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The failure of our collective consciousness is collapsing the life chances of everyone on the planet under 40. … History does repeat itself, although not always in ways we recognize. Working on climate change, I imagine myself at times transported by a time machine back to Germany in 1936. I know what will happen next. All the signs of that catastrophic future are already visible. The people I speak to treat me with kindness. They listen to what I say. They agree such things are possible. But they do not think they will happen here. The more agitated I become at their calm confidence in the constancy of the present, the more concerned they become about my welfare.

Tom Burke (professor in environmental science), *The Times*, 21 August 2010.

The Optimum Population Trust (UK): London

<http://tinyurl.com/optj2>

INTRODUCTION

Techno-optimists like to think that the future of agriculture will follow the path of improvement that has occurred during the last few decades. However, there is a growing awareness of the many factors which are likely to reduce food production, some of which are: a reduction in the available arable land due to new buildings and roads, erratic weather due to climate change including floods and droughts, falling water tables, and loss of fertile soil due to erosion and desertification. And agriculture is in peril for less drastic reasons, one of which arises from the many problems associated with pesticides. Chapter 13 of David and Marcia Pimentel's book *Food, Energy, and Society* provides a comprehensive survey of the impact of pesticides and herbicides — giving further cause for concern about the future of food supply.

In *The Great Warming*, Brian Fagan shows the fragility of all agricultural systems in the light of varied climatic conditions, and provides powerful historical evidence that long droughts are likely to be associated with the warming climate that has been occurring over the last century (and shows no signs of abating). His fine book is but one of many warnings that have been given about our perilous situation. Pages 7-13 survey that, and also the attempts by many people to point at the dangers ahead. It also looks at the tendency that humans have either to ignore problems or to indulge in delusions until disaster strikes. Yet there is one bright example of a society which kept its population in balance with its resources for millennia, namely a small island Tikopia. How much comfort can be drawn from their example remains an open question.

Over many years Lester Brown has been trying — latterly through the Earth Policy Institute — to draw the attention of the public to the looming problems of agriculture. One of several books that have been sent to me by Walter Youngquist is Brown's most recent one *World on the Edge: How to Prevent Environmental and Economic Collapse*. Youngquist and I are equally in admiration of Brown's grasp of agricultural realities and dismayed at the unreality of his rose-tinted view of the future of renewable energy. This piece, pp. 14–16, reviews both aspects of the book.

Lester Brown is particularly good on irrigation, pointing out that half the world's population live in countries where water tables are falling, and worldwide 70% of water is used for irrigation. However, in the UK little is used for irrigation; most is used for commercial and residential purposes. This year, in February, water companies have already predicted a drought for a large swathe of the south and east of England. As usual the media look for solutions, such as repairing leaking water pipes, or water transfer from the north, but exclude from their thoughts any mention of the UK's excessive population, which we already cannot feed and clothe. As fossil fuels become more expensive, the situation will get far worse, as the next two items explain.

There is a steady stream of plans for running the world on renewable energy, from flights of fantasy filling a few pages in *Scientific American*, to books such as the 370 page volume produced by the Centre for Alternative Technology (CAT). CAT has done much useful work, and runs courses relevant to living more ecologically, so one might hope to get some sound thinking from that organization. But the title of their book, *Zero Carbon Britain 2030*, immediately suggests that this is a flight of fantasy. Nevertheless, coming from a respectable source, it deserves close study, if only because it is a representative example of this genre of wishful thinking. That is what the next two items do.

On pages 17–19 Andrew Gilligan reviews Chapter 7, *Land Use and Agriculture*. The chapter is typical of the genre in expecting a large area of the country to be devoted to growing energy crops. Gilligan shows that this would be far more ecologically detrimental than the authors of the report casually assume.

On page 20-25 I take a look at Chapter 8, *Renewables*. This chapter of *Zero Carbon Britain 2030* is also typical of the genre in that it fails to appreciate the difficulty of integrating uncontrollable inputs, such as wind, photovoltaics and tidal flow, into a grid, and the consequent need for a large amount of *controllable* electrical input. In the review I take a close look at what might be achieved, noting that without the benefits of fossil fuels an optimum population for the United Kingdom is likely to be in the region of a third of its present population. CAT has been offered every opportunity to respond to both reviews.

Pages 26–27 are a contribution from Kenneth Smail, Professor of Anthropology (Emeritus) of Kenyon College Gambier, Ohio. Since the 1970s — when the world population was about 4 billion, and due to the Arab oil embargo there was growing awareness of a population problem — the great majority of those who try to get their voices heard on the subject of population call only for a *stabilization* of the population, and continue to do so even now that the world population has risen to 7 billion. Only a small group of scientists are bold enough to realize that the human population needs to be much smaller, in preparation for the time that fossil fuels run out, and in recognition of the huge damage being done to the Earth's ecology by the present population,. The title of Ken Smail's piece shows he is one of them: *The Overarching Issue of the Century: Acknowledging and Confronting the Inevitable: A Significant Reduction in Global Human Numbers and other Inconvenient Truths*.

The last page, *Experience of Wind Turbines in the Pacific Northwest*, has a bearing on the aforementioned review of Chapter 8 in *Zero Carbon Britain 2030*, insofar as it provides empirical evidence of the difficulties encountered when incorporating large amounts of erratic inputs of electricity (from wind power) into an electrical system.

I have Walter Youngquist to thank for supplying me with much of the material in this issue, which I do with great admiration for his continued energy — having passed the age of ninety. David Pimentel and Martin Desvaux have continued to be helpful with their comments on the material I send them. As always Yvette Willey has accomplished for me the not inconsiderable task of proof reading.

All internet addresses given in previous OPT Journals as pointers to the availability of these journals on the internet are now superseded. The webpage to access all OPT Journals, current ones and previous ones, is now: http://tinyurl.com/optj2

When David Willey founded the Optimum Population Trust (OPT) in 1991, he set out the two main aims of the OPT as:

- To promote and co-ordinate research into criteria that will allow the optimum population of a region to be determined.
- To increase awareness, particularly among those who influence opinion, of the results of this research.

The OPT Journal, which started publication in 2001, has remained focused on these aims. However OPT has spread its aims to cover wider matters; to reflect this the 'working name' of the organization has been changed to *Population Matters*. The OPT Journal retains its name, in part because it has now become a familiar name amongst its readers, and in part because it remains the best description of what the journal is about. The website of Population Matters is to be found at www.populationmatters.org

FOOD, ENERGY, AND SOCIETY (3rd edition), Part 7

by David Pimentel and Marcia H. Pimentel, compiled by Andrew Ferguson

Chapter 13. Environmental and Economic Costs of the Application of Pesticides Primarily in the United States

161.5 Although pesticides are generally profitable in agriculture, their use does not always decrease crop losses. For example, despite the more than 10-fold increase in insecticide (organochlorines, organophosphates, and carbamates) use in the United States from 1945 to 2000, total crop losses from insect damage have nearly doubled from 7% to 13%. This rise in crop losses to insects is, in part, caused by changes in agricultural practices. For instance, the replacement of corn-crop rotations with the continuous production of corn on more than half of the corn acreage has resulted in an increase in corn losses to insects from about 3.5% to 12% despite the more than 1000-fold increase in insecticide (organophosphate) use in corn production. Corn today is the largest user of insecticides of any crop in the United States.

ACUTE POISONINGS

162.0 Human pesticide poisonings and illnesses are clearly the highest price paid for all pesticide use. The total number of pesticide poisonings in the United States is estimated to be 300,000 per year. Worldwide, the application of 3 million metric tons of pesticides resulted in more than 26 million cases of nonfatal pesticide poisonings. Of all the pesticide poisonings, about 3 million cases are hospitalized and there are approximately 220,000 fatalities and about 750,000 chronic illnesses every year.

162.7 U.S. data indicate that 18% of all insecticides and 90% of all fungicides are carcinogenic. Several studies have shown that the risks of certain types of cancers are higher in some people, such as farm workers and pesticide applicators, who are often exposed to pesticides.

PESTICIDE RESISTANCE IN PESTS

168.3 In addition to destroying natural enemy populations, the extensive use of pesticides has often resulted in the development and evolution of pesticide resistance in insect pests, plant pathogens, and weeds. An early report by the United Nations Environmental Program suggested that pesticide resistance ranked as one of the top four environmental problems of the world. About 520 insects and mite species, a total of nearly 150 plant pathogen species, and about 273 weed species are now resistant to pesticides. …

Despite efforts to deal with the pesticide resistance problem, it continues to increase and spread to other species. A striking example of pesticide resistance occurred in northeastern Mexico and the lower Rio Grande of Texas. Over time extremely high pesticide resistance had developed in a tobacco budworm population on cotton. Finally approximately 285,000 ha of cotton had to be abandoned, because the insecticides were totally ineffective because of the extreme resistance in the budworm.

169.2 One of the major costs of resistance in tropical countries is associated with malaria control. By 1985, the incidence of malaria in India after early pesticide use declined to about 2 million cases from a peak of 70 million cases. However, because mosquitoes developed resistance to pesticides, as did malarial parasites to drugs, the incidence of malaria in India has now exploded to about 60 million cases per year. Problems are occurring not only in India, but also in the rest of Asia, Africa, and South America. The total number of malaria cases in the world is now 2.5 billion.

HONEYBEE AND WILD BEE POISONINGS AND REDUCED POLLINATION

169.6 Honeybees and wild bees are vital for the pollination of fruits, vegetable, and other crops. Bees are essential to the production of about one-third of U.S. and world crops. Their benefits to U.S. agriculture are estimated to be about $40 billion per year. Because most insecticides used in agriculture are toxic to bees, pesticides have a major impact on both honeybee and wild bee populations.

