CARBON CAPTURE AND STORAGE

My subject is Carbon Capture, Usage, and Storage.

The most abundant greenhouse gas is H_2O, i.e. water vapour, followed by carbon dioxide, methane, nitrous oxides, and numerous other gases. These gases are shorter lived than carbon dioxide in the atmosphere, e.g. methane (CH^4) has a life of only 12 years, and although NO^x gases are 300 times more harmful to the climate than CO_2, their life is only 120 years. Carbon dioxide is not broken down by any natural chemical process, but is removed through natural processes such as absorption by the oceans (by plankton) and forests (by photosynthesis) – it can remain untreated in the atmosphere for between 300 to 2000 years.

The highest recorded historical CO_2 level of 300ppm occurred approx. 330 thousand years ago. That figure was exceeded in 1950, and has since risen by nearly 50% to 417ppm.

The balance provided by the natural carbon sinks is being upset.

The excess carbon dioxide is causing acidification of the oceans, which is in turn affecting living organisms, e.g. the dying coral reefs around the world.

Existing rain forests are still being exploited by unstable governments, e.g. Brazil and Indonesia. The remaining rain forests must be retained, but to replace them with sufficient forest area to reduce the level of CO_2 to acceptable levels will require an area the size of the USA, take fifty years to supply and plant, and will still require watering and maintenance as it grows – maybe a further 20 years before it can begin to serve its planned purpose.

Carbon capture will be required to provide an alternative solution. The following argument maintains that the most important consideration for deploying carbon capture and storage will be to make the largest possible contribution to arresting climate change.

Existing technologies

CCS can help the world to decarbonise, and it's already doing so.

For example, in the North Sea there is one successful project that has been burying carbon dioxide one kilometre below the sea floor at the rate of a million tonnes a year since 1996.

In Norway, CO_2 is being pumped underground to assist with the removal of oil.

One of the world's largest carbon-removing direct air capture machine is a carbon-sucking unit the size of a shipping container. The Orca plant in Iceland captures and stores about 4,000 tonnes of CO_2 a year.

However, there are matters arising from these proposals. Is leaving CO_2 stored underground a responsible approach for future generations to deal with? Can such a storage procedure become widespread enough to discount the fact that we have far more fossil fuel reserves than we can safely burn? The Norwegian concept for the use of CO_2 will not offset the CO_2 from burning the oil/gas reclaimed. The 4,000 tonnes annual capacity of the Orca plant is about three seconds' worth of global emissions.

There are many proposals for carbon capture, but all are untested technologies.

Different methods of carbon capture currently take place at different sites.

Something called “point-source carbon capture technology” is currently the best alternative option, which involves scrubbing CO_2 from exhaust gases in the chimneys of factories and power plants. Here, CO_2 is emitted in the highest volumes and concentrations are thousands of times higher than those found in the atmosphere. The recent Glasgow climate pact committed 197 countries to “phasing down unabated coal”. Unabated coal refers to when power stations or factories burn coal without capturing and storing the carbon dioxide (CO_2) generated.

Other methods capture carbon directly from the air, either by using chemical reactions that bind the carbon using lots of energy or by growing carbon-hungry plants which can be burned for energy and the resulting emissions subsequently captured.

Other “negative emissions technologies” that take greenhouse gases out of the air are being developed, but so far none are ready for mass deployment.

Current vs. Future Supplies

Authorities consider we already have enough oil/gas discoveries to take us to zero consumption. Is it time to stop fossil-fuel exploration and halt the development of all new oil and gas fields? We cannot safely set fire to all the fuel we’ve already found, so why look for more? Emissions from using those barrels of oil currently accessible would raise global temperatures by almost 0.6°C. Using the natural gas would add another 0.2°C. And as for the coal, burning it all would raise temperatures by a further 2°C. In May, the International Energy Agency (IEA) explicitly called for an end to new oil and gas fields, as well as to new coal mines and mine extensions, around the world.

Plans for keeping climate change to 1.5°C targets generally include CCS, but none envisage it as more than a small part of a large mix of approaches. For example, the IEA’s scheme to achieve net zero emissions by 2050 involves capturing and burying carbon dioxide at a relatively ambitious rate of 7.8 gigatonnes of carbon dioxide per year. But achieving this would still only allow us to consume an extra 1% of existing oil reserves each year. Countries need to massively ramp up investment to be compliant with the Paris agreement’s target of limiting global warming to 1.5°C. Some of this money would be public funding, and people would reasonably expect it to fund projects which are morally sound. However, funding for carbon capture and storage is insufficient. At the current rate of deployment, 700 million tonnes of CO_2 storage capacity will be added by 2050 – only 10% of what is required.

Examples of main industries creating CO2

Farming is typical of yield against the consequences of methods employed.

