Society of Operations Engineers

Securing Safe and Sustainable Reductions in Atmospheric Carbon Dioxide

March 2023

Executive Summary

Actions taken, for whatever reason, to reduce the amount of atmospheric carbon dioxide must be focused on lowering the amount of atmospheric carbon dioxide and in supporting today's and future generations meet their needs and wishes. This includes any actions taken to address climate change arising from the global warming attributed to high amounts of atmospheric carbon dioxide.

Many of the promoted actions for addressing global warming, through reducing emissions of carbon dioxide, actually result in increased emissions and higher amounts of atmospheric carbon dioxide. They also hinder today's and future generations to meet their needs and wishes through the operation of equipment – the nuts and bolts of modern day life that are taken for granted and relied on by consumers, industry, government, military and healthcare. The consequence is that we are presently on an inefficient and unsustainable route for reducing the amount of atmospheric carbon dioxide and thus addressing global warming arising from high levels of atmospheric carbon dioxide.

This paper explains why all actions for sustainably and efficiently addressing global warming, arising from high amounts of atmospheric carbon dioxide, must be focused on lowering the amount of atmospheric carbon dioxide. This whilst also continuing to meet those needs and wishes of today's and future generations that are achieved through the operation of equipment.

Lowering the amount of atmospheric carbon dioxide means taking actions that together secure a nett physical flow of carbon dioxide out of the atmosphere. That is the rate of carbon dioxide flowing out of the atmosphere being greater than that flowing in.

There are several examples of actions promoted as addressing global warming, which are working against lowering the amount of atmospheric carbon dioxide. These include going all electric, increasing the use of hydrogen and installing equipment to remove carbon dioxide from the atmosphere. For all three, they could, in the future, aid in reducing the amount of carbon dioxide in the atmosphere, but only when all electricity production (and hydrogen production in the case of hydrogen) is free of carbon dioxide emissions into the atmosphere. Until then their use risks increasing the amount of carbon dioxide in the atmosphere.

Using carbon-based renewable fuels, as with fossil fuels, results in emissions of carbon dioxide into the atmosphere. To reduce the amount of atmospheric carbon dioxide, we must disregard if the energy source is renewable or not. We need to focus on securing energy with no resulting emissions of carbon dioxide into the atmosphere. With 100% carbon dioxide capture and storage, carbon-based renewable and fossil fuels can be used without emissions of carbon dioxide into the atmosphere.

We need to ensure only the use of technologies that enable total electricity generation and demand to be balanced free of any resulting emissions of carbon dioxide into the atmosphere. Also, rather than prohibiting the provision of certain goods and services, we need to secure the provision of all goods and services, local and global, in ways that do not result in additional human originated carbon dioxide emissions into the atmosphere.

Efficiently and sustainably lowering the amount of atmospheric carbon dioxide does mean ending the use of carbon offsets. Carbon offsets do not result in ether a reduction in the rate of carbon dioxide entering the atmosphere, or an increase in the rate it is leaving.

Lowering the amount of carbon dioxide in the atmosphere does mean seeking the most efficient solutions to problems. The most efficient solution is now either the most efficient

solution that is free of carbon dioxide emissions into the atmosphere, or the solution that results in the least amount of carbon dioxide entering the atmosphere.

To know how we are doing we need to be answering the question, "*by how much did we lower the amount of carbon dioxide in the atmosphere today?*" The answer itself must be based on honest, rigorous and accurate measuring and reporting of the total actual amounts of carbon dioxide entering and leaving the atmosphere, together with the actual change in the amount of carbon dioxide in the atmosphere across the day.

It is essential that once we know by how much the amount of carbon dioxide in the atmosphere changed today, we build on this to;

1. Secure an increased level of general understanding of how and why carbon dioxide enters the atmosphere. In particular, how the everyday use of equipment by all, results in additional carbon dioxide entering the atmosphere and, crucially, how this can be ended or reduced, whilst continuing to meet those needs and wishes of today's and future generations that are achieved through the operation of equipment.
2. Secure an increased level of general understanding of how human action affects the rate of carbon dioxide leaving the atmosphere and how the total rate can be increased.
3. Have a honest understanding of how past actions to address global warming are impacting on the amount of atmospheric carbon dioxide today.

Failure to achieve on any of these three understandings, risks a further proliferation of actions that work against lowering the amount of atmospheric carbon dioxide. The result, a continued increase in the amount of atmospheric carbon dioxide.

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Introduction

This paper looks at actions for sustainably and efficiently addressing the global warming arising from high amounts of the greenhouse gas carbon dioxide (CO_2) in the atmosphere (atmospheric carbon dioxide). It explains why all actions must be both focused on lowering the amount of atmospheric carbon dioxide and supporting today's and future generations' needs and wishes through the operation of equipment – the nuts and bolts of modern day life that are taken for granted and relied on by consumers, industry, government, military and healthcare.

The paper first explores, in Chapter 1, the task of reducing the amount of atmospheric carbon dioxide from the perspective of the operations engineer. It then considers, in Chapter 2, currently promoted actions for addressing global warming, which are not supporting reducing the amount of atmospheric carbon dioxide today. Chapter 3, sets out an operations engineering approach to securing safely and sustainably true reductions in the amount of atmospheric carbon dioxide.

This paper has been produced because of concerns within the Society of Operations Engineers (SOE) that too many of the actions for addressing global warming are currently not contributing to reducing the amount of carbon dioxide in the atmosphere and often actually increasing it. Also, that some of these actions' outcomes appear to have the unintended consequence of making it unnecessarily harder for today's and future generations to efficiently meet their needs and wishes through the operation of equipment. The consequence is a fear that currently we are on an inefficient and unsustainable route for reducing the amount of atmospheric carbon dioxide and thus addressing the global warming arising from higher amounts of atmospheric carbon dioxide than would occur naturally.

