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Guidance

Post-combustion carbon dioxide capture: emerging techniques

Emerging techniques on how to prevent or minimise the environmental impacts of post-combustion carbon dioxide capture.

From: **Environment Agency (/government/organisations/environment-agency)**

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Applies to England, Northern Ireland and Wales

Guidance for Scotland (https://www.sepa.org.uk/regulations/climate-change/carbon-capture-and-storage/)

Contents

Emerging techniques are novel techniques for an industrial activity that, if commercially developed, could provide one of the following:

- a higher general level of protection of the environment
- at least the same level of protection of the environment and higher cost savings than existing best available techniques

You can fit post-combustion carbon capture (PCC) plants to new or existing power and energy from waste (EfW) plants to capture the carbon dioxide (CO_2) in the flue gas.

The CO_2 can be either:

- stored in permanent underground geological storage facilities
- used as a product

These environmental regulators (referred to as 'the regulators') worked with the UK CCS Research Centre (https://ukccsrc.ac.uk/), industry and other stakeholders to develop an 'evidence review (https://ukccsrc.ac.uk/best-available-technology-bat-information-for-ccs/)' which informs this guidance:

- Environment Agency
- Natural Resources Wales
- Northern Ireland Environment Agency (an executive agency of the Department of Agriculture, Environment and Rural Affairs)

Except where regulations apply, this guidance for emerging techniques is not a regulatory requirement but identifies best practice to address important environmental issues.

The regulators expect operators to follow this guidance, or to propose an alternative approach to provide the same or greater level of protection for the environment.

> For carbon capture developments in Scotland, use the Scottish Environment Protection Agency (SEPA) guidance on carbon capture and storage (https://www.sepa.org.uk/regulations/climate-change/carbon-capture-and-storage/).

1. Who this guidance is for

This guidance is for:

- operators when designing their plants and preparing their application for an environmental permit
- regulatory staff when determining environmental permit applications
- any other organisation or members of the public who want to understand how the environmental regulations and standards are being applied

The guidance covers both new plants and retrofits to existing plants.

This guidance covers PCC plants that use amine-based technologies to capture CO_2 from the flue gases of:

- power and combined heat and power (CHP) plants fuelled by natural gas and biomass
- EfW plants

The guidance does not include carbon capture for use, though much of this guidance is relevant where you use post combustion capture solvents such as amines.

When you apply for an environmental permit (https://www.gov.uk/guidance/check-if-you-need-an-environmental-permit) for this activity, you must tell your regulator whether you are going to follow this guidance. If not, you must propose an alternative approach which will provide the same or greater level of protection for the environment.

In England, Wales and Northern Ireland these installations are permitted under the:

- Environmental Permitting (England and Wales) Regulations 2016
- Pollution Prevention and Control (Industrial Emissions) Regulations (NI) 2013

For environmental permitting purposes, a PCC plant is a Part A (1) 6.10 (a) activity in its own right when the CO_2 is being captured for geological storage. It could also be a directly associated activity with a combustion activity installation when the CO_2 is captured and used for other purposes.

The guidance is informed by an evidence review (https://ukccsrc.ac.uk/best-available-technology-bat-information-for-ccs/) which summarises the available evidence. This guidance refers to relevant sections in the evidence review.

The large combustion plant (LCP) BAT reference document (BREF) (https://eippcb.jrc.ec.europa.eu/reference/large-combustion-plants-0) identifies carbon capture as an emerging technique but does not address all the potential effects of carbon capture, and it is not listed in the waste incineration (WI) BREF (https://eippcb.jrc.ec.europa.eu/reference/waste-incineration).

Where BAT for an activity is not addressed in existing BREFs or where all the potential environmental effects are not addressed, the regulators must follow Article 14(6) of the Industrial Emissions Directive (IED) (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32010L0075&from=EN#d1e1666-17-1).

