The Potential Wider Environmental Effects of Industrial Decarbonisation

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In this briefing note, Adam Clegg and Laurence Caird, of Air Quality Consultants Ltd., explore the challenges of industrial decarbonisation, the technologies coming forward, the potential for air quality and climate change trade-offs, and other cross-media effects associated with the introduction of these technologies.

The Need for Industrial Decarbonisation

In 2015, the UK Government, together with 195 other nations, signed the Paris Agreement[1]. The Paris Agreement makes a commitment to reduce greenhouse gas (GHG) emissions to prevent annual average global temperatures rising more than 2 degrees above pre-industrial levels by 2100. The ideal target of the Paris Agreement is to restrict global temperature rise to 1.5 degrees above pre-industrial levels.

In response to the Paris Agreement, the UK Government has committed to reducing national GHG emissions to net zero by 2050. This commitment was enshrined in UK law in 2019[2] through the Climate Change Act 2008 (2050 Target Amendment) Order 2019. The commitment includes reducing all UK GHG emissions from domestic, commercial, industrial, transport, waste and energy sources to net zero by 2050.

The Department of Business Energy and Industrial Strategy (BEIS) estimate total UK GHG emissions from industry to be just over 70 Mt/yr, which is equivalent to approximately 15% of the UK's total carbon footprint (estimates based on 2018 data). Unlike sectors such as transport and domestic heating, which involve lower quantities of emissions from a very large number of individuals or businesses, the UK's industrial carbon emissions are dominated by a relatively small number of large emitters, principally those in the oil refining, chemicals, iron and steel, cement production and other energy intensive sectors, such as glass and lime. BEIS estimates that around half of the UK's industrial carbon emissions are concentrated within 'industrial clusters', which are locations with a high density of large industrial activity in South Wales, Merseyside, Humberside, Teesside, Southampton and Grangemouth.

Primary carbon emissions from these sectors relate to the substantial energy provision many of these processes require. Most processes source energy from the combustion of fossil fuels, which results in carbon emissions to atmosphere. This energy production accounts for over 85% of carbon emissions from UK industry, with much of the remainder associated with chemical processes where carbon dioxide or other greenhouse gases are a by-product, such as cement production.

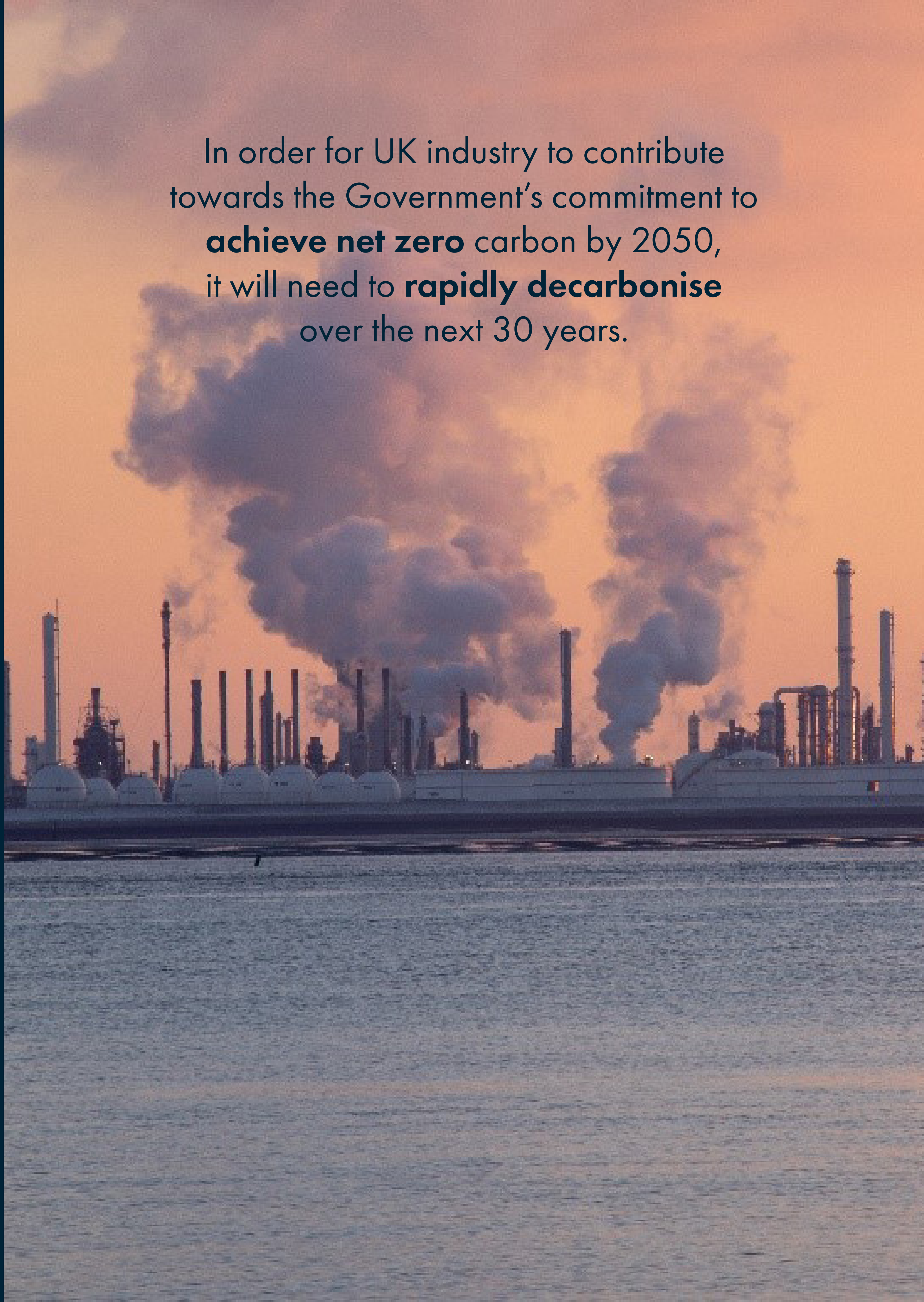
In order for UK industry to contribute towards the Government's commitment to achieve net zero carbon by 2050, it will need to rapidly decarbonise over the next 30 years. In order to do this, a robust and ambitious decarbonisation strategy is required, identifying key technologies and measures that need to be delivered to achieve carbon neutral industry, together with key targets and milestones for carbon reduction on the pathway to 2050.

