

# Keadby Next Generation Power Station

## Environmental Permit Application

### Appendix E2 - Assessment of Best Available Techniques for Cooling

**The Environmental Permitting (England and Wales) Regulations 2016**

**Applicant: Keadby Next Generation Limited**

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## Document Version Control

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## GLOSSARY

Abbreviation	Description
ACC	Air-Cooled Condenser
BAT	Best Available Technique
BATc	Best Available Technique Conclusions
BRef	BAT Reference Document
CCGT	Combined Cycle Gas Turbine
CoC	Cycles of Concentration
CRT	Canals and River Trust
CT	Cooling Tower
DCO	Development Consent Order
DCS	Distributed Control System
EA	Environment Agency
EMS	Environmental Management System
FEED	Front End Engineering Design
GT	Gas Turbine
HRSG	Heat Recovery Steam Generator
LCP	Large Combustion Plant
LP	Low Pressure
NTS	National Transmission System (natural gas)
OTC	Once-through cooling
SAC	Special Area of Conservation
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
ST	Steam Turbine

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# 1. Introduction

This Appendix provides an assessment of the cooling options for the Keadby Next Generation Power Station ('KNGPS' or the 'Proposed Installation'). The purpose of this Appendix is to inform which potential cooling technology represents Best Available Techniques (BAT) for the Proposed Installation when considering environmental, capital and operating costs against potential benefits for each cooling option.

Arup has prepared this BAT assessment using concept engineering information related to the initial design parameters of the Proposed Installation, available information about the local environment and the existing standards and guidelines presented in published guidance, including:

- Best Available Techniques (BAT) Reference Document for Large Combustion Plants<sup>1</sup> (LCP BRef);
- BAT Conclusions for Large Combustion Plants<sup>2</sup> (LCP BATc);
- BAT Reference Document for Industrial Cooling Systems (Industrial Cooling BRef)<sup>3</sup>;
- Environment Agency (EA) Internal Report - Understanding the Environmental Impacts of Cooling Water Systems June 2024 (update to the EA Evidence Document SC070015/SR3 Cooling Water Options for the New Generation of Nuclear Power Stations in the UK (June 2010));
- The Eels (England and Wales) Regulations 2009.

The United Kingdom (UK) is no longer a member of the European Union (EU). Most EU legislation as it applied to the UK on 31<sup>st</sup> December 2020 is now a part of UK domestic legislation, under the control of the UK's Parliaments and Assemblies as a form of domestic legislation known as 'retained EU legislation'. This is set out in Sections 2 and 3 of the European Union (Withdrawal) Act 2018. Section 4 of the European Union (Withdrawal) Act 2018 ensures that most remaining EU rights and obligations, including directly effective rights within EU treaties, continue to be recognised and available in domestic law after exit.

The Main Supporting Document provides an overall view of the Environmental Permit application being made for the Proposed Installation. A BAT assessment has also been prepared for the LCP Proposed Installation (Appendix E1), recognising that the overall integration of this aspect will determine BAT for cooling for the Proposed Installation.

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<sup>1</sup> Best Available Techniques (BAT), Reference Document for Large Combustion Plants Industrial Emissions Directive 2010/75/EU of the European Parliament and of the Council, July 2021. Available at: [Large Combustion Plants | EU-BRITE](#)

<sup>2</sup> Commission Implementing Decision Establishing Best Available Techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for Large Combustion Plants, European IPPC Bureau, November 2021. Available at: [Large Combustion Plants | EU-BRITE](#)

<sup>3</sup> Integrated Pollution Prevention and Control Reference Document on the application of Best Available Techniques to Industrial Cooling Systems, December 2001. Available at: [EXECUTIVE SUMMARY](#)

## 1.1 Proposed Installation

The combined cycle gas turbine (CCGT) electricity generating station will include a single high-efficiency gas turbine (GT), heat recovery steam generator (HRSG), steam turbine (ST), steam cooling and condensate recovery systems and exhaust gas treatment, as well as ancillary plant, including cooling infrastructure, and flue gas stack.

The Proposed Installation will be designed to run on 100% hydrogen and capable of operating on 100% natural gas from the start of operations. When hydrogen becomes available and operation with hydrogen firing is commercially viable, the Proposed Installation will be upgraded to operate on a blend of natural gas and hydrogen or 100% hydrogen, dependent on its availability.

The ability to run on either fuel type will enable the Proposed Installation to facilitate the earliest possible decarbonisation of the electricity system, by ensuring that the technology is hydrogen-enabled, and switchover from natural gas to hydrogen can occur with minimal outage time as soon as the fuel is available, rather than awaiting fuel availability to commence development.

