5.3.2 Challenges

The main challenges of hydrogen as a combustion fuel for waste collection identified through this study relate to hydrogen supply, conversion considerations and limited carbon reductions.

Hydrogen supply

This is a key issue for hydrogen, whether as a combustion fuel or for hydrogen fuel cell electric vehicles, as set out in Section 5.2. The hydrogen fuelling capacity needs to be addressed – at present this tends to be clustered around hydrogen hubs (for example, northern Netherlands and Scotland for the European market). Expansion of the hydrogen vehicle fleet has been cited to be dependent on fuelling station capacity, and the availability of hydrogen at the fuelling station. For dual fuel hydrogen and diesel vehicles, fuelling infrastructure for both diesel and hydrogen is required.

For bulk purchases of hydrogen, ULEMCo considers that the use of hydrogen in dual fuel vehicles works out to be around 15% more expensive[46] than using diesel alone, for the same performance. However, the pump price for hydrogen at public fuelling stations can be significantly higher[47], at over €10/kg depending on the location.

Conversion considerations

At present there is a limited number of providers of vehicle conversions. It is not currently possible to obtain a new hydrogen combustion RCV (with or without diesel dual fuel), nor is it commercially possible to convert a diesel RCV to combust solely hydrogen. This position is subject to change as developments take place.

For vehicle conversions, one key consideration is the location of the hydrogen fuel tanks on the vehicle. This was something that Aberdeen City Council had to manage with its recent conversions, as the size of the vehicles and the length of the chassis determines whether the tanks need to be placed on the roof or underneath the chassis. If placed on the roof, issues such as aesthetics and overall vehicle height may arise.

Limited carbon reductions

The carbon reductions are capped based on diesel replacement levels in the dual fuel conversions. This is around 30-40%; zero emissions conversions are in development but are not available for RCVs at present. The hydrogen and diesel are combusted as a combined fuel; the actual amount of hydrogen used (and therefore the carbon emissions reductions) depend to a certain degree on the driving style. More diesel is used during acceleration, whereas hydrogen usage is optimum in start-stop conditions, which is encountered frequently during RCV operations.

Given that the engine will automatically revert to full diesel usage, the NOx emissions will not be more than for diesel alone.

As with all fuel types, the full environmental impact will depend on how the hydrogen is produced. Green hydrogen produced from renewable energy will give the greatest environmental benefits.

5.4 Hydrogen vehicle summary

Hydrogen as a vehicle fuel has been quoted as being *"the nirvana for fuel, but we are some way away yet"* in commentary and discussion through this study. Hydrogen production and supply tends to be in key clusters or hubs, which follows the strategic direction in the region; the supply and distribution of hydrogen outside these areas remains a key challenge.

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[46] Octopus Hydrogen | Suppliers of 100% green hydrogen (octohydrogen.com) (Accessed 01/02/22)
[47] Platts launches hydrogen pump prices in Germany, Japan and California | S&P Global Platts (spglobal.com) (Accessed 01/02/22)

The vehicle supply chain, long lead times and the high capital cost of vehicles are also key challenges. As with all new developments, the economics of supply are led by demand. It is expected that the vehicle capital cost should reduce as demand increases.

The key advantages of hydrogen are the zero carbon emissions at the point of use, and the longer vehicle range achievable compared to battery electric vehicles. The environmental credentials of using hydrogen for either combustion or fuel cell will depend on how the hydrogen is produced; in a fuel cell vehicle, the environmental impacts of the battery also merit consideration.

6 Natural gas

6.1 Introduction

Compressed natural gas (CNG) is a well-established fuel for road transportation. Information from Energy Vision[48] reports that in the USA, 20% of transit buses run on natural gas and 60% of refuse truck orders are natural gas models. While still a fossil fuel, CNG offers benefits in terms of reduced emissions compared with diesel, with further carbon savings from using renewable natural gas (RNG)[49].

The commentary in this report relates to CNG and RNG from discussions with a municipality (City of Toronto) and waste management companies. Other municipalities are also moving to RNG to decarbonise their waste fleet; an example being Liverpool City Council in the UK[50].

City of Toronto, Canada

When many of Toronto's diesel vehicles reached the end of life in 2013/14, they were replaced with natural gas vehicles, resulting in lower costs and emissions. The City wanted to make use of biogas produced from anaerobic digestion of the organic waste and decided to upgrade it and inject it into the natural gas grid to create renewable natural gas. The capex cost for the vehicles was higher than the diesel equivalent, however the cost of the fuel is considerably cheaper and lower emissions are achieved.

Further detail can be found in Appendix C.

A case study of the experience of the City of Toronto Council's use of natural gas vehicles for waste collection in the Canada is provided in Appendix C. Toronto is generating RNG from food waste collected by the council and blending it with natural gas from the grid. The municipality-wide commitment has made the business case for the vehicles and other gas applications viable.

48 What_is_RNG.pdf (energy-vision.org) (Accessed 31/0/22)
49 World Biogas Association | RNG refuse trucks poles ahead of electric for clean air and carbon reduction (Accessed 01/02/22)
50 Liverpool City Council unveils biogas-powered refuse trucks (edie.net) (Accessed 01/02/22)

Waste Management Inc on the use of CNG

Waste Management Inc (WM Inc) is a leading waste management company in the US, also covering Canada and Hawaii. The company started working with natural gas over 20 years ago when its use was mandated in California. Following a learning curve with LNG, the company started to build its portfolio with CNG, which it found easier to manage.

The success of the company's contract with Seattle City Council in 2009 with new CNG vehicles saw the start of the wider transition to natural gas. The full costs and performance of the service were shown to be favourable, and the leadership team at WM Inc backed the direction for CNG. The contract has since been re-awarded to WM Inc in 2019 for another ten years, requiring 122 CNG vehicles.

Today WM Inc has 11,000 natural gas vehicles in operation in US and Canada, out of a total fleet of 20,000 vehicles. The company's aim is to have 90-95% of vehicles on natural gas by 2025/26, and to be 100% RNG positive by the same date, with RNG from the company's landfill sites. The company has achieved NOx reduction through the natural gas programme.

WM Inc has also developed 178 gas fuelling stations to service the fleet, a move that has involved huge investment but is justified by the payback over the longer term. When the company establishes a new natural gas station, it trains all local first responders as part of the service.

"WM Inc has embraced the natural gas technology, but is fuel agnostic, considering other fuels as they develop"

Discussion between FRM and Waste Management Inc, January 2022

6.2 Benefits

The main benefits of using CNG (and RNG) vehicles for waste collection that have been identified through this study are reduced emissions, lower fuel costs and similar vehicle performance to diesel.

Reduced emissions

It is well-documented that the emissions from vehicles using natural gas are lower than for diesel, and this is also reported by those we spoke to as part of this study. Overall greenhouse gas emissions are further reduced by the replacement of fossil natural gas with RNG, biogas produced from waste treatment processes, which harnesses the gas that would otherwise be vented to atmosphere. While the generation and use of RNG requires capital infrastructure to capture and clean the biogas, this is a useful way to decarbonise the natural gas supply, as being done by Toronto City Council. The World Biogas

Figure 15: Biogas plant (photo courtesy of City of Toronto Council, Canada)

Association states that RNG is the only vehicle fuel with the capacity to be carbon negative[51]. It has also been suggested that RNG is a cleaner fuel than natural gas, with higher methane content.