In March 2021, BEIS published the UK Government's Industrial Decarbonisation Strategy[3], which sets out targets and actions to reduce industrial emissions to net zero by 2050. The Strategy targets a two-thirds reduction in carbon emissions by 2035 (compared to 2018 emissions) and a 90% reduction by 2050, with the residual 10% of emissions to be offset in 2050 to achieve net zero.

A number of key technologies are identified in the Strategy that will help UK industry achieve these targets.. These technologies include Resource Efficiency and Energy Efficiency (REEE), Electricity, Hydrogen, Bioenergy, and Carbon Capture Utilisation and Storage (CCUS) targeted at the industrial cluster sites and also more dispersed sites.

Whilst measures such as REEE will also generate positive cross-media effects by reducing emissions of air pollutants through the reduction in primary energy consumption, it is important to recognise that not all of these measures have similar positive cross-media effects.

Here, we investigate the potential negative cross-media effects for three principal technologies proposed by the Government's Industrial Decarbonisation Strategy; namely, Carbon Capture Utilisation and Storage (CCUS), Hydrogen, and Bioenergy with CCUS (BECCS).



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[1] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[2] https://www.legislation.gov.uk/ukdsi/2019/9780111187654

[3] https://www.gov.uk/government/publications/industrial-decarbonisation-strategy

Carbon Capture Utilisation & Storage

Carbon Capture Utilisation and Storage (CCUS) is a method of removing carbon dioxide from a process stream so that it can be utilised as a raw material in other industrial sectors, or stored, typically in underground geological formations where it cannot re-enter the atmosphere. CCUS can be applied either pre-combustion, where solid fuels undergo gasification to produce a synthetic gas ('syngas'), with the carbon dioxide removed from the syngas before it is combusted, or applied post-combustion, where the carbon dioxide is captured from the flue gases before they are discharged to atmosphere.

There are a variety of methods for capturing carbon dioxide, but the most common is to scrub the syngas or stack discharge with an amine-based solvent. The carbon dioxide is absorbed in the solvent, with a subsequent regeneration process separating the carbon dioxide from the solvent, which is then recycled back to the scrubber.

An undesired cross-media effect associated with this process is that the scrubbing and regeneration process is not 100% efficient in recovering the amine solvent. The solvent can degrade through oxidation, thermal degradation, chemical reactions with other species, or can be lost through evaporation or carry-over with the cleaned flue gas ('slippage'). Ammonia, nitrosamines, nitramines, amides, aldehydes and volatile acids are the main degradation products, with ammonia being the principal by-product. Amine slippage rates of up to 16 mg/m3 (milligrams per cubic meter) have previously been reported in pilot trials of CCUS plants, although more recent trials indicate much lower rates of slippage, suggesting an improvement in process control optimisation[1].

