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We are faced by temptation; if we can, by thinking irrationally, make ourselves believe that our everyday actions are really good and unselfish, we shall continually do so. To quote Julian Huxley again (*Evolutionary Ethics*, p. 31), we shall build up "an idealized ethical mask, strangely compounded of moral aspiration, spiritual conceit, and hypocrisy, in which we can disguise ourselves from ourselves, or which we can present to the world to enhance our self-respect and our apparent moral stature."

The chief methods which we use in building up this admirable picture of ourselves are Selection of the Evidence and Rationalization. I hope to show later how all-pervading these methods are in our daily lives.

Rupert Crawshay-Williams *TheComforts of Unreason* (1947, p. 22).

The Optimum Population Trust (UK): Manchester

<www.members.aol.com/optjournal> & <www.optimumpopulation.org>

INTRODUCTION

After he had finished reading *A Green History of the World*, David Willey, founder of OPT, shared my view that if everyone could be persuaded to read Clive Ponting's book, OPT's work would be substantially done. But the number of facts packed into its 400 pages make it somewhat indigestible. Roger Martin, who did a brief review for the April 2004 OPT Journal, described it as a "flawed masterpiece." A good description, for despite its factual density it remains the most admired of Ponting's books. There remains a need for an easier read, so I am immensely pleased that Martin Desvaux has undertaken the task of writing a synopsis. His chapter-by-chapter summaries will appear in several instalments in the OPT Journal. I very much hope that someday the entire synopsis will be published as a suitable school primer.

The next four papers in this issue, which fill 16 pages, focus on wind power. That focus can be justified on the grounds that wind has a power density of about 10 kilowatts of electricity per hectare (kWe/ha). While that is very low compared to oil, which is of the order of 2000 kW/ha, it is large compared to any other well-developed *renewable* energy source (except for photovoltaic modules which are too expensive). Even the most useful source, hydroelectricity, has a low power density. On a 'collection area' basis, Howard Hayden estimates that all US dams average 0.05 kWe/ha. On the basis of their reservoirs, I calculate the power density of US dams at about 1.4 kWe/ha.

So with its *relatively* high power density, the question is whether wind power might be the sovereign solution that would make it possible to support something like the present 6 billion population without fossil fuels. From the evidence presented here, that appears extremely unlikely. Supporting, in moderate comfort, without the use of fossil fuels, a population larger than about 2 billion remains an unsolved problem. Note that while we continue to use fossil fuels, the main problem is one of overloading the atmosphere with carbon.

Page 24 comprises extracts from a paper published in *World Watch* by Herman Daly. The extracts give cogent reasons in support of item 2 of the *Social and Ecological Consequences of Globalization* (OPTJ 3/1, pp. 23). Daly neatly encapsulates this particular effect as, "the abrogation of a basic social agreement between labor and capital over how to divide up the value that they jointly add to raw materials."

Pages 25-31 comprise a paper on hydrogen, *The Hydrogen Economy: Reality or Fantasy*. To some extent this is complementary to the subject of wind, insofar as it is apparent from the wind papers that the essence of the problem with wind is variable supply. If variability could be overcome by storing the electricity as hydrogen, which could later be used to regenerate electricity, that would greatly change the potential of wind power. The inefficiency of the total process mitigates against that possibility.

Finally, a psychological insight comes from Jay Hanson, founder of the **dieoff** website. We surely need reminding, from time to time, that OPT faces a nearly insuperable psychological problem in persuading the world of the need for action, because human beings suffer from the weaknesses so admirably described by Rupert Crawshay-Williams in *The Comforts of Unreason* (see the extract on the title page).

As usual, I have received a great deal of help from many sources in compiling this issue. I would particularly like to thank Edmund Davey and 'George', for their participation in the *Plain Man* papers; Martin Desvaux for contributing his synopsis and for help in many of the papers; David Gosden for literary guidance; and as always David Pimentel and Yvette Willey. I wish, too, that there had been space to include a neat introduction to the wind problem sent to me by Jim Duguid; that was not the only thing that had to go, so as to keep to my self-imposed limit of 32 pages per issue.

CLIVE PONTING'S *A GREEN HISTORY OF THE WORLD*. Part 1

A synopsis by Martin Desvaux PhD CPhys MInstP (martindesvaux@aol.com)

The farther backward you can look the farther forward you are likely to see.

Winston Churchill

Introduction.

With an ever-increasing awareness of the effects of global warming on climate change and the pressing need to forecast — and try to ameliorate — the consequences of humankind's behaviour, many books have been written in recent years about the perils of the overpopulated, warming and post-oil world. But bearing in mind Churchill's words, I believe that it is imperative to supplement any study of our effect on the environment with this book by Clive Ponting. As my first passion is physics, with history coming a close second, I was pleased to accept Andrew Ferguson's invitation to write a synopsis of *A Green History of the World* for the OPT Journal, especially as it is currently out of print. Clive Ponting tells me he is working on a revised and updated edition to be published by Pimlico in late 2006/early 2007.

It may seem odd to write a synopsis of a book that is already 15 years old. After all, with our fast-moving understanding of the environment and its link with population, perhaps one should be looking at more recent studies. Nevertheless, I am convinced that, as the past cannot change (but only our view of it), Ponting's 1991 perspective is a useful guide to the future. Indeed, in reading his book, it is frightening to recognise how the mistakes of our predecessors are being repeated today by a civilisation which not only should know better, but which should be taking diligent measures to prevent the catastrophe that must surely be just around the corner.

In undertaking this task, I have tried to relate the work to how things have moved in the last 15 years and to comment on any specific reflections or lessons Ponting's book may have provided. *Italicised* passages indicate direct quotations, made with permission from Clive Ponting. As is usual, an ellipsis … signifies where a passage has been skipped. My personal comments have been almost entirely confined to the end notes, or are made obvious by use of the first person singular.

The book has 407 pages plus a seven-page list of further reading. It is extremely well researched and is compulsory reading for anyone wanting to get to grips with a subject which is all-too-slowly gaining in importance. While politicians wax eloquently — and often ignorantly — about economic growth and better deals for all, their constituencies are for the most part blissfully unaware of the coming problems when critical resources start to run out, and of how we are trashing our environment for future generations. We owe Clive Ponting a debt of gratitude for his pioneering historical study, which provides signposts to the future, based on mankind's turbulent relationship with the environment. This book could be mistaken for a university textbook that needs detailed study to extract the full essence of its message. Not everyone has time to do that. I therefore hope that my modest synopsis will provide readers with an overview to help them to understand our ecological inheritance and to share my disquiet at the poisoned chalice we are passing to our descendants. Hopefully, it will inspire us to continue to lobby those people of influence and power to wake up and take seriously the urgent problems already so evident to anyone 'who has eyes to see and ears to hear'.

Preface

"As some people climb mountains because they are there, others find themselves writing books because they are not there." It is with these quotable words in the preface that Clive Ponting introduces his *A Green History of the World*. This expression of intent is a signal that this book will be interesting, informative, worrying and written with scholarship. He explains: "*There are many books about the current state of the environment and the prospects for the future but few probe very far into the past or explore the extent to which the environment has shaped human history and none covered the ground and asked the questions that to me seemed to be important."*[1] His preface covers two pages but the above two sentences are an adequate apology for undertaking this seminal work even though his reputation as a historian had not yet been established.

Chapter 1: The Lessons of Easter Island

Ponting's opening paragraph spells out the direction his book will take. "*Easter Island is one of the most remote, inhabited places on earth. Only some 150 square miles in area, it lies in the Pacific Ocean, 2,000 miles off the west coast of South America … At its peak the population was only about 7,000. Yet, despite its superficial insignificance, the history of Easter Island is a grim warning to the world*."

Easter Island was colonised by an estimated 20-30 adventurous Polynesians in the 5th century AD. They found a densely wooded island of volcanic origin with poor soil, only 30 species of vegetation, no mammals and a little water in the calderas of extinct volcanoes. Their diet was mainly restricted to chickens and sweet potatoes, which they had brought with them, along with other less successful species. When European sailors first visited the Island some 1200 years later they found 3,000 people left together with evidence of a once-flourishing society now living in *'squalor and barbarism'*, at war with each other and practising cannibalism in a desperate attempt to survive. The population continued to decline and after 1877 the island was *"taken over by Chile and turned into a giant ranch for 40,000 sheep, run by a British company, with the few remaining inhabitants confined to a single small village."*

How could this have happened? It appears that growing their simple crops was not labour intensive and the population, once developed and having little else to do, established clans and developed a culture of erecting stone monuments at *ahu* – centres for ceremonial and ancestor worship purposes. *"The Easter Islanders engaged in elaborate rituals and monument construction… The statues were carved* [in a quarry] *using only obsidian tools... which took up immense amounts of peasant labour..."* Then: *"The most challenging task was to transport the statues… weighing several tons, across the island and then erect them on top of the ahu."* Moving the statues several miles from quarry to *ahus* was done by felling trees and using the trunks as rollers. When the population peaked in about 1550, competition between the clans for making statues, and thus felling of trees, would also have peaked. As a result, the population started to collapse through *"massive environmental degradation brought on by deforestation of the whole island."*

In the closing paragraph Ponting concludes with the thought-provoking words: *"Like Easter Island the earth has only limited resources to support human society and all its demands. Like the islanders, the human population has no practical means for escape. How has the environment of the world shaped human history and how have people shaped and altered the world in which they live? … For the last two million years humans have succeeded in obtaining more food and extracting more resources on which to sustain increasing numbers of people and increasingly complex and technologically advanced societies. But have they been any more successful than the islanders in finding a way of life* *that does not fatally deplete the resources that are available to them and irreversibly damage their life support system?"*

Chapter 2: Foundations of History

The early history of the planet shows how it shaped the environment and, consequently, human history. *"Human history has been affected by the action of large scale geological and astronomical forces over long periods of time. Although the amount of land on the globe has remained broadly constant its distribution has altered radically*"

Starting 200 million years ago, three major processes lasting 140 million years combined to create the environment which was to be the cradle of humankind:

1) Continental drift (convection within the magma between the earth's solid core and relatively thin crust) caused flows which are still increasing the separation of continents. The original continents, Laurasia and Gondwanaland, separated by the Tethys Sea, were originally situated over the South Pole. They drifted north and broke up into the current configuration between 60 and 200 million years ago. As a result, the evolutionary changes of plants and animals were heavily influenced by the climatic conditions which varied slowly with the drift of the land masses.
2) The energy output of the sun increased.
3) A further significant influence, initially proposed by Milhankovic in 1922, was the variation of the earth's tilt and orbit around the sun. Three cycles with periods of 21,000 years (closeness of approach to the sun); 45,000 years (tilt of the axis); ~100,000 years (change in the elliptic axes of orbit) all combine to explain the major variation in global temperature as well as the regularity of the ice ages.

Ponting stresses*: "The various forms of life on earth, including humans, do not exist independently, they are part of ecosystems … There are many types of ecosystems such as tropical forest, grassland , prairie, coral reef but the foundation of all of them … is photosynthesis …*[which is] *the only way that energy is introduced into the system."* Starting from a bare-rock world, decaying primitive lichens established enough soil for grasses and other plants to evolve. These plants were subsequently broken down by decomposers to recycle their nutrients and the continuous build-up of soil over millions of years enabled trees and other vegetation to evolve. "*As the ecosystem develops and changes, so do the plants and animals that can be supported …*[the] *retreat of an ice sheet … exposes bare rock, which within a few thousand years is converted into a climax temperate forest. This development has occurred countless times during the earth's history."* In particular, rain forests: *" … are remarkable not just for the quantity of life found there but also for the diversity. A typical four square mile patch of forest will contain the following species (not individuals) — 1,500 flowering plants, 750 trees, 125 mammals, 400 birds, 100 reptiles, 60 amphibians, 150 butterflies and probably about 50,000 insects*". However: "*The soil is thin, acidic and poor quality with very little humus. If the ecosystem is destroyed by forest clearance most of the nutrients are destroyed too; there is little available in the soil to support crops and grass and the exposed ground can quickly turn into a hard baked clay*.[2]

Ponting alludes to Lovelock's Gaia theory[3] when *adding "To fully understand the individual parts of an ecosystem, it is necessary to see them as part of a bigger whole. All the parts of an ecosystem are interconnected through a complex set of self-regulating cycles, feedback loops and linkages between different parts of the food chain.*" This theory is one of the most important in the interpretation of global ecology, and really rates a more detailed mention and readers are encouraged to get hold of Lovelock's book.[3] Most species have a symbiotic relationship with their habitat, but: "*The most important task in all human* *history has been to find a way of extracting from the different ecosystems in which people have lived enough resources for maintaining life… Inevitably this has meant intervening in natural ecosystems. The problem for human societies has been to balance their various demands against the ability of the ecosystems to withstand the resulting pressures."*

Chapter 3: Ninety-nine Percent of Human History

Fossil records show humans progressed from early forms, one of which was known as *Homo erectus*, which survived until about 100,000 years ago *"when the first anatomically modern skeletons, named in a piece of immense self-flattery **Homo sapiens**, are found in east and southern Africa. By about 30,000 years ago fully modern human types (**Homo sapiens sapiens**) were widespread throughout the world."* These stone age humans were hunter-gatherers up to about 8000 BC, by which time the population had grown to a total approaching four million.

