Carbon neutrality—what does it mean?

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The achievement of carbon neutrality has become an inescapable feature of the news media and like most long-running news stories, the momentum of the reporting often loses the underlying facts as the tale unfolds in everyday exposure. This article seeks to restore some of those facts and questions the assumptions and direction that politicians and the press (the two seem inextricably linked these days so that it is often difficult to know who leads who) are taking us in the quest to avert anthropogenic-related climate change. A case for carbon neutrality achieved through carbon trading, rather than politicians posturing on the world stage for national carbon emission reduction, is made on the basis that whether or not man is critically affecting climate, at least a global mechanism is thereby in place to cope.

Introduction

The word "neutrality" connected with carbon these days is yet another example of how language has been corrupted by advertising and political correctness. Like "organic",[1] its scientific significance seems to have become lost in the miasma of advertisements. "Carbon neutrality" as a phrase has not quite reached the depths of corruption of "organic" and one would imagine in the context of climate change that it means as much carbon is sequestered as produced. As part of the climate change bandwagon "must have", achieving "carbon neutrality" is politically almost essential. For instance, in 2007 Prince Charles claimed that his estate, the Duchy of Cornwall, had attained carbon neutral status, achieved by reducing household carbon emissions by 9%, by taking fewer flights and moving towards "green" electricity.[2] Similarly, the BBC has reported (as part of an investigation into ways of economizing after the rapid rise in the cost of oil and, hence, utility bill increases) that people are turning toward wood stoves for cooking and heating.[3] Such intentions, albeit driven by economics, are given plaudits as part of the worthy trek on the road to carbon neutrality.

[1] What used to be material containing carbon now seems to mean anything not grown with pesticides or fertilizers.
[2] Prince rated as "carbon neutral". BBC News, 26 June 2007, http://news.bbc.co.uk/2/hi/uk_news/6241232.stm
[3] Catherine Wynne, Demand hotting up for wood stoves. BBC News, 9 June 2008.

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So what is carbon neutrality? As portrayed by the press as part of the campaign to preserve the ecological status quo of the planet, it is designed to entice individuals and industry to comply with new societal norms, but the facts justifying those norms are either buried in the small print or seem to have become lost in the momentum of the campaign; economies of truth are regarded as a small price to pay for the benefits of mass communication and compliance. Taking a step back, one might be forgiven for naïvely thinking that carbon neutrality means that the carbon produced and emitted into the atmosphere by politically correct individuals in living their lives was being balanced by equal amounts of carbon sequestered out of the atmosphere over the same period of time. It takes only a cursory investigation to realize that this cannot be true and with a little more thought one might come to ask if it is really desirable or necessary.

Just a simple example suffices to explode the myth of the wood-burning stove. Wood, coal and oil all have originally sequestered carbon from the atmosphere and soil to be formed, but over different periods of time: wood over the life of the tree (say 20 to 30 years), coal starts as wood but then needs to be buried for a few hundred million years, and similarly for oil, which is believed to originate from molluscs feeding on phytoplankton and then buried. Thus as long as one tree is planted to replace each one burned, then the process would seem to be carbon neutral. For wood one might have to wait two or three years before burning a tree again, whereas for coal and oil, unfortunately, one would have to wait a large number of millennia. So to be carbon neutral, the purchaser of the wood-burning stove would have to ensure that trees were planted to replace those burnt, but no such link exists in the purchase of a stove. One could argue that if the wood was bought from the UK Forestry Commission, who have a mandate to maintain their forests, then this might indeed be construed as being carbon neutral. Another aspect is that although burning wood releases carbon dioxide into the atmosphere in the same way as burning coal or oil or gas, it is less efficient, releasing less carbon dioxide than coal and less heat for the same mass. Moreover, there could be other problems in the wood-burning drive to carbon neutrality, for unlike with smokeless coal and oil, other products of wood combustion, especially from treated wood, are also formed, which may infringe the Clean Air Acts. And we have not taken into account the vast amounts of fuel consumed to reduce the iron ore and forge the stove from cast iron.[4]

Looking at the case of Prince Charles, the matter is more complex. Certainly reducing household energy usage will reduce the carbon dioxide emitted by power stations, and as Prince Charles is also using solar or wind-powered electricity then there is a further saving. But what of flights, how are they offset? The same question can be asked about motorized land travel. Without looking at the accounts for the Duchy of Cornwall, one must assume that Prince Charles has bought into a carbon offset programme. Carbon offset, although not currently required as part of the purchase of our wood-burning stove, would provide a means of achieving true carbon neutrality.

