Document 2 – Introduction to EV Charging

In this document the key basics to Electric Vehicle (EV) charging infrastructure will be explained in order to give the reader the necessary foundation of knowledge to understand and work with more complicated topics.

1 EV Charging System

The purpose of EV charging infrastructure is to supply electricity to an EV in order to supply energy to a rechargeable battery, which requires Direct Current (DC) electricity to charge. The systems differ in the type of electricity that is supplied from the chargepoint to the vehicle. Both shall be described below using the typical arrangement with the chargepoint connected to a local domestic or commercial electrical system connected to the electricity distribution network.

1.1 AC Charging System

In an Alternating Current (AC) charging system, the chargepoint supplies AC electricity to the vehicle. Most EVs are fitted with an on-board charger to rectify AC electricity to DC. The DC energy is then supplied to the vehicle’s Battery Management System and subsequently the battery.

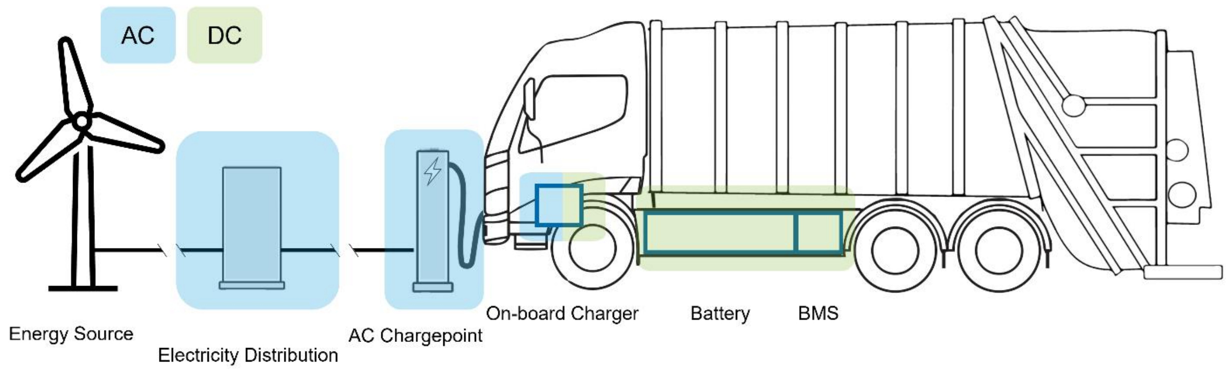


Figure 1: AC Charging System

AC Charging Power

AC charging systems can be either single or three-phase; in a single-phase system the power transfer is done by a single conductor in the chargepoint, charging cable and EV whereas in a three phase system there will be three, with the voltage and current separated by 120° phase angle. In the UK the single-phase electricity voltage is 230 V and the three-phase electricity voltage is 400 V.

The maximum charging power of the system depends on the rating of the chargepoint, the rating of the vehicle’s on-board charger (OBC) and the number of supply phases for each. Typical power ratings are shown in Table 1. Note that the classifications are not standardised, this is the terminology used by Cenex.

Table 1: AC Charging Powers using Type 2 Standard

	Chargepoint Input Voltage	Chargepoint Output Phases	Chargepoint Output Current	Chargepoint Rated Output Power	Comment[1]
Slow	230 V	Single-phase	16 A	3.7 kW	Low power – not suited for refuse vehicles.
Standard			32 A	7.4 kW	Unlikely to be suitable for low power vehicles unless no three-phase electricity
Fast	400 V	Three-phase	16 A	11 kW	Three phase power more suited for refuse vehicles, 22 kW likely to be preferred.
			32 A	22 kW	
Rapid	400 V	Three-phase	60 A	43 kW	Rarely used

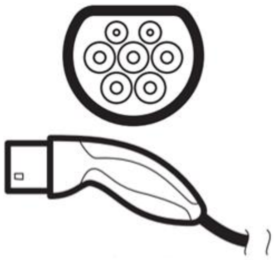
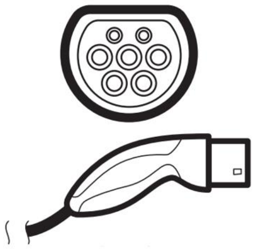
AC Charging Standards

“Type 2” charging is the dominant standard for AC EV charging in the UK. As AC charging is typically relatively low power (< 22 kW), there are two options for physically connecting to AC chargers:

1. The EV is connected by a cable that is kept with the vehicle and is fully disconnected from the chargepoint (and the vehicle) when not in use. This option is most common for public AC charging as it reduces the likelihood and impact of vandalism or accidental damage.
2. The chargepoint has its own hard-wired “tethered lead” which is kept with the chargepoint. This option is more convenient for the EV user and is most common for domestic or private workplace or depot-based charging locations.