Lower fuel cost

The pump price of natural gas is significantly lower than diesel – Toronto City Council based its business case on a price of Can$0.22 per litre[52] compared with Can$1.23 per litre for diesel, with a price for RNG of Can$0.84 per litre, which includes the capex for biogas capture and cleaning. When blended with natural gas in the supply pipeline, the additional cost of using RNG is marginal: the move to CNG for Toronto paved the way for closing the loop with RNG.

Pump prices vary for both diesel and CNG across the world. However, it is generally understood that natural fuel costs are lower than for diesel[53].

Similar performance

In terms of the vehicle range and driveability, it is reported through this study that CNG (and therefore RNG) gives similar performance to diesel vehicles. There was comment that there is some loss of power compared with diesel, but the drivers have since adjusted and the vehicles are liked by the workforce. This latter point of particular importance at present due to widespread driver shortages. Other comments in relation to the performance are that the vehicles are quieter, and refuelling is quicker than diesel.

One waste management company reported more maintenance issues with CNG, while the London Borough of Camden in the UK is understood to have developed specialist maintenance expertise through the waste management company which delivers the service on its behalf, Veolia. The Municipality of Kampen in the Netherlands reported lots of operational problems with its CNG vehicle. Although not an exhaustive study of natural gas vehicles, these issues may be relatively isolated.

Importantly, RNG is chemically identical to CNG, so there should be no warranty issues with using the renewable fuel in a natural gas engine.

6.3 Challenges

The main challenges of using CNG (and RNG) identified through this study are higher vehicle capex and fuelling infrastructure.

Higher vehicle capex

Natural gas RCVs are more expensive than the diesel equivalent. Figures provided through this study indicate approximately US$30k more, suggesting a higher capex of around 10% more. This additional capex will need to be taken into consideration with the lower fuel costs and the emissions reductions, as well as the cost of any refuelling infrastructure required.

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[51] NGV RNG Driving Down (worldbiogasassociation.org) (Accessed 01/02/22)

[52] CNG is sold by weight - 1kg of CNG has the energy equivalent to 1.462L of diesel (Energy-Content-Factsheet-FINAL-EN.pdf (cngva.org))

[53] CNG Europe | Map of Natural Gas Vehicle (NVG) Compressed natural gas (CNG) filling stations in Europe, Mappa Stazioni di rifornimento di metano, Landkarten Methantankstellen erdgastankstellen (Accessed 01/02/22)

Fuelling infrastructure

The availability of public fuelling stations for CNG (and RNG) varies geographically, with the general view that more investment is needed in public infrastructure. Certainly, the view from a waste management contractor in France is that the network of service stations is insufficient, and private fuelling stations may need to be developed depending on the location. This is also the approach adopted by WM Inc in the USA. As with all fuel types, development of supporting infrastructure is a long term and capital-intensive investment.

6.4 Natural gas vehicle summary

The use of natural gas as a fuel for waste collection vehicles offers benefits in terms of reduced vehicle emissions. The overall carbon impact can be further reduced by capturing biogas from waste treatment processes to use in vehicles as RNG. While the capital cost of the vehicles is higher than for diesel, the fuel costs are lower. However, the potential for natural gas depends on the fuelling infrastructure which may need to be developed locally.

7 Hydrogenated / Hydrotreated Vegetable Oil

7.1 Introduction

As summarised in Section 2.4, hydrogenated (or hydrotreated) vegetable oil (HVO) is a "drop in" fuel that can be used as a direct replacement for diesel in existing vehicles. This is a useful option to aid the transition to alternative fuels as it does not require new vehicles or any significant investment in infrastructure, providing a reliable fuel source is available. This is summed up neatly by Pendle Borough Council, UK, in a press release in October 2021[54]:

"We're not ready to cover the cost or logistics of moving the fleet to electricity. The next best thing for us was to investigate more eco-friendly fuels so we can continue to deliver services in the most efficient way."

This is reiterated by both the Municipality of Kampen in the Netherlands, and major Dutch waste contractor RMN. Longer term, both these organisations are interested in a transition to hydrogen fuel cell vehicles but recognise that the vehicle market and supporting hydrogen infrastructure is yet some way from achieving this economically.

Reinigingsbedrijf Midden Nederland (RMN) on the use of HVO100

RMN is a wholly owned company of 6 municipalities in the Utrecht region of Netherlands, delivering environmental services for the municipalities, including household waste collections.

Following a Netherlands government mandate to reduce CO_2 emissions by 50% by 2024, RMN started using HVO100 on its 40 Euro 5 engines during 2021. The use of HVO allows the company to use the same standard diesel engines with no modifications required, no warranty implications from Scania and DAF, while retaining a re-sale value at the end of their 8-year frontline life.

Due to the mixed age of the fleet, not all vehicles are suitable to use HVO. Overall, the company has achieved c.30% reductions in CO_2 and reduced NOx from its vehicles. Further CO_2 reductions are achieved through the use of engine lubricants.

HVO100 is supplied locally by Orange Gas, through public fuel stations. The pump price is around €0.20 more expensive per litre than diesel, but RMN reports that the consumption / fuel efficiency is the same. There are also savings from 50% reduction in AdBlue usage and vehicle maintenance costs are around 5-7.5% lower as the HVO100 is a cleaner fuel than diesel.

HVO100 is seen as a stepping-stone for RMN; longer term the company is exploring the potential for hydrogen as a fuel when the vehicles are more readily available, the fuel infrastructure is sufficient locally and to tie in with vehicle replacement schedules. Converting diesel vehicles to hydrogen fuel cell would involve significant carbon and cost implications.

"HVO100 is right choice for RMN now, but will be kept under review"

Discussion between FRM and RMN, January 2022

[54] Eco fuel for Pendle's bin wagons and street sweepers - Pendle News Room (Accessed 20/01/22)

A case study of the experience of Kampen municipality's use of HVO for waste collection vehicles in the Netherlands is provided in Appendix C. Kampen is using HVO as a transition fuel to reduce vehicle emissions until investment can be made in hydrogen fuel cell vehicles.

Municipality of Kampen, Netherlands

All vehicles within Kampen's waste fleet run on HVO100 with the expectation of one vehicle which uses compressed natural gas. HVO100 is a fuel substitution and doesn't require any vehicle modifications, this also means that no additional training is required. Use of this fuel is estimated to give an 80-90% reduction in carbon compared to diesel. However, HVO100 costs approx. 15% more than diesel, and the vehicles use 10-20% more HVO100 than diesel.

In the future, Kampen aims for all vehicles to be hydrogen-electric, using hydrogen fuel cells.

Further detail can be found in Appendix C.

7.2 Benefits

The main benefits of using HVO reported through this study relate to the ease of use and lower emissions.

Ease of use

It is generally seen that running a fleet on HVO should be an "easy option" (subject to fuel supply, see below). Those operating the vehicles on HVO report that it works well with Euro 5 and 6 engines, with no vehicle modifications. However, it is not so good for vehicles of an earlier emissions standard, so depending on the make-up of the fleet, it may be that it is not possible to run a whole fleet on HVO. The overall view is that the driving characteristics are the same as for diesel, with no technical issues or loss of power, and no specific training requirements. Commentary was only available for European vehicles; the suitability may vary depending on the engine type in other parts of the world.

The views on maintenance and servicing appear to be divided, with some experiencing lower maintenance costs (believed to be due to the cleaner nature of HVO), some experiencing no change, and others suggesting more maintenance is needed. It has also been commented that the consumption of exhaust fluid, AdBlue, is reduced due to the cleaner burn of HVO.