Carbon offsets

At first sight the carbon offset scheme appears to be an excellent concept and consists of two basic approaches. The first is for individuals or companies to produce power from renewable sources such as solar, hydro or wind or, in the not too distant future, waste and feed it into the

[4] G.C. Holt and J.J. Ramsden, Introduction to global warming. In: J.J. Ramsden and P.J. Kervalishvili (eds). *Complexity and Security*, pp. 147–184. Amsterdam: IOS Press (2008).

national electricity supply system. The carbon benefit is then the carbon dioxide per kilowatt hour of electricity that would have been produced by a present generation coal, gas or oil-supplied power station. This amount of carbon may then be offset against energy taken from a conventional power station or the production of carbon dioxide from an industrial process (e.g., cement manufacture). In other words it is a means of at least maintaining the status quo as energy demand inexorably increases with an increasing population and with the increasing dependence upon products requiring energy to manufacture and buildings requiring a continuous energy input to be habitable. The second approach concerns the direct sequestering of carbon dioxide from the atmosphere using biomass or chemical processes, which has the potential to reduce the effect of anthropogenic carbon emissions and restore the global carbon balance. This is a much more complex process that needs to be looked at with time as a parameter, and raises the most concern when claims for carbon neutrality are made.

In the last five years a number of carbon offset companies have emerged. Most of these companies offer an eclectic mix of offsets based on reforestation projects, hydroelectricity, wind farms and solar energy. However, the economic model underlying this offset industry is somewhat opaque. For instance, take a wind farm offset where presumably the total cost of development, installation and maintenance of a wind farm over its useful life is used to place a value on the electricity generated and then, by comparison with a conventional power station, a cost for the carbon not emitted into the atmosphere. As an example, say an onshore wind farm costs £20M to install and lasts 20 years with a maintenance cost of £1M per year producing 20 MW. To recover the cost of installation, the electricity would need to be sold at £0.01 per kWh.

More detailed analysis of electricity generation costs by wind, nuclear, gas, oil and coal[5] over the power station's full life-cycle is shown in Table 1.

Table 1. Energy generation costs.

Nuclear cost per kWh	£0.037
Coal	£0.040
Onshore wind	£0.055
Offshore wind	£0.083

Typical generation costs at present are about £0.05 per kWh generating 0.3 kg of C. The UK selling price is around £0.12 per kWh.[6] The cost of the carbon is thus nearly £50 per metric ton of CO_2 based on typical generation cost.

Thus a polluter might wish to buy 1% of the carbon offset over the lifetime of the wind farm project, equivalent to say 1% of its total cost. Quite reasonable one might say, but then the wind farm is already paid for by selling its output, so the carbon offset sale is pure profit.

For an enterprise at least purporting to save the planet, there would seem to be many opportunities for huge profits with little evidence of regulation. Is this reminiscent of the current international credit crisis?

As a more complex offset involving reforestation or tree-planting, the wood-burning stove

[5] *Overview of modelling of the relative electricity generating costs of different technologies*. Table 9 London: Department of Trade and Industry (July 2006).
[6] Southern Electricity 2009 tariff.

