Society of Operations Engineers

Review of the UK Government's White Paper: Powering our net zero future

Executive Summary

This review of the UK Government's Energy White Paper: Powering Our Net Zero Future (Department for Business Energy and Industrial Strategy, 2020) is from the perspective of ending carbon dioxide (CO_2), originated by equipment operation, entering the atmosphere.

The White Paper sets out actions to support achievable reductions of greenhouse gases, but also appears to promote sustainability of energy supplies in ways that threaten this goal. To meet the stated aim of stopping global warming, the concentration of greenhouse gases entering the atmosphere, through both human action and natural occurrence, must be less than the rate at which they are removed. From an operations engineering perspective this means both reducing the rate of CO_2 emissions arising from the use of equipment and increasing the rate of CO_2 removal from the atmosphere.

The use of nuclear and forms of renewable energy that do not result in CO_2 emissions, clearly helps in reducing current rates of increase. Action to support natural processes, such as plant growth, can significantly contribute to improving the rate of CO_2 removal from the atmosphere.

Biofuels are plant-based forms of renewable fuel and are sustainable substitutes for fossil fuels. However, harvesting and burning plant-based forms of renewable fuel increases atmospheric CO_2 concentrations. Although seen in some quarters as a 'carbon neutral' activity, the combustion of biofuels, without the use of technology to capture and sequester CO_2 emissions, has the same effects on increasing atmospheric CO_2 as burning fossil fuels. It would be far more advantageous to grow, harvest, burn and then capture the resulting emissions. This would support increasing the rate of atmospheric CO_2 removal and lowering the rate of CO_2 re-entering the atmosphere.

For industry, transport and domestic use, the production of hydrogen as a distributed energy source and the move to electrifying vehicles are rightly being promoted as means of reducing greenhouse gas emissions. However, these initiatives will inevitably increase the demand for electricity. Consequently, reduction in atmospheric CO_2 concentrations will only be achieved when nearly all electricity generated has zero emissions of CO_2.

Recommendations for The White Paper

The White Paper would better support eliminating atmospheric CO_2, generated through equipment operation, if it did not credit the use of biofuels as CO_2 emissions free. To continue to do so incentivises actions that risk increasing greenhouse gas levels during the transition to a future clean energy state. More generally, we suggest amending the White Paper so it is clear to all readers that:

1. The ending of all greenhouse gas emissions is not the objective and is unachievable due to naturally occurring cycles.
2. The objective is to halt the current rise in the concentration of carbon based greenhouse gases within the atmosphere.
3. To lower the concentration of carbon based greenhouse gases within the atmosphere, the average total rate of carbon based greenhouse gases emitted (through both human action and natural occurrence) must be lower than the total rate at which all carbon based greenhouse gases are removed.
4. Energy gained from renewable and sustainable energy sources potentially results in increased emissions of CO_2, unless the resulting CO_2 is captured and sequestered.
5. The lowering of greenhouse gas concentrations in the atmosphere is independent of using materials of biological origin as energy sources.
6. Preventing the handling and combustion of waste material releasing CO_2 is a key part of reducing greenhouse gases entering the atmosphere.

In addition, the Glossary's meanings may be further refined as follows:

a. Anthropogenic Greenhouse Gas Emissions: Addition to the atmosphere of gases originated by human action that are a cause of increased concentrations of greenhouse gases in the atmosphere, including carbon dioxide, methane and others.

b. Bioenergy: Refers to heat or electricity produced using material of biological origin.

c. Bioenergy with Carbon Capture and Storage: Refers to bioenergy processes (such as burning biomass for electricity) during which any carbon dioxide produced is captured and stored.

d. Biofuel: A material of biological origin used as a fuel.

e. Biomass: Refers to any material of biological origin used as a feedstock for products (e.g. wood in construction to make chemicals and materials, like bio-based plastics), or as a fuel for bioenergy.

f. Clean Electricity: Types of electricity generating technologies that emit little or no greenhouse gases.

g. Clean Hydrogen: Hydrogen that is produced with significantly lower greenhouse gas emissions compared to current methods of production – methods include reacting methane with steam to form hydrogen and then capturing the carbon dioxide by-product (steam methane reformation with CCUS), processing methane to form hydrogen and solid carbon (methane pyrolysis) and using clean electricity to split water into hydrogen and oxygen (electrolysis).

h. Greenhouse Gas Emissions: Addition to the atmosphere of greenhouse gases.

i. Hydrogen for heat: The combustion of hydrogen produces no carbon based greenhouse gas emissions at point of use, making it a possible replacement for natural gas as a fuel source for heating homes and other buildings.

j. Low-carbon electricity generating technologies: Types of electricity generating technologies that emit little or no carbon dioxide into the atmosphere, which includes wind, solar, nuclear and carbon based fuels using CCUS.

k. Negative Emission: Achieved by human intervention to remove additional greenhouse gases from the atmosphere.

l. Net Zero: Refers to a point at which the rate of greenhouse gases originated by UK human activity entering the atmosphere equals the additional rate of greenhouse gases leaving the atmosphere attributable to human actions credited to the UK.

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Introduction

The Society of Operations Engineers (SOE) is a professional engineering institution (PEI) whose mission is to bring about a world where all aspects of operations engineering is conducted safely, ethically and at ever-higher levels of sustainability and efficiency. SOE is seeking to secure that any actions, presented as supporting ending CO_2 originated by equipment operation entering the atmosphere, are safe and conducted in ways that are truly sustainable, efficient and underpinned with an ethical approach.

An ethical approach is one founded on honesty and integrity; respect for life, law, the environment and public good; leadership and communication with accuracy and rigour.

This review of the UK Government's Energy White Paper: Powering Our Net Zero Future (Department for Business Energy and Industrial Strategy, 2020) is from the perspective of ending carbon dioxide (CO_2), originated by equipment operation, entering the atmosphere.

The White Paper sets out actions that can support ending CO_2 entering the atmosphere as a result of operating equipment. It provides practical and achievable means of eliminating CO_2 emissions arising from the use of equipment, through its promotion of offshore wind, nuclear power, greener buildings and Carbon Capture, Usage & Storage (CCUS). However, SOE is concerned that the ethical approach to the use of renewable energy is rather weak. Consequently, this increases the risk of not securing currently achievable real net reductions in CO_2 atmospheric emissions originating from operating equipment.

To support a stronger ethical approach, this paper explains why currently using certain sources of renewable energy to power equipment has the potential to increase CO_2 emissions.