SOE through its specific professional engineering sectors, promotes safe, efficient, sustainable and ethical operations engineering[1] for the benefit of society as a whole. It is a united organisation of engineering disciplines for those engaged in engineering operations. These disciplines include engineer surveying, environmental engineering, plant engineering and road transport engineering. Therefore, if society truly wishes to address the amount of atmospheric carbon dioxide, particularly that arising from equipment operation, then the SOE has the role of promoting that all resulting actions are conducted safely, efficiently, sustainably and in an ethical manner.

In producing this paper, SOE is not taking a view on global warming, climate change, their causes, or effects. SOE's position is simply that, if society truly wishes to reduce the amount of atmospheric carbon dioxide, be that to address global warming, climate change, or any other issue, then it needs to focus on actions that have a real and positive effect on lowering the rate of carbon dioxide entering the atmosphere and or increasing the rate of carbon dioxide leaving the atmosphere. These positive actions being founded on rigorous and honest measurement and reporting. This to deliver the desired outcome safely and efficiently. Further, determining what are the needs and wishes of today's and future generations is outside the scope of operations engineering. Therefore, SOE is not taking a view on which technologies should be promoted, when and for what purpose equipment should be used, or which needs and wishes, if any, that are currently secured through the operation of equipment

[1] Operations engineering is typically taking proactive actions that ensure the equipment we all use, both directly and indirectly, in our everyday lives runs safely, reliably and efficiently. It covers the specifying, evaluation, acquisition, commissioning, operation, management, inspection, testing, maintenance, repair, refurbishment, development and disposal of vehicles and fixed, mobile and removable machinery, plant, equipment and systems, and all activities related or incidental to any of them.

should be honoured. This even in the quest to lower the amount of atmospheric carbon dioxide.

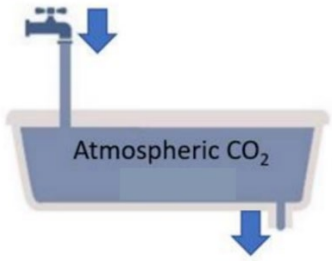
Chapter 1 - Reducing the amount of atmospheric carbon dioxide

From the perspective of the operations engineer, before any actions are taken to address a problem, the problem and root cause need to be established. Our understanding is that the objective is to prevent further climate change and possibly reverse what has happened already. We also understand that the hypothesis is that climate change has been caused by global warming, meaning that to fix climate change global warming must be addressed. That global warming is occurring because the amount of carbon dioxide in the atmosphere is higher than would occur naturally, meaning that the amount of atmospheric carbon dioxide must be reduced. The task is therefore to reduce the amount of atmospheric carbon dioxide.

To reduce the amount of atmospheric carbon dioxide, so as to prevent further climate change and possibly reverse what has happened already, we need to first establish why the amount of atmospheric carbon dioxide is higher than that which would not trigger global warming and thus climate change.

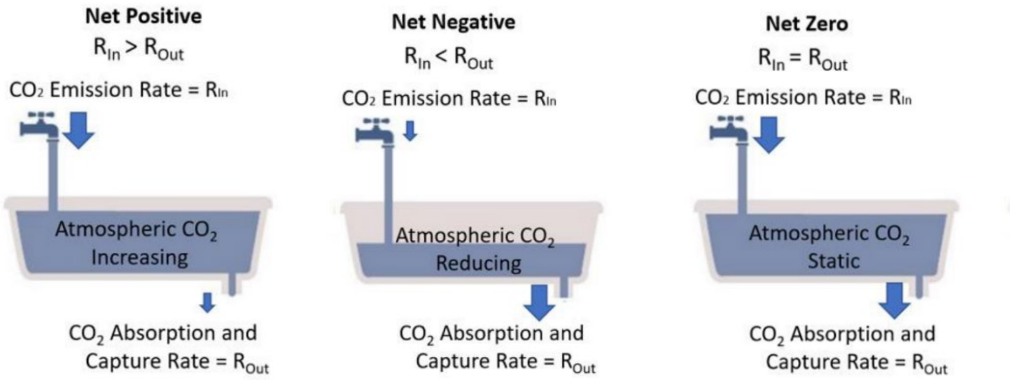
Consider the planet's atmosphere as a bath of water, as shown in **Figure 1 – The atmosphere as a bath of water**. The water in the bath represents carbon dioxide and the water level represents the amount of carbon dioxide in the atmosphere.

Figure 1 – The atmosphere as a bath of water



With the bath taps running and the drain plug partially open, a water level is established. This will rise (see **Figure 2 Net Positive**) or fall (see **Figure 2 Net Negative**) as a function of input and output flows. To stabilise at a constant level, the flow in must be the same as the flow out (see **Figure 2 Net Zero**).