case is worth examining in some detail. For example, take 1 kg of coal compared to 1 kg of wood burnt in the stove. Coal on average is about twice as dense as wood and 1 kg, taking say one hour to burn completely, releases about half a kilogram of carbon as carbon dioxide and produces nearly 6 kW. Wood releases half as much carbon (0.25 kg of C per 1 kg) and half as much energy as coal.[4] Now suppose that as an offset, a tree is planted. Grown from seed it might take two or three years to achieve a weight of 1 kg (roughly, a sapling 1 m high and 3 cm in diameter). The dry biomass of such a tree is about 0.3 kg,[7] and the sequestered carbon is half that amount or 0.15 kg. Tree growth is not linear and one might argue that this 0.15 kg of carbon was sequestered in the last year of the three and then in subsequent years the tree will become heavier and sequester more carbon. Tree growth measured by trunk radius is roughly linear with biomass once a tree is established (cf. the biomass equation:[7] $y = \exp(\beta_0 + \beta_1 \ln x)$, where y = total aboveground biomass (kg) for trees 2.5 cm and larger in d.b.h. (tree diameter at base height) (cm), and x = d.b.h., so that near the end of say a 20 year life the tree may be sequestering 3 kg of carbon per year, and weigh in excess of 400 kg.[8]

This fairly crude example shows that the offset tree by age four has sequestered all the carbon emitted (0.25 kg) by burning the 1 kg of wood. Moreover, over a 20 year lifetime, this tree provides further fuel for the future while ensuring carbon neutrality for a wood-burning stove consuming about 12 kg of wood per year.

Given this scenario, what should be the economic model? One might for instance wish to deduct the value of the wood at the end of the tree's life, and the question arises whether all the carbon sequestered by the tree was actually from the atmosphere—or was some sequestered from the soil? Should the cost be one twentieth of the cost of planting and maintaining the tree for an offset of 3 kg of carbon a year, or should some other model be employed? In reality a hybrid model is adopted, somewhere between the equivalent cost of the emitted carbon from a conventional power station, £50 per metric ton of CO_2, and the negligible cost of some 100 tree seedlings.[9]

Similarly to the wind farm, the production of wood from tree planting may well be self-financing so that the sale of carbon offsets is pure profit.

Monitoring and verification

Verification organizations have emerged and one of the best is the "gold standard" operated by a Swiss-based non-profit foundation,[10] which provides an auditing function ensuring that offset projects are indeed sequestering carbon. For the case of trees and forests, monitoring is not an exact science as the example of the biomass calculation demonstrates. Better techniques are emerging where synthetic aperture radar on orbiting satellites measures directly the biomass of the woodland or forest.[11] However, although these bodies administering standards seek to

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[7] T.R.H. Pearson, S.L. Brown and R.A. Birdsey, *Measurement Guidelines for the Sequestration of Forest Carbon* (General Technical Report NRS-18). United States Department of Agriculture Forest Service Northern Research Station (2007).

[8] Tree mass will at least increase as trunk radius squared if not cubed.

[9] Mass of C is approximately 0.27 that of CO_2.

[10] The Gold Standard Foundation, Geneva-Cointrin, Switzerland. http://www.cdmgoldstandard.org/materials.php

[11] Environmental Change Institute, Oxford University. http://www.eci.ox.ac.uk/research/biodiversity/linkcarbon.php

regulate against double accounting of carbon sequestration or carbon saving, they seem to place no restraint on the economic model underlying the sale of the offset.

Deforestation accounts for nearly 20% of the annual greenhouse gas emissions arising from anthropogenic activity.[4,12] Moreover, as the rainforests are one of the major elements of the ecosystem's ability to regulate the atmosphere it would seem that projects aimed at preventing deforestation have a double benefit. In this case perhaps the economic model should be based purely upon market forces. For although it is possible to estimate the carbon that would have been sequestered by the trees destroyed, the cost now is the loss to the developer in not removing the trees and using the land for some profitable purpose. In much of South America the deforestation is often by farmers wishing to develop the land for cash crops such as maize for biofuels, an example of the irony of political pressure to have an impact on climate change without proper attention to the probable consequences. In such a case the cost of the offset carbon is likely to be high if the would-be deforestation farmer demands an equivalent income for life of his virtual cash crop.[13]

The carbon offset process in all cases relies on certification that carbon output reduction or sequestration of a given quantity is occurring and then these certificates may be traded like shares or bonds. However, the intrinsic value of these "carbon shares" appears arcane, with some national governments awarding grants for new industrial development if carbon offsets are used but many ignoring this embryonic trade.