"In nearly every case people lived in small mobile groups. It was without doubt the most successful and flexible way of life adopted by humans." While not a high productivity existence, their life was more Eden-like than Thomas Hobbes's description of: "nasty, brutish and short". Studies of the Bushmen of south-west Africa, the Hazda of east Africa, as well as the Australian Aborigines showed that, on average, gathering food only took a couple of days a week. The rest was leisure. Hunting was more precarious and less favoured as the chance of making a kill was only ten percent. Gathering was an eco-friendly activity. Bushmen knew their environment intimately and moved around to take advantage of the availability of the 'crops' of fruits, roots and nuts. In this way they did not over-stress any particular area. Sustainability at its best![4]

Tribes had to adjust the balance of gathering and hunting to suit their environment. Further north, in Canada, the: *"Netzilik Inuit … way of life depended on exploitation of every part of their environment. Houses…made from snow and ice …clothing, kayaks, sledges and tents came from skins of animals and bones provided tools and weapons*." They did the rounds of hunting salmon, salmon trout, seals, and caribou. "*In each of the phases of communal hunting there were social customs to ensure that everybody was fed and nobody was penalised because of poor luck or lack of skill."* Hunter-gatherers from the arctic to the equator had, by necessity, a nomadic existence; they were unencumbered by material goods and made no significant or lasting impact on the environment. Population control was practised out of perceived practical necessity. "*All gathering and hunting groups, both contemporary and historical, seem to have tried to control their numbers so as not to overtax the resources of their ecosystem*." In the case of the Inuit, numbers were kept in balance by "*protracted weaning of infants … infanticide … abandonment of the aged."* The development of human societies has been traced to four basic traits that distinguish humans from other primates: increase in brain size; ability to stand upright leaving the arms free to use tools and weapons; use of speech; use of technology to overcome hostile conditions. With stone and bone tools early humans managed to survive. Low sea levels in the last ice age enabled migrating groups to gain access to the Americas from eastern Siberia and to Australia from Asia. By a process of growth and fragmentation humans settled most of the world.

In the plains of northern America they hunted bison. In the north-west seal, salmon and other foods were plentiful. With the introduction of preserving (drying and smoking meat and rendering to oil for use in leaner times) and the invention of snares, nets and the bow and arrow (about 23,000 years ago), hunting became more efficient and left time for ceremony and the development of culture. Villages of about 1000 people developed socially stratified societies, many with a slave culture, until the Europeans came in the 16th century. Many groups, at this stage of evolution, would have had a limited impact on their environment by rotating hunting grounds over several years. However, many others have altered their environment considerably by tree felling, and caused other damage by the use of burning to encourage preferred plants to grow at the expense of others.

As humans spread and increased in numbers their impact began to tell: "*Gathering and hunting could even have had an impact on animal populations on a continental scale. A number of species became extinct around the end of the last glaciation ... in Eurasia five large animals — the woolly mammoth, woolly rhinoceros, giant Irish elk, musk ox and steppe bison — together with a number of carnivores became extinct ...* [mainly as a result of] *the changing environment ...*[but] *hunting by humans would have had a devastating impact on a population already in decline."* In the Americas, "[The] *first settlers left a trail of destruction across the continent. Two-thirds of large mammals present when humans first arrived were driven to extinction*".

Thus the early picture emerges of small groups of hunter-gatherers living in relative natural affluence in an Eden-like harmony with their environment. These conditions were amenable to the growth of human groups, which then splintered and migrated when these became too large for the territory to sustain. Over about 40,000 years, the process led to an increasing impact of humans on their environment. They developed more sophisticated and effective tools for hunting which helped them to survive as they migrated into more hostile areas. The world was very slowly becoming the kingdom of humankind.

Then, in about 8,000 BC, *"... the methods humans used to obtain their food began to change in a number of locations across the globe... Its consequences were far more radical than anything that had gone before. It brought about the most fundamental alteration in human history — and one which made possible all the subsequent developments in human society."*

It occurs to me that this could be seen as the point in time at which humans had eaten from the biblical 'tree of knowledge'.[4]

Endnotes

1. Since *A Green History of the World* was written, an increasing number of other books have appeared on the subjects of global warming, extinction of species and genocide, as well as on the end of oil. However none to my knowledge have looked at the ecological history of our planet in the depth that Ponting has achieved.

2. Those permitting the destruction of the Amazon and other rain forests should take note!

3. James Lovelock: *GAIA The Practical Science of Planetary Medicine*; ISBN 1-85675-191-0. The theory postulates that the Earth acts as negative-feedback organism and reacts to remove the source of its distress, rather like antibodies do in humans. In this way the planet regulates its climate — within limits — for the good of its inhabitants. Forcing the climate beyond these limits courts catastrophe. Many scientists predict that this will be triggered by the current unprecedented rate of global warming.

4. With plenty of food around for tribes who thrived and survived, one can see how the myth of the Garden of Eden was passed down through the generations before being 'modified' by priests/leaders to end up in the book of Genesis. It is plausible to me that the banishment of Man in Genesis Ch. 1.3 occurred once he had multiplied beyond the carrying capacity of his environment, and was told "in toil you shall eat of it all the days of your life." Here 'it' refers to the tree of knowledge, i.e. the onset of agriculture around 8,000 BC. This makes an interesting, if speculative argument for 'original sin' being Man's disregard for his own environment. This analogy would place the so-called 'forbidden fruit from the tree of knowledge' firmly in the role of the knowledge of agriculture — a paradigm shift in human knowledge from which there was no going back! By starting farming, early Man had to work much harder. Ancestral memories of the 'good old hunter-gatherer days' would have been passed down by word of mouth (as is common in all primitive tribes even today); writing did not evolve until about 3000BC with the Cuneiform script of the Sumerians. The story of the great transition could then have evolved into a God-centred story to explain our existence. By 1500 BC, when the book of Genesis is estimated to have been written down by Moses, the mutation of the facts could have become encapsulated in the Genesis text.

A PLAIN MAN`S QUESTIONS CONCERNING WIND POWER

Asked by Edmund Davey; answers provided by Andrew Ferguson

Edmund I follow the general thrust of your arguments about wind power, but I cannot see why you attach so much importance to the *peak* infeed factor. To be honest, I am suspicious too, because no one else seems to attach the same importance to it. Indeed I hardly hear anyone mention the *peak* infeed from a wind system.

Andrew You are right to be suspicious, but I think the arguments are sound. Let me do my best to explain.

Although numbers don't matter, but rather the principles, it is probably easiest to have some numbers in mind. So let us take the UK as a rough basis for an imaginary scenario. The UK's domestic electricity supply is about a mean 45 GW (1 GW = 1 billion watts). Now let's suppose that we want to install so much wind capacity that it will occasionally produce 20 GW. That is fairly realistic, insofar as the low point in demand is somewhere around 20 GW, so wind would never, or very rarely, be producing too much electricity. I am simplifying by assuming that there are no other inflexible inputs, as there would be if nuclear power was part of the mix.

Edmund OK I get the picture. We install sufficient wind turbines to occasionally produce at the level of low demand, say during a summer night.

Andrew That's right, but there is no way we can know how many wind turbines to install without knowing what the *peak* infeed factor is. For instance, if we just installed wind turbines with a rated capacity of 20 GW, they would never all be producing at their maximum rated output at the same time, so we would never get 20 GW. However, if we know that the *peak* infeed factor is 80% (that is likely to be about right based on data from E. ON Netz, with wind turbines spread over 800 km), then we know that if we install 20 / 0.80 = 25 GW, then occasionally they will produce the 20 GW that we are aiming for.

Edmund I can see that for whatever maximum wind infeed you want, you need to know the *peak* infeed factor, but I cannot see that it is so very important apart from that.

Andrew Well let's continue with the analysis. I'm sure you will agree that the wind turbines that we have installed are not going to produce anything like the *peak* infeed all the year. In fact we know how much they will produce, provided we know the (mean) infeed factor — that is what proportion of their rated capacity they are going to deliver to the grid over the course of a year. Keeping to approximate reality, let us choose the Dti's estimated load factor in the UK for 2003, namely 24%. That tells us that the 25 GW of wind capacity we have decided to install will produce a mean 25 x 0.24 = 6 GW.

Edmund OK, so now we know that the wind will produce a mean 6 GW, that is 6 GWyr per yr, but what do we do with that?

Andrew We use it to find how much the wind will contribute and how much what I call the DIB (the dominant in-harness backup) will have to produce. You see wind shows no tendency to produce electricity when it is actually needed —that is, it is not demand-following — at least not in most places (South Australia is an exception). Indeed E. ON Netz showed that it tended rather to do the reverse, and the same is true of Denmark. So if we cannot use wind for demand-following, the best we can do is to use the wind infeed in conjunction with the DIB to produce a steady output.

Edmund That is where I get a bit stuck, because there is not really any such thing as a dedicated DIB waiting to compensate for the variability of wind. What really happens is that all the flexible plant that is in the whole system shares the task.

Andrew That is true. But it hardly matters, because we are not primarily concerned with how much plant has to be available, but rather how much electricity has to be produced by demand-following plant. We are not trying to assess how much plant we need, but *how much electricity* has to be produced to compensate for the variability of the wind.

Edmund Ah! I think I see it at last. The DIB, whatever demand-following plant is being used, has to have a peak infeed of 20 GW, and be capable of producing an annual mean 14 GW, to supplement the wind's contribution of an annual mean 6 GW.

Andrew You are absolutely right, and we could have arrived at that figure by dealing in percentages. That is to say, because the infeed factor is 24% and the *peak* infeed factor is 80%, wind contributes 24 / 80 = 30%, leaving the DIB to produce the remaining 70%. 70% of 20 GW is the 14 GW that you arrived at.

Edmund Yes that is clear. The mean 14 GW of electricity that is not produced by wind, because infeed from wind is not steadily at peak, is going to have to be produced by demand-following plant, as a consequence of having introduced wind into the system.

Andrew You have got it exactly. That is why it is uncertain whether introducing wind into a system saves any fossil fuel at all. All these complex and detailed studies of wind, such as E. ON Netz (by far the shortest in fact, as well as the best), fail to take into account the extra fossil fuel that has to be used as an inevitable consequence of introducing wind. They mainly focus on the plant capacity needed, and problems of ramp rates, rather than the amount of electricity that will have to be produced by demand-following plant.

Edmund I really believe that I can see the picture now, but one other thing bothers me. Surely we need to study the wind structure carefully, to see how much time the whole wind system is producing nothing, or close to nothing. Surely that is very important.