This means that the regulators must set permit conditions covering emission limit values (ELVs) together with other permit conditions. These conditions must be based on the regulators own assessment of emerging techniques using the criteria listed in Annex III of the IED (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32010L0075&from=EN#d1e32-57-1). The regulators consulted industry and other stakeholders when developing the evidence review (https://ukccsrc.ac.uk/best-available-technology-bat-information-for-ccs/) on which this guidance is based.

Permit conditions must also protect the environment by setting conditions to ensure operators do not breach any environmental quality standards (Article 18 of the IED (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32010L0075&from=EN#d1e1918-17-1)).

If you operate a large combustion plant, you will need to comply with the:

- IED Chapter III Annex V ELVs (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32010L0075&from=EN#d1e32-59-1)
- BAT associated emission limits (BAT AELs) identified in the LCP BAT conclusions (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017D1442&from=EN)

If you operate an energy from waste plant, you will need to comply with the:

- IED Annex VI ELVs (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02010L0075-20110106)
- BAT AELs identified in the WI BAT conclusions (https://eippcb.jrc.ec.europa.eu/reference/waste-incineration-0)

Your regulator may grant a temporary derogation (https://www.gov.uk/guidance/best-available-techniques-environmental-permits) of BAT-associated emissions levels (BAT AELs) for up to 9 months, on the basis that carbon capture is testing and using an emerging technique (see Article 15(5) of IED (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32010L0075&from=EN#d1e1802-17-1)). (Derogation means having less strict emission limit values in the permit than the emission levels associated with the best available techniques.) You should discuss this with your regulator if this is likely to apply.

Your regulator will make a decision on the emission limits and other permit conditions that will apply on a case-by-case basis. They will do this based on the elements outlined in this guidance and the most appropriate source of reference.

2. Power plant selection and integration with the PCC plant

2.1 Energy efficiency in plants with PCC

You must maximise the thermal energy efficiency of the plant and of the supply of heat for the associated PCC plant.

You should refer to the LCP BREF (https://eippcb.jrc.ec.europa.eu/reference/large-combustion-plants-0) or waste incineration BREF (https://eippcb.jrc.ec.europa.eu/reference/waste-incineration-0) which give BAT definitions (BAT AELs) for the efficiencies of new and existing plants. Also refer to section 4.13 of the IED environmental permitting regulations guidance on Part A installations (https://www.gov.uk/government/publications/environmental-permitting-regulations-guidance-on-part-a-installations).

For natural gas power plants, lower heating value efficiencies of 60% or above without CO_2 capture are reported in the LCP BREF to be achievable for large-scale new combined cycle gas turbine installations.

New biomass power plant efficiencies will depend on:

- the size and type of boiler
- whether you use sub- or super-critical steam conditions

You can reduce the impact of adding PCC by using power plant technologies that have the highest thermal efficiencies, since these have low specific CO_2 emissions (tonnes CO_2 per megawatt hour).

If you expect to use more fuel to meet the heat or power needs of PCC, you should select the most efficient power plant technologies for that fuel and capture any additional CO_2 from that process.

You should apply fuel input, electricity output and CO_2 emission metrics in the same way as you would to a power plant with fully integrated PCC (see section 2.3 on supplying heat and power for PCC operation).

2.2 Dispatchable operation

In line with the needs of a UK electricity system with a large amount of intermittent renewable generation, all thermal power plants, including those with CO_2 capture, are likely to be dispatchable.

This means that the power plant operator can be asked to operate the plant at any required output, up to its full load, at any time, and sustain this output indefinitely.

CHP plants and EfW plant are not expected to be dispatchable, but some variation in output is likely. However, they may not be able to meet the requirements for good quality CHP over periods when electrical output is constrained. The design of the plant may be changed to help variable operation, possibly with a slight impact on full load thermal efficiency.

Where you plan to install CO_2 capture onto a CHP plant, you must design the plant so that it can operate efficiently during periods of power only mode.

The primary purpose of an EfW plant is to treat waste. Therefore, they need to operate continuously. The PCC plant design and operation must be compatible with this.