Nitrogen is the basis for modern farming, but such fertilisers are derived from natural gas and generate CO_2 in the process. While the application of nitrogen-based fertilizers is still vital to sustaining the current population, the surplus of nitrogen leaking into the environment is leading to numerous concerning developments. The current method of using and producing nitrogen fertilizers has led to reductions in biodiversity and the acceleration of climate change through the production of carbon dioxide as well as nitrous oxides.

I would like to suggest a change in the title of our Government’s document to “The Ten Point Plan for a Green CARBON Industrial Revolution”.

Carbon is the building element of life. The active ingredient can be obtained by heating any biological or biologically-derived substance (bio-waste, plastics, car tyres, etc.) to approx. 500°C in the absence of oxygen – a process called pyrolysis. Some CO_2 will result, but this can be reclaimed from the exhaust gases.

A farmer in Australia has won an award for replacing nitrogen products with carbon-derived fertilisers obtained through pyrolysis. He has increased milk and crop yields, reduced animal methane emissions, and improved the general health of his animals.

Aircraft use an incredible amount of fuel. A Boeing 747-400 jumbo jet carried 63,000 gallons (240,000 litres) of jet fuel, and burnt through it at a rate of 4 litres (0.9 gallons) per second. Just one flight could emit as much CO_2 as many people do in a year.

A private jet will typically burn around 210 gallons of fuel per hour, producing around 6,030kg of CO_2 in a three-hour flight. Typically the jet is configured to seat between six and eight passengers; if there were seven on board, the average amount of CO_2 per person would be 860kg.

However, compared to other sectors, aviation is a relatively small contributor to global greenhouse emissions, but it is one of the fastest growing. Between 2000 and 2019, there was a 5% average rise in flights per year, but by 2019 it accounted for 2.5% of the world's CO_2 emissions.

The overall contribution to climate change is even higher – it also results in emissions of water vapour, soot, sulphur aerosols, water contrails, and those vapour trails further reduce the output of solar energy systems.

International shipping is a crucial part of the global economy – 90% of the world’s trade is transported by sea. But almost all ships use fossil fuels, and so the sector is also a major emitter of greenhouse gas pollution – with emissions roughly on a level with the entire nation of Germany.

Progress on cutting emissions in shipping has been slow. In fact, emissions are no lower now than they were ten years ago. The sector’s record was under scrutiny at COP26 – the latest UN climate summit in Glasgow. The International Maritime Organization (IMO) – the UN body charged with delivering international shipping’s strategy on tackling climate change – has a target to cut emissions by 50% by 2050. The UN Secretary General Antonio Guterres criticised this, arguing the IMO’s pledges are not aligned with the Paris Agreement’s goal of limiting global heating to 1.5°C, but are “more consistent with warming above 3°C”.

International shipping must make a radical change in course. It must cut emissions by a third this decade and get on a path to zero emissions before 2050. The technologies and practices already exist to meet the targets. Efficiency of shipping can be improved by slowing speeds to save fuel, fitting CCS technology, and connecting to electricity grids when in port. The rapid roll-out of zero-emission fuels such as hydrogen and ammonia to new and existing ships in the 2030s is the other key component.

Policies and Politics

To give underground carbon storage sites the greatest chance of success, it currently makes sense to develop them in places where the geology has been thoroughly explored and where there is lots of relevant expertise. This would imply pumping carbon into underground storage sites in northern Europe, the Middle East and the US, where companies have spent centuries looking for and extracting fossil fuels. Storing carbon is roughly the reverse of extracting it from the ground, and there is an opportunity for workers in the oil and gas industry to lend their skills and expertise to this endeavour.

On the other hand, it might be important to develop storage sites in economies where the current and future demand for carbon capture and storage is greatest. These competing aims pull in different directions. The regions with the best prospects are not often those with the greatest expected need.

Developing storage sites in economies where expected demand for carbon capture is highest overwhelmingly favours developing regions of Asia. In India and China, for instance, coal power stations are expensive to retrofit with CCS, and will need lots of carbon capture and storage capacity to decarbonise. If developing regions are expected to decarbonise without sufficient support to roll out carbon capture and storage, it could mean they will have to throttle development to reduce emissions.

Increasing carbon capture and storage capacity as quickly as possible could benefit future generations by reducing the severity of climate change. So, you could argue that developing the most promising sites in Europe is the best way forward. However, directing investment for storage facilities from wealthy countries to developing regions could help address the debt the former owes the latter for causing the brunt of the climate crisis.

Should developed countries assist developing countries? Poor countries cannot afford oil/gas on open market, making coal their only option, but all fossil fuels are now rising in price. This means that even developed countries are moving back to coal – with the consequent increase in price, e.g. Germany (due to plant maintenance issues and Europe's proposal to move away from atomic energy) and Japan (they have no fuel reserves of their own, plus their Government is committed to moving away from atomic energy following Fujishima).

Environmentalists are attacking the supply side of fossil fuels, but even if fossil fuels could stop production immediately, there will be an overshoot of climate change temperature – temperatures could rise from 2degC to 4degC before returning to a stable level.