[1] The suitability of each charging power will be discussed further in a future guidance document.

Table 2: AC Charging Standards

	Chargepoint		Vehicle	
	Chargepoint	Connector	Connector	Vehicle
Option 1	 Female Socket	 Male plug	 Female plug	 Male Socket
Option 2	 Tethered lead			

Note that the E-one eRCV charges using industrial commando sockets (BS EN 60309) at 43 kW. This is not an EV charging standard and therefore has limited functionality – load management, a key technique for managing charging at depots (to be explained in a following document), for example will not be possible - and is not recommended as a permanent solution.

1.2 DC Charging System

In a Direct Current (DC) charging system, the chargepoint performs the rectification process to convert AC input to DC which is supplied to the vehicle. This avoids any limitation in power from the vehicle's on-board charger (OBC), which is designed to be lightweight and low-cost, and bypassed in DC charging. Therefore DC charging is used for higher power transfer. As a result, DC chargepoints are typically larger, heavier and more expensive than AC chargepoints.

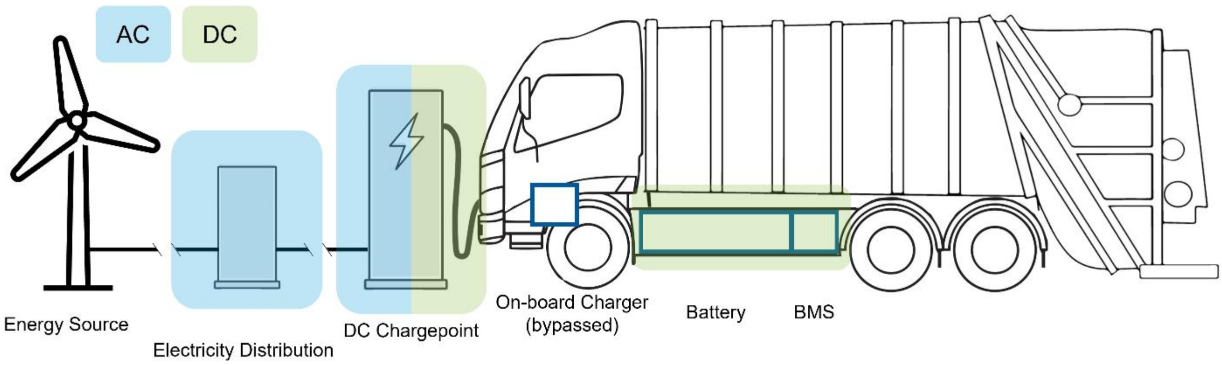


Figure 2: DC Charging System

DC Charging Power

The maximum charging power of a DC system will also be limited by either the rating of the chargepoint itself or the vehicle electronics. Due to the high input currents involved, where connected to an AC input, DC chargepoints require a three-phase supply[2].

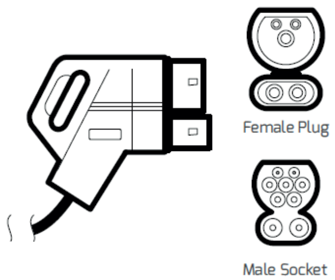
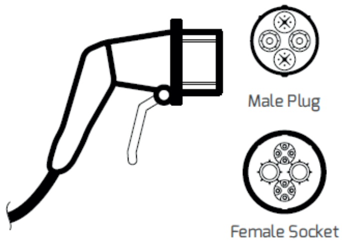
Table 3: DC Charging Power

	Power	Comment[3]
Rapid	50 kW	Most vehicles with a DC charging inlet will be capable of charging at a minimum of 50 kW.
Ultra-Rapid	150 kW	There are currently few available EVs that can charge at 350 kW.
	350 kW	

DC Charging Standards

For DC charging there are two standards used in the UK, CCS and CHAdeMO, shown in Table 4:

Table 4: DC Charging Standards

CCS (Combined Charging Standard)[4]	CHAdeMO
	
	
The CCS standard integrates two DC pins to the Type 2 AC standard and therefore both Type 2 AC and CCS DC charging is achieved with the same inlet.	The CHAdeMO standard is not integrated. The above image shows the Type 2 AC and CHAdeMO DC standard side by side on a Nissan Leaf.
CCS is the most dominant DC charging standard in the UK and Europe and is seeing use by larger vehicles such as refuse collection vehicles.	CHAdeMO is only used by Japanese manufacturers such as Nissan and Mitsubishi. However even Nissan are using CCS for more recent EVs such as the Ariya.