The Proposed Installation is to be sited adjacent to the existing Keadby Power Station site, which comprises of two operational power stations, Keadby 1 and Keadby 2. The Proposed Installation will be to the west of the Keadby 2 Power Station and covers an area of approximately 15ha.

A detailed description of the Proposed Installation is provided in Section 4.2 of the Main Environmental Permit Supporting Document.

### Cooling Load Assessment

Cooling is required for the CCGT to condense the steam after it has passed through the low-pressure (LP) section of the ST; a vacuum is maintained in the condenser in order to minimise the steam condensation temperature and therefore maximise the electrical generation from the steam turbine. By condensing the steam to the lowest temperature, the thermal efficiency of the steam cycle is maximised, and thus the highest electrical efficiency is obtained.

The cooling load associated with the CCGT plant will be of the order 410 - 445 MWth, comprising a main condenser cooling duty of 400 - 430 MWth and an additional auxiliary load of the order of 10 - 15 MWth.

## 1.2 Available Cooling Water Options

A number of options are available to provide cooling to the CCGT.

The Keadby 1 Power Station is cooled via once-through cooling (OTC) using existing abstraction licence (03/28/85/007) from the River Trent and an existing discharge outfall into the tidal River Trent, which forms part of the Humber Estuary Special Area

of Conservation (SAC), Special Protection Area (SPA) and Site of Special Scientific Interest (SSSI). If the Keadby 1 Power Station was to cease operation prior to the operation of the Proposed Installation, there would be potential to transfer the abstraction licence, however it is understood that the operational life of Keadby 1 will be extended, and therefore there is no guarantee that a licence transfer would be possible, and therefore that sufficient abstraction water from the River Trent would be available for the Proposed Installation.

The Keadby 2 Power Station is cooled by 12 hybrid (wet/dry) cooling towers using water taken from the Stainforth and Keadby Canal via an abstraction licence by the Canals and River Trust (CRT) (MD/028/0083/014).

In 2023 a variation to the Keadby 2 abstraction licence was granted for the already permitted Keadby 3 Carbon Capture and Storage (CCS) Power Station for additional cooling water abstraction from the Stainforth and Keadby Canal. As the Proposed Installation will be an alternative to the Keadby 3 CCS Power Station (as detailed in the Main Supporting Document) it is anticipated that the abstraction licence would be applicable to KNGPS to provide cooling water.

## 2. BAT Cooling Options

### 2.1 Typical Industrial Cooling Systems

The Industrial Cooling BRef document describes the key typical cooling systems used for industrial installations:

- Once through cooling system;
- Wet cooling system;
- Hybrid systems; and
- Air-cooled condensing system.

A brief description of each of these technologies is provided in the following sections.

#### Once-through Cooling

Once-through cooling (OTC) uses water pumped from a controlled water (such as an estuary, river or other surface water feature) via a large water inlet, directly in a heat exchanger or condenser, after which the heated water is discharged directly back into the surface water. OTC is typically used for large cooling capacities (>1,000 MWe).

OTC systems involve significant water requirements, with the Industrial Cooling BRef stating that such cooling systems can consume up to 86 m<sup>3</sup>/hour/MWth. OTC can be used either as a direct cooling medium, passing through a heat-exchanger against the stream to be cooled, or as an indirect cooling medium where a secondary heat-exchanger and recirculating cooling fluid are used (typically where there is a high environment risk if contamination of the cooling water occurs). Indirect OTC cooling is less efficient than direct cooling due to this secondary heat-exchange process and therefore has not been considered further in this assessment.

Once-through systems are affected by the availability of sufficient surface water and the water quality, as well as discharge limitations, for example the effect of the thermal load on the receiving water body and its ecological sensitivity. As all the cooling water used in once-through systems is usually discharged (rather than being recirculated), it undergoes only mechanical screening and coarse filtration to prevent serious damage to downstream equipment so that there is no change in water chemistry between the circulating water and the source water. Scale deposition of biological fouling is a common issue with once-through cooling systems and if the water is particularly corrosive (i.e. sea water or estuarine water, as would be the case for water within the River Trent at the Proposed Installation's location) the impact on material costs can therefore be significant.

Other environmental considerations include:

- The use of energy for pumping;
- The risk of eel or fish entrainment or impingement;

- Bio-fouling, scaling or corrosion; and
- The use of additives with subsequent discharge to the controlled water.

In addition, to minimise sediment entrainment, a forebay structure may be required and to ensure sufficient head of water to reach the plant, intake tunnels may be required at depth. If required these add further capital cost and maintenance obligations.