Amine solvents used for CCUS, such as monoethanolamine (MEA), have associated health effects and the Environment Agency is currently consulting on new environmental assessment levels (EALs) for MEA in response to the projected growth in CCUS[2]. The main potential health effect, however, relates not from the amine slippage, but through the degradation of amines to nitrosamines, such as N-nitrosodimethylamine (NDMA), N-nitrosodiethylamine (NDEA) and N-Nitrosodiethanolamine (NDELA), where assessment metrics proposed for the protection of human health are established in terms of ng/m3 (nanograms per cubic meter), an order of magnitude lower than that proposed for MEA.

Amines, nitrosamines and nitramines undergo further complex, multiphase chemical reactions in the atmosphere that either affect their degradation through photolysis or reactions with chlorine, nitrate and hydroxyl radicals or ozone, or can result in their additional formation through reactions with certain oxides of nitrogen. These reactions are an important component of understanding and assessing the potential impacts of CCUS plants on human health.

In terms of the principal degradation product of amine solvents in CCUS plants, i.e., ammonia, whilst it too is associated with potential impacts on human health, its assessment levels are much higher than those proposed for NDMA. Rather, the main potential cross-media effect here relates to impacts on designated nature conservation sites, both through the direct effects of exposure to ammonia and the indirect effects associated with nitrogen and acid deposition and the acidification and eutrophication of habitats and ecosystems. This is analogous with potential cross-media effects from another commonly applied emissions control technique for oxides of nitrogen, i.e., ammonia slippage in selective catalytic reduction (SCR) plants.

Although amine scrubbing is a well-established technique in the oil and gas industry for removing hydrogen sulphide from sour (i.e., high sulphur) gases, the Environment Agency consider the risks associated with amine degradation from post-combustion CCUS could be higher due to different compositions of the gas streams being treated[3]. Post-combustion CCUS could also affect the dispersion characteristics of the flue gases by reducing discharge temperatures and velocities. The Environment Agency is currently developing new guidance for establishing Best Available Techniques for new-build and retrofit post-combustion CCUS plants which may address such aspects.

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[1] https://www.sepa.org.uk/media/155585/review-of-amine-emissions-from-carbon-capture-systems.pdf

[2] https://consult.environment-agency.gov.uk/environment-and-business/new-air-environmental-assessment-levels/

[3] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/296425/geho041

Hydrogen

Industrial scale hydrogen production can be delivered using a variety of techniques, each assigned a different 'colour':

- **Grey hydrogen** – hydrogen production using steam methane reforming (SMR) where a number of chemical and physical processes can be used to extract and separate the hydrogen found in methane / natural gas. The overall process is strongly endothermic, i.e., heat must be supplied to the process for the reaction to proceed, usually through combustion of a fuel, whilst the process of generating additional hydrogen from the carbon monoxide generated in the reformer vessel via the water-gas shift reaction produces carbon dioxide as a reaction product. In grey hydrogen production, the carbon dioxide produced from fuel combustion and the water-gas shift reaction is discharged to atmosphere.
- **Blue hydrogen** – like grey hydrogen, blue hydrogen is generated using SMR but with the additional application of CCUS to capture carbon dioxide emitted from the process.
- **Green hydrogen** – hydrogen produced through the electrolysis of water using electricity generated from renewable power sources.

