A BEST AVAILABLE TECHNIQUES (BAT) REVIEW FOR POST-COMBUSTION CAPTURE ON EFW

Jon Gibbins[a], Mathieu Lucquiaud[b]

a University of Sheffield,S3 7RD, UK. j.gibbins@sheffield.ac.uk

b University of Edinburgh, UK. m.lucquiaud@edinburgh.ac.uk

The UKCCSRC is supported by the EPSRC as part of the RCUK Energy Programme
Flexible Funding 2020: Co-Cap: Collaboration on Commercial Capture

The Translational Energy Research Centre is part-funded by the European Regional Development Fund and the Department for BEIS

Contents:

- Overview of previous power PCC BAT review
- EfW BAT review proposed scope
- EfW BAT review proposed timetable

https://www.gov.uk/guidance/post-combustion-carbon-dioxide-capture-best-available-techniques-bat

GOV.UK Topics Departments Government activity

→ Coronavirus (COVID-19) | Guidance and support

Home > Business and industry > Business and the environment

Guidance

Post-combustion carbon dioxide capture: best available techniques (BAT)

The available techniques which are the best for preventing or minimising emissions and impacts on the environment from post-combustion carbon dioxide capture.

From: Environment Agency

Published 2 July 2021

The University of Edinburgh

The University Of Sheffield. Energy Institute

Translational Energy Research Centre.

UKCCS RESEARCH CENTRE

https://ukccsrc.ac.uk/best-available-techniques-bat-information-for-ccs/

Best Available Techniques (BAT) information for CCS technologies

The UKCCSRC is involved in activities with the UK Environmental Regulators (Environment Agency, Scottish Environment Protection Agency, Natural Resources Wales, Northern Ireland Environment Agency), industry and other stakeholders, to help identify Best Available Techniques (BAT) for CCS-related technologies. A list of BAT-related activities and resources is below:

- **Hydrogen Production from Methane with CCS – Possible Near-Term Technologies for the UK**
  An expert workshop held on Thursday 16th July 2020
- **BAT Review for New-Build and Retrofit Post-Combustion Carbon Dioxide Capture Using Amine-Based Technologies for Power and CHP Plants Fuelled by Gas and Biomass as an Emerging Technology under the IED for the UK**
  Published 1st July 2021

For further information, please follow the links provided or contact us.

Full title:

BAT Review for New-Build and Retrofit Post-Combustion Carbon Dioxide Capture Using Amine-Based Technologies for Power and CHP Plants Fuelled by Gas and Biomass as an Emerging Technology under the IED for the UK

- Regulator reviews were undertaken with the Environment Agency, Scottish Environment Protection Agency, Natural Resources Wales and The Northern Ireland Environment Agency.

- Industry reviews were undertaken with the help of the Carbon Capture and Storage Association and its members, who formed a BAT subgroup to the CCS Technical Working Group for the purpose. The Chemical Industries Association and a number of individual industrial and research organisations active in the field also participated.

- July 2020 to July 2021:
    - Two draft versions discussed with industry
    - Five meetings/workshops with industry
    - Plus further meetings/draft reviews with regulators
    - 105 pages

The University Of Sheffield. Energy Institute
Translational Energy Research Centre.
UKCCS RESEARCH CENTRE

https://www.gov.uk/guidance/post-combustion-carbon-dioxide-capture-best-available-techniques-bat

1. Who this guidance is for

This guidance covers plants using:

- amine-based technologies to capture CO_2 from the flue gases of power only
- combined heat and power (CHP) plants fuelled by natural gas and biomass

This guidance is for:

- operators when designing their plants and preparing their application for an environmental permit
- regulatory staff when setting conditions in environmental permits
- 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.

Current BAT identifies carbon capture as an emerging technique in the large combustion plant (LCP) BAT reference document (BREF) but does not address all the potential effects of carbon capture. This situation is addressed by Article 14(6) of the Industrial Emissions Directive (IED) where regulators must set permit conditions covering emission limit values (ELVs) together with other permit conditions.