Andrew That has some effect, but not very much, because it only determines how much demand-following plant we have to have available, not how much electricity has to be produced by demand-following plant, *which is something we have already determined*. Let's follow that idea through with a couple of examples. Let us suppose, first of all, that the situation is as above, but on average there are 30 days in the year during which there is zero output from the wind. In that case, it would be necessary to have sufficient demand-following plant to fill in between 20 GW and zero, i.e. demand-following plant of 20 GW capacity. Now, for a second case, let us suppose that the wind infeed never drops below 10% of capacity, that is 2.5 GW. In that case the amount of demand-following plant needed would be 20 – 2.5, i.e. plant with 17.5 GW capacity. However, having to have available an extra 2.5 GW of demand-following capacity is not that important. What is important is how much electricity has to be produced by the demand-following plant which operates the DIB. We have already calculated that, and the two assumptions we have just made, and of course any number of variants on them, are not going to make any difference to our calculation that the DIB must provide a mean 14 GW.

Edmund I see. That is really the whole key to the matter. It is all a question of how much electricity has to be produced by demand-following plant, rather than how much demand-following plant must be available.

Andrew You have it exactly in a nutshell.

Edmund While that all seems perfectly clear, I still have a niggling worry in the back of my mind that there are hidden complexities about the efficiencies of the delivery of electricity for demand-following requirements. That is to say, I am not entirely happy about the idea of treating the DIB as though it is separate, when really the DIB is spread throughout all the system — at least it exists in all the plant which can deliver electricity with a degree of control over "dispatch," as I think the professionals call it, that is what you term "flexible" plant. Can you convince me that there is not something we are overlooking there?

Andrew I reckon I can, if we build up the picture by degrees. Let us first look at Figure 1, in which the yearly pattern of demand is shown as it would be approximately in the UK, at least in a simplified scenario, and without any wind input. There is a constant input shown at the bottom from nuclear input. I have put that in just to keep roughly to present reality, but that is not germane to the main point. However, note that if we assume that nuclear operates most efficiently when allowed to operate as close to full output as possible, then it is appropriate to show it as providing a flat infeed, that is to say a base load.

Now take a look at the horizontal line representing the 'valley' demand, showing the lowest point of demand. As mentioned previously, in the UK, on an average year that's about 20 GW. The mean demand is about 45 GW. Figure 1 does not approximate to those ratios, but then it is not showing the daily variations, which would amplify the variations. As we are describing a whole year on a fairly small horizontal scale, demand is smoothed out, so we cannot see the daily variations although these are of substantial magnitude. We don't need to look in that amount of detail, as the principle remains the same.

What you can see is that the shaded area that I have marked CV (for Consumer Variations) is *variabl*e electrical demand which has to be satisfied somehow.

Edmund As I see it, there are essentially two ways of doing that, although with many intermediate possibilities. You could install highly efficient plant to produce all the infeed needed between the top of nuclear and the valley demand — essentially extending the base load — and gain efficiency in that way. Then you would fill in the CV area with plant ideally suited for demand-following, say OCGT (Open Cycle Gas Turbines).

Alternatively you could fill the block above nuclear and below valley demand with say old-fashioned coal-fired plant, which has some capacity for varying its output without losing efficiency. That type of plant could perhaps expand its output sufficiently, when needed, so as to provide all the electricity needed in the CV area.

Andrew You are entirely right about the range of possibilities. The situation becomes more complicated when one considers using coal-fired plant, especially as coal technology is under constant development. Still let us leave that to another discussion, and merely recall that at the present time UK policy is to continue to switch to gas-fired plant. The problem of introducing wind arises because the most efficient gas-fired plant, CCGT (Combined Cycle Gas Turbines), is likely to achieve 50% efficiency *when allowed to operate at constant load*, but the efficiency drops off rapidly if CCGT plant has to perform demand-following operations.

Edmund So what you argue is that on balance it is best to operate with plant of maximum efficiency as far as possible, and use only as much demand-following plant as is needed?

Andrew That is how the figures look to me. Perhaps Figure 2 helps to make the point. Above the top of the nuclear area is a wiggly line which shows an imaginary, but

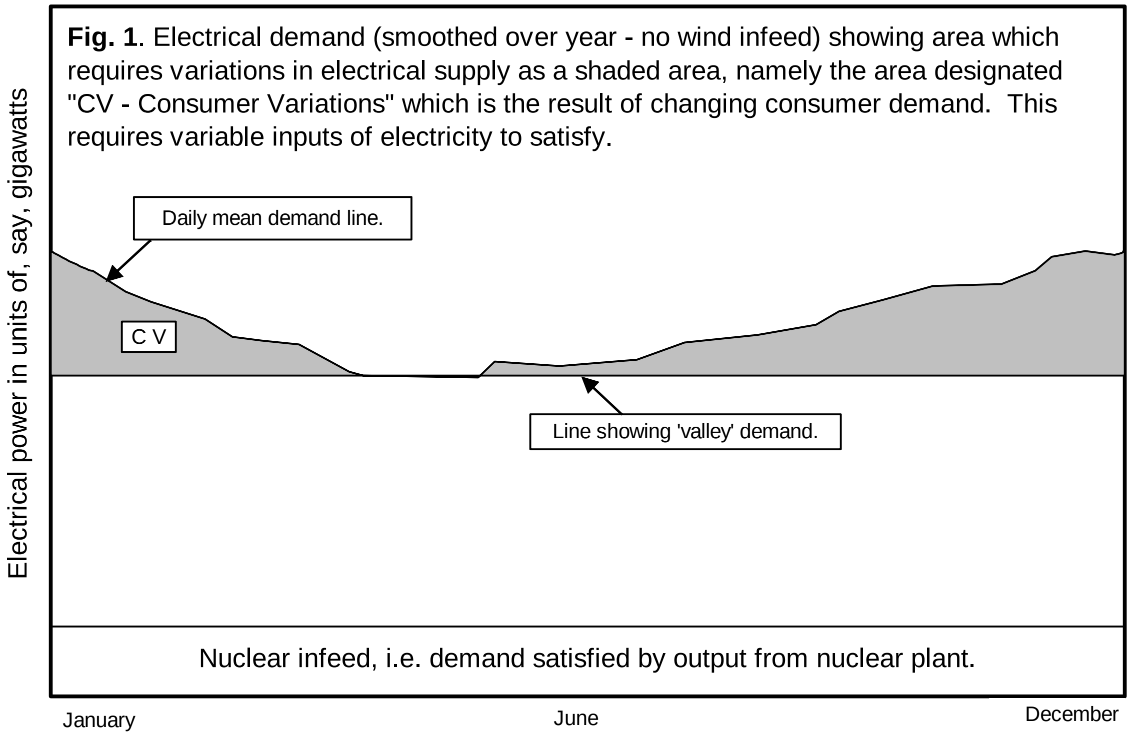

Fig. 1. Electrical demand (smoothed over year - no wind infeed) showing area which requires variations in electrical supply as a shaded area, namely the area designated "CV - Consumer Variations" which is the result of changing consumer demand. This requires variable inputs of electricity to satisfy.

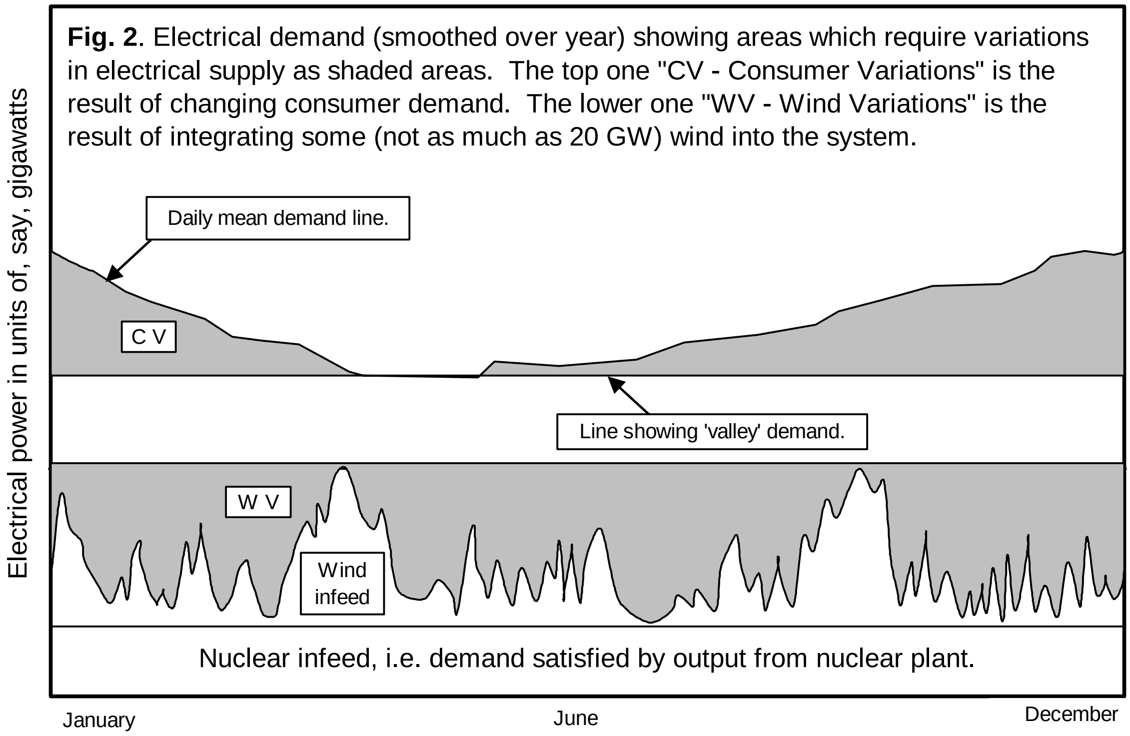

Fig. 2. Electrical demand (smoothed over year) showing areas which require variations in electrical supply as shaded areas. The top one "CV - Consumer Variations" is the result of changing consumer demand. The lower one "WV - Wind Variations" is the result of integrating some (not as much as 20 GW) wind into the system.

hopefully fairly realistic, wind infeed. Of course there would be more short-term changes than can be shown on this diagram. Above the wind line is a shaded area marked WV (for Wind Variations). Just as the variations in consumer demand produce a requirement for variable inputs of electricity, the introduction of wind has exactly the same effect of requiring variable inputs of electricity. So now it is apparent that if one had built only just enough flexibility into the system to cover the CV requirement — *by whatever means* — then introducing wind would require more electricity to be produced *variably*, so as to cover the WV requirement.

Edmund I can see that there are many ways of providing the flexibility, but unless the system is being run very inefficiently to start with, it does seem improbable that there will be flexibility to spare to cope with wind. However, let me be absolutely clear that your argument, that introducing wind is likely to increase the use of fossil fuel, applies only to the theoretical case of a system which is almost entirely dependent on gas-fired plant to provide flexible power.

Andrew Yes that is my fairly narrow contention, and I admit firm data is lacking. Moreover I would like to stress that one cannot say that in every situation introducing wind into a system will increase the use of fossil fuel. What I can say, with a fair degree of certainty, is that neither the 16 page E. ON *Netz Wind Report 2004*, nor the 490 page Dena (Germany Energy Agency) grid study, nor the 88 page South Australian study, nor the 166 page Sustainable Development Commission report, gave consideration to the amount of electricity that would have to be produced to satisfy the DIB, and what the result of that would be in terms of loss of efficiency.

Edmund So, in short, none of these reports address the most important question.

Andrew Again you have put it in a nutshell.

Edmund Looking at Figure 2 another point occurs to me. I know that the figures are very much simplified in that they do not show the *daily* variation, which amounts to something like the same amount of variation as between summer and winter, but even then it occurs to me that the CV area is sufficiently predictable that one could probably introduce some highly efficient plant to operate within it. On the other hand, the WV area is far less predictable and one would really be forced to use fully flexible, and hence less efficient plant.

Andrew That seems a good point to me Edmund, and the above analysis does not show up all the problems with wind by any means. For instance, in Japan problems in using wind were encountered at only 0.2% penetration.

Edmund Can that really be right? Problems when wind was supplying only 0.2% of total electrical supply?

Andrew It is rather surprising I agree, but Japan is a special case. Its topography means that the wind is gusty, and the essential problems arose, in 2005, with respect to frequency control caused by the erratic infeed. There are other problems which arise in less special cases. For instance, if consumer demand is increasing at the same time that wind is dropping then there may not be sufficient ramp rate (rate at which infeed can be increased) available from the flexible plant to increase the infeed at the rate required. Nevertheless, it seems to me that it is not necessary to chase down every one of these problems, because the overarching problem is the need to *use* — not merely to *have* —more flexible, low efficiency, plant to deal with the vagaries of wind.