This report does not investigate these different views, other than to suggest that the different vehicle types, applications and driving styles are likely to have a bearing on maintenance and servicing regimes, just as they would for diesel.

The experience is that there are no warranty issues associated with the use of HVO, provided it meets the appropriate fuel grade. It is understood that much work has been undertaken in this area with vehicle manufacturers over the last few years to get to this position. Importantly for the international second-hand vehicle market, the vehicles still have a resale value at the end of their first frontline service life (typically 7-10 years for a refuse collection vehicle). This may be of relevance for the existing sales routes for second-hand vehicles into developing countries.

Lower emissions

Figures published by suppliers of HVO report a reduction in carbon emissions of around 90% - this seems to be a universally accepted figure relating to HVO100. Lower substitution / purity levels of HVO (i.e., HVO80) will give correspondingly lower carbon emission reductions.

Portsmouth City Council in the UK, which has recently moved over to using HVO to comply with the city's Clean Air Zone, quotes a useful comparison[55]:

"Eleven HGVs using the new fuel [HVO] produce the same CO_2e as one HGV using regular diesel, and that's the change we need to see locally."

The benefits for NOx emissions appear to be inconsistent from the fuel suppliers (see Section 2.4). However, one waste management contractor reported lower NOx emissions from using HVO in its contribution to this report.

7.3 Challenges

The main challenges of using HVO reported through this study relate to fuel supply, cost, and efficiency).

Fuel supply

A secure supply of fuel is a challenge that needs to be addressed. For those contributors to this report who use HVO extensively, the supply is not an issue. In the Netherlands, it is readily available at fuelling stations across the country provided by the private sector[56]. In Sweden, a contributor to the survey reported that HVO is also widely available and delivered in bulk for onsite storage, although it is acknowledged that HVO may be more difficult to source if supply does not meet increased demand.

In the UK, HVO supply is currently an issue for a major waste management contractor. The company commented for this study that it believes that it should be using HVO as an "easy transition fuel" but is encountering difficulties with the procurement of a sustainable supply. This has been reiterated by another UK municipality which has encountered cost and supply issues for HVO as the fuel is not currently available through a procurement framework. On a broader level, there are concerns over the environmental and ethical of production and supply.

No experiences in supply from countries outside Europe were available as part of this study.

Efficiency

The suppliers of HVO might claim that there is no reduction in fuel efficiency or increased consumption, however, the view from those using the fuel for waste collection who contributed to this study tend to disagree. Consumption / fuel efficiency impacts are indicative, but figures suggest 10-20% more HVO is needed than diesel.

[55] Council makes switch to green diesel for a cleaner collection - LAPV (Accessed 20/01/22)
[56] refueling locations - OrangeGas (Accessed 20/01/22)

Cost

It is widely acknowledged that the pump price of HVO is higher than for diesel, typically 10-15% more. It commands a premium due to the principles of supply and demand, but also carries a premium for its renewable certification[57]. Coupled with the reduced efficiency resulting in increased consumption (per litre), the use of HVO has an overall cost of at least 20% greater than diesel. This should be balanced against the ability to use existing vehicles (in the main) with no modifications or additional vehicle capital cost.

7.3.1 HVO vehicle summary

HVO is seen as a useful step in the transition to a cleaner waste collection vehicle fleet. The supply of HVO is a developing market. Securing a suitable supply of HVO may be an issue in some geographical locations. Depending on the supply network, local fuelling infrastructure at the vehicle depot may need to be developed.

The additional costs from fuel price and increased consumption are seen to be outweighed by the immediate emissions benefits, and, critically, the ability to use existing vehicles.

[57] For example: Renewable Fuels Assurance Scheme | Fuels | Zemo Partnership

8 Summary

The adoption of alternative fuels for waste collection vehicles is a rapidly changing landscape. It is clear from the online survey responses to Stage 1 of the project, and the detailed discussions held with municipalities, waste management companies and vehicle providers in Stage 2, that there is a significant and genuine interest in moving away from fossil fuels for waste collection activities. This is driven largely from a need to decarbonise municipal services in response to climate emergencies and national or local carbon reduction policies, as well as improving local air quality.

Importantly, and this is recognised by the stated “fuel agnostic” nature of some of the vehicle manufacturers and waste management companies, there is no universal preference of which fuel type to adopt. Consideration has to be given to route planning and vehicle range, fuelling / charging infrastructure, driving experience and total overall costs. On that latter point, the total overall costs of some alternative fuels are reported to be lower than for the diesel equivalent, however, the initial capital cost can be significantly more. A change in the way assets are accounted for may be required for some municipalities to support widespread adoption of alternative fuel vehicles.

Supporting infrastructure is a key issue for many fuel types. Even fuels involving “simple” changes, such as replacing diesel with HVO, requires a reliable source of fuel, which has proved problematic for some. Substantial changes, such as electric and hydrogen or investing in renewable natural gas generation, require supply and fuelling infrastructure to be developed locally, at significant cost. The suitability of the local grid capacity to accommodate widespread charging of electric vehicles needs early assessment prior to committing to the technology, with the capital cost of substations taken into account in the business case for change. The hydrogen market is developing in many countries in regional clusters or hubs; it may be some way from widespread commercial viability for many applications.

Vehicle technology is constantly developing, particularly in terms of hydrogen and electric vehicles. There is a risk that investing now may lead to early obsolescence, particularly with regards to electric vehicle battery capacity. Furthermore, the cost and disruption of developing supporting infrastructure for the move to an alternative fuel is likely to lock many municipalities in to longer term arrangements. Many municipalities have been trialling different vehicles for this purpose, prior to committing, or using a transition fuel, such as HVO or hybrid.

One of the main obstacles to adoption of alternative fuels is the higher capital cost, particularly for electric or hydrogen vehicles, which are widely understood to be at least 2-3 times the cost of a diesel equivalent. In many cases, vehicles have been purchased with the assistance of grant funding to demonstrate operational performance. It is expected that the capital cost of alternative fuel vehicles will reduce in coming years as supply increases with vehicle manufacturers moving away from fossil fuel combustion engines. In the meantime, choice is restricted in many areas, and vehicle lead times are long.

Each municipality has a different energy and fuel supply situation. As such there is no universal single solution; the optimum fuel will depend on the particular situation. A municipality-wide commitment, that links with national or regional policy direction, to a particular fuel will aid the transition process, particularly with regards to the mindset change and training that is likely to be required in many situations. There is a growing bank of operational experience on the use of alternative fuels for waste collection vehicles around the world from which municipalities and waste management service providers can learn.

8.1 Recommendations for further work

This report presents a limited snapshot of the experiences of some municipalities that have adopted alternative vehicle fuels for waste collection services, supplemented by broader discussion from waste management companies and vehicle manufacturers. It is not intended to be an exhaustive survey, however the summary findings for each fuel type may be of interest to municipalities seeking to adopt, or transition to, alternative low emission fuels.

There are several issues raised in the discussion with contributing organisations that warrant further investigation. In summary, these relate to the following.

End of life vehicle management

This study focuses on the adoption of alternative vehicle fuels for waste collection in upper / middle income countries. Traditionally, vehicles would find a "second life" in lower income or developing countries at the end of their front-line service life. This arrangement may not be appropriate for alternative fuel vehicles in countries where there may be insufficient power supply for everyday needs, let alone a fleet of electric waste collection vehicles.