Figure 2

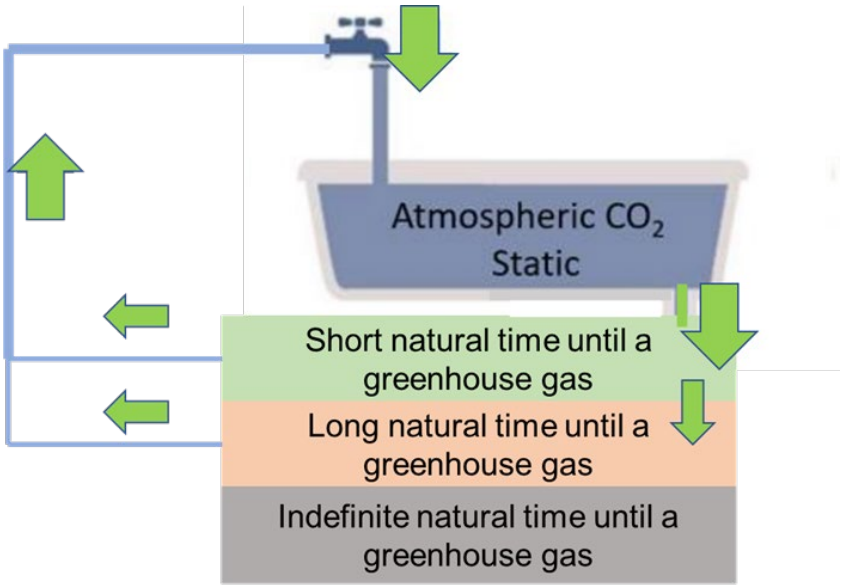


In all three cases it is not the total amount of water flowing into, or out of the bath that determines the water level, but the difference in rates of the inlet and outlet flows. For the

atmosphere, if the average rate of carbon dioxide moving into the atmosphere is equal to the average rate leaving, then the amount of atmospheric carbon dioxide remains constant. If over time there is a difference between the average rate of movement into and out of the atmosphere, the amount of carbon dioxide in the atmosphere changes accordingly.

The atmosphere, as a bath of water, is just one part within the natural carbon cycle (see **Figure 3 – the natural carbon cycle**). We assume that without external events, in the natural carbon cycle the amount of atmospheric carbon dioxide is constant through there being a balance between the flow in and flow out.

Figure 3 – the natural carbon cycle



In the natural carbon cycle, carbon atoms not in the atmosphere, can be viewed as falling into three categories. First, in a short natural time until a greenhouse gas. An example would be carbon atoms, which were within carbon dioxide until recently absorbed by grass. The grass will be shortly eaten by animals. Through the animals breathing out carbon dioxide and releasing methane (CH_4), the carbon atoms quickly return to the atmosphere as part of carbon dioxide or methane.

Second, in a long natural time until a greenhouse gas. An example would be carbon atoms which were within carbon dioxide until absorbed by a tree. The tree may then hold the carbon for many years before they die and eventually release the carbon atoms, as part of carbon dioxide or methane, back into the atmosphere.

Third, in an indefinite natural time until a greenhouse gas. Examples are carbon atoms within fossil fuels in the ground. Potentially these atoms will never be released into the atmosphere.

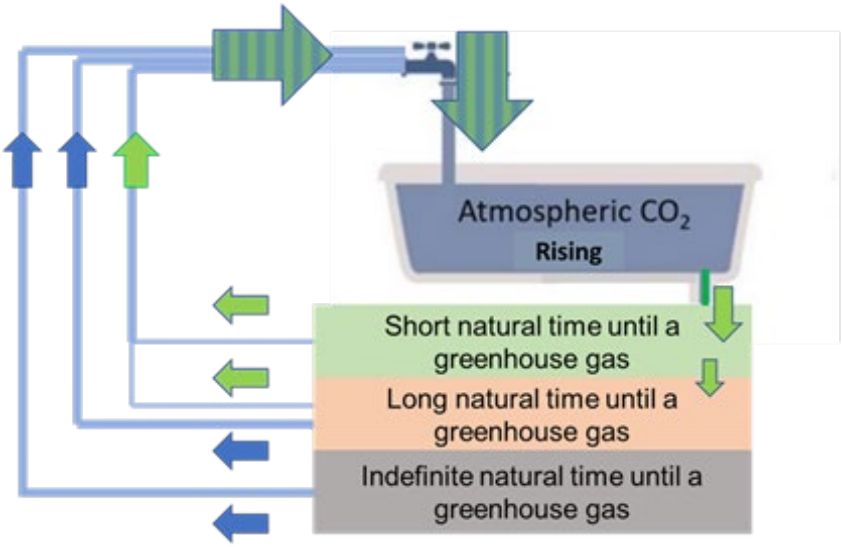
As was shown in Figure 2 Net Zero above, for the amount of carbon dioxide within the atmosphere to be constant, the rates of flow into and out of each point in the cycle must be equal. Human action has undoubtedly increased the average rate of total emissions of carbon dioxide into the atmosphere. This through shortening of the natural time until the carbon-based molecules re-enter the atmosphere. For example, burning fossil fuels (carbon with indefinite natural time until a greenhouse gas) releases carbon, within carbon dioxide. Without the burning, the carbon in the fossil fuel would have remained trapped for a potentially indefinite number of years and thus not contribute to increasing the amount of carbon dioxide

present in the atmosphere. In the natural cycle of growth and decay, wood (carbon in a long natural time until a greenhouse gas) releases carbon dioxide and methane into the atmosphere over extended periods of time. However, burning carbon-based renewable fuels, such as wood, reduces the remaining time until carbon is released, within carbon dioxide, into the atmosphere from potentially many decades to a few minutes.

Human actions have also probably reduced the rate at which nature removes carbon dioxide from the atmosphere. An example would be deforestation, where human action to clear trees has probably reduced nature's total atmospheric carbon dioxide removal rate capability.

The effects of reducing the time to release carbon into the atmosphere and restricting the rate it can be removed, are depicted in **Figure 4 – Today's Carbon Cycle**. Here the amount of carbon dioxide in the atmosphere is rising.