2.3 Supplying heat and power for PCC operation

You will need to use low grade (for example 130°C) heat and electrical power to operate the PCC plant. You should work out the amounts needed based on factors that include the:

- selected solvent
- PCC plant configuration
- CO_2 capture rate
- CO_2 delivery pressure

You should supply this heat and electricity from the main plant. Where not possible, this will need to be by fuel combustion in ancillary plants (with CO_2 capture) that are then also treated as a power or CHP plant system for performance calculations.

The ratio between heat supplied as steam (or otherwise) and electricity output lost will depend on the:

- temperature at which you need to supply heat
- steam condenser cooling water temperature

You should consider using a back-pressure turbine if it is not possible to supply enough steam to the PCC plant by extracting steam from a condensing turbine.

If the plant needs to supply heat for district heating, and extracting steam to supply the PCC plant will mean there is insufficient steam to do this, you should consider using heat pumps or other plant to reduce the amount of steam required to meet that heat demand.

3. PCC plant design and operation

3.1 Purpose

The purpose of the PCC plant is to maximise the capture of CO_2 emissions for either use or secure geological storage.

You should aim to design your plant to achieve a CO_2 capture rate of at least 95% during normal operating conditions, although operationally this can vary, up or down.

You will need to justify proposing a design CO_2 capture rate of less than 95% as an annual average of all normal operating conditions. You can submit a cost benefit analysis as part of your application.

You will need to deliver CO_2:

- at local transport system pressures (gas phase such as 35 bar or dense phase such as 100 bar)
- with levels of water, oxygen and other impurities as required for transport and storage such as that for the system operator National Grid (NGC/SP/PIP/25 Dec.2019)

The PCC plant must also have acceptable environmental risks through preventing or minimising emissions or render them harmless.

You must achieve environmental quality standards for air emissions from the PCC plant and their subsequent atmospheric degradation products (including, for example, nitrosamines and nitramines). You should confirm this using:

- atmospheric dispersion and reaction modelling tools
- specific site parameters which will define plant-specific ELVs

For discharges to air, you should refer to the following guidance and information:

- Air emissions risk assessment for your environmental permit (https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit)
- Environmental permitting: air dispersion modelling reports (https://www.gov.uk/guidance/environmental-permitting-air-dispersion-modelling-reports)
- UKCCS Research Community - BAT information for CCS (https://ukccsrc.ac.uk/best-available-technology-bat-information-for-ccs/)
- Hazard ranking of substances for development of EALs for substance emissions to air from carbon capture technologies (https://ukccsrc.ac.uk/wp-content/uploads/2023/02/Prioritisation-of-carbon-capture-chemicals-interim-report_FINAL-1.pdf)
- AQMAU recommendations for the assessment and regulation of impacts to air quality from amine-based post-combustion carbon capture plants (https://ukccsrc.ac.uk/wp-content/uploads/2021/11/AQMAU-C2025-RP01.pdf)

Your PCC system design should aim to minimise the overall electricity output penalty on the EfW, power or CHP plants from all aspects of PCC plant operation, as much as possible. It should do this while meeting the CO_2 capture requirements set out in this guidance.

3.2 Solvent selection

While the process design for the PCC plant is likely to be generally similar for all solvents, the amine solvent you select will determine details of the design and performance.

Solvent types and published performance figures are described in the PCC evidence review (https://ukccsrc.ac.uk/best-available-technology-bat-information-for-ccs/). There is particular concern about impacts on the environment from nitrosamines and other potentially harmful compounds formed by reaction of the amines and their degradation products with nitrogen oxides (NOx) in the flue gases. Check the environmental standards for air emissions (https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit#environmental-standards-for-air-emissions) for the protective environmental assessment levels.

