Society of Operations Engineers

Ending carbon dioxide originated by equipment operation entering the atmosphere

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Executive Summary

This Society of Operations Engineers (SOE) position paper *Ending carbon dioxide originated by equipment operation entering the atmosphere* sets out the practicable engineering solutions already operating, or potentially very close to practicable operation, which together offer the prospect of ending CO_2 originated by equipment operation entering the atmosphere. These engineering solutions offer 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, but without resulting CO_2 entering the atmosphere.

While ending CO_2 originated by equipment operation entering the atmosphere removes most of the true human originated (anthropogenic) greenhouse gases entering the atmosphere, it is probable that concentrations of CO_2 in the atmosphere would continue to rise. Human actions, such as deforestation, have probably reduced both natural CO_2 absorption and natural temporary carbon storage capabilities. This has probably created an imbalance between natural rates of CO_2 entering and leaving the atmosphere. Therefore, in addition to ending CO_2 originated by equipment operation entering the atmosphere, action may be required to both increase rates of CO_2 removal from the atmosphere and temporary carbon storage capabilities. The increased CO_2 removal rates through actions such as tree planting and operation of equipment for extracting CO_2 from the atmosphere. The extension of temporary natural carbon storage times being through actions such as all material from felled trees used only in ways that delay or prevent it becoming CO_2.

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:

<u>The need to end CO_2 originated by equipment operation entering the atmosphere</u>

- Rising concentrations of greenhouse gases, which include CO_2, in the planet's atmosphere is a widely held concern of today's society. The prevailing view is that currently concentrations of greenhouse gases in the atmosphere are higher than would naturally occur and that this is primarily due to anthropogenic emissions of greenhouse gases. In addition, that the high concentrations of greenhouse gases in the atmosphere is probably causing the current global warming. Therefore, to reduce global warming, the current concentrations of greenhouse gases in the atmosphere need reducing and that this requires, amongst other actions, a cut in anthropogenic emissions of greenhouse gases entering the atmosphere.
- The operation of equipment results in significant quantities of CO_2 entering the atmosphere. It follows that if society wishes to cut anthropogenic emissions of CO_2 it needs to end CO_2 originated by equipment operation entering the atmosphere.

<u>Meeting the needs and wishes of today's society and future generations</u>

- 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 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.
- 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.

SOE's unique PEI role in ending CO_2 originated by equipment operation entering the atmosphere

- Currently achievable real net reductions in CO_2 originated by equipment operation entering the atmosphere are not being realised. This is probably due to a general lack of awareness and understanding of how the use of equipment creates CO_2 emissions.
- Addressing the general lack of awareness and understanding of how the use of equipment creates CO_2 emissions is the key foundation for implementing effective solutions. This being the ending of CO_2 entering the atmosphere, which originated from operation of the equipment used to meet the needs and wishes of today's society and future generations.
- SOE, as part of delivering its public benefit, is uniquely positioned for providing independent leadership in:
    1. raising general awareness and understanding of how the use of equipment can currently result in CO_2 entering the atmosphere and how this can be ended or reduced;
    2. using an holistic approach to assessing initiatives for ending or reducing 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 total anthropogenic CO_2 entering the atmosphere.

Safety first

- All actions to end or reduce CO_2 originated by equipment operation entering the atmosphere must be conducted safely.

Operational engineering facts

- 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 have 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.

Contents

Introduction

Rising concentrations of greenhouse gases in the planet's atmosphere is a widely held concern of today's society. The prevailing view is that currently concentrations of greenhouse gases in the atmosphere are higher than would naturally occur and that this is primarily due to emissions of greenhouse gases originated by humans (anthropogenic emissions of greenhouse gases). In addition, that the high concentration of greenhouse gases in the atmosphere is probably causing the current global warming. Therefore, to reduce global warming, the current concentrations of greenhouse gases in the atmosphere need reducing and this requires a cut in anthropogenic emissions of greenhouse gases.

The operation of equipment[1] currently results in large emissions of the greenhouse gas carbon dioxide (CO_2) into the atmosphere. These emissions are probably a significant proportion of the total anthropogenic emissions of greenhouse gases. It follows that if society wishes to eliminate anthropogenic emissions of greenhouse gases, it needs to end CO_2 originated by equipment operation entering the atmosphere.

When viewed from the perspective of operations engineering[2], it is clear that there are practicable engineering solutions already operating, or potentially very close to operation, which allow the use of energy without emissions of CO_2 into the atmosphere. This suggests that ending CO_2, originated by equipment operation, entering the atmosphere is achievable in ways that offer the real prospect of being able to pass on for future generations a better environment, where the benefits of today's lifestyles can still be enjoyed. To achieve this effective action is needed, which is itself dependent on a holistic, accurate and honest approach being adopted. This includes acknowledging that for various reasons, some currently promoted courses of action on climate change may actually be working against reducing total anthropogenic CO_2 emissions. Also, that while we have already made significant technological progress in CO_2 emission free harvesting of energy, there are still large hurdles to clear before fully achieving zero emissions of CO_2 originated by equipment operation entering the atmosphere; not least the financial cost.

This paper considers the practicable engineering solutions already operating, or potentially very close to operation and how a holistic, accurate and honest approach can be promoted. It also highlights current initiatives ostensibly to reduce greenhouse gas emissions, which risk actually increasing total emissions of CO_2 into the atmosphere.