Figure 4 – Today's Carbon Cycle



To reduce the amount of carbon dioxide in the atmosphere, there needs to be a reduction in the rate at which carbon atoms become part of greenhouse gas molecules entering the atmosphere. There also needs to be an increase in the rate at which carbon dioxide is removed from the atmosphere. We need to return to the natural carbon cycle (see **Figure 3 – the natural carbon cycle**), which is effectively Net Zero (see **Figure 2 Net Zero**), and then move on to Net Negative (see **Figure 2 Net Negative**).

In its *"Review of the UK Government's White Paper: Powering our net zero future"*, SOE identified four actions that could move today's carbon cycle towards greater quantities of carbon not being part of carbon dioxide molecules within the atmosphere. These were:

1. Reducing the rate at which carbon atoms become part of greenhouse gas molecules entering the atmosphere, naturally occurring and human originated. For equipment operation this means reducing or ending the burning of all forms of carbon that result in emissions of carbon dioxide into the atmosphere, including carbon within fossil and renewable fuels.

2. Reducing the rate at which carbon atoms become part of greenhouse gas molecules entering the atmosphere, through storing naturally occurring and human originated

carbon dioxide before it enters the atmosphere. For equipment operation this means using carbon dioxide capture and long-term storage technologies to capture and place in long term storage the resultant carbon dioxide molecules, arising from the combustion of the carbon.

3. Increasing the rate at which carbon dioxide is removed from the atmosphere and reducing the rate at which carbon atoms become part of greenhouse gas molecules entering the atmosphere. This through human actions, including increasing the number of plants (such as trees) to increase nature's atmospheric carbon dioxide removal rates and carbon storage capabilities. Also, but only once all energy harvesting is carbon dioxide emission free, by operating equipment to remove atmospheric carbon dioxide and then storing the carbon dioxide outside of the atmosphere.

4. Reducing the rate at which carbon atoms become part of greenhouse gas molecules entering the atmosphere, through reducing the rate of natural conversion of carbon into carbon-based greenhouse gases. This by delaying, or preventing, the decomposition of plant material. An example of this would be increasing the use of wood as structural material.

A further action to reduce carbon-based greenhouse gas emissions would be to harvest other energy molecules from carbon compounds, such as hydrocarbons and carbohydrates, without burning of the carbon atoms. Examples would be the hydrocarbons methane and polyethylene (C_2H_2). Here, once all energy harvesting is carbon dioxide emission free, the methane and polyethylene could be converted, using processes such as pyrolysis, into hydrogen for use as a fuel. The resulting carbon has a potentially indefinite natural time until it becomes a greenhouse gas in the atmosphere. This offers the prospect of the many forms of hydrocarbon and carbohydrate-based waste materials being used as feedstock for harvesting hydrogen for fuel and returning the carbon to indefinite natural time until it becomes part of a greenhouse gas in the atmosphere.

Because "Today's Carbon Cycle" encompasses both naturally occurring and human originated flows of carbon dioxide into and out of the atmosphere, SOE has questioned the definition of "Net Zero" as set out in the UK Governments 2020 White Paper[2]. The White paper's meaning of "Net Zero" was given as:

> *'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 human originated greenhouse gas emissions, such as carbon dioxide originated by equipment operation. The rate of greenhouse gases leaving the atmosphere at any point in time is the sum of all naturally removed greenhouse gases, plus any human action to remove greenhouse gases. Therefore, "Net Zero" under the mathematics of the White Paper's 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;

[2] SOE's June 2021 review of the UK Government's White Paper: Powering our net zero future Department for Business Energy and Industrial Strategy, 2020

> "*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.*"

It should also be reiterated that achieving Net Zero does not mean reducing the amount of carbon dioxide in the atmosphere. At Net Zero (see **Fig 2 Net Zero**) the current high levels of atmospheric carbon dioxide remain high. Only when the total amount of carbon dioxide entering the atmosphere is less than the amount leaving (see **Fig 2 Net Negative**) does the amount of atmospheric carbon dioxide fall.

Reducing the amount of atmospheric carbon dioxide means having more carbon dioxide flowing out than is flowing into the atmosphere.

Chapter 2 – Currently promoted actions addressing global warming

Having established that to reduce the amount of atmospheric carbon dioxide means getting to a situation where more carbon dioxide is flowing out than flowing into the atmosphere, we now need to focus on actions that result in lowering the current nett flow of carbon dioxide into the atmosphere and eventually achieve a nett flow out. However, all actions to achieve a nett flow of carbon dioxide out of the atmosphere must be within the boundaries of continuing to meet those needs and wishes of today's and future generations. This as part of ensuring none of the actions taken risk compromising the respect for life, the law, the wider environment and public good.

Many of the current actions presented as addressing global warming are currently focused on reducing emissions of the greenhouse gas carbon dioxide resulting from the use of fossil fuels, rather than lowering the amount of atmospheric carbon dioxide. The result, too many of these actions are currently contributing to higher amounts of atmospheric carbon dioxide, the opposite to the intended outcome. Further, some of the actions' outcomes work against continuing to meet those needs and wishes of today's and future generations that are currently met through the operation of equipment. Hence the concern that currently we are on an inefficient and unsustainable route for reducing the amount of atmospheric carbon dioxide and thus addressing the global warming attributable to high amounts of atmospheric carbon dioxide.