You have a choice between:

- solvents using primary amines that may require more heat for regeneration but will not readily form stable nitrosamines in the PCC plant, especially if a high level of reclaiming is used to remove degradation products
- solvent formulations including secondary amines or other species that may have lower regeneration heat requirements but may readily form nitrosamines with NOx in the flue gases in the PCC plant – for controls, see section 3.3 on features to control and minimise atmospheric and other emissions

The potential absorber stack emissions and resulting environmental impacts will depend on the selected solvent.

Your air emissions risk assessment (https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit) should assess your plant design and operation, taking into account local environmental factors. It should include:

- direct emissions of solvent components

- formation of additional substances in the PCC system and emissions of those substances
- formation of further additional substances in the atmosphere from emissions from the PCC system

The potential for solvent reclaiming and other cleaning methods is also an important factor in solvent selection. You should make sure it is practicable to remove all non-solvent constituents from the solvent inventory as fast as they are added during operation, to avoid accumulation. Your assessment should demonstrate that you will:

- recover a high fraction of the solvent in the feed to the reclaimer during reclaiming
- minimise reclaimer wastes and that they can easily be disposed of

You must work out the performance of your solvent, including reclaiming requirements and modelling emissions to atmosphere. Determine this through realistic pilot (or full scale) tests using fully representative (or actual) flue gases and power plant operating patterns over a period of at least 12 months. You do not need to do this for your plant if information on the solvent performance is already available from pilots, tests, or regular operation at a similar plant.

3.3 Features to control and minimise atmospheric and other emissions

3.3.1 Flue gas cleaning

You will need to consider the following, depending on the flue gas source and the solvent selected.

Sulphur oxides (SOx) removal (and hydrochloric acid (HCl) for EfW)

SOx in the flue gas will readily react with amines to produce heat stable salts.

These products are typically stable under reclaimer conditions, but the heat stable salt formation with SOx can be, at least partly, reversed by alkali addition in the solvent reclaiming process.

SOx levels will affect solvent consumption but are expected to have a limited effect on emissions. For most gas, biomass and waste fuels that have intrinsically low S levels, adding more upstream SOx removal (and HCl removal for EfW) is likely to be primarily an economic decision.

SOx removal can be in the power plant flue gas desulphurisation unit, flue gas treatment system or in the PCC direct contact cooler.

SOx levels in the existing flue gases from an amine PCC plant will be expected to be at extremely low levels.

NOx removal

The impact of NOx in the flue gas will vary significantly with the solvent composition. If the amine blend will form stable nitrosamines with NOx in the flue gas, then you must reduce NOx to as low a level as practicably possible (see LCP BREF (https://eippcb.jrc.ec.europa.eu/reference/large-combustion-plants-0) and EfW BREF (https://eippcb.jrc.ec.europa.eu/reference/waste-incineration-0)) using selective catalytic reduction (SCR).

EfW plants may be fitted with selective non catalytic reduction (SNCR) which does not reduce NOx in flue gas as much as SCR. If you are retrofitting PCC plant to an EfW plant which has SNCR NOx abatement, you should make sure the selected solvent is compatible with the abated flue gas.

Both SCR and SNCR can result in ammonia (NH_3) slip. If necessary, it is expected that (NH_3) slip could be addressed in a suitably designed PCC unit. In all cases, you must assess the effects of NOx in the flue gas on atmospheric degradation reactions and this may also affect the need for SCR.

If SCR is not fitted to a new build power plant, it is generally considered BAT to maintain space so it could be retrofitted, should this be considered necessary to meet ELVs in the future.

Aerosols

Sulphur trioxide (SO_3) droplets and fine particulates should not be present in the flue gas. If they arise in the PCC process, they can cause significant amine emissions.

The level of emissions (mainly solvent amines) is not directly related to aerosol measurements. Monitoring aerosols is difficult and aerosol quantities may also vary significantly over time.

Aerosols might be present, for example, because of significant SOx in the flue gas. Where they are present, you should carry out long-term testing on a pilot plant or the actual plant, with all planned countermeasures in place, to show satisfactory operation. You should also carry out regular isokinetic sampling in the operational plant to assess total vapour and droplet emission levels.