It is recognised that the EA typically considers direct OTC as potentially representing BAT for plants located in close proximity to a coastal or estuarine water source, as this maximises the thermal efficiency of the system and in theory there is sufficient water available. However, other cooling options can also represent BAT based on site-specific considerations.

### Wet Cooling Systems

Wet cooling towers use water as the main cooling medium with the heat lost through contact with air. The heat load in the cooling water is removed by evaporation within a cooling tower and the cooled water is recirculated within the system typically via a reservoir (cooling tower basin).

Cooling water is lost through evaporation and drift (entrainment of droplets), and the continuous evaporation results in a concentration of any dissolved salts present within the cooling water. In order to maintain the dissolved solid content to prevent precipitation, the cooling water is controlled to a design “cycles of concentration” (CoC) value, with a quantity of water removed from the basin (blow-down). In order to maintain the volume of water within the cooling tower recirculation, make-up water is added to the system to compensate for the losses from evaporation and blow-down.

The Industrial Cooling BRef states that the volume of make-up water required for power stations using an open loop wet cooling system can be 1 - 5% of that required for similar sized OTC systems.

Cooling water from the process is pumped to the top of the cooling tower and the water is distributed, by spray, over the cooling tower packing, to maximise the contact with air flow through the packing.

Drift eliminators are employed at the top of the tower to minimise the entrainment of water droplets within the air flow. The air exiting the tower will be saturated with water, and therefore visible plumes will frequently occur as the warm air mixes with colder atmospheric air causing condensation of the water vapour. The extent of the plume formation is dependent on weather conditions, with colder or more humid air resulting in larger plumes.

Several alternative designs for the water-air evaporative cooling stage can be employed, including:

- Natural-draught air flow, which relies on a pressure differential between top and bottom of the tower, generated by the change in density of the air, to induce a draught of air up the tower in a counter-flow to the cooling water; and

- Mechanical-draught air flow, which uses mechanically generated air flow using fans either at the top (induced-draught) or bottom (forced draught) of the tower; within these systems the air flow can be perpendicular to the water flow (cross-current) or in the opposite direction to the water flow (counter-current).

### *Natural Draught Cooling Towers*

Natural draught towers are made from reinforced concrete and may be 80 - 150m in height; they can emit continuous visible plumes when operational and therefore can present significant visual impact, as well as the potential for generating large visible plumes, plume grounding and the risk of icing of roads during certain weather conditions. Natural draught towers are best suited for areas of high relative humidity; and are high capital cost.

As such, natural draught towers are not considered to be appropriate for the Proposed Installation due to efficiency issues arising from typically lower relative air humidity, limited turndown flexibility, cost effectiveness for the cooling duty required and the visual impact of water plumes and the towers themselves. The use of natural draught cooling towers has therefore been discounted from this assessment.

### *Mechanical Draught Cooling Towers*

Mechanical draught towers are typically smaller than natural draught towers, and therefore the capital investment is lower. However, the use of mechanical fans to drive the air flow through the towers represents a parasitic load on the process and can also generate additional noise emissions.

Mechanical draught systems also produce visible plumes, albeit at lower tower exit height than for natural draught systems. The impacts from visible plumes depend on the proximity and sight-lines of nearby receptors.

The make-up water can be drawn from saline or non-saline sources, but in both cases, the water intake system needs to be protected from organic growth to prevent blockages. Disinfection processes (e.g. chlorination) are required for legionella protection, although this has a potential environmental impact from the discharge; alternatively, thermal treatment can be employed although this is more complicated to operate and may affect thermal efficiency of the process. Where saline water is used, the material of construction for heat-exchangers must be able to withstand the more corrosive effects from salinity and are higher capex.

Wet cooling towers are typically not suitable for installations located in close proximity to transport routes or residential receptors due to their high visual impact from high cooling towers and tendency to produce large visual plumes which can result in overshadowing of property and ice formation on roads in certain conditions.

### Hybrid ('Wet-Dry') Cooling

Hybrid cooling (also known as plume-abated mechanical draft cooling) uses a combination of dry air cooling and evaporative cooling methods.

The cooling water is first dry-cooled, by passing through tube banks in the hybrid cooling towers over which air is drawn by forced draught fans; the cooling water then passes to a wet cooling stage where it is sprayed over packed bed elements, to provide an extended, and therefore more efficient, air/ water contact surface area. In the wet cooling stage, the water is cooled by two effects: the direct contact of the cold air flow with the water, and the cooling effect of the evaporation of a small proportion of the water.

This method of cooling is more efficient than air-cooled condenser (ACC); it benefits from the more efficient water-cooling heat exchange characteristics but still relies on the ambient air conditions to achieve some cooling (the 'approach temperature difference' between cooling water and the ambient wet-bulb temperature). Due to the application of air cooling, the water demand for these cooling systems is lower than that for fully wet systems.