This review places greenhouse gas emissions, which include emissions of CO_2, into two groups: Those that occur independent of human actions – natural greenhouse gas emissions; and those that are originated by human actions – anthropogenic greenhouse gas emissions. It also explores the fundamentals behind reducing concentrations of atmospheric CO_2, i.e. ensuring that the average rate (kg/year) of all CO_2 entering the atmosphere, over time, is less than the average rate (kg/year) of all CO_2 extracted (naturally and through human actions). Average annual rates are used to reflect that CO_2 emissions into and extraction from the atmosphere can vary seasonally. Based on this understanding, we propose that by actively increasing the proportion of the earth's carbon atoms, that do not make up part of carbon based atmospheric greenhouse gas molecules, there will be a decrease over time in carbon based atmospheric greenhouse gas concentrations.

We introduce the case for a fundamental change in the approach to the management of waste containing carbon atoms, based on actively increasing the proportion of this planet's carbon atoms that are not part of carbon based greenhouse gas molecules within the atmosphere. That is, proactive action to prevent, or at least delay, such waste becoming carbon based greenhouse gases in the atmosphere.

We also question the definitions within the White Paper's Glossary in the context of promoting the highest accuracy and rigour when considering renewable energy. We have included suggested changes to these definitions.

Background

Operations engineering is the engineering discipline focused on the equipment operating today to deliver society's current requirements. This focus means that operations engineering does not have an interest in promoting the operation of particular types of equipment. Operations engineers and the SOE are uniquely placed to provide independent guidance on the practical operational engineering issues that need addressing, if energy consumption is to become free of CO_2 emissions into the atmosphere.

SOE, as part of delivering its public benefit, provides independent leadership through:

1. Raising general awareness and understanding of how the use of equipment can currently result in higher rates of CO_2 entering the atmosphere and how this can be eliminated or reduced;
2. Using a holistic approach in assessing initiatives for ending or reducing the rate of CO_2 originated by equipment operation entering the atmosphere;
3. Promoting that all associated communications, leadership and decisions are made with the highest degree of honesty, integrity, accuracy, rigour and with respect for life, the law, the environment and the public good; and
4. Promoting wide acknowledgment that, for various reasons, some currently promoted courses of action on climate change may actually be working against reducing the overall rate of CO_2 emissions entering the atmosphere.

SOE is not calling for the cessation of equipment operation that results in CO_2 entering the atmosphere. SOE's interest is securing that actions taken, which are purported to end or reduce the rate of CO_2 emissions originating from the operation of equipment, are done so within an ethical approach of having the highest degrees of honesty, integrity, accuracy and rigour. The objective being that such action positively contributes to a safe, efficient and sustainable net reduction in the concentration of CO_2 within the atmosphere.

The consequence of not applying this ethical approach may mean that current large investments in plant and equipment, ostensibly to reduce greenhouse gas emissions, are at risk. Such investments appear founded on current incentives and sentiments, which promote the use of the renewable energy biofuel. However, using biofuel generally results in emissions of CO_2. Therefore, such investments do not contribute to reducing greenhouse gas emissions. If current incentives and sentiments move from promoting the use of biofuel to reducing emissions of anthropogenic greenhouse gases into the atmosphere, there is a risk that these large investments may become unsustainable.

> UK Government's 2020 consultation on ending the sale of new petrol, diesel and hybrid cars and vans

In its response to the UK Government's 2020 consultation on ending the sale of new petrol, diesel and hybrid cars and vans, SOE welcomed the clear statement of intent from the Government to industry and consumers that it wanted to see new cars and vans delivering as many zero emission miles as possible, as fast as possible. However, SOE expressed concern that the proposal within the consultation actually offered limited reduction in 'well-to-wheel' greenhouse gas emissions. SOE explained why the consultation's promoted actions offered very limited reductions in the well-to-wheel emissions in the long term, and risked creating large increases in such emissions in the short term. SOE's key areas of concern were:

1. The approach taken was not technology neutral. The Government said it was driving the uptake of the cleanest vehicles by continuing to take a technology neutral approach to meeting its ambitions and yet put a ban on new petrol and diesel engine cars from 2035. SOE explained that a technology neutral approach would instead involve banning the sale of new cars and vans that had a well-to-wheel emissions, of air pollutant and greenhouse gases together, greater than a set limit.

2. The estimates of CO_2 emissions from additional electricity generation – for the charging of electric vehicles' batteries and production of hydrogen – were based on the current UK energy mix. SOE explained that the increased demand for electricity was more likely to be met by the current marginal electricity generation mix, which is more responsive to changes in demand and relies predominantly on fossil fuels.
3. Hydrogen is proposed as a fuel on the grounds of zero tailpipe CO_2 emission, while accepting large CO_2 emissions from the hydrogen production processes. SOE argued that hydrogen should be promoted as a fuel only when the corresponding additional electricity generation and hydrogen production can be greenhouse gas emission free.

> UK Government's 2020 Ten Point Plan for a Green Industrial Revolution

SOE wrote to the Secretary of State for Business, Energy and Industrial Strategy on the UK Government's 2020 Ten Point Plan for a Green Industrial Revolution (the Plan). SOE explained that the Plan offered the real prospect of being able to pass on to future generations the ability to benefit from the use of equipment, as we can today, without the resulting emissions of CO_2 we currently produce. SOE offered to help in securing that the Plan could develop in ways that ensured reductions in emissions of CO_2, resulting from the operation of equipment, were achieved safely and efficiently.

SOE explained that the Plan's proposals on advanced offshore wind, nuclear power, greener buildings and carbon capture and storage (CCUS) provided a practical and achievable route to eliminating CO_2 emissions arising from the use of equipment. However, we cautioned that, for various reasons, some currently promoted courses of action on climate change may actually work against reducing total CO_2 emissions. In particular, encouraging the growth in zero tailpipe emissions vehicles, while marginal electricity generation continued to be from CO_2 emitting plant. It also raised concerns at the presentation of biofuels as contributing to reducing global warming, when in most cases their use actually results in high levels of CO_2 emissions.

> UK Government's 2020 Energy White Paper Powering our Net Zero Future

The White Paper appears to build on the Plan. It too provides practical and achievable means of eliminating CO_2 emissions arising from the use of equipment, through its promotion of offshore wind, nuclear power, greener buildings and CCUS.

Unfortunately, the White Paper gives a number of examples that suggest either a general lack of awareness and understanding of how the use of equipment creates CO_2 emissions, or a lack of rigour with terminology. This creates an overall impression of a White Paper based on late twentieth century concerns about security and sustainability of energy supplies. Since then, solutions have been developed to address those concerns. These include broadening energy supplies away from a reliance on the fossil fuels coal and oil. This was primarily through promoting nuclear and renewable energy. With nuclear and some forms of renewable energy being CO_2 emission free, they appear to have now been adopted in the fight against increased concentrations of greenhouse gases in the atmosphere. However, the fact that some renewable energy results in emissions of CO_2 appears not to be understood fully. The consequence of which, is the current apparent promotion of sustainable energy sources, which result in emissions of CO_2 into the atmosphere, are claiming to reduce global warming when they do not.