Other amine aerosol emission abatement techniques include:

- cooling the flue gas gradually through the acid dewpoint
- Brownian Demister Units
- wet electrostatic precipitators
- high lean solvent temperatures

These techniques can reduce aerosol emission by enhancing aerosol growth in the top of the column, and the water wash. You may need to use a combination of these or other techniques.

Other flue gas impurities

You may need to remove materials in the flue gas that would accumulate as impurities in the solvent to lower concentrations than is required under the relevant BAT AELs. This is to ensure satisfactory PCC plant operation. Whether you need to do this will depend on the specific solvent properties and the effectiveness of the solvent management equipment (such as filtering and reclaiming).

You should assess the effects of flue gas impurities through realistic, long term pilot testing. In general, your PCC plant must abate these types of flue gas impurities before the residual flue gases are finally released to atmosphere.

3.3.2 PCC system operation

Operating temperatures

You must establish and maintain optimum temperature and appropriate limits in the solvent stripping process.

Elevated temperatures can cause some thermal degradation of the solvent. But higher peak average temperatures during regeneration are also likely to promote reduced energy requirements and higher CO_2 capture levels. You must balance both to ensure the right environmental outcome.

Where feasible, you should avoid locally higher metal skin temperatures, such as from the use of superheated steam in heaters, as this provides no benefit and can result in degradation.

Solvent degradation

You should minimise oxidative degradation of the solvent by limiting solvent residence times in the absorber sump and other hold-up areas. Direct O2 removal from rich solvent may be developed in the future but has not yet been proven at scale.

3.3.3 Absorber emissions abatement

Water wash

You must use 1 or 2 water washes or a scrubber before returning amine or other species to the solvent inventory. Capture levels are limited by vapour or liquid equilibrium, with volatile amines captured less effectively. Any aerosols present will also not be captured effectively. Water washes alone are ineffective in preventing NH_3 emissions, as concentrations will increase until the rate of release balances the rate of formation (and possibly addition from SCR or SNCR slip).

Acid wash

An acid or other chemically active wash or scrubber after the water wash will react with amines, NH_3 and other basic species and reduce them to very low levels (for example, 0.5mg to 5mg per m3 per species or lower).

You should implement an acid wash as it is considered to be BAT, unless:

- emission levels are already at acid wash levels with a water wash
- you can show that the need to dispose of the acid wash waste outweighs the benefits of the additional reduction in emissions to atmosphere

Depending on PCC system configuration, an absorber acid wash can also counteract NH_3 slip from an SCR system.

If an acid wash is not fitted, you should consider a second water wash as an acid wash if:

- emissions performance is worse than expected
- you wish to change to a more volatile solvent

An acid wash is not likely to trap aerosols.

Droplet removal

You must prevent emissions of aerosols. To do this you could use standard droplet removal sections after washes. These will prevent droplet carryover from the wash. However, they are not effective against very fine aerosols arising from SO_3 or other aerosol mists.

Stack height

Where modelling predicts that you may need to raise the temperature at the point of release to aid dispersion, you can:

- increase the design stack height
- add flue gas reheating

Flue gas reheating can also reduce the plume visibility. Heat from cooling the flue gas before the PCC plant or waste heat from the PCC process should be used for flue gas reheating (see section 4 on cooling).

3.4 Process and emissions monitoring

3.4.1 Role of monitoring

The main purpose of monitoring the PCC process is to show that the emissions from the process, primarily to air, are not causing harm to the environment.

You must also carry out monitoring to show that resources are being used efficiently. This includes:

- energy and resource efficiency
- CO_2 capture rate
- verification that the CO_2 product is suitable for safe transport and storage

You will need to develop a monitoring plan for both a commissioning phase and routine operation.

During the commissioning phase you will need to optimise the operating envelope for the process. When you have achieved this the process operation will then become routine, along with the monitoring.