In considering how to end CO_2 originated by equipment operation entering the atmosphere, this paper does not take a view on the validity or otherwise of global warming. Nor of the effects of different concentrations of greenhouse gases in the atmosphere, of the causes of high concentrations of greenhouse gases in the atmosphere, or of the importance of this issue relative to other sustainability issues. SOE's interest is only in securing that any actions to end CO_2 originated by equipment operation entering the atmosphere are safe, effective and best enable today's society to achieve, or move closer

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[1] 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.

[2] 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.

to achieving, its needs and wishes in ways that do not compromise future generations achieving their needs and wishes.

It is likely that if all equipment operation became free of CO_2 emissions, concentrations of CO_2 in the atmosphere would continue to rise. Human actions, such as deforestation, have probably reduced both natural CO_2 absorption and natural temporary carbon storage capabilities. This has probably created an imbalance between natural rates of CO_2 entering and leaving the atmosphere. Therefore, in addition to ending CO_2 originated by equipment operation entering the atmosphere, action may be required to both increase rates of CO_2 removal from the atmosphere and temporary carbon storage capabilities. The increase of CO_2 removal rates being through actions for extracting CO_2 from the atmosphere, such as tree planting and operation of CO_2 extraction equipment. The extension of temporary natural carbon storage times being through actions such as all material from felled trees used only in ways that delay or prevent it becoming CO_2. These actions are in addition to, they are not substitutes for the ending of CO_2 originated by equipment operation entering the atmosphere.

Background

Greenhouse gases are chemicals in the atmosphere that absorb and emit radiant energy within the thermal infrared range. The main greenhouse gases in the Earth's atmosphere are the liquid molecule H_2O (in the form of water vapour, i.e. clouds) and the gaseous molecules CO_2, CH_4 (methane) and NO_x (nitrogen oxides). With the exception of CH_4, all of these greenhouse gases are often released into the atmosphere, directly or indirectly, with equipment operation. The level of potential emissions varies between equipment. However, when considered from the operations engineering perspective technology, engineering arrangements and engineering based practices are available that could end CO_2 originated by equipment operation entering the atmosphere.

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. The use of such equipment and thus operations engineering, is central to the operation of today's infrastructure and essential technologies that provide our transport, energy, health, food and running water. Minimising the amount of atmospheric pollution arising from the operation of such equipment is one of the proactive actions of the operations engineer[3].

From the operations engineering perspective, all equipment operation involves the harnessing of energy so as to provide heating, cooling, pressure, vacuum, motion (as acceleration and deceleration), light and chemical reactions. There are six direct forms of atmospheric pollution arising from the operation of equipment and the associated harnessing of energy. These are in the forms of solids, liquids, gases, light, sound and heat. Good operations engineering practice is securing a balance that delivers safely and efficiently the desired outcome and, in this case, no resulting emissions of CO_2 into the atmosphere.

This harnessing of energy often involves combustion that results in the release of CO_2. The action of cooling can also result in the release of CO_2. Any loss of heat, light or sound from equipment is generally a wasting of energy and therefore inefficient.

CO_2 emissions are directly from the piece of equipment operating such as a diesel-powered vehicle, or indirectly such as operating a "zero emissions" electric powered vehicle. For countries such as the UK, except in a limited number of circumstances, the operation of "zero emissions" electric powered vehicles currently results in CO_2 emissions into the atmosphere. This is because usually the extra electricity needed to power the equipment is from electricity generation plant that emits CO_2 into the atmosphere. The result is an increase in generation from such plant and thus of CO_2 emissions. These indirect CO_2 emissions occur not only from "zero emissions" electric powered vehicles, but also from electric heating, cooling, motion and light. Indirect CO_2 emissions from electrically powered equipment only stop when, at the given point in time, all the electricity generation feeding the grid system does not result in CO_2 entering the atmosphere.

[3] Operations engineers are typically persons whose engineering specialism is operations engineering and who have the academic and additional learning in engineering or technology with at least the minimum time of training and experience required to be registered as Chartered Engineer (CEng), Engineering Technician (EngTec), or Incorporated Engineer (IEng) with the Engineering Council.

Chapter 1 - The role of SOE in ending CO2 originated by equipment operation entering the atmosphere

The Society of Operation's Engineers (SOE) is a professional engineering institution (PEI)[4] whose mission is to bring about a world where all aspects of operations engineering are conducted safely, ethically and at ever higher levels of sustainability and efficiency. Each of these aspects is a critical component in any project to end CO_2 originated by equipment operation entering the atmosphere.

Among the various engineering disciplines, operations engineering is the one focused on the equipment operating today to deliver today's society's requirements. Operations engineering's focus on equipment being operated, means it does not have vested interests in the promotion of particular types of equipment. As such operations engineering and thus SOE is uniquely placed for providing independent guidance on the practical operational engineering issues that need be observed if energy consumption is to become CO_2 emission free. This being through SOE, as part of delivering its public benefit, providing independent leadership in:

1. raising general awareness and understanding of how the use of equipment can currently result in CO_2 entering the atmosphere and how this can be ended or reduced;
2. using an holistic approach in assessing initiatives for ending or reducing 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 total anthropogenic CO_2 entering the atmosphere.