Consideration needs to be given to the recyclability and decommissioning of the vehicle if it will not be suitable for a second operational life, or whether various components can be replaced or retrofitted to support a second life.

Life cycle analysis

The term "low emission" has been used throughout this report in relation to the emissions at the point of use, i.e., the vehicle exhaust or tailpipe. The use of such fuel is driven by a desire to reduce the carbon impact of the waste collection activities or to improve the air quality in the local area. Less consideration has, perhaps, been given to the overall environmental, sustainability and social impacts associated with the manufacture of the vehicle and the fuel. These impacts can be significant. Particular concern has been raised over the impacts associated with electric battery and component manufacture, and its end-of-life management. A full life cycle analysis of the vehicle production, fuel generation, use of the vehicle and its end of life will be useful to further inform municipalities on the most appropriate approach for their situation.

Vehicle supply chain capacity assessment

One repeated issue raised during this study has been the vehicle supply chain, in particular, long lead times and limited choice. To a certain degree, the lead time has been an issue in some areas for conventional diesel waste collection vehicles for some years, so this is not a new problem. However, an understanding of the capacity of the market to provide alternative fuel vehicles in different geographical areas would be helpful for municipalities seeking to make the transition away from fossil fuel.

Appendix A

Stage 1 Questionnaire

Sustainable Vehicle Research for Waste & Recycling Collection

The International Solid Waste Association (ISWA) is carrying out research on the current activity around sustainable waste collection technologies. The primary aims are to understand the path towards acquisition and use of low emissions and alternative fuel vehicles, their performance, cost and the challenges faced.

We welcome your input and answers to the following short questionnaire. **Responses from all municipalities are wanted, even if you do not use low emission or alternative fuel waste collection vehicles**. With your permission, we may have a follow up call / email / virtual meeting to discuss in more detail.

ISWA has appointed the independent consultancy Frith Resource Management Ltd to co-ordinate the research. For more information please visit their website www.frithrm.com, or contact cherie@frithrm.com.

The project is being supported by ISWA and NVRD. Additional funding has been provided by CIWM, in the UK, to use the information gathered to provide further guidance to Municipalities on the adoption of sustainable waste and recycling collection vehicles.

THANK YOU FOR YOUR TIME AND INPUT TO THIS RESEARCH

Your details

Privacy and data protection

As part of the research, we will collect some personal information from you, such as your name, telephone number and email address, so that we may contact you for a follow up discussion with your agreement. We will securely store this information for a period of 12 months following the completion of the project. We respect your trust and protect your privacy, and therefore will never share or sell this data with any third parties (other than ISWA, NVRD and CIWM, which are funding this project). This data will only be used for the purposes of this project, and will not be used by Frith Resource Management Ltd for any marketing purposes without your prior agreement. By participating in this survey, you agree that we will process your data in line with our Privacy Policy. If you would like to see a copy of our Privacy Policy, have any questions or change your mind, please contact us on +44 (0)1746 552423 or cherie@frithrm.com.

1) Name:	
2) Email:	
3) Job title:	
4) Municipality / organisation:	
5) Country:	
For this survey, "low emission" is less than 50g CO_2/km measured at the vehicle tailpipe, but we are also interested in alternative fuels that may not meet this standard but are lower than petrol, diesel or liquified petroleum gas (LPG)	
6) Are you considering or have you considered low emission or alternatives to fossil-fuelled (petrol, diesel and liquefied petroleum gas) waste and recycling collection vehicles?	Yes / No
If you answered.... **YES**, please go to **7** **NO**, please go to **17**	

For this survey, "low emission" is less than 50g CO_2/km measured at the vehicle tailpipe, but we are also interested in alternative fuels that may not meet this standard but are lower than petrol, diesel or liquified petroleum gas (LPG)	
7) As you answered Yes to Question 6 - What are your motivations for considering low emission or alternative fuel vehicles?	Legal YES / NO Political YES / NO Environmental YES / NO Ethical YES / NO Financial YES / NO Other________________________________
8) Please provide any further comments on your response.	
9) Have you introduced low emission or alternative waste and recycling collection vehicles?	Yes / No
If you answered.... **YES**, please go to **10** **NO**, please go to **17**	
10) As you answered Yes to Question 9 - What barriers did you have to overcome, or what challenges did you face?	Funding or cost YES / NO Availability of technology YES / NO Provision of supporting infrastructure YES / NO Operational issues YES / NO Other________________________________
11) Please provide any further comments on your response.	
12) What type(s) of fuel have you adopted and approximately what proportion of your waste & recycling collection vehicles are they?	Electric YES / NO __________% Hydrogen YES / NO __________% CNG / LNG YES / NO __________% Hybrid YES / NO __________% Biofuel YES / NO __________% Other________________________________
13) If you chose Hybrid, Biofuel or Other to the question above, then please give information on the fuel type.	

14) What positive effects has your Municipality seen through introducing low emission or alternative fuel waste & recycling collection vehicles?	
15) Would you have done anything differently, and if so, what?	
16) Would you be willing to discuss your experiences with low emission or alternative fuel waste & recycling collection vehicles with us?	

For this survey, "low emission" is less than 50g CO_2/km measured at the vehicle tailpipe, but we are also interested in alternative fuels that may not meet this standard but are lower than petrol, diesel or liquified petroleum gas (LPG)

17) As you answered No to Question 6 or 9 - What are your reasons for not considering or using low emission or alternative fuel vehicles?	Funding or cost YES / NO Availability of technology YES / NO Reliability or track record YES / NO Lack of supporting infrastructure YES / NO Operational concerns YES / NO Contractual constraints YES / NO Other_______________________________
18) Please provide any further comments on your response.	
19) When might you consider or use low emission or alternative fuels?	Within 6 months / 6-12 months / 1-2 years / 2-5 years / 5+ years (Please delete as appropriate)

Thank you for taking part in the survey.

Please email your response to cherie@frithrm.com

Appendix B

Stage 2 Sample Questions

ISWA Sustainable Vehicle Research

Introduction

The International Solid Waste Association (ISWA) is carrying out research to understand the current activity around sustainable waste collection technologies. The primary aims are to understand the use of low emission and alternative fuel vehicles, their performance, cost and challenges faced.

Thankyou for taking part in the first stage of the survey through the online survey. The project team believes that your experiences will be of interest to others seeking to adopt similar vehicles, and we would like to discuss this further with you through an online meeting (MS Teams or similar).

ISWA has appointed the independent consultancy Frith Resource Management Ltd to undertake the research. For more information please visit their website www.frithrm.com, or contact cherie@frithrm.com.

The project is being supported by ISWA and NVRD. Additional funding has been provided by CIWM to use the information gathered to provide further guidance to Municipalities on the adoption of sustainable waste and recycling collection vehicles.

THANK YOU FOR YOUR TIME AND INPUT TO THIS RESEARCH

Privacy and Data Protection

As part of the research, we will collect some personal information from you, such as your name, telephone number and email address, so that we may contact you for a follow up discussion with your agreement. We will securely store this information for a period of 12 months following the completion of the project. We respect your trust and protect your privacy, and therefore will never share or sell this data with any third parties (other than ISWA, NVRD and CIWM, which are funding this project). This data will only be used for the purposes of this project, and will not be used by Frith Resource Management Ltd for any marketing purposes without your prior agreement. By participating in this survey, you agree that we will process your data in line with our Privacy Policy. If you would like to see a copy of our Privacy Policy, have any questions or change your mind, please contact us on +44 (0)1746 552423 or cherie@frithrm.com.