What is the cost? Table 2 shows what "Greatest Planet"[14] charges annually to achieve carbon neutrality for various sizes of business based upon the number of employees. The

Table 2. Estimated CO_2 emissions and carbon offset costs according to Greatest Planet.[14]

Descriptions	Number of Employees							
	01–5	06–10	11–25	26–50	51–100	101–250	251–500	Over 500
Building/office energy use	Small	Small	Small	Small or Medium	Medium	Medium or Large	Large	Very Large
Computer/server energy use	Small	Small	Small	Small or Medium	Medium	Medium or Large	Large	Very Large
Vehicle fleet size	N/A	N/A	N/A	N/A or Small	Small	Small or Medium	Medium or Large	Large
Employee travel	None or Limited	None or Limited	None or Limited	Limited or Moderate	Limited or Moderate	Moderate or Substantial	Moderate or Substantial	Substantial
Employee commuting	None or Little	None or Little	Little	Little or Moderate	Moderate	Moderate or Substantial	Substantial	Substantial
Average CO_2 emissions per annum (tons)	60 to 80	80 to 100	100 to 125	125 to 175	175 to 250	250 to 350	350 to 500	Available on request
Carbon offset cost levied (UK)	£249	£299	£349	£399	£499	£749	£999	Available on request

[12] B. Metz, O.R. Davidson, P.R. Bosch, R. Dave and L.A. Meyer (eds), Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007 Cambridge: University Press (2007http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-ts.pdf

[13] Typically the soil, initially enriched from the ashes of the burnt trees, is exhausted after two or three years and can only continue to be productive with the addition of artificial fertilizer.

[14] Greatest Planet. http://www.greatestplanet.org/about.html

estimate of the carbon output is dependent on five factors: the energy use of machines, heating, travel, number of employees and amount of company-owned transport. The cost of a carbon offset for a year is then shown, but how this is calculated is something of a mystery as the company invests in many carbon sequestration projects including reforestation and it is not possible to determine the contribution from each of these projects bought by the offset price. One has to ask whether £250 per annum is good value for money for a small business given that all one obtains is a certificate and a "green" feeling! If businesses were forced to engage in offsets then it should reduce the demand for energy from conventional power stations as the investment by companies such as "Greatest Planet" results in more carbon-neutral energy production and natural carbon sequestration.

A carbon neutral future

In the UK, building regulations are being driven to reduce energy consumption and eventually achieve carbon neutrality in individual houses and offices. The so-called level 6 design is aimed at achieving "net zero carbon" by 2013 for public property and by 2016 for private dwellings. The current level 3 design standard (much improved insulation and reduced energy consumption but not carbon neutral) is already mandatory for public sector buildings. This carbon neutrality will be achieved by various techniques dominated perhaps by the most obvious, namely improved insulation—conduction through walls and roofs will be reduced by a factor of almost 3 using a matrix of insulating materials. Water will be managed through both rainwater collection and waste water recycling. The energy management system is the most interesting, however. It includes controlled ventilation, solar panels to provide hot water in summer, solar panels for electricity and a wood pellet boiler. A typical assessment of the heating and lighting requirements of a house are at about 8 kW on average throughout the year, with nearly 5 kW from 46 m^2 of roof solar panels and a 10 kW wood pellet boiler (supplying typically only 2 kW because of the insulation's effectiveness).[15]

At today's prices, a house finished to level 6 regulations would be unaffordable to most people. The solar panels, solar heating and wood pellet boiler are all very expensive capital items, although advances in *nanotechnology* are both improving photovoltaic efficiency and reducing price. Again there is no apparent link between the carbon output of the wood pellet boiler and the need to have offsets, which may accrue from the photovoltaic output so that real carbon neutrality is achieved. There is an assumption that the wood burned will be replaced. From this example it is clear that the Government will probably have to employ the tax system to force a connexion to replace burned wood if true carbon neutrality is to be achieved.

