Science and Technology Development to Integrate Energy Production and Greenhouse Gas Management

Duane Pendergast, Computare

(Note: This discussion paper has been prepared for optimal use with the Internet. A few linked illustrations and most references will not be available without an active connection)

INTRODUCTION

Knowledge, especially in use of energy has enabled our species to flourish in numbers and with living standards unimaginable to our ancestors. Humans now influence much of life on earth. Concerns that greenhouse gas emissions from the fossil fuels we burn for energy will lead to changing climate with disastrous consequences are rampant. Many propose that we improve the efficiency of energy use and conserve resources to lessen greenhouse gas emissions and avoid climate catastrophe.

Sadly, the most optimistic outcome for such a strategy is a diffident postponement of the climatic doomsday. We began our heavy dependence on fossil fuels some two hundred years ago. We have been continuously improving the efficiency of the machines which deliver useable energy - to the point some are near perfection. Improved efficiency, in turn, encourages new applications. Our population grows, thanks to the rich economy and improved food supplies resulting from efficient access to energy. Our neighbors in developing countries recognize the benefits of energy use. They strive to emulate our technology. Our collective greenhouse gas emissions increase enormously even as efficiency increases. Improving energy efficiency is a commendable way to spread energy benefits to more people now and in the future. Unfortunately, using fossil fuels more efficiently has not reduced overall greenhouse gas emissions. Clearly, we need to develop a different paradigm if we are to control the greenhouse gas content of the atmosphere.

How can we break out of this efficiency improvement trap? Perhaps we need to step back and reconsider the role of humans and their knowledge of energy use. Life on earth depends on the cycling of energy and carbon. Perhaps close examination of the carbon cycle will reveal means to assist natural forms of carbon storage outside of the atmosphere.

This paper reviews the carbon cycle from the point of view of past and present human influence. Potential future human input to the cycle through science and technology to manage atmospheric greenhouse gas are considered.

The review suggests that humans will need to ingeniously exploit even more energy to integrate its use with control of atmospheric greenhouse gases. Continuing development and application of energy is essential if the development of human society is to be sustained through the coming centuries. The continuing development of nuclear energy seems an essential energy supply component.
THE CARBON CYCLE

We learned early in our education that plants take carbon dioxide from the atmosphere, lakes and oceans to manufacture their food using water and energy from light. Plants, and animals, use that carbon carrying food as an energy source. Lifeless carbon bearing material from plants and animals is incorporated into the soil, oceans, fossil fuel and other carbon reservoirs or “sinks”. Humans have learned how to recover fossil fuels. We are recycling them by burning them in power plants, planes, trains, and automobiles to release carbon dioxide and water vapor to the atmosphere. Their carbon content is thus returned to the cycle of life. The whole complex process is driven by flows of energy.

Figure 1, from the United Nations Intergovernmental Panel on Climate Change (IPCC)\(^1\), provides a quantitative overview of the carbon cycle circa 1998.

Figure 1 – Estimates of the carbon cycle circa 1998

The greenhouse gas “problem” is boldly stated here in the red boxes and circles as “driven by fossil fuels and land clearing”. This human activity adds some 7.9 billion tonnes of carbon, mostly as carbon dioxide from fossil fuel combustion, to the atmosphere annually. About 4.6 billion tonnes of this is absorbed by earth’s systems leaving a net additional accumulation in the atmosphere of about 3.3 billion tonnes per year.

Note that the atmosphere contains some 760 billion tonnes of carbon in the form of carbon dioxide. Living land plants store about 500 billion tonnes of carbon in the materials they manufacture from water and carbon dioxide as they grow. The total store of fossil fuels is estimated at 3000 billion tonnes of coal and 300 billion tonnes of oil and gas deposits. Earth’s complement of soil stores about 2000 billion tonnes of carbon in materials produced by once living things. Another 40,000 billion tonnes is dissolved in earth’s oceans. Some 100 million billion tonnes is incorporated in sedimentary rocks such as limestone. These massive deposits of carbon bearing materials are all considered to be products of earth’s life over eons.
Some salient information can be derived from the figure if it is taken as the continuing status quo. Our oil and gas deposits will last less than fifty years. The carbon content of the atmosphere would be doubled from its current amount in 230 years at the current addition rate, and tripled by the time estimated fossil fuel reserves are depleted. Of course these estimates are simplistic in the extreme. We need to look at the carbon cycle in some more detail.