CROP AND CROP PRODUCT LOSSES

172.0 When residues of some herbicides persist in the soil, crops planted in rotation are sometimes injured. This has happened with a corn and soybean rotation. When atrazine or Sceptor herbicides were used in corn, the soybean crop planted after was seriously damaged by the herbicides that persist in the soil. This problem also had environmental problems associated. For example, if the herbicide treatment prevents another crop from being grown, soil erosion may be intensified.

GROUND- AND SURFACE WATER CONTAMINATION

172.7 Certain pesticides applied at recommended dosages to crops eventually end up in ground- and surface waters. The three most common pesticides found in ground water are aldicarb, alachlor, and atrazine. Estimates are that nearly one-half of the ground water and well water in the United States is or has the potential to be contaminated. … With 16 million wells in the United States, the cost of monitoring all the wells for pesticides would cost $17.7 billion per year.

Two major concerns about ground water contamination with pesticides are that about one-half the human population obtains its water from wells and once groundwater is contaminated, the pesticide residues remain for long periods of time. Not only are there extremely few microbes present in groundwater to degrade the pesticides, but the ground-water recharge rate is less than 1% per year.

FISHERY LOSSES

173.2 Pesticides are washed into aquatic ecosystems by water runoff and soil erosion. About 13 t/ha/year are washed or blown from pesticide-treated cropland into adjacent locations including rivers and lakes. Pesticides also can drift during application and contaminate aquatic systems. Some soluble pesticides are easily leached into streams and lakes.

Once in aquatic ecosystems, pesticides cause fishery losses in several ways. These include high pesticide concentrations in water that directly kill fish; low doses that may kill highly susceptible fish fry; or the elimination of essential fish foods, like insects and other invertebrates. In addition, because government safety restrictions ban the catching or sale of fish contaminated with pesticide residues, such fish are unmarketable and are an economic loss.

WILD BIRDS AND MAMMALS

174.2 Many bird kills caused by pesticides have been reported. For instance, 1200 Canada Geese were killed in one wheat field that was sprayed with a 2:1 mixture of parathion and methyl parathion at the rate of 0.8 kg/ha. Carbofuran applied to alfalfa killed more than 5000 ducks and geese in five incidents, while the same chemical applied to vegetable crops killed 1400 ducks in a single application. Carbofuran is estimated to kill one to two million birds each year. Another pesticide, diazinon, applied to three golf courses killed 700 Atlantic brant geese of the wintering population of just 2500 birds.

MICROBES AND INVERTEBRATES

175.9 Pesticides easily find their way into soils, where they may be toxic to arthropods, earthworms, fungi, bacteria, and protozoa. Small organisms are vital to ecosystems because they dominate both the structure and function of ecosystems. …

Earthworms and insects aid in bringing new soil to the surface at a rate of up to 200 tons/ha/year. This action improves soil formation and structure for plant growth and makes various nutrients more available for absorption by plants. The holes (up to 10,000 holes per square meter) in the soil made by earthworms and insects also facilitate the percolation of water into the soil.

ETHICAL AND MORAL ISSUES

177.0 Although pesticides provide about $40 billion per year in saved U.S. crops, the data of this analysis suggest that the environmental and social costs of pesticides to the nation total approximately $10 billion. From a strictly cost/benefit approach, it appears that pesticide use is beneficial. However, the nature of the environmental and public health costs of pesticides has other trade-offs involving environmental quality and public health.

177.6 In addition to the ethical status of ecological concerns are questions of economic distribution of costs. Although farmers spend about $10 billion per year for pesticides, little of the pollution costs that result are borne by them or the pesticide-producing chemical companies. Rather, most of the costs are borne off-site by public illnesses and environmental destruction.

CONCLUSION

178.5 Our assessment of the environmental and health problems associated with pesticides was made more difficult by the complexity of the issues and the scarcity of data. For example, what is an acceptable monetary value for a human life lost or a cancer illness due to pesticides? Equally difficult is placing a monetary value on killed wild birds and other wild life; on the death of invertebrates, or microbes lost, or on the price of contaminated food and groundwater.

GREAT WARNINGS AND THE GREAT WARMING

by Andrew R.B. Ferguson

Abstract

Brian Fagan's 2008 book *The Great Warming* is an addition to the fine collection of books that have given the human race 'great warnings' about the danger of continuous growth in human population. The environmental problems being created by human behaviour are one thing we need to warn ourselves about; another concerns the weakness of the human mind when it comes to facing up to uncomfortable realities. Here both problems are surveyed. There is one outstanding example of a group of people who were wise enough to adjust their lives to the reality of their situation, the Tikopians. Whether some other groups of people on Earth will manage the same feat remains an open question.

Walter Youngquist, petroleum geologist and author of *GeoDestinies*, kindly sent me a copy of Brian Fagan's 2008 book, *The Great Warming*. Brian Fagan is emeritus professor of anthropology at the University of California, Santa Barbara. He has a remarkable grasp of both the history of human lifestyles and civilizations, and also a detailed understanding of the various scientific advances — using cores from sediments, corals, and ice — made in recent decades, which have made it possible to reconstruct the temperatures and extent of rainfall in various far flung places over millennia. The relevance of Fagan's book to our concerns about overpopulation is summed up in this extract from his preface (p.xvii):

> We already know that some 20 million to 30 million tropical farmers perished as a result of droughts during the nineteenth century, when there were far fewer people on earth. Now we are entering a period of sustained warming with millions of people already at risk, living as they do on agriculturally marginal lands, or, in the case of Arizona and California, in huge cities looting water from aquifers and rivers.
>
> The Medieval Warm Period tells us much about how humans adapt to climate crisis, and offers forewarning of lengthy droughts when warming occurs. We are entering an era when extreme aridity will affect a large portion of the world's now much higher population, where the challenges of adapting to water shortages and crop failures are infinitely more complex.

A mainstay argument of those who wish to reassure themselves, and us, about possible detrimental effects associated with climate change is that such changes have already been experienced during the Medieval Warm Period, which, they assert, was on the whole benign. Fagan shows that while this warming did indeed bring benefits to much of northern Europe, extending out to Iceland and the northern parts of America, even in this area it was not a simple matter of enjoying warmer weather, for during that period there were considerable climatic variations within a generally warmer average. But far more importantly, he shows that this may have been a result of the El Niños/Southern Oscillation, and the benign situation in northern Europe was largely reversed in South America and the western part of North America, where people's lifestyles, and some civilizations, were disastrously effected by long periods of drought as this brief paragraph indicates (p141):

> The lake Chichancanab core not only mirrors that from Cariaco, though it can be dated somewhat less accurately (plus or minus twenty years), but also documents drought

> conditions lasting until A.D. 1075. The climate record is now unequivocal. Drought cycles during the early Medieval Warm Period settled over the Maya lowlands at about fifty year intervals, at the same time as profound aridity affected western North America.

Fagan does not attempt to settle with any degree of certainty whether the Medieval Warm Period was a temperature change of similar magnitude to that which has been occurring over the last century. However, a graph on page 17 comprising “a reconstruction of northern hemisphere temperatures, compiled from the work of six different research teams,” covering the period 1000 A.D. to 2007, shows that through this thousand year period, even the research team which estimated the greatest fluctuations in temperature found none that were more than about two-thirds of the prolonged rise of about 0.8ºC that the graph shows has occurred since 1900 (with barely a glitch in its upward path). Thus the title of the book, *The Great Warming*, appears justified. But whether the current changes exceed or only match the changes of the Medieval Warm Period, the message from this book remains the same, namely that droughts have been a scourge throughout human history, sometimes wiping out civilizations, and often forcing substantial relocation of populations as deserts expand. As Fagan says in the preface, these changes are much harder to accommodate with our present level of population (especially when one bears in mind the fact that now about half the world is malnourished). These warnings from Fagan are immensely important, but it seems to me that it would be of benefit to place them within a setting of the many warnings about overpopulation that have been given over the last two hundred years. I pick out a few as ‘Great Warnings’.

The famous *Essay on the Principle of Population* by Thomas R. Malthus in 1798, and its later editions, have proved to be accurate in the predictions about how world population would increase if its expansion were to be largely unconstrained. But Malthus did not foresee the huge changes that would come from releasing the energy in coal once efficient steam engines were developed (this started about 1810), nor the Haber-Bosch process of fixing nitrogen from the air. This and other developments made it possible to support many more people. One can usefully speculate as to how Malthus would have replied were someone to have put to him the proposition that food supply might be far less limited than currently appeared to be the case, for the limits on crop growth might be overcome by producing and using fertilizers on an industrial basis, and in particular using more nitrogen fertilizer which it might be possible to synthesize from nitrogen in the air. I surmise that Malthus would have replied that such things *might* come to pass, but we should not risk the lives of millions until we are sure that they would. Perhaps he would also have been wise enough to say that should it happen, we would need to monitor carefully the downsides of interfering with natural processes to that extent. In summary, the warning Malthus gave was true in principle, but “events” have postponed the time when the truth of his warnings about exponential population growth have become readily apparent.