I am fortunate in knowing someone who is in charge of a large amount of generating plant, and so can advise me on the extent to which the simplifications inherent in *A Plain Man's Questions Concerning Wind Power* are misleading in practice. To put the advice that I have received into what I deem to be the most easily assimilated form, I have constructed a dialog, in which I ask my source of information (whom I call George as the actual words are mine rather than his) to discuss one of the main implications of the previous piece, namely that even with perfect wind forecasting, the efficiency of the remaining plant would suffer. As this dialog shows, that conclusion is not unequivocally true in all circumstances.

A PLAIN MAN'S QUESTIONS: WIND POWER IN THEORY AND PRACTICE

Asked by Andrew Ferguson; answers provided by 'George'

Andrew George, I gather you have some reservations about the analysis that is put forward in *A Plain Man's Questions Concerning Wind Power.* You contend that if it were possible to forecast the wind exactly, then introducing wind power would not increase the demand-following problems which arise from the inevitable changes in consumer demand, by day and by season.

George That is my contention although it is hedged around with qualifications.

Andrew Let me start with an overview of the argument that I am proposing. In 1900 the average efficiency of U.S. thermal generation of electricity was about 8%. By 1960 it had surpassed 30%. A few years later it was around 33%. During the last 50 years it has stagnated around that 33% figure.[1] Yet we know that CCGT (Combined Cycle Gas Turbine) plant can achieve about 50% efficiency (rated to the same conditions as a coal-fired unit), and that 'supercritical' coal units can also achieve around 50% efficiency. That means there is scope for increasing the efficiency from 33% to 50% provided that we can produce all the electricity using the highest efficiency fossil fuel plant in its most efficient mode of operation. With CCGT, that means allowing it to operate at close to full capacity. With supercritical coal units, that means allowing them to operate within their "sweet spot" range. I contend that, while the flexibility provided by the latter would probably be enough to allow maximum efficiency to be maintained when coping with variations in *consumer* demand, it is unlikely to be sufficient to also cover the variations introduced by integrating a significant amount of wind power.

Comparison of the 33% and 50% figures show that there is scope to save 34% of the fossil fuel used for generating electricity. It is generally agreed that wind could not contribute more than 20% of electrical supply. If introducing wind has the effect of keeping the efficiency of fossil fuel plant down at 33%, then even if the electricity produced by wind produces *no* green house gases (not even those arising by construction and maintenance), then it would still save fuel not to use wind. This is because we would be wasting 80% of the 34% potential saving achieved by increased efficiency. That is to say we would save 20% with the wind, but we would waste 80 x 0.34 = 27% by reducing the potential for efficiency. I have spelt that out in detail, because some people cannot believe that introducing wind could actually result in the use of *more* fossil fuel.

To see to what extent theory and practice differ, I think it best to introduce reality gradually into the analysis. Let me start from an extreme — admittedly entirely impossible — scenario, before moving on to a more realistic second scenario.

Suppose, in Scenario 1, that the UK citizens use 45 GWyr/yr of electricity, and they never vary their demand, i.e. their demand remains constant at 45 GW through the whole year. I presume you would agree that given sufficient natural gas, one could satisfy that constant demand at something close to the efficiency of CCGT plant, albeit slightly degraded by the need to keep spinning reserve to cover sudden failure.

Now, as Scenario 2, suppose that demand varies similarly to how it varies in reality — day by day and seasonally — except that one could always predict *with perfect accuracy* what that demand would be.

Would you agree that the overall efficiency of electrical generation would drop compared to that in Scenario 1, and that it would drop *despite knowing in advance exactly what would happen?*

For whether you used CCGT, or a mix of OCGT and CCGT, plant could not be operated at the efficiency achieved in the constant demand situation of the first scenario. So the plant efficiency would drop significantly compared to the first scenario. Introducing OCGT would definitely cause a degradation and using CCGT would cause degradation because of the need to vary its output below the optimum.

George Your Scenario 1 is an extreme case, in which all the electricity is produced by CCGT — the most efficient type of plant available. Thus the overall efficiency, at constant demand, would be close to 50%.[2] I certainly agree that in those circumstances, if instead of the constant demand of Scenario 1, we vary the output, as per Scenario 2, that must lead to a degradation in the overall efficiency — to well below the approximate 50% of Scenario 1. However, that is too unrealistic a situation to be very helpful in seeing how demand variations can be dealt with efficiently in the real world. In both the UK and the USA we are becoming aware of the imminent insecurity of natural gas supplies. So let me suggest changing your Scenario 1 to make it say Scenario 1a. In Scenario 1a, let us posit that only 30% of the mean 45 GW is produced by CCGT with the remaining 70% being produced by the most efficient coal plant that has been used extensively, namely 'supercritical' coal-fired plant.

Andrew OK, I agree that is more realistic, at least looking to the future. Officially the UK is aiming to cease using coal-fired plant, but I think it is only a matter of time before it becomes apparent that doing that it is not a realistic aim.

George Please note that I am keeping to your brief of using the most efficient plant, but now we are being more realistic in accepting that we cannot use 100% CCGT. Note, too, that the important point about introducing supercritical coal-fired plant is that it has a 'sweet spot' in that the efficiency stays constant over about 40% of its operating range.

Andrew That is one point about which I have been uncertain. I thought that it was only the conventional coal-fired plant that had that wide 'sweet spot'.

George There is plenty of information regarding the efficiency curve versus load for a number of supercritical units. Supercritical plant is still a Rankine cycle machine.

Andrew OK that's fine then. I note that this has not changed the overall efficiency of the available fossil-fuelled plant but merely increases its overall flexibility.

George What we are aiming to do is to produce a mean 0.30 x 45 = 13.5 GW (that is 13.5 GWyr/yr) from CCGT, with the remaining mean 45 - 13.5 = 31.5 GW coming from supercritical coal-fired plant. To keep to maximum efficiency, we would operate the supercritical plant at about 80% capacity, so it had the flexibility to reduce to 60% or increase to 100% without losing efficiency. Thus to produce a mean 31.5 GW we would have 31.5 / 0.80 = 39 GW of coal capacity. The amount of *flexible* output built into that would be limited by the 40% 'sweet spot' range. Doing the arithmetic then: out of the 31.5 GW coming from the supercritical plant, a mean 0.60 x 39 = 23.5 GW would be inflexible, leaving a mean 31.5 - 23.5 = 8 GW as flexible output (note the *power* range available is 16 GW, but the electrical input is a mean 8 GW). Seasonal variations would require starting and stopping units. That would be needed anyhow for periodic maintenance and, as is done now, the schedules would be aligned to fit in with seasonal variations in demand. I surmise that 8 GWyr/yr of flexible output might be about sufficient to provide for variations in consumer demand. In summary then, by these means, the electricity demanded by Scenario 1a and Scenario 2 can be delivered with the same efficiency.

Andrew So keeping to my requirement of using the most efficient plant, you have convinced me that, at least with substantial use of supercritical coal-fired plant, there is a fair chance of being able to cover variations in consumer demand without losing efficiency. That's fine, but suppose that we now introduce *perfectly forecast* wind power, so as to provide 6 GW from wind, which would require another 14 GW of flexible input, as calculated in the *Plain Man's Questions Concerning Wind Power*. How would you find the additional flexibility required to provide that?

George OK, I will assume that in the course of satisfying the variations in consumer demand we have used up all the 'sweet spot' flexibility that is available from the supercritical plant. In that situation, from time to time, in order to deal with wind, we would have to close down and open up flexible plant, so as to provide for the further 14 GWyr/yr of flexible input that is needed as a result of introducing wind. Moreover I agree that in this scenario, opening up and closing down plant is the only way we could introduce the additional flexibility that variation in the wind demands. So what loss of efficiency would occur? If a unit is not cycled very often — shut down and returned to service that is — the efficiency loss is effectively zero. However, wind may blow strongly for an afternoon, die away overnight, and come back strongly next day. It all depends how often that happens; so there is no clear general answer to what the loss of efficiency would be in closing down and opening up supercritical plant to follow the variations of wind. What can be said is that perfect accuracy of wind forecasting would greatly reduce the extent of the loss of efficiency.

Andrew Now I see why the accuracy of wind forecasting is of pre-eminent importance. I had previously thought that opening up and closing down supercritical plant would always seriously impair the overall efficiency. I see now that whether introducing wind power into a system will actually save fossil fuel depends on the precise mix of plant, the extent of wind variation, and the accuracy of wind forecasting.

George That is generally true. In the real world there are many factors which determine the mix of plant that is used. These include: making full use of existing plant even though it is not as efficient as it might be, because it happens to be already there; keeping plant available especially to take advantage of the high prices that will be obtained for supplying electricity only when needed at times of peak demand or when rapidly dropping wind infeed increases the ramp rate. That is to say, generating firms are trying to minimize their costs and maximize their revenue. Maximizing the efficiency of fuel use is only one consideration for them. Suppliers, too, are concerned with minimizing their costs and with ensuring that the ramp rates can deal with the combined effects of changes in consumer demand and changes in wind infeed. In such a complex situation, it is really hard to have any clear idea of the loss of efficiency that is caused by the need to deal with variations in infeed from the wind.

Even if winds were perfectly forecast, there would be occasions when it would not be worth trying to make use of a few hours of strong winds, for example. In that case, simply not making use of the full wind output would ensure that the efficiency of the fossil fuel plant could be maintained. That would of course lower the infeed factor from the wind turbines, thus increasing the cost of 'wind electricity'. There are further complications in the real world. For instance, by regulatory fiat, electricity suppliers may not be allowed to reject available wind infeed.

In general, I contend that the efficiency of the fossil fuel plant can always be maintained provided the consequent increased cost is accepted, provided also that regulatory restrictions do not force the acceptance of all wind. For instance, if changes in wind can *not* be forecast with precision, then scheduling could be arranged so as to take from wind only that part of the wind output which could be absolutely guaranteed to be there in six hours time, say. That way the efficiency of the fossil fuel plant could be maintained, but the penalty would be to increase the cost of the electricity contributed by the wind.

Andrew I fully appreciate the force of your arguments. However, there is one further point which we have not yet touched on. We have agreed that the ability to use the output from perfectly forecast wind without decreasing the efficiency of the fossil fuel plant is a consequence of being able to close down and open up supercritical plant without a significant loss of efficiency. I believe that integrated gasification/combined cycle (IGCC) plant, which combines gas-turbine and steam-turbine cycles, offers improved prospects of being able to sequester carbon dioxide emissions, together with worthwhile reductions in other emissions. I know that experience of this type of plant is still somewhat limited, and that it is several times as expensive as CCGT, but will IGCC plant offer the same advantageous 40% 'sweet spot'? Could it also be closed down and opened up without significant loss of efficiency?

George Provided that the IGCC plant was designed for the purpose of being closed down on one day and opened up the next, then the losses would be fairly small. In fact the losses would be virtually limited to the amount of residual heat in the system that would be lost overnight. But it is an open question whether it would be possible to design IGCC for that purpose while maintaining the relatively high efficiency that IGCC and supercritical plant are capable of. There are also economic factors to consider: that is to say designing IGCC plant to allow it to cycle could be expensive, although I appreciate that your primary concern is efficiency rather than cost. I will return to efficiency later, but for the moment let us note that the advantage of IGCC is chiefly that it facilitates capturing emissions, including — most importantly — sequestering the carbon dioxide.

I still have not answered your question about the 40% 'sweet spot' range. The honest answer is that there is limited experience with IGCC, and I don't know the answer.

Now back to efficiency: Manufacturers tend to make the efficiency of their plant appear good if they can. For instance, they choose the Lower Heating Value (LHV) of the coal input, which is only about 90% of the Higher Heating Value (HHV). That enhances the apparent efficiency by about 5%. Thus one always needs to be sure that comparisons are made on the same basis. Supercritical and IGCC, operating at full load and using the HHV of coal, would both rate at about 40% efficiency. That is still a worthwhile improvement on conventional coal-fired plant, which on the same basis would be about 35% efficient.[3]

Andrew You have convinced me that, *with perfect wind forecasting*, and ignoring the cost aspects, there is at least a chance that wind could be introduced into a highly efficient, low emission, system (e.g., using IGCC to reduce emissions), without greatly impairing the efficiency of the plant that provides the DIB (dominant in-harness backup) for the wind. But in practice, wind is far from being perfectly forecast, so I think we can conclude that overall the extent of saving of fossil fuel by introducing wind is uncertain.