[2] It is also possible to connect DC chargers with a DC input – this will be discussed in a future document.

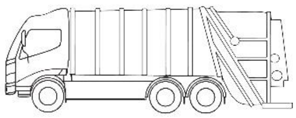
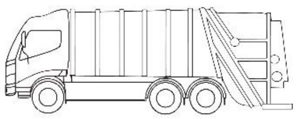
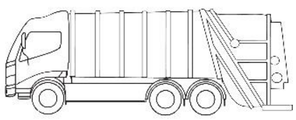
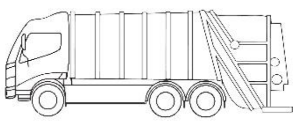
[3] The suitability of each charging power will be discussed further in a future guidance document.

[4] Formally "CCS Combo 2" to indicate that the DC charging is combined with a Type 2 connector. Combo 1 also exists but is not used in the UK and Europe.

2 System Charging Power

The maximum charging power delivered to the vehicle depends on the limiting factor in the system/ This can be either the chargepoint or the vehicle, as illustrated in Table 5 which includes charging specifications provided by manufacturers for a number of example eRCVs:

Table 5: Charging System Power

	Standard 7 kW AC (32 A single-phase)	Fast 11 kW AC (16 A three-phase)	Fast 22 kW AC (32 A three-phase)	Rapid 50 kW DC	Ultra-Rapid 350 kW DC
Terberg Kerbloader / Electra  AC Charging: 22 kW[5] DC Charging: N/A	7 kW	11 kW	22 kW	N/A	N/A
Dennis Eagle eCollect  AC Charging: N/A DC Charging: 40 kW	N/A	N/A	N/A	40 kW	40 kW
Romaquip  AC Charging: 22 kW DC Charging: 100 kW	7 kW	11 kW	22 kW	50 kW	100 kW
RVS EMOSS e-One  AC Charging: 22 kW[5] DC Charging: 150 kW	7 kW	11 kW	22 kW	50 kW	150 kW

[5] 44 kW AC charging also available on Terberg Kerbloader and RVS EMOSS E-One, however this is achieved using commando connectors which is not a recommended permanent EV charging infrastructure standard.

3 Charging Profiles

EV manufacturers will advertise a charging power for its AC and/or DC charging system. Unfortunately, and somewhat confusingly, when an EV is charged it will not be done at this power constantly for the duration of the charge. As an example, if you connect a compatible EV with an empty 100 kWh capacity battery to a 22 kW AC chargepoint and charge for four hours, you will almost certainly have a battery that is charged to less than 88 kWh at the end of the session.

The fact that charging power is not constant is very important to consider when designing any charging system to ensure that the charging infrastructure selected and the time for charging to meet operational requirements are satisfactory.

Firstly, the EV manufacturer's advertised charging power (such as those used in Table 5) will be the vehicle's rated charging power. This should be the maximum charging power achievable however in some cases the actual maximum power achievable will differ.

However, more importantly, even if the advertised charging power is accurate, the average charging power – particularly for higher powered charging - will vary as a result of a number of variables. The most important of these are:

1. The battery state of charge (SOC) at the start and end of the charging session. For eRCVs, these will depend on the battery pack size and the required energy of the vehicle's daily operations.
2. Any limitations placed on the charging process by the vehicle's BMS in order to protect the battery. This is most likely to occur for higher powered charging.

Exact charging profiles vary between vehicles. In general the charging session will have a ramp up at the start of the charging session and a ramp down at the end, with power often reduced to protect the battery at high (>80%) SOC. Charging also becomes less efficient (and therefore more costly) at high levels of SOC. In addition, deep cycling between very high (>80%) and very low (<15%) SOC can adversely affect battery health.

A typical charging profile for an EV will have the following shape:

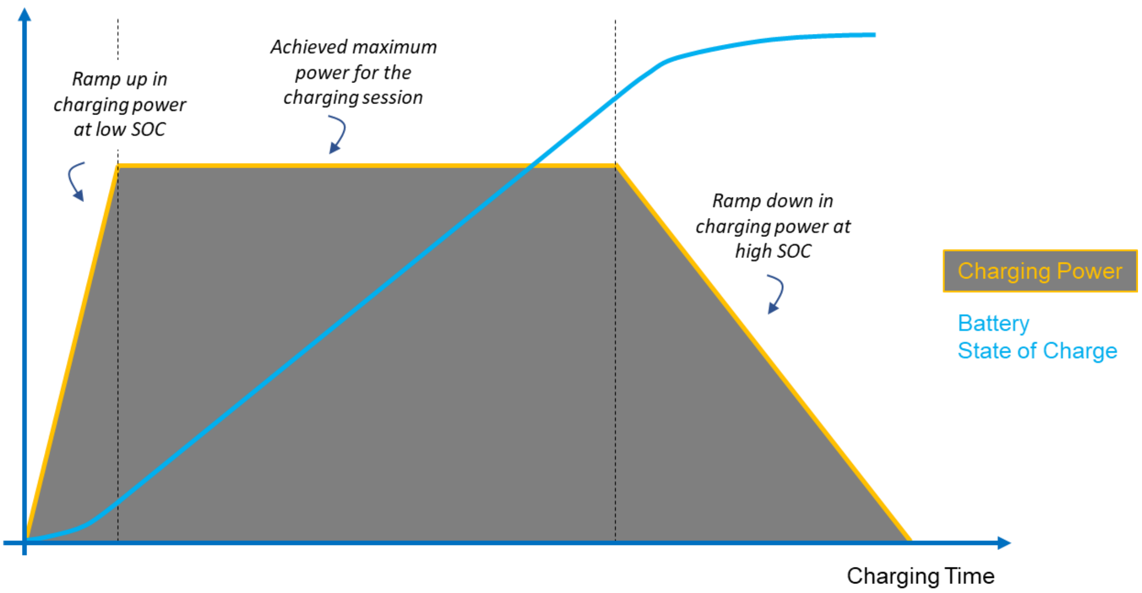


Figure 3: Example EV Charging Profile

From early data collected from the Newport's Dennis Eagle eCollect's charging behaviour, it appears that at 40 kW the charging is not derated even when the battery state of charge exceeds 80%. The following real charging sessions show the 40 kW DC advertised charging power maintained until the battery is almost fully charged (>95%).

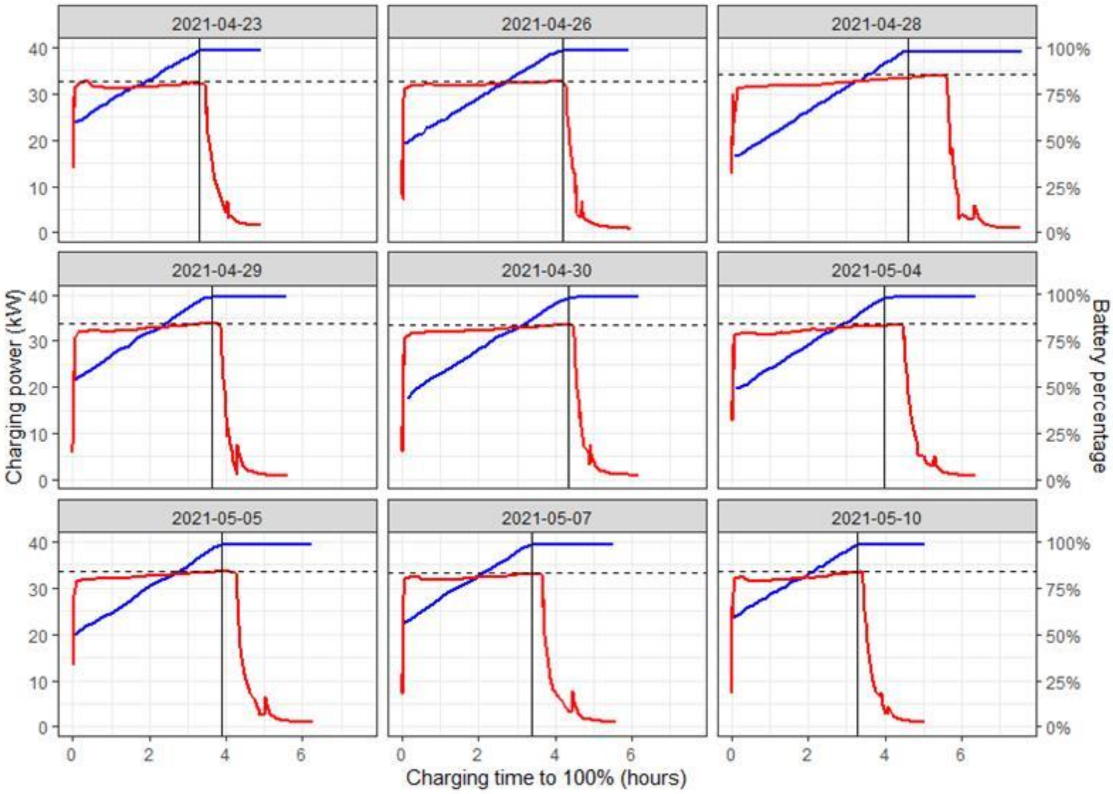


Figure 4: Example Dennis Eagle eCollect Charging Sessions

This sustained charging at the advertised power is most likely because the charging power (40kW) is still modest relative to the size of the battery pack (300 kWh). It is anticipated that for eRCVs which are compatible with higher charging power charging, the charging power would be derated once the battery reaches a high SOC, as per Figure 3.