It is likely that you will need to do more extensive monitoring during commissioning than during routine operation. As PCC is an emerging technique, you will need to develop monitoring methods and standards. You should include proposals for this in your permit application.

You must demonstrate compliance with ELVs in the permit by monitoring emissions at authorised release points. You must also show that you are managing the process to prevent (or minimise) the formation of solvent degradation products.

Where monitoring shows that degradation products are being formed (and may be released), you must reduce these and any solvent emissions to the permitted level. This process control monitoring will also be part of the permit conditions.

3.4.2 Point source emissions to air

You must include monitoring to demonstrate compliance with:

- IED Chapter III ELVs (https://environment.ec.europa.eu/topics/industrial-emissions-and-safety/industrial-emissions-directive_en#provisions-for-large-combustion-plants) and Chapter IV
- LCP BREF BAT AELs (https://eippcb.jrc.ec.europa.eu/reference/large-combustion-plants-0)
- WI BREF BAT AELs (https://eippcb.jrc.ec.europa.eu/reference/waste-incineration-0) at normalised conditions

You must also monitor for:

- ammonia
- volatile components of the capture solvent
- likely degradation products such as nitrosamines and nitramines

Your monitoring may be by either:

- continuous emissions monitoring (‘online’)
- periodic extractive sampling (‘offline’) – where aerosol formation is expected, this must be isokinetic

Emission sampling points must also comply with [M1 sampling requirements for stack emission monitoring (https://www.gov.uk/government/publications/m1-sampling-requirements-for-stack-emission-monitoring)](https://www.gov.uk/government/publications/m1-sampling-requirements-for-stack-emission-monitoring).

3.4.3 Process control monitoring

You should use process control monitoring or periodic sampling with offline analysis to control the CO_2 capture and the solvent reclaiming performance. Parameters you should consider monitoring include:

- absorber solvent quality – percentage active solvent
- CO_2 loading both rich and lean solvent
- maximum solvent temperature
- heat stable solvent content
- solvent colour or opacity
- soluble iron and other metals and degradation products
- in water or acid washes and scrubbers – pH, conductivity, loading of abated substances, flow rate
- solvent usage

3.4.4 Monitoring of CO_2

You should also include:

- CO_2 mass balance
- CO_2 in fuel combusted
- CO_2 capture rate (as a percentage)
- CO_2 released to the environment
- CO_2 quality

3.4.5 Monitoring standards

The person who carries out your monitoring must be competent and work to recognised standards such as the [Environment Agency's monitoring certification scheme (MCERTS) (https://www.gov.uk/government/collections/monitoring-emissions-to-air-land-and-water-mcerts)](https://www.gov.uk/government/collections/monitoring-emissions-to-air-land-and-water-mcerts).

MCERTS sets the monitoring standards you should meet. The Environment Agency recommends that you use the MCERTS scheme where applicable. You can use another certified monitoring standard, but you must provide evidence that it is equivalent to the MCERTS standards.

There are no prescriptive BAT requirements for how to carry out monitoring. Monitoring methods need to be flexible to meet specific site or operational conditions.

You must use a laboratory accredited by the United Kingdom Accreditation Service (UKAS) (https://www.ukas.com/) to carry out analysis for your monitoring.

3.5 Unplanned emissions to the environment

You should propose a leak detection and repair programme that is appropriate to the solvent composition. This should use industry best practice to manage releases, including from joints, flanges, seals and glands.

You must provide a hazard and mitigation assessment for the plant. This must consider the risks of accidental releases to environment. This should also consider the actual composition of the fluids, gases and vapours that could be released from the plant after an extended period of operation. (Not only fresh solvent as initially charged.)

3.6 Capture level, including during flexible operation, start-up and shutdown

Capturing at least 95% of the CO_2 in the flue gas during normal operating conditions is considered BAT. You can base this on average performance over an extended period (for example, a year). To achieve this, you should make sure the design capture level for flue gas passing through the absorber equates to at least 95% of the CO_2 in the total flue gas from the plant. Over the averaging period, your capture level may vary up or down.