1. Figure 1.17, p. 41 of Smil, V. 2003. *Energy at the Crossroads*. Cambridge, Massachusetts: MIT press.
2. 60% is often given as the efficiency of the best CCGT plant, but this is only in theory, and is arrived at using the LHV (lower heating value) of the gas. The LHV of coal is about 90% of the HHV. To make the fairest comparison with coal plant, it is most realistic to ascribe an efficiency of 50% to CCGT.
3. Any reader who has relied on older data will be surprised by this 35% efficiency figure for conventional plant, a mere 5% lower than George's figure for supercritical and IGCC. I was puzzled, and quoted to him the information that I had come across in Professor Vaclav Smil's *Energy at the Crossroads* (ref. endnote 1). He responded to the various points I raised. I leave the text largely in the form he wrote it, using 'G.' to indicate his input, and 'A' for my input. G commenced with this general response.

   G. My experience with 1960 vintage power plants would confirm Smil's data, but 1990 and more recent vintage power plants are far more efficient. The 35% I quote is for a 1985 vintage power plant and is net at the transmission bus after step up to 345 kV for transmission. We are getting ready to start up a new subcritical coal unit with a design 37% efficiency at the high voltage bus. I look forward to its operation and performance verification. The new unit has SO_2 and NO_x ratings equal to or better than the two IGCC units currently in operation in the US. Old King Coal has not been standing around waiting for other technologies to pass him by.

   A. I see, but with 35% efficiency being ascribed to coal-fired plant with, under the same conditions, 40% being ascribed to supercritical and IGCC, the latter provide only a 1 - (35/40) =12.5% saving in fuel use compared to conventional.

   G. That is why we are building a subcritical unit, as the efficiency difference was too small to make up for the additional initial cost of a supercritical unit.

   A. Is full account being taken of the energy used in emissions reduction? I checked back in Smil (2003:233), and found that he said:

   > But neither electrostatic precipitators nor FGD [Flue Gas Desulfurization] do anything to lower the emissions of nitrogen oxides, and both systems consume some of the electricity generated by the plant. Fly-ash removal needs at least 2–4% of the generated total, and, depending on the process, FGD can use up to 8% of the gross electricity generation and hence these effective controls actually lower appliance overall fuel conversion efficiency.

   G. These numbers are no longer valid with the new technologies. The 35% figure is a net figure, as mentioned above.

   A. Smil appeared to indicate that significant PFBC development was in the offing. He started off by saying, "Pressurized fluidized bed combustion (PFBC) produces gas that is capable of driving a gas turbine and operating it in a combined cycle.

   G. This technology is still around but reliability issues and operating costs have placed it in a back burner position for acceptance.

   A. But Smil then went on to describe imminent PFBC developments:

   > Second generation PFBC will be integrated with a coal gasifier to produce a fuel gas that will be burned in a topping combustor, adding to the flue gas energy entering the gas turbine. PFBC boilers will occupy a small fraction of space taken up by conventional units burning pulverized coal and the process — predicated on the introduction of new burners, corrosion resistant materials, sorbents, and gas turbines, expected to be commercially available before 2010 — will combine near-zero NO_x, SO_2, and PM emissions with overall 52% conversion efficiency (DOE, 2001b). This performance would represent a 30–50% efficiency gain compared to conversion achieved in standard coal-fired power plants

   G. It's a nice thought, but it did not work in reality to attain utility class reliability and low operating costs. Anyhow the DOE method of measuring efficiency is misleading (it's based on using the energy in the gas produced from coal as the input to the efficiency calculation, not the coal itself).

   A. Many thanks. I can see that Smil is out of date and relying on hope rather than firm achievement.

WHY WIND POWER WORKS FOR DENMARK, by Hugh Sharman

A commentary by Andrew R.B. Ferguson

Abstract

Drawing on data from the above titled paper by Hugh Sharman, it is manifest that introducing a significant amount of wind power (say 15% of electricity) into the UK is likely to prove more difficult than doing the same in west Denmark. Moreover, even if the use of wind is supported by concerted efforts to introduce combined heat and power, and to use biomass, the overall effect on carbon emissions is likely to be insignificant.

The author of the paper *Why Wind Power Works for Denmark* is Hugh Sharman, principal of international energy consulting broking company Incoteco (Denmark) ApS. Sharman's paper was published in May 2005, in the journal of Civil Engineering (pp. 66-72). The paper contains a wealth of information, but for the sake of brevity I am going to choose only some salient points to comment on. Before embarking, we should note that west Denmark (population 2.7 million) has a separate grid from east Denmark. Sharman's paper concerns itself with west Denmark.

Wind penetration

How far has Denmark progressed along the road of making full use of wind? At the end of 2003, west Denmark had an installed wind capacity of 2374 MW (see endnote 1 for the meaning of symbols and terms), which works out at 880 watts of installed wind capacity per person. For the UK to have a similar wind penetration, with its population of 60 million, it would need to have 53 GW of wind capacity. That is a formidable amount, considering that the total electricity demand in the UK, in 2004, was a mean 46 GW. In other words, Denmark is a good example of an attempt to make maximum use of wind. Therefore there should be much to learn from Denmark, provided that its wind conditions are similar.

Similarity of wind conditions

The best guide to similarity of wind conditions comes from load factors. We can use data from one of Sharman's graphs (his Fig. 6), in order to tabulate the load factors for UK onshore and for west Denmark (the UK data is in fact the somewhat dubious Dti data):

Table 1. Load factors for UK onshore, and west Denmark

Year	UK %	west Denmark %
1999	28	20
2000	28	21
2001	26	20
2002	30	19
2003	24	21

It is clear that wind conditions in the UK are significantly better, though not dramatically so. But apart from that, what is particularly interesting is the plunge in the UK onshore load factor from 30%, in 2002, to 24%, in 2003. Sharman comments:

> As time goes by and the development of wind power at the best wind sites gives way to less favourable ones, the specific output at each new site in the UK is likely to decline further.

While that argument — of declining site quality — makes sense, some Dti data relies substantially on estimates, and also it is an open question whether the explanation does not lie mainly in the way the 'load factor' is being measured. If the figures in the table are in fact 'infeed factors' then there are other reasons for the drop. By 'infeed factor', I mean the actual amount of electricity *fed into the grid* from the wind turbines, rather than the amount of electricity *produced* by the wind turbine. Most reports fail to make the meaning of 'load factor' clear, although the difference can be very significant. When a new regulation was introduced into the UK that suppliers of wind power electricity must state the output to be delivered four and a half hours ahead, this led to a 14% drop in infeed to the grid. In view of some of Sharman's figures showing the relation between wind strength and output, that is not at all surprising.

Sharman's Figure 11 shows that between wind speeds of 5 m/s and 13 m/s, the power output in west Denmark increases linearly with the change in wind speed. Each 1 m/s increase in wind speed produced an increase in output amounting to *about* 10% of the rated capacity of the wind turbines.[2] On that basis, and assuming that wind suppliers must guarantee their stated production, we can say that if the suppliers of wind lack confidence in the wind forecast to the extent of only 1 m/s, the proportion of electricity produced by the wind turbines that would *not* be sent to the grid would vary according to the output as follows.

Table 2. Loss of infeed due to an uncertainty of wind strength of 1 m/s

Wind speed in m/s appropriate to actual output (1 m/s = 2.24 mph)	6.5	7.4	8.2	9.1	10.0	10.8	11.7	12.6
	%	%	%	%	%	%	%	%
Elec. produced as proportion of installed capacity	20	30	40	50	60	70	80	90
Output sent to grid after allowing for 1 m/s error	10	20	30	40	50	60	70	80
So waste of power due to uncertainty of wind	**50**	**33**	**25**	**20**	**17**	**14**	**12**	**11**

It is apparent that only as we get to the higher wind speeds do the losses of input to the grid become relatively painless; one hardly needs to point out that at those higher wind speeds it becomes even harder to forecast wind speed to within an accuracy of 1 m/s. The conclusion is obvious. The amount of electricity from wind turbines that is fed into the grid is highly dependent upon both the accuracy of forecast and the regulations concerning what the penalties are for suppliers of wind electricity who fail to deliver what they have stated they will deliver. Much uncertainty surrounds the subject when (as is usual) load factors are given without specifying whether they are capacity factors (the amount of electricity produced) or infeed factors (the amount of electricity fed into the grid), or without explaining the regulations that apply to delivering electricity to the grid.

Interconnectedness

What is dramatically different between west Denmark and the UK is the degree of interconnectedness to adjacent countries. As Sharman explains, "West Denmark is tied into the much bigger grids of its neighbours Sweden, Norway and Germany with a total interconnector capacity of 2400 MW." This works out at 889 watts of interconnector capacity for each of the 2.7 million inhabitants of west Denmark. Were the 60 million inhabitants of the UK to enjoy such interconnectedness, the interconnector capacity would be 53,000 MW. In fact the UK has only one 2000 MW connector (to France).

The next question is how much does west Denmark need to make use of its interconnector capacity in order to cope with its variable wind output? Let us note, incidentally, that the interconnector capacity is approximately the same as the 2374 MW rated capacity of the wind turbines, so there is plenty of interconnector capacity available. Sharman produces a graph which shows that, hour by hour, the net exchange over the interconnectors closely mirrors the wind output. For example, when the mean power output from the wind turbines, over an hour, is 1400 MW, the power fed through the interconnectors is 1400 MW. Of course the correlation is not always perfect, but it is so striking that the graph looks, at first glance, as though the net exchange is a mirror image of the wind output. Thus Denmark relies on adjacent countries to balance its wind output. The reason that it is able to do this is not only the interconnectors, but also because of the substantial use of hydropower in Norway and Sweden. As Sharman says:

> The success of the interconnections has much to do with the extent to which Sweden and Norway generate hydropower — which can supply 50% and nearly 100% of their respective needs from water turbines. Hydropower output can be adjusted very rapidly as the highly variable wind power flows through the interconnectors.

As Sharman also observes, since the UK lacks adequate interconnectors to nations using large amounts of hydropower, it will have to meet the fluctuations in wind output by varying the output of its fossil fuel plant. The extent to which it is possible to do that without loss of efficiency, and without incurring excessive cost, requires a lengthy discussion and is the subject of another paper. Here we will dwell briefly on the task that the fossil fuel plant would have to accomplish.

Sharman gives figures to show that the *peak* infeed from the wind system in west Denmark, during 2003, was 84%. We can also make use of the 80% figure from the 800 km spread of the E.ON Netz grid (in Germany). Together, these confirm that the UK should be able to lower its *peak* infeed to 80%. Thus with the mooted 53,000 MW of wind capacity, the peak infeed from the wind turbines would be 42,000 MW. With say a 25% infeed factor, the wind turbines would supply a mean 13,000 MW. Thus fossil fuel plant would be called upon to provide a mean 29,000 MW of balancing power, at outputs anywhere between 42,000 MW and zero MW. The task of doing that without loss of efficiency is daunting, especially on those fortunately rare occasions when a change over the full range occurs during a 24 hour period.

Anticipated difficulties in introducing significant wind power into the UK.

It is evident that the UK will find difficulty in arriving at the degree of wind penetration that has been achieved in west Denmark. Sharman gives figures to show what that penetration is in terms of actual output rather than capacity. Expressed in terms of mean power, west Denmark's production from wind generators during 2003 was a mean 498 MW, out of total electricity *production* of a mean 3082 MW; that is wind produced 16%. A different figure can be given based on the mean electrical *consumption* of 2283 MW.

On that basis, wind supplied 22%. One reason for encountering different figures for wind penetration is that both these measures have some validity. Whichever figure we use, it is clear that while the better winds of the UK will help the UK to some extent, its lack of connections to nations that make massive use of hydropower will make it hard for the UK to attain west Danish levels of wind penetration.