> SOE's February 2021 position paper: Ending carbon dioxide originated by equipment operation entering the atmosphere

In its February 2021 position paper, SOE explained why currently achievable real net reductions in CO_2 originated by equipment operation entering the atmosphere are not being realised. It set out why SOE has a key role to play in ending CO_2, originated by equipment operation, entering the atmosphere. This being primarily through promulgating the following messages:

- The need to end CO_2 originated by equipment operation entering the atmosphere;
- Meeting the needs and wishes of today's society and future generations;
- SOE's unique professional engineering institution role in ending CO_2 originated by equipment operation entering the atmosphere; and
- Safety first.

SOE also set out its operational engineering facts; namely:

- Renewable energy does not mean CO_2 emissions free energy. Renewable energy sources fall into two categories, those that do not create CO_2 emissions (e.g. solar and wind) and those that potentially do (e.g. biofuels).
- For no CO_2 originated by equipment operation to enter the atmosphere, the burning of fuels containing carbon (fossil fuels and biofuels) has to be limited to those processes employing technologies that eliminate any CO_2 emissions into the atmosphere.
- For no CO_2 originated by equipment operation to enter the atmosphere, the energy harvesting process has to be one that does not result in emissions of CO_2 into the atmosphere.
- Changing from fossil fuel sourced energy to biofuel sourced renewable energy does not result in large reductions of CO_2 entering the atmosphere.
- A move to greater use of hydrogen as a fuel source will probably not result in significant reductions of CO_2 entering the atmosphere until both the extra electricity generation required to meet any associated additional electrical power demand and the hydrogen production processes themselves result in no CO_2 emissions into the atmosphere.
- A move to greater use of zero emissions equipment, such as electric vehicles, will probably only achieve significant reductions in total CO_2 emissions into the atmosphere when the extra electricity generation, required to meet any additional electrical power demand, is largely free of CO_2 emissions into the atmosphere.
- Generally gaining higher operational energy efficiencies from all energy using equipment contributes to reducing CO_2 emissions. However, when eliminating CO_2 emissions into the atmosphere is the primary objective, securing no emissions of CO_2 into the atmosphere with low efficiency is more effective than securing high efficiency with CO_2 emissions.
- Operation of large-scale flexible energy storage and fuel production plants enables increased use of inflexible CO_2 emission free electricity generation, such as nuclear and wind.

Renewable Energy

Renewable energy is sources of energy that can be renewed or are not diminished by use. The White Paper describes renewable energy as 'Energy that is collected from resources which are naturally replaced in human timescales such as sunlight, wind, rain, tides and waves[1]'. Traditionally sustainability, in relation to equipment operation and the energy it uses, has focused on the sustainability of fuel resources. More recently, the focus has moved to addressing global warming by addressing rising concentrations of greenhouse gases in the atmosphere, in particular anthropogenic emissions of greenhouse gases.

All renewable energy sources support the sustainability of energy resources, but only some are CO_2 emission free. Renewable energy sources fall into two categories, those that do not create CO_2 emissions (e.g. hydro, solar and wind) and those that currently do (e.g. biofuels). Solutions that can help in achieving both sustainability of fuel resources and ending CO_2 originated by equipment operation entering the atmosphere, based on the use of renewable energy, are available and have been adopted. However, there are other solutions available, some of which are already adopted, which only aid sustainability and actually compromise reducing the total rate of CO_2 emissions into the atmosphere.

> Renewable energy sources that, without using CO_2 emissions elimination technology, create CO_2 emissions

Within this review, Biofuel refers to one form of material that is of biological origin and used as a fuel. Biofuel can be a gas (in this review biogas), liquid (bioliquid), or a solid (biomass). Bioenergy, within this review, refers to energy derived from biofuels.

It is valid to argue that material of biological origin is unique among renewable energy sources. Its carbon content gives it the wide array of applications in which it can substitute for products and activities derived from fossil forms of carbon. As a substitute for fossil fuels, biofuel can aid in the sustainability of the remaining fossil fuels, through its use reducing the demand for fossil fuels. As an alternative fuel source to fossil fuels, biofuel contributes to the diversity of fuels and thus the security of energy supplies. In addition, biofuel with CO_2 capture and sequester technology, when compared to fossil fuel with CO_2 capture and sequester technology, is a sustainable form of CO_2 emission free energy harvesting. Unlike fossil fuels, biofuels can, therefore, be incorporated into a strategy of grow, harvest, burn and then capture the resulting emissions, which supports both increasing the rate of atmospheric CO_2 removal and lowering the rate of CO_2 re-entering the atmosphere. However, currently there is little use of CO_2 capture and sequester technology, such as CCUS, to eliminate emissions of CO_2 into the atmosphere after combustion of carbon based fuels. Consequently, CO_2 emissions from equipment using biofuels are very similar to those using fossil fuels. When assessing if there will be real reductions in CO_2 emissions by replacing fossil fuels with biofuels, applying the highest levels of accuracy and rigour are essential.