Currently a large proportion of equipment[3] operation and its resulting energy consumption results in emissions of carbon dioxide into the atmosphere. Equipment operation is therefore likely to be a significant contributor to the current amounts of human originated atmospheric carbon dioxide. Engineering recognises this and already has safe and efficient solutions for delivering a sustainable reduction in the amount of atmospheric carbon dioxide. This in ways that also meet those needs and wishes of today's and future generations that are currently met through the operation of equipment. However, with the focus currently on reducing emissions resulting from the use of fossil fuels, rather than lowering the amount of atmospheric carbon dioxide, a number of these solutions are being applied in ways that currently result in increased amounts of atmospheric carbon dioxide.

Below are ten examples of actions, relating to the operation of equipment, that are being promoted as addressing global warming. Each of these, in countries such as the UK, currently work against lowering the amount of atmospheric carbon dioxide, or against continued operation of equipment to meet the needs and wishes of today's and future generations.

1. The call - Go all electric now

Going all electric, including the use of electric vehicles and heat pumps, provides a solution for cutting emissions local to the point of use, arising from the use of energy, whilst continuing the operation of equipment to meet the needs and wishes of today's and future generations. Nevertheless, until all electricity production is free of carbon dioxide emissions into the atmosphere, going all electric risks greater emissions of carbon dioxide into the atmosphere. This because currently increasing electricity demand, in countries such as the UK, generally increases electricity production from carbon-based fuels and thus the emissions of carbon dioxide into the atmosphere.

[3] Equipment in this document means any device, electrical or mechanical, that enables the user to utilise heating, cooling, pressure, vacuum, motion (as acceleration and deceleration), light, or chemical reactions for gaining a desired outcome.

It is because of this concern, namely that the increased use of electric vehicles before all electricity generation is carbon dioxide emission free, will result in greater emissions of carbon dioxide into the atmosphere; that SOE responded to a UK Government consultation on ending the sale of new petrol, diesel and hybrid cars and vans[4]. SOE's response set out why the 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.

For an efficient and sustainable reduction of atmospheric carbon dioxide we need all electricity production free of carbon dioxide emissions into the atmosphere before commencing a large-scale drive to go all electric.

2. The call - Use more hydrogen now

Using more hydrogen provides a solution for cutting emissions of carbon dioxide local to the point of use, arising from the use of energy. However, at present in countries such as the UK, using hydrogen, as an energy source, produced by processes such as steam methane reforming natural gas and electrolysis increases the rate of carbon dioxide emissions into the atmosphere. Thus, using more hydrogen currently has a negative impact on lowering the amounts of atmospheric carbon dioxide. Until all hydrogen and all electricity production are free of carbon dioxide emissions into the atmosphere, the production of hydrogen will increase emissions of carbon dioxide into the atmosphere.

Concerned that using more hydrogen currently has a negative impact on lowering the amounts of atmospheric carbon dioxide, SOE has questioned having colour coded hydrogen[5]. SOE's position is that it cannot see any engineering reason as to why hydrogen production with low, or no emissions of carbon dioxide into the atmosphere has to also be a low consumer of carbon, or carbon compounds. Also, that through using 100% effective carbon dioxide capture and storage technology, to ensure that there are no emissions of carbon dioxide into the atmosphere, producing hydrogen using large quantities of carbon or carbon compounds may be one of the most efficient ways of delivering zero carbon dioxide emissions into the atmosphere from equipment operation.

For an efficient and sustainable reduction of atmospheric carbon dioxide we need all electricity and hydrogen production free of carbon dioxide emissions into the atmosphere, before commencing a large-scale increase in the use of hydrogen.

3. The call - Install equipment to remove carbon dioxide from the atmosphere now

Installing equipment to remove carbon dioxide from the atmosphere provides another tool to aid reducing the amount of atmospheric carbon dioxide. Nevertheless, at present in countries such as the UK, operating such equipment also risks increasing the rate of carbon dioxide emissions into the atmosphere. As with 1 above, until all electricity production is free of carbon dioxide emissions into the atmosphere, employing more electrically powered equipment to remove carbon dioxide from the atmosphere risks greater emissions of carbon dioxide into the atmosphere.

[4] 2020 Response by the Society of Operations Engineers to UK Government consultation on ending the sale of new petrol, diesel and hybrid cars and vans Government is seeking views on bringing forward the end to the sale of new petrol, diesel and hybrid cars and vans from 2040 to 2035, or earlier if a faster transition appears feasible.

[5] SOE's response to the Department for Business, Energy and Industrial Strategy's consultation on a UK Low Carbon Hydrogen Standard

For an efficient and sustainable reduction of atmospheric carbon dioxide we need all electricity production free of carbon dioxide emissions into the atmosphere before commencing large-scale use of equipment to remove carbon dioxide from the atmosphere.

4. The call - Replace fossil fuels with carbon based renewable fuels

Using carbon based renewable fuels, such as biofuels, supports using fewer fossil fuels. The chemical compositions of the carbon-based renewable fuel and the fossil fuel it is replacing, determines the resultant reduction, or increase, in carbon dioxide emissions into the atmosphere. The problem is that in all cases, replacing fossil fuels containing carbon with renewable fuels containing carbon does not end emissions of carbon dioxide into the atmosphere.

As with fossil fuels, without 100% carbon dioxide capture and storage, using carbon-based renewable fuel results in emissions of carbon dioxide into the atmosphere. Being a renewable energy source does not affect the rate of emission into, or the rate of extraction from the atmosphere. With 100% carbon dioxide capture and storage, carbon-based renewable and fossil fuels can be used without emissions of carbon dioxide into the atmosphere. This negates replacing fossil fuels with renewable carbon-based fuels as a means of stopping emissions of carbon dioxide into the atmosphere.