Appendix 1 sets out how SOE delivers public benefit through assisting its members improve and elevate their technical and general understanding, knowledge, skill and competence in the particular engineering field of operations engineering. This includes assisting its members in their applications for UK Engineering Council and the Society for the Environment registration.

SOE promoting registration with the Society for the Environment (as REnvP or CEnv), together with the associated professional development, is a direct input promoting the reduction of CO_2 emissions when operating equipment. Here it is by engineers and technicians in the workplace influencing equipment operations in their day to day activities.

[4] A PEI is an organisation licensed by the Engineering Council to assess individuals for inclusion on the national engineering register. They can also be licensed to accredit academic programmes and professional development schemes.

Chapter 2 - The role of safety in ending CO2 originated by equipment operation entering the atmosphere

Ensuring safety is a key part of operations engineering. As such, it sets the boundaries within which all actions to end CO_2 originated by equipment operation entering the atmosphere must stay.

For operations engineers, safety is ensuring that interactions with equipment are free from any malfunction or failure that could result in harm to an individual, groups of individuals, or life and resources more generally within the surrounding environment. It also encompasses all forms of wellbeing. Achieving reliable operation of equipment is a key part of this.

When considering how to operate equipment so that there are no resulting emissions of CO_2 into the atmosphere, it must be within the boundaries of ensuring that the equipment will always be operating safely and reliably. It means that within the framework of safety, efficiency, sustainability and ethical standards, safety sets the limits, the effect of which limits the efficiency at which equipment can operate. Safety also sets limits, the effect of which creates boundaries on the degree of sustainability achievable. However, ethical standards set what society requires of safety and therefore the limits that safety sets.

Chapter 3 – The role of ethical standards in ending CO2 originated by equipment operation entering the atmosphere

The Engineering Council and the Royal Academy of Engineering have jointly created a Statement of Ethical Principles for all engineering professionals (see **Appendix 2**). The statement sets out four fundamental principles for ethical behaviour and decision-making. These are:

1. Honesty and integrity;
2. Respect for life, law, the environment and public good;
3. Leadership and communication;
4. Accuracy and rigour.

Applying these four principles is a key component in achieving actual net reductions and ultimately elimination of equipment operation induced CO_2 emissions into the atmosphere. It means securing that:

1. good intentioned actions, to reduce CO_2 atmospheric concentrations, do not unintentionally result in increasing CO_2 originated by equipment operation emissions entering the atmosphere;
2. agendas that are not about reducing CO_2 concentrations are not able to adversely impact delivering the ending of CO_2 originated by equipment operation entering the atmosphere; and
3. balance is explicitly achieved between ending CO_2 originated by equipment operation entering the atmosphere and delivering other public good issues.

<u>Honesty and integrity</u>

To achieve real reductions and then end CO_2 originated by equipment operation entering the atmosphere, all decisions require the highest degree of honesty and integrity. This means greater levels of honesty and integrity from:

1. all in recognising the degree to which all our use of equipment, directly and indirectly, is contributing to CO_2 entering the atmosphere;
2. those putting forward projects to eliminate or reduce emissions of CO_2, of the net overall reduction in CO_2 entering the atmosphere they claim will be achieved; and
3. all in declaring conflicts of interest relating to CO_2 emissions when promoting projects that will involve the use, directly or indirectly, of energy.

<u>Respect for life, law, the environment and public good</u>

Achieving real reductions and then ending CO_2 originated by equipment operation entering the atmosphere in ways that are sustainable, is dependent upon proactive respect for life, the law, the environment and the public good. As safety sets one of the boundaries, within which the equipment must operate, so too does the law and other environmental concerns. Each one of these contributes to the net public benefit, even if they limit the reduction of CO_2 originated by equipment operation entering the atmosphere. To ensure legislation delivers its objectives, whilst enabling the maximum total reduction of CO_2 originated by equipment operation entering the atmosphere, the effects overall on the energy supply chain need to be considered using operational engineering based data and understanding of processes.

Leadership and communication

Currently achievable real net reductions of CO_2 originated by equipment operation entering the atmosphere appear not to be being realised. This appears to be due to a general lack of awareness and understanding of how the use of equipment results in CO_2 entering the atmosphere.

If we all are to make informed choices as to both the importance of and actions for ending CO_2 originated by equipment operation entering the atmosphere, we all need a greater understanding of how our use of equipment, directly and indirectly, results in emissions of CO_2. It is incumbent upon all those in leadership positions to promulgate a wider understanding of:

1. what creates equipment operation induced CO_2 emissions;
2. the complex interdependencies and conflicts between the different forms of sustainability; and
3. how individual decisions affect the quantity of CO_2 originated by equipment operation entering the atmosphere.

Accuracy and rigour

To achieve real reductions and then end CO_2 originated by equipment operation entering the atmosphere, accuracy and rigour by all is essential at all times. Failure to do so risks uninformed decisions and implementation of actions, designed to reduce CO_2 emissions, which actually result in additional CO_2 entering the atmosphere.

Chapter 4 – The role of sustainability in ending CO2 originated by equipment operation entering the atmosphere

Promoting sustainability standards for operations engineering is proactively encouraging the development, promulgation and adoption of operations engineering based solutions and practices that enable today's society to achieve, or move closer to achieving, its needs and wishes in ways that do not compromise future generations achieving their needs and wishes.