Hybrid tower systems are comparable in size to mechanical draught cooling towers. However, the additional fans result in a higher associated auxiliary power load and greater noise generation than fully wet cooling methods. In common with ACC, noise generation from fans may be higher than from fully wet cooling methods, however the footprint of hybrid towers is much smaller than ACC as a result of the efficiency of the wet-cooling section.

The hybrid tower system requires make-up water to compensate the losses through evaporation and the purge of concentrated salts in the recirculated water; however, the water consumption is approximately 10% of that for wet cooling systems. The Industrial Cooling BRef states that the consumption of water for an open hybrid tower is typically around 0.5 m<sup>3</sup>/hour/MWth compared to 86m<sup>3</sup>/hour/MWth for an open once-through system.

Hybrid cooling towers can intermittently generate visible plumes of water vapour under certain weather conditions, in particular during cold or humid weather, however the incidence of such plumes is significantly less than for fully wet-cooling systems as the evaporated water is heated (thus increasing the saturated vapour pressure of water in the emission from the hybrid tower) as the vapour passes across the dry cooled section.

Hybrid cooling has higher capex and parasitic loading than fully wet systems. However, hybrid cooling may represent BAT where plume-abatement and visual impact of tall towers or visible plumes are considered important.

### [Dry Air-Cooling Condensers \(ACC\)](#)

Dry air-cooled condensers (ACC) provide cooling by passing a cooling flow of air over finned tubes within a bank of condensing heat exchangers which contain the medium to be cooled (typically steam). These banks of heat exchangers are normally mounted in an elevated structure to allow good and even air flow across the heat exchange surfaces; the air flow is created by large fans.

Direct ACC circulates the process stream (steam in the case of CCGT) through the heat exchanger, whereas indirect ACC circulates a secondary cooling medium

(typically water) through the heat-exchanger and this returns to cool the process stream via a condenser.

ACC requires no off-site infrastructure and relies solely on the supply of electrical energy to operate the fans. Whilst this represents a more substantial parasitic load on the plant than for some cooling options, there is no requirement to pump cooling water.

The heat-transfer characteristics of the air-cooled heat exchangers means that this is typically the least favourable arrangement for UK CCGT plant efficiency; this is particularly marked at higher ambient air temperatures.

ACC has the added disadvantage of the noise generated by the fans and the larger footprint required to achieve the necessary level of cooling.

However, ACC offers benefits in other areas such as avoiding the environmental impacts associated with water abstraction and discharge, as well as the construction effects of the associated pipework infrastructure; and heat is discharged directly to the air without the generation of visible plumes created by wet methods.

## 2.2 Indicative BAT for Power Station Cooling Systems

BAT for cooling systems is defined in the Industrial Cooling BRef document and this document is referenced in the LCP BRef and the EA's Understanding the Environmental Impacts of Cooling Water Systems document.

Indicative BAT for cooling in relation to power stations is defined as follows:

*“In an integrated approach to cooling an industrial process, both the direct and indirect use of energy are taken into account. In terms of the overall energy efficiency of an installation, the use of a once-through system is BAT, in particular for processes requiring large cooling capacities (e.g. >10 MWth). In the case of rivers and/ or estuaries once-through can be acceptable if also:*

- *Extension of heat plume in the surface water leaves passage for fish migration;*
- *Cooling water intake is designed aiming at reduced fish entrainment, as required under the Eels Regulations; and*
- *Heat load does not interfere with other users of receiving surface water.*

*For power stations, if once-through is not possible, natural draught wet cooling towers are more energy-efficient than other cooling configurations, but application can be restricted because of the visual impact of their overall height.”*

This preference for considering OTC as BAT has been called into question, not least because of the age of the Industrial Cooling BRef (2001) but also a number of studies, particularly in the US, suggest that the impact on fish may be greater than previously thought.

Freshwater reaches of rivers are now considered unsuitable for direct-cooled stations, and the EA's own work confirms the use of tower cooling for river-cooled stations to be indicative BAT for sites situated close to large rivers (Evidence Document SC070015/SR3). However, depending on the local environmental sensitivities, in accordance with EA Technical Guidance, hybrid or air-cooled systems can also be regarded as BAT, subject to an appropriate and site-specific assessment.

## 3. Existing Environment

### 3.1 Overview

This section describes the environmental context for the Proposed Installation, in particular the local environment with the potential to be impacted by the cooling options under consideration.

The Proposed Installation Site is located 5km to the west of the town of Scunthorpe, adjacent to the village of Keadby.