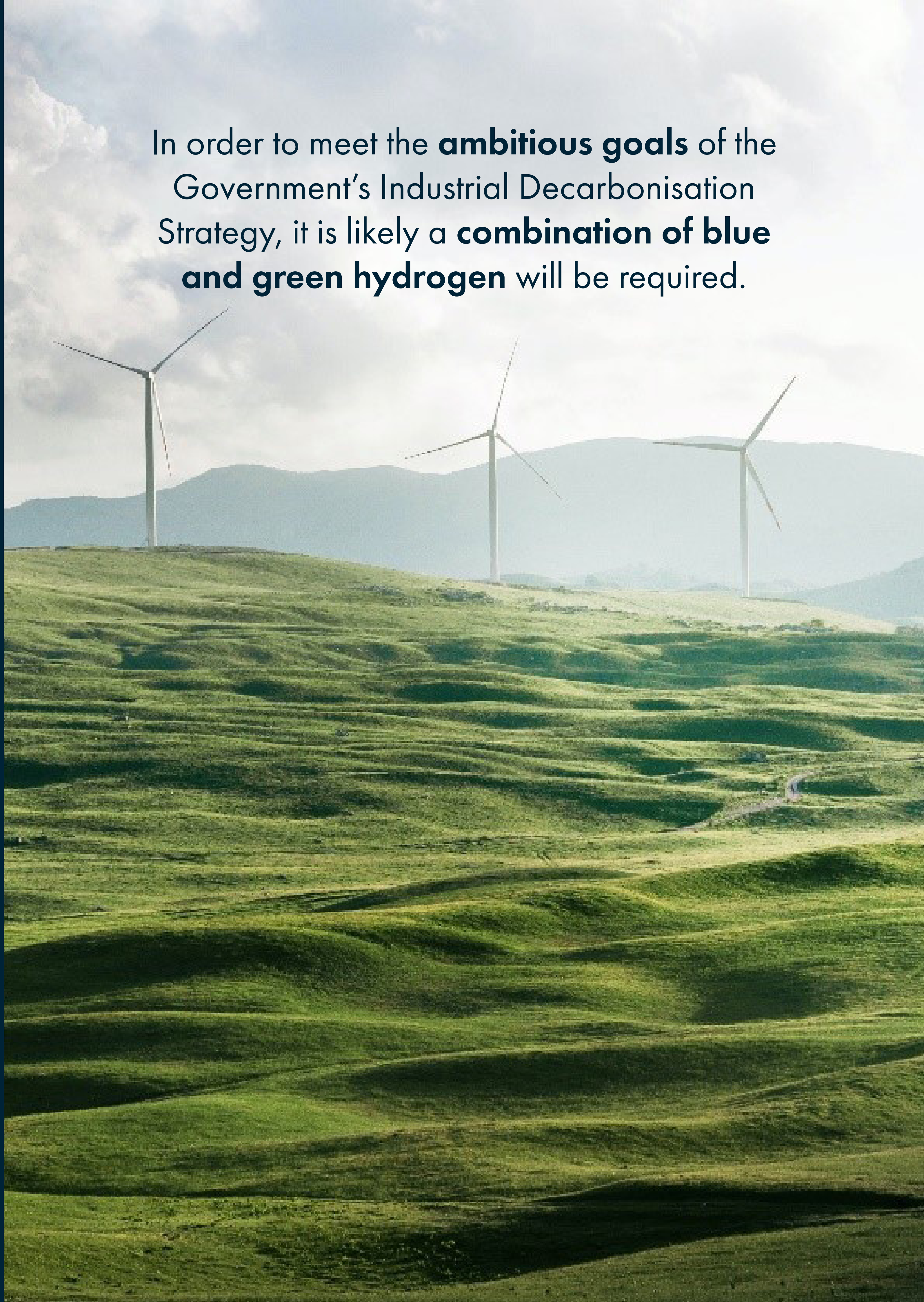
The hydrogen generated by these technologies can be used as a direct replacement for natural gas and, with hydrogen containing no carbon, the principal production of combustion is water vapour, resulting in carbon savings from fuel combustion. Alternatively, the hydrogen can be used to generate electricity in fuel cells.

In order to meet the ambitious goals of the Government's Industrial Decarbonisation Strategy, it is likely a combination of blue and green hydrogen will be required.

Whilst blue hydrogen will assist the move towards carbon net zero, the combustion of fuel in the reformer may result in emissions to air of other combustion products, including oxides of nitrogen, as CCUS plants do not fully capture these other pollutants.

Green hydrogen is associated with no/much lower direct emissions of air pollutants. However, dependent on the type of electrolysis technique applied, the electrodes can require the use of precious metals, and indirect effects could occur from the increased extraction and refining of metal ores to support the additional demand for such metals. This is a similar consideration for the batteries used in electric vehicles.

Irrespective of which technique is used to produce hydrogen, when hydrogen is combusted to generate energy, peak flame temperatures are higher than those from the combustion of natural gas. This promotes the thermal formation of oxides of nitrogen and could result in a net increase in such emissions from energy generation, although such an outcome could be mitigated through re-optimising combustion control systems or application of secondary emission control techniques.



In order to meet the **ambitious goals** of the Government's Industrial Decarbonisation Strategy, it is likely a **combination of blue and green hydrogen** will be required.