Today's engineering based technology coupled with ongoing innovation and development creates a means of sustainably securing the energy required to operate the equipment providing for the needs and wishes of today's society, with no resultant CO_2 entering the atmosphere. This offers probably the most practical and socially acceptable means for achieving meaningful sustainable reductions in CO_2 originated by equipment operation entering the atmosphere.

Renewable Energy

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, in particular anthropogenic emissions of greenhouse gases.

Renewable energy sources fall into two the categories of those that do not create CO_2 emissions (e.g. wind and solar) and those that currently do (e.g. biofuels).

Solutions, based on the use of renewable energy[5] are available and have been adopted that can help in achieving both sustainability of fuel resources and ending CO_2 originated by equipment operation entering the atmosphere. However, there are other solutions available, some of which have been adopted, that only aid in achieving one of these two forms of sustainability and actually compromise achieving the other. Table 1 shows the renewable energy sources for electricity generation fitting into these two sustainability groups.

Table 1 Renewable Energy Sources for Electriciy Generation

Renewable Energy Sources for Electriciy Generation	
Carbon Dioxide Producing Fuels	**Carbon Dioxide Emission Free Fuels**
Biogas (without CO_2 emission elimination)	Geothermal
Bioliquids (without CO_2 emission elimination)	Hydro
Biomass (without CO_2 emission elimination)	Marine
	Solar
	Wind

[5] Renewable energy is sources of energy that can be renewed or is not diminished by use.

As shown by Table 1, while the use of all renewable energy sources supports the sustainability of energy resources, only some are CO_2 emission free. This means that when considering current electricity supply, the percentage generation from renewable sources is only an indication of electricity generated from sustainable fuel sources. Currently it is not an indication of the amount of generation that is not emitting CO_2 into the atmosphere. The same applies to transport, where the percentage of vehicles using biofuels is an indication of the percentage using sustainable fuel resources. Again, it currently is not an indication of percentage of vehicles that are not emitting, directly or indirectly, CO_2 into the atmosphere.

Nuclear Energy

Harvesting the energy source nuclear power does not result in CO_2 emissions. Therefore nuclear power offers a source of energy that is not CO_2 emitting and can replace those current CO_2 emitting (e.g. fossil fuels and biofuels) sources of energy. However, nuclear power, like fossil fuels and biofuels, does result in the releasing of additional energy so potentially adding directly to global warming.

Carbon based fuels

For no emissions of CO_2 into the atmosphere, the burning of fuels containing carbon (fossil fuels and biofuels) has to be limited to those processes employing technologies eliminating CO_2 emissions into the atmosphere.

Unless technology to eliminate CO_2 emissions into the atmosphere from equipment is used, energy secured from carbon based fuels results in CO_2 entering the atmosphere. Two common compound groups used for energy are carbohydrates and hydrocarbons, both of which are carbon and hydrogen based. However, the development of technologies to eliminate CO_2 emissions from equipment, such as “carbon storage and capture” does offer the prospect of being able to continue using carbon based fuels as part of the energy mix. This means that the traditional solution for reducing emissions of CO_2, through controls to reduce the burning of carbon based fuels, can be replaced with a simple control on actual CO_2 emissions into the atmosphere, regardless of fuel source type.

A number of biofuel-fuelled power plants incinerate methane (CH4), as a biofuel, to form CO_2 and H_2O. This reduces the amount of CH_4 entering the atmosphere, but increases emissions of CO_2. Notwithstanding that SOE does not take a view on if it is better to emit CO_2 than CH_4, employing technologies eliminating CO_2 emissions from such equipment into the atmosphere does offer a means of incinerating CH_4 without CO_2 entering the atmosphere.

While employing technologies eliminating CO_2 emissions into the atmosphere provides a route for continued use of carbon as a fuel, storage and disposal of the captured CO_2 needs to be in a sustainable way. In particular, that there is no leakage into the atmosphere from CO_2 storage and no adverse environmental impact from such storage or dumping. For example, dumping captured CO_2 in the oceans risks increased oceanic acidification.

Hydrogen based fuels

Energy secured from hydrogen-based fuels potentially offers CO_2 emissions free energy. This also extends to hydrogen compounds, which do not have carbon within them. Currently most hydrogen production is from natural gas or biogas resulting in CO_2 emissions. Clearly, in the context of ending CO_2 originated by equipment operation entering the atmosphere, hydrogen production has to become CO_2 emission to atmosphere free.

Other sustainability issues

Marine, nuclear, solar and wind energy sources, while CO_2 emission free, tend to have limited controllable flexibility in energy output. Therefore, they cannot reliably adjust their output to match electricity demand, which is a historical prerequisite for a stable alternating current electricity system. Energy storage and electrically powered flexible fuel production, such as flexible hydrogen production, offers a means of having electricity systems using only inflexible CO_2 emission free electricity generation (e.g. nuclear, solar and wind). Here, by regulating the energy flow into and out of storage and the electrically powered fuel production rates, e.g. hydrogen production, a balance is achievable between total electricity generation and total system demand. Thus, the current electricity balancing arrangements of generation to demand changes to that of matching total electricity demand to available generation. It also offers such balancing without requiring changes in usage patterns by existing consumers.

Electric Vehicles

Electric vehicles in all forms currently offer a number of environmental benefits arising from having no emissions from the vehicle itself (“zero tailpipe emissions”). However, currently in countries such as the UK and in many other high-energy consumption countries electric vehicles usually result in emissions of CO_2 into the atmosphere. These emissions can be greater than those emitted by a comparable diesel powered vehicle.