The Proposed Installation Site comprises an area of 'Keadby Common' which was previously used for arable agriculture but has recently been used as a laydown and soil storage area for the construction of the Keadby 2 Power Station. Beyond the Proposed Installation, land use is almost entirely low-lying arable land interspersed with scattered villages, however, the immediate Site surroundings have been developed in recent years with power related infrastructure, including the existing Keadby 1 and 2 Power Stations, the pylons associated with the existing National Grid 400kV Substation and the operational Keadby Windfarm to the north and east of the site.

A number of environmental receptors have been identified in the vicinity of the Site. All distances are given as the shortest distance between the receptor and the closest point of the Proposed Installation boundary.

### 3.2 Residential Receptors

The nearest settlement is the village of Keadby which is located approximately 1km east of the Proposed Installation.

Other settlements nearby include: Gunness (580m) to the east on the eastern bank of the River Trent; Althorpe (1.7km) to the south-east; Ealand (2.2km) and Crowle (3.6km) to the west. Closer to the Site are a small number of residential areas and individual residential properties.

### 3.3 Ecological Receptors

The nearest statutory and non-statutory nature conservation designations to the Site include European Statutory Designated sites comprising Special Areas of Conservation (SACs), Special Protection Areas (SPAs), Ramsar sites and Sites of Special Scientific Interest (SSSIs) as well as non-statutory sites such as National Nature Reserves (NNRs) and Local Wildlife Sites (LWSs) within 10km of the Site. Table 3.1 details all the identified ecological receptors, however only the Humber Estuary (1) and Stainforth and Keadby Canal (14) receptors are considered likely to be impacted by selection of water source and cooling technique.

**Table 3.1: Sensitive Ecological Receptors in the Vicinity of the Proposed Installation**

Site	Designation	Distance and Direction from the Proposed Installation (km)
Humber Estuary	SAC, SPA, SSSI and Ramsar	1.3 km east
Thorne Moor	SAC, SPA and SSSI	6.3 km northwest
Hatfield Moor	SAC, SPA and SSSI	10.4 km west
Crowle Borrow Pits	SSSI	2.9 km west
Hatfield Chase Ditches	SSSI	3.4 km southwest
Eastoft Meadow	SSSI	3.7 km northwest
Belshaw	SSSI	7.7 km southwest
Risby Warren	SSSI	9.1 km east
Messingham Heath	SSSI	9.9 km southeast
Keadby Boundary Drain	LWS	600 m west
Stainforth and Keadby Canal Corridor	LWS	150 m south
Keadby Warping Drain	LWS	290 m north
South Soak Drain	LWS	250 m south
Keadby Wetland	LWS	695 m east
Keadby Wet Grassland	LWS	710 m east

### 3.4 Surface Waters

The River Trent is saline at the location of the Proposed Installation, and forms part of the Humber Estuary designation, as described above. The river is expected to contain juvenile and adult eel, and would require the use of eel screens, eel/ fish suitable pumps, and limits on abstraction approach velocity in accordance with current regulations and guidance.

The River Trent also experiences pronounced spring and neap tides that result in significant (diurnal and seasonal) variation in suspended sediment within the river at the existing Keadby 1 abstraction point. The requirement for large screen areas to comply with the Eels Regulations would require the management and mitigation of silt and sedimentation, particularly during periods of plant down-time and start-up associated with dispatchable operation.

As the Stainforth and Keadby Canal has potential connectivity for eel migration from the river, any new abstraction point would require appropriate mitigation (screens and approach velocity restrictions) to meet the Eels Regulations. The canal also contains other aquatic organisms (duckweed, waterweed and Zebra mussels) that would require additional maintenance of screens to avoid blockages.

## Abstraction

The existing Keadby Power Station site currently holds several abstraction licences for surface water abstraction, as follows:

- 3.4.1 The abstraction licence for Keadby 1 Power Station for non-evaporative cooling and boiler make up (licence number 03/28/85/0007), allows for the abstraction of up to 324,000,000 m<sup>3</sup>/year or up to 984,000 m<sup>3</sup>/day (approximately 41,000 m<sup>3</sup>/hour) from the River Trent.
- 3.4.2 A further abstraction licence for boiler make-up for Keadby 1 Power Station allows for up to 1,700 m<sup>3</sup>/day (approximately 70 m<sup>3</sup>/hour) from the Stainforth and Keadby Canal.
- The abstraction licence for Keadby 2 Power Station for evaporative cooling (MD/028/0083/014) allowed for abstraction of up to 4,950,000 m<sup>3</sup>/year or up to 1,253 m<sup>3</sup>/hour from the Stainforth and Keadby Canal.