Cenex makes the following recommendations:

1. Speak to the eRCV supplier to understand whether the advertised charging power is representative of the actual achievable maximum charging power and what the charging profile will be for the anticipated charging behaviour.
2. Understand any limitations of the charging infrastructure and ensure chargepoints are installed as per manufacturer's instructions (for higher power equipment that require ventilation installing in a confined space could result in reduced power due to overheating).
3. If possible, specify vehicles with battery sizes that can operate between 15-80% SOC. This will not only reduce any anxiety associated with running at low SOC but increase charging efficiency and allow you to more easily predict the time taken to charge.
4. In absence of any specific information from the manufacturer, assume an additional 25%[6] in charging time (equivalent to assuming average power is 80% of the rated power). For example, if 200 kWh is required and the advertised vehicle charging power is 50 kW, allow for five hours to charge rather than four.

> It is imperative that the effect of average charging power is accounted for when designing an operationally critical EV charging system.

[6] This is a conservative value to use in the absence of data. If SOC is between 15-80% then the average charging power can be close to the rated power and therefore a smaller percentage used.

4 Charging Power as Range or Operational Hours

The charging power in kW is not overly informative when planning and deploying charging infrastructure.

The range or operational time added per hour of charging varies massively depending on the vehicle being charged and its operations. For example, a passenger car or light commercial vehicle might achieve a driving efficiency around 0.3 kWh/mile whereas early data collected from the Welsh fleet suggests the number for refuse collection vehicles is between 4 and 8 kWh/mile due to the vehicle size, weight, the stop-start nature and low average speed of its driving, and the power draw from auxiliary loads.

It is therefore more useful to think of the miles of range added for the specific vehicle type. Figure 5 shows this assuming 16 hours available for charging overnight at the depot. Note that the range added is reduced by 25% to account for the effects discussed in section 0 as per the following equation:

$$Range\ Added\ (miles)^{7} = \frac{16\ (charging\ hours) \times Charging\ Power\ (kW)}{1.25 \times Driving\ Efficiency\ (kWh/mile)}$$

Output Value: Miles of range added
Charging time: Maximum, 16 hours
25% safety factor applied

Charging Power (kW)	Driving efficiency (kWh/mile): 8	7	6	5	4
7	11	13	15	18	22
11	18	20	23	28	35
22	35	40	47	56	70
50	80	91	107	128	160
150	240	274	320	384	480
350	560	640	747	896	1120

Figure 5: Miles of range added by charging power and vehicle driving efficiency

As it is the more "efficient" vehicles that perform the longer routes, it is perhaps more useful to think about the charging output as the amount of operational time in hours added by charging and consider driving efficiency in terms of the energy required per hour of operation. From data obtained the driving efficiency of Welsh eRCVs varies from 14-24 kWh per hour of operational time. Here the desired output is for 8 hours of operational time as a minimum for all vehicle driving efficiencies.

$$Operaional\ Time\ Added\ (hours) = \frac{16\ (charging\ hours) \times Charging\ Power\ (kW)}{1.25\ \times Driving\ Efficiency\ (kWh/hour)}$$

[7] Charging power is the rated power or advertised charging power of the system, 1.25 factor included to account for reduced charging power.

Output Value: Operational time (hours)
Charging time: Maximum, 16 hours
25% safety factor applied

Charging Power (kW)	Driving efficiency (kWh/hour) 24	22	20	18	16	14
7	4	4	4	5	6	6
11	6	6	7	8	9	10
22	12	13	14	16	18	20
50	27	29	32	36	40	46
150	80	87	96	107	120	137
350	187	204	224	249	280	320

Figure 6: Hours of operation added by charging power and vehicle driving efficiency

What these charts show is that to be useful for overnight depot charging of Welsh eRCVs - for which 8 hour shifts of typically 20-30 miles is representative - AC charging at 22 kW is likely to be useable. In addition, for vehicles with lower driving efficiency (due to either the vehicle itself or the operations it performs) and/or longer operational routes higher power DC charging may be required.

This concept will be discussed further in a subsequent document.