Stage 2 Questions

Questions marked * are of key importance

1 **** Contact details***

Name:
Email:
Job title:
Municipality / Organisation:
Country:

<u>Please note that all references to low emissions vehicles relate to low emission and alternative fuel waste and recycling collection vehicles</u>

2 ***Municipality / Context***

- * What is the approximate population of your Municipality and the number of households?

- * What is the approximate size of your Municipality (square kilometers)?

- * How rural is the Municipality? And topography? (in your opinion)

- * What are the approximate waste tonnages (per year / waste type)? (Residual waste, dry recycling, food waste, garden waste)

- How many depots does the Municipality operate from? What waste streams do they serve?

- Is your collection outsourced? Yes / No
  If yes, until when (year) and name of contractor?

- * Are there any national or local policies that have driven you to change to low emission or alternative fuel vehicles? Yes / No
  If Yes please provide details

3 ***Waste & recycling collection fleet***

- * How many and what types of waste and recycling collection vehicles are in your fleet? (Including residual waste, dry recycling, food waste, garden waste, bulky waste)
- * How many of these are low emission or alternative fuel and what type(s) (electric, hydrogen / CNG[1] / hybrid), and what waste types are they used for?

Vehicle payload	Total number - all types	Total number - Low emission	Electric	Hydrogen	CNG / LNG	Hybrid (please describe)	Biofuels (please describe)	Other low emission (please state)	Waste types
Less than 5tonnes									
5-10 tonnes									
10-20 tonnes									
More than 20 tonnes									

[1] CNG includes Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG)

-

4 Low emission vehicles

For each type of low emission or alternative fuel vehicle used (Electric, hydrogen / CNG / Hybrid / Biofuel):

- When were the vehicles acquired?

- * What was the lead time for the vehicles to be delivered from placing the order?

- * What is the make, model and approximate capital cost of each vehicle type?

- Are any of the vehicles part of a trial? Yes / No
  If yes, please provide details.

- * What is the approximate range (distance covered) of each type of the vehicles before refuelling/recharging (km)?

- * How has the vehicle distance range impacted your collection routes?

- * What is the approximate life span of the different types of vehicles?

- What are the total daily hours of operation (per vehicle per day)?

5 Financing / Budgets

- * Did you need to acquire extra budget to fund the vehicles?
  If so, where was this funding from, i.e. corporate borrowing, grants

- Did you purchase the vehicles or are you leasing them?

- * Is the saving in operating costs sufficient to cover the increased capital cost of the vehicles?

6 Fuelling Technology / Infrastructure Requirements

- * How do you fuel / charge the vehicles?

- Where are the fuel / charging points located? How many fuelling / charging points are there in each location?

- * Are there sufficient fuel /charging points? Yes / No
  If no, please provide details (how many more are needed / costs / when will these be installed / constraints)

- * Has additional fuelling / charging infrastructure been required? Yes / No
  If yes, please provide details (what /why / cost / grants)

- * What is the fuel supply availability? Please provide details

- What are the prices of fuel / energy for the low emission vehicles?

- * What is the fuel / energy usage and how this compares to previous vehicles?

- * Do you know the origin of the fuel, or how it has been generated? Please describe

7 Maintenance and Servicing

- * What is the approximate cost and frequency for maintenance and servicing?

- * Is this more frequent and more expensive than standard vehicles? Yes / No
  If yes, please provide an indication of the difference in frequency and cost

- Does your Municipality have any in-house maintenance capability, or is this outsourced?

8 Other Information

- * What are the carbon implications for your Municipality from changing to low emission or alternative fuel vehicles? How are these calculated?

- * What are the other improvements or benefits gained from changing to low emission or alternative fuel vehicles? (e.g. air quality, noise, operating costs, operator working conditions, complaints from the community)

- What are the staff training requirements and health and safety implications of moving to low emission or alternative fuel vehicles?

- Were there any other challenges faced, and if so, what were they and how were they managed?

- * What are the future plans of the Municipality regarding low emissions or alternative fuel vehicles for waste services?

- Does your Municipality have any goals or standards for CO_2, CO, particulates and NOx, including timescales for meeting them? Do these follow any national standards?
  Do you think the goals are achievable? Which technology or energy do you think would be most successful in your country?

- * Do you have any recommendations or advice for others thinking about adopting similar vehicles?

Appendix C
Municipality case studies

ISWA
International Solid Waste Association

Aberdeen City Council, UK

SITUATION

- **Location**
  Aberdeen City Council, Scotland, UK
- **Area**
  185 sq km
- **Population**
  109,000 households (2020)
  Population of 229,000 (2020)
- **Waste generation**
  Approx 98,000 tonnes per year
- **Fleet**
  Waste fleet of approximately 60 vehicles
- **Influencing Policies**
  Hydrogen Strategy (2015-2025) – sets out aims to maintain and build on Aberdeen's progress with the hydrogen rollout, and to become the leading hub in Scotland

HYDROGEN JOURNEY

Aberdeen's hydrogen journey began in 2015, with a fleet of 10 hydrogen fuel cell buses. Following the success of this, the use of hydrogen was expanded to other vehicles such as cars, and more recently, refuse vehicles.

VEHICLE CONVERSIONS

Aberdeen has opted to convert diesel vehicles to hydrogen-diesel combustion hybrids, replacing around 30% of diesel with hydrogen. The first vehicles to be converted were two 2018 standard diesel RCVs. The conversion process was undertaken by ULEMCo.

Three further diesel RCVs (2020 plated) are currently being converted and are due for delivery imminently. Another 17 vehicles are also scheduled for conversion. The long-term plan is for the whole fleet to be using alternative fuels.

The main challenge for the conversion was the placement of the hydrogen fuel tanks, which is determined by the size of the vehicle and chassis length. The 12t vehicles have their tanks fitted to the roof. Smaller tanks were fitted under the chassis of the 18t and 26t vehicles, as fitting standard tanks on the roof made the vehicles too high for some routes.

EXPERIENCE

The original RCV conversions have been running for a number of years with no real operational issues. The driving experience is similar to 100% diesel, other than a slight loss of power when driving up hills. No loss in payload / capacity has been noted.

Training of drivers for the first two vehicles was provided by ULEMCo.

ADDITIONAL VEHICLES

Aberdeen is awaiting the delivery of a new hydrogen fuel cell waste vehicle, this will be a UK first. This is part of the HECTOR project, part funded by Interreg North West Europe and has been developed through Geesink with Hyzon/Holthausen hydrogen fuel cell technology. The vehicle has zero emissions, however, lead times and capital costs are high.

KEY CONSIDERATIONS

- An assessment of fuelling infrastructure will be needed, should the whole fleet be converted.
- Aberdeen has a large fleet and turnover of staff, so ease of use is important.
- Retrofitted vehicles are estimated to offer a 20-30% reduction in carbon emissions due to direct fuel replacement.
- The cost of conversion to hydrogen dual-fuel is relatively moderate compared to a hydrogen fuel cell vehicle, however the emissions savings are limited.

FUELLING

There are two publicly accessible hydrogen filling stations in Aberdeen, one owned by BOC, the other by Aberdeen City Council. Both stations offer hydrogen at 350 and 700 bar.

