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We are struck by the extraordinary technological optimism shown in discussions on new sources of energy, and on climate mitigation proposals such as carbon sequestration and geoengineering. Indeed, a great deal of this book is devoted to a detailed examination of these ideas and their likely consequences. Much of this optimism has been the result of the undoubted successes — and high public profile, given the widespread ownership of its products — of the new Information Technology (IT). For IT, forecasts have often not kept pace with the progress actually made. Yet IT projections are exceptional — most technology forecasts for other areas severely under-estimate the difficulties and time needed to bring them to market. As we shall see in Chapter 4, this optimism is shared by both most experts as well as the general public.

The Rise and Fall of the Carbon Civilisation, Patrick Moriarty and Damon Honnery (2010).

The Optimum Population Trust (UK): Manchester

<www.populationmatters.org>

INTRODUCTION

The New York Times recently reported on a study made by the RAND corporation regarding fuel policy within the US Defense department. The report pointed out, in effect, that to provide the United States with *ten per cent* of its current fuel use from renewable sources would require *one hundred per cent* of the cropland currently under cultivation in the US. This is a subject that David Pimentel has been writing about for decades. I hope that pages 3-6, extracts from *Food, Energy, and Society* by David and Marcia Pimentel, will make readers understand why David Willey and I judged this book to be second in importance only to Clive Ponting's *A Green History of the World.*

Pages 6-11 carry a review of another important book, namely one by two Australian doctors of science, Patrick Moriarty and Damon Honnery It is a rare example of a realistic appraisal of the problems of energy, although, as pointed out in the review, it seems doubtful that adequate account has been taken of the problems of introducing uncontrollable inputs (wind, waves, tidal flow) into an electrical grid.

This weakness in Moriarty and Honnery's book is to be found everywhere. On page 12, in *Selection of the Evidence Concerning Uncontrollables*, I give an example of how the media usually glosses over the problem, taking an example from a report on photovoltaics.

Professor David MacKay's book *Sustainable Energy — Without the Hot Ai*r is important, partly because he goes to great lengths to make it comprehensible to laymen. It fully deserves the 14 pages (13-26) given to reviewing it. Unfortunately it too has a dire weakness, again not recognizing the extent of the problem with uncontrollables. I sent my draft review to David MacKay (and several others including another reviewer) to see if MacKay had an explanation for his lack of adequate treatment of this problem.

Val Stevens kindly sent me two articles from *Nature* (18 Nov 2010). The first piece was by Richard Heinberg and David Fridley with the title, *The end of cheap coal*. As the title suggests, it lends support to the argument put forward by David Rutledge, as outlined in *Rutledge's Hypothesis* (OPTJ Oct 2008 pp. 22-28). I mention that in passing, as only the second piece, *Questioning economic growth* by Peter Victor, an economist at York University, Toronto, is relevant to my two page review (pp. 27-28) of *Supercapitalism: The Battle for Democracy in an Age of Big Business* by Robert Reich. Peter Victor points out the need to stop or even reverse growth (as long advocated by Herman Daly), and proposes such things as reduced working time. He says that whether such changes would be possible to achieve under capitalism is still an open question. The book by Robert Reich suggests that that it is unlikely, because he argues that governments have effectively lost power to international business organizations. Moreover, as things stand at present, those international business organizations have little choice but act the way they do. Reich's solution is for democracy to exercise more control, but to my mind he fails to address the troublesome fact that democracies have little power in a world where globalization holds sway. Yet he does not suggest moving away from globalization, as we have in the Optimum Population Trust (OPTJ 3/1, April 2003, pp. 23-25).

It was Eric Rimmer who provided me with the New York Times article, and he was very helpful to me in getting *Selection of the Evidence Concerning Uncontrollables* into shape. He also made useful comments on the review of MacKay's book, as did Martin Desvaux with an eagle eye, talking of which, Yvette Willey continues to provide the invaluable service of picking up what I have found to be my inevitable slips.

FOOD, ENERGY, AND SOCIETY (3rd edition), Part 5

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

[Not everyone will be familiar with all the units used here, so I will start with some notes on energy units. **MJ,** or megajoules, are millions of joules. Here we are often dealing with amounts in the order of 10,000 MJ (the alternative unit is **GJ,** that is billions of joules). To give an idea of what 10 GJ represents, it is about equivalent to half a tonne of dry wood or 300 litres of gasoline. The basis of **quads** is the British Thermal Unit (a quadrillion of them). 1 quad is equal to 1.055 EJ (1 exajoule is 1 x 10^{18} joules).]

Chapter 12. Energy inputs in Crop Production in Developing and Developed Countries

137.3 The energy and economic aspects of 20 cropping systems in developing and developed countries were analysed. In developing countries, labor input was a major cost in terms of energy and economics while, as in developed countries, the major costs were mechanization and fertilizers. The energy inputs per hectare in developing countries range from 7732 MJ (wheat) to 54,647 MJ (cassava); in the United States (developed), the energy inputs range from 10,085 MJ (soybean) to 210,817 MJ (apple). Food calories produced per hectare in developing countries ranged from only 12,403 MJ (tomato) to 196,510 MJ (cassava); in the United States, production ranged from 37,947 MJ (wheat) to 128,755 MJ (apple). Grain yields per hectare increased as much as fourfold during the Green Revolution but most of this increase was due to fossil energy inputs including fertilizers, irrigation, and pesticides. Despite the Green Revolution and genetic engineering technologies, per capita grain yields during nearly two decades have been declining — a distressing trend with more than 3 billion people malnourished worldwide.

138.1 This is the largest number and percentage of malnourished humans ever recorded in history. The United Nations University (1999) projects that Africa will be able to feed only 40% of its population in 2025. Recent reports from the Food and Agriculture Organization of the United Nations and the U.S. Department of Agriculture, as well as from numerous other international organizations, further confirm the serious nature of the global food shortages (Population Summit of the World's Scientific Academies, 1994). …

Great pressure is being placed on all the resources essential for food production, and especially fossil energy, which is a finite resource.

Through continued use, cropland is degraded, water is polluted, fossil energy supplies diminished, and biological resources lost, and all these resources are vital to human survival. These losses further restrict present agricultural production and its expansion to meet additional food needs. Although increases in crop yields have been achieved in fossil-fuel dependent agriculture, intensive use of cropland production is causing widespread soil erosion.

WORLD ENERGY RESOURCES

Humans rely on various sources of power for food production, housing, clean water, and a productive environment. These range from human, animal, wind, tidal, and water energy to wood, coal, gas, oil, and nuclear sources. Of these, fossil fuel resources have been most effective in increasing food production and feeding a growing number of humans, and help alleviate malnourishment and numerous other diseases.

About 445 quads of fossil and renewable energy sources are used worldwide each year for all human needs. In addition, about 50% of all the solar energy captured by photosynthesis and incorporated in biomass worldwide is used by humans. Although this amount of biomass energy is very large (approximately 600 quads), it is inadequate to meet the food needs of all humans. To compensate, about 384 quads of fossil energy (oil, gas and coal) are utilized each year worldwide. Of this amount, 91 quads are utilized in the United States (about 17% in the food system). Yearly, the U.S. population consumes about 53% more energy than all the solar energy captured by harvested U.S. crops, forest products, and all other vegetation.

The current high rate of energy expenditure throughout the world is directly related to many factors, including rapid population growth, urbanization, and high resource-consumption rates. Indeed, fossil energy use has been increasing at a rate even faster than the rate of growth of the world population. Energy use has been doubling every 30 years whereas world population has been doubling every 40 years.

139.1 Some developing nations with high population growth rates are increasing fossil fuel use in their agricultural production to meet the increasing demand for food and fiber, for instance, in China between 1955 and 1992, fossil energy use in agriculture for irrigation and for producing fertilizers and pesticides increased 100-fold.

The overall projections of the availability of fossil energy resources for mechanization, fertilizers, and pesticides are discouraging because the availability of fossil fuels is limited.

139.5 Youngquist (1997) reports that current oil and gas exploration drilling data have not borne out some of the earlier optimistic estimates of the amount of these resources yet to be found in the United States. Both the production rate and proven reserves continue to decline. … Analyses suggest that by 1998 the United States had already consumed about three-quarters of its recoverable oil.

METHODOLOGY

139.7 The energy expenditures and economic costs of major food crop production systems both in developed and developing countries are analysed, including some systems dependent on human labor and draft animal power. For data on developed countries, information on food crop production in the United States was used because abundant data were available and they are similar to intensive crop production systems in other developed nations. For example, in the United States the average energy input [per hectare] for wheat production is about 17.8 GJ, in Germany the average is reported to be 17.5 GJ, and in Greece input is 21.1 GJ. …

In developed countries, most of the energy inputs are fossil energy inputs for mechanization and fertilizers whereas in developing countries the major energy expenditure is for human labor. For instance, in U.S. grain production, the labor input was approximately 10 h/ha while in many developing countries the labor input was approximately 1000 h/ha. Labor is a vital component of crop production. … and also is substituted for mechanization and other farming activities. …

140.4 In addition to labor, assigning an energy value to manure is difficult. Properly applied manure can be substituted for commercial nitrogen, phosphorus, and potassium fertilizers produced using high inputs of fossil energy. But different types of manure are used, are handled differently, and are applied in various ways, the values obtained by investigators are highly variable. For example, the nitrogen content of manure varies from

3% to 20% (dry weight) depending on the type of livestock manure used and how it was handled.

140.7 Fossil fuels differ in their relative importance in agriculture, with liquid fuels used more extensively than natural gas and coal. However, no attempt was made to rate and identify the amount of liquid fuel (oil) used in each cropping system.

[All the above were direct quotes from the David and Marcia Pimentel's book, *Food, Energy, and Society* (3rd edition). On pages 141 and 142, Pimentel presents two tables covering corn (maize) production in Indonesia and in the United States. These tables offer a cornucopia of information from which I will try to extract some of the most relevant points.

The annual yield from a hectare of corn in Indonesia was 1200 kg, only 15% of the U.S. yield. In Indonesia, the per hectare energy inputs from nitrogen amounted to 5544 MJ, which works out at 4.6 MJ per kg of corn yield (and nitrogen input was probably higher than that as manure inputs added a further 3.4 MJ per kg of yield). In the U.S., the energy input from nitrogen was 11,252 MJ; that works out at only 1.4 MJ per kg of yield. But Indonesia is only using 71 kg/ha of nitrogen (but adding manure to that) which is about half the nitrogen fertilizer per hectare of the U.S. So what can Indonesia do to increase its yield? Let us compare the energy inputs to the output (output being measured in terms of the energy in the corn).