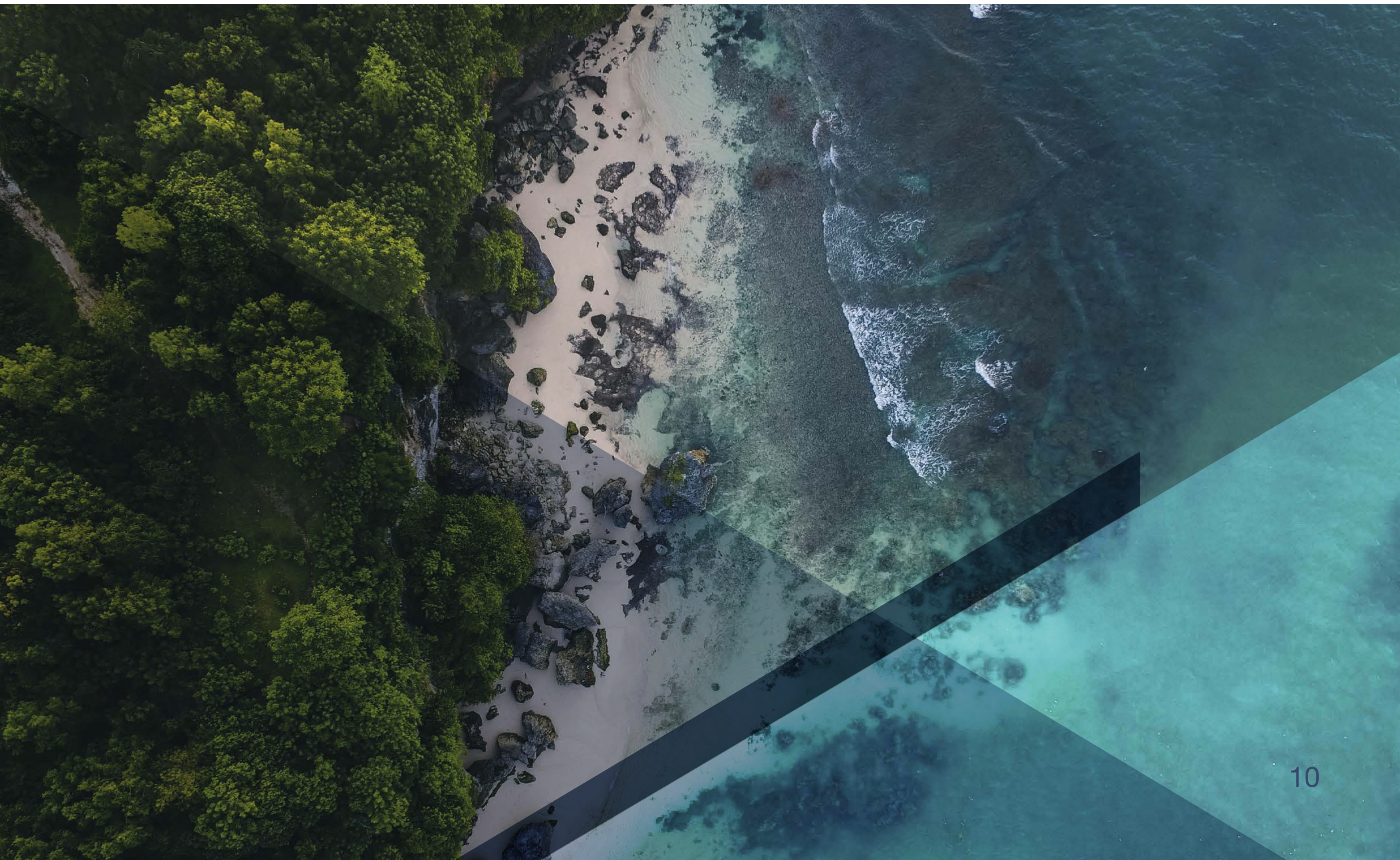
As plants grow, they absorb CO_2. Biofuel is a processed plant based fuel and therefore a product of CO_2 extracted from the atmosphere. Fossil fuels are decomposed plant based fuels and therefore products of CO_2 extracted from the atmosphere. The difference between the two fuels is the time between the plants absorbing the CO_2 and the fuel being available for combustion. The relatively short time (human timescales) for biofuels, makes it a sustainable fuel source, while the relative long time for fossil fuels effectively means they are not sustainable. However, the level of sustainability of a fuel does not influence the amount of CO_2 it makes when burnt.

[1]UK Government's Energy White Paper: Powering Our Net Zero Future (Department for Business Energy and Industrial Strategy, 2020) page154

Plants naturally decay. In doing so, a significant proportion of their carbon atoms eventually enter the atmosphere as part of greenhouse gases, such as CO_2 and methane (CH_4). If a plant burns, it is the same carbon atoms forming the greenhouse gas entering the atmosphere as form the greenhouse gas entering the atmosphere through natural decay.

Unlike fossil fuels, where virtually no CO_2 would ever enter the atmosphere without combustion of the fuel, a significant proportion of the CO_2 released when burning biofuels would have naturally become part of a greenhouse gas at a later point in time. This would have been through the natural decay of the plant, together with animals eating the plants and then exhaling the carbon atoms as CO_2, or excreting them to form CH_4.

The natural decay of plant material appears to be taken as suggesting that the burning of biofuel results in a lower overall amount of extra CO_2 entering the atmosphere than if fossil fuels are burnt. Unfortunately, this does not take into account that by burning the biofuel the time that the carbon atoms are not part of greenhouse gas molecules in the atmosphere shortens. The consequence being that the rate of the carbon atoms re-entering the atmosphere, as a greenhouse gas, increases. The full natural time of a carbon atom not being part of a greenhouse gas molecule within the atmosphere is from the moment a plant gains that particular carbon atom through photosynthesis, until that carbon atom re-enters the atmosphere – as part of a greenhouse gas molecule – through natural processes. Harvesting and burning is seen in some quarters as being a 'carbon neutral' activity, despite the current difference between the rates of CO_2 emissions and removals actually resulting in continued increases in atmospheric CO_2 concentrations.



Achieving maximum time that carbon atoms are not within greenhouse gases in the atmosphere

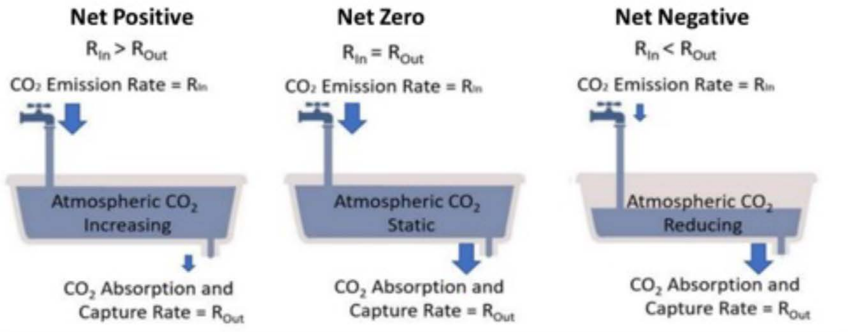
The importance of achieving the maximum time that a carbon atom is not within a greenhouse gas molecule in the atmosphere becomes apparent when viewed from the perspective that there is probably a finite amount of carbon on the planet. Here each of the planet's carbon atoms is in one of two states:

1. in the atmosphere as part of a greenhouse gas molecule, which includes CO_2 and CH_4; or
2. not in the atmosphere as part of a greenhouse gas molecule.

Carbon atoms as part of greenhouse gas molecules are continually passing into the atmosphere. This is caused by a number of reasons, including the natural processes of animals eating and breathing and the biodegrading of dead plants and animals. In addition, carbon atoms, as components of greenhouse gas molecules, are extracted from the atmosphere. This is due to a number of processes such as, photosynthesis by plants taking CO_2 from the atmosphere.