These CO_2 emissions are due to the amount of electricity generated from CO_2 emission free generation usually being significantly less than the total demand. This means that, at times when emission free generation is less than the total demand, any additional use of electricity, including extra demand to power electric vehicles, results in additional generation from CO_2 emitting electricity generation plant.

Currently in the UK, the CO_2 emitting electricity generation plant, which adjusts its output to balance total generation to total demand, is for most of the time combined cycle gas turbines (CCGT) driven generation using natural gas as the fuel. Thus, to balance for an increase in electricity demand, such as the addition of an electric vehicle, it is usually by increased generation from a CO_2 emitting CCGT driven generation plant. The use of electric vehicles will only result in zero CO_2 emissions travel when the extra electricity generation is by plant that is itself CO_2 emission free.

Chapter 5 – The Role of efficiency in ending CO2 originated by equipment operation entering the atmosphere

Efficiency is securing the minimum amount necessary of both resources used and waste produced to achieve fully desired outcomes. Resources normally include, but are not limited to, time, energy, materials and finance. This means that a highly efficient energy system is one that results in the minimum wasted energy (energy losses). Energy efficient equipment operation (low energy loss equipment operation) is probably the most effective way of ensuring that today's society achieves its needs and wishes in ways that least compromise future generations achieving their needs and wishes.

Where the objective is ending CO_2 originated by equipment operation entering the atmosphere, then efficiency as described above becomes a secondary issue. Here it is better to encounter reduced efficiency due to the operation of devices eliminating, or reducing CO_2 emissions, than to maintain high efficiency with full CO_2 emissions. Consequently, a three-part approach to efficiency is required, namely:

1. Before considering efficiency, identify the processes available to produce the desired output that do not result in emissions of CO_2 into the atmosphere.
2. Where processes free of CO_2 emissions into the atmosphere are available, then the efficiencies of the different processes are then considered.
3. Where processes free of CO_2 emissions into the atmosphere are not currently available, then in a bid to reduce such emissions, the processes available to produce the desired output that have the minimum emissions of CO_2 into the atmosphere are considered. Invariably, in this situation, the most efficient system will result in the lowest CO_2 emissions.

Reducing CO_2 emissions into the atmosphere where achieving zero CO_2 originated by equipment operation entering the atmosphere, is not practicable

The remainder of this Chapter 5 is all set within the above framework of the three part approach where reducing emissions, rather than eliminating, is seen as a temporary fix until practical solutions ending CO_2 originated by equipment operation entering the atmosphere are developed.

Almost all CO_2 emissions resulting from the operation of equipment are attributable to the burning of compounds containing carbon. Of that burning, a significant proportion is from providing the power to operate equipment. The higher the combined operational energy efficiency of an individual piece of equipment and its supporting energy supply chain, the lower the amount of energy consumed to achieve the objective of operating the equipment. Except in a limited number of circumstances and regardless of the actual energy source; currently the lower the amount of energy used, the lower the amount of compounds containing carbon are burnt globally. The effect is lower global CO_2 emissions originated by equipment operation entering the atmosphere.

The savings on CO_2 emissions by higher energy efficiencies are generally independent of the actual energy source used. The energy source can be CO_2 emitting or CO_2 emission free. This is because when a piece of equipment using CO_2 emission free energy uses less energy, it frees up that CO_2 emission free energy for use by other equipment. That in turn reduces the demand for CO_2 emitting energy. However, achieving the highest operational energy efficiency is often not simply achieving the highest thermal efficiency theoretically achievable for a particular process. There are two main reasons for this, the technical and safety limitations and achieving balance between project requirements.

Technical and safety limitations

Every piece of equipment will have a maximum theoretical thermal efficiency. As a demonstration, consider motive power using heat engines. The Carnot Cycle and the Second Law of Thermodynamics defines the maximum thermal efficiency theoretically achievable. The maximum thermal efficiency for a Carnot cycle is a ratio of the heat engine's inlet and outlet absolute temperatures. The greater the difference between an engine's start of cycle ("inlet") and end of cycle ("outlet") temperatures, the higher its maximum thermal efficiency. Thus to increase efficiency means securing the highest inlet temperature and lowest outlet temperature possible. In practice, the inlet temperature is limited to a temperature at which the equipment can operate safely and reliably. In addition, for the majority of processes the waste heat temperature (the outlet temperature) will not be lower than the surrounding ambient air temperature, unless additional energy is used. By using insulation, there is little wasted energy from the engine itself so securing the maximum motive power from the available energy.

Practical applications of a heat engines can only achieve around 70% of the theoretical Carnot cycle thermal efficiency. In terms of energy efficiency, the current maximum energy conversion from carbon-based fuels is quite inefficient at around 35% for petrol engines, around 45% for diesel engines, around 46% for gas turbines and around 63% for CCGTs. Therefore, the choice of heat engine can make a significant difference to the exhausted heat from the engine, and therefore CO_2 emissions into the atmosphere.

Balance between project requirements

The operating regime may dictate that the equipment cannot, or should not, be operated at maximum energy efficiency. This is usually because a balance between the following is required for any project to be successful, namely:

- delivering the project's primary purpose;
- meeting the projects financial requirements;
- complying with safety and legal requirements;
- the limitations of available technology;
- agreements made with external stakeholders; and
- for the operating regime envisaged, achieving the minimum energy consumption over the whole life of the project.