In Indonesia, the input/output ratio is 1:1.07, so conversely the input is 93% of the output. In the U.S. the input/output ratio is 1:4.07, making the input only 25% of the output. But there is also the question of the absolute amount of energy used per hectare. The total energy used per hectare in the United States is 70% higher than in Indonesia. That vital extra 70% of energy may not be available or affordable in Indonesia, and as fossil fuels become scarce, it is unlikely to be available in the U.S. either. As Pimentel observes (p. 142.9), in the U.S., "Nitrogen fertilizer represents the single largest input, about 40% of the total energy inputs while 25% is expended for labor reducing mechanization."

On pages 133-144, wheat yields in Kenya are compared with those in the United States. The wheat yield in Kenya is 67% of that in the U.S. In Kenya, inputs amount to 30% of the output whereas in the United States they amount to 47% of the output, giving a clear indication of the relationship of output to the availability of input. And so the comparisons continue, until on page 150 the individual studies are summed up in a table covering all these data for various countries, covering soybean, potato, sweet potato, cabbage, tomato, orange, apple, corn. The conclusion is inescapable. Not only will it be difficult to increase yields, it will be difficult to maintain them as fossil fuel energy becomes scarce.]

FOSSIL ENERGY USE AND CROP YIELDS

153.3 When the availability of fossil energy became readily available, especially in developed nations, this supported the 20- to 50-fold increase in the use of fertilizers, pesticides, and irrigation. From 1950 to 1980, U.S. grain production per hectare increased three to four times. For example, where fertilizer use on corn increased from about 5 kg/ha in 1945 to about 150 kg/ha (30 times), corn yields increased by about four times. The rate of yield increases during the 30-year period from 1950 to 1980 was about 3% per year. However, since 1980, U.S. grain crop yield increases declined to only about 1% per year. This is because crops have limits in the amounts of fertilizers and pesticides that they can tolerate and use.

RISE AND FALL OF THE CARBON CIVILISATION[1]

by Patrick Moriarty and Damon Honnery, a review essay by Andrew Ferguson

Abstract. This is an exceptionally informative book, well structured and well written. Without being too long it covers all the relevant ground thoroughly. It is somewhat over optimistic in its suggestions for resolving the problems, but outlines them brilliantly; and the subject matter is so well presented that readers can make their own decision about what is going to be politically possible in the likely circumstances. Using their data, my interpretation results in the conclusion that for the longer term the global aim needs to be to reduce population to about 2 billion.

The title of the book is well chosen, but the subtitle, "Resolving global environmental and resource problems," owes more to hope than to reality. At least that is the conclusion that my analysis will lead to.

Despite its short length, 200 pages, the book comprehensively surveys most of the important issues, including global climate change, vital material resources, degree of uncertainty about forecasting the future, renewable energy, nuclear energy, improving efficiencies, carbon sequestration, geo-engineering, and the need for a new economy. That list approximates to the chapter headings. Based on a wealth of background reading, every subject is impressively covered. The writing is excellent. It makes no compromises with the science, yet matters are presented with such clarity that it is easy for anyone with a grounding in science to follow. I will pick out a few places where this concern for the layman falls short, but such lapses are very much the exception. With regard to the subtitle, let us first observe that the authors are less optimistic than the subtitle words might suggest. On page 2 they say:

> We are struck by the extraordinary technological optimism shown in discussions on new sources of energy, and on climate mitigation proposals such as carbon sequestration and geoengineering. Indeed, a great deal of this book is devoted to a detailed examination of these ideas and their likely consequences. Much of this optimism has been the result of the undoubted successes — and high public profile, given the widespread ownership of its products — of the new Information Technology (IT). For IT, forecasts have often not kept pace with the progress actually made. Yet IT projections are exceptional — most technology forecasts for other areas severely under-estimate the difficulties and time needed to bring them to market. As we shall see in Chapter 4, this optimism is shared by both most experts as well as the general public.

The excessive optimism to which they draw attention pervades not only the popular media (e.g. *New Scientist* and *Scientific American*) but extends to academia, so it is good to see the authors — both doctors of science — showing realism. They take account of most aspects of the world's problems and the scale of those problems, including something often underplayed or ignored, namely the inevitable drive of the poor for better lifestyles. On page 12, after pointing out that the world is already in overshoot, they make this point:

> We have reached this scale of overshoot even though only a small fraction of the global population presently enjoys high standards of material consumption. Any further growth in global population, or any movement towards OECD income levels — which are themselves expected to continue rising — by the great majority of the world

> population presently living in low-income countries, will place even greater stresses on Earth's resources and pollution absorption capacity.

On page 20, in a superb chapter on climate change, we encounter the first example of a point at which the authors are perhaps not sufficiently helpful to laymen. They mention that Roger Pielke, in a paper *A broader view of the role of humans in the climate system,* "argued that a more accurate way of quantifying climate change is to look at how the Earth's energy balance is changing as a result of the global imbalance between insolation and outgoing thermal radiation." Taking data from another paper, based on Pielke's idea, the authors then tabulate the energy flows *over the last half century* into (a) the ocean, (b) melting glacial systems, (c) land surface and (d) the lower atmosphere. By far the biggest figure is 200,000 EJ (1 exajoule = 10^{18} joules) into the oceans. They go on to mention that a mere 200 EJ is sufficient energy to raise all of the water in Lake Eyrie (in the North American Great Lakes system) from 0ºC to 100ºC. However, most laymen don't have any idea of how that would relate to the huge volume of water in the oceans. Something on these lines would surely be helpful: "The extent of the mixed layer in the oceans is normally taken as 75 metres. The mooted 200,000 EJ would be sufficient to raise the temperature of that by 1.7ºC;[2] yet the measured rise in temperature between the decade 1950-59 to the decade 2000-09 was 0.53ºC.[3] This suggests that a good proportion of the heat is carried down below the mixed layer. The mixed layer is only one fiftieth of the total ocean volume. Thus a complete interpretation of the 200,000 EJ figure is fraught with difficulty, but the above calculation gives an insight into the *potential* for an increase in temperature, and indicates that there are longer-term problems which cannot be assessed even by five decades of measurements of temperature rise."

A more serious lapse in addressing the needs of laymen occurs on page 81 in the chapter on renewable energy, where it is stated:

> The real question is: how much biomass energy of any type can the world sustain? The answer to this question has varied greatly. As discussed above, a figure of 1,174 EJ has been cited, but values as high as this seem most unlikely, given that the total terrestrial NPP [Net Primary Production] is only 1,900 EJ. More recently, a Dutch study included water and land-use availability constraints, and gave a minimum global estimate of 65 EJ, with an upper limit of around 300 EJ. A US study put the sustainable potential of biomass even lower, at only 27 EJ; higher levels would either threaten food supplies or worsen global climate change.

What are laymen to make of that range, between 1,174 and 27 EJ? I suggest that scientists attempting to address the general public should recognize that there are always some crackpot scientific papers; laymen deserve to be shown a back-of-envelope calculation to see which papers might fall in that category. In this case, a rough calculation is easy. Globally there are about 1,500 million hectares (Mha) of cropland, 3,300 Mha of pasture and grassland and 4,200 Mha of forest and woodlands. Forest is being lost at an alarming rate, and part of the reason is to turn it into cropland or grazing land, and partly to satisfy the demand for timber. Thus there would seem little hope of finding *any* new lands suitable for growing biomass. Let us nevertheless choose a high figure for what might possibly be achieved by assuming that somehow 1,000 Mha can be found to grow biomass for energy purposes. This won't be the best land, which will likely go to cropland, thus it would be optimistic to assume a yield of 4 t/ha/y (average forest yield is estimated at 3 t/ha/y). The energy density of wood is 18 GJ (1 gigajoule = 10^9 joules) per tonne. Thus the total energy made available per year would be $(1000 \times 10^6) \times 4 \times (18 \times 10^9) = \underline{\underline{72}}$ EJ. This immediately shows that anything above 72 EJ is crackpot.

Another crackpot figure, that the authors do not give guidance on, is population size. Regarding it, they say, on page 3:

> A good example of technological optimism is provided by Jesse Ausubel. In a recent interview article entitled 'Ingenuity wins every time', Ausubel argued that the world can support 20 billion people, almost three times its year 2010 population.

Clearly Jesse Ausubel is as crackpot as Professor of Marketing Julian Simon, whom many academics took the bother to refute (although this did not seem to much abate the popularity of his fantasies expressed in various books). The authors don't bother to do this with Ausubel but later, on page 52, they return to the point about inequity mentioned earlier, with these words:

> The trouble is that most of the world's population aspire to the material living standards of the OECD — all would like to be 'OECD-equivalent people'. At this level of affluence the world may only be able to sustainably support a far lower population level than today. According to the Optimum Population Trust in the UK, this figure is between 2.7 and 5.1 billion.

But they don't comment further on that estimate, published on the Optimum Population Trust (OPT) website. Maybe the reader will wonder if the OPT estimate is as misleading as that of Ausubel (but in the opposite direction). Yet very simple calculations can show that to support people in a modest lifestyle and not exceed a safe level of carbon emissions, the lower figures are in the ball-park, indeed probably high.[4] Calculations related to renewable energy are more complicated, but that is something we will return to later.

Doubtless the authors have quoted the website figures correctly, but to be more precise, OPT has been making these calculations every two years based on the *Living Planet Reports* (LPR) 2000, 2002, 2004, 2006, and 2008, and our favoured presentation is for a lifestyle that is West European but *with energy use reduced to 40%* of 2001 usage. On this basis, we estimate the sustainable population falls in the range of 3.0-3.6 billion. However, as we have always stressed, this does not include the limit set while we are relying on fossil fuel, for which the carbon dioxide calculation gives a limit of 2.2 billion.[4] Two points should be made about our figures: (a) although we use LPR data, we do so on the basis of a careful assessment that the land normally allocated to carbon absorption is equal in area to the land needed for renewable energy generation; (b) we claim only that these figures are ball-park figures —a billion less or more would not be surprising. The data, including that on renewable energy, is simply not accurate enough to do more than get in the ball-park.