These conditions must be based on their own determination of BAT using the criteria listed in Annex III of the IED. They should also consult with operators during this process.

https://www.gov.uk/guidance/post-combustion-carbon-dioxide-capture-best-available-techniques-bat

2. Power plant selection and integration with the PCC plant

2.1 Efficiency of fuel use in power and CHP plants with PCC

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

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.

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 level
- CO_2 delivery pressure

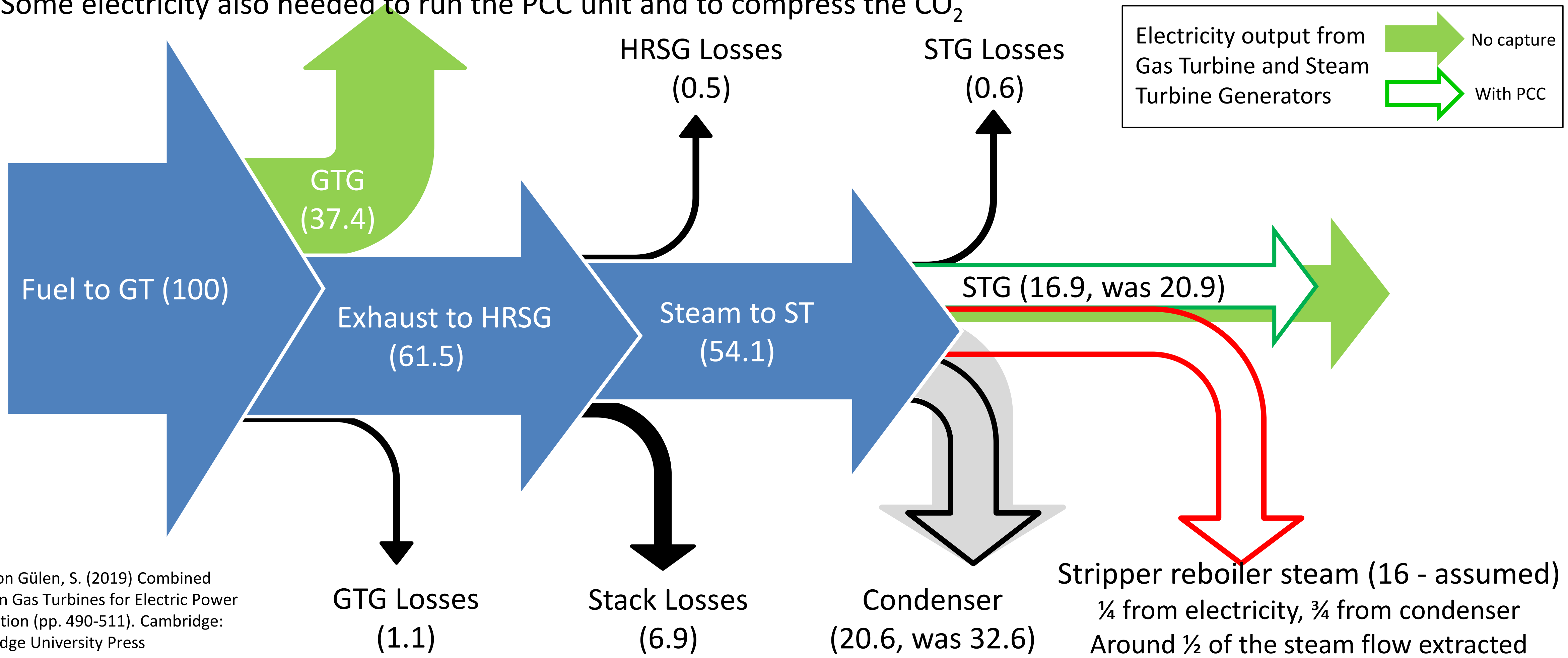
You should supply this heat and electricity from the main power plant. Where not possible, this will need to be by fuel combustion in ancillary plants (with CO_2 capture) that are then also treated as a power plant system for performance calculations.