Where reducing, as opposed to eliminating, emission of CO_2 into the atmosphere is an objective, achieving the balance between the project's requirements can lead to counterintuitive selections of equipment. Thus, in this situation, when specifying new equipment a comparison of total CO_2 emissions into the atmosphere between the different processes available needs to be conducted. For the operational phase, this should be based on the total mass of CO_2 released into the atmosphere for 1kJ of energy used in creating the desired outcome (heating, cooling, pressure, vacuum, motion, light, or chemical reaction).

Where the energy used is not derived from the combustion of carbon, the total mass of CO_2 released into the atmosphere for 1kJ of energy used in creating the desired outcome will be zero. Therefore, as explained above, for eliminating or reducing CO_2 emissions arising from the operation of equipment, the preferred energy source is the one that does not result in the release of CO_2, even if that is a less thermally efficient solution.

Minimising emissions of CO_2 into the atmosphere

Notwithstanding that, the desired energy source is one that does not result in the release of any CO_2 into the atmosphere; currently the only energy sources available often result in such emissions of CO_2. Here the objective should be to secure the engineering arrangement that results in the minimum total mass of CO_2 released into the atmosphere for 1kJ of energy used in creating the desired outcome.

The total mass of CO_2 released from a given process is dependent upon four different variables. The variables are:

1. The mass of CO_2 emitted from burning 1kg of the fuel used as the initial source of energy. This is based on the chemical composition of the fuel (where the higher the proportion of carbon in the fuel the higher the emissions of CO_2) and the effects of any devices fitted to reduce CO_2 emissions.
2. The net calorific value (kJ/kg) of the fuel used as the initial source of energy. Here the higher the net calorific value the smaller the amount of fuel required.
3. The combined energy losses (kJ) incurred in providing energy to the piece of equipment producing the desired outcome.
4. The overall energy consumption (kJ) of the piece of equipment producing the desired outcome.

What is the desired outcome of the piece of equipment is a key question. This must be answered accurately, if the most energy efficient operational solution and therefore minimum release of CO_2 is to be achieved. An example is specifying a car that will be used predominantly in a congested city with significant stop start compared to one that will be used predominantly for high mileage motorway cruising. The most energy efficient solution for the former might be a battery powered electric car, while the latter could be a diesel engine powered car.

Energy storage devices

Batteries as electricity storage devices can be chemical based, e.g. the lead acid battery. They can also take other forms such as electricity generation using pumped water storage, flywheels and compressed gases.

Batteries are not 100% efficient. The process of charging and then discharging a battery uses energy, some of which is lost in the form of heat. This means that the use of batteries contributes to a greater electricity demand than if the equipment was taking a direct feed from the local electricity distribution system. This will usually result in greater levels of CO_2 emissions than if the device's power is directly from the grid system. In addition, when batteries charge at times where total electricity demand exceeds total CO_2 emission free generation then, as with any added demand, the charging of the battery is causing an increase in CO_2 emitting generation.

While the use of batteries generally results in an increase in electricity demand, there are situations where it can result in an overall reduction in CO_2 gas emissions. As covered in Chapter 4, where CO_2 emitting free generation is greater than the local system's total demand (local demand and export from the local system) then the charging of the batteries can allow the generation to continue. Once the CO_2 free generation is less than the local system's total demand, the battery becomes a generator. This results in an overall reduction in CO_2 emitting generation.

The use of energy storage, in the form of batteries as described above or as hydrogen production, therefore offers the prospect of being able to increase significantly the proportion of inflexible generation used. It also offers greater efficiency in the use of inflexible CO_2 emission free generation.

Efficiency of equipment energy supply chains

Examples of the effect on CO_2 emissions of the different components within a piece of equipment's energy supply chain are the energy supply chains for electric cars with batteries and for diesel cars.

Electric car

The car's energy comes from its battery, which incurs energy losses through charging and discharging. Electricity is delivered to the battery via an electrical distribution system, which receives its electricity from an electrical transmission system. Electricity distribution and transmission systems incur energy losses between entry and exit. Currently in the UK the electricity transmission system usually receives this additional electricity from a CCGT driven generator. Although high efficiency, the use of a CCGT for generating the electricity still results in a large proportion of the energy used being wasted. Thus, for the car to carry out a unit of work (1kJ) the amount of energy required from the gas delivered to the CCGT is:

> *the sum of the energy consumed by the car (kJ) in doing its unit of work (1kJ), the energy loss incurred in charging/discharging the car's battery (kJ), the energy loss (kJ) incurred in transmitting and distributing the electricity from the CCGT driven generator to the car's battery and the energy loss (kJ) incurred in generating the electricity*.

Having determined the amount of energy (kJ) required from the gas delivered to the CCGT, the mass of fuel (kg) required and thus the CO_2 emissions can be determined. As described above, this is based on the fuel's net calorific value (kJ/kg) and the CO_2 emissions from burning 1kg of the fuel, less any CO_2 emissions abatement being employed.

In addition, when calculating the total CO_2 emissions for 1kJ of energy as work done by the car, also to be included is the mass of CO_2 emitted in extracting and processing the material for 1kg of delivered fuel. In addition, the mass of CO_2 emitted, in delivering that fuel to the generating plant, needs to be included.