In the wind energy section of the renewable energy chapter, on page 86, the authors say:

> Denmark, the country with the highest wind penetration, has experienced almost no growth since 2000.

The authors are here surveying the extent of growth in the installation of wind turbines, but neither here nor later do they point out a vital fact about Denmark's experience. The amount of electricity from wind turbines that the Danes produce amounts to about 25% of their total electricity demand, yet the amount of electricity from wind turbines they manage to use *directly* is only about 8.5%. The rest they have to persuade Norway to take, which Norway can do by lowering the output from their hydro turbines. This problem with using the output of the wind turbines directly is partly due to poor internal transmission lines from the west coast of Denmark (where the wind turbines are mainly placed) to the more populated east side. However, the fact that the Danes have not bothered to build adequate internal transmission to ameliorate the problem introduced by the wind turbines producing electricity at inconvenient times gives an indication of the difficulty of integrating the uncontrollable output of wind turbines.

In the chapter on *Engineering for Greater Energy Efficiency* we read, on page 136:

> Robert Ayres and his co-workers have pointed out that the system efficiency of power stations was often higher in the US in the early years of the 20th century than it is today. Then, utility companies used small power plants located in urban areas close to their consumers. Electrical conversion efficiencies were very low by modern standards, but because they sold heat as well, they could achieve combined efficiencies of over 50%. Much of the progress in technical efficiency has been at the expense of efficiency at a larger scale.

The quotation of 50% appears to be an example of a common fallacy about Combined Heating and Power (CHP), namely that there is a straight comparison to be made between the combined efficiency of the heat output and electricity output of a CHP plant with the efficiency of producing electricity. There is some gain but not always great and CHP has some disadvantages. This is what David Mackay[5] says in an acute review of CHP (p. 149).

> The ideal CHP systems are slightly superior to the "new standard way of doing things" (getting electricity from gas and heat from condensing boilers). But we must bear in mind that this slight superiority comes with some drawbacks — a CHP system delivers heat only to the places it is connected to, whereas condensing boilers can be planted anywhere with a gas main; and compared to the standard way of doing things, CHP systems are not so flexible in the mix of electricity and heat they deliver; a CHP system will work best only when delivering a particular mix; this inflexibility leads to inefficiency at times when, for example, excess heat is produced in a typical house, much of the electricity demand comes in relatively brief spikes, bearing little relation to heating demand.

But strictures on the analysis are minor. The book is very sound in nearly all its details. When it comes to taking an overview, as is done in Chapter 10, *The New Economy*, then there is room for differing views. What I shall do is make my own calculation *using their figures* except where noted, as this will provide the best basis for further comments.

Making best use of the energy supply that should be available in 2050

The controllable electric supply will consist of:

20 EJ	from hydro (currently 12 EJ. This is their optimistic estimate for 2050).
10 EJ	from geothermal (and other minor sources other than wind and solar).
50 EJ	from biomass.
72 EJ	from fossil fuel for power stations (I choose this as part of the 124 EJ which they estimate that could be made available while keeping within a safe limit of carbon emissions). The rest of the 124 EJ is allocated for transport as explained below.
152 EJ	total thus far. We will assume that this is all controllable although this is not strictly true in the case of hydro, which may not be available at times of drought.
65 EJ	supplement from wind and solar. Because of its uncontrollable nature wind and solar are unlikely to be able to constitute more than 30% of an electrical grid (Denmark's trouble at 8.5% is not the only indicator of problems with too much uncontrollable input), thus the supplement available from uncontrollables is 3/7 x 152 = 65 EJ (i.e. 65 / (152 + 65) = 30%). This type of estimate does not exist in the author's text, but as will be seen our overall results are similar.
217 EJ	total electricity thus far.

52 EJ	fossil fuel for transport. Current global usage for transport is 77 EJ, of which 35 EJ is for private vehicles. A drastic reduction of the latter to 10 EJ would thus give 52 EJ for transport. This deduction in turn determined the 72 EJ shown above as being available for producing electricity.
49 EJ	from nuclear. Currently 20 EJ. A very convincing case is made for why it is unlikely that more than 49 EJ/y could be produced by 2050 (or increase much thereafter without dire problems).
318 EJ	Grand total of all energy available in 2050, electric and non-electric.

This is actually a slightly higher result than the authors give, as on page 182 they say, “Although the figures we have calculated are only indicative, we think a total of about 300 EJ of primary energy could be available to supply our energy needs while limiting global temperature rise to 2ºC.”

At 2 kW/p (63 GJ/y), 318 EJ allows a population of 5.0 billion.[6] On a couple of occasions the authors quote the view that life remains tolerable at 1 kW per person (e.g. 24 kWh/day/p), but they also mention a paper with another view, *Distribution of energy consumption and the 2000 W/capita target*. Moreover Vaclav Smil, the doyen of renewable energy experts, has made an estimate of a need for 2 kW per person to maintain good education and health care. Some instructive statistics, to put these figures into perspective, are that the average power consumption for the USA was about 3.7 kW per person until the 1890s when electricity and widespread rail traffic increased consumption.[7] Even 3.7 kW/p is a bit fanciful when one considers that in the USA power consumption is now about 11 kW/p and in West Europe about 5 kW/p. It is idle to imagine that, when energy is scarce, it will be shared out equally between the whole world. Those with the economic strength to do so will preserve at least a modicum of comfort for themselves before leaving the rest to be shared out between the others. So even an *average* of 2 kW/p would be somewhat skimpy for the poor, but nevertheless, let us take 2 kW/p as an average, and conclude that if developed countries can manage such reductions as are needed to enable an *average* 2 kW/p (the current *world* average is about 2.4 kW/p), a population of 5.0 billion could be supported in 2050 without further damaging the ecosystem. Of course population won’t actually reduce by then to 5 billion, and this figure is mainly just a measure of overshoot.

But 2050 is only 40 years away, and we should be looking ahead further than that. It is arguable as to when fossil fuels will be totally exhausted (exhausted in terms of practical extraction that is) but some put it at about the end of this century. Whether or not it is longer than the end of the century, to safeguard the future we should redo the above calculation without assuming *any* fossil fuel input. As the authors show, there are not great prospects for much increasing the estimates for energy from renewable sources, or nuclear energy, and repeating the calculation without fossil fuel arrives at a grand total of 163 EJ, which, at 2 kW/p, gives a population that can be supported in moderate comfort of 2.6 billion. And there is an element of optimism in even that. While fossil fuel is available it can be used for transport. Without the fossil fuel, liquid fuels will either (a) have to be produced from biomass, which will require energy both for growing the feedstock *and for supplying energy for growing, harvesting and conversion* which amount of input energy is currently about the same as is in the ethanol produced; or (b) if not from biomass, then from converting electricity to hydrogen by electrolysis (about 70% efficient), and compressing it for storage (more loss), or perhaps converting the hydrogen to methane (which would have many advantages, one being that it has an energy density about 3.5 times that of hydrogen), but conversion to methane would incur further losses. Note too that if the purpose is to store the hydrogen to produce electricity later, then reconversion by turbine may be in the order of 50% efficient (if it can be made to equal modern gas plant), making the overall efficiency only 35%. Fuel cells are often mentioned for reconversion, but it is optimistic to think that fuels cells will be cheap enough to use for the purpose.

Summary

The book is excellent in looking at all the details of energy sources, and shows realism in what is likely to be politically possible, except that in regard to the latter, it surely goes too far in suggesting 1 kW/p as something which might be accepted voluntarily, and perhaps it is partly for that reason it fails to point out the sort of population levels that we should be striving for in order to reduce the extent of the die off which seems likely to occur if we run out of fossil fuels before significantly reducing population size.

Let us finish by asking which of the five inconvenient truths avoided by Al Gore (climate change was the only one he did not avoid) are also avoided by our authors. I'm glad to say that they meet them all head on with the exception of number four:

> **The fourth inconvenient truth** arises from the fact that it is bound to be a slow process to reduce the per capita emissions of the developed nations. Thus the action that would most rapidly ensure that there was some mitigation in burgeoning use of fossil fuels would be to prevent the populations of the developed nations growing by net immigration (as is happening in the USA and to a lesser extent in the European Union).

This is a very instructive book, outstanding in many ways, and it is in sharp contrast to many popular articles and books based on starry-eyed optimism about what technology is likely to deliver.

1. *Rise and Fall of the Carbon Civilisation* by Patrick Moriarty and Damon Honnery. Springer. 2011. Hardcover (ISBN: 978-1-84996-482-1, Oct. 11, 2010) US$116; GBP 90; Aus$216 incl. postage from, http://www.boomerangbooks.com.au/Rise-and-Fall-of-the-Carbon-Civilisation/Patrick-Moriarty/book_9781849964821.htm
2. The volume of the mixed layer, extending 75 m down, is 2.7 x 10^{16} m^{3,}= 2.7 x 10^{22} cc, or ml (data from John Harte's *The Spherical Cow*).
   200,000 x 10^{18} J = 200,000 x 10^{18} / 4.186 = 4.78 x 10^{22} calories.
   So increase in temperature = 4.78 x 10^{22} / 2.7 x 10^{22} = 1.77ºC.
   Mixed layer is 1/50 of the total ocean volume (data from John Harte's *The Spherical Cow*), so increase in temperature for the whole ocean were it to be evenly mixed would be 1.77 / 50 = 0.035ºC.
3. http://en.wikipedia.org/wiki/Instrumental_temperature_record
4. Since the international conference in 1992, climatologists have been warning that the world needs to get down to annual emissions of about 9,000 Mt of carbon dioxide per year. Actually when the world was emitting that amount, the atmospheric concentration was *increasing*, but as the atmospheric concentration has now reached 390 ppm, 9,000 Mt/y holds out some promise for reducing the concentration. As mentioned later in the main text, 2 kW per person is probably about the minimum acceptable average for a lifestyle of minimum opulence, and this would be associated with about 4 tonnes of carbon dioxide release per year. Thus the limit to population *on emission grounds* while we are reliant mainly on fossil fuels is around 9,000 million / 4 = 2,200 million people.
5. MacKay, D.J.C. 2008. *Sustainable Energy — without the hot air*. UIT Cambridge. ISBN 978-0-9544529-3-3 Available free online from www.withouthotair.com
6. The 5.0 billion calculation is simply 318 EJ / 63 GJ, i.e. 318 x 10^{18} / 63 x 10^{9} = 5 billion.
7. Page 20 of 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.