Another important warning about the limits to growth came from the British economist Stanley Jevons, author of the well respected book *The Coal Question* (1865). Jevons was notable, too, for pointing out what is now known as the Jevons’ paradox, namely that increasing the efficiency with which a fuel can be used tends to i*ncrease* rather than decrease its consumption (because when a given amount of fuel can do more, people decide to use more of it). We can again surmise his response to a proposition relevant to his thesis, which might go like this: it is known that in some parts of the world oil seeps out of the ground, and in places natural gas escapes, so there might be other hydrocarbons which would replace coal when that runs out. It seems likely that Jevons would have replied in similar vein to the reply we surmised for Malthus, namely that this *might* come to pass, but we should not risk the lives of millions until we are sure of the extent of such resources and that their extraction can be carried out economically.

About the same time, John Stuart Mill was warning of the dangers of exponential growth in human population, which he saw would end in damage to the rest of the natural world. He saw that there is a need to decide at what point to call a halt to human population growth. Neither of the questions we have imagined being put to Malthus or Jevons would have seemed of much importance to Mill, for he would have seen that either of these developments would be likely to lead to even more damage to the rest of the natural world, and hence to the quality of life for humans. It is generally agreed by scientists studying the natural world that humans are now causing the sixth great extinction (Leakey and Lewin, 1996), so he would have been right.

Now let us move forward a century to more recent warnings which have had the benefit of another hundred and fifty years of scientific endeavour, giving us a far more detailed understanding of the Earth that is our home.

In 1979 David and Marcia Pimentel published the first edition of their book *Food, Energy, and Society*. This book covers both the concerns of Malthus and Jevons, showing clearly the extent to which increases in food production and the availability of energy have gone, and must go, hand in hand. Forecasting the extent to which it will be possible to produce sufficient energy from renewable sources was at the time of writing, and it remains so, a matter of dispute, but the authors, noting the many problems that already existed in irrigation, soil erosion, and inadequate diets, reached the conclusion that to support people in even a modest version of a civilized lifestyle, a sensible aim for world population would be 2 billion, and for North America 200 million. The book also showed that some of the touted solutions for producing energy from sustainable sources have enormous difficulties and downsides — in particular producing ethanol from corn, which has a pathetically low energy density, and sugarcane is not much better. Moreover growing either sugarcane or corn (maize) in the conventional manner is a serious cause of soil erosion.

The only book comparable to *Food, Energy, and Society* for its insight into the problems ahead was Clive Ponting's 1991 book *A Green History of the World*. Being a history, it was no part of the purpose of the book to predict the future, but aspects of it did this effectively. The book shows a history of humans polluting water supplies, causing land to become barren, either by long periods of irrigation or by causing soil erosion, and it shows how populations have always expanded until the point at which any natural change, such as drought, would cause a major famine. The accounts he gives of recurrent famines in China and Europe provide a salutary warning.

The scope of *A Green History of the World* is wide enough to give an indication of likely problems ahead for a society reliant on fuel supplies, both because of emissions upsetting the climate, and because of society coming to be reliant upon finite energy sources. However, exactly when the problems of finite fossil fuels, and hence energy shortage, would become the paramount problem has always been a highly technical one. A host of petroleum geologists, starting with M. King Hubbert, have tried to warn the world that oil supplies are likely to peak around the beginning of the twenty-first century. But the first popular exposition of their thinking, with a definite warning of the problems ahead, was given in 1997 by Colin Campbell in his *The Coming Oil Crisis*. The book gives pen portraits of the many outstanding petroleum geologists who have contributed to understanding oil depletion. I will not attempt to list them, but only add that

Walter Youngquist has been a part of that effort, with many papers on the subject, and his book *GeoDestinies* covers not only the depletion of fossil fuels but many vital resources.

One problem in looking ahead, regarding energy supplies, arises due to the difficulty of estimating coal resources. Energy optimists who find it hard to dispute that oil and gas supplies will peak within decades tend to say that is not of supreme importance, as coal resources are "huge." Estimating the amount of coal that can *realistically* be extracted is so difficult that, as David Rutledge has shown, even when done with enormous care such estimates can be wrong by an order of magnitude. In the Earnest C. Watson lecture at Caltech in 2007, Rutledge showed that the method used by M. King Hubbert to estimate the peak of oil can, at least in many cases, be applied to coal. In this lecture (and he followed it up with a paper in the *International Journal of Coal Geology* in 2010), he gave the world a warning that even if carbon capture could solve the emission problem of coal, it would be unwise to expect coal to greatly extend the overall peak of fossil fuel supplies. The only upside is that this limitation in the amount of fossil fuel that is likely to be extracted, might, *just might*, prevent the ultimate disaster of runaway temperature increase.

Whenever an appropriate opportunity presents itself, David Pimentel draws attention to the paramount dangers of soil erosion. Within *A Green History of the World* Clive Ponting devotes considerable space to the subject (Ponting,1991, p69, 74, 75, 76, 77):

> Recent evidence from central Jordan suggests that as early as 6000 BC, within about a thousand years of the emergence of settled communities, villages were being abandoned as soil erosion caused by deforestation resulted in a badly damaged landscape, declining crop yields and eventually inability to grow enough food. …
>
> The wholesale loss of trees in the highlands of China was one of the main causes of the often disastrous flooding of the Yellow river (so-called because of the amount of soil it carries from erosion upstream), which regularly resulted in major changes of course by the river in the lowlands and huge loss of life. The same sequence of events can be seen in Japan. …
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> The same problems can be identified in the great medieval Christian kingdom of Ethiopia. The original centre of the state was in the northern area — Tigre and Eritrea. Continual deforestation produced a badly degraded environment of poor soils and eroded hillsides, some in such a ruined state that they could no longer support shrubs or even grass. …
>
> This process of long-term environmental decline can be traced around the Mediterranean and the Near East in every area. …
>
> In Greece the first signs of large-scale destruction began to appear around 650 BC as population rose and settlements expanded. … by 590 in Athens the great reformer of the constitution, Solon, was arguing that cultivation on steep slopes should be banned because of the amount of soil being lost. …
>
> About 300 BC Italy and Sicily were still well forested but the increasing demand for land and timber resulted in rapid deforestation. The inevitable consequence was much higher levels of soil erosion, and as the earth was carried down in the rivers, the gradual silting up of ports and the estuaries.

With reference to more recent consequences, Ponting returns to the subject on page 258:

> In every part of the world modern agriculture has led to severe soil erosion in the wake of deforestation, ploughing up of grasslands and the cultivation of steep slopes. These actions have been exacerbated by the introduction of extensive monocropping and

> overgrazing. Depending on the geography of the affected area, soil erosion has led to dust storms, flooding, loss of fertility and even the abandonment of cultivation.

Within the framework of his *Green History,* Ponting is thorough on soil erosion, but the subject is so important that it deserves a book to itself. The one by David Montgomery, *Dirt: The Erosion of Civilizations* (also sent to me by Walter Youngquist), does a fine job. It was reviewed on pages 7-12 of the April 2010 OPT Journal. I will not here cover too much detail from this excellent book, but focus on one matter of vital importance which the author illuminates in detail, namely that *preserving a livably environment over a long period is not impossible*. He illustrates this with a study of the small island of Tikopia, which he compares with another, somewhat larger, Polynesian island Mangaia. He shows how the Mangaians destroyed their environment in much the same way as happened in Easter Island. In Tikopia, the story was very different (p223):

> Land use on Tikopia began much as that on Mangaia did. After people arrived about 900 BC, a shifting pattern of forest clearing, burning, and cultivation increased erosion rates and began to deplete the island's native fauna. After seven centuries on the island, the islanders intensified pig production, apparently to compensate for loss of birds, mollusks, and fish. Then instead of following the path taken by the Mangaians and Easter Islanders, Tikopians adopted a very different approach.
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> In their second millennium on the island, Tikopians began adapting their agricultural strategy. Plant remains found in the island's sediments record the introduction of tree crops. The decline in the abundance of microscopic charcoal records the end of agricultural burning. Over many generations, Tikopians turned their world into a giant garden with an overstory of coconut and breadfruit trees and an understory of yams and giant swamp taro. Around the end of the sixteenth century, the island's chiefs banished pigs from their world because they damaged the all-important gardens.
>
> In addition to their island wide system of multistory orchards and fields, social adaptations sustained the Tikopian economy. Most important, the islanders' religious ideology preached zero population growth. Under a council of chiefs who monitored the balance between the human population and natural resources, Tikopians practiced draconian population control based on celibacy, contraception, abortion, and infanticide as well as forced (and almost certainly suicidal) emigration. … Tikopian society prospered for thousands of years on a tiny isolated outpost.

Tikopia only ceased to prosper in the manner described when discovered by the rest of the world. It is hardly necessary to point out that with modern methods of contraception "draconian" methods are not necessary. But unfortunately, wherever education, wide availability of contraception, and small families have become the norm, and the Total Fertility Rate drops below replacement, some politicians worry about declining populations. They fail to see the manifest need for a declining population.

All these books present 'Great Warnings' of the dangers ahead. Brian Fagan's *The Great Warming* is one powerful reason to heed them, for it shows the fragility of all agricultural systems in the light of varied rainfall, and provides powerful evidence that long droughts are likely to be associated with the warming climate that has been occurring over the last century (and shows no signs of abating). It should be said that all the books I have picked out to comment on are 'milestones' that I have chosen. There are many other impressive books and booklets such as several by Lindsey Grant, particularly notable to my mind is his small book *The Collapsing Bubble; Growth and Fossil Energy*; several books and papers by Garrett Hardin, two by Kenneth Deffeyes on the peak of oil production; the excellent series of three booklets produced between 1993 and 1995 by Robert Engelman of *Population Action International* which covered the problems of water, air, and land; Howard Hayden's *The Solar Fraud*; John Houghton's *Global Warming: The Complete Briefing*; Leakey and Lewin's *The Sixth Extinction*; Walter Youngquist's *GeoDestinies*; and Patrick Moriarty and Damon Honnery's *The Rise and Fall of the Carbon Civilisation*, to mention just a few that come readily to mind.