The problem is with demand, i.e. the use of the fuels, their efficiency of generation, and the need to reduce the demand for that energy.

There may be various technologies to remove CO_2 from air, but none are sufficiently advanced to be employed. Consequently, mass fuel switching could cause problems if new equipment is initially too scarce, unreliable, or more expensive to buy or run than existing equipment. Governments will need to support people vulnerable to fuel poverty (including the elderly, renters and those living in rural areas) through the fuel switching process. Additionally, actually meeting the growing demand for low-carbon energy will mean significantly expanding the country's current electricity generation capacity. Ensuring there are no delays in providing this power to citizens will be crucial – but the supply of fossil fuels will still be required while introducing these new technologies.

There is likely to be civil unrest if the 2050 target is not achieved. If society changes quicker than it can retrain and relocate existing workers, or provide new workers, it will see significant disruption through unemployment and labour shortages. A rapid transition to net zero inevitably risks swathes of workers in energy, transport and resource extraction suddenly looking for new work, e.g. while some steelmakers may produce wind turbines just as easily as oil rigs, but aeroplane pilots may not be remotely as equipped to drive trains.

Climate change proposals will cost the World at least £3 trillion (i.e. a million million, or 10^{12}) every year to 2030, whereas the overall cost to the UK could be as much as £1.4 trillion.

World leaders must be united to recognise these facts and moral dilemma, and consider the choices with urgency.

CO2 Use

The CO_2 currently being used in industry is generated from the process of making fertiliser. It is relatively cheap and easy to separate. However, if that system fails, there is no ready alternative. CO_2 concentrations in the atmosphere are about 420 ppm, i.e. 0.042% of all the gases, making separation of the CO_2 from the air difficult, and far more expensive.

Technologies which can capture carbon from power station chimneys or even directly from the air are being developed, but they aren't available at the scale needed. Two UK-based competitions to drive innovation in carbon capture and storage technology were launched in 2005, but subsequently closed by successive governments, the last one ending in 2015 without much success.

There are various carbon capture units currently operating at selected locations globally, such as at the Boundary Dam coal-fired power station in Canada, but they are unlikely to offer the solution to the CO_2 supply that industries need. They use liquids to absorb and purify the greenhouse gas at high temperatures, which produces over 99% pure CO_2, but liquid adsorbents decompose at high temperatures leaving toxic byproducts. The process also requires a lot of energy and is therefore expensive.

Ten years of research and engineering are usually needed before any new carbon capture technology can be deployed at the necessary scale. Industries which use CO_2 must plan for new carbon capture technology being available many years in the future, rather than expect immediate solutions.

Carbon capture involves the removal of CO_2 from the process, liquidizing and storing the product, but there are currently no substantial markets for its use.

Once a suitable CCS system is available and a market has been created, captured CO_2 should not be stored underground, but in industrial reserves – steel tanks on the same site as the power plant the CO_2 came from or the factory where it might be used. Industrial reserves need to be readily accessible as a backup supply.

Given that all these technologies are some way off being rolled out widely, society runs the risk of regular shortages.

The UK

The UK is only a small country – there are much larger countries that are causing a much larger problem. It needs a global effort. Internationally, the UK could become more economically competitive within a decarbonised world, demonstrating how industrialised countries can achieve economic growth while cutting carbon emissions and encouraging social wellbeing.

It could involve developing new businesses to provide essential services like heating and transport in more efficient, sustainable ways.

Achieving net zero greenhouse gas emissions in the UK by 2050 is a massive challenge. It will mainly be achieved through cutting emissions from fossil fuels, but will create a rapid, deep transformation across the UK's energy system.

Conclusions

There are options for removing carbon from the atmosphere, such as planting trees or direct air-capture machines; and to prevent it getting there in the first place, such as carbon capture and storage. There are proposals to replace fossil fuels with zero-carbon alternatives, such as green hydrogen. However, none of these options are ready to be deployed at anything like the scale necessary to offset the more than 40 billion tonnes of CO_2 which countries emit each year.

The need to remove and safely store carbon becomes more severe by the day. The recent UN emissions gap report warned that while a 30% reduction in projected carbon emissions by 2030 is needed to see a 2°C world, and a 55% reduction for 1.5°C, whereas current pledges have us on course for a mere 7.5% reduction.

Governments energy transition plans must rely on the new, complex technologies being added to our roster, to help generate greener energy and reduce the amount of CO_2 in the atmosphere. These will include carbon capture and storage, as well as advanced nuclear power such as small modular reactors, and green hydrogen produced using low-carbon electricity. The speed with which these inventions are developed and adopted, both in industry and society, will have to increase if we are to meet climate goals.

Across the world, countries are seeking to buy time before taking the decisive action that will be necessary, but given the time and costs involved in developing storage sites, and the real possibility that the storage sites may not be sufficient for the amount of carbon that countries emit, this is a question which cannot be delayed.

Remember, every gram of carbon dioxide added now must be removed at a later date.