You should set out any potential ‘other than normal operating conditions’ (OTNOC) for the CO_2 capture plant in your permit application. You should include a PCC OTNOC management plan in your management system to measure and minimise occurrence and impact of these periods. OTNOC includes periods of start-up and shutdown.

Your PCC OTNOC management plan must compliment any OTNOC management plan for the facility it serves and consider internal and external causes of OTNOC. An example of OTNOC would be when the CO_2 transport and storage network is down.

As the fraction of intermittent renewable generation in the UK rises, many CCS enabled plants will need to start and stop more often, and possibly also operate at variable loads. It is therefore important, for current or future intermittent operation plant, that you aim to maximise CO_2 capture during these periods, including during start-up and shutdown, to maintain high average capture levels.

You should therefore capture CO_2 during plant start-up and shutdown as part of using BAT. A method to maintain capture during start-up and shutdown using solvent storage has been identified in chapter 7 of the PCC evidence review (https://ukccsrc.ac.uk/best-available-technology-bat-information-for-ccs/). This, or alternatives that can achieve equivalent results, is considered BAT. You will need to provide justification and a cost benefit analysis if you are not proposing capture during start-up and shutdown.

If your PCC plant is not initially constructed with this capability, your permit application should show how you may retrofit it.

Your PCC OTNOC management plan should include measures to minimise any CO_2 emitted during start-up and shutdown periods.

Some plants (including EfW) may not have frequent start-ups and shutdowns, so investment in solvent storage (or an alternative) is likely to be an economic decision. You should outline this in your cost benefit analysis.

Where the CO_2 is being captured for secure geological storage, the transport and storage system may not always be available. When it is not, it is not appropriate to capture CO_2. You will need to make sure the PCC plant is bypassed so that electricity, CHP generation or waste incineration can continue. You must not include these periods in any capture efficiency calculation, but you must keep a record of these, and CO_2 quantities emitted for reporting purposes.

The CO_2 transport and storage system (including non-pipeline transfer) may sometimes need to be constrained – that is, it cannot take all the CO_2 you are producing. You should plan how you would meet this constraint as far as is practicable.

You should detail both situations in your permit application. You must show how you will manage the plant to minimise emissions to the environment, including during start-up and shutdown.

3.7 Compression

You should select CO_2 compressors based on the expected duty. You should consider how any waste heat arising may be used.

For base load operation, you should use integrally geared units because they give the:

- maximum full-load efficiency
- minimum number of compression trains

For flexible and part-load operation, smaller compression trains (for example 2 at 50% compared to 1 at 100%) may be preferable. The use of different types of compressor or pump in series may also be preferable, to give greater flexibility at the expense of slightly lower full-load efficiencies.

3.8 Noise and odour

The LCP BREF (https://eippcb.jrc.ec.europa.eu/reference/large-combustion-plants-0) and EfW BREF (https://eippcb.jrc.ec.europa.eu/reference/waste-incineration-0) already cover noise impacts for the main power plant. You only need to consider additional process steps in PCC technology that have high potential for noise and vibration. In particular, CO_2 compression could be an area of concern.

Once you have identified the main sources and transmission pathways, you should consider the use of common noise and vibration abatement techniques and mitigation at source wherever possible.

For example:

- use of embankments to screen the source of noise

- enclosure of noisy plant or components in sound-absorbing structures
- use of anti-vibration supports and interconnections for equipment
- orientation and location of noise-emitting machinery
- change of the frequency of the sound

The handling, storage and use of some amines may result in odour emissions, so you should always use best practice containment methods. Where there is increased risk that odour from activities will cause pollution beyond the site boundary, you will need to send an odour management plan with your permit application.

3.9 Hot potassium carbonate post combustion capture plant

Using electrically powered hot potassium carbonate as an alternative solvent to amines for capturing CO_2 is an emerging technique that may have some advantages where the on-site availability of steam supply is insufficient for amine regeneration.