The Tikopians have shown that it is possible for humans to grasp the realities of their lives and take appropriate action, but in most cases the human mind has failed miserably. Thus to work at the weakness of the human mind is as pertinent as studying the damage being done to the physical environment and the risks that are being taken.

Michel de Montaigne, in his essays written towards the end of the sixteenth century, was living at a time and in a place where there was perpetual persecution of Protestants by Roman Catholics and vice-versa, each group doing dire things to the other. To take sides was dangerous, but Montaigne did his best by pointing out that beliefs about both the gods and the natural world were often contradictory, and it must be wise to hold all such views as *tentative,* since there was no evidence to show which was correct.

The most comprehensive study of the weakness of the human mind in reflecting reality was published in 1841: *Extraordinary Popular Delusions and the Madness of Crowds* by Charles Mackay. He covers three financial bubbles, The Mississippi Scheme, the South Sea Bubble and Tulip Mania in Holland; also the alchemists who hoped to change lead into gold; belief in prophecies and fortune telling; the Crusades (instigated by Pope Urban II); witch hunting (instigated by Pope Innocent VIII); duels, ordeals, and the love of relics. These are just some of the many follies that are covered in his 700 page book.

Another milestone, and a rather charming one, which points out the tendency of the human mind to be guided by what it is comfortable to believe rather than the evidence, is the 1947 book by Rupert Crawshay-Williams *The Comforts of Unreason: A Study of the Motives behind Irrational Thought*.

In recent times, we have had an egregious example of such follies in the person of the chairman of the Federal Reserve Bank, Alan Greenspan, whose thinking encapsulated the widely held belief that the financial markets had discovered a wonderful new way of making money with negligible risk, and thus could ensure prosperity and a stable financial situation; also he was guilty of the nearly universal error of believing in perpetual growth. One of the many economists willing to suspend their critical minds was a sub-editor of *The Times*, Anatole Kaletsky, who wrote on 27 October 2005, "Sooner or later, however, even the flat-earth monetarists of Europe will wake up to the revolution in economic cosmology wrought by Alan Greenspan — and he will be remembered as Copernicus, Columbus and Galileo, rolled into one." The Prime Minister of Great Britain, Gordon Brown, was only a bit more restrained in his praise for what he believed was the great advances being made in the financial world.

Margaret Hefferman, in her book *Wilful Blindness* (2011), looks at Alan Greenspan's fall from grace in detail, surveys other follies, and describes the insights into the failings of the human mind gained by modern science, showing that there is an unabated human tendency to (a) follow the herd, (b) believe what it feels 'comfortable' to believe and to that end remain wilfully blind to contradictory evidence.

In conclusion, the damage that humans are inflicting on the planet is real, and the dangers that this damage will bring are imminent, but wilful blindness threatens to cancel out the benefit of all the Great Warnings we have received. We will be lucky if there are even a few places on Earth where humans show the foresight of the Tikopians.

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WORLD ON THE EDGE [1]

by Lester R. Brown — A Review Essay by Andrew R.B. Ferguson)

Abstract. The first half of Lester Brown's latest book is a brilliant resumé of the problems the world faces, but the second half, with its suggestions of how to prevent environmental and economic collapse — his so-called Plan B — is entirely unrealistic.

Paul Ehrlich's *Population Bomb* published in 1971[(1)] made a considerable impact at the time, drawing people's attention to the fact that overpopulation would soon lead to disaster. However, in the longer term the effect of the book was not entirely helpful. Because by overestimating how quickly mass starvation would start to become apparent, the book soon came to be cited as an example of yet another venture into doom saying.

Predicting the exact time when disaster will become apparent is something to be avoided. The book *Food, Energy, and Society* by David and Marcia Pimentel, the first edition of which was published in 1979, with the third edition in 2008,[(2)] avoided predictions about the time and extent of disaster, but provided irrefutable evidence of the relationship between food, energy, and the sort of society that can be supported by a combination of these two factors. Having considered (1) the damage to life support systems being done by the existing population, (2) the near certainty of fossil fuel becoming scarce in this century, and (3) that it was far from certain that renewable energy sources would provide adequate substitutes, it was suggested that a wise target for world population — to allow all people to enjoy a modest but civilized lifestyle — was in the order of 2000 million.

Over decades, Lester Brown has produced many fine books showing that humans are damaging their life support systems. The phase of deeper disasters that we are entering now is apparent to all. Brown's latest book, *World on the Edge*, provides a fine survey of those imminent and current dangers. The first four chapters are superb. I will mention their well-chosen titles, and then give some extracts from each.

Chapter 1 is titled *On the Edge*. The following paragraph from it refers to many of the subjects which are treated in more detail in the rest of the piece (p6):

> We are liquidating the earth's natural assets to fuel our consumption. Half of us live in countries where water tables are falling and wells are going dry. Soil erosion exceeds soil formation on one third of the world's cropland, draining the land of its fertility. The world's ever-growing herds of cattle, sheep, and goats are converting vast stretches of grassland to desert. Forests are shrinking by 13 million acres per year as we clear land for agriculture and cut trees for lumber and paper. Four fifths of oceanic fisheries are being fished to capacity or over-fished and headed for collapse. In system after system, demand is overshooting supply.

Chapter 2 is titled *Falling Water Tables and Shrinking Harvests*. The following is an example of the many facts that are gathered under this heading (p22):

> Saudi Arabia's growing food insecurity has even led it to buy or lease land in several other countries, including two of the world's hungriest, Ethiopia and Sudan. In effect, the Saudis are planning to produce food for themselves with the land and water resources of other countries.

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1. *World on the Edge: How to Prevent Environmental and Economic Collapse* by Lester R. Brown. 2011. New York, London: W.W. Norton & Company. US$15.95. 240 pp.

In neighbouring Yemen, replenishable aquifers are being pumped well beyond the rate of recharge, and the deeper fossil aquifers are also being rapidly depleted. As a result, water tables are falling throughout Yemen by 2 meters per year. Near the capital, Sana'a — home to 2 million people — tap water is available only once every 4 days; in Taiz, a smaller city to the south, it is once every 20 days. …

Half the world's people live in countries where water tables are falling as aquifers are being depleted. And since 70 percent of world water use is for irrigation, water shortages can quickly translate into food shortages.

Chapter 3 is titled *Eroding Soils and Expanding Deserts*. These excerpts give some indication of the ground covered therein (p36):

Today, roughly a third of the world's cropland is losing topsoil at an excessive rate, thereby reducing the land's inherent productivity. An analysis of several studies of soil erosion's effect of U.S. crop yields concluded that each inch of topsoil lost, wheat and corn yields declined by close to 6 percent. …

Wang Tao, one of the world's leading desert scholars, reports that from 1950 to 1975 an average of 60 square miles of land turned to desert each year. Between 1975 and 1987, this climbed to 810 square miles per year. From then until the century's end, it jumped to 1,390 square miles of land going to desert annually. …

While China is battling its expanding deserts, India, with scarcely 2 percent of the world's land area, is struggling to support 17 percent of the world's people and 18 percent of its cattle. According to a team of scientists at the Indian Space Research Organization, 24 percent of India's land area is slowly turning into desert. …

While Nigeria's human population was growing from 37 million in 1950 to 151 million in 2008, a fourfold expansion, its livestock population grew from 6 million to 104 million, a 17-fold jump. With the forage needs of Nigeria's 16 million cattle and 88 million sheep and goats exceeding the sustainable yields of grassland, the northern part of the country is slowly turning to desert. …

As countries lose their topsoil, they eventually lose their capacity to feed themselves. Among those facing this problem are Lesotho, Haiti, Mongolia, and North Korea.

Chapter 4 is titled *Rising Temperatures, Melting Ice, Food Security.* Once again Brown presents many relevant considerations (p49):

Recent studies indicate that a combination of melting ice sheets and glaciers, plus the thermal expansion of the ocean as it warms, could raise sea level by up to 6 feet during this century, up from a 6 inch rise during the last century.

Even a 3-foot rise in sea level would sharply reduce the rice harvest in Asia, home to over half the world's people. It would inundate half the rice land in Bangladesh,…

The number of people affected by the melting and eventual disappearance of glaciers will be huge. The prospect of shrinking dry-season river flows is unfolding against a startling demographic backdrop: by 2030 India is projected to add 270 million people to its population of 1.2 billion and China is due to add 108 million to its 1.3 billion. While farmers in China and India are already losing irrigation water as overpumping depletes aquifers, they are also facing a reduction of river water for irrigation. …

Bolivia is also fast losing the glaciers whose ice supplies its farmers and cities with water. Between 1975 and 2006, the area of its glaciers shrank by nearly half. Bolivia's famed Chacaltaya glacier, once the site of the world's highest ski resort, disappeared in 2009.

The next section of the book expands on the likely consequences of these changes, such as environmental refugees and a growing number of failing states. Like the first section, it is entirely sound. It is only in section 3 (which starts at page 99) — where Brown attempts to lay out his so-called Plan B for dealing with the problems — that the book enters the realm of fantasy. On page 16 Brown gives an overview of Plan B writing that it

> has four components: a massive cut in global carbon emissions of 80 percent by 2020. A stabilization of world population at no more than 8 billion by 2040; the eradication of poverty; and the restoration of forests, soils, aquifers, and fisheries.