Typically, the best heat supplied to lost power ratio will exceed 4:1 for regeneration heat supplied at 130°C.

The University of Edinburgh
The University Of Sheffield. Energy Institute
Translational Energy Research Centre.
UKCCS RESEARCH CENTRE

Effective heat supply for regeneration

- At low temperatures so of little value for generating electricity
- The PCC unit's reboiler partially replaces the power plant's steam condenser, where heat is rejected to cooling water
- Typically 4 or more units of heat can be supplied from a power plant for every 1 unit reduction in electricity output
- Important to use CHP plants to run PCC units in non-power applications to get the same benefit (or use waste heat)
- Some electricity also needed to run the PCC unit and to compress the CO_2



Based on Gülen, S. (2019) Combined Cycle. In Gas Turbines for Electric Power Generation (pp. 490-511). Cambridge: Cambridge University Press

https://www.gov.uk/guidance/post-combustion-carbon-dioxide-capture-best-available-techniques-bat

3.1 Purpose

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

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

You should capture CO_2 during start-up and shutdown as part of using BAT.

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

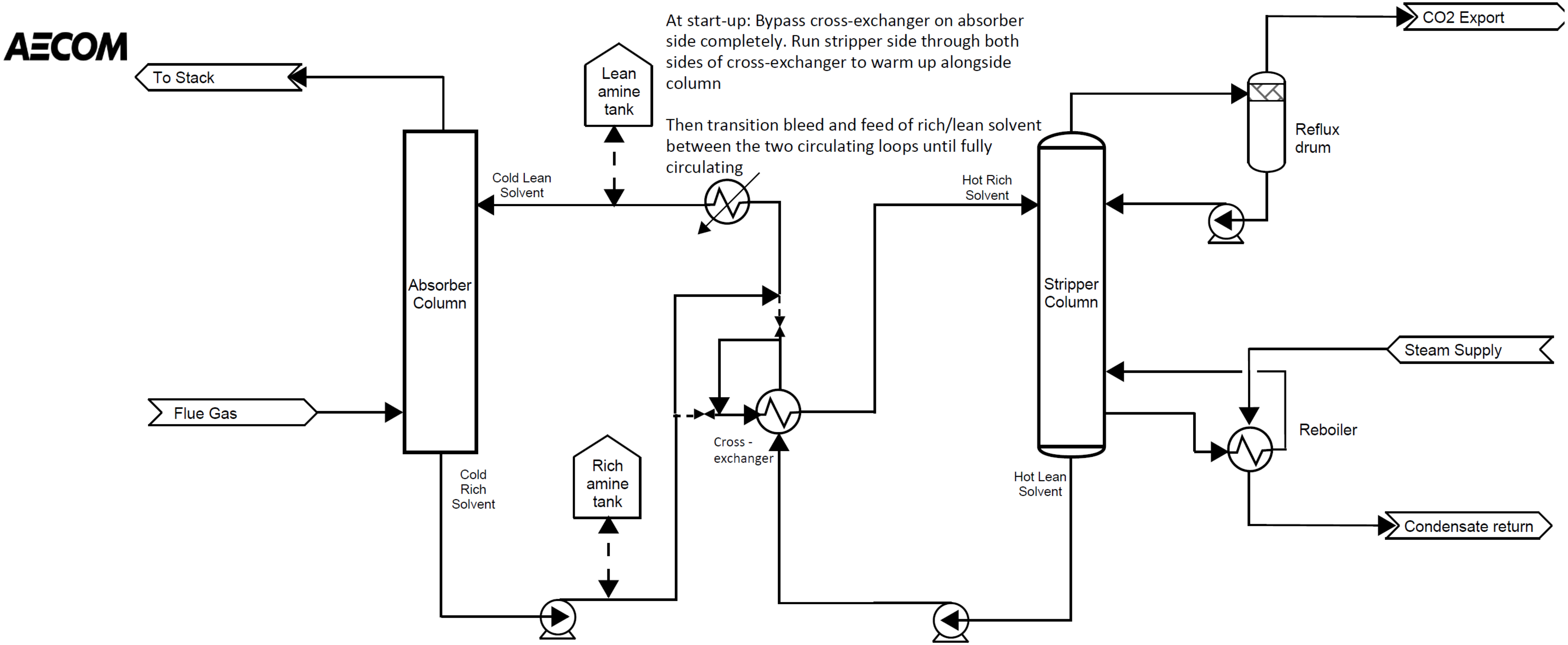
You must achieve environmental quality standards for air emissions from the PCC plant and their subsequent atmospheric degradation products (including, for example, nitrosamines and nitramines).