For an efficient and sustainable reduction of atmospheric carbon dioxide we need to disregard the fuel source and focus on securing no emissions of carbon dioxide into the atmosphere.

5. The call - Increase the use of renewable energy

Increasing the use of renewable energy facilitates a reduced demand for energy from fossil fuels, if all other factors remain constant. But, as explained in 4 above, using the carbon-based renewable fuel does not end emissions of carbon dioxide. Thus, simply increasing the use of renewable energy risks continued emissions of carbon dioxide into the atmosphere.

To deliver the objective of lowering the amount of atmospheric carbon dioxide, rather than increasing the use of renewable energy, society needs to increase its use of carbon dioxide emission free energy sources. Using carbon dioxide emission free energy sources, such as the various forms of geothermal, nuclear, hydro, marine (including tidal and wave), solar and wind, supports lowering the rate of carbon dioxide emissions into the atmosphere and therefore lowering the amount of atmospheric carbon dioxide.

For an efficient and sustainable reduction of atmospheric carbon dioxide we need to disregard if the energy source is renewable or not and simply focus on securing no resulting emissions of carbon dioxide into the atmosphere.

6. The call - End the use of fossil fuels

For the reasons set out in 4 and 5 above, as with carbon containing renewable fuels, ending the use of fossil fuels helps in reducing emissions of carbon dioxide into the atmosphere if all other factors remain constant. However, replacing carbon-based fuels with carbon free energy sources may not work in all situations. Particularly where the carbon is not being used for energy, but as a component in chemical reactions. For example, in iron production, where carbon is used to convert iron oxide into iron. Originally the carbon-based renewable fuel charcoal was the reducing agent used in iron production. Sustainability issues (resulting scarcity of wood) led to the use of the fossil fuel coke as an alternative. Thus, ending the use of fossil fuels risks having to end large scale iron production. Would ending large scale

processes, such as iron production, help in meeting the needs and wishes of today's and future generations?

100% carbon dioxide capture and storage enables the use of carbon-based fuels, such as charcoal and coke, as a source of carbon with no resulting emissions of carbon dioxide into the atmosphere. Thus, cutting the rate of carbon dioxide emissions into the atmosphere resulting from the operation of equipment is not about cutting the use of fossil fuels, or carbon-based fuels. It is about restricting the use of carbon-based fuels, fossil fuels and carbon-based renewable fuels, to processes employing technologies that result in zero emissions of carbon dioxide into the atmosphere.

For an efficient and sustainable reduction of atmospheric carbon dioxide we need to disregard the fuel source and focus on securing no emissions of carbon dioxide into the atmosphere.

7. The call - Use more carbon-based renewable fuel fired flexible electricity generation

Most carbon free electricity generation, such as nuclear, solar and wind, has insufficient flexibility to continuously balance total electricity generation to total demand. Carbon-based electricity generation (renewable and fossil) currently provides much of the required flexibility for balancing changes in electricity demand, but also emissions of carbon dioxide into the atmosphere.

Increased use of flexible large-scale energy storage and fuel production plants allows the total demand to be balanced against total electricity generation. This reduces and potentially removes the need for carbon-based electricity generation (renewable and fossil fuelled).

For an efficient and sustainable reduction of atmospheric carbon dioxide, we need to disregard the energy source of the technologies used, to balance electricity generation and demand, and instead focus on securing that the balancing actions of electricity generation and demand are free of any resulting emissions of carbon dioxide into the atmosphere.

8. The call - Close local production plants

Closing a country's production plants reduces that country's emissions of carbon dioxide into the atmosphere. Unless that country's demand causing the operation of the production plants ceases, production for that country will continue elsewhere. This results in the same, or higher, levels of global carbon dioxide emissions into the atmosphere. Rather than forcibly closing production plants, a more honest approach is, arguably, to forcibly end the demand causing the operation of the plants. It is difficult to see how forcibly ending a demand, through either preventing the use of energy to operate the equipment, or banning products and services, provided by the equipment, supports today's and future generations in securing their needs and wishes.

For an efficient and sustainable reduction of atmospheric carbon dioxide we need to focus on meeting the demand for products in ways that are free of any emissions of carbon dioxide into the atmosphere, local or global.

9. The offered solution - Use carbon offsets

Carbon offsets do not in themselves result in either a reduction in the rate of carbon dioxide entering the atmosphere, or an increase in the rate it is leaving the atmosphere. An example of why using carbon offsets does not help in reducing the amount of atmospheric carbon

dioxide is causing emissions of carbon dioxide into the atmosphere through the burning of aviation fuel and then offsetting it with planting trees to claim a balance and thus “net zero”. While this may satisfy other concerns, it does not reduce the rate of emissions of carbon dioxide into the atmosphere or the demand for carbon-based fuels, such as fossil fuels. Here we are offsetting a high-rate emission of carbon dioxide into the atmosphere today, with low-rate of extraction in the future. It may take 20 years for the planted trees to absorb the carbon dioxide emitted by a plane travelling from London to New York today. The result is an increase in the amount of carbon dioxide in the atmosphere. Here the totals may balance, but the rates are different. Only when the rates of emission and extraction are equal and take place at the same time, will the nett effect on the amount of atmospheric carbon dioxide be zero. Even then there has not been a reduction in emissions of carbon dioxide or in the demand for carbon-based fuels by this action.

For an efficient and sustainable reduction of atmospheric carbon dioxide we need to avoid any use of carbon offsets when measuring flows of carbon dioxide in and out of the atmosphere.