The impracticability of achieving such goals (and their insufficiency) is probably readily apparent to most readers of this journal. Mainly without arguing the case (most of which has been argued in other issues of the OPT Journal), I will list the many fallacious assumptions underlying Brown's Plan B:

1. It is highly unlikely that carbon emissions will reduce significantly until fossil fuels become scarce as the following figures illustrate. In 1990, scientists said that carbon emissions needed to be *reduced* by 60-80%. Politicians indicated their determination to take appropriate action. However, by 2010 emissions had *increased* by 40%.
2. On present evidence of the limitations, renewable energy is only likely to replace a small proportion of the energy being used today. Brown has almost unlimited belief in the efficacy of wind power, with almost no understanding of its limitations.
3. As vital oil and gas supplies become scarce, the price will rise, with rich countries paying whatever it takes to provide them with what they regard as their minimum requirements, while poor countries go without, greatly diminishing their agricultural potential.
4. As fossil fuels become scarce, globalization is bound to break down (not appreciated by Brown).
5. Many countries (or failed states) are barely aware of the significance of the size of their populations. Other countries become alarmed if they see their populations decreasing. So it is unrealistic to talk about saving the whole world. It is only countries that have come to see the overarching importance of establishing a sustainable population size that have a chance of saving themselves from disastrous consequence.
6. Even with a degree of wisdom rarely shown by humans, when relying on renewable energy the much reduced energy resources available will be unable to support anything like a population of 8 billion. It is therefore misleading to talk about merely stabilizing population — that is in any but a few countries such as Sweden and Finland.

In summary, the early chapters of Brown's book are excellent, but the part associated with the subtitle of the book, *How to Prevent Environmental and Economic Collapse*, is a misleading excursion into fantasy. Only a few farsighted people, of whom Paul Ehrlich and David and Marcia Pimentel are good examples, have seen the need for a much reduced population, for the time when humans can no longer make use of the immense amount of energy stored in fossil fuels — and even before that on account of the damage already being done to our life support systems. Lester Brown is not to be counted among them.

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"ZERO CARBON BRITAIN 2030" from the Centre for Alternative Technology

Chapter 7, *Land use and agriculture*, reviewed by Nigel G. Gilligan,
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Abstract
ZCB2030[*1] sets out proposals for a major change in agricultural land use in the UK. The aim is to increase food security and reduce our dependence on imported fossil fuels. Most of our grassland would be ploughed up for energy crops, principally "elephant grass". CAT claims that this would be good for overall UK biodiversity, but an examination of the change from grassland leads to a contrary conclusion — it is likely to be catastrophic.

1. ZCB2030 — an outline

ZCB2030 points to the UK's growing balance of payments deficit driven by an increasing need to import fossil fuels. There are many obstacles to a solution. The UK is far from being "food secure" — we are only 61% self-sufficient in all foodstuffs.[*2] As meat production is very inefficient in land use, ZCB2030 envisages a huge reduction in meat consumption. Even with that accomplished (not at all easy), the claims in ZCB2030 look untenable. The plan is to provide sufficient food for the UK in addition to producing sufficient non-fossil fuel oil and gas to make Britain carbon-neutral by 2030.

CAT heralds the plan as "the beginning of a new experiment", and also claims that: *"In many parts of Britain, the appearance of the landscape would change, but there would be a great deal more useful habitats for wildlife, so the whole biodiversity would benefit".*

Something which CAT fails to recognize is that grassland is rich in biodiversity. We depend on "services" from other species in order to feed ourselves, have clean water, breathe clean air, etc. Given CAT's bold and positive assertion on biodiversity, I wish to concentrate on this aspect of the plan alone.

2. The scale of land use changes

Grassland is not a monoculture, but contains a variety of grass species plus other herbs (such as flowers) suiting the soil type and management regime. Temporary or intensive grassland is created by ploughing and seeding regularly. It is the richest in grass output, but the poorest in terms of grass species, and is generally used for dairy cattle. "Permanent grassland" ranges in quality from "improved" to "semi-improved", to "unimproved" — which is the least disturbed and richest in grass and herbs. (LIG is short for "lowland improved grassland"; LUG for "lowland unimproved grassland."). ZCB2030 proposes (Table 7.5a, page 225) that most grassland (but not temporary or intensive grassland) be available for growing energy crops. Nearly all current LIG would have a variety of new energy crops growing on it, the principle one being miscanthus, an indigenous grass in parts of Asia. Most of LUG is allocated for land use other than grassland.

3. General biodiversity loss in Britain

The UK National Ecosystem Assessment[*3] shows that over 30% of the services provided by our natural environment are in decline. The Lawton Report.[*5] *Making Space for Nature*, found that nature in England is highly fragmented and unable to respond effectively to new pressures such as climate and demographic change.

There are government targets to prevent further loss of our UK wildlife biodiversity. The latest White Paper on the subject, "The Natural Choice: securing the value of nature," [*6] outlines the policy: "*We will move from net biodiversity loss to net gain, by supporting healthy, well-functioning ecosystems and coherent ecological networks.*"

Other quotes are illuminating: *"Some 84% of European crops and 80% of wildflowers rely on insect pollination. Over the last 20 years, the area of crops dependent on insect pollination has increased by 38%. During the same period, there has been a 54% decline in honey bee colony numbers in England. More than 50% of our landscapes now have fewer species of bees and hoverflies than in 1980. … Creating a patchwork of flower-rich meadow … would assist bumblebees and other pollinating insects. It could reverse the alarming decline in pollinating insects such as bumblebees across England."*

We have lost 97% of our wildflower grassland in the post-war period. Fewer flowers means less pollinating insects, leading to even fewer flowers. The effects are widespread, profound, and continuing.

4. Miscanthus growers information

DEFRA and Natural England[*4] have issued growers advice for miscanthus. This is a summary:

- weeds (otherwise known as flora) are totally eliminated by use of broad-spectrum herbicides
- wholesale ploughing up of grasslands is a necessary part of the plan
- small-scale biodiversity assessments of a short-term nature have been carried out by comparing with replacement of cereal crops, not grassland.

It is evident that the last mentioned study of cereal crops is inadequate on three counts, being small-scale, short-term, and making comparison only with cereal crops.

5. The official view of biodiversity impacts from miscanthus crops

There are numerous positive comments within ZCB2030 about land use changes of this magnitude. On page 217, it is stated: *"Plantations of energy crops are fairly recent arrivals in the British landscape, and little research has been done on their biodiversity effects. The evidence that does exist suggests a strongly positive effect relative to the replaced grassland, largely as a result of increased micro-habitat diversity, available biomass for food, complex edge effects, lower inputs of agrochemicals, and reduced physical disturbance (Haughton et al., 2009)."*

Applying this conclusion to miscanthus does not seem credible, and is certainly counter-intuitive. Nor is this reference accessible via the Internet.

The Game and Wildlife Conservation Trust study (page 217) also refers to some positive findings, but the report is very unclear as to what parameters are actually being studied — what is the starting point, and what species are being looked at! It has no credibility as a research report.

The Semere & Slater study is more thorough, but it has no relevance to long-term and efficient miscanthus production. The salient quote is that: *"Miscanthus fields were richer in weed vegetation and had greater bare ground patches than reed canary-grass. Percentage weed cover in the Miscanthus fields ranged from 48% to 68%, compared to 5% in reed canary-grass fields*." Using this report as a basis for conclusions about biodiversity benefits displays a serious lack of judgment by CAT.

On page 200, ZCB2030 claims the strategy is to minimise any soil disturbance that might release carbon. On the same page the ZCB2030 plan states, "Tillage of previously untilled land has no net effect." And on page 201, ZCB2030 claims that converting grassland to perennial crops need not cause a loss of carbon, referencing St Clair et al, but no further explanation of the claim is offered, and the reference cannot be readily checked on the Internet. On page 214 indication is given of the need to till: "*Clearly this option would involve disturbance of previously untilled land. There might be an initial penalty in terms of*

CO_2 emissions during site preparation and establishment of the new perennial crop, but such evidence as there is suggests that in this special case, the opposite is true (Richter et al., 2007)." In this case the reference document can be accessed on the Internet, but it makes no mention of any matter relating to CO_2 emissions.

A farming community wildlife forum has a quote from a biodiversity researcher who says that "you might as well pour bleach on the field" as convert it to miscanthus. I believe that the ZCB2030 assessment of biodiversity impacts amounts to sophistry.

Because of a lack of any credible research reports on the likely impacts of replacing nearly all of our grasslands with miscanthus or other energy crops, what follows is my own analysis, using a method known as common sense.

6. The likely impacts on grasslands converted to miscanthus production

It may be helpful to take a simple overview of a grassland ecosystem. In reality it is very complex, but imagine a great mass of dependent links, like a spider's web, between species which depend on grass, or a grassy environment, or use the sward for protection, or to predate on any of the other species. If there is no grass, there are no herbs, the vital pollinating insects that depend on them disappear, so do the slugs and snails, the frogs, the seed and insect eating birds, the raptors, the voles, the rabbits, the foxes. At the smaller invertebrate level the list goes on and on. That grassland ecosystem is destroyed if you remove the grass. The complexity of the ecosystem depends on the intensity of management, with LIG being the least biodiverse, whilst LUG is arguably the richest habitat for wildlife in the UK. And as has already been explained, there is a spectrum of quality between the worst of LIG, and the best of LUG.

The miscanthus crop does not provide *any food for any invertebrates except two, and no mammals, and no birds.* There are many more negative aspects not listed above.