Figure 2 provides some more information from the IPCC on details of the carbon cycle. (Some of the numbers differ slightly from the previous figure as it was prepared much earlier on the basis of data from the 1980’s.)

Figure 2 – The “natural” carbon cycle

For the purpose of this discussion, the main points to be taken from this figure is that some 120 and 90 billion tonnes of carbon is estimated to be circulated between the atmosphere and the land and oceans, respectively, every year. Plants absorb about 120 million tonnes of carbon from the atmosphere, as carbon dioxide, per year. About the same amount is returned to the atmosphere by the process of respiration of plants and animals and decay of dead organic material. The oceans absorb and release about 90 billion tonnes with a great deal of this due to circulation from cold to warm ocean regions.

A significant observation suggested by this figure is that earth’s plants can absorb the equivalent of the carbon content of the atmosphere in only about six years.

Note that this part of the cycle is deemed, in the IPCC assessment, report to be “natural” even though humans manage and influence much of the plant and animal life on earth. Perhaps this terminology is misleading. It tends, perhaps shrewdly, to restrict attention to the “human perturbation” component of the carbon cycle illustrated in Figure 3 following.
This IPCC defined subset of the carbon cycle centers attention on annual changes from fossil fuel use and land use changes and identifies them as the human perturbation. It shows 5.3 billion tonnes being added to the atmosphere from fossil fuel use and another 0.1 billion tonnes from cement production which drives carbon dioxide from the limestone used to make it. Humans are converting some land to different uses – presumably from forests to agriculture – adding another 1.7 billion tonnes to the atmosphere. At the same time it seems, land based ecosystems are absorbing a net amount of 1.9 billion tonnes and the oceans absorb about 1.9 billion tonnes. The net addition to the atmosphere from these human activities is 3.3 billion tonnes annually in agreement with the estimates from 1998 shown in Figure 1.
Life in the ocean seems to go on almost in carbon cycle isolation from that on land – at least in the short term of a few centuries. Ocean organisms absorb about 103 billion tonnes of carbon annually (GPP – Gross Primary Production) to produce food. They use 58 billion tonnes themselves (autotrophic respiration) as food and incorporate 45 billion tonnes in their structure (NPP – Net Primary Production). Animals consume a major fraction of this and return carbon to the water (heterotrophic respiration – 34 billion tonnes). Detritus from plants and animals moves some carbon bearing material to deeper water. Some is diverted through shells and dissolved material into the deep ocean. The net absorption of some 2 billion tonnes annually from the atmosphere is thought to be a simple result of maintaining equilibrium with the rising carbon dioxide content of the atmosphere. The organic material in the whales and fish we’ve taken from the ocean is too slight to show on Figure 4 as a transfer to land.

Figure 4 – Carbon Cycling in the Ocean
Finally, and perhaps of most importance to us, we come to the carbon cycle on land as shown in Figure 5. Here we see more detail on the fate of the 120 billion tonnes of carbon absorbed annually from the atmosphere by plants (GPP – Gross Primary Production). Half of this (autotrophic respiration - 60 billion tonnes carbon) is almost immediately used by the plants themselves as food, returning carbon dioxide to the atmosphere. That leaves 60 billion tonnes (NPP – Net Primary Production) to be incorporated in their leaves, stems, roots, fruits and seeds. Some 55 billion tonnes carbon content is co-opted by animals – of many sorts - and ultimately returned to the atmosphere as carbon dioxide (heterotrophic respiration). Some 4 billion tonnes is consumed by combustion. That leaves about 1 billion tonnes to be incorporated into soil or dissolved in water and washed down rivers to the ocean.