The EA varied the licence to abstract from Stainforth and Keadby canal (MD/028/0083/014) in 2023 to add an additional abstraction location and to increase the abstraction volumes to an aggregated annual volume of 12,200,000 m<sup>3</sup>/year. The licence states the purpose of abstraction is for evaporative cooling, boiler feed water, make-up or top-up water and process water.

As stated previously, this variation was for the purpose of providing cooling water to the proposed Keadby 3 CCS Power Station, and therefore as the Proposed Installation is an alternative to this already permitted Installation, it is considered that the additional cooling water could be used for the Proposed Installation.

Whilst it is understood that there is spare capacity in the Keadby 1 River Trent abstraction, it is not considered that there is sufficient spare capacity to provide the quantities required for the Proposed Installation. In addition, as stated previously, Keadby 1 will continue to operate for as long as it remains viable, and therefore there would be uncertainty as to whether a transfer of the abstraction licence to the Proposed Installation could be made for the when the Proposed Installation will be operational.

Due to the issues associated with abstraction from the River Trent, and the fact that abstraction from the Stainforth and Keadby Canal is already licenced, this would be the preferred source of cooling water for the Proposed Installation.

## Discharge

The Environmental Permit for the existing Keadby Power Station site (EPR/YP3133LL/V013) includes a discharge of cooling water and process waters via the Keadby 1 outfall (Emission Point W1) to the River Trent, with the following conditions:

- Daily maximum flow: 15m<sup>3</sup>/s;
- Total daily volume: 985,670m<sup>3</sup>/day;

- Oil or Grease: No visible emission; and
- Absolute Discharge Temperature: 35°C (98<sup>th</sup> percentile)
- Suspended solids 60mg/l

As Keadby 1 employs OTC, there are no contaminants present in the returned water, and therefore there is limited monitoring requirements on this discharge point.

Keadby 2 Power Station shares the same outfall, but discharges into the Keadby 1 cooling water infrastructure at a compliance point (Emission Point W10). As Keadby 2 is cooled via Hybrid Cooling Towers, there are more monitoring controls in place on the compliance point, namely:

- pH: 5 – 10
- Daily maximum flow: 100l/s
- Residual chlorine: 0.2mg/l
- Conductivity: <5000uS/cm
- Oil and Grease: No visible emission
- Absolute Discharge Temperature: 35°C

The cooling water discharge from the permitted Keadby 3 CCS Power Station was also proposed to use the same outfall and an additional compliance point (Emission Point W12) was added to the Environmental Permit for the existing Keadby Power Station site to manage this. This discharge has similar controls in place for the Keadby 2 Power Station, namely:

- pH: 6 – 9
- Daily maximum flow: 83.5l/s
- Residual chlorine: 0.2mg/l
- Conductivity: <5000uS/cm
- Oil and Grease: No visible emission
- Absolute Discharge Temperature: 46.6°C

As the Proposed Installation is an alternative to the permitted Keadby 3 CCS Power Station, it is envisaged that the Proposed Installation would also share the same outfall to the River Trent (Emission Point W1) which is associated with the existing Keadby Power Station Environmental Permit. As such, a compliance point would be included in the Proposed Installation's Environmental Permit at the point where the discharge into the W1 outfall occurs, which would have similar controls in place to those already permitted for Keadby 3.

### 3.5 Climate Change Considerations

The exchange of heat is driven by the temperature difference between the 'hot' and 'cold' side of a heat exchanger. Therefore, the efficiency of any cooling system is dependent on the temperature of the cooling medium and how effectively heat can be transferred from the process to the media.

#### Effects of Air Temperature Change

For air-cooled systems, the dry bulb temperature, which is higher than the wet-bulb temperature, defines the minimum temperature for cooling.

In effect this means that during hot, dry weather, air-cooled systems are much more limited in the cooling performance achievable compared with wet-cooled systems and are affected more generally by fluctuations in air temperature than wet systems. The condenser performance and consequently the ST output (and hence plant generation efficiency) is limited by the ambient temperature and in warm ambient temperature this can significantly de-rate the ST for systems using ACC.

#### Effects of source water temperature change

For wet (evaporative) cooling systems, and hybrid cooling systems, the wet bulb temperature (a function of atmospheric temperature, relative humidity and air pressure) influences the rate of evaporation as this is the theoretical lowest temperature to which water can be cooled by evaporation. Therefore, in case of a rise in surface-water temperature from the abstraction source, this would have a more limited impact on the efficiency of the plant as the variability in water temperature and wet bulb temperature is less significant than that of dry bulb which governs air cooler performance.