7. Conclusion

ZCB2030 is proposing a one-off harvesting of our grasslands, and has cherry-picked the biodiversity benefits. It would be like a scorched-earth policy, with no retreat and no opportunity for a U-turn (as the rich grassland cannot be easily recovered). The web of grassland life would be the collateral damage. (Biodiversity-rich grassland obviously cannot be restored if any potential re-colonisation source has also gone.) Because of the scale of change, even the mobile species would have nowhere else to go. In short, CAT proposes carrying out an extremely dangerous experiment, with the near certainty of profound damage and irretrievable consequences.

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"ZERO CARBON BRITAIN 2030" from the Centre for Alternative Technology

Chapter 8, *Renewables*, reviewed by Andrew Ferguson

Abstract. The plan set out by the Centre for Alternative Technology (CAT) aiming at a goal of Britain achieving no *net* emissions of carbon dioxide by 2030 is, unfortunately, not based on reality. This is mainly due to it relying on a mistaken belief that an electrical system can accommodate an almost unlimited amount of uncontrollable input, and partly due to using land that is needed for growing food and fibres for growing biomass. Allowing only a plausible amount of uncontrollable input suggests that to be sustainable the population of Britain needs to reduce to about 20 million.

I have always admired the Centre for Alternative Technology (CAT) for its efforts to find out more about how humans could live in ways that are less ecologically damaging, and for its magazine *Clean Slate* which provides information about those activities. However, I was much troubled when CAT engaged itself in a project to which it gave the title *ZeroCarbonBritain2030* (ZCB2030), which boldly proclaimed the possibility of ensuring that Britain could so change its energy technology that it could achieve no *net* emissions of carbon dioxide by 2030. This seemed to me a fatuous hope, and I felt no more inclined to study it than I would a treatise on a perpetual motion machine ! But when I conveyed my thoughts to CAT, they sent me a copy of the 368 page book describing the scheme, "*Zero Carbon Britain 2030* (the second report)." I decided that I should at least take the time to study the chapter on renewables to see where the authors — none specified but fifteen participants listed — thought that the required renewable energy could be obtained for satisfying Britain's approximate current 60 million inhabitants.

It did not take long to find out that the major failing of the analysis was the same as that which weakens many similar plans for a future based on renewable energy, including David MacKay's otherwise excellent book, *Sustainable Energy — without the hot air* (2008), and to a lesser extent Patrick Moriarty and Damon Honnery's *Rise and Fall of the Carbon Civilisation* (2010). These two books were reviewed in the April 2011 issue of the OPT Journal (http://tinyurl.com/optj2). The common fault of such plans is a failure to recognize that uncontrollables can only contribute 30%, at most, to the total amount of electricity supplied via the grid. I have given the reasons for this in many previous issues of the OPT Journal, but they are germane to this review and I will briefly reiterate them.

Any system delivering electricity to a grid in an uncontrollable manner, with output peaks interspersed with troughs of lower value (as do all uncontrollables), can only be fitted into an electrical power generation system provided the peak supply from the uncontrollable does not exceed the system demand. It is sometimes suggested that wasting some of the electricity delivered at the peaks of output would not matter much. This is a difficult matter to get a clear handle on, but whether it would be practical is certainly dubious. The subject was dealt with in fair detail in the article *The Problem with Uncontrollables* (OPTJ 10/1, pp21-24), but mainly with reference to the United Kingdom. I look at it again in a more general way at Appendix A, but suffice it to say that the matter is sufficiently dubious as to require empirical demonstration of feasibility.

Lowest demand for electricity in the UK is around 66% of the average demand. So uncontrollables can only fit into the system provided that the peak of their output does not exceed 66% of the average electricity demand. If we suppose that the annual capacity factor (also known as load factor) of wind turbines in Britain improves to 35% (compared to the 2005 value of 28%), then the wind turbines could contribute 0.35 x 0.66 = 23% of the electricity delivered by the system; but the remaining 77% would need to be delivered by controllable systems.

Renewable energy enthusiasts put much store by the possibility of flattening demand, even to the extent that there is no 'lowest demand' — i.e. demand always stays near the average. That is a fairly incredible goal, but to probe the ultimate limits of that assumption let us imagine that it is achieved. With a 35% load factor wind turbines could satisfy 35% of *average* electrical demand, i.e. supply 35% of the total electricity.

Not only is a complete flattening of demand unlikely, but there are other factors which reduce the size of the uncontrollable that can be fitted into the system. First, if Combined Heat and Power (CHP) plays a part in the system, when there is a strong demand for heat there are usually practical limits as to how much the electrical output of the system can be turned down and the heat output turned up. Secondly, if there is nuclear power in the system, there is no likelihood that the nuclear plant can be almost turned off to accommodate peaks of output from the uncontrollables. Both these factors further limit the size of the uncontrollable that can be fitted in. Thus while we may satisfy more than 23% of electrical demand, we are unlikely to get anywhere near to 35%. To assume that uncontrollables can satisfy 30% of the total demand for electricity would be optimistic.

In case this logic and arithmetic is less than convincing, I will mention that Lenzen (2009, p19) stated that, "the main barrier to widespread wind power deployment is wind variability, which poses limits to grid integration at penetration rates above 20%." And in an impressive analysis, Jim Oswald (2007) showed that the United Kingdom would have difficulty in handling more that 25 GW of wind capacity even if the wind turbines were placed all over Britain to try to limit the peaks. At a 35% load factor, that would contribute about (25 x 0.35) / 44 [GW average demand] = 20% of electrical demand.

After that lengthy introduction, we can now set about analysing a fairly realistic contribution from renewables were we to attempt to follow the ZCB2030 proposals — that is after making them fairly realistic by using only a realistic amount of uncontrollables. What would be fairly realistic? As just explained, an upper limit for uncontrollables is for them to provide 30% of the whole of the electricity supply. Put another way, uncontrollables can supplement controllables to the extent of increasing the total to 1 / 0.70 = 143%; that is they can add 43% to the output of the controllables.

Table 1 extracts data taken from Figure 8.9 on electricity generation, page 261 of ZCB2030, but adjusted to show only a realistic contribution from uncontrollables. Note that all the figures shown in bold in Table 1 are taken directly from Fig. 8.9. Now let us look in more detail at some of the lines in the table.

The first three lines under the section headed "Electrical output from controllables" refer to sources that are somewhat limited in the extent to which their output can be controlled: (1) Hydro is often limited in summer because the water in the reservoir needs to be retained for other purposes than providing electricity when wanted; (2) CHP is limited to the extent that if heat is required there is not likely to be the flexibility in the system to ensure that the CHP system delivers only heat and no electricity; (3) "Fixed tidal" is also somewhat limited; for instance, if one releases water when there is only a small head of water, then little electricity is generated. Only biogas and biochar are fully controllable. Thus the subtotal shown for the controllables contribution is supremely optimistic.

It should also be noted that to provide the amount of electricity shown from CHP, about 2.3 million hectares of good quality land would be needed to grow biomass crops (based on 9 t/ha/yr of crops with a calorific value 18 GJ/t, with 30% efficiency of transformation to electricity, giving a power density of 1.54 kW(e)/ha). In this chapter of ZCB2030, I see no mention of the fact that the UK only supplies about 70% of the food it consumes and 15% of the wood it uses; thus far from having any land to spare, the UK is already lacking land to provide for its ecological demands. However, we will skip that omission for the present analysis. One explanation for the omission that would be offered by the authors is that by reducing our meat intake we would need less land for food, but it remains to be demonstrated that the land freed up would be sufficient to provide food, fibres and the proposed amount of biomass.

Next in Table 1 under the heading "Electrical output from uncontrollables," the first line is the vital one — and the one which illustrates a huge difference from ZCB2030. It gives the figure for the above mentioned maximum 43% addition to the controllables as about 1.98 kilowatt hours per person per day (kWh/p/d), rather than the surmised contribution of 'renewable uncontrollables' (wind, wave, tidal stream and solar PV) suggested by the ZCB2030 plan, which amounts to 33.5 kWh/p/d (that is as much as 87% of the 38.5 kWh/p/d total electricity planned by ZCB2030 — far above the 30% limit).

Table 1 shows nuclear as an uncontrollable. This is not strictly true, as nuclear power stations can accept some variation in their output albeit at an economic penalty. However, as mentioned, we have been optimistic about the controllability of hydro, CHP, and fixed tidal, so being somewhat pessimistic about nuclear merely balances things out a bit.

When low grade heat is required for heating, it is better to use the electricity to drive heat pumps rather than use its electrical energy directly. Heat pumps vary in their Coefficient of Efficiency (COP). MacKay (2008, p154) suggests COP 4 is realistic. A recent study by the Energy Savings Trust found that in practice the average was 2.2. However, for current purposes I use COP 4, meaning that the heat provided will be four times the energy in the electricity itself. Following the plans in ZCB2030 closely (producing 6.93 kWh/p/d from the heat pumps, as shown, instead of 6.76 kWh/p/d), it is assumed that 25% of the electricity is used to provide heat via heat pumps. Note that the electricity used to produce heat must not be counted twice, so appropriate adjustments are made in Table 1.

After this subtraction, the amount of electricity available for other purposes is 5.2 kWh/p/d, while the total heat output from CHP, heat pumps, and solar hot water is 10.4 kWh/p/d. Adding the two we get a total of 15.6 kWh/p/d.