An analogy to aid visualising the principles of the carbon based greenhouse gases in the atmosphere, is a bath of water (**see Figure 1**. A Graphical Representation of the principles of the carbon based greenhouse gases in the atmosphere). The bath is the atmosphere, the water is the carbon based greenhouse gases and the water level is the concentration of carbon based greenhouse gases in the atmosphere. With the bath taps on, a water level established and the drain from the bath partially blocked, the level of the water will rise if either or both the flow in increases and or the flow out decreases. Equally, the level will fall if the flow in decreases and/or the flow out increases. To stabilise at a constant level, the flow in must be the same as the flow out. The key point being, that it is not the total amount of water flowing into, or out of, the bath that determines the water level in the bath, but the difference between the flows in and out over time. For the atmosphere, if the average rate (kg/year) of carbon based greenhouse gas molecules, moving into the atmosphere is equal to the average rate (kg/year) of carbon based greenhouse gas molecules leaving the atmosphere, then the amount of the carbon based greenhouse gases in the atmosphere remains constant. If over time there is a difference between the average rate (kg/year) of movement into atmosphere and the average rate (kg/year) of movement out, the amount of the carbon based greenhouse gases in the atmosphere changes. The assumption is that without an external event happening, over time the concentration of the greenhouse gases in the atmosphere will tend to stabilise around a given level through natural processes. Here the average rates (kg/year) of the carbon based greenhouse gas entering and leaving the atmosphere will be very similar.

Figure 1. A graphical representation of the principles of the carbon based greenhouse gases in the atmosphere



External events causing the average rate (kg/year) of greenhouse gas entering the atmosphere to increase above the average leaving rate (kg/year) results in the concentration of the greenhouse gas in the atmosphere rising over time. Equally, external events that result in the average rate (kg/year) of greenhouse gas entering becoming less than the average rate (kg/year) leaving, results in the concentration of the greenhouse gas in the atmosphere decreasing over time. Human actions, such as deforestation, have possibly created the external events to reduce the average rate (kg/year) of greenhouse gases extracted from the atmosphere (partially blocking the bath's drainpipe). Equally, human actions, such as burning carbon compounds, have possibly created the external events to increase the average rate (kg/year) of greenhouse gas entering the atmosphere (opening the taps further to increase the flow of water into the bath). If correct, then these two actions will each have contributed to an increase in atmospheric concentrations of the greenhouse gases containing carbon atoms (the water level in the bath has risen).

Humans have probably achieved an increased average rate (kg/year) of total emissions of the greenhouse gas CO_2 into the atmosphere through shortening the time carbon atoms are not part of greenhouse gas molecules in the atmosphere. For the burning of fossil fuels, this reduction of the time remaining not in a greenhouse gas within the atmosphere is from an infinite number of years to zero. For the burning of biofuels, this reduces the time of a carbon atom remaining not as a greenhouse gas molecule in the atmosphere from between a few and, potentially, a few hundred years to zero. The analogy with the bath of water is that the water draining from the bath is now being collected and almost immediately pumped back into the bath. The effect is that the overall rate of water flowing into the bath increases. Therefore, if humans wish to reduce the concentration of CO_2 in the atmosphere, they need to extend the average time that carbon atoms are not part of greenhouse gas molecules within the atmosphere. This extension being back to and, for organic material probably beyond, the natural times.

There appears to be four ways of extending the time that carbon atoms are not part of greenhouse gases in the atmosphere:

1. Reducing or ending the burning of all forms of carbon that result in emissions of CO_2 into the atmosphere, this includes carbon within both fossil fuels and biofuels;
2. Storing the resultant greenhouse gas molecules outside the atmosphere after combustion of carbon, using CO_2 capture and sequester technologies, such as CCUS, at the end of any carbon molecule burning process;
3. Introducing plants, such as trees, with greater carbon storage capability (time and quantity) than those already in place, including to areas where currently no plants grow;
4. Artificially delaying or preventing the decomposition of plant material into greenhouse gases.

Artificially extending the natural time of carbon outside the atmosphere

> Reducing or ending the burning of all forms of carbon that result in emissions of CO_2 into the atmosphere

Today's engineering based technology, coupled with ongoing innovation and development, creates a means of securing the energy required to operate the equipment providing for the needs and wishes of today's society in ways that result in no CO_2 originated by that equipment's operation entering into the atmosphere. Engineering based solutions for ending CO_2 originated by equipment operation entering the atmosphere are probably the most practical and socially acceptable ways for achieving meaningful reductions in anthropogenic CO_2 emissions. In particular, engineering based solutions for ending CO_2 originated by equipment operation entering the atmosphere enables an increased use of electrically powered equipment (e.g. electric cars and vehicles) and hydrogen as a fuel without increased electricity generation from CO_2 emitting plant.

Generally, gaining higher operational energy efficiencies from all energy using equipment contributes to reducing CO_2 emissions – through enabling lower consumption of energy to deliver the desired outcome. However, when eliminating CO_2 emissions into the atmosphere is the primary objective, securing no emissions of CO_2 into the atmosphere with low efficiency is more effective than securing high efficiency with CO_2 emissions.

In addition to improving operational energy efficiencies there are a number of other methods for reducing or ending the burning of all forms of carbon that result in emissions of CO_2 into the atmosphere. These include introducing greater use of nuclear energy, renewable energy that has no CO_2 emissions and energy from carbon based renewable and fossil fuel energy sources using technology that prevents CO_2 emissions into the atmosphere.

> Storing the resultant greenhouse gas molecules outside the atmosphere after combustion of carbon

Using technology to capture CO_2 following the combustion of biofuels, offers a means of artificially extending the natural time that carbon atoms are not part of the greenhouse gas molecules in the atmosphere. Because plants have extracted CO_2 from the atmosphere and CO_2 capture technology prevents the CO_2 re-entering the atmosphere, the combustion of biofuels using CO_2 capture and sequester technologies effectively places the carbon atoms, as CO_2 molecules, in indefinite storage outside of the atmosphere. Here the gain is the reduction in natural rate of greenhouse gas emissions into the atmosphere. However, unless human action, such as growing more plants, enables the plants to extract more CO_2, than would otherwise have been extracted naturally, there has not been any additional extraction of CO_2 from the atmosphere.

The burning of biofuels using CO_2 capture and sequester technologies offers both the prospect of indefinite storage of CO_2 outside the atmosphere and the release of heat. The White Paper describes this as delivering the negative emissions. Unfortunately, many incentives designed to encourage the use of sustainable fuels (renewable fuels) appear to treat the harvesting and burning of biofuels without using CO_2 capture and sequester technologies as if they are still delivering negative emissions. Further, there are currently a number of situations where the burning of carbon, appears to be encouraged. These include the accessing of heat through:

1. Burning of biofuel;
2. Burning of waste; and
3. Burning of methane.

> Burning of biofuel

Burning of biofuel is beneficial to the sustainability and security of fuel supplies. However, the degree to which the burning of biofuels actually helps in reducing greenhouse gas concentrations is dependent upon two factors; namely if CO_2 capture and sequester technology is employed and the source of the biofuel.

If fossil fuels burn without CO_2 capture and sequester technology, one unit of greenhouse gas enters the atmosphere. If burnt with CO_2 capture and sequester technology, zero greenhouse gas enters the atmosphere.