The above demonstrate that if the efficiency of any link in the process is improved then the mass of CO_2 emitted for 1kJ of energy as work done by the car reduces. Equally, any drop in efficiency of any link, including within the car itself, results in an increase in the mass of CO_2 emitted.

Diesel Car

Applying the above analysis to the diesel engine car, for the car to carry out a unit of work (1kJ) the amount of energy required is;

> *the sum of the energy consumed by the car (kJ) in doing its unit of work.*

Again having determined the amount of energy required from the diesel delivered to the car, the mass of diesel fuel (kg) required and thus the CO_2 emissions can be determined. As described above, this is based on the diesel fuel's net calorific value (kJ/kg) and the CO_2 emissions from burning 1kg of diesel fuel, less any CO_2 emissions abatement employed.

As with the electric car the additional mass of CO_2 emitted in extracting and processing the material for 1kg of delivered diesel fuel and the mass of CO_2 emitted in delivering that kg of diesel fuel to the car have to be included.

While the diesel engine has fewer links in the energy supply chain and therefore a lower number of energy losses, it does not mean that operating a diesel engine car, when compared to operating an electric car, will always result in the emission of less CO_2. This is because a high-energy efficiency CCGT electricity generating plant, as indicated above, has a significantly higher thermal efficiency than a high-energy efficiency diesel engine operating within a vehicle. In practice if the two cars, one electric one diesel, are almost identical (other than their propulsion system) carry out the identical task and use the latest technologies for high-energy efficiency, they will currently have very similar levels of CO_2 emissions. Particular factors that will determine which is the most energy efficient are energy delivery losses and the actual operating regime.

Delivery losses for the electric car are linked to where the car will be recharged and therefore what are the transmission and distribution energy losses. Equally, where the diesel car is to be refuelled and thus the amount of CO_2 emitted in delivering the fuel. The intended operating regime for the vehicle will also have a significant impact on the vehicle's own efficiency. Because of their different characteristics, the two types of vehicle will have different operating regimes where they are the most efficient.

The key point on electric and diesel car selection is that in countries, such as the UK, where currently the additional electricity generation used to power the electric cars is usually from CO_2 emitting fuels, the overall emissions of CO_2 from operating either vehicle are very similar. Just because an electric car itself does not emit CO_2, does not mean that it results in no emissions of CO_2; rather, operating an electric car results in similar levels of emissions of CO_2 to those of a similar diesel engine car.

A petrol engine car's CO_2 emissions have the same calculations as for the diesel engine car. However, through their higher compression ratios, diesel engines (as indicated above) are inherently more energy efficient than petrol engines. Therefore, in general, operation of petrol vehicles will result in higher emissions of CO_2 than both diesel and electric vehicles.

For hydrogen-fuelled vehicles, currently CO_2 emissions appear to risk being higher than for electric and diesel vehicles. This is because, as described above, hydrogen fuel is currently produced from natural gas or biogas resulting in high CO_2 emissions, or by electrolysis with a high electrical load and therefore, in countries like the UK, currently high CO_2 emissions.

Similar CO_2 emission issues arise when considering domestic heating and cooking. Heating and cooking with mains gas benefits from high efficiency delivery of the fuel to site and conversion of the gas into heat for heating or cooking. Electricity used in a conventional way has the efficiency losses of converting the gas into electricity, transmitting the electricity and distributing the electricity. The resulting overall efficiency of electricity heating and cooking will usually be less than using mains gas. However, because the inefficiencies of batteries are avoided, electricity used for heating and cooking usually results in less CO_2 emissions per unit of energy used than if it is being used in an electric car.

Heating using electricity to power a heat pump can result in the lowest levels of CO_2 emissions. This is because the energy used comes from two sources. First from the gas used to provide the electricity to power the heat pump. Second, from the low temperature heat; here the heat pump lifts the low temperature heat to a sufficiently high temperature to be usable for heating. Only the provision of the electricity to power the heat pump results in emissions of CO_2. The energy secured from the low temperature heat does not create any additional emissions of CO_2. This potentially gives the overall process a lower CO_2 emissions rate for heating than using either gas directly, or electricity generated from gas (powering conventional electric heaters).

Chapter 6 – SOE's positions on ending CO2 originated by equipment operation entering the atmosphere

A key part of reducing anthropogenic CO_2 emissions into the atmosphere is ending CO_2 originated by equipment operation entering the atmosphere. However, to be achievable and sustainable, eliminating such emissions has to be in ways that future generations can continue to benefit from the use of equipment as we can today. Leadership by SOE means promulgating the following messages:

<u>The need to end CO_2 originated by equipment operation entering the atmosphere</u>

- Rising concentrations of greenhouse gases, which include CO_2, in the planet's atmosphere is a widely held concern of today's society. The prevailing view is that currently concentrations of greenhouse gases in the atmosphere are higher than would naturally occur and that this is primarily due to anthropogenic emissions of greenhouse gases. In addition, that the high concentrations of greenhouse gases in the atmosphere is probably causing the current global warming. Therefore, to reduce global warming, the current concentrations of greenhouse gases in the atmosphere need reducing and this requires, amongst other actions, a cut in anthropogenic emissions of greenhouse gases entering the atmosphere.
- The operation of equipment results in significant quantities of CO_2 entering the atmosphere. It follows that if society wishes to cut anthropogenic emissions of CO_2 it needs to end CO_2 originated by equipment operation entering the atmosphere.