SELECTION OF THE EVIDENCE CONCERNING UNCONTROLLABLES

by Andrew R.B. Ferguson

Selection of the evidence is probably the most common method by which people persuade themselves — and try to persuade others — that things are as they would wish them to be rather than how they actually are. The method is often employed in media outlets such as *New Scientist* and *Scientific American*, and is very popular in academic papers concerned with renewable energy. *New Scientist*, 30 October 2010, provided a typical example with a piece titled *Solar power could overload the grid*. This short journalistic report outlines the problems of photovoltaics thus:

> A small surge can be accommodated by switching off conventional power generators, to keep the overall supply to the grid the same. But if the solar power input is too large it will exceed demand even with all the generators switched off. Stephan Köhler, head of Germany’s energy agency, DENA, warns in an interview with the *Berliner Zeitung* on 17 October that at current rates of installation, solar capacity will soon reach those levels, and could trigger blackouts.

The report goes on to say that the subsidies for citizens and businesses installing photovoltaics has been such that “Solar capacity could reach 30 gigawatts (GW), equal to the country’s weekend power consumption, by the end of next year.”

Is it up to a journalist only to report Stephan Köhler’s assertion that the maximum output of 30 GW of photovoltaic capacity (which would be about 30 GW) could trigger blackouts in the German system (one which provides an average supply of 74 GW), when the figure of 30 GW is likely to mislead many people without much knowledge of photovoltaics? There are two matters that are germane to the subject which should not be omitted. Their omission could be regarded as selection of the evidence.

First, an important question is how much electricity 30 GW of capacity would produce. That is determined by what is known as the ‘capacity factor’, which is controlled by the amount of insolation. In a very sunny place, with wind to keep the panels cool, 20% would be possible, but Germany is not that sunny, and the capacity factor currently being achieved is barely 10%. Only marginal improvements are possible, as the amount of sun is the controlling factor. Making the panels more efficient — so that a smaller area captures the same amount of electricity — would make no difference. Even if we allow for some improvement, and say that a 12% capacity factor could be achieved, the 30 GW of capacity would only produce an average power of 0.12 x 30 = $\underline{3.6}$ GW. That is a less than 5% of the German electrical supply in 2008 — an average power of 74 GW. Incidentally, electrical power demand had been increasing at 1.5% per year over the previous six years.

Second, if the grid has to handle 30 GW of photovoltaic capacity, then when PV is producing at full capacity, it leaves no room for wind turbines or other uncontrollable inputs. Moreover wind turbines offer a considerably better capacity factor, which makes it apparent that installing so much photovoltaic capacity will prove to be a mistake, unless an economical way of storing electricity is found.

The temptation to believe that wind and sun can replace fossil fuels is great. People like to console themselves with the thought that when fossil fuels run out we will be able to maintain our present population and lifestyles using renewable energy. Thus they argue that the problem of uncontrollables can be alleviated by diminishing the fluctuations in demand, and by having a Europe-wide grid. But quantifying the difference that such things would make is close to impossible. The matter could not even be simulated, since the results would depend significantly on how people behave — something which is almost impossible to predict.

SUSTAINABLE ENERGY — WITHOUT THE HOT AIR * by David J.C. MacKay

A Review Essay by Andrew R.B. Ferguson.

Abstract. Written in a pleasing, light-hearted style, this book by Professor David Mackay makes matters of energy comprehensible to laymen. He is tackling the most important issue that humanity faces, namely whether it will be possible, when fossil fuels run out, to support civilized lifestyles using renewable energy, and whether, in the meantime, it will be possible to greatly reduce carbon emissions. He recognizes the fundamental problem, which is that although dried biomass provides a *controllable* form of energy, it has a power density that is too low to make a sufficient contribution to energy needs to support civilized lifestyles. Since all renewables with a higher power density produce electricity, he contemplates a society run substantially on electricity. Unfortunately he fails to fully face up to the difficulties of introducing so much *uncontrollable* electricity into a grid, and his proposals for storing electricity do not have the potential to be scaled up to a realistic size. Nevertheless, the book is a mine of information, and a good starting point for anyone who wants to play a part in thinking about these problems.

None of the reservations which I will make in due course should be taken to detract from the fact that, for several reasons, Professor David MacKay's *Sustainable Energy — without the hot air* is a brilliant book. Moreover it can be accessed for free on the internet.

The presentation and layout of the book is superb. Skilful use is made of different colours in the text; helpful and interesting graphs and pictures are interspersed. Also important is that the book has been designed to satisfy many different readers. At the end of each chapter there are *Notes and further reading*. These expand on some of the facts that have appeared in the previous text, making reference to the relevant page. Furthermore there is a separate Part III to the book, *Technical Chapters*, which is replete with amazingly complicated formulae to satisfy those who enjoy such things. MacKay makes it clear to whom the generality of the book is aimed when he says (p. 28.3), "The main thread of the book is intended to be accessible to everyone who can add, multiply, and divide. It is especially aimed at our dear elected and unelected representatives, the Members of Parliament."

The second reason that this book excels is that MacKay devises a method of presenting energy issues in a way that is easy for everyone to grasp. Whenever possible he uses units of power in terms of kilowatt hours per day per person (kWh /d /p). This might seem slightly strange to scientists as, for example, 24 kWh /d = 1 kW (a unit of power), and the unit kWh /d appears to be an unduly complicated way of expressing average power, but the unit has several advantages: (a) People are familiar with a kilowatt hour because it is a unit of electricity (also a unit of natural gas nowadays), which people have to pay for; (b) kWh /d are conveniently small units for personal use: each UK citizen uses — directly and indirectly — about 125 kWh per day; (c) Although one can refer to an "average kilowatt", people easily miss the word "average", whereas in asserting say a consumption of 24 kWh /d , it is immediately evident that some of that may, for instance, have been consumed in the morning using the washing machine and mowing the lawn, some used in the evening, and some being attributable to the manufacturing and distribution chain; (d) by

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* MacKay, D.J.C. 2008. *Sustainable Energy — without the hot air*. UIT Cambridge. 372 pp. £20. ISBN 978-0-9544529-3-3 Available free online from www.withouthotair.com

expressing everything in terms of “per person,” mind-boggling millions and billions are avoided. Thus I can fully agree with one of the reviewers, Graham Stuart MP, when he says the book is “readable, accessible and thorough,” within this context:

> David MacKay sets out to dispel half truths, distortions and nonsense which make up so much of what we are told about climate change and our energy needs. This book is readable, accessible and thorough. He cuts through unfounded opinion and takes us to facts and figures which speak for themselves. It is a useful guide for both laymen and experts. I heartily recommend it.

That is but one of many well deserved commendations. However, I will dwell on some points where it seems appropriate to me to make reservations about the book. First I will tackle what I deem the major issues, and then turn to sundry matters which MacKay deals with, that are useful to know about but of more peripheral importance.

Pumped storage

Recognizing that the big problem with the uncontrollables (wind, solar, waves, tidal flow) is that power may not be available when needed, or vice versa, MacKay devotes a few pages to considering whether the only tried and tested method of storing electricity, pumped storage — i.e. having two lakes and pumping water up to the top one to store energy when needed — could be expanded so as to be significantly useful in a renewable energy world. On page 191.9 he writes, “Nor is the total [the total for all four pumped storage installations in the UK] energy stored (30 GWh) anywhere near the 1200 GWh we are interested in storing in order to make it through a big lull.”

He arrives at 1200 GWh (billions of watt hours) within the context of providing an *average* 10 GW of electricity (about 20% of UK supply) from wind. By assuming a lull of 5 days, the energy that needs to be stored is 5 x 24 x 10 GW = 1200 GWh. However an average 10 GW is equal to 4 kWh /d /p, which works out at 3% of current *total* energy use.

On page 204, an initial plan is presented showing electricity consumption per person as 18 kWh /d for “electrical things,” 12 kWh /d for electricity to be used for heating via heat pumps, and 18 kWh /d for transport. That totals to 48 kWh /d as electricity. The plan also shows 5 kWh /d /p from wood, 1 kWh /d /p as solar hot water, and 2 kWh /d /p as biofuel. We will soon see why the total of 56 kWh /d /p is much lower than the total current energy supply he is aiming to replace, 125 kWh /d /p. Note that uncontrollables have to be used *as much as possible* because mostly they have a much greater power density (defined as power gathered per unit area, normally measured in watts/m^2 or sometimes as kilowatts per hectare. 1 W/m^2 = 10 kW/ha).

Let us follow MacKay fairly closely by considering that there will occasionally be periods of 10 days during which there is such a lull in the uncontrollables that they are only able to deliver *half* their average supply. Thus the other half of the electricity would need to be stored. So, based on the above average 48 kWh /p, the storage needed to replace half the average output of the uncontrollables over ten days would amount to (48 / 2) x 10 = 240 kWh /p. For the UK’s 60 million people, that amounts to 14 400 GWh.

Dinorwig is the Queen of the four pumped storage stations in the UK, and can store 9 GWh. 14 400 GWh would require 14 400 / 9 = 1600 Dinorwigs. The gap between 14 400 GWh and what MacKay suggests as a practical limit also becomes apparent when he says, on page 194.5, “By building more pumped storage systems, it looks as if we could increase our maximum energy store from 30 GWh to 100 GWh or perhaps 400 GWh.” 400 GWh would be 400 / 14 400 = 2.8% of our estimated requirement for dealing with possible 10 day lulls. Of course MacKay goes on to consider alternative storage methods, but as economic possibilities they are all speculative. Pumped storage is the one non-speculative energy store that we can be sure would work at a bearable cost. In summary, MacKay appears to imply that pumped storage can play a more significant role in solving the problems associated with uncontrollables than seems at all likely.

It is good to see that MacKay at least notes the problems of *seasonal fluctuation* when he writes (p. 201.1): "How to ride through these very-long time scale fluctuations? Electric vehicles and pumped storage are not going to help store the sort of quantities required. A useful technology will surely be long-term thermal storage." But there, by implication, we are being invited to put our faith in an untried technology to solve the problem of seasonal fluctuation. We will consider that proposed 'solution' later.