Figure 5 – Carbon cycling on land

The IPCC, as noted in Figure 2, deemed plant and animal carbon cycling as “natural”. What about the plants and animals under human control? Is that not a “human perturbation” too in the context of Figure 3? Humans directly control and manage a major part of earth’s vegetation and animal life. We also influence the carbon cycle through our use of forests. Our review of the carbon cycle thus raises some questions. Are these IPCC figures and data subtly downplaying the role of human influence on the carbon cycle? Is human use of fossil fuels overemphasized as the source of the problem? Are
humans involved in other major activities which influence the carbon cycle and composition of the atmosphere?

**HUMANS AND THE CARBON CYCLE**

Much recent study of (the past 100 years) the potential for human influence on climate has, indeed, focused on the growth of industry and the explosive growth in use of fossil fuels. Human development of agriculture tends to be overlooked as a possible initiator of carbon cycle and climate change. Some investigators are beginning to consider the role of early agriculture. William Ruddiman, Professor Emeritus of Environmental Sciences, University of Virginia is one. He considered the possibility that the development of agriculture some ten thousand years ago may have subsequently influenced greenhouse gases and modified climate much earlier than that attributed to the industrial age. His review, published in 2003, suggests agriculture may have begun to alter the composition of the atmosphere as early as eight thousand years ago. I discuss some implications of his work in more detail on Computare’s website.

The influence of agriculture has expanded many-fold since those early days. What role does, or could, it play in the management of greenhouse gases? Vitousek suggests that humans appropriate about 40% of land plant production. Figure 5, above, indicates that plants absorb 60 billion tonnes of carbon annually from the atmosphere which is incorporated into their structure. Thus, humans control about 24 billion tonnes annually of the carbon removed from the atmosphere by plants. That’s much more than the 6.3 billion tonnes we added from fossil fuels in 1998 shown in Figure 1. Is it possible we have greater opportunities to control atmospheric greenhouse gas levels than to simplistically reduce fossil fuel consumption? Could we take lessons from the carbon cycle and strategically use more energy to help us manage levels of greenhouse gases in the atmosphere? I believe we can.

**ENERGY AND THE CARBON CYCLE**

Many scientists have embraced the idea that greenhouse gas emissions will drastically and negatively induce change climate. Others are not so sure and present cogent arguments for their counter case. We will continue to study the role greenhouse gases play in climate change. It may turn out we need to turn our attention - seriously - to managing greenhouse gases in Earth’s atmosphere.

The movement to control carbon emissions, as exemplified by the Kyoto Protocol, has become more and more focused on improving energy efficiency as noted in the introduction. Environmental organizations such as the David Suzuki Foundation and the Pembina Institute for Appropriate Development have provided governments and citizens with extensive plans and advice on the resolution of the climate change issue. Inevitably, their advice focuses narrowly on an imperative to improve energy efficiency to reduce emissions and to develop inherently costly greenhouse gas free “renewable” energy sources. The reports generally continue the theme to conserve initiated by the energy shortages of the 1970’s. The climate change issue becomes a platform to promote the pre-established agendas of these organizations.

The carbon cycle itself provides much insight into methods of managing carbon and the production and use of energy. It seems that with our already broad involvement in Earth’s carbon cycle through agriculture, forestry and energy science we may be able to develop the means to manage carbon bearing atmospheric greenhouse gases. If we are to be successful, we must re-focus our attention to the problem. We will need to concentrate our intellectual energy on maintaining an appropriate level of greenhouse gases on the atmosphere. We will need to integrate our energy use with other activities.
which influence the carbon cycle. We may need to expand the use of energy to ensure the management of greenhouse gases.

**USING ENERGY TO REDUCE GREENHOUSE GASES**

Some examples of proposed technologies which are rooted in directly addressing the primary goal of atmospheric greenhouse gas reduction are discussed in this section. It seems many of them will require humans to use even more energy.

**Greenhouse Gas Free Energy**

Let’s start with sources of energy which are deemed greenhouse gas free. Solar energy and resultant wind energy are supplied to us on a regular basis from fusion energy on the sun, and generate few greenhouse gases once constructed. Wind turbines are a beautiful expression of engineering art and are often the subject of beautiful photographs as shown in Figure 6. Unfortunately, although the fusion energy source from the sun is steady and reliable, the rotation of the earth and the vagaries of weather make both solar and wind energy intermittent and unreliable. An interesting study of a system to provide electrical energy to the United States from wind and solar generation is available from the University of Victoria’s Institute for Integrated Energy Systems.