<u>Meeting the needs and wishes of today's society and future generations</u>

- 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 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.
- Engineering based solutions for ending CO_2 originated by equipment operation entering the atmosphere enables an increased use of electricity-powered equipment (e.g. electric cars and vehicles) and hydrogen as a fuel without increased electricity generation from CO_2 emitting plant.

SOE's unique PEI role in ending CO_2 originated by equipment operation entering the atmosphere

- Currently achievable real net reductions in CO_2 originated by equipment operation entering the atmosphere are not being realised. This is probably due to a general lack of awareness and understanding of how the use of equipment creates CO_2 emissions.
- Addressing the general lack of awareness and understanding of how the use of equipment creates CO_2 emissions is the key foundation for implementing effective solutions. This being the ending of CO_2 entering the atmosphere, which originated from operation of the equipment used to meet the needs and wishes of today's society and future generations.
- SOE, as part of delivering its public benefit, is uniquely positioned for providing independent leadership in:
    1. raising general awareness and understanding of how the use of equipment can currently result in CO_2 entering the atmosphere and how this can be ended or reduced;
    2. using an holistic approach to assessing initiatives for ending or reducing 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 total anthropogenic CO_2 entering the atmosphere.

Safety first

- All actions to end or reduce CO_2 originated by equipment operation entering the atmosphere must be conducted safely.

Operational engineering facts

- 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 have 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.

Appendix 1 - SOE delivering public benefit

SOE's mission is:

(A) the improvement and elevation of the technical and general understanding, knowledge, skill and competence of persons engaged or desiring to be engaged in operations engineering or in any related employment, and the integrity and repute of the profession thereof;

(B) the promotion and encouragement of the advancement of science, technology and practice, and inventions and improvements, in the field of operations engineering and any other related branches of engineering, and the dissemination and exchange of ideas, information and knowledge thereof; and

(C) the promotion; by means of (A) and (B) above, but without prejudice to their generality thereof; of standards for operations engineering that benefit the community at large; in particular, but not being limited to, safety, efficiency, sustainability and ethical standards.

(A) and (B) are primarily delivered by SOE assisting its members improve and elevate their technical and general understanding, knowledge, skill and competence in the particular engineering field of operations engineering.

Reflecting its delivery of public benefit, SOE specialises in assisting its members improve and elevate their technical and general understanding, knowledge, skill and competence in the particular engineering field of operations engineering through:

a. offering access to knowledge sharing and professional learning using technical information and advice via its website, magazines and technical events;

b. providing structured continuous professional development (CPD);

c. providing support to members working towards or maintaining their UK Engineering Council and the Society for the Environment registrations; and

d. assessing members' applications for UK Engineering Council and the Society for the Environment registration.

Professional registration for operations engineers underpins the systems and processes that ensure the current and future safeguarding of society. It provides all with confidence that by using registrants, society is using operations engineers that have qualifications that are independently verified, have and maintain the knowledge and skills required of registrants and have signed up to ethical standards set for registered operations engineers. It also provides employers, government and wider society with confidence that registrants possess and maintain the knowledge, skills and commitment required to meet the operations engineering and technological needs of today, whilst also catering for the needs of future generations.

Appendix 2 - The Engineering Council and the Royal Academy of Engineering Statement of Ethical Principles for all engineering professionals

The statement sets out four fundamental principles for ethical behaviour and decision-making. These are:

1. Honesty and integrity

Engineering professionals have a duty to uphold the highest standards of professional conduct including openness, fairness, honesty and integrity. They should:

- act in a reliable and trustworthy manner
- be alert to the ways in which their work and behaviour might affect others and respect the privacy, rights and reputations of other parties and individuals
- respect confidentiality
- declare conflicts of interest
- avoid deception and take steps to prevent or report corrupt practices or professional misconduct
- reject bribery and improper influence

2. Respect for life, law, the environment and public good

Engineering professionals have a duty to obey all applicable laws and regulations and give due weight to facts, published standards and guidance and the wider public interest. They should:

- hold paramount the health and safety of others and draw attention to hazards
- ensure their work is lawful and justified
- recognise the importance of physical and cyber security and data protection
- respect and protect personal information and intellectual property
- protect, and where possible improve, the quality of built and natural environments
- maximise the public good and minimise both actual and potential adverse effects for their own and succeeding generations
- take due account of the limited availability of natural resources
- uphold the reputation and standing of the profession

3. Accuracy and rigour

Engineering professionals have a duty to acquire and use wisely the understanding, knowledge and skills needed to perform their role. They should:

- always act with care
- perform services only in areas in which they are currently competent or under competent supervision
- keep their knowledge and skills up to date
- assist the development of engineering knowledge and skills in others
- present and review theory, evidence and interpretation honestly, accurately, objectively and without bias, while respecting reasoned alternative views
- identify, evaluate, quantify, mitigate and manage risks
- not knowingly mislead or allow others to be misled

4. Leadership and communication

Engineering professionals have a duty to abide by and promote high standards of leadership and communication. They should:

- be aware of the issues that engineering and technology raise for society, and listen to the aspirations and concerns of others
- promote equality, diversity and inclusion
- promote public awareness and understanding of the impact and benefits of engineering achievements
- be objective and truthful in any statement made in their professional capacity
- challenge statements or policies that cause them professional concern.

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