The need for carbon neutrality

Before examining offsets in further depth, one might question if they are necessary at all. Certainly anthropogenic carbon dioxide generation has increased dramatically over the last 50 or 60 years and there is some evidence that this, coupled with other natural phenomena related to the earth's orbit round the sun and the cycle of ice ages, could lead us to a point of instability

[15] *Total Masterplan Solutions*, Kingspan Off-Site Ltd. http://www.kingspanlighthouse.com/contact.htm

in the earth's ecosystem.[4] The northern hemisphere seasonal cycle of atmospheric carbon dioxide, which varies by about ± 2 ppm (Figure 1), unchanged over decades, is equivalent to a total swing of just over seven gigatons of carbon, which is about the same as the annual anthropogenic output. This well established fact, due to the natural growing cycle of northern hemisphere ocean phytoplankton and land photosynthesis, alone allows one to argue without detailed consideration of the possible causes of climate change that the current situation is sustainable, and although man should not be seeking to increase carbon dioxide output, there may not be a need to decrease it. The Kyoto, and more recently Posen, agreements on climate change may be too radical but given the world's failure in the past to abide by international rules[16] they are perhaps a necessary if not quite achievable target.[17] Leaving aside the issue of whether the Earth is globally carbon neutral, at a local level it is desirable not least just to reduce energy demand from diminishing fossil fuels. Accepting that global warming is in some part due to anthropogenic activity, the aspiration to reduce or at least contain man-made carbon dioxide emissions, the goal of carbon neutrality, if not strictly achievable, is at least laudable.

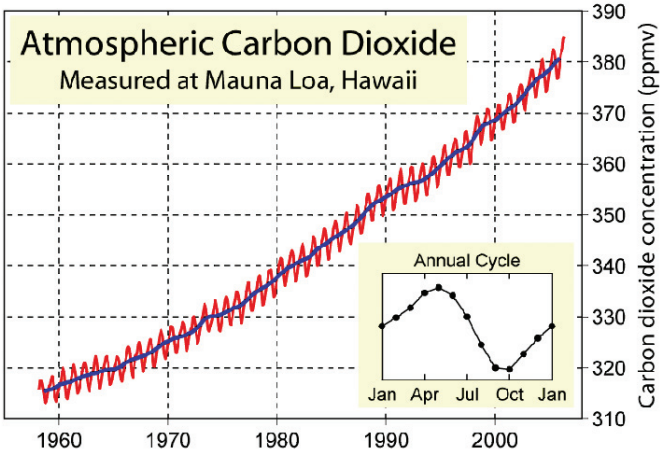

Figure 1. Seasonal carbon cycle. Atmospheric CO_2 values (ppmv) derived from *in situ* air samples collected at Mauna Loa, Hawaii.[18]

The global stage

Globally, both the Kyoto and Posen agreements seek real reductions going beyond carbon neutrality but it is difficult to see how this can be accomplished given that the world population and consequently energy demands are still growing almost exponentially.[4]

[16] The implementation of the Montreal Protocol of 1989 on ozone layer-destroying chemicals is a notable exception.

[17] O. Tickell, We need to turn carbon into gold. BBC News, 9 December 2008. The answer has to be to make forests worth more alive than dead to governments and forest owners

[18] Source: C. D. Keeling, S. C. Piper, R. B. Bacastow, M. Wahlen, T. P. Whorf, M. Heimann, and H. A. Meijer, Exchanges of atmospheric CO_2 and $^{13}CO_2$ with the terrestrial biosphere and oceans from 1978 to 2000. I. Global aspects. SIO Reference Series, No. 01-06, 88 pp. San Diego: Scripps Institute of Oceanography (2001).

If by 2016 all new houses in the UK are carbon neutral then overall there might be some diminution in individual energy use and carbon generation, but to achieve real reductions then all the key areas of power generation, transport, industry, agriculture and deforestation will need to be controlled and regulated globally (see Figure 2).