If biofuel, derived from the growing of dedicated crops, is harvested and then burnt without CO_2 capture and sequester technology, one unit of greenhouse gas enters the atmosphere at the same rate as combustion of a fossil fuel. However, here human actions of growing dedicated crops results in additional extraction of CO_2 from the atmosphere. There has been a net reduction in the average concentration of CO_2 in the atmosphere. The longer the time the carbon atom is then held outside the atmosphere before combustion, the lower the rate at which the carbon molecules re-enter the atmosphere and therefore the greater the net reduction in the average concentration of CO_2 in the atmosphere.

If biofuel, derived from the growing of dedicated crops, is harvested, burnt and then the CO_2 captured and sequestered, then one additional unit of CO_2 is first extracted from the atmosphere. On combustion, zero greenhouse gas enters the atmosphere. However, this is not a reduction of one unit of anthropogenic greenhouse gas emissions, but a reduction of one unit of natural greenhouse gas emissions. Without human action, the crop would have degraded into CO_2 within the atmosphere at natural rates.

> Burning of waste

Energy from waste, usually as electricity or electricity and heat, can support the sustainability of fuel sources and efficient management of waste. In each of these cases, the use of CO_2 capture and sequester technologies, such as CCUS, allows combustion of the carbon with no resulting CO_2 entering the atmosphere.

The burning of non-biodegradable waste without using CO_2 capture and sequester technology results in emissions of CO_2 into the atmosphere. As this waste would not degrade into greenhouse gases, its combustion increases CO_2 concentrations in the atmosphere in the same way as burning fossil fuels. This is even though the material is used twice, first for the initial product and second as an energy source.

The burning of non-biodegradable waste using CO_2 capture and sequester technology results in zero emissions of CO_2 into the atmosphere. Here there is neither a resulting increase nor decrease of CO_2 concentrations in the atmosphere.

The burning of biodegradable waste without using CO_2 capture and sequester technology results in emissions of CO_2 into the atmosphere. This waste would have degraded into greenhouse gases over time. However, through combustion of the waste, the resulting CO_2 enters the atmosphere at a significantly higher rate than the natural rate. Therefore, this has a greater impact on increasing CO_2 concentrations in the atmosphere than would have been the case if the waste had degraded into greenhouse gases naturally.

The burning of biodegradable waste using CO_2 capture and technology results in zero emissions of CO_2 into the atmosphere. As this waste is generally biofuel, the effects on CO_2 concentrations in the atmosphere are as described above for the combustion of biofuel using CO_2 capture and sequester technology.

> Burning of methane

CH_4 is viewed as a more potent greenhouse gas than CO_2. It is therefore captured (harvested) and burnt as a means of preventing it entering the atmosphere. CH_4 is a biofuel in the form of biogas. As biogas, unless human action is taken to capture and store the gas, it will enter the atmosphere almost immediately.

The burning of CH_4, without using CO_2 capture and sequester technology, results in emissions of CO_2 into the atmosphere. However, the CH_4 would have entered the atmosphere naturally at almost the same rate. Thus, there is no overall increase or decrease in the atmosphere's greenhouse gas concentrations. CO_2 concentrations are higher, but CH_4 concentrations are lower.

The burning of CH_4 using CO_2 capture and sequester technology results in zero emissions of CO_2 into the atmosphere and, by default, zero emissions of CH_4 into the atmosphere. Further, where the CH_4 forms naturally then its capture as CO_2 by human originated action is reducing natural greenhouse gas emissions. Therefore, the burning of naturally occurring CH_4, using CO_2 capture and sequester technology, contributes to reducing greenhouse gas concentrations in the atmosphere.

Methane pyrolysis, is a process of converting CH_4 into solid carbon and the gas hydrogen. Biodegradable waste and some forms of non-biodegradable waste can be processed into CH_4. This offers the prospect of securing hydrogen from waste and CH_4, without emissions of CO_2 entering the atmosphere. Further, it offers the storage of solid carbon. Storing a solid is more efficient than storing a gas, as solids are denser than compressed gas and easier to contain. Methane pyrolysis also works with the fossil fuel natural gas, for which the extraction and delivery infrastructure already exists. However, the development of such technology is somewhat dependent on government policy being clearly technology neutral.

> Introducing plants, such as trees, with greater carbon storage capability than those already in place

Introducing plants, such as trees, with greater carbon storage capability (time and quantity) than those already in place, including to areas where currently no plants grow, is one of a number of actions available for increasing the rate at which CO_2 is extracted from the atmosphere. For the bath analogy above, these actions are clearing the drain so that the rate that the water can flow out of the bath increases.

Determining the carbon storage capability requires the highest degree of honesty, integrity, accuracy and rigour. A new tree sapling may double its mass in one year. However, this increase in mass will be a small fraction of the mass increase, in the same year, achieved by a tree thirty years older. Thus, the optimal point for felling a tree grown primarily for building material is likely to be much earlier than one grown primarily for absorbing CO_2 from the atmosphere and then subsequently storing the carbon within the building material.

> Artificially delaying or preventing the decomposition of plant material into greenhouse gases

Artificially delaying or preventing the decomposition of plant material into greenhouse gases is a human originated action, which lowers the rate of carbon within plant-based material re-entering the atmosphere as part of greenhouse gases. Actions to prevent decomposition of plant material include, preventing animals eating the plant material, preserving felled timber and other organic material against rotting and placing waste material in long-term storage, where it will not become greenhouse gases in the atmosphere.

For the bath analogy above, these actions are placing restrictions, or blockages, in the pipes supplying water to the bath. The rate that the water can flow into the bath is lowered.

Efficient and sustainable methods of preventing carbon based greenhouse gases entering the atmosphere

CO_2 capture and sequester processes are similar to the production of hydrogen as a distributed energy source and the move to electrifying vehicles. Each of these are rightly being promoted as means of reducing greenhouse gas emissions. However, all of these initiatives will inevitably increase the demand for electricity. Consequently, reduction in atmospheric CO_2 concentrations is only achieved when nearly all electricity generated has zero emissions of CO_2.

CO_2 capture and sequester processes, through their use of energy, make the carbon burning equipment they support less efficient than the same equipment without CO_2 capture and sequestering. However, the purpose of fitting CO_2 capture and sequester processes is to capture and store the CO_2 emissions from the equipment. Therefore, the loss in efficiency is the cost of securing no emissions of CO_2 into the atmosphere.

While some of the captured CO_2 from CO_2 capture and sequester processes, such as CCUS, can be used in other processes, it is likely that large amounts CO_2 will move into storage. The question then becomes, is storing captured CO_2 an efficient and sustainable way of preventing carbon atoms becoming part of greenhouse gases in the atmosphere? This compared with allowing the full natural time that a carbon atom, initially captured from the atmosphere by a plant, remains outside of greenhouse gases within the atmosphere. Further, how does the use of CO_2 capture and sequester technologies compare, in efficiency terms, with using processes to break hydrocarbons and carbohydrates into hydrogen and solid carbon waste? Points to consider are that in natural processes CO_2 capture is only once, which is during processes such as photosynthesis. The storage of carbon within CO_2 involves two captures, first by processes such as photosynthesis and second through using CO_2 capture and sequester technologies, such as CCUS. In addition, natural processes just hold the carbon component of CO_2, while storage of CO_2 is of both the CO_2's carbon and oxygen components.