Photovoltaics (PV) and more storage problems

David MacKay makes it clear that his preliminary survey of the limits of renewable energy refers to physical limits without taking sociological limits into account. Let us look to see whether he is giving due consideration to the problems associated with those physical limits. That he has reservations in making his preliminary proposals is signalled by the title of the section, *Fantasy time: solar farming*. In it, he explores the possibility of covering 5% of the UK with 10% efficient PV panels (the meaning of "efficient" is often ambiguous, but it is clear from his calculation that he is referring to capturing 10% of the insolation, which is about right for the module itself, but he does not consider the modules being on flat ground or flat roofs, in which case, to avoid shading, they need as much space between them as they occupy themselves). He estimates that this 5% would provide 50 kWh /d /p. He then goes on to observe (p. 41):

> Could this flood of solar panels co-exist with the army of windmills we imagined in Chapter 4? Yes, no problem: windmills cast little shadow, and ground-level solar panels have negligible effect on the wind. How audacious is this plan? The solar power capacity required to deliver this 50 kWh per day per person in the UK is more than 100 times all the photovoltaics in the whole world. So should I include the PV farm in my sustainable production stack? I'm in two minds. At the start of this book I said I wanted to explore what the laws of physics say about the limits of sustainable energy, assuming money is no object. On those grounds, I should certainly go ahead, industrialize the countryside, and push the PV farm onto the stack. At the same time, I want to help people figure out what we should be doing between *now* and 2050. And today, electricity from the solar farms would be four times as expensive as the market rate. So I feel a bit irresponsible as I include this estimate in the sustainable production stack in Figure 6.9 – paving 5% of the UK with solar panels seems beyond the bounds of plausibility in so many ways. If we seriously contemplated doing such a thing, it would quite probably be better to put the panels in a two-fold sunnier country and send some of the energy home by power lines.

In the next 60 pages, MacKay repeatedly shows 50 kWh /d /p from PV farms as part of the renewables production stack; so it seems fair to ask whether he has considered every aspect of what "the laws of physics say about sustainable energy." We have already noted the great — and currently only 2.8% solved — difficulty of incorporating sufficient storage to take care of a 10-day lull during which uncontrollables are able to provide only half of their average supply (or a complete lull for five days as posited by MacKay). Although he does not appear to notice the fact, MacKay is introducing another problem of intermittency by suggesting as much as 50 kWh /d from PV — namely periods of excessive output.

What capacity will be needed for the PV panels to produce their designated output? 50 kWh /d /p, or 50 x 2.5 = an *average* 125 GW /UK (2.5 is a useful factor to remember to convert kWh /d /p into an average GW /UK figure). The capacity factor of PV in the UK may be as high as 12.5%. At that capacity factor, the *capacity* of the PV panels would need to be 125 / 0.125 = 1000 GW (more of course if the capacity factor is lower).

MacKay's theoretical stack, shown on page 79, includes the 50 kWh /d /p from PV, and several other sources of renewable electricity, wave, deep offshore wind, shallow offshore wind, and onshore wind, all of them adding up to 127 kWh /d /p, or an average 320 GW. Thus the 1000 GW, which would be produced with all the PV plant delivering at its peak capacity, will be *three times* the average electricity demand, and *more than* three times when demand is low. As that problem is associated with the laws of physics, it's worth a mention; and another fact deserving a mention is that the erratic 1000 GW peak PV input problem is likely to be exacerbated by inputs from wave and tidal power. Here, as elsewhere, MacKay does not seem to be fully aware that the major problem of *renewable* electricity is that the plant only delivers a fraction of the power that it delivers at its peak.

Back to reality and more storage problems

One excuse for MacKay allowing himself to be somewhat lax in considering the problems associated with such a massive use of PV is because by time he gets to page 109 he explains that these theoretical limits will run up against obstacles when brought up for public consultation. He makes what I deem to be a fairly realistic, albeit rather arbitrary, estimate of the effects of public consultation on his assay of *theoretical* limits, as follows:

Table 1	kWh /d /p	
~~Geothermal~~	1	too immature!
Tide	11	
~~Wave~~	4	too expensive!
~~Deep offshore wind~~	32	not near my radar!
~~Shallow offshore wind~~	16	not near my birds!.
~~Biomass~~ (food, biofuel, wood, waste incineration, landfill gas)	24	not in my countryside!
~~PV farm~~ (200 m^2 /p)	50	too expensive!
~~PV (10m^2 /p on houses)~~	5	too expensive!
~~Solar heating~~	13	not on my street!
~~Wind~~	20	not in my backyard!

Along with the laws of physics, MacKay is here injecting some tongue-in-cheek sociological judgement into his analysis, but anyhow his surmises result in the production of a reduced stack which goes like this:

Table 2	kWh /d /p
Tide	3
Offshore wind	4
Onshore wind	3
Hydro	0.3
Biomass	4
Solar PV	2
Solar hot water	2

That totals up to 18 kWh /d /p with 12 kWh /d /p coming from uncontrollables. MacKay summarizes this speculation about the results of public consultation thus (p. 109.9):

> *After the public consultation.* I fear the maximum Britain would ever get from renewables is in the ballpark of 18 kWh /d per person.

The first thing that we should note is that if he is right, it gives an estimation of the long-term maximum population. Although we Brits currently luxuriate in 125 kWh /d per person, OPT has always argued (following Vaclav Smil) that it would be possible to maintain a civilized lifestyle on only 2 kW /p (48 kWh /d /p). One way to supply each person with this minimum 48 kWh /d /p, instead of 18 kWh /d /p, is by the expedient of reducing population proportionally, that is to (18 / 48) x 60 = 22 million. That expedient is not easy, but nothing else suggests itself by way of a possible solution and, as noted later, it involves a course of action which would meet with the approval of most of the population, excepting politicians, economists, and the commercial world.

Although that reduction to around 20 million is necessary, it will serve to make this analysis easy to follow if we imagine that Britain fails to heed the warnings of OPT (surprising but possibly true!) and does no better than hold the population at 60 million.

An overview of MacKay's presentation can be gained by analyzing the 'cartoon' plan for replacing the existing total energy of 125 kWh /d /p, which he presents on page 204. It comprises three major categories of energy consumption:

1) *Transport*: Noting that this currently requires 40 kWh /d /p, he assumes a good deal of transport could be replaced by electrical vehicles, and since electrical motors are so much more efficient than internal combustion engines we could reduce that energy requirement to 18 kWh /d /p of *electricity*. As we will see later, uncontrollables can contribute no more than about 30% to an electricity grid (less than that if a lot comes from photovoltaics). This implies that 18 x 0.7 = **13 kWh /d /p** will need to come from a *controllable* source.

2) *Heating*: This currently uses 40 kWh /d /p, but heat pumps can supply more heat energy than is contained in the electricity, so he reduces the requirement to 12 kWh /d /p. That suggests that 12 x 0.7 = **8 kWh /d /p** needs to come from a *controllable* source.

3) *Electrical things*: He notes that currently these require 45 kWh /d /p to produce the electricity to power them. Since 27 kWh /d /p is lost in conversion from fossil fuels, he estimates that the 45 kWh /d /p of fossil fuels could be replaced directly with 18 kWh /d /p of electricity. That suggests that 18 x 0.7 = **13 kWh /d /p** needs to come from a *controllable* source.

Totalling up the need for *controllable* electricity we arrive at **34 kWh /d /p**. We have already noted that pumped storage can only make a small contribution to solving the irregularities of uncontrolled inputs, so most of the burden of providing controllable electricity will have to be satisfied by producing electricity from biomass. 34 kWh /d /p is an average 85 GW for the UK. As noted later (Table 4), the power density of producing electricity from biomass is about 0.17 W/m^2. To produce an average 85 GW will therefore require 50 million hectares, *more than twice the total area of the UK. MacKay appears to fail to recognize that the feasibility of producing so much electricity depends totally on an ability to provide the requisite amount of controllable input*. An eight page article, in the October 2010 issue of the OPT Journal covers this same point at some length.

Is it really impossible to provide more than 30% of electricity from uncontrollables, as suggested? Let us check whether it is likely to be true by starting with that 30% assumption. Using the earlier example, the electricity totals up to 48 kWh /d /p, or an average 120 GW. On the assumption that only 30% can come from uncontrollable inputs, 48 x 0.30 = 14 kWh /d /p, or an average 35 GW, can come from uncontrollables. It would be fairly in line with MacKay's assessment of what is possible, to assume that we provide that 14 kWh /d /p from uncontrollables using the distribution shown in Table 3.

Table 3. A plan to provide 14 kWh /d /p (average 35 GW) from uncontrollables

	kWh /d /p	So required capacity	
Tide (load factor 25%)	3	3 x 2.5 / 0.25 =	30 GW.
Offshore wind (load factor 35%)	5	5 x 2.5 / 0.35 =	36 GW.
Onshore wind (load factor 30%)	4	3 x 2.5/ 0.30 =	33 GW.
Solar PV (load factor 12.5%)	2	2 x 2.5 / 0.125 =	40 GW.
Total	14		139 GW.

It now becomes apparent why it is likely to be impossible to cover more then 30% of electrical requirement from uncontrollables. The aim here is to provide an average 120 GW of electricity, and at times of low demand the need is certain to fall below that, yet we see from Table 3 that when all the uncontrollables are delivering at full capacity, their output will amount to 139 GW. We can conclude that although the whole wind system is unlikely to deliver at full capacity, there is clearly potential for trouble when, as shown in Table 3, uncontrollables are delivering 30% of the energy.

The DESERTEC fantasy

MacKay dwells on the possibilities of using the car batteries of an all-electric fleet as an additional store of energy, and also of using concentrated solar power situated in north Africa, the latter having the advantage of adding some storage capacity. The car battery idea is probably pie-in-the-sky. There are other problems with concentrated solar power.

Why is the idea of using car batteries as a general facility for storing unwanted electricity an improbability? It is because people tend to leave their cars all over the place: parked under trees, in lay-bys in the countryside, on what were once front lawns, half on pavements, in side streets and in car parks. There is no chance of having a charging facility at every place that people feel inclined to park, and anyone who has seen people's reluctance to waste their time on going to get a parking ticket from the nearest meter will know that people are not going to bother to plug into a charger every time they stop.

So on to DESERTEC. MacKay puts considerable store by it, and it is a pleasing fantasy, thus deserving a section to itself. DESERTEC is based on concentrating solar power. In a really hot place, like north Africa, concentrating solar power appears to have a head start, as Table 4 shows (Mackay p. 177).