### 3.6 Key Considerations

Nearby residential receptors are considered to be the most sensitive receptors to visual and noise impacts from the cooling options. The internationally designated ecological receptor (Humber estuary) is considered to be the most sensitive to water impacts from the cooling options. Potentially significant impacts would be:

- Visual impact of evaporative water plumes (visible plumes) from cooling towers, and cooling towers themselves, on adjacent and nearby residential receptors;
- Noise from pumps or fans with mitigation required to avoid impacts on local residential receptors; and
- The abstraction of water, with mitigation required to avoid entrainment of aquatic organisms;

Impacts on river water chemistry and biodiversity from the discharge of water with thermal plume and potential water treatment chemicals, requiring mitigation in the form of treatment prior to discharge, and specific discharge regimes;

Temporary construction impacts from installation of additional intake and outfall pipework.

## 4. Cost Benefits of Available Cooling Options

### 4.1 Identifying Available Options for Assessment

#### Surface Water Source and Discharge Considerations

The current abstraction licence from the Stainforth and Keadby Canal, in place for the proposed Keadby 3 Power Station, is considered to be applicable to the Proposed Installation, as only one of the two proposed Power Stations would be constructed, as detailed in the Main Supporting Document.

An intake structure would be constructed within the Canal with equipment to comply with the Eels Regulations and relevant conditions within the abstraction license together with intake pipework, a wet well pumping station and chlorination plant. A pipe would be constructed from this inlet into the Proposed Installation.

To achieve the required cooling water quality standards for use in recirculating (cooling tower) options, water from the canal would require the following additional treatment stages:

- Media filtration
- pH correction
- Anti-scalant and biocide dosing

There would not be sufficient water available from the canal for OTC, and therefore although it is not considered to be an available option, due to the potential continued operation of Keadby 1, for the purpose of the assessment a scenario where OTC water could be provided from the River Trent under the existing Keadby 1 abstraction licence is included.

Implementation of OTC is limited by the allowable temperature rise (deltaT,  $\Delta T$ ) of receiving water which is controlled by restricting the temperature of the cooling water discharge. For the assessed cooling options comprising OTC, two scenarios have been considered, a 10°C allowable cooling water temperature rise with 35°C maximum at discharge outfall (as assumed for Keadby 1 Power Station), and an 8°C allowable cooling water temperature rise and 32°C maximum at discharge outfall (lower than Keadby 1).

#### Land Availability

The total available area for the Proposed Installation is approximately 150,000m<sup>2</sup>; any cooling option implemented will need to consider the footprint of the Proposed Installation. The estimated available area includes the area required for the CCGT plant, natural gas and hydrogen Above Ground Installations, cooling, heat exchangers, water treatment plant and other site infrastructure.

### Discounted Options Based on Technical Viability

Several cooling options have been discounted from the assessment as they are not considered technically viable, as follows:

- Installation of new natural draught towers is likely to attract public opposition and challenge within the current planning regime, as a result of the significant visual impact from structure massing and continuous visible plumes. Mechanical draught cooling towers would be of smaller footprint and height than natural draught towers but would still produce visible plumes. Visible plume from condensed water vapour, likely to be continuous, would have a potential for significant visual impacts, icing or fogging on local roads, and loss of light at local properties. Based on the previous precedent for Keadby 2, natural draught towers and mechanical draught wet cooling towers have been discounted from further assessment.
- The Stainforth and Keadby Canal is understood to have insufficient water supply to provide for the OTC requirements; abstraction from the canal is therefore considered only for those options which use cooling towers (make-up water).
- Air cooling (ACC) for the CCGT has been discounted as it is not expected to achieve the necessary level of generation efficiency with the available space, which would make the operation unviable. This is due to the lower net electrical output & efficiency, relative to other cooling techniques which are broadly comparable. As water is available in the area for cooling, it is not considered necessary to consider ACC further. It is also considered that the footprint associated with ACCs would be larger than the space available within the Installation for cooling.

## 4.2 BAT Options Assessment

An assessment<sup>4</sup> of the remaining potential cooling options for the Proposed Installation has been carried out to evaluate the techniques, that could be applied.

For the design reference case, summer, winter and minimum flow operations have been considered, as well as two potential cooling water temperature rises and maximum temperatures at the discharge outfall.

The assessment included consideration of the overall cooling duty of each option, water consumption, water source and necessary treatment, parasitic energy load and capital costs for equipment, pipework and intake and outfall upgrades.

The assessment included options leading to 8°C or 10°C potential cooling water temperature rise and 32°C or 35°C maximum at discharge outfall. A total of 18

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<sup>4</sup> AECOM Cooling Study Technical Note, 2024.

combinations of cooling water source, cooling technologies, potential cooling water temperature rises and maximum temperatures at discharge outfall were assessed.