Green hydrogen is generated from renewable electricity from the grid. The cost of hydrogen is approx. £10/kg, subsidised by the Council to make it comparable with diesel.

The Council has announced bp as its preferred bidder for a commercial partnership to accelerate the city's hydrogen ambitions. The joint venture will see bp operate a green hydrogen production and distribution hub from 2024.

"We need the vehicles to be easy to use for our workforce..."

Information correct as of January 2022

ISWA
International Solid Waste Association

City of Groningen, Netherlands

SITUATION

- **Location**
  Groningen, Northern Netherlands
- **Area**
  198 sqkm
- **Population**
  230,000 (137,000 households)
- **Waste generation**
  Approx. 115,000tonnes per year
- **Facilities**
  Depot which has been adjusted for safe storage of hydrogen vehicles
  Hydrogen fuelling station
- **Collection vehicles**
  Combination of hydrogen and diesel RCVs
- **Influencing Policies**
  Energy Neutral by 2035
  Groningen Carbon Neutral – Emission free inner city by 2025

"Hydrogen is new to everyone, and not everyone will see the advantages in the beginning"

Photographer: Martin Vonk

FLEET

The waste fleet consists of a total 90 trucks, of which 40 are refuse collection vehicles (RCVs). Three of the RCVs are fuelled by hydrogen fuel cells. It is planned to expand the waste fleet to 12 hydrogen-fuelled RCVs in 2022.

The hydrogen vehicles were converted from standard diesel and electric RCVs.

The Groningen hydrogen refuse trucks are supported by **'HyTrEc2', an Interreg North Sea Region project, 'Hector' and Interreg North West project, and 'Revive' & 'HEAVENN', Horizon 2020 projects by the FCH-JU**.

Interreg North Sea Region HyTrEc2
Interreg North-West Europe HECTOR
HEAVENN
REVIVE
FCH FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

Photographer: Martin Vonk

OUR JOURNEY

The transition from gas to green energy started in 2014 due to earthquake concerns in the area from gas extraction, and the aim to be energy neutral by 2035. Groningen is part of the hydrogen valley in northern Netherlands. Green electricity is generated through Groningen's own solar field, in which the 43,000 solar panels (each 280W) generate 12MW of electricity, including surplus which allows for the production of green hydrogen through electrolysis. Hydrogen is compressed into tanks for use at the fuel stations (provided by Holthausen in a private venture).

Hydrogen fuel cells generate electricity within the vehicle to give an extended range over an electric vehicle. The RCVs operate with 4 tanks of 5kg of hydrogen; more tanks could be added, but the trade-off is the loss of payload.

Hydrogen fits in with strategic plans for the region, but the vehicles are less efficient than diesel so a hybrid fleet may be appropriate.

"If we don't do anything, then nothing would happen"

KEY CONSIDERATIONS

- Hydrogen fuel cell vehicles have a longer range than electric vehicles
- Refuelling is fast – currently less than 10 minutes per vehicle
- Hydrogen is a new technology, problems are inevitable and there are few vehicle providers
- Training for mechanics is required
- Invest in fuelling stations and adjustments to depot (hydrogen dangerous to store)
- Long vehicle lead time currently - up to 2 years for vehicle and conversion

COSTS & BUDGET

The capital costs of hydrogen fuel cell vehicles are 2-3 times more than the equivalent diesel vehicle. However, the life expectancy is 15 years with a battery refurbishment needed after 6-7 years, compared to 10 years for diesel. The pump price for hydrogen and diesel are similar.

The Gronigen hydrogen refuse trucks are supported by the European projects The cooperation of these projects has been invaluable for sharing knowledge and finance. It is hoped that the price of trucks will reduce as the demand increases, and EU funding will not be required long term.

Municipality of Kampen, Netherlands

SITUATION

- **Location**
  Kampen, Netherlands
  North-west of Overijssel
  Largest city in the region

- **Area**
  162 sq km

- **Population**
  22,000 households, 54,000 residents

- **Waste generation**
  Residual waste - c.3,300tpa
  Organics – c.6,100tpa
  Dry recycling – c.5,500tpa

- **Facilities**
  HVO100, certified as 100% non-fossil, provided by 4 Orange Gas in the area

- **Influencing Policies**
  Driven by national policy - Netherlands Climate Agreement is for 30-40 city centres to have zero emissions by 2025 (not Kampen)

FLEET

Kampen's waste collection fleet comprises:

6 Refuse Collection Vehicles

2 spare vehicles

All the vehicles run on HVO100 (hydrogenated vegetable oil) except for one vehicle that uses CNG (compressed natural gas).

"…there are no technical issues with HVO, just cost & supply considerations…"

OUR JOURNEY

In 2018, the political direction in Kampen was to transition to electric fleet - this proved challenging, and other low emission fuels were considered to aid the transition.

It was decided locally that CNG was preferable to diesel; following an 18-month lead time a CNG vehicle was received in August 2020. Software issues were experienced for 6 months, meant that drivers were reluctant to use the new vehicle. The issues were resolved and the CNG vehicle is used 2-3 days per week for bulky waste collections.

In July 2020, all remaining diesel vehicles started using HVO50, then subsequently moved to HVO100 a year later. HVO100 is quoted to give 80-90% reduction in carbon compared with diesel.

In the longer term, Kampen's aim is for all vehicles to be hydrogen-electric, using hydrogen fuel cells.

"... with hindsight we wouldn't have purchased a CNG vehicle as HVO has been preferable..."

KEY CONSIDERATIONS

- HVO is a fuel substitution and requires no vehicle modifications, and there is no impact on vehicle warranties
- HVO100 is more expensive than diesel
- No training requirements - drivers just need to remember to fill with HVO instead of diesel!

COSTS & BUDGET

HVO100 tends to cost 15% more than diesel, and the vehicles use approximately 10-20% more HVO100 than diesel.

The future transition to hydrogen fuel cell vehicles is a challenge for a small council with only 6-8 vehicles. The key barriers are vehicle capex and hydrogen fuelling infrastructure.

Currently, it is 20-30km to the nearest hydrogen fuel station, which requires a 2h round trip. The council is also in discussion with the local gas station to provide hydrogen.

Infrastructure is being developed transition to hydrogen-electric vehicles.

New York City, USA

SITUATION

- **Location**
  Department of Sanitation New York City (DSNY), USA

- **Area**
  472 sq km

- **Population**
  3.2 million households (2015-2019)
  8.4 million residents (2019)

- **Waste generation**
  10,000 US tons/day refuse (c.9,000tonnes/day)
  2,000 US tons/day recycling (c.1.8tonnes/day)

- **Fleet**
  Approximately 6,000 vehicles of which over one third are waste collection vehicles
  All refuse vehicles are multifunctional, and are also used for snow clearance

- **Influencing Policies**
  A prior mandate in New York City required 80% reduction in GHGs of overall fleet by 2035, from the 2005 baseline.

  This has now been updated by Executive Order 53, which states that all vehicles must be electric by 2040.

FLEET

DSNY has been trialling electric vehicles for nearly 9 years. Since September 2020, DSNY has been trialling the following vehicle:

Mack LRe @ 72,000 lbs GVW – otherwise identical to DSNY's other refuse collection vehicles

DSNY plans to order 7 new Mack LRe units to continue testing, which are due to arrive by the end of 2022.