10. The claim - 100% carbon dioxide capture and storage should not be used as it is inefficient.

Gaining higher operational energy efficiencies from all energy using equipment and energy producing processes contributes to reducing carbon dioxide emissions. Therefore, inefficiencies need to be avoided. Employing 100% carbon dioxide capture and storage is less efficient than not using it. Nevertheless, when eliminating carbon dioxide emissions into the atmosphere is the primary objective, we are seeking the most efficient means of securing the required energy with no resulting emissions of carbon dioxide into the atmosphere. Current burning of carbon-based fuels without 100% carbon dioxide capture and storage does not achieve this, it is very inefficient at eliminating carbon dioxide emissions resulting from equipment operation.

A similar argument is placed against some forms of nuclear power. Here the argument is that a large amount of carbon dioxide is emitted during nuclear plant construction and during the decommissioning and demolition processes. However, until all energy harvesting is free of carbon dioxide emissions into the atmosphere, all equipment construction and demolition, including nuclear and renewable energy plants, will result in such emissions. Thus, when all energy harvesting is free of carbon dioxide emissions into the atmosphere, all equipment, including nuclear and renewable energy plants, construction and demolition will be free of such emissions.

During the transition to all energy harvesting being free of carbon dioxide emissions into the atmosphere, the aim should be that the construction of all energy harvesting equipment, which when operational will be free of carbon dioxide emissions into the atmosphere, achieves a nett positive balance. The nett positive balance being that the energy harvesting equipment is designed to provide more energy free of carbon dioxide emissions into the atmosphere than the total energy consumed across all aspects of its construction. This if the equipment is expected to operate until all energy harvesting is free of carbon dioxide emissions into the atmosphere. If the equipment is not expected to operate until all energy harvesting is free of carbon dioxide emissions into the atmosphere, then the nett positive balance becomes one where there is more energy produced free of carbon dioxide emissions into the atmosphere, than the total energy consumed across all aspects of the equipment’s construction, operation, decommissioning and demolition.

For an efficient and sustainable reduction of atmospheric carbon dioxide we need to seek the solutions that secure the highest overall nett reduction in carbon dioxide emissions into the atmosphere.

Chapter 3 - Securing safe, efficient and sustainable reductions in the amount of atmospheric carbon dioxide

From the perspective of the operations engineer, securing safe, efficient and sustainable reductions in the amount of atmospheric carbon dioxide requires the measuring and checking of actions' outcomes against their predicted effect. Therefore, actions to reduce the amount of atmospheric carbon dioxide need to be measured against the resulting change. It also means all measuring of and reporting on the resulting change being founded on the four fundamental principles for ethical behaviour and decision-making of the Engineering Council and the Royal Academy of Engineering joint Statement of Ethical Principles for all engineering professionals. The four fundamental principles being:

1. honesty and integrity;
2. respect for life, law, the environment and public good;
3. leadership and communication; and
4. accuracy and rigour.

These four principles form the basis for achieving actual nett reductions in the amount of atmospheric carbon dioxide safely and efficiently, whilst continuing to meet the needs and wishes of today's and future generations.

To be effective, reporting on performance against a task needs to be in a form that is easily communicated to and understood by all. Therefore, for the task of reducing the amount of atmospheric carbon dioxide, the question to be answered for each day is, **"*by how much did we lower the amount of carbon dioxide in the atmosphere today?*".** Today is now the first point in time where action can be taken without further delay. Today is the only point in time where we can actually measure by how much the amount of carbon dioxide in the atmosphere changed today. Today is the day where we can actually assess the performance of actions taken in the past against their forecast effect on today.

Here we are considering the difference of two actual flow rates, carbon dioxide entering and leaving the atmosphere across a 24-hour period. This means that applying equivalents of financial accounting principles, such as including prepayments, deferred income, debtors and creditors in the balance, does not provide a true reflection of what actually happened today. Thus, all events of the past and predicted effects in the future of actions taken today and in the past need to be ignored, we are only interested in what actually flowed in and out of the atmosphere today. Because past and future events need to be ignored, there must not be any offsetting of any events occurring today against past and future events.

Ignoring all actions of the past and today in the reporting is not dismissing the need for action. Actions today and every day into the future are essential if the amount of atmospheric carbon dioxide is to be lowered. Their effect will materialise on a "today" sometime in the future.

Two illustrations as to why past and future activities need to be ignored in the daily reporting are set out below.

1. A seed planted today will over time grow into a tree, by removing carbon dioxide from the atmosphere. It cannot be included in today's numbers, as on the day of planting it does not extract any atmospheric carbon dioxide. What should be included in today's emissions are any emissions of carbon dioxide into the atmosphere resulting from today's planting process. Further, the planting of the seed today cannot be

taken as an offset against the burning of a mature tree today. The extra carbon dioxide entering the atmosphere today, from burning the mature tree, will not be fully balanced by the new tree for many years.

2. A seed was planted forty years ago and has grown into a tree, through removing carbon dioxide from the atmosphere. Over the forty years, through its growth, the tree has made an average nett contribution to removing carbon dioxide from the atmosphere. If today the tree is felled and burnt as a biofuel, the whole of the forty years nett removal of carbon dioxide is emitted back into the atmosphere. Today, the whole of the nett gain is lost. If today the tree is felled and burnt as a biofuel, but using 100% carbon dioxide capture and storage, there are no emissions, the nett gains of the past are retained. Today we achieve "net zero", not "net negative", as today there have been no emissions into the atmosphere and no removal of carbon dioxide from the atmosphere.

To answer the question "*by how much did we lower the amount of carbon dioxide in the atmosphere today?"* we need to know:

1. how much carbon dioxide entered the atmosphere today and where it came from;
2. how much carbon dioxide left the atmosphere today and why; and
3. the nett change in the amount of carbon dioxide within the atmosphere across today.