Table 4. Power per unit land or water area (power density). [Note that all these show *electrical* power densities except for 'plants'. After conversion to electricity the power density of plants is likely to be at best 0.5 x 0.35 = 0.17 W /m^2.]

	W /m^2
Concentrating solar power (desert)	15
Solar PV panels	5-20
Hydroelectric facility	11
Tidal stream	6
Tidal pools	3
Offshore wind	3
Wind	2
Plants	0.5 (0.17 W/m^2 after conversion to electricity)
Rain-water (highlands)	0.24
Solar chimney	0.1

From now on we will refer to “concentrating solar power” as “solar thermal electricity,” the thermal being helpful in emphasizing that this is a form of renewable energy which can be stored as heat. It is apparent from the above list that, *in the sunnier places*, in terms of power density, PV is about the same as solar thermal electricity. As to capacity factor, in sunny places PV can reach a capacity factor of 20%, close to that of solar thermal electricity. Howard Hayden estimates the capacity factor of solar thermal electricity (using troughs in the Mohave desert in California) as 22% (2004, p. 190.6). Importantly solar thermal electricity (as well as being much cheaper than PV) offers the advantage that the energy captured can be stored (in molten salt at a temperature of at least 310ºC). That helps a bit, but as we will see later, seasonal variation is its major problem.

Turning again to MacKay’s earlier plan to provide 48 kWh /d /p as electricity from uncontrollable renewables, it will be recalled that we had to find a way to store 14 400 GWh, to manage a 10-day lull (a lull during which renewables could only produce half their average output). Even under the hypothesis of building 400 GWh of pumped storage, only 3% of the total requirement would be satisfied, with 14 000 GWh still to find.

There are several types of solar thermal plant, but heating up salt is probably much the same however it is heated, so we can draw on the data supplied by MacKay with reference to one of the European demonstration plants, designated PS10, near Seville, Spain. That power station produces 24.2 GWh /y, which is an *average* power of 2.76 MW, equal to an average daily output of 66 MWh. The average power density for this particular central power system is only 10 W/m^2, but we need not be concerned that the power density may be only two-thirds of the value given in Table 4, because power density is of secondary importance. What we are most interested in is storage capacity, first to deal with a low capacity factor. According to MacKay (p. 184.9), the PS10 unit can store 20 MWh, i.e. 20 / 66 = 30% of its average daily output. Because in solar thermal electricity systems most of the power is gathered around six hours in the middle of the day, a 30% store is unlikely to be enough to completely flatten out its output, although it could well suffice to follow the pattern of usual demand (much lower at nights of course).

But additional salt will be required to provide protection against lulls with respect to the 14 000 GWh of required storage we calculated previously. So for the UK we will need 14 000 GWh / 20 MWh = 700 000 times as much salt as is currently held in just one of these units. How much additional salt does that indicate per unit?

For the UK, the electricity we are aiming to produce from uncontrollables, 48 kWh /d /p, is an *average* 120 GW. Since each unit has an *average* output of 2.76 MW, we are going to need 43 000 units So to get to that, the extra salt each unit needs to be able to store is 700 000 / 43 000 = 16 times as much salt as it currently has.

There are two possible problems: heat loss for year-long storage, and cost. Taking heat loss first, so far only *24 hour* storage had been considered. Ted Trainer (2007, p. 46.7) tells us that “Sandia claim losses are already close to 1%,” with an implication that there might be some further improvement. But on that basis, one might surmise (vital data is missing in this as many areas) that over a year the losses (and hence the input needed to compensate for them) would be about 365%. Adding in the basic input, the total heat needed to produce the stored electricity would be 465%, more than 4 times what it would be for direct delivery. Yet we are only storing enough electricity for a lull of five full days.

As to cost, the aim is to store 14 000 GWh, so for each of 60 million UK citizens we need to store 233 kWh. How much is that going to cost? Trainer (2007, p. 46.9) cites two estimates of storage cost both of which are close to US$35 / kWh. So the cost per person will be $8170. Considering that as only capital cost, and amortising it over 20 years, that is about $408 per person per year. But that does not account for heat losses. Also the lulls are the *minor difficulty* : as we will see, the major problem lies in seasonal variation.

There are also practical matters which MacKay leaves for others to attend to. Hayden (2004, p. 189.9) tells us that "between 71% and 80% of the sunlight that strikes the mirrors is reflected to the pipes containing the therminol. They achieve this high efficiency by washing the mirrors every five or so days, and with a high-pressure wash every ten to twenty days," yet water is scarce in the desert, and pipes to carry it liable to sabotage. It is becoming evident why MacKay left the practical problems for others to figure out!

If the required *average* 120 GW (assuming for the moment it is all produced by solar thermal to try to provide enough storage) is produced at the power density shown in Table 4 (15 W/m^2), the area needed will stretch over a square of about 90 km by 90 km.

Seasonal variation

We now turn to the most intractable problem of all, namely seasonal variation. Trainer (2007) provides data on that too. Trainer tells us that output from the SEGS unit in California during winter is only 20% of that in summer (p. 168), and adds that, "Winter performance could be improved by realigning troughs east-west, but that would lower annual output." 20% is a ratio of 5 to 1; and in 2002 the ratio was worse, 9.5 to 1. He also tells us that about 41% of SEGS VI annual output occurs in the summer months, and over the four winter months of the year the cumulative output was about 10%. The situation is likely to be fairly similar in north Africa as it is about the same latitude. As MacKay indicated, the seasonal shift problem does not seem amenable to any tried and tested solution — only hand-waving solutions are available at present! *As compared to other methods of solar capture, solar thermal electricity greatly magnifies the problem of seasonal variation because very high insolation is required to produce satisfactory results.*

There is another form of solar thermal which largely overcomes the problem of seasonal variation, namely umbrella shaped dishes, which are controlled to face directly at the sun wherever it is. The problem there is finding a way to link their output to a large heat store, which we have seen to be of fundamental importance to overcome daily variation and lulls.

With so many hard-to-pin-down variables, it would seem necessary to maintain a level of suspended disbelief about the possibility of integrating different types of renewable, as well as the viability of any particular one, like solar thermal electricity. Is my thesis on the limits open to empirical test? In the course of time, harsh reality will put it to the test, but I suggest that it would be possible to test it before then by using the input from many small scale units, with their outputs and storage capacity boosted in the virtual world of a simulator, to see whether, in any combination, they could match an image of demand — or maybe even a flat demand if we can get some empirical evidence about the extent to which it will be possible to sometimes restrain and sometimes encourage demand throughout each 24 hour day. Two things are certain : any uncontrollable power source with a capacity factor of around 30% or less is hard to integrate into an electrical system, and seasonal variation can be a huge headache.

Incidentally, suspicion is in order about the 15 W/m^2 claimed for solar thermal electricity. Hayden (2004, p. 190.9) estimates the power density of SEGS (the biggest experiment in trough type heating that has been carried out) as 11 W/m^2. It is easy to be misled about power density of these systems. SEGS gets about 25% of its power from gas, which it uses to make sure that the therminol is delivered to the steam turbine at 371 ºC. The gas input needs to be excluded in calculating the power density.

A Renewable energy plan

In Chapter 27, *Five energy plans for Britain,* MacKay explains the objective of this chapter, which looks at various plans we have touched on, thus (p. 203):

> To avoid the plans taking many pages, I deal with a cartoon of a country, in which we consume power in just three forms: transport, heating, and electricity. This is a drastic simplification… but I hope it is a helpful simplification, allowing us to compare and contrast alternative plans in one minute. Eventually we'll need more detailed plans, but today we are so far from our destination that I think a simple cartoon is the best way to capture the issues.

All five plans produce lots of electricity, and all plans aim to produce a total of 70 kWh /d /p (an average 175 GW). It may be worth noting that arguably this is effectively quite close to current consumption, because the energy is nearly all delivered as a 'high-grade' form of energy, namely electricity. Were we to generate say 30 kWh /d /p of the 70 kWh /d /p as electricity *from fossil fuels*, then at 35% efficiency our power consumption would work out at (70 -30) + (30 / 0.35) = 125 kWh /d /p, which is about our current overall power usage. On the other hand, were we to try to turn some of our electricity into say methanol or hydrogen, there would be substantial conversion losses, so it is hard to say whether 70 kWh /d /p would suffice to maintain present energy supply. Nevertheless 70 kWh /d /p is the figure for MacKay's plans, and the amount we will now consider.

Of the five plans, the only one that is really relevant to OPT's concerns (which are of a long-term nature) is plan G, which Mackay introduces with these words:

> Some people say "we don't want nuclear power, *and* we don't want coal!" It sounds a desirable goal, but we need a plan to deliver it. I call this "plan G," because I guess the Green Party don't want nuclear or coal, though I think not all Greens would like the rest of the plan. Greenpeace, I know, *love* wind, so plan G is dedicated to them too, because it has *lots* of wind.
>
> I make plan G by starting again from plan D, nudging up the wave contribution by 1 kWh /d /p (by pumping money into wave research and increasing the efficiency of the Pelamis converter) and bumping up wind power fourfold (relative to plan D) to 32 kWh /d /p, so that wind delivers 64% of all the electricity. This is a 120-fold increase of British wind power over today's levels. Under this plan, *world* wind power in 2008 is multiplied by four, with all of the increase being placed on or around the British Isles.

The reason that this plan is relevant to OPT is not because we share the perspective of Greenpeace but rather that OPT takes a long view, realizing that to change population size takes time, and well before the UK population has reduced to a sustainable level, there may well be scarcely any coal (Rutledge, 2010) or uranium available.

MacKay gives a plan for delivering an average 175 GW (70 kWh /d /p) in plan G. I present it as Table 5, making some changes (as will be noted) and adding three columns.

One change is to split the energy from *tides* into what I deem might be 'controllable' (coming from *estuaries and lagoons*) and 'uncontrollable', coming from *tidal flow*. I also rearrange the order, so we can see that 48 kWh /d /p is uncontrollable, and only 2 kWh /d /p controllable (although this could be slightly higher if all the wood were used to produce controllable electricity). Bearing in mind that about 70% or 33 kWh /d /p needs to be controllable, this is clearly not viable. I should mention that the "pumped heat" of row 12 is heat extracted from the earth or air by the heat pump, with the electricity for so doing appearing in other rows.