When Carbon Capture Utilisation and Storage is applied in combination with **bioenergy**, it is possible to create a **carbon negative** process.

Bioenergy with CCUS (BECCS)

Bioenergy refers to electricity and heat generated using organic matter as a fuel source. The climate benefits of bioenergy over fossil fuel-based energy sources are that they can be carbon neutral, as combustion of the organic material simply releases carbon which was removed from the atmosphere during the growing cycle of the organic matter.

Bioenergy sources including biomass plants and anaerobic digestion plants, which can operate on a range of organic feedstocks including specifically grown crops and trees, green waste and organic by-products (e.g. used grain from beer brewing or used cooking oils) or from sewage sludge.

When CCUS is applied in combination with bioenergy, it is possible to create a carbon negative process, i.e., the process becomes a net sink of carbon from the atmosphere.

There are, however, potential air quality trade offs as most bioenergy processes involve combustion which results in the release of combustion products such oxides of nitrogen and sulphur, and fine particles into the atmosphere. These emissions and their potential impacts on human health and sensitive ecological habitats should be carefully considered in the planning of bioenergy facilities.

In addition, care is required when sourcing bioenergy feedstocks to ensure that GHG emissions from transport of the feedstock from source to plant are minimised and do not outweigh the benefits of using a biomass in favour of other fuels. For example, a UK-based biomass facility operating on wood sourced and imported from Canada will result in substantially higher GHG emissions from transport and shipping than use of a locally-sourced biomass (or is at least reliant on decarbonisation of international road transport and shipping to fully decarbonise).

Overall, biomass supplies are limited by the availability of land for growing biomass and the time required to grow and mature certain biomass crops (e.g. trees), which makes this resource relatively scarce. BEIS has proposed to develop a new Bioenergy Strategy in 2022 that will review the amount of sustainable biomass in the UK and how this can be used across all economic sectors to meet its net carbon ambitions On 20 April 2021, it opened a call for evidence to strengthen the Government's evidence base in support of the development of this strategy[1].

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[1] https://www.gov.uk/government/consultations/role-of-biomass-in-achieving-net-zero-call-for-evidence

Conclusion

The technologies promoted in the Industrial Decarbonisation Strategy will be crucial to meet the Government's ambitions to move the UK towards carbon net zero by 2050 and meet its legal obligations under the Paris Agreement.

However, as with any strategy or policy to drive through improvements in one aspect of the environment, it is important that a holistic view is taken and consideration made of the potential cross-media effects that could occur to avoid repetition of the failings of previous policies, such as the promotion of diesel in road transport and biomass combustion in dense urban areas for their carbon benefits, which had impacts in terms of increasing the challenges local authorities faced in controlling nitrogen dioxide and fine particulate matter concentrations in urban areas.

Reducing GHG emissions is rightly seen as one of the highest environmental priorities of our time with global implications, and it is important that adoption of these technologies is promoted. However, it is also incumbent as air quality practitioners that we recognise and advise on the measures available to limit the potential wider environmental impacts of these technologies that may occur at a local level.

As the technologies promoted in the UK Government's Industrial Decarbonisation Strategy are emerging techniques, new policy and guidance is rapidly evolving, and it is important for operators of industrial installations and developers of the new technology to adapt and be fully appraised of the latest developments. Irrespective of exactly how the future policy and guidance landscape may develop, assessment of all relevant environmental emissions from a new project will remain a core requirement.

Since its inception in 1993, Air Quality Consultants has become the leading independent air quality and climate change practice in the UK. We have a strong and proven track record providing air quality and climate change services to private and public sector clients, both within the UK and internationally. Our experts are able to perform the requisite assessments to determine the potential impacts on local air quality associated with various low carbon technologies. We can also advise on the options available to mitigate such impacts and complete the necessary Best Available Technique assessments to support permit applications for new builds or permit variations for retrofits. Through our Environmental Policy & Economics Practice (https://www.environmentalpolicyandeconomics.com), which includes experts at the forefront of UK and European industrial pollution control policy, we can provide further strategic insight and economic analysis to ensure the successful implementation of low carbon technology without compromising local air quality.

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The Logika Group comprises Air Quality Consultants Ltd, Noise Consultants Ltd and Logika Consultants Ltd. The Group supports a wide range of public and private sector clients in the UK and internationally in the provision of services in the fields of air quality, climate change, environmental policy, evaluation and impact assessment, environmental noise, strategic environmental advice, biodiversity, water management green infrastructure and landscape design solutions.

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