Attempting to reducing carbon emissions

Sharman explains that Denmark has followed other paths beside the use of wind power in its attempt to reduce carbon emissions. The main one has been to make use of combined heat and power plants (CHP). Sharman describes the efforts thus:

> In 1900 west Denmark had six large power stations, all of them designed as combined heat and power plants providing district heating to west Denmark's largest towns. Five are coal-fired power stations and the sixth is designed for ultra-supercritical steam operation on gas. The coal-fired station near Aalborg has since been extended and this and the gas-fired station are now the most efficient Rankine-cycle plants in the world. The installed capacity of the main thermal power stations at the end of 2003 was 3.5 GW.
>
> During the past 15 years there was also an intensive construction programme to upgrade the district heating plants in most Danish towns and villages to combined heat and power. The total capacity of these 'de-centralised' power units in 2004 was 1450 MW.

So Denmark has made extensive efforts to deliver heat and power efficiently. It has also taken steps to encourage the burning of biomass. Furthermore it has introduced more wind power than is likely to be viable in the UK. So what overall success has there been during nearly 15 years? Very little judging from the fact that Denmark's carbon dioxide emissions have *increased* slightly between 1990 and 2002.[3] Of course other factors may have led to the increase, but those factors are equally likely to be operative in the UK, and are likely to remain so even if the UK attempts to follow Denmark in the above extensive efforts. As far as the wind turbine contribution is concerned, it has to be said that if wind turbines have led to any *reduction* at all in the *increase* in carbon emissions which would otherwise have occurred, then that *reduction in the increase* is hard to detect.

Endnotes

1. A watt is a unit of power, defined as 1 joule/second. 1 MW is 1 x 10^6 watts, that is a million watts. 1 GW is 1 x 10^9 watts, a billion watts. 1 metre/sec (m/s) = 2.24 mph.

   There is no general agreement about the use of the terms that describe wind output, but I prefer to use the following terms (with the denominator being the rated capacity of the wind turbines):

   a) "Infeed factor" — the amount of electricity fed to the grid;

   b) "Capacity factor" — the amount produced by the wind turbines. This is the higher figure often stated by wind energy associations;

   c) "Load factor" as a reference to the general idea contained in the previous two, i.e., when it is impossible to be sure what the figures are actually referring to.

2. Sharman's Figure 11 actually shows a figure of about 12%. The 10% figure has been chosen to err on the side of optimism.

3. This information is drawn from another paper by Sharman: *The Dash for Wind: West Denmark's Experience and the UK's Energy Aspirations*, accessed February 2005, and taken from the web at: http://www.glebemountaingroup.org/Articles/DanishLessons.pdf

Perhaps there is a need to reiterate the reason that OPT is so interested in wind turbines. Fossil fuels provide a very high power density (the amount of power obtained divided by the area used for collecting it). Very roughly, oil extraction can be equated to capturing *all* the sunlight that falls on a particular place on the Earth in the course of a year. As an average figure for the USA, that is 2000 kilowatts per hectare (or 200 W/m^2). The best available estimates suggest that using a mix of renewable energy sources, a power density of 3 kilowatts per hectare could be achieved. We use that figure, and eco-footprinting, to calculate that it might be possible to support, in moderate comfort, a population of 2 billion, using only renewable energy. Wind turbines appear to have the potential to significantly raise that very low figure of 3 kW/ha. However, the more that one studies the problems of making use of this intermittent power source, the more apparent are the limitations as outlined below.

WIND IN WISCONSIN

by Andrew R.B. Ferguson

Abstract

A recent wind report showed that the load factor being achieved in Wisconsin was 21.5%. Since considerable obscurity surrounds the subject of capacity factors, there are cogent reasons for studying any capacity factors that become available. There is also a need to encourage the publication of other closely related data about the delivery of electricity from a specified collection of wind turbines, for there is often an absence of relevant data as well as uncertainty about the precise meaning..

Easily located at **www.windcows.com** is a 144 page report, dated 1 July 2004, titled *A Study of Wind Energy Development in Wisconsin*, offered as a 4.5 MB pdf file. The report concerns 55 turbines with a total capacity of 53 MW. It states that these produce about 100,000 MWh per year — only about 0.15% of all the electricity used in the state. Small though that is, it occurred to me that the report may throw light on the uncertainty surrounding the load factors of wind turbines in the USA. The general uncertainty for the USA arises because of two data sets which, it seems to me, are at too great a variance to be plausible. In the first edition of Howard Hayden's *Solar Fraud*, he states: "In 1998, wind turbines in the United States produced 3.5 billion kWh, equivalent to around the clock average power of 399 MWe. The wind turbine capacity was 1700 MWe. The average *capacity factor* was therefore 399/1700, or 23.5%."

Yet on page 28 of the second edition,[1] Hayden writes: "In 2002, wind turbines in the United States produced 10.5 billion kWh, equivalent to around the clock average power of 1200 MWe. The wind turbine capacity was 4000 MWe, but the effect was as if the wind blew hard for 30% of the time."

I found it improbable that in four years there would be so great an increase in the capacity factor, from 23.5% to 30%, and I asked Hayden if he could check that the data were being measured in the same way. So far, he has not managed to throw any light on the subject (which is also obscure in the UK). Thus any relevant data, even of the minor kind provided by the Wisconsin report, has to be of some interest.

Since the Wisconsin report indicated that the 53 MW capacity produced an output of 100,000 MWh during the year — a mean power of 11.4 MW — the load factor (or capacity factor) is 21.5%.

Of course the figures from Wisconsin are not likely to be representative of the average in the USA, but all such reports should be examined to see if they contribute to knowledge of capacity factors. Figures to establish capacity factors are rarely given. When they are, it is usually without giving sufficient detail to know if the electricity that is said to be *produced* by the wind turbines is the same amount as that *delivered to the grid*. In the UK, when the generators of wind turbine electricity had to specify their output four and a half hours ahead, it led to a 14% drop in the electricity delivered to the grid, so the difference is of some importance.

Because this Wisconsin report did not mention the capacity factor being achieved, it is not surprising that it did not recognize the importance of *peak* capacity factor, i.e. the maximum output that is actually achieved from the rated 53 MW of wind capacity. With wind turbines spread over 800 km, as they are in the E.ON Netz network in Germany, there was a useful reduction (from the rated capacity) in the *peak* capacity factor. It was down to about 80% of the turbine capacity (data for 2003). However, that would not be true of Wisconsin's 53 MW of capacity. For such a small capacity, with a presumably small geographical spread, it is unlikely that the *peak* capacity factor would be significantly below 100%. Taking it at 100%, means that in the course of delivering the aforementioned mean 11.4 MW of electrical power, the wind intermittently achieves 53 MW of power, which of course is a problem for the demand-following fossil fuel plant, which must supply the remaining mean power of 53 - 11.4 MW = 41.6 MW.

The other factor that the report did not mention is the maximum output during that half of the year when the wind is at its lowest; more precisely, during the 4380 hours when the wind is weakest. For 2003, the E.ON Netz figure was 11%, meaning that, during the low-wind half of the year the wind turbines were producing only about 5.5% of their capacity. In the absence of data, about all that can be said about Wisconsin, as indeed about the UK (with a mean capacity factor of 24% in 2003), is that it is unlikely to be lower than 5.5%, since the E.ON Netz network achieved a capacity factor of only 16% in 2003.

All three factors given or thus deduced, 21.5%, 100% and 5.5% are important. The chief point of this memorandum is to encourage the publication of more useful wind reports — especially ones which lead to a clear knowledge of the load factors (in precisely defined terms) that are being achieved.

Another important point to bear in mind is the degree to which wind is 'prioritized'. If electricity suppliers are *required* to accept all wind, however inconvenient it may be to do so, then of course higher infeed factors for wind turbines can be achieved. Note, incidentally, that I prefer to use the following terms (with the denominator being the rated capacity of the wind turbines):

a) "Infeed factor" — the amount of electricity fed to the grid;
b) "Capacity factor" — the amount produced by the wind turbines. This is the higher figure often stated by wind energy associations;
c) "Load factor" as a reference to the general idea contained in the previous two, i.e., when it is impossible to be sure what the figures are actually referring to.

Of course, the terminology that is used is not important provided the meaning is made clear.

1. Hayden, H. C. 2004. *The Solar Fraud: Why Solar Energy Won't Run the World* (2nd edition). Vales Lake Publishing LLC. P.O. Box 7595, Pueblo West, CO 81007-0595. 280 pp.

David Willey and I eventually decided that globalization fell within the scope of what OPT is trying to do, saying in the introduction to our paper, *The Social and Ecological Consequences of Globalization* (OPJ 3/1):[1]

> Globalization — making the world into a free market for capital and goods — does have implications for carrying capacity, as well as many dire effects, so we think it is now time to produce a final version of this paper, which was first circulated as a "discussion paper" in April 1999.

James Goldsmith, 1995, and Edward Goldsmith & Jerry Mander, 2001, in their respective books, addressed the arguments against globalization. But still it was satisfying to find that, in the September/October 2004 issue of *World Watch*, Herman Daly, professor in the school of public affairs in the University of Maryland and a former World Bank economist, covered the subject on lines closely similar to ours, putting special emphasis on the population implications. With that introduction, I will let Daly speak for himself.

POPULATION, MIGRATION, AND GLOBALIZATION by Herman E. Daly

using only direct quotations, as selected by Andrew R.B. Ferguson

What are the consequences of globalization for national community? Here in the United States, we have seen the abrogation of a basic social agreement between labor and capital over how to divide up the value that they jointly add to raw materials (as well as the value of the raw materials themselves, i.e., nature's oft-uncounted value added). That agreement has been reached nationally, not internationally, much less globally. It was not reached by economic theory, but through generations of national debate, elections, strikes, lockouts, court decisions, and violent conflicts. That agreement, on which national community and industrial peace depend, is being repudiated in the interests of global integration. …

Some feel that U.S. economic policies have harmed third-world citizens, and that easy immigration to the U.S. is a justified form of restitution. I have considerable sympathy with the view that U.S. policies (precisely those of globalization) have harmed third-world citizens, but for reasons already stated, no sympathy with the idea that easy immigration is a fair or reasonable restitution. For restitution I would prefer a series of small grants (not large interest-bearing loans), accompanied by free transfer of knowledge and technology. …

Global economic integration and growth, far from bringing a halt to population growth, will be the means by which the consequences of overpopulation in the third world are generalized to the globe as a whole. … In the scramble to attract capital and jobs, there will be a standards-lowering competition to keep wages low and to reduce any social, safety, and environmental standards that raise costs. …

Demographers and economists have understandably become reluctant to prescribe birth control to other countries. If a country historically "chooses" many people, low wages, and high inequality over fewer people, higher wages, and less inequality, who is to say that is wrong? Let all make their own choices, since it is they who will have to live with the consequences.

But while that may be a defensible position under internationalization, it is not defensible under globalization. The whole point of an integrated world is that these consequences, both costs of overpopulation and benefits of population control, are externalized to all nations. …

The old conflict between Marx and Malthus, always more ideological than logical, has now for practical purposes been further diminished. After all, both always held that wages tend toward subsistence under capitalism. Marx would probably see globalization as one more capitalist strategy to lower wages. Malthus might agree, while arguing that it is the fact of overpopulation that allows the capitalist's strategy to work in the first place.

1. OPTJ 3/1. 2003. *Optimum Population Trust Journal*, Vol. 3, No 1, April 2003. Manchester (U.K.): *Optimum Population Trust*. 32 pp. Archived on the web at http://members.aol.com/optjournal2/optj31.doc

"THE HYDROGEN ECONOMY": REALITY OR FANTASY?

by Andrew R.B. Ferguson

Except that short titles are more handy, I would title this article:

> Comments on "Appendix G: *Hydrogen production technologies: additional discussion*", from the report, "*The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs*," 2004, which was produced by the "Committee on Alternatives and Strategies for Future Hydrogen, Production and Use," which committee made use of advice from the 'Board on Energy and Environmental Systems', 'Division on Engineering and Physical Sciences', the 'National Research Council' and 'National Academy of Engineering', in brief, a report by the US National Academy of Sciences.