![Figure 6 - Wind farm on the southwest coast of Denmark.](image)

Nuclear energy provides greenhouse gas free energy and beautiful images as well. Figure 7
is from a presentation by Atomic Energy of Canada Ltd. following completion of two CANDU 6 reactors in China. The beautiful earth tone of this photograph, particularly the sky and water, reminds us of human impact on the environment. No doubt intensive agriculture in China has contributed to the erosion of land by water. Hopefully the reactor will help reduce the haze in the air, and we will see later they may have a role to play in replenishing depleted soil.

These sources of energy all have shortcomings relative to the convenience of portable liquid fuels. Solar and wind energy also require complementary storage to compensate for their intermittency. They are all limited to stationary installations. The long dreamed of development of hydrogen technology to store and transport energy is expected to extend their range of application and make these greenhouse free sources of energy more relevant to transportation.

Interestingly, the extra processes involved in the production and use of hydrogen will tend to reduce energy efficiency and tend to increase overall energy use as we seek to switch to less greenhouse gas intensive sources and new sources of energy to fuel our transportation systems.

**Capture and Sequestration of Carbon Dioxide from Power Plants**

Current fossil fuel power plants burn their fuel with air, producing an exhaust stream of carbon dioxide, water and nitrogen which is released to the atmosphere. Perhaps taking a clue from natures initiatives to sequester excess carbon, we are considering pumping it back into the ground. Two of the variations shown in this [diagram](#) from a dedicated website use the recovered carbon dioxide to flush out additional oil and natural gas. Two simply store it in emptied oil and gas reservoirs or in underground saline water. Another variation contemplates burning the fuel in pure oxygen to avoid the separation from nitrogen.

Substantial new science and technology initiatives are needed to develop and prove these concepts. It is underway. These applications will require increased energy use for separation and pumping. Some will recover additional fossil fuel resources.
Zero Emission Coal

Another group of energy pioneers is also taking a cue from nature’s lessons. They propose to feed a mixture of coal, lime and water into a chemical reactor to produce hydrogen and carbon dioxide. A process flow chart\textsuperscript{14} (See Figure 1 of this linked document) shows the hydrogen being used in a fuel cell to produce electricity. In an additional step, the carbon dioxide could be combined with minerals to capture the carbon dioxide and sequester it in the form of rock. Development work is underway supported by governments and industry. The international ZECA Corporation\textsuperscript{15} has been formed to develop this energy production and greenhouse gas management opportunity.

Iron Fertilization of the Ocean to Enhance Atmospheric Carbon Dioxide Absorption

A proposal from the 1980’s suggested a scheme to remove carbon from the ocean surface and deposit it deep in the ocean. More carbon dioxide could then be dissolved at the surface. Essentially, the ocean is fertilized with iron to increase plankton growth which would then sink. Results of a test, reported this year, did produce sinking plankton. A press release\textsuperscript{16} suggests “billions of tonnes of carbon dioxide could be removed from the atmosphere each year”.

Much more development work needs to be done to demonstrate the practicality of this initiative. If it works, and we decide to control atmospheric greenhouse gases, another new energy using industry could evolve to mine and spread iron over the ocean simply to remove carbon dioxide from the atmosphere.