We have always argued (based chiefly on Vaclav Smil's careful analysis) that it would be possible to maintain a civilized life on 48 kWh/p/d, even though that is far below the current total consumption of energy in the UK, which in terms of primary energy is 125 kWh/p/d. But much is lost in extraction of energy and in transformation to electricity, and the total energy supplied to consumers is 88 kWh/p/d. In order to get up to this minimum 48 kWh/p/d, using the energy shown in Table 1, it would be necessary to reduce the population from its current 60 million to 22 million (Table 1, 3rd line from the end). With such a reduced population there is a fair chance that we could feed ourselves, provide ourselves with fibres such as timber, and have sufficient land to spare to grow the biomass ZCB2030 plans for.

The last line of Table 1 shows that realistically only 18% of the electricity that CAT plans for is likely to be produced by the system. That concludes the main analysis of this Chapter 8, but let us deal with some queries that may have arisen in the reader's mind.

Even though the CAT plans indicate that transport is to be run on electricity, there will be a need for some liquid fuel, for instance when using tractors and harvesters. When dipping into another chapter I noted that ZCB2030 recognizes the need for some liquid fuels, but unless yet more biomass is to be grown on land that is *not* to spare, that would mean using some of the electricity to produce liquid fuels, and in the process of doing that more energy is lost, so the availability of even the above 15.6 kWh/p/d as a final supply is optimistic.

Table 1. ZeroCarbonBritain2030 (ZCB2030): a realistic interpretation of their data on electricity supply (p261)

Constants and variables

Terawatt hours per year per UK into kilowatt hours per person per day =	0.0456621	(line 1)
Addition to controllables from uncontrollables assuming 30% load factor =	0.428571	(line 2)
Assumed coefficient of performance (COP) of heat pumps	4.00	(line 3)
Assumed proportion of total electricity generated that is used for heat pumps	0.25	(line 4)
Assumed efficiency of CHP in producing electricity	30%	(line 5)
Assumed efficiency of CHP in producing heat	50%	(line 6)
Realistic minimum energy requirement of civilized life is assumed to be	48	kWh/p/d (presently 125 kWh/p/d)

N.B. Numbers in bold indicate that they have been taken directly from Fig. 8.9, p 261, of ZCB2030.

	TWh/y/UK	kWh/p/d	Load factor	Notes
Electrical output from controllables				
Hydro	**7.23**	0.33	24% and 16%	24% for large scale 16% for small scale[a]
Fixed tidal	**36.00**	1.64	34%	ZCB2030, p251, gives a capacity of 12 GW
Biomass CHP	**31.40**	1.43		This would require about 2.3 Mha of land [b]
Biogas	**24.14**	1.10		This is 4.6 times the present amount.
Biochar	**2.19**	0.10		Uses 18 million tonnes of waste (p250).
Subtotal	100.96	4.61		
Electrical output from uncontrollables				
Max addition to controllables (43%)	43.27	1.98		See line 2: "Addition to controllables..."
Nuclear	**7.50**	0.34	81%	Load factor av. for world (MacKay 2008, p173)
Subtotal	50.77	2.32		
Grand total electrical output	151.73	6.93		
Electrical output used for heat pump	37.93			The proportion of electricity is set in line 3.
So remaining electrical output	113.80	5.20		
Heat output from CHP	52.33	2.39		Heat efficiency of CHP set in line 6.
Output from heat pumps (thermal)	151.73	6.93		Agrees closely with ZCB2030, p264.
Solar hot water	**24.00**	1.10		ZCB2030 Fig. 8.12, p264.
Subtotal of heat output	228.06	10.41		
Total electrical and heat output	341.86	15.61		Note: minus electricity for heat pumps.
UK population to provide minimum 48 kWh/d/p		20	million people	(as compared to the present 60 million)
CAT target for electricity output	842.00	38.45		

Realistic fraction of the CAT target for electricity likely to be achieved using grand total, 151.73 TWh/y, is 18%

Notes to Table 1

a. Referencing MacLeay (2007), MacKay (2008, p56) writes that, in 2006, large-scale hydro produced 3515 GWh (0.14 kWh/p/d) from plant with 137 GW capacity, thus giving a capacity factor of 24%, and that small-scale hydro produced 212 GWh (0.01 kWh/p/d) from a capacity of 153 MW, giving a capacity factor of 16%.

b. The calculation was done using a biomass yield of 9 t/ha/y, of calorific value 18 GJ/t, giving power density of 5.1 kW/ha, and assuming that the electricity is produced with an efficiency of 30%.

It might be thought that although wind could only add 43% to the controllables, PV, for instance, could add to that 43%. This is true, but the extent is very small. The reason it could contribute some more is that the peak output of PV comes at midday, and although electricity demand is low at summer weekends, it is unlikely to be as low as in the middle of the night. Let us say, for example, that at such times demand drops to only 86% of average demand. Then while wind can be fitted in to the extent that its peaks reach 66% of electricity demand, PV can be deployed to fill the gap between 66% and 86%. However, the contribution would be tiny, because in the UK the capacity factor of PV is about 10%. Thus if a PV system is added, so that its peaks fill in the newly available 20% of electricity demand, its actual contribution to the electricity supply is one tenth of that, namely 2%. The mistake is often made by renewable energy enthusiasts of assuming that with lots of different sources for uncontrollables, there will be great benefits because the supply will flatten itself out; they conveniently ignore the possibility that the different sources might equally well experience their peaks at around the same time.

The fundamental difference between this analysis and the ZCB2030 proposal is about the role of uncontrollables. My analysis, those cited by Lenzen in his review of the literature, and the study made by Oswald, are all *theoretical* analyses (although Oswald makes use of comprehensive data about wind speeds over the whole of Britain). It would be reassuring to back up those theoretical analyses with empirical examples. The conditions needed to provide good examples are twofold: (1) A specified area that is able to produce *more* electricity from wind turbines than it can practically make use of within its electrical grid; (2) the internal transmission lines are sufficiently good to be able to distribute the wind turbine electricity all over the specified area. With respect to item (1) Denmark is ideal, as the amount of wind turbine electricity produced over the year sometimes reaches about 25% of its consumption. However it fails on item (2), since its internal transmission system, taking electricity generated on the windy west coast to the densely populated east coast, is said to be inadequate. It is this lack of transmission capacity which, at least partly, accounts for the fact that the amount of wind turbine electricity that is used directly in Denmark is only about 9% of its electricity consumption. The rest has to be exported to other nations, which it is fairly easy to do as there are good connectors to the Scandinavian countries to the north, whose electricity supply comes largely from hydro (which can be turned off to allow wind to replace the supply). But other countries do not enjoy such advantages, and this 9% is at least suggestive of difficulties setting in quite early.

Further evidence comes from China. A report by the Worldwatch Institute, dated 28 February 2011, about wind turbines in China said, “Chinese industrial experts have warned that wind power should not exceed 10 percent of local grid capacity to avoid the risk of a grid collapse.” This again suggests that difficulties can arise at a lower wind penetration than the 20% cited by Lenzen. But not too much can be read into China’s experience as there may be special reasons for difficulties, such as poor flexibility of their controllable systems. At present the empirical evidence about the limits of wind penetration is weak, but the theoretical case is strong.

Conclusion. As with nearly all proposals by renewable energy enthusiasts, the major fault in the CAT project is to fail to take account of the limited possible contribution of uncontrollables to an electrical system. An additional fault is to ignore the fact that Britain only manages to grow about 70% of the basic foods it consumes, and 15% of the fibres consumed in the form of wood and wood products. So there is no ecologically productive land available to grow significant amounts of biomass.

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Appendix A. Over sizing uncontrollables — an overview

Looking in a more general way at the numbers given in *The Problem with Uncontrollables* (OPTJ 10/1, pp21-24), the following possibilities and problems of overloading a system with uncontrollables become apparent.

To make an analysis with *varying* electrical demand is very difficult, but renewable energy enthusiasts often argue that demand can be flattened by such things as recharging batteries during off-peak hours, and being able to control demand by temporarily turning off non-essential electrical machinery. It seems improbable that completely flat demand could be achieved, but in order to simplify the analysis we will assume it can.

We will take as a first option the installation of wind turbines such that their installed generating capacity exceeds electrical demand by 25%. With turbines that achieve a capacity factor of 30%, this would mean that about (0.30 x 1.25) = 37.5% of electrical demand would be satisfied by those wind turbines. If we assume that, as in Germany, output from wind turbines as an entire group reaches no more than 80% of installed capacity, then no electricity would be lost (as 0.80 x 125% = 100%).

As a second option, let us consider a turbine group with an installed capacity that exceeds demand by 150%. The losses then become significant. Such is the curve of output against actual wind that the wind turbines would now satisfy 66% of the electricity demand (a 76% increase over 37.5%), this has been achieved by doubling the installed wind capacity.

There are further introduced costs which are likely to prove more significant. First, with the wind turbines now satisfying 66% of demand, the controllable power plant — that has to be available to take over from the wind turbines during a lull — will have to reduce its capacity factor to 100 - 66 = 34%. It will be expensive to have controllable plant and operators sufficient to produce 100% of demand but actually satisfying only the unsatisfied 34% of electrical demand. The consequence is that although this controllable electricity may not be as expensive as peak electricity is today, it will certainly be expensive.

Perhaps a more terminal problem is that with wind satisfying 66% of electrical demand, whenever there is a rapid decrease in wind, a large amount of plant will have to be brought on line over a short period of time. This means that the plant that satisfies the remaining 34% of demand will have to be largely rapid-response plant, which means that it will be significantly less efficient than it might be. The very high efficiency of some gas turbines is achieved mainly by using combined cycle turbines, and these are not amenable to being brought rapidly on line. Indeed it may be impossible to achieve the required flexibility using biomass powered plant: in February 2011 it was reported by the Worldwatch Institute that "Chinese industrial experts have warned that wind power should not exceed 10 percent of local grid capacity to avoid the risk of a grid collapse." The Chinese controllable plant would be fuelled by coal, and biomass would behave similarly.