The nett actual change in the amount of carbon dioxide within the atmosphere across a day is equal to how much carbon dioxide actually entered the atmosphere during the day, less how much actually left.

Note, to simply calculate two of the parameters and use the third as a balancing number does not provide the level of accuracy and rigor required. Each of the three parameters must be determined independently. Any resulting imbalance suggests incomplete totals in one or more of the three parameters. An example of missing carbon dioxide emissions into the atmosphere would be the current practice of crediting the burning of biofuels, used to replace fossil fuels, as carbon dioxide emission free. Equally, carbon dioxide entering the atmosphere through the natural breakdown of other carbon-based greenhouse gases already in the atmosphere, such as methane, must be included in the total of carbon dioxide entering the atmosphere on a given day.

A further potential source of error would be any inclusion of "CO_2 equivalents". That is, including the other greenhouse gases which have been assigned a global warming potential value. To do so would not be accurately answering the question "*by how much did we lower the amount of carbon dioxide in the atmosphere today?"* It would be answering the question "*by how much did we lower the CO_2 equivalent of greenhouse gases in the atmosphere today?"*.

Understanding the three parameters, with the balance check across the three, aids a better understanding of the mechanics behind managing the amount of atmospheric carbon dioxide. However, delivering and measuring the objective is still only achievable if underpinned by behaviours and decision-making that are based on honesty, integrity, accuracy and rigour. Any adjustment of the reported rates of carbon dioxide entering and leaving the atmosphere across a day, or the nett change in the amount of carbon dioxide within the atmosphere on that day, to support other objectives, creates false balances that will not reflect what is actually happening to the amount of carbon dioxide in the atmosphere.

Society already has data relating to each parameter. The key challenge is understanding how and why the current data has been obtained. In particular, what is the true confidence level for each piece of data and what was the true purpose behind collecting the data? That is, to what extent is the data founded on rigorous and honest measurement and reporting? Then, having established this understanding, what confidence level can we apply to current reporting of the three parameters and what needs to be done to improve the confidence levels?

From an operations engineering perspective, having established a firm foundation against which to report progress, it becomes essential that we build on this to achieve an increased level of general understanding of how and why carbon dioxide enters the atmosphere. In particular, how the everyday use of equipment by all, results in carbon dioxide entering the atmosphere and, crucially, how this can be ended or reduced, whilst continuing with the operation of equipment to meet the needs and wishes of today's and future generations. Equally, how human action affects the rate of carbon dioxide leaving the atmosphere and how the total rate can be increased. Failure to achieve an increased level of general understanding, about all three points risks a further proliferation of actions, relating to the operation of equipment, promoted as addressing global warming, which work against lowering the amount of atmospheric carbon dioxide. The result, a continued increase in the amount of atmospheric carbon dioxide.

Conclusions

Actions taken, for whatever reason, to reduce the amount of atmospheric carbon dioxide must be focused on lowering the amount of atmospheric carbon dioxide. This includes any actions taken to address climate change arising from the global warming attributed to high amounts of atmospheric carbon dioxide. They must also support today's and future generations in meeting their needs and wishes.

Many of the promoted actions for addressing global warming, through reducing emissions of carbon dioxide, actually result in increased emissions and higher amounts of atmospheric carbon dioxide. They also hinder today's and future generations meet their needs and wishes through the operation of equipment. The consequence is that we are presently on an inefficient and unsustainable route for reducing the amount of atmospheric carbon dioxide and thus addressing global warming arising from high levels of atmospheric carbon dioxide.

Securing safe and sustainable reductions in the amount of atmospheric carbon dioxide requires:

1. A clear dual objective of reducing the amount of atmospheric carbon dioxide and continuing to meet the needs and wishes of today's and future generations.

2. All actions being founded on adherence, by all, to;
    i. honesty and integrity;
    ii. respect for life, law, the environment and public good;
    iii. leadership and communication; and
    iv. accuracy and rigour.

3. A focus on actions that support achieving a real nett rate of carbon dioxide leaving the atmosphere. This means actions that:
    a) reduce the actual rate of all carbon dioxide entering the atmosphere, naturally occurring and human originated; and
    b) increase the actual rate of carbon dioxide leaving the atmosphere, by natural processes and human actions.

4. Securing a wider and deeper understanding of how our actions are impacting on the amount of atmospheric carbon dioxide. This through a rigorous, honest and accurate approach by all. Specifically in:
    a) measuring and reporting on:
        i. the rate at which carbon dioxide is entering the atmosphere and the quantities from the different sources;
        ii. the rate at which carbon dioxide is leaving the atmosphere and the reasons for this; and
        iii. the nett change in the amount of atmospheric carbon dioxide over a given period of time.
    b) applying a focused measurement of achievement, namely, "*by how much did we lower the amount of carbon dioxide in the atmosphere today?*";
    c) having no credits or debits associated with actions and events of the past, or forecast for the future, applied to the actual physical quantities measured today; and
    d) restricting the measuring and reporting of carbon dioxide to:
        i. today's actual physical nett change in the amount of atmospheric carbon dioxide;
        ii. today's actual physical quantity of carbon dioxide entering the atmosphere; and
        iii. today's actual physical quantity of carbon dioxide leaving the atmosphere.

Society of Operations Engineers

Society of Operations Engineers
22 Greencoat Place, London SW1P 1PR
T: +44 (0) 20 7630 1111
E: info@soe.org.uk
W: soe.org.uk