The most viable options for the cooling at the Proposed Installation are defined in Table 4.1 and their operational and cost parameters considered within the assessment are compared in Table 4.2, together with a ranking assigned to each option according to the overall energy efficiency, water consumption, specific cooling cost (lifetime costs per MWth cooling duty) and capex, and an overall ranking.

The options that include OTC using water from the River Trent, are ranked proportionately lower, taking into consideration the uncertainty over the availability of this cooling water in light of the potential continued operation of Keadby 1 and the potential environmental impact of abstraction and discharge in light of the Eels Regulations requirements (albeit with applied mitigation), and therefore are considered less favourable.

The higher deltaT allowance for each comparable pair of OTC options (10°C vs 8°C) results in a higher overall ranking, due to lower volume flow and hence pumping costs and parasitic load.

**Table 4.2: Cooling Options Assessed for the Proposed Installation**

Option	CCGT Plant
1	Once Through cooling using water abstracted from the River Trent with a temperature difference of 10°C between intake and outfall
2	Once Through cooling using water abstracted from the River Trent with a temperature difference of 8°C between intake and outfall
3	Hybrid (plume abated mechanical draft) cooling tower using treated water from the River Trent (desalination Reverse Osmosis)
4	Hybrid (plume abated mechanical draft) cooling tower using treated water from the Stainforth and Keadby Canal
5	Hybrid (plume abated mechanical draft) cooling tower using water from the River Trent i.e. brackish water with no reverse osmosis desalination

**Table 4.3: Cooling Options Estimated Performance and Operating Parameters**

Option Ref	Cooling Water Flow (t/h)	River Water Abstraction (t/h)	Canal Water Abstraction (t/h)	Footprint (m <sup>2</sup> ) <sup>1</sup>	Impact on CCGT EE%	Impact on Parasitic Load	Ranking (1 = highest)				Overall rank
							Specific Cooling (GBP/MWth) <sup>(2)</sup>	LHV Efficiency	Capex Cost <sup>(3)</sup>	Opex Cost	
1	36,140	36,140	N/A	100	1	1	3	1	2	4	2
2	46,188	46,188	N/A	89	2	2	5	2	3	5	3
3	33,446	520.5	N/A	2,310	4	4	2	4	5	3	4
4	33,212	N/A	516.8	2,310	3	3	1	3	1	1	1
5	33,446	520.5	N/A	2,310	5	5	4	5	4	2	5

- (1) The viability of each option has been assessed on the basis of the total footprint of the Proposed Installation – options in excess of available area ranked lowest
- (2) Specific cooling cost is based on the plant lifetime cooling duty vs capital and operation costs (including water treatment, utilities, plant maintenance & replacement costs)
- (3) This includes the installation of Intake & Abstraction Pumps, Water Treatment plant, Outfall works, Heat Exchanger (cooling), Cooling Water Pumps, Cooling Equipment and associated major pipe work for the cooling system.

### Discounted Options on the basis of Water Abstraction Volume

A number of options have been discounted on the basis that the required abstraction rate from the River Trent would be in excess of the current abstraction consent volume for Keadby 1 power station and therefore unlikely to be viable.

Options with a high river abstraction volume for OTC that have therefore been discounted for the Proposed Installation include Options 1 and 2.

### Identified BAT Option

Option 4, hybrid cooling using water abstracted from the Canal, represents the highest-ranking option with consideration of the overall efficiency of the plant, potential for environmental impacts resulting from abstraction and discharge of make-up cooling water, visual impacts of footprint and building massing and visible plumes, and costs. This option also provides for greater integration and flexibility within the cooling system for the Proposed Installation as a whole, representing the BAT.

## 5. BAT Conclusion

The assessment of cooling techniques for the Proposed Installation has considered a range of options, for the design reference case, under summer, winter and minimum flow operations, as well as two potential cooling water temperature rises and maximum temperatures at discharge outfall.

The assessment included consideration of the overall cooling duty of each option, net power generation, water consumption, water source and necessary treatment, parasitic energy load from pumps, and fans, and capital costs for equipment, pipework and intake and outfall upgrades.

The options for cooling configuration for the Proposed Installation were ranked according to the overall energy efficiency, water consumption, specific cooling cost (lifetime costs per MWth cooling duty) and capex.

The use of hybrid cooling towers, with water sourced from the Stainforth and Keadby Canal, was ranked the highest, this therefore is the preferred option for the Proposed Installation. As the abstraction licence for the Canal has been varied for the additional water required for the proposed Keadby 3 CCS Power Station, which is an alternative to KNGPS, it means that the required water for cooling is available.