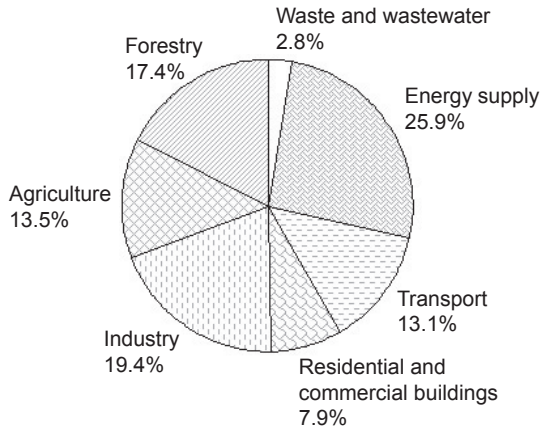

Figure 2. Anthropogenic sources of greenhouse gases in 2004.[12]

In the area of transportation, there is much ongoing research to wean us away from fossil-fueled vehicles and advances in *nanotechnology* for hydrogen storage and fuel cells should in 10 to 15 years time make some impact. But this must be viewed with some scepticism since the former "third world" countries India and China are both demanding individual transport systems (i.e., private motor-cars running on metalled roads) in order to emulate the lifestyle of the developed countries, so that growth in demand there may outstrip savings elsewhere.

Power generation is another area where mankind seems to be chasing its tail due to population growth and lifestyle trends. Nuclear energy, increasing use of wind, solar and water power will probably meet increasing demand but there is likely still to be a significant dependency on coal, oil and gas-powered electricity generation.

The carbon offset principle with its promotion of carbon sequestration would seem to be essential (within the bounds of practicability) for both the burgeoning transport and power generation industry if mankind is to achieve global future parity with the status quo, let alone carbon neutrality.

Difficulties with offsets

Cheap motoring and air travel are not going to disappear no matter how much the "green lobby" may complain. The concept and expectation of driving somewhere for the most trivial reason and regular holidays overseas by the population of developed countries have become too deeply entrenched (indeed they have been actively promoted for many decades by private enterprise and governments) even if some guilt might be experienced by individuals like Prince Charles. Similarly the desire for manufactured products requiring energy for their production will not be quenched unless a global climate disaster actually occurs. So what is to be done?

The concept of offsets seems to be the only realistically attainable solution to encourage and finance the growth of alternative technologies emitting little or no carbon dioxide to produce energy, provide transportation and create the sophisticated goods upon which world trade and the global economic system depends.

Unfortunately, governments around the world are neither tackling the problem uniformly globally nor locally. In the UK, some industries are penalized for too much carbon emission while others are not: e.g., the Enhanced Capital Allowance (ECA) scheme,[19] which enables some companies to reduce their tax burden; motorists are actively penalized through petrol taxes and a jungle of complicated restrictive laws; and air travellers are burdened by huge departure taxes. Yet countries such as India and China are only just starting to recognize the problem and seem disinclined to discourage motoring (the Chinese[20] and Indian car industries show little sign of being affected by world recession).

Share trading in carbon bonds (Certified Emissions Reductions (CERs) each worth the equivalent of one tonne of greenhouse gas carbon dioxide) has not had much success;[21] values vary between $3 and $30. Note that in the UK the current cost to produce a tonne of carbon dioxide is about £50.This may be due to the global economic recession which has focused the media away from the issues of climate change while also reducing the money available for action, and to the problem of ascribing an intrinsic value to the carbon bonds. In contrast, a bank (for instance) has an intrinsic value based upon its assets and turnover (subject, of course, increasingly to perceptions in the financial press of profitability), whereas the carbon share at present could be the value of a tax penalty, a portion of the cost of the carbon sequestering installation or the current cost of power generation per unit quantity of carbon emitted, hence the price variability depending on the company offering the share and the means of offset.

However, apart from some tax incentives, no government has insisted on carbon offset certificates as a means of showing carbon neutrality. So far companies buying certificates have been motivated only by consumer and shareholder demand to be climate-friendly, although there are rumours that the new administration in the USA might legislate.[22]

Can nanotechnology contribute to achieving carbon neutrality?

Some pundits suggest that nanotechnology is the enabler of another industrial revolution. This may be so, but will it resolve the climate change issue either by providing "clean" energy or through carbon sequestration? This is a difficult question to answer, for like the steam engine

[19] The Enhanced Capital Allowance (ECA) scheme: If a business invests in a high efficiency boiler from the Energy Technology Product List, it can claim a 100% first-year capital allowance of £1,000 against taxable profits in the year of investment. Assuming the company pays corporation tax at 28% the effect of the first-year allowance would be to reduce the business's tax bill by £280 (£1,000 @ 28%). Thus, the first-year allowance can confer a cash flow advantage. See http://www.eca.gov.uk/etl/default.htm

[20] Chris Hogg, China's car industry overtakes US. BBC News, 10 February 2009.