Agriculture and Forestry

Our brief review of the carbon cycle, above, indicated human agricultural activity cycles about four times as much carbon annually as is released from fossil fuel combustion. Science and technology increase the productivity of this the plants under our control tremendously. Irrigation, fertilizer, and plant selection and breeding increase the annual turnover of carbon. The first two of these are subtly integrated with energy production. Energy to supply irrigation water is taken from potential renewable electricity production provided by the hydrogeological cycle. Fertilizer production requires energy – and some is made from fossil fuels. At the same time stocks of carbon in standing forests have decreased and carbon stored in soils has been released to the atmosphere.
Figure 8 – Atmosphere – plant – soil carbon cycle components

Figure 8 outlines interactions of plants with the atmosphere and soils. Growing plants absorb carbon dioxide and incorporate it in their structure. Some is moved into the soil by roots. Decay of plant material produces carbon dioxide. Much is released to the atmosphere. Some, more durable carbon compounds tend to remain in the soil. Large quantities have been trapped in the soil over long times. Current agricultural practice tends to release some of it to the atmosphere by enhancing oxidation and decay of plant derived materials.

Scientists and agricultural engineers are involved in trying to better understand the part of the carbon cycle related to plants interaction with our soil. No-till farming is cited as one means of capturing carbon from the atmosphere and returning it to the soil carbon sink. Research is underway in to better manage animal wastes from intensive farming. Some promote the preservation and extension of forests as carbon sinks.

So far the role of agriculture and forest based carbon sink management is fraught with ambiguity. The scientific basis is uncertain. How much of the organic material left on the land is incorporated in soil? How long will it stay there? How much can be incorporated in soils? The basic approach to management for potential carbon sinks is undecided. Should we account for carbon taken from forests and built into our houses? Could carbon in lumber used to build houses be kept from the atmosphere? How should we manage carbon bearing wastes now going to landfills and sewers? Are landfills and sewers the wisest way to dispose of waste carbon bearing organic materials?

We may ultimately harness growing plants to more effectively remove carbon dioxide from the atmosphere and incorporate it into long lasting carbon sinks. I’m personally excited about some surfacing ideas on the production and use of charcoal as a soil amendment and fertilizer. Some charcoal, presumably from forest and grass fires centuries ago, is found in soil demonstrating its durability. Deposits of carbon rich black soils have been found in the Amazon. Archeologists are discovering evidence it was possibly man made some two or three thousand years ago. Some scientists suggest it was deliberately produced by a variation of slash and burn agriculture. These soils remain highly productive long after their formation.
Interest is building in this concept. One organization, Eprida, is proposing a process which produces charcoal based fertilizer and hydrogen fuel from agricultural and other wastes. This could include a wide range of materials including waste wood, straw, manure, and sewage sludge. This appears to be another opportunity to integrate energy production with greenhouse gas management. Some sacrifice of hydrogen fuel output will be required to produce charcoal. The Eprida website, referenced above, outlines the process and provides a great deal of illustrated background information. Ongoing research and development of this concept has potential to resolve much of the uncertainty associated with agriculture based carbon sinks.

An earlier section indicated humans are responsible for agriculture and forestry activity which absorbs 24 billion tonnes of carbon from the atmosphere annually. Permanently sequestering a portion in soil could dwarf the relatively modest emission reductions mandated by the Kyoto Protocol while re-building our soil resource. The magnitude of the carbon sink which might be realized could conceivably even exceed the current annual release of some 6 billion tonnes carbon from fossil fuel shown in Figure 1.

As a mechanical engineer, my training revolved around burning fossil fuels. I was raised on a farm. The prospect we may be able to burn fossil fuels to release carbon dioxide, and then process the plant material produced by it to establish a durable carbon sink which enhances the soil, intrigues me. I think we will be hearing much more about this concept.

Managing the carbon cycle – the primary goal

There are many other technical approaches to keep greenhouse gases from the atmosphere.

The foregoing examples are intended to show that some of them may increase energy use. Those who focus on reducing energy use through efficiency improvement have created an impression that is the paramount means of reducing greenhouse gases in the atmosphere. Societies developed on the basis of early recognition of the benefits of harnessing energy sources are now deemed the energy gluttons of the world in spite of continuing and highly successful initiatives to increase efficiency of processes involved in its use.

There is still some scope for improving energy efficiency beyond the huge improvements that have been implemented over the past two centuries. We will continue with such improvements as are achievable within the environmental and economic constraints of sustainable development. Improving energy efficiency is a secondary approach which can help reduce emissions by individuals and processes and extend resources to increase overall benefits. The most optimistic conservation strategies only briefly delay exhaustion of the fossil fuel resource. Long term survival of human society and many of earth’s ecosystems requires a more active approach.