Partnership with Effenco for start-stop vehicle engine technology – DSNY has 26 vehicles fitted but would like more as an interim technology while electrifying the fleet - Can achieve 30% reduction in fuel usage

"...infrastructure is the key ..."

OPERATIONAL EXPERIENCES

Trialling of the vehicle has only taken place in more central areas of New York City, where the terrain is largely flat. When more electric vehicles are received, these will be tested in areas such as Staten Island and The Bronx, where the topography is much hillier.

Crews had good first impressions of the vehicles due to its high torque, responsive nature and ability to carry the necessary payload. From a safety aspect, the vehicle is much quieter than diesel, enabling the crew to hear each other better, and be more aware of their surroundings.

The truck used for the pilot is now being tested for its snow ploughing capabilities throughout the winter period.

"...Should have started the infrastructure assessment earlier – charging infrastructure is a limiting factor ..."

VEHICLE CHARGING

- Partially-renewable electric power is generated from a combination of hydro and natural gas
- Currently have 13 DC fast chargers in 7 different locations across the City
- If the trials continue to be successful, up to 300 electric refuse vehicles could be introduced each year. Therefore, much more investment in charging infrastructure would be required

COSTS & BUDGET

- A rear-loading electric vehicle costs $550,000 in comparison to the diesel equivalent of $360,000 – this increased capex is much smaller than in other parts of the world
- Power is very expensive depending on the location. Charging infrastructure capex can be between $35,000 - $40,000
- Annual capital budget of $160 million, but it has been difficult to secure vehicles due to Covid-19
- DSNY is hopeful that there would be grant money available to purchase these vehicles, through the Federal EPA, State Funding, the Diesel Emissions Reduction Act (DERA) etc.

Rotterdam City Council, Netherlands

SITUATION

- **Location**
  Rotterdam, Netherlands
- **Area**
  324 sqkm
- **Population**
  650,000 residents
- **Waste generation**
  c.252,000 tonnes per year
- **Facilities**
  Two depots where electric vehicles are charged
- **Collection**
  Collect five different waste streams – glass, textiles, paper, organic waste and general waste
- **Influencing Policies**
  All Council vehicles to be zero emissions by 2030, with staged targets:
  - 2023: all personal vehicles to be emission free
  - 2025: all light vehicles to be emission free
  - 2030: all heavy vehicles to be emission free

  Political preference for electric vehicles

FLEET

As of 2021, Rotterdam City Council has three electric refuse vehicles within the fleet:

2 Electric Rear-Loading Collection Vehicles

1 Electric Vehicle fitted with a crane – for emptying underground containers of $5m^3$

There are currently 91 other vehicles used for Rotterdam's waste collection service, all of which use diesel fuel. When these reach their end of life, they will be replaced with electric vehicles.

"...adopting a slow and steady approach to fleet development..."

OUR EXPERIENCE

The waste collection service in Rotterdam operates in two shifts, however the electric vehicles only operate one, as they don't have enough battery capacity. This is also not a full shift due to battery capacity. There are also route planning implications as the electric vehicles have a lower range than diesel vehicles

The range of the electric vehicles has not been as great as their diesel counterparts. The rear-loaders and crane vehicle have ranges of 130km and 70km respectively, but ideally, this would need to double. However, electric vehicle battery capacity has improved over the last few years. Battery technology is developing all the time, so there is hope that by the time the full fleet is electrified, the battery capacity will be even more efficient.

No additional training was required for the crew, and they have reported good experiences with the electric vehicles due to their good acceleration capabilities and responsiveness.

It is expected that the electric refuse vehicles will have a longer life span and that the total life cost of these vehicles will be lower than their diesel equivalent, as there are fewer moving parts creating wear and maintenance needs.

INFRASTRUCTURE

There is currently enough power to allow for these three vehicles to charge, via overnight chargers (22kW/hour) or DC chargers (100kW/hour).

One of the two depots also has a 600kW battery which stores surplus electricity, this will aid Rotterdam in purchasing more vehicles. However, with aims to buy another 5 eRCVs in the next year, infrastructure must be developed further as the electricity supply is not sufficient to charge many more vehicles.

In addition to the higher capital cost of electric vehicles, the infrastructure needed to charge the vehicles will be expensive. Enhancing the electricity supply at one of the depots is likely to involve significant cost.

CARBON SAVINGS

- Estimated saving of 43 tonnes of CO_2 per year has been made per vehicle for the electric rear-loading vehicles
- Estimated saving of 73 tonnes of CO_2 per year for the crane vehicle

ISWA
International Solid Waste Association

Shenzhen, China

SITUATION

- **Location**
  South of Guangdong Province (coastal, adjacent to Hong Kong); major sub-provincial city, known as the Silicon Valley - 4th largest city in China

- **Area**
  Approximately 1,990 sq km

- **Population**
  Overall 17.56 million (2020)
  (Contract covers a population of 2 million people, 10% of overall city area)

- **Waste generation**
  1,800 t/day

- **Facilities**
  Public charging points located near to secure company parking facilities

- **Collection**
  Food, kitchen and mixed general waste

- **Influencing Policies**
  – China's first Special Economic Zone Developed as an Eco-City
  – China's first climate commitment and sustainable transport policies
  China's first carbon trading pilot program

FLEET

Waste collection is outsourced to INFORE Environment, whose fleet for the collection of approximately 2 million people comprises 197 vehicles:

64 Refuse Collection Vehicles (31t) - diesel

133 smaller vehicles (7t) - electric

The electric vehicles are used for food and kitchen waste and for mixed general waste collection. The electric vehicles are produced by Changsha Zoomlion Environmental Industry Co., Ltd.

**"...over the whole of the life cycle,
it is cheaper
to have electric vehicles..."**

KEY CONSIDERATIONS

- Electric vehicles require fire risk and charging awareness but no special driver training
- Battery life / range of electric vehicles

OUR JOURNEY

Two years ago, Shenzhen outsourced its waste collection and street cleansing contract to Changsha Zoomlion Environmental Industry Co., Ltd, a wholly-owned subsidiary of INFORE Environment. This public-private partnership (PPP) contract is for 10% of the city area, approximately 2 million people.

The smaller (7t) vehicles are 2 years old and all electric to meet national/local policies and carbon targets. The vehicles are charged overnight at social (public) charging points, and parked in nearby company car parks. Quick top-up charges are also undertaken around the city during the day by the drivers, using power from the national grid.

The electric vehicles operate for 6h, plus 2h travel time to the start of the round. The fleet operates on single or double shifts – the second shift will start with the vehicle being charged.

Through the contract, it is planned to convert the entire waste collection fleet to electric over the next 3 – 5 years. The challenge is the range of the larger vehicles is only 200km before requiring charging, and 130km for the smaller vehicles.

COSTS & BUDGET

The annual waste collection service cost for the contract is RMB 520 million ($81 million). The contract duration is 15 years, and the electric vehicles were introduced early in the contract.

The PPP contractor manufactures and supplies the vehicles. Shenzhen is also unique in its internal infrastructure and its concentration of high-tech companies, which have helped to facilitate its network of public charging points for electric vehicles that the smaller vehicles utilise.

The service costs of the electric vehicles are about 25% of the diesel equivalent and if driven well there are no additional maintenance costs.