The configuration of the plant is similar with flue gas clean up, absorber and desorber columns and solvent reclamation. The process is carried out at pressures between 10 and 100 pounds per square inch (PSI) and so requires a flue gas compressor – see the PCC evidence review (https://ukccsrc.ac.uk/best-available-technology-bat-information-for-ccs/).

Advantages include:

- potentially less hazardous than other solvents
- can be driven by electricity – no need to extract steam
- pressurised capture process – smaller volumes of gases
- higher tolerance to oxygen

Disadvantages include:

- requires a complex large compressor, expander, heat recovery or exchanger which is expensive and high maintenance
- use of electricity is less efficient than steam
- not as effective on flue gas with low CO_2 concentration – for example, combined cycle gas turbine (CCGT)
- some CO_2 slip so achievable capture efficiency is likely to be 90% not 95%

Where you choose to use this carbon capture technique you should justify why in your permit application.

4. Cooling

You will be able to achieve the best power and CO_2 capture plant performance by using the lowest temperature cooling available. You should use the hierarchy of cooling methods as follows:

- direct water cooling (such as seawater)
- wet cooling towers
- hybrid cooling towers
- dry cooling – direct air-cooled condensers and dry cooling towers

Power plants that are retrofitted with PCC using steam extraction, or that are intended to be able to operate without capture, can share water cooling between the power plant and the PCC system. This is because the cooling load on the main steam condensers falls with increased steam extraction rate. This shift away from condenser cooling will not apply for systems with direct air-cooled condensers.

It may also be possible to reuse cooling water after the main condensers for higher-temperature cooling applications in the PCC plant. However, site specific water discharge temperature limits may be an issue for direct cooling.

A feature of PCC is that you have to remove heat from a flue gas stream that was originally not cooled. You can still achieve rejection of heat to atmosphere by heating the flue gas leaving the absorber, using heat from the incoming flue gas. You can do this either:

- directly – such as using a rotary gas-gas heater
- indirectly – such as using a heat transfer fluid or low-pressure steam

Lean and rich solvent storage may also help you achieve satisfactory PCC performance during periods of high cooling demand.

You should refer to the Environment Agency's evidence on cooling water options for the new generation of nuclear power stations in the UK (https://www.gov.uk/government/publications/cooling-water-options-for-the-new-generation-of-nuclear-power-stations-in-the-uk) when considering options for cooling. This gives an overview of UK power station cooling water systems in use in the UK and abroad.

5. Discharge to water

For discharges to water, you should refer to the guidance on surface water pollution risk assessment for your environmental permit (https://www.gov.uk/guidance/surface-water-pollution-risk-assessment-for-your-environmental-permit).

For best practice in plume dispersal modelling, see the Joint Environmental Program report 'A protocol on projects modelling cooling water discharges into TrAC waters within power station developments (https://www.energy-uk.org.uk/publications/a-protocol-on-projects-modelling-cooling-water-discharges-into-trac-waters-within-power-station-developments-may-2019/)'.

6. For more advice from your regulator

You can request advice before applying for your permit (https://www.gov.uk/guidance/get-advice-before-you-apply-for-an-environmental-permit).

For more advice from your regulator, in:

- England, contact the Environment Agency: enquiries@environment-agency.gov.uk
- Wales, contact Natural Resources Wales: enquiries@naturalresourceswales.gov.uk
- Northern Ireland, contact the Northern Ireland Environment Agency: IPRI@daera-ni.gov.uk

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27 March 2024

Updated the guidance in several sections to reflect feedback from stakeholders including changing the title from 'best available techniques' to 'emerging techniques'. Also added content that relates directly to carbon capture at energy from waste plants.

3 November 2022

Updated section 6. The Environment Agency has removed the requirement to consider climate change adaptation from the permit application process. Instead, you need to integrate climate change adaptation into your management system.

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