That lengthier title still requires a further explanation, to the effect that David Pimentel kindly sent me a dozen well-chosen pages from that appendix to the 240 page book. The following comments relate to those pages. That may seem to rather circumscribe this critique, but those pages actually get to the nub of the question which naturally arises from the name of the book, "*The Hydrogen Economy*." That question is whether there is a source of power which will be available to produce hydrogen (an energy carrier) in adequate quantity, when fossil fuels become scarce. In other words, is 'The Hydrogen Economy' a fantasy or a real possibility? Let us investigate.

For those who wish to see the whole of Appendix G, there is access to it via the web. Appendix G covers pages 198 to 239. You can start at the beginning of the appendix by going to:

http://books.nap.edu/books/0309091632/html/198.html

The Appendix asks the right questions. The questions that we will address here are how accurate is the information used, and has the committee remembered to include all possible relevant factors. Needless to say, I have some points to raise on both aspects.

p. 225 says:

> Estimates show that U.S. wind resources could provide more than 10 trillion kWh (Dayette et al., 2003; Elliott and Schwartz, 1993) which includes land areas with wind class 3 or above (corresponds to wind speeds greater than 7 meters per second at a height of 50 m [7 m/s = 16 mph]), within 20 miles of existing transmission lines, and excludes all urban and environmentally sensitive areas. This is over 4 times the total electricity currently generated in the United States.

We may note that this 10 trillion kWh/yr estimate is 13 times as much as the figure of 777 billion kWh/yr given by the AWEA only a few years ago (OPTJ 2/2, p. 42), but as 10 trillion is supported with two references, the latest in 2003, we can take the figure as valid. However, the committee are misleading in suggesting that 10 trillion kWh/yr is equal to 4 times the total electricity currently generated in the United States, namely 3.7 trillion kWh/yr. In fact, by the time transformation losses and inputs have been taken into account, the 10 trillion kWh/yr is unlikely to be sufficient to replace the 3.7 trillion kWh/yr currently being used, leaving nothing over for hydrogen production.{1}

Perhaps we should note, too, that 10 trillion kWh/yr, supplied with turbines operating at 30% capacity factor, would cost, at $1 per watt of capacity, about 3.8 trillion dollars, which spread over 30 years is equal to 127 billion dollars a year. Such expenditures are possible today, but probably not in a renewable energy world.

The costs of electrolysers and fuel cells is somewhat uncertain at the present stage, since the committee says, page 222:

> The committee find it plausible that electrolyzer capital costs can fall by a factor of 8 — from $1000 per kW in the near term to $125 per kW over the next 15 to 20 years, contingent on similar cost reductions occurring in fuel cells. This reduction seems obtainable when considered against the claims by fuel cell developers that they can bring the cost of fuel cells to $50/kW from today's nearly $5000/kW prices.

What can be said is that at present costs, the electrolysers would add a further $600 billion and the fuel cells an extra $1800 billion to the bill, for a total of $2400 billion. With the reductions considered "plausible" by the committee, the total costs would be reduced to an eighth of that, and amount to $300 billion. That would be small compared to the total wind turbine cost of $3800 billion. The most important question, and the most difficult to answer, is what costs could be borne in a renewable energy world. {2}

p. 228. AWEA's claim that wind turbines can pay — in energy terms — for the materials used to make them in as little time as 3 to 4 months could be misleading. For one thing, that estimate, more or less certainly, uprates the turbine output to its thermal equivalent, which is dubious logic when looking to a renewable energy world (in which we are likely to use electrical energy when, with fossil fuel available, we would have used thermal energy). Moreover, the statement appears not to include energy inputs for access roads and maintenance. One thing that always needs to be borne in mind is that wind turbines produce *electricity*, whereas the mining of minerals, transport of same, the installing of the wind turbines and transmission lines, and the maintenance of these, all involves a *liquid* form of energy, which is much more difficult in a renewable energy world. In short, there is no easy answer to how much of a wind turbine's output is required, directly or indirectly, to satisfy the inputs. The ratio given in Pimentel and Pimentel (1996, p. 206) is 1:5, i.e. input is a fifth of the gross output. I think that this is probably in the ball park, while admitting that any attempt at a proper analysis involves a good deal of surmise.

p. 229 says, "The energy content of common biomass collected from natural ecosystems contains only on the order of 0.4 percent of the primary incoming energy. …higher yields (in the 1 to 5 percent range) have been reported for some crops (e.g., sugarcane)". Both those figures are incorrect. 3 t/ha/yr is a generally agreed annual natural yield of wood, and taking the insolation at 200 W/m^2 it represents about 0.1%. This agrees with Pimentel and Pimentel who say on page 36: "0.1 percent is the average conversion for all natural vegetation in North America." With regard to the sugarcane figure, even with the high yields of sugarcane achieved in Brazil, 80 fresh t/ha/yr (stalks only), and after adding cane tops, green leaves and dry leaves, energy capture is 16 kW/ha (OPTJ 5/1 p. 4). Taking insolation in cane growing areas as 2200 kW/ha, that would be 0.7% of insolation.

In Appendix G, the mean yield for switchgrass is taken to be 12.2 dry t/ha/yr. The calorific value of switchgrass is 18.4 MJ/kg (El Bassam, 1998, p. 262). So *gross* energy yield is 225 GJ/ha/yr = 225 / 31.5 = 7.14 kW/ha. At the average U.S. insolation of 1900 kW/ha, that is 7.14 / 1900 = 0.4%. With only a few special crops, such as sugarcane, is the yield of crops significantly above 0.5%, so the upper end of the range given, 5%, is in error by an order of magnitude. By such confusions, we can easily be led into a fantasy world! Incidentally, the 5% probably refers to the peak efficiency in capturing insolation, for Pimentel and Pimentel (1996, p. 14) state that, "during sunny days in midsummer and when plants are nearing maturity, crops such as sugarcane capture as much as 5 percent of the sunlight reaching them."

p. 230. Three sets of figures are given on this page showing the fraction of hydrogen, by weight, which the committee estimate could be extracted from dry biomass. The fraction is about 8.0%. Corn cobs (7.6% H_2 by dry weight) and rice hulls (8.4% H_2 by dry weight) are two items with unusually high hydrogen content, so it appears that the committee are assuming that just about all the hydrogen can be extracted from the biomass. This seems somewhat improbable, especially as the PyNe (Pyrolysis Network) April 2004 issue, p. 11, reported 2% extraction of free hydrogen, by weight, from "wheat straw." However doubtless that operation was not designed to maximise hydrogen extraction. Perhaps somewhere else in the report the committee justify their high hydrogen extraction figure.

We should also note that with hydrogen's calorific value of 120 MJ/kg, and with that of dry biomass being about 17.5 MJ/kg, the hydrogen extraction rate in terms of heat value is (0.08 x 120) / 17.5 = 55% of the calorific value of the biomass. Again this seems improbably high but as will be shown later we hardly need to concern ourselves whether it is right, since even at this high gross extraction rate, biomass provides a very low *net* energy capture (amount of energy captured per ha per year), partly because of the points of the next paragraph.

The biggest omission of the report is the failure to account for the inputs in producing, harvesting and converting the switchgrass into hydrogen. In order not to take too many nutrients out of the soil, I would have thought that once the hydrogen had been extracted, the nutrients from the crop should be returned to the soil, but the process of doing so would add further inputs — in the form of liquid energy — to those required for planting, fertilizing, harvesting and transport. I imagine another input might be drying the crop, at least on occasions. Perhaps some of the inputs could come from the rest of the feedstock but, as with wind, a plague of questions surrounds the different *types* of inputs needed (a good reason for the appendix to ignore the problem altogether!).

p. 232 says, "Considering the low energy content of biomass, between 0.2 percent and 0.4 percent of the total available solar energy is converted to molecular hydrogen." It must be doubtful if that is right. Let us make the assumption that all 8% of the hydrogen which the biomass contains is captured, i.e. made available; then 12.2 t/ha/yr will give 12.2 x 1000 x 0.08 = 976 kg of hydrogen = 976 x 120 MJ = 117 GJ/ha/yr = 117 / 31.5 = 3.71 kW/ha. Taking the average insolation in the US as 1900 kW/ha, that is 3.71 / 1900 = 0.2%. Thus the upper end of the range, 0.4 %, is about double a possibly realistic value for the proportion of insolation that ends up as hydrogen.

p. 233 says, "Currently, the solar-to-electrical conversion efficiency of newer photoelectric processes is 15 to 18 percent". Within the context, this could be misleading. The efficiency of PV in the field is in the region of 70% of the efficiency under test conditions, so in the field, the 15% becomes 10.5% and the 18 percent 12.6%. Moreover with a 2 to 1 shading ratio, as percentage of insolation captured, those figures are halved (see below — the comment referenced page 235b — for a more precise explanation). However the above is merely taking note in passing, since even at 5% of insolation, PV is 50 times better than natural biomass (0.1%) at capturing insolation. PV problems are not 'power density', but rather *cost* and *intermittency*, as mentioned later.

p. 235a. The *Introduction* to the *Hydrogen from Solar Energy* section starts:

> It has been estimated that solar energy has the potential of meeting the energy demand of the human race well into the future.[29]

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29. Nathan Lewis, California Institute of Technology: "Hydrogen Production from Solar Energy," presentation to the committee, April 25, 2003.

I see this observation as dangerously misleading. Of course there would be no problem if we could capture *all* insolation that falls on land. But virtually the only large scale *flexible* energy source is biomass, and the efficiency of capture is about one part in a thousand — as Pimentel and Pimentel (1996, p. 36) says is the case "for all natural vegetation in North America and is about the average for U.S. Agriculture." Thus taking mean insolation of the USA as 2000 kW/ha, *gross* energy capture is 2.0 kW/ha. As we have seen with switchgrass, we can maybe push that up to 7.14 kW/ha (0.4% of insolation), but we also need energy in liquid form, and the *net* energy capture for that is very low. Taking ethanol from corn as an example and including benefits from co-products, it is a mere 0.6 kW/ha (OPTJ 3/1, p. 11), about 0.03% of insolation. Moreover ethanol from corn, like ethanol from sugarcane, is *not sustainable*. Hydrogen from wind turbine electricity is dubious because of intermittency and cost (see below), and hydrogen from biomass is at best a gross 55% of the energy in the biomass, so the 7.14 kW/ha *gross* that we calculated above for switchgrass becomes 3.9 kW/ha *gross* as hydrogen. If we allow that a third of that will go to inputs, then the figure becomes a *net* 2.6 kW/ha (0.14% of insolation). With such percentages, the prospects of "meeting the energy demand of the human race well into the future" seem doubtful to say the least.

Wind turbines, despite their intermittency, could deliver some electricity directly, but we should take note of the fact that Denmark started running into difficulties when electricity from wind turbines constituted 13% of their total electricity production (by time the 21% level was reached, 40% of wind turbine output had to be offloaded to other countries). The State of South Australia have decided they will need to at least pause in expansion of wind at the point at which it will be supplying 10% of electricity (having already noted difficulties), and E.ON Netz GmbH, in their *Wind Report 2004*, recounted considerable difficulties in integrating wind even though it only contributes 4% of German electrical supply. Taking these factors into account, a *net* energy capture of 3.0 kW per ha of ecologically productive land seems in the ball park (see also page 17 of OPTJ 2/2). Americans currently use about 9 kW of thermal energy per person *net* (net of the energy needed to collect it). Thus each American would require 3 ha of ecologically productive land to maintain present energy use from renewables. For 300 million Americans that amounts to 900 Mha. That is approximately equal to the ecologically productive land area of the USA (including lakes and rivers but excluding urban, marshes and desert)!