Table 5. Mackay's plan G.					
Row No.		kWh /d /p	Subtotals	Load factor	Peak output
1	Solar in deserts	7		0.22	32
2	Tide (uncontrollable)	1.9			
3	Wave	3			
4	PV	3		0.125	24
5	Wind	32		0.33	97
6	Waste	1.1	48 (subtotal uncontrollable electricity)		
7	Tide (controllable)	1.8			
8	Hydro	0.2	2 (subtotal controllable electricity)		
9	Wood	5			
10	Solar HW	1			
11	Biofuels	2			
12	Pumped heat	12	20 (subtotal of not-electricity energy)		
	Total.	70			

As already shown, there seems to be no solution to the problem of dealing with lulls and seasonal variation when 48 kWh /d /p is being supplied from uncontrollable sources.

With battery storage being a forlorn hope, this plan G belongs to fairyland, but then MacKay admits that is probably the case, *and with his other plans too* : he finishes the chapter with a section titled “**All these plans are absurd!”** and goes on to observe:

> If you don’t like these plans, I’m not surprised. I agree that there is something unpalatable about every one of them. Feel free to make another plan that is more to your liking. But make sure it adds up!
>
> Perhaps you will conclude that a viable plan has to involve less power consumption per capita. I might agree with that, but it is a difficult policy to sell – recall Tony Blair’s response when someone suggested he should fly overseas for holidays less frequently!
>
> Alternatively, you may conclude we have too high a population density, and that a viable plan requires fewer people. Again a difficult policy to sell.

What he doesn’t mention is that there is a great difference between the two policies he mentions. In the UK, where Total Fertility Rate is 1.9, our population would be falling were it not for unbalanced migration. Balanced migration is a policy that the majority of the population would support. It is the politicians, economists and business world who combine to thwart the popular will.

In summary, despite all the warm praise the book has very deservedly received from the critics, there will doubtless be those in Greenpeace, Friends of the Earth, the Earthwatch Institute, New Scientist, the Centre for Alternative Technology, and all the other renewable energy drum beaters, who will say something like: “Well yes, it is a useful book, but it is too gloomy a way of looking at things!” If my analysis is correct, then it is not gloomy enough to the extent that it glosses over the problems of dealing with uncontrollable inputs into the electricity grid, *which types of input are necessary to use because they are the only renewable energy sources with a satisfactory power density*. Let us now proceed to take a look at sundry matters that MacKay covers very usefully.

Sundry Technical stuff

Number of homes

MacKay has these wise words to say about the renewable energy debate (p. 3.2):

> This heated debate is fundamentally about numbers. How much energy could each source deliver, at what economic and social cost, and with what risks? But actual numbers are rarely mentioned. In public debates, people just say, “Nuclear is a money pit” or “we have a huge amount of wave and wind.” The trouble with this sort of language is that it’s not sufficient to know that something is huge: we need to know how the “huge” compares with another “huge,” namely our *huge energy consumption*. To make this comparison we need numbers, not adjectives.

Thus he wants all of us to get out our calculators and be able to combat propaganda such as the misleading claim that wind would do a lot, but nuclear power very little (page 19.2):

> The total permitted offshore wind power of 33 GW will on average deliver 10 GW, which is 4 kWh per day per person; and the replacement of all the retiring nuclear power stations would deliver 10 GW, which is 4 kWh per day per person. Yet in the same breath, anti-nuclear campaigners say that the nuclear option would “do little,” while the wind option would “power all UK homes.” The fact is, “powering all UK homes” and only reducing emissions by 4%” are the same thing.

The number of homes that a certain amount of electricity will provide is a popular propaganda tool of the renewables industry — yet to most people it is fairly meaningless. Mackay helpfully tells us (p. 329) that the British Wind Energy Association defines the power of a “home” as 4700 kWh per year, equal to 0.54 kW or 13 kWh per day. As there are about 20 million homes and 60 million people, that is slightly more than 4 kWh /d /p, which is less than 4% of our overall power consumption of 125 kWh /d /p, and nearly 25% of our 18 kWh /d /p electricity consumption. He adds that a few other organizations use 4000 kWh/y per household as a benchmark.

Number of servants

On page 24.7 Mackay says, “One kilowatt-hour per day is roughly the power you could get from one human servant. The number of kilowatt-hours per day is thus the effective number of servants you have working for you.” Some of the energy we use is converted by internal combustion engines at about 20% efficiency, and the power stations convert fossil fuel energy to electricity at about 35% efficiency. If we use electricity to provide heat, that is 100% efficient, but if we use it to drive an electric motor it is more like 80% efficient. If we have the latest gas boiler our heat may be provided with 90% efficiency.

MacKay’s estimate of about one kilowatt-hour per day gets confirmation and explanation from David Pimentel (2008, p. 12.5) when he says, “One person working a 10 hour day, at the rate of one tenth of a horsepower (1hp =746 watts) does 0.75 kWh per day.” Fossil fuel, when used to drive engines, does not directly do work for us (as human labour does), but taking the conversion of fossil fuel heat into work at 30%, that still means we currently have (125 x 0.30) / 0.75 = 50 servants working for us. When thinking about a renewable energy world, it is important always to bear in mind that building and maintaining transmission grids, and building, installing and maintaining wind turbines at sea, and doing the same for wave machines, would probably be impossible *without energy of the right type* to provide that work (50 servants slaving for each of us).

The power density of green stuff, and fallacies about CHP and heat pumps

On page 49.1 MacKay tells us:

> In the World Energy Assessment published by the UNDP, Rogner (2000) writes: "Assuming a 45% conversion efficiency to electricity and yields of 15 oven dry tons per hectare per year…."

Both of the assumptions in that quotation are egregiously mistaken. El Bassam (1998, p. 33.9) gives considerable details about the efficiency of wood burning:

> Where the production of electricity is to be maximised, the steam engine or turbine will exhaust into a vacuum condenser and conversion efficiencies are likely to be in the 5–10% range for plants of less than 1MWe, 10–20% for plants of 1 to 5MWe and 15–30% for plants of 5 to 25MWe. Low-temperature heat (< than 50 ºC) is usually available from the condenser, though this is insufficient for most applications so it is normally wasted by dispersal into the atmosphere or a local waterway. The average conversion efficiency of steam plants in the USA is approximately 18%.

It must be remembered that because wood has to be collected from a large area, it often makes more sense to have smaller power stations. El Bassam goes on to consider that more efficiency can be achieved — 50-80% by combined heat and power (CHP). That leads into the subject of a common fallacy, namely to think that combined heat and power is *far* more efficient, than the normal 35% given for the production of electricity from fossil fuels. In Chapter 21, *Smarter Heating*, MacKay does an excellent job of showing that CHP *may* be no more efficient than separate generation of heat and electricity. He then goes on to consider the use of heat pumps.

The diagram on page 150 shows heat pumps which are producing just heat having an efficiency of 185%, twice that of a condensing gas boiler. He comments on the next page thus: "Let me spell this out. Heat pumps are superior in efficiency to condensing boilers, even if the heat pumps are powered by electricity from a power station burning natural gas." But OPT is looking ahead to coping without fossil fuels. The prospect of using heat pumps dims greatly when much electricity has to be produced from renewable sources.

As noted, the World Energy Assessment figure of 15 dry tons per hectare is optimistic for our climate. 10 tons would be stretching it, and that would only be maintained with fertilizer inputs. What would be the power density of producing electricity from wood using a realistic yield? 10 tons of dry wood would produce 5.71 kW/ha. Using El Bassam's implied 30% conversion efficiency, that is 1.7 kW/ha, or 0.17 W/m^2 (Table 4).

To see how crucial that very low power density is, let us consider that we want to supply everyone with an average 1000 watts (1kW or 24 kWh /d /p) of *heat*. Using heat pumps that are 185% efficient, we would only need 1000 / 1.85 = 540 watts of electricity. It is reasonable to assume that because of the variability of wind, wind power could only supply 30% of that. But that leaves 70%, i.e. 380 watts to supply from a controllable energy source. In a renewable energy world that is likely to come down to burning biomass. The area required, using the result of the previous paragraph, would be 380 / 0.17 = 2200 m^2 of ecologically productive land. About 18 Mha of the UK's 24 Mha can be classified as ecologically productive. Thus each person has a 3000 m^2 share of ecologically productive land. So we would be using more than two-thirds of it to supply each person with an average 24 kWh /d /p of heat. It is hardly necessary to remind people that we also need to feed ourselves and produce timber for construction as well as electricity for other purposes.

Table 4 shows the power density of plants as 0.5 W/m^2. Would it be better to produce the whole 1 kW (24 kWh /d /p) by burning wood in a wood burning stove that managed to achieve a 50% efficiency, making the power density 0.25 W/m^2? To provide the 1000 W of heat at that power density would require 4000 m^2. Thus it would appear that burning the wood directly would use *more* land; but there are problems with the heat pump option. The wind turbines have to be installed and maintained. To make electricity production fairly efficient, the wood has to be carried to the power plant over considerable distances. Transmission lines have to be built and maintained. And since we have not found an answer to producing liquid fuels in adequate quantities, it may be that horses have to be used to carry fuel and materials to their destination.

In summary, heat pumps would help us save some fossil fuels, but their usefulness in a renewable energy world is suspect. For large building projects, we need to think in terms not of our present life of energy affluence, but in terms of a country like Cuba.

It was mentioned briefly that 0.5 W/m^2 is a realistic figure for the power density of plants in the UK. Figures given for plant efficiencies can be misleading, and it is worth dwelling on something MacKay mentions on page 49.5:

> Zhu et al. (2008) … say that the highest solar energy conversion efficiencies reported for C3 and C4 crops are 2.4% and 3.7% respectively; and, citing Boyer (1982), that the average conversion efficiencies of major crops in the US are 3 or 4 times lower than those recorded record efficiencies (that is about 1% efficient).

There may be some scope for improving efficiencies, but a 3.7% efficiency seems highly improbable. In an insolation of 220 W/m^2 (very sunny climate) it represents an energy capture of 0.037 x 220 = $\underline{\underline{8.14}}$ W/m^2 or 81.4 kW/ha. Even if the biomass has the high calorific value of 20 GJ/t, to produce that amount of energy would need a yield of 128 *dry* tons per ha per year. Compare that with sugarcane — a C4 crop with an exceptionally high yield (and consequently associated with high soil erosion). It has an average yield of about 90 t/ha/y, but that is fresh material with about 71% moisture content, so the *dry* matter amounts to about 26 t/ha/y. 26 dry t/ha/y, at 17.5 GJ/t, in an ambient insolation of 220 W/m^2, is 0.66% efficient, so the suggested 1% is high even with the high inputs required to grow sugarcane. The power density of 26 dry t/ha/y is about 1.4 W/m^2, but sugarcane is a special crop, needing special conditions, and it would not be grown just to provide heat. Conclusion : MacKay's figure of 0.5 W/m^2 for biomass is realistic.