There is also a problem with the storage of biomass to deal with say a ten day period when there is little wind. Natural gas or even coal stocks would not be much of a problem, but to store the amount of biomass needed to deal with lulls may prove to be an insuperable problem. Biomass needs to be kept fairly dry if it is to burn efficiently.

The above is not a rigorous analysis, and indeed it is probably impossible to achieve that as a theoretical exercise. *The important point is that those who are trying to cajole us into a sense of security about future energy supplies need to do so on the basis of what is probable, not what just might be; because the quality of life — and in many cases the lives — of billions of people will depend on having sufficient energy once fossil fuels become scarce.* If it is *uncertain* that we will have sufficient energy, then there is one action which will definitely alleviate the scale of disaster should it occur, that is to have a smaller population. But that is a solution which always seems to take a back seat !

THE OVERARCHING ISSUE OF THE CENTURY

Acknowledging and Confronting the Inevitable: A Significant Reduction in Global Human Numbers and other Inconvenient Truths

by J. Kenneth Smail, (Ph.D Yale, 1976), Professor of Anthropology (Emeritus) of Kenyon College Gambier, Ohio 43022, (excerpts by Andrew Ferguson, with approval of the author, from a May 5, 2008 online article published on the *Culture Change* website maintained by Jan Lundberg)

It has become increasingly apparent over the past half-century that there is a growing tension between two seemingly irreconcilable trends. On one hand, moderate to conservative demographic projections indicate that global human numbers will almost certainly reach 8 to 9 billion by mid-21st century, only two generations from the present. On the other, prudent and increasingly reliable scientific estimates suggest that the Earth's long-term sustainable human carrying capacity, at what might be defined as an "adequate" to "moderately comfortable" developed-world standard of living, may not be much greater than 2 to 3 billion. It may in fact be considerably less, perhaps in the 1 to 2 billion range, particularly if the normative life-style (level of consumption) aspired to is anywhere close to that currently characterizing the United States.

As a consequence of this modern-day "Malthusian dilemma," it seems reasonable to suggest that it is now time — indeed, past time — to think boldly about the midrange future, and to consider alternatives that go beyond merely slowing the growth, or even the stabilization, of global human numbers. In this brief essay, I shall argue that it has now become necessary for the human species to develop and implement, as quickly as possible, a well conceived, clearly articulated, flexibly designed, broadly equitable, and internationally coordinated program focused on bringing about a very significant reduction in global human numbers over the next two or more centuries. In simple quantitative terms, this effort will likely require a global population "shrinkage" of at least two-thirds to three-fourths, from a probable mid-to-late 21st century "peak" in the 9 to 10 billion range to a future (23rd century and beyond) "population optimum" of not more than 2 to 3 billion, or perhaps even fewer.

Obviously, a demographic change of this magnitude, whether brought about by conscious human design or ultimately by forces beyond human control, will require a major reorientation of human thought, values, expectations, and lifestyle(s). Unfortunately, there is no guarantee that such a program will be successful. Moreover, if humanity fails in this effort, it seems likely that nature's even harsher realities will almost certainly be imposed. Speaking as a professional physical anthropologist/human evolutionary biologist, it is entirely possible that this rapidly metastasizing — yet still partly hidden — demographic and environmental crisis could emerge as the greatest evolutionary/ecological "bottleneck" that our species has yet encountered. …

Notwithstanding the numerous difficulties in addressing a problem of such complexity, it is nonetheless surprising how little scientific and public attention has been directed toward establishing empirically quantifiable, scientifically testable, and socioculturally agreed-upon parameters for what the Earth's long-term human carrying capacity — or flexibly defined "optimal population range" — might actually be. Unfortunately, with only a few notable exceptions, many otherwise well-qualified scientific investigators and public policy analysts have been rather hesitant to take a clear and forthright position on this profoundly important matter, certainly destined to become the overarching issue of the current century.

It is difficult to say whether this unfortunate reticence is due to ingrained investigatory caution, concerns about professional reputation and advancement (particularly among younger investigators), the increasingly specialized structure of both the scientific and political enterprises, personal qualms about reaching conclusions that have potentially unpalatable social and political ramifications, or other unspecified (and perhaps deeply-rooted) ideological, moral, or religious reservations. Or perhaps, given its global nature and seemingly endless ramifications, the chief difficulty in dealing with the complex population/environment conundrum represents little more than a manifestation of “scale paralysis,” that enervating sense of individual and collective powerlessness when confronted by problems whose magnitude seems overwhelming.

Certainly the rough approximations of global human carrying capacity put forth during the past century show considerable variation, ranging from fewer than 1 billion to well beyond 20 billion (an order of magnitude or more). It is, however, important to note that over the past two decades there have been a growing number of investigators and organizations who have put forth reasonably well-thought-out positions on future global population optimums. Interestingly enough, these estimates have all clustered in the 1 to 3 billion range. This is an important development, since it is patently obvious that it will be difficult to engender any sort of effective public response to the above-mentioned global crisis if future population goals (i.e., desired demographic optimums) continue to be imperfectly understood and poorly articulated. …

Notwithstanding our current addiction to continued and uninterrupted economic growth, surely the dominant political mantra of the 20th and early 21st centuries, it is essential for humanity to recognize that there are, after all, finite physical, biological and ecological limits to the Earth’s long-term sustainable carrying capacity (i.e., the “natural capital” that supports us). And to recognize further that we are now drawing down on the principal, as well as the interest, of this precious “capital,” as many of these finite limits have already been reached (and in a number of instances surpassed). …

That there will be a large-scale reduction in global human numbers over the next two or three centuries appears to be inevitable. The primary issue may well be whether this lengthy and difficult process will be comparatively benign or unpredictably chaotic. More specifically, is modern humanity capable of a comprehensive organized effort to compassionately reduce global human numbers, or will brutal self-interest prevail — either haphazardly or selectively — resulting in an unprecedented toll of human lives? Clearly, we must begin our "new manner of thinking" about this critically important issue now, so that Albert Einstein's prescient and very legitimate concerns, expressed more than 60 years ago, about human (and civilizational) survival into the 21st century and beyond may be addressed as rapidly, as fully, and as humanely as possible.

Don’t speak to me of shortage. My world is vast
And has more than enough — for no more than enough.
There is a shortage of nothing, save will and wisdom;
But there is a longage of people.

Garrett Hardin (1975)

EXPERIENCE OF WIND TURBINES IN THE PACIFIC NORTHWEST

by Andrew R.B. Ferguson

The Bonneville Power Administration in Idaho provides about 30% of the electricity supply for the Pacific Northwest which covers the Columbia river basin — a good site for hydro power and wind turbines. Walter Youngquist kindly sent me a few pages from the Northwest Power and Conservation Council's Spring 2011 magazine, *Council Quarterly*.

Hydroelectricity would seem to be an ideal way of balancing out the erratic input from wind turbines, as the hydro turbines can be turned off and on in a very short time. It is only because of the massive use of hydro dams in Norway and Sweden, and good interconnectors, that Denmark can achieve its approximate 20% wind penetration. However, hydroelectricity is not always an ideal companion for wind power as the experience of the Bonneville Power Administration shows: with wind turbines supplying 10% of the total supply (the capacity of the wind turbines is 5563 megawatts so total supply must therefore be of the order of an average 17 GW), the Bonneville Power Administration are already running into problems. It is worth looking at the reasons.

The Council report says, "One of the biggest challenges has been the growing frequency of periods when wind and hydro generate more energy than we can use." At first sight this might seem surprising, because the hydro turbines should be easy enough to turn off, but problems arise in doing that, as the report explains: "The oversupply issue is thorny since the two obvious options — spilling water or curtailing wind have downsides. Too much spill can harm fish and taking wind offline hurts the bottom line of the wind operators. The Bonneville Power Administration has been curtailing wind generation during periods of oversupply."

It would not be necessary to "spill water" (let it out without sending it through the turbines) if there was still room in the reservoir to hold more water, but it has to be done when the dam is full. The trouble is releasing water fast enough to accommodate the rapid increase in input from wind turbines does damage to wildlife as the report explains:

> Historically, the combination of high springtime runoff and low demand has led to episodes of excessive energy in the region, causing operators to send water over spillways instead of through turbines. The recent large-scale development of wind power to meet state renewable portfolio standards has added to the frequency and magnitude of these events. But too much spill can cause trauma to migrating fish, which is why Bonneville decided to curtail wind when we have too much energy.

As was mentioned above, the report says that "taking wind offline hurts the bottom line of the wind operators." It should be noted, too, that getting the hydro operators to spill water so that the wind turbines can take precedence would hurt the bottom line of the hydro operators. Moreover, the same would be true were fossil fuel gas turbines being used as the controllable source of power to balance wind turbine inputs. In the latter case it is not that gas would be wasted by being burnt, but rather that the fossil fuel plant would have to be operated at a lower capacity in order to allow wind to take precedence.

Although it is consistently denied by the renewable energy lobby, Manfred Lenzen's authoritative study[1] indicates that uncontrollable inputs into an electricity grid (e.g. from wind and photovoltaics) are unlikely to be able to exceed about 20%. The difficulties encountered by Bonneville, at just 10% penetration, add weight to this conclusion.

1. Lenzen, M.. 2009. *Current state of development of electricity-generating technologies – a literature review*. *Integrated Life Cycle Analysis*. Dept. of Physics, University of Sydney.