Reducing carbon based emissions rates into the atmosphere, through increasing the current times that carbon atoms are not within greenhouse gases in the atmosphere, introduces a new paradigm around waste and the storage of carbon atoms outside of the atmosphere. Within this paradigm, how should stable waste be stored? Here stable waste is waste material that will not naturally degrade into a greenhouse gas, e.g. plastics that are not biodegradable. Given that the stable waste will store the carbon within it almost indefinitely, is it better to store stable waste in that form, rather than converting it to CO_2? If it is, does this also apply where the conversion to CO_2 enables the harvesting of energy and the resulting CO_2 captured using CO_2 capture and sequester technologies? Similar questions apply to waste from which naturally occurring greenhouse gases will eventually form. In addition, to what extent could substituting the use of biodegradable materials, e.g. paper, with non-biodegradable materials, e.g. plastic, reduce total concentrations of greenhouse gases in the atmosphere?

Analysis of the White Paper's terminology

To illustrate the issues with the White Paper's current drafting, consider the following statement, which is factually correct but easily misinterpreted:

'Biomass is unique amongst renewable technologies in the wide array of applications in which it can be used as a substitute for fossil-fuel based products and activities, from power generation to hydrogen production and even new forms of plastics. Along with its ability to deliver negative emissions, this makes biomass one of our most valuable tools for reaching net zero emissions.'

A clearer statement would be:

Material of biological origin containing carbon when used as a feedstock for products is unique amongst renewable technologies in the wide array of applications in which it can be used as a substitute for fossil-based carbon sources, both in production of the products and in the harvesting of energy. In addition, it has the ability to store carbon extracted from the greenhouse gas carbon dioxide through processes such as photosynthesis and thereby can contribute to lower concentrations of carbon dioxide in the atmosphere.

> Analysis of the White Paper's glossary

The White Paper appears to have adopted a number of positions that themselves promote actions that actually work against reducing total anthropogenic CO_2 emissions. There are ten particular phrases in the White Paper's Glossary, where the presented meanings are at best unhelpful. This is when considered from the perspective of trying to end CO_2 originated by equipment operation entering the atmosphere.

1. Bioenergy

The White Paper's meaning is ***'Refers to heat or electricity produced using biomass or gaseous and liquid fuels with a biological origin such as biomethane produced from biomass.'***

Here biomass appears to be used both as a descriptor of solid material of biological origin, and as the generic description of material of biological origin. A less confusing meaning would be:

Bioenergy: **Refers to heat or electricity produced using material of biological origin.**

2. Bioenergy with carbon capture and storage

The White Paper's meaning is: ***'Refers to bioenergy processes (such as burning it for electricity) during which carbon is captured and stored. If carefully managed, using sustainable biomass, BECCS can generate 'negative emissions' because while providing energy it also captures and stores the atmospheric CO_2 that is absorbed by plants as they grow.'***

The first sentence is factually correct. The second sentence carries the issues. Because the 'negative emission' occurred during photosynthesis, the carbon capture and storage process after burning the biomass is not contributing to removing CO_2 from the atmosphere. The carbon capture and storage is preventing newly created CO_2 entering the atmosphere and artificially extending the storage period of the carbon atoms initially extracted, as CO_2 molecules, from the atmosphere during photosynthesis. Further, it is not clear why only sustainable biomass can generate 'negative emissions'. If this is correct, a clear explanation is required. Without clarity on the need for sustainable biomass, a more accurate meaning would be:

Bioenergy with carbon capture and storage: **Refers to bioenergy processes (such as burning biomass for electricity) during which any carbon dioxide produced is captured and stored.**

[2]UK Government's Energy White Paper: Powering Our Net Zero Future (Department for Business Energy and Industrial Strategy, 2020) page 53

[2]The meaning of Bioenergy with Carbon Capture and Storage in the Energy White Paper's Glossary refers to CO.

3. Biomass

The White Paper's meaning is ***'Refers to any material of biological origin used as a feedstock for products (e.g. wood in construction or to make chemicals and materials, like bio-based plastics), or as a fuel for bioenergy (heat, electricity and gaseous fuels such as biomethane and hydrogen) or biofuels (transport fuels).'***

Biofuels are not given a meaning in the White Paper Glossary, but this biomass meaning suggests biofuels are only transport fuels. Clarity is needed as to what biofuels are. In addition, the meaning of bioenergy should not include hydrogen, as hydrogen is not 'heat or electricity produced using material of biological origin'. To avoid confusion around biofuels the meaning should be:

Biomass: **Refers to any material of biological origin used as a feedstock for products (e.g. wood in construction or to make chemicals and materials, like bio-based plastics), or as a fuel for bioenergy.**

4. Clean electricity

The White Paper's meaning is: ***'Types of electricity generating technologies that emit little or no fossil fuel derived greenhouse gas from generation.'***

Greenhouse gas derived from material of biological origin has exactly the same effect on concentrations of greenhouse gases in the atmosphere as greenhouse gas derived from fossil fuels. A less misleading meaning would be:

Clean electricity: **Types of electricity generating technologies that emit little or no greenhouse gases.**

5. Clean hydrogen

The White Paper's meaning is: ***'Hydrogen that is produced with significantly lower greenhouse gas emissions compared to current methods of production – methods include reacting methane with steam to form hydrogen and then capturing the carbon dioxide by-product (steam methane reformation with CCUS) or using renewable electricity to split water into hydrogen and oxygen (electrolysis).'***

Methane pyrolysis is another method of forming hydrogen from methane. Renewable electricity is not necessarily clean electricity.

A more helpful meaning would be:

Clean hydrogen: **Hydrogen that is produced with significantly lower greenhouse gas emissions compared to current methods of production – methods include reacting methane with steam to form hydrogen and then capturing the carbon dioxide by-product (steam methane reformation with CCUS), processing methane to form hydrogen and solid carbon (methane pyrolysis) and using clean electricity to split water into hydrogen and oxygen (electrolysis).**

6. Greenhouse Gas Emissions

The White Paper's meaning is: ***'Addition to the atmosphere of gases that are a cause of global warming, including carbon dioxide, methane and others.'***

The meaning as written may be correct, but if so then a more correct phrase in relation to achieving Net Zero would be Anthropogenic Greenhouse Gas Emissions.