Tidal pools (estuaries and lagoons)

On page 311, Mackay explains how to calculate the potential energy created by flooding and ebbing tides. The calculation is based on allowing all the water to flow into the pool (or estuary blocked by a barrage) at high tide, and all the water to flow out of the pool at low tide. This provides a starting point for an analysis. The formula for the energy 'created' is, **2dg(R/2)^2 / (time in seconds)**, where d is the density of water in kg/m^3, g is the gravitational constant 9.8, R is the tidal range between flood and ebb tide in metres, and the time in seconds is 12 hours if the energy 'created' is only captured in one direction of flow, but 6 hours if captured in both directions. Thus, taking the estuary at La Rance as an example, where energy has mainly only been captured in one direction of flow, and the mean tidal range is 10.9 m (MacKay p. 311.8), the potential is:

$$2 \times 1000 \times 9.8 \times (10.9 / 2)^2 / (12 \times 3600) = 13.5 \text{ W/m}^2$$

However, as mentioned, this assumes that all the water is trapped at high tide, and then, after waiting for 6 hours, is all released in a rush at low tide. If the enormous expense of building generators to achieve this flow were to be accomplished, the result would be a spike of electricity every 12 hours which would be a nightmare to those running the grid. It is not surprising that in practice a quite different policy has to be followed. After 30 years of experience at La Rance, (two-way flow was introduced in 1997) it is apparent that the actual power density achieved, from its 22 km^2 area, is 2.77 W/m^2 . This is 21% of the 13.5 W/m^2 potential. It is therefore obvious that calculation of the potential can provide only a *relative* indication. It is also evident that when, on p. 84.9, MacKay says, "In practice, the in-flow and the out-flow would be spread over a few hours, which would reduce the power delivered a little." in using the words "a little" by way of referring to 79%, he is understating the truth of the matter.

MacKay tells us, on p. 87.9, that the engineers' report on the Severn barrage indicates a likely capture of 17 TWh/y. Yet they are planning on a one-way flow capture. Considering the 500 km^2 area, this indicates a power density of 3.88 W/m^2. That is 40% higher than that achieved at La Rance, and so should be treated with some suspicion.

Tidal lagoons are created by building walls in the sea. Apart from the effort of building the walls, they have some advantage, provided that two lagoons can be built. By treating them differently, e.g. one full, one empty, the power output can be smoothed out, and with judicious pumping enhanced. The general tidal range around the UK is about 4 metres. A 4 metre range, with a two-way flow energy capture, has a potential of 3.63 W/m^2. Applying the 21% fraction from La Rance, so as to get close to reality, we arrive at 0.76 W/m^2. On p. 320.9, MacKay says that with this two lagoon system, output can be boosted by pumping: "One lagoon's water level is always kept above mean sea-level; the other lagoon's level is always kept below mean sea-level. This power density of 4.5 W/m^2 is 50% bigger than the maximum possible average power density of an ordinary tide-pool in the same location (3 W/m^2)." But it is still a low power density.

Conclusion

MacKay's book is a treasure trove of facts and stimulating logical analysis, but generally tends towards assessing the theoretically possible rather than attempting the more difficult task of estimating what might happen in practice. Empirical evidence regarding some aspects of renewable performance is often in scant supply and there are weaknesses in any analysis. Ted Trainer continuously tries to extract information from companies running solar thermal plant about seasonal variation, but often meets up with a reply that such information is commercially sensitive.

Unfortunately, even MacKay's theoretical analysis is to some extent flawed by underestimating the problems of uncontrollable inputs into an electrical grid. Nevertheless the book is in many ways admirable, for in addition to writing in a sympathetic (to human failings), light-hearted tone, David MacKay has a crystal clear mind, and seems to have almost every relevant available fact at his finger tips (except about managing uncontrollables). Moreover, it is laid out so as to be as helpful to the reader as possible.

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SUPERCAPITALISM: The Battle for Democracy in an Age of Big Business*

by Robert Reich — a review essay by Andrew Ferguson

In *The Ascent of Money*, Nial Ferguson did a fine job of describing the history of money, with emphasis on the important developments that have occurred since the Italian Renaissance. At about that time, loans became such an important feature that the possibility of obtaining them could determine whether or not wars could be launched. The broad historical picture is interesting, but Robert Reich's book, *Supercapitalism: The Battle for Democracy in an Age of Big Business*, which focuses on the years since 1970, is more relevant to the world's current predicament. It is a well researched and written book.

Surely everyone has wondered at the exact mechanisms that have introduced such regrettable consequences as low or declining wages and benefits, insecurity about jobs, widening inequality, loss of community, and the advertising of indecent products being too much thrust into the faces of those who would prefer more modesty in their society. What has caused these changes to occur during past decades?

Most of us probably feel we already have a pretty good idea, but Reich analyses the reasons with a range of evidence that few could assemble. He points out that the immense *improvements in communications* and *modes of transport*, chiefly containerization, automatically lead to vast changes: Supply chains operate throughout the world, with manufacturers of goods taking components and resources from wherever they are cheapest.

Excellent communications make a hugh difference to investors as well as consumers. They can constantly monitor performance to see where to get the best deal, and then, with a few clicks of a mouse, transfer their investment from one company to another. With his usual assiduity, Reich validates this fairly obvious notion with interesting data:

> In the 1990s, the average investor hung on to a share of stock for a little more than two years. By 2002, the average holding period was less than a year. By 2004, it was barely six months.

With the current credit crunch, it became apparent that many financial advisers knew less than they thought they did, yet in general these changes would appear to be a step forward for investors. Whether they are a step forward or not, it is how things now happen. Thus there is worldwide competition for profitability, so Chief Executive Officers (CEOs) can no longer operate as they used to – as corporate statesmen, balancing the interests of consumers, the workforce, and investors. They could do that at one time, because large companies were heavily regulated, near monopolies. But now every CEO has to do at least as well as worldwide rivals, or get displaced due to the combined effects of consumers keen to get the best bargain, and investors wanting to get the highest possible return on their money. With performance making the difference between a share value falling precipitately or climbing rapidly, it is small wonder that investors are willing to reward handsomely those CEOs who are both astute and ruthless enough to lead the competitive pack. Here are some of the figures which Reich provides to demonstrate those rewards:

> The *average* take-home pay for the twenty-six managers of major hedge funds in 2005 was $363 million, a 45 percent increase over their average earnings the year before. … The family of Wal-Mart founder Sam Walton has a combined fortune estimated to be about $90 billion. In 2005, Bill Gates was worth $46 billion; Warren Buffett, $44 billion. By contrast, the combined wealth of the bottom 40 percent of the United States population that year – 120 million people – was estimated to be around $95 billion.

As Reich points out, we are all of two minds, in that we like the improvements brought to us as consumers and investors, but deplore our loss of power as citizens to oppose such accumulation of wealth. At first, I feared that Reich would merely argue that we needed to renounce our inclination to profit from the benefits being offered to us as consumers and investors, but he does see that the situation is equivalent to the "Tragedy of the unmanaged commons," the famous example from ecology, in which any individual cannot be expected to voluntarily put one less cow on the commons — to prevent overload — while seeing others doing so and gaining thereby. This is how Reich puts it (p. 127):

> We might make different choices if we understood and faced the social consequences of our purchases or investments *and* if we knew all other consumers and investors would join us in forbearing from certain great deals whose social consequences were abhorrent to us. But we will be unlikely to make the sacrifice if we think we are the only consumer or investor who refrains.

Quite correctly, Reich argues that what is needed as a first step is to control the power of commercial organizations, which, perhaps especially in the USA, has burgeoned over the last decades, even though how their influence operates is not always easy to pin down:

> The fundamental problem does not, for the most part, involve blatant bribes and kickbacks. Rather, it is the intrusion of supercapitalism into every facet of democracy – the dominance of corporate lobbyists, lawyers, and public relation professionals over the entire political process; the corporate money that engulfs the system on a day-to-day basis, making it almost impossible for citizen voices to be heard. Not only do campaign contributions have to be severely limited, but also corporate expenditures on lobbying and public relations intended to influence legislative outcomes. [Reich mentions twenty-one instructive books on that theme.]

If reduction in the power of commercial organizations can be achieved, then, Reich argues in his concluding paragraph, we could regain our power as citizens:

> We are all consumers and most of us are investors, and in those roles we try to get the best deals we possibly can. That is how we participate in a market economy and enjoy the benefits of supercapitalism. But those private benefits often come with social costs. We are also citizens who have a right and a responsibility to participate in a democracy. We thus have it in our power to reduce those social costs, thereby making the true price of the goods and services we purchase as low as possible. Yet we can accomplish this larger feat only if we take our responsibilities as citizens seriously, and protect our democracy. The first step, which is often the hardest, is to get our thinking straight.

Unfortunately Reich's book itself does not entirely serve to get "our thinking straight." It skips over too much. While he points out that people in undeveloped countries are prepared to work for a tiny fraction of the wage that is normal in a developed country, he does not go on to suggest changes in the global trade rules that might overcome this problem. Yet this certainly appears to be an intractable problem of globalization.

It would be impossible for the whole populations of China and India to develop to the same extent as Europe and north America, because it would soon overwhelm the physical limits of extraction of the many types of raw materials needed for modern civilization, and, most imminently, exhaust the remaining supplies of fossil fuels. Little can be achieved by citizens regaining power if they do not know what they should be aiming for. What they should be aiming for is to abandon the ruinous path of globalization, and to reduce their populations to levels which can be sustained by the *ecological resources within their own boundaries*. The question is this: Are citizens, if they regain power, wise enough to move in that direction, or must we wait for Mother Nature to cull our excessive numbers?

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* *Supercapitalism: The Battle for Democracy in an Age of Big Business*, by Robert Reich. USA: Alfred A. Kopf, 2007; UK: Icon Books Ltd, 2008. £12.99.