You should confirm this using:

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

PCC can also capture at a high level while power plants are starting and stopping

- Issue being addressed is GT starting up and running before steam is available to regenerate PCC solvent
- The DPA (reasonably) penalises CO_2 emissions all times
- Solution is to store lean and rich solvents in tanks so that absorber can be run independently of the stripper



AECOM (2020) for BEIS, Start-up and Shut-down times of Power CCUS Facilities.
https://www.gov.uk/government/publications/start-up-and-shut-down-times-of-power-carbon-capture-usage-and-storage-ccus-facilities

https://www.gov.uk/guidance/post-combustion-carbon-dioxide-capture-best-available-techniques-bat

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.

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 that may form nitrosamines with NOx in the flue gases in the PCC plant

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.

You must work out the solvent performance, including reclaiming requirements and 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.

Table A2.1 Examples of PCC pilot-scale testing to de-risk commercial projects

Solvent	User	Test Site name	Approx. CO_2 captured	Intended commercial project	Reclaiming	Approximate dates
MHI KS-1	Southern	Plant Barry	500 tpd	Petra Nova	Repeated successful reclaiming reported	2011 – 2014 (>13,000 hrs)
HTC/Doosan	SSE	Ferrybridge	100 tpd	Ferrybridge	Not known	2011-2012
Cansolv DC-103	RWE	Aberthaw	50 tpd	Aberthaw	'Amine purification unit' included but no report of use	2013
Fluor	Uniper	Wilmhelmshave n	70 tpd	Maasvlakte	Thermal reclaimer integrated with stripper and vapour compression and use reported	2012-2015 (~7000 hrs)
Hitachi	SaskPower	Shand	120 tpd	Shand	Thermal reclaimer venting to the stripper included but no report of use.	2015 – 2016? (8000 hrs planned)
Cansolv DC-201	Shell	Technology Centre Mongstad	80 tpd	Peterhead	No report of reclaiming identified in public domain sources	November 2014 to May 2015; 2016
Aker S-26	Norcem	Brevik	3.5 tpd	Brevik	Reclaiming predicted to have happened, but no report in public domain sources	May 2014, for 18 months
Cansolv DC-103	Fortum Oslo Varme	Klemetsrud	3.5 tpd	Klemetsrud	No reclaimer fitted	March – December 2019 (>5,000 hrs)

https://www.gov.uk/guidance/post-combustion-carbon-dioxide-capture-best-available-techniques-bat

3.3 Features to control and minimise atmospheric and other emissions

3.3.1 Flue gas cleaning

- SOx removal
- NOx removal
- Aerosols
- Other flue gas impurities

3.3.3 Absorber emissions abatement

Water wash

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, 0.5 to 5mg per m^3 per species or lower).