A less misleading meaning would be:

Greenhouse gas emissions: **Addition to the atmosphere of greenhouse gases.**

7. Hydrogen for heat

The White Paper's meaning is: *'The combustion of hydrogen produces no long-lived greenhouse gas emissions at point of use, making it a possible low-carbon replacement for natural gas as a fuel source for heating homes and other buildings.'*

How long is long-lived? In addition, is no long-lived hinting at water vapour, which is a greenhouse gas? A clearer meaning would be:

Hydrogen for heat: **The combustion of hydrogen produces no carbon based greenhouse gas emissions at point of use, making it a possible replacement for natural gas as a fuel source for heating homes and other buildings.**

8. Low-carbon electricity generating technologies

The White Paper's meaning is: *'Types of electricity generating technologies that emit little or no carbon, which include renewables, nuclear, CCUS.'*

Most fossil fuel and fuel for bioenergy used in electricity generating technologies emit little or no carbon, but without technologies such as CCUS, they do emit large amounts of CO_2. Any emission of carbon from an electricity generating plant will be as soot, a black solid. Soot is an indication of inefficient plant operation. Efficient plant operation requires converting all of the carbon in the fuel into the invisible gas CO_2. Thus, using electricity generating technologies that emit little or no carbon does not mean little or no CO_2 emissions. Further, CCUS is not a form of electricity generation; it is a technology to facilitate electricity generation using carbon-based fuels without emissions of CO_2 into the atmosphere. A more accurate meaning would be:

Low-carbon electricity generating technologies: **Types of electricity generating technologies that emit little or no carbon dioxide into the atmosphere, which includes wind, solar, nuclear and carbon based fuels using CCUS.**

9. Negative Emission

The White Paper's meaning is: *'Achieved by removing greenhouse gases from the atmosphere, for example, through direct air capture or bio-energy production with carbon capture.'*

Nature removes the greenhouse gas CO_2 from the atmosphere. At best, such removal of greenhouse gases can be credited as nature's negative emissions. Unless human action has enabled the removal of greenhouse gases, such negative emissions cannot be credited as removing anthropogenic greenhouse gas emissions.

A more honest meaning would be:

Negative emission: **Achieved by human intervention to remove additional greenhouse gases from the atmosphere.**

10. Net Zero

The White Paper's meaning is: ***'Refers to a point at which the amount of greenhouse gas being put into the atmosphere by human activity in the UK equals the amount of greenhouse gas that is being taken out of the atmosphere.'***

The rate of greenhouse gases entering the atmosphere at any point in time is the sum of all natural emissions of greenhouse gases, such as the natural processes of animals eating and breathing and the biodegrading of dead plants and animals, plus anthropogenic greenhouse gas emissions, such as CO_2 originated by equipment operation. The rate of greenhouse gases leaving the atmosphere at any point in time is the sum of all natural removal of greenhouse gases plus any human action to remove greenhouse gases. Net Zero under the mathematics of the current meaning is not achieved until the natural emissions rate is zero.

A more effective meaning for reducing greenhouse gas concentrations in the atmosphere would be:

Net Zero: **Refers to a point at which the rate of greenhouse gases originated by UK human activity entering the atmosphere equals the additional rate of greenhouse gases leaving the atmosphere attributable to human actions credited to the UK.**

There are two phrases and meanings, which would benefit the White Paper to include in the Glossary. These are Anthropogenic greenhouse gas emissions and biofuel. It is not clear why biofuel is only referred to as a transport fuel.

Anthropogenic greenhouse gas emissions: **Addition to the atmosphere of gases originated by human action that are a cause of increased concentrations of greenhouse gases in the atmosphere, including carbon dioxide, methane and others.**

Biofuel: **A material of biological origin used as a fuel.**

Recommendations for the White Paper

The White Paper would better support eliminating atmospheric CO_2, generated through equipment operation, if it did not credit the use of biofuels as CO_2 emissions free. To continue to do so incentivises actions that risk increasing greenhouse gas levels during the transition to a future clean energy state. More generally, we suggest amending the White Paper so it is clear to all readers that:

1. The ending of all greenhouse gas emissions is not the objective and is unachievable due to naturally occurring cycles.
2. The objective is to halt the current rise in the concentration of carbon based greenhouse gases within the atmosphere.
3. To lower the concentration of carbon based greenhouse gases within the atmosphere, the average total rate of carbon based greenhouse gases (through both human action and naturally occurring combined) emitted into the atmosphere has to be lower than the total rate at which all carbon based greenhouse gases are removed from the atmosphere.
4. Energy gained from renewable and sustainable energy sources can potentially result in increasing emissions of CO_2 into the atmosphere, unless resultant CO_2 is captured and sequestered.
5. The lowering of greenhouse gas concentrations in the atmosphere is wholly independent of using materials having biological origin as an energy source.
6. Preventing the handling and combustion of waste material releasing CO_2 is a key part of reducing greenhouse gases entering the atmosphere.

In addition, being clearer in the Glossary's meanings, through the addition of two meanings and modification to ten others, to become:

a. Anthropogenic greenhouse gas emissions: Addition to the atmosphere of gases originated by human action that are a cause of increased concentrations of greenhouse gases in the atmosphere, including carbon dioxide, methane and others.

b. Bioenergy: Refers to heat or electricity produced using material of biological origin.

c. Bioenergy with carbon capture and storage: Refers to bioenergy processes (such as burning biomass for electricity) during which any carbon dioxide produced is captured and stored.

d. Biofuel: A material of biological origin used as a fuel.

e. Biomass: Refers to any material of biological origin used as a feedstock for products (e.g. wood in construction or to make chemicals and materials, like bio-based plastics), or as a fuel for bioenergy.

f. Clean electricity: Types of electricity generating technologies that emit little or no greenhouse gases.

g. Clean hydrogen: Hydrogen that is produced with significantly lower greenhouse gas emissions compared to current methods of production – methods include reacting methane with steam to form hydrogen and then capturing the carbon dioxide by-product (steam methane reformation with CCUS), processing methane to form hydrogen and solid carbon (methane pyrolysis) and using clean electricity to split water into hydrogen and oxygen (electrolysis).

h. Greenhouse gas emissions: Addition to the atmosphere of greenhouse gases.

i. Hydrogen for heat: The combustion of hydrogen produces no carbon based greenhouse gas emissions at point of use, making it a possible replacement for natural gas as a fuel source for heating homes and other buildings.

j. Low-carbon electricity generating technologies: Types of electricity generating technologies that emit little or no carbon dioxide into the atmosphere, which includes wind, solar, nuclear and carbon based fuels using CCUS.

k. Negative emission: Achieved by human intervention to remove additional greenhouse gases from the atmosphere.

l. Net zero: Refers to a point at which the rate of greenhouse gases originated by UK human activity entering the atmosphere equals the additional rate of greenhouse gases leaving the atmosphere attributable to human actions credited to the UK.

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