Should we finally determine there is an imperative to manage greenhouse gases in the atmosphere, there are technical solutions. As we seek to develop them it is imperative our strategy remain focused on that primary goal. An expansion of energy use will likely be required to implement practical solutions.

Integrating nuclear energy and the carbon cycle

Where does nuclear energy fit into this strategy? Nuclear power is often somewhat simplistically touted as an alternative energy source to avoid greenhouse gas emissions from the fossil fuel we now depend on. It is more than that. It is an energy source which can be developed to develop and sustain
human society far beyond that seemingly possible with dwindling fossil fuels. Indeed, nuclear energy can be deployed to help manage the carbon cycle as suggested by the examples in the preceding section.

Nuclear energy can be used for an expanded range of applications, by developing applications for the direct use of heat and/or the production of alternate fuels such as hydrogen or possibly liquid fuels. Water and soil may become limiting constraints to sustainable development. Incentives may develop to reduce the use of water for hydroelectricity and use the energy otherwise generated to expand irrigation and the carbon dioxide absorption capability of living plants. Nuclear energy could replace the loss of electricity. In some areas fresh water could be pumped, using nuclear energy\textsuperscript{20}, from regions of little use to enhance agriculture. The use of nuclear energy for desalination has long been studied. Perhaps this may become another opportunity to expand agricultural production.

Future integration of energy supply with greenhouse gas management could come from development of technology associated with building and enhancing earth’s soils as suggested in the examples above. Conversion of a fraction of waste organic materials into charcoal soil enhancements seems a promising technology to explore as a means of coping with greenhouse gas emissions. Nuclear technology could be an essential source of energy to drive this process. In the longer term, damage to soil suggested by the brown water in Figure 7 might be repaired. Should this prove workable we might even come to view greenhouse gas emissions as an asset. We might wish we could generate more.

Obviously the challenges presented here will provide many interesting opportunities for future generations to contribute to sustainable development right here on earth. Science and technology provide the foundation and means to evaluate and develop solutions.

**Conclusions**

More efficient use of energy is often touted by short term thinkers as the way to managing greenhouse gases. Experience, over the past couple of centuries tells us increasing efficiency of energy use simply expands applications and human population to increase overall energy use. Since we depend mostly on fossil fuels for energy now, there is a strong correlation between energy use and greenhouse gas emissions. Many have come to see those emissions as a constraint to sustainable development as they may result in damaging climate change. That possibility is still under scientific investigation. Continuing study may eventually convincingly demonstrate it really is a problem.

There is by no means a hard and fast correlation between energy use and greenhouse gas emissions. There are means of producing energy, even from fossil fuels, while controlling emissions. Technology can be envisaged which will actually mange the make up of the atmosphere. Such technology will depend on careful human use of possibly even more energy.

There are many other potential constraints to sustainable development. Foremost of these is the developing shortage of fresh water. Humans also depend on earth’s limited stores of soil. There may come a time when we have to restore and build soil as a part of sustainable development. Recent observations on the historic development of soil, driven by considerations of the potential need to sequester carbon dioxide, point the way toward a possible solution based on integrating our energy use with nature’s management of carbon, water and life on earth as represented by the carbon and hydrogeological cycles.

The technological challenges to develop our sources of energy while respecting nature and the environment are tremendous. I’m sure the nuclear industry will make a major contribution.
1 Apparently no longer posted on the IPCC website as of 04/09/10.
2 Climate Change 2001: The Scientific Basis, Working Group I, Intergovernmental Panel on Climate Change, Figure 3.1a. http://www.grida.no/climate/ipcc_tar/wg1/097.htm#fig31 (Posted as of 04/09/10)
3 Ibid, Figure 3.1b
4 Ibid, Figure 3.1c
5 Ibid, Figure 3.1d
13 Figure showing CO2 sequestration schemes http://www.co2captureproject.org/technologies/tech_img2.gif Posted as of 04/09/13 at http://www.co2captureproject.org/technologies/index.htm