[21] Market analyst Point Carbon (Worldwatch Institute) predicted in February that the volume of high-value Certified Emission Reductions (CERs)—carbon credits from United Nations-approved projects—would fall 45% in 2009. http://www.worldwatch.org/node/6061

[22] CLEAN ENERGY; *Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,* F:\TB\EC\CLICH09_001.XML, 30 March 2009.

technology that was at the heart of the Industrial Revolution of the 17th century, steam engines are not identified as the primary reason for the growth of the British Empire but rather they facilitated an economic supremacy.

Nanotechnology is already becoming all-pervasive in cosmetics, sunscreens, paints, medicine and electronics, and tends to provide an economic advantage through promoting national growth and raised living standards for those countries manufacturing and exporting such products. In many cases, however, the technology requires a significant energy input and hence arguably exacerbates attempts to reduce anthropogenic carbon emissions. However, some developments in nanotechnology will indubitably help. Frictionless nanoparticle coatings reduce wear of machinery and save energy (the apotheosis of the development of lubricants), developments in quantum dots and photovoltaic materials will save energy in lighting and generate affordable renewable energy respectively, biofuels from hitherto intractable waste using nano-engineered enzymes, fuel cell developments and hydrogen storage in a nanostructured matrix to power electric cars, and nanoparticle-catalysed water purification using sunlight[23] thus saving energy in the developing world, are all examples of contributory benefits, but is there a panacea from nanotechnology and will it be remembered as the climate saviour? The answer is maybe.

Many nanotechnologists believe that the Holy Graal is the design of a personal nanofactory. This device, which may become as ubiquitous as a personal computer, will use raw materials such as propane as the carbon source and electricity to construct everyday items using molecular assembly.[24] Some progress has been made toward this goal with the manufacture of microscale items such as shaped particles and quantum dot arrays but the production of even an artefact as simple as a carbon-based teacup is still a gleam in the eye. Nevertheless, when such personal nanofactories become a reality, possibly by 2050 or thereabouts, carbon may rapidly become in short supply as the atmosphere will provide a free source and coal or wood burning may become essential to supply a burgeoning consumer demand.[25]

Conclusion

Regardless of the rather nebulous perception of "carbon neutrality" gleaned from the press and advocated by politicians, the concept when properly defined and regulated will actually become an essential part of modern life. Like many political imperatives in today's complex society, the ensuing results may not be fully predictable—this may often be traced to lack of initial clear thinking by policy- and law-makers. The concept of carbon neutrality seems to be a classic example, and rather than concentrating on percentage reductions of anthropogenic carbon, governments might be better employed in thinking of international means backed by regulation and tax penalties or incentives that would encourage all of us, not just the climate change opportunists, to want to achieve carbon neutrality.

[23] A. Iles, Microsystems for the enablement of nanotechnologies. *Nanotechnology Perceptions*, 5 (2009) 121–133.
[24] R. A. Freitas, Economic impact of the personal nanofactory. *Nanotechnology Perceptions*, 2 (2009) 111–126.
[25] T. Toth-Fejel, A few lesser implications of nanofactories: global warming is the least of our problems. *Nanotechnolgy Perceptions*, 5 (2009) 37–59.

The Bush regime in America took the view that technology would resolve the greenhouse gas problem; the new administration seems to have accepted that this will not be the case and that, although technology developments will help, in the final accounting it will take political will. It has been predicted that the revolution in *nanotechnology* will fundamentally change our climate,[25] since personal nanofactories (and possibly bottom-up assembly techniques) will make all our structures and machines from carbon sequestered from the atmosphere. If this becomes reality in perhaps 30 or 40 years hence, then the world may need to revert to fossil fuel burning in order to restore the carbon dioxide levels so that plants and trees continue to grow. The carbon offset market might then have to be reversed in direction but at least by then it should, and needs to, be in place, reputable and working.