"… electric vehicles are preferred by the crews, as easier to drive, and has less noise & vibration…"

Information correct as of December 2021

City of Toronto, Canada

SITUATION

- **Location**
  City of Toronto, Canada
- **Area**
  630 sq. km
- **Population**
  6.7 million residents
- **Waste generation**
  Approx. 900,000 metric tpa - Residual waste, recycling, food waste and garden waste (seasonal), household hazardous waste etc.
  Diversion of approx. 170,000 tpa food waste landfill
- **Influencing Policies**
  City Council declared a Climate Emergency in October 2019

  Toronto have TransformTO targets to reduce greenhouse gas emissions by 65% by 2030 and to be net-zero by 2050.

FLEET

Toronto's waste fleet historically consisted of 201 Class 7/8 diesel vehicles.

As many of these reached the end of life in 2013/14, a business case was developed to replace them with natural gas vehicles. This resulted in savings on fuel costs, lower emissions and quieter vehicles.

Through improved operational efficiency, the fleet now consists of 179 natural gas vehicles. This resulted in savings on fuel costs, lower emissions and quieter vehicles.

"...there is no reason why this technology could not be introduced worldwide..."

CLOSING THE LOOP WITH RNG

The Council's business case for the change to natural gas vehicles included the future consideration of biogas recovery from its Organics Processing Facilities (OPF), pre-processing followed by AD.

Instead of just flaring the biogas at its OPF, breaking down biogas to carbon dioxide, Toronto wanted to explore how to biogas could be better used and look at a closed loop approach.

The City installed biogas upgrading equipment facility at one of its organics processing facilities as part of a 15-year contract with the local utility provider. This allows the City to capture the biogas, upgrade it into renewable natural gas (RNG) and then inject it into the natural gas grid, thus moving the RNG anywhere in the City.

The Dufferin OPF and RNG Facility was fully commissioned at the end of 2021 and processes 55ktpa of organics, producing 2.9 million m^3 of RNG per year.

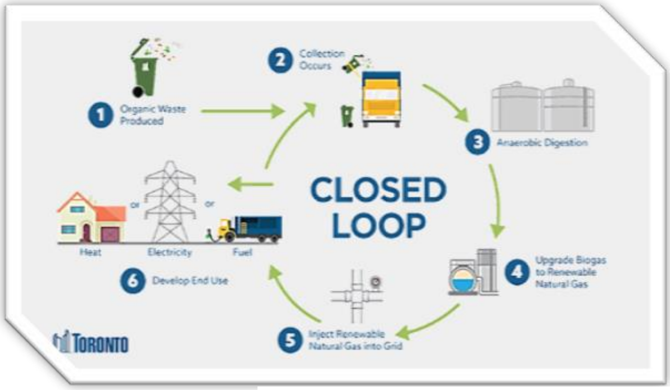
The second RNG facility, with a production capacity of 4.6 million m^3 of RNG per year is likely to be operational in 2023. The associated OPF was commissioned in 2014, and is currently processing 75ktpa of organics per year, with the biogas going to flare.
Both of these biogas plants are estimated to reduce GHG emissions by over 14,500t eCO_2 per year.

The RNG produced at these will be stored in the distribution network, and then blended in 2023 with the natural gas that the City bulk purchases, to create a low-carbon fuel blend.

For the waste collection fleet, vehicle filling stations for NG/RNG have already been built at various collection yards to service the fleet on site.

KEY CONSIDERATIONS

- The RNG/NG blend will be used to fuel waste collection vehicles, vehicles from other departments, and to provide heating for the City of Toronto Council buildings
- "Socialising" the cost of the RNG blend across all City departments will help Toronto to become carbon neutral by 2050, while reducing the incremental cost for divisions



Closed Loop System (Toronto City Council)

COSTS

When the vehicles were being replaced, the capex of a natural gas vehicle was approximately $40k-$50k more than the diesel equivalent. However, the cost of natural gas was almost $1/litre less than diesel. This helped off-set the incremental cost over the life of the vehicle.

The CAPEX and OPEX to produce RNG at Dufferin is approx. $0.84/litre, which is more expensive than the cost of natural gas. However, once this is blended, it is only $0.02-$0.05/litre more than NG, depending on the volume of NG the cost is socialised across.

This marginally more expensive fuel will aid Toronto in meeting its TransformTO goals and becoming carbon neutral by 2050.

Westminster City Council, London, UK

SITUATION

- **Location**
  London, England
  City Centre
- **Area**
  21 sqkm
- **Population**
  120,000 households, 220,000 residents
- **Waste generation**
  192,000 tonnes/year residual
  28,000 tonnes/year recycling
  Food waste being rolled out across the city
  No garden waste service
- **Facilities**
  2 main depots (waste)
  10 small depots (street cleansing)
- **Collection**
  Outsourced to Veolia until 2024
- **Influencing Policies**
  Some of the streets in Westminster have significantly high levels of carbon emissions and high air pollution levels
  2015-2020 Greener City Action Plan
  2018 Air Quality Manifesto
  2019-2024 Westminster City Council Air Quality Action Plan
  2030 Carbon neutral
  2021/22 City for All strategy

FLEET

Westminster City Council committed to converting its entire diesel fleet of 226 vehicles to electric by 2030. In 2021 low emission vehicles included:

3 Electric Refuse Collection Vehicles (eRCVs)
2 Electric 10-20t Waste/Recycling Vans
65 Electric & hybrid Street Cleaners

"...ensure charging infrastructure is viable before committing to electric vehicles..."

The comments contained in this summary are those of Edward Yendluri as Project Manager for the electrification project rather than Westminster City Council's views

KEY CONSIDERATIONS

- Sufficient electric vehicle charging infrastructure & power supply
- High upfront capital costs
- Technical reliability on electric vehicles means any vehicle failure results in no cleaning or waste services which is a statutory requirement

OUR Fleet Electrifications JOURNEY

Westminster City Council (WCC) in partnership with Veolia, have tested various alternative fuel technologies such as HVO, CNG, Hydrogen and battery powered waste trucks to address its waste fleet emissions. WCC secured funding from the Innovate UK and launched two major fleet trials H2 powered trucks and upcycling old refuse trucks to fully electric.

H2: In this project a two-diesel truck were retrofitted with Hydrogen cylinders and H2 was generated on a small scale and got injected into the diesel ICE to increase fuel efficiency and reduce emissions however the reliability of H2 supply was a significant risk which made the vehicles availability to just over 50% during the trial period.

Upcycling: WCC in partnership with Magtec, Veolia and Sheffield Council, upcycled two end of life diesel trucks to fully electric. This was a great success and vehicles are still in use in WCC. In 2021, Dennis Eagle is the only supplier, but Mercedes should be an option soon.

Calculating the Carbon footprint of waste services by km per litre / km travelled and switching to tail pipe **zero emission vehicles have over 90% less carbon impact than diesel vehicles**

COSTS & BUDGET

Over 7-8 years life span of the vehicles TOC, electric trucks are cheaper than diesel RCV's. eRCVs require greater upfront capital (c£450,000 per vehicle with a quarter being battery costs), whilst diesel have higher operating costs (c£360,000 per vehicle).
Typical maintenance costs for eRCV are £10,000 - £13,000 year, similar to diesel. Staff require electric vehicle and charging infrastructure training.

Depots depending on grid energy can be challenging, particularly if urban located. eRCVs require 22KW & 44KW chargers based on their specification can operate both AC and DC. Costs c£25,000 per 44kw charging point, reducing if more are installed.

"...be brave & trial electric vehicles to check your requirements & consider leasing the batteries where possible..."

Information correct as of November 2021