You should implement an acid wash as 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

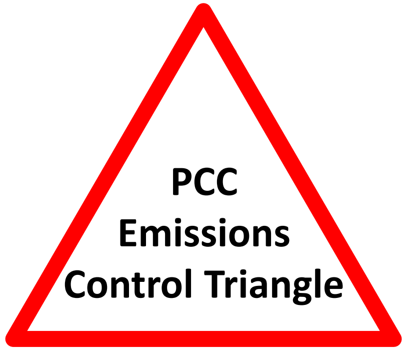
If an acid wash is not fitted, you should consider a second water wash as an acid wash if:

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

Ensuring satisfactory environmental performance for amine PCC

- Main concern is conversion of emitted amines into carcinogenic nitrosamines and direct nitrosamine emissions
- Allowable levels in the environment are currently too low to measure directly and have to be estimated by modelling
- Impact depends on:
  - Amount and type of amines and other species in the vented flue gas (plus amines emitted from other plants)
  - Amounts of other species, principally NOx, in the atmosphere to react
  - Atmospheric conditions, such as water vapour/droplet, sunlight, wind for dispersion
- UK likely to have multiple amine and other pollutant emission sources in future CCS clusters, all of which will need to be included in impact modelling
- Range of measures to control emissions – see right:

A. Determine the possibilities for environmental impacts from emissions by solvent selection



B. Reduce degradation and impurity addition rates and accelerate degradation production and other impurity removal rates (all additions must be balanced by removals)

C. Trap potential emissions at the absorber exit

D. Dilute and disperse emissions

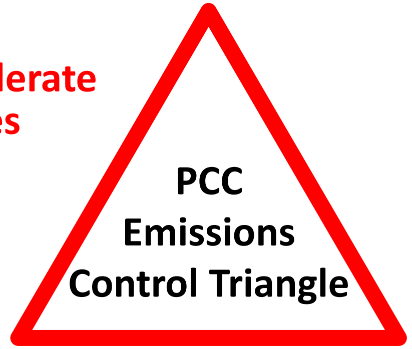
Ensuring satisfactory environmental performance for amine PCC – slide for reference only

A. Determine the possibilities for environmental impacts from emissions by solvent selection

Solvent selection locks in the potential for different types of emissions and the impacts of those emissions due to the toxicity of the substances, also potential rates of formation and removal of unwanted substances:

a) Potential for absorber stack emissions and environmental impacts
- 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

b) Potential for solvent reclaiming
- Primary: can unwanted components realistically be removed from the solvent inventory during operation to avoid impurity accumulation and the formation of degradation products?
- Secondary: can a high fraction of good solvent be recovered during reclaiming?
- Reclaiming rate can be adjusted to compensate for rates of formation/accumulation



B. Reduce degradation and impurity addition rates and accelerate degradation production and other impurity removal rates (all additions must be balanced by removals)

Flue gas cleaning can reduce the following, but hard to get to zero
- SOx – affects solvent consumption but limited effect on emissions
- NOx – impact on emissions varies with solvent
- Aerosols – may not be present, but serious if they are
- Materials that accumulate as impurities in the solvent (metals, chlorine, fly ash etc)

Absorber operation
- Peak temperatures in the stripping process
- Minimising the effect of oxygen (reduced residence times - direct O_2 removal not demonstrated at scale)

Remove unwanted impurities
- Must have solvent reclaiming technique available that removes all impurities to avoid accumulation
- Other partial removal techniques may be helpful if they reduce the need for reclaiming by targeting critical components

C. Trap potential emissions at the absorber exit

Absorber exit measures
- Water wash – effective against amines but not NH_3
- Acid wash – effective against NH_3 and amine vapour loss, less so for mist
- Droplet removal – required after washes
- Elevated lean solvent & wash temperatures to avoid mist – only of benefit if aerosols in the flue gas, otherwise disbenefits
- **Other engineered measures possible**

D. Dilute and disperse emissions

Flue gas heating to aid plume dispersion

https://www.gov.uk/guidance/post-combustion-carbon-dioxide-capture-best-available-techniques-bat

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 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.