There seems little doubt, therefore, that Pimentel et al. were prescient when, in 1998, they argued that Americans need to start the process of halving their energy consumption per capita and of reducing the population of North America to 200 million. In that context, the complacent view quoted above, expressed at the start of the *Introduction* to *Hydrogen from Solar Energy* section, seems in direct opposition to wisdom. On the above estimate, of a 3 kW/ha energy-to-land ratio, a population of 200 million, using *half* as much energy as today, would require, *for energy provision*, 300 Mha of ecologically productive land. Perhaps that would leave sufficient cropland and pasture for food, and forest for timber, and perhaps it would even allow some fertile land for the rest of nature!

p. 235b. The first paragraph on the right side of the page, referring to PV, ends with the words, "The current technology gives about 18 percent cell efficiency and 15 percent module efficiency." While that is strictly true, it is somewhat misleading, as the efficiency of PV in the 'real world', that is out in the field, is less. To be somewhat more precise than I was in my comments on page 233, I should say that out in the field the module captures about 70% of the insolation falling on a horizontal flat plate of the same area as the module. Thus, if the insolation on a horizontal plate is 200 W/m^2 (typical of the US), and the module efficiency is 15% the energy capture, using an optimally inclined module, will be 200 x 0.15 x 0.70 = 21 watts/m^2, which is 21 / 200 = 10.5% of the insolation on a horizontal plate of the same area. (Of course the insolation falling on an optimally inclined plate, namely the module, is higher, but it is easier, and satisfactory, not to bother about the precise amount of insolation that falls on the module).

I also note that no mention is made of the capacity factor of PV cells, although that is almost as much of a problem as the fairly low capture rate of 10.5% of insolation, or 5.25% allowing for shading. The term 'capacity factor' is used somewhat vaguely, so let us use 'infeed factor' meaning the amount of electricity that is fed into the grid as a proportion of peak power. Under average US insolation — of about 2000 kW/ha — the infeed factor of PV is about 14% (e.g. 21 watts / 150 watts of rated capacity = 14%). The significance of this becomes apparent when considering the possibility of making hydrogen using a *constant* electrical supply. With a 14% capacity factor, for continuous operation, only 14% of the electricity would come from PV, with the remaining 86% coming from a flexible power source. Clearly that is not as good as wind turbines if they can achieve an infeed factor of 30%, with a peak infeed of 80%. That would mean 30 / 80 = 38% could come from wind and 72% from a flexible power source. The cost of PV probably rules it out anyhow, but perhaps one should not lose sight of its infeed factor problem.

General problems of renewable energy

The two great problems of renewable energy are:

(1) the low *net* 'energy capture' (also called 'power density') that can be achieved from *flexible* energy sources (for large quantities of energy, 'flexible' essentially amounts to biomass, for while hydropower is usually highly flexible, it is limited);

(2) the high total dollar cost of producing hydrogen from an intermittent wind source such as wind turbines.

Wind turbines admittedly have a fairly high energy capture, and thus escape the first problem. We may note, in that regard, that a turbine of 1 MW of capacity needs about 25 hectares of protected space, and at a 30% capacity factor it would produce 300 kW. On that basis, its power density, *gross*, is 300 / 25 = 12 kW/ha. One can also note that turbines only monopolize about 2% of the land, and on that basis power density is 600 kW/ha. There is also the point that the output is electrical, and the 600 kW of *electricity* per ha could be uprated to 1820 kW of thermal equivalent energy per ha. However, the final step is not really legitimate in a renewable energy world, where it is easier to come by energy, *at a high power density*, in the form of electricity than in the form of thermal energy — in other words, electrical energy may need to be used in lieu of thermal energy in a renewable energy world.

As we have seen with reference to page 225, 10 trillion kWh/yr of output from wind turbines would probably not be sufficient to replace the 3.7 trillion kWh/yr of electricity which is consumed by the US at present. Thus while maximum installation of wind turbines might almost satisfy electricity demand, the remaining two thirds of fossil fuel consumption, including the most difficult, liquid energy, remains uncovered.

Let us briefly review the problems associated with exploiting the wind resource:

(a) the cost of installation and maintenance of the wind turbines including access roads, and we must note that if electrolysis is 70% efficient and fuel cells are 60% efficient then there is a need for 1 / (0.7 x 0.6) = 2.4 times the installation of wind turbines, in order to produce the same amount of electricity, after producing the hydrogen and returning it to electricity, as compared to supplying the electricity directly.

(b) the cost of the electrolysers being run on an intermittent basis due to wind variability (Appendix G assumes a cost reduction from $1000 per kW to $125 per kW).

(c) the cost of hydrogen storage.

(d) the cost of the fuel cells needed to produce electricity from hydrogen.

(e) *the substantially raised costs of all the foregoing items, in a renewable energy world, because energy will be more expensive when fossil fuels become scarce.*

The last of those items is vital, though hard to quantify. In my opinion, because of that, whether it will be possible to overcome the intractable problem of low *net* energy capture of naturally flexible energy sources (biomass) — by using the high energy capture of wind and transforming it into hydrogen — is almost certain to remain a matter of speculation. The Precautionary Principle suggests that we should not assume the answer to be the one that we would prefer, any more than we should with hydrogen fusion, especially as costs (a) to (d) already look formidable, and require drastic reductions from present costs to make them viable today.

The full extent of the problem with wind variability is perhaps not widely appreciated. There is an excellent graph of wind output for one month, hour by hour, recorded at Lake Benton II wind farm, to which Ted Trainer kindly drew my attention. It can be located on the net by going to:

http://www.ehirst.com/PDF/WindIntegration.pdf

and searching for "Fig. 3." (the figure is on page 15, but a search may be faster).

Conclusion

The difficulties associated with having to rely on renewable energy are significantly greater than one might gather from reading "Appendix G, *Hydrogen production technologies: additional discussion*," of the National Academy of Sciences report, "*The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs*." In the absence of fossil fuels, the energy sources available are sufficient to support only a much smaller population. There are absolutely no grounds for concluding that, "solar energy has the potential of meeting the energy demand of the human race well into the future."

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{1} Why 10 trillion kWhe/yr from wind power is not sufficient to deliver to the consumer 3.7 trillion kWhe/yr of electricity.

Denmark started running into trouble with the variable output of wind when the wind input reached 13% of the total, and by the time wind had reached 21% of the total it was having to export 40% of it to nations such as Norway, with ample hydropower, which could shut off the hydro to accommodate the wind power. Clearly this is not possible on a wide scale, so we would be wise to assume that only 15% of total electricity can be supplied *directly* by wind power.

Let us now calculate the wind power needed to deliver, to consumers, 3.7 trillion kWhe/yr, the present consumption of electricity in the U.S.A.

15% could be delivered directly, so 555 x 10^9 kWhe of the 10 trillion kWhe/yr output would be needed for that.

The remaining 85%, 3.15 x 10^{12} kWhe, would need to be produced by first producing hydrogen by electrolysis (about 70% efficient, and then by converting the hydrogen back to electricity with a fuel cell (about 60% efficient). Thus the overall efficiency is 0.70 x 0.60 = 0.42. Thus the 3.15 x 10^{12} becomes 3.15 / 0.42 = 7.5 x 10^{12} kWhe/yr.

So the total electricity required is 555 x 10^9 + 7.5 x 10^{12} = 8.0 x 10^{12} kWhe/yr.

Thus the wind electricity left 'spare' is 10 – 8 = 2.0 x 10^{12} kWhe/yr.

The amount of electricity needed to produce the 2.3 litres (160 gm) of liquid hydrogen which, when used with a fuel cell, provides the same motive energy as 1 litre of gasoline, is about equal to the calorific value of the gasoline (OPTJ 3/2, p 21). Thus the 2.0 x 10^{12} kWhe/yr of electricity could produce 2.0 x 10^{12} kWh/yr worth of gasoline equivalent (in terms of ability to move a vehicle).

2.0 x 10^{12} kWh/yr is a fifth of the total wind output of 10 x 10^{12} kWhe/yr, and it is probably a pretty fair estimate that the inputs needed for building and maintaining wind turbines and all the associated infrastructure is a fifth of the output (it may be more after including the electrolysers and fuel cells). Thus *all* the electricity to 'spare' is needed as input.

It would be true to say that not all the input would need to be in the form of electricity. But in a renewable energy world, if heat is required, say for making steel, then since wind power offers *by far* the best power density of any renewable source, it would make sense to use electricity. In other words, for each kW of thermal energy required as input, the best option would be to use a kWhe of wind output. In fact it is an underestimate to say that 1 kWhe would suffice. With 15% of the electricity being supplied directly, and 85% being supplied via hydrogen, each kWhe of wind turbine output only delivers to the factory or consumer 0.15 + 0.85 x 0.42 = 0.51 kWhe. Thus if the 20% figure is a correct estimate of the inputs required, the 2.0 x 10^{12} kWh/yr would not even suffice to supply all the required inputs.

{2} Electrolyser and fuel cell costs

Making use of the figures in the previous endnote, with the electrolysers working at 70% efficiency, the 7.5 x 10^{12} kWhe/yr going through electrolysers would produce 0.70 x 7.5 = 5.25 x 10^{12} kWh/yr of hydrogen. If the present capital cost, of $1000/kW, refers to output, then that means the capital cost is $1000 x (5.25 x 10^{12} / 8760) = $600 billion.

The output from the fuel cells, at 60% efficiency would be 0.60 x 5.25 x 10^{12} = 3.15 x 10^{12} kWhe. If the present capital cost, of $5000/kW, refers to output, then that means the cost is $5000 x (3.15 x 10^{12} / 8760) = $1800 billion.

Many readers will be acquainted with the admirable <dieoff.org> website which Jay Hanson started and ran for many years, but has now handed over to Tom Robertson. In an email, 9 January 2003, he explained to me how he had reached his understanding of the human predicament. Finding out exactly how those who see the human situation clearly have reached their state of knowledge could make for an interesting series. The series has the title, *Paths to Wisdom.* This is *Number 1*. The article is simply made up of extracts from Jay's email.

To encourage others to come forward with similar accounts, perhaps I should reveal that I have reached the same conclusions as Jay, but by a different route, mainly through reading *The Comforts of Unreason,* when I was about 16, and more recently, *A Green History of the World*; *Food, Energy, and Society*; *The Coming Oil Crisis, Extraordinary Popular Delusions and the Madness of Crowds*, and *The March of Folly*. That has been my path. Such wisdom as I have accumulated leads me to regard the main activity that I am engaged in — editing this journal — as one of chronicling a point in history when humans encountered the demise of cheap energy, and of recording their inability to grasp the implications until far too late. Doubtless others have followed different paths to wisdom. I will be glad to feature them in future issues.

PATHS TO WISDOM, NUMBER 1

By Jay Hanson, 78-7230 Puupele Road, Kailua-Kona, HI 96740, USA

My first clue that something was terribly wrong with our society was my personal experience with our political system. The more I studied the American political system the more 'irrational' it looked. I finally decided it wasn't anything like the 'democracy' it claimed to be. It turns out that America is actually a stealth plutocracy!

Working full time for more than a decade, I studied it all: the history of our so-called 'democracy', the fundamentals and history of modern economics, sociology, cybernetics, system theory, biology, ecology, microbiology, evolution theory, physics, etc.

After several years of research, I concluded that little — if any — of the so-called 'social sciences' (including hneoclassical economics) taught in our universities had anything relevant to say about the real world. Instead of discovering facts and principles, most social sciences are little more than political programs designed to 'rationalize' (invent socially-acceptable excuses for) the current plutocracy. . . . I eventually concluded that all social sciences could be safely discarded because they had absolutely nothing to say about sustainability. . . .

With great reluctance, I was forced to conclude that our present system of capitalism was totally 'irrational' and utterly incompatible with energy laws. My only hope was that some new form of sustainable society was possible. So I began to study human nature intending to discover what kind of sustainable societies might work. . . .

A human cannot have a specific thought unless it has been enabled by an earlier brain 'wiring' operation (e.g., pre-programmed, formal education, reflection, critical thinking). Moreover, older brains are much harder to 'wire' than younger brains. . . .

In short, people cannot think a thought unless the brain has been previously 'wired' to think it. Brains are mostly hardwired by age 25. By middle age, people may need two or three years of hard work to understand something completely new. . . .

Once one understands human nature, then one also understands that continued social stability is impossible given the energy reality on this planet. In other words, we have been pre-programmed to overshoot and crash like other animals <http://www.dieoff.org/page80.htm>.

There are absolutely no humane solutions available to the ruling elite. The best the poor can hope for is a painless death.

END