Final comments on power PCC BAT review

- BAT Review and BAT Guidance processes completed after ~ 1 year of development and consultation
- Limited evidence for BAT due to incomplete reporting of most testing, FEED studies and deployment
- 95% capture level seems have been an acceptable new 'standard'
- Atmospheric emissions proving a challenge, especially given the potential for large numbers of PCC units in the UK CCUS clusters – many sites, different amines, other pollutants etc.
- Trade-offs in solvent selection, probably with no ideal combination of properties – but health, safety and environment have to take priority
- Acid wash viewed as a back-up if not included from the outset, including for ammonia from SCR
- Reclaiming identified as a major topic of interest
- Realistic pilot testing is required to give assurance of performance - commercial guarantees are a matter of judgement, possibly involving quite limited penalties
- Permitting is the sole responsibility of the operator
- Hope to be able to update the BAT Review with better evidence soon!

The University Of Sheffield. Energy Institute
Translational Energy Research Centre.
UKCCS RESEARCH CENTRE

EfW post-combustion BAT review

- A review has to be based on public domain evidence
- Scope – applications: Retrofit and new EfW combustion plants
- Scope – PCC technologies: amine and hot potassium carbonate, 95% capture level
- Existing PCC Amine BAT review for power and CHP a starting point
- Additional material: EfW characteristics: flue gas and integration

  Hot pot capture

  EfW experience to date with PCC
- Trade-offs in solvent selection, probably with no ideal combination of properties – but health, safety and environment have to take priority
- Limited information in the public domain and independently verified
- Realistic pilot testing is required to give assurance of performance - commercial guarantees are a matter of judgement, possibly involving quite limited penalties
- Permitting is the sole responsibility of the operator

The review will in particular consider:

- PCC at EfW (i.e. waste incineration and co-incineration) plants which burn municipal waste including black bag waste, RDF and SRF, and those that burn waste wood.
- New EfW plants that will be fitted with PCC from the outset and retrofit of PCC at existing plants (but not PCC-readiness as this will be covered by other work)
- PCC solvent technologies using amines and hot potassium carbonate
- Operational principles and, to the extent that public domain information is available, ranges of achievable performance and optimisation trade-offs that may be encountered (parallel BEIS study for evidence)
- Upstream flue gas treatments and tradeoffs for particular solvents
- Degradation and atmospheric emissions characteristics and control measures for solvents (to the extent that public-domain information is available)
- Disposal of PCC system wastes, including any which can be burned within the plant and implications for discharges to sewer or water.
- Likely heat and electricity requirements for PCC and how this can be supplied in the most efficient way (including implications of retrofit steam take-off at existing plants for energy efficiency and ability to deliver heat for district heating).
- Space requirements for additional equipment associated with PCC, where data is available

Any other relevant factors listed under Annex III of the Industrial Emissions Directive.

The University Of Sheffield. Energy Institute

Translational Energy Research Centre.

UKCCS RESEARCH CENTRE

Indicative project timetable

Approx. date	Activity and approx. interval
18/11/2021	Initial meeting with the UK regulators and industry stakeholders to discuss the scope of the review and elicit initial input (~4 working weeks)
3/1/2022	Outline for the review and questionnaires circulated for comment by regulators (2 weeks)
17/1/2022	Send questionnaires to industry stakeholders (2 weeks)
31/1/2022	Industry stakeholder responses returned (2 weeks)
28/2/2022	Analysis of industry responses and other relevant sources of information and first draft of review sent to UK Regulators for comment (4 weeks)
11/3/2022	Regulator comments returned and discussed, review updated as necessary (2 weeks)
28/3/2022	Draft review to industry stakeholders (2 weeks)
8/4/2022	Industry stakeholder responses returned (2 weeks)
wb 18/4/2022	Meeting(s) to discuss specific points with industry stakeholders (2 weeks)
2/5/2022	2nd draft review circulated for final comments by regulators and industry stakeholders (2 weeks)
6/5/2022	Comments received (1 week)
23/5/2022	Final review ready for publication on UKCCSRC web site (2 weeks)