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Even if all of the world's sugar cane crop were converted to ethanol, the annual ethanol yield would be less that 5% of the global gasoline demand in 2010. Even if the entire U.S. corn harvest was converted to ethanol, it would produce an equivalent of less than 15% of the country's current annual gasoline consumption. Biofuel enthusiasts envisage biorefineries using plant feedstocks that replace current crude oil refineries — but they forget that unlike the highly energy-dense oil that is produced with high power density, biomass is bulky, tricky to handle, and contains a fairly high share of water.

Vaclav Smil, *Energy Transitions*, p115, 2010

The Optimum Population Trust (UK): London

<http://tinyurl.com/optj2>

INTRODUCTION

David and Marcia Pimentel's book *Food, Energy, and Society* contains valuable insights into the problems ahead, as must be apparent from the five previous instalments. But it is to be doubted that anything will surpass the value of the three pages of extracts from Chapter 12 which open this issue. They sum up the essential nature of the interrelation between food and energy, showing the extent of the problems that the world faces today, with our attempts to increase food supply (necessitated by the excessive population), causing increasing damage to our life support systems.

As *Food, Energy, and Society* makes crystal clear, energy is interrelated with food. A fourteen page critique of Vaclav Smil's latest book *Energy Transitions* commences on page 7. Vaclav Smil is an outstanding scholar of the history of energy, its development and the part it has played in allowing the development of modern civilization. However, there has often been one serious flaw in his analyses. The flaw appears to have its origin in his desire to look forward with optimism to the future. It may be significant that he spells out his belief in the duty of scholars to be optimistic by placing at the front of an earlier book, *Global Ecology*, a quotation from Ralph Waldo Emerson (*The Method of Nature*, 1841) : "Whilst the multitude of men degrade each other, and give currency to desponding doctrines, the scholar must be a bringer of hope and must reinforce man against himself."

Be that as it may, as recently as 2003 he was reassuring his readers with these words: "What comes after fossil fuels? This question should not be asked with either regret or unease." The picture painted in his latest book, *Energy Transitions,* published in 2010, is very different. In it Smil at last recognizes that there are likely to be great problems in changing to renewable energy. However, he goes only some way to recognizing the extent of those problems, because like so many others he does not give adequate consideration to the limitations of introducing uncontrollable inputs from renewable energy sources into an electricity grid. This is a subject that this journal has already treated extensively but one which it will return to.

I have Donald Mann, president of Negative Population Growth, to thank for sending me Smil's book. Without that stimulation I would likely have passed it by, as while reviewing Smil's previous book *Energy at the Crossroad*, it seemed apparent to me that Smil's optimism would always overcome his sense of realism. I'm glad to say it appears that may have been a premature judgement.

Eric Rimmer brought to my attention a graph showing the probable course of liquid energy supply (oil) up to the year 2200. He thought it would be a good idea to link this to the oil supply per person over this period of time. Initially, with population still expanding, the rate of decline of per capita oil supply will necessarily be even faster than the rate of decline of oil itself. A significant die-off in human numbers seems inevitable as fossil fuels become scarce, but when this will take effect is impossible to predict with accuracy, so in this article our analysis shows population levelling off at an arbitrary figure of 9000 million. Then the decline in per capita oil supply decreases at the same pace as the decline in oil supply. Our article, pp. 21-24, *Liquid Fuel, Population, and Liquid Energy Supply per Person*, is based on data about oil supply from petroleum geologist Jean Laherrère. It provides a good deal of background information as to why his estimates are likely to be approximately true.

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The fact that oil supply per capita will decrease in line with decrease in oil supply may seem so self-evident that it does not need to be laboured. Yet the fact is overlooked even by those who should know better. Lester Brown, in *World on the Edge* (p15), says:

> Once the world reaches peak oil and peak water, continuing population growth would mean a rapid drop in the per capita supply of both. And since both are central to food production, the effects on the food supply could leave many countries with potentially unmanageable stresses. And these are in addition to the threats posed by increasing climate volatility.

What that statement skips over is that even with a *stabilized* population, the drop in oil supply will be rapid. The drop will be 'rapid' in the sense that the rate of decrease in oil supply is likely to be considerably faster than it would be possible to reduce population. That is one of many reasons why it is only those who have seen the need to *reduce* population who have shown foresight.

Lester Brown would probably defend his aim of only stabilizing population on the grounds that there will be a transition to renewable energy. As is apparent from Smil's *Energy Transitions*, it is less than probable that more than a partial transition will occur. All renewable energy projects have great drawbacks. On page 25-27 we take a look at the considerable difficulties that are related to one renewable energy source, solar thermal, for which some respected writers have great hopes. For instance, David MacKay's impressive book, *Sustainable Energy – without the hot air*, sees solar thermal in North Africa as an important contributor to the UK's problems.

Although Lester Brown is absurdly unrealistic with respect to renewable energy (particularly about wind turbines), he marshals his evidence superbly when it comes to showing the extent of the problems that the world faces. The final page of this issue, *The Population Bubble*, draws extensively from Brown's most recent book, *World on the Edge*.

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

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

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

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

FOOD, ENERGY, AND SOCIETY (3rd edition), Part 6
by David Pimentel and Marcia H. Pimentel, compiled by Andrew Ferguson

Chapter 12. Energy inputs in Crop Production in Developing and Developed Countries [this chapter continued from previous issue]

FOSSIL ENERGY USE AND CROP YIELDS

153.5 The significant achievement of using fossil energy to increase crop yields, and cereal grains in particular, started in 1950 with the advent of the Green Revolution. During the 1950s, plant breeders developed wheat, rice, corn, and other cereal crops to have short statures so that large quantities of fertilizers, especially nitrogen, could be applied in production. The short stature was essential to prevent the plants from growing and then falling over (lodging) which formerly resulted in a loss of the crop.

The availability and use of fossil fuels also was instrumental in the success of the Green Revolution. During the 1950s, plant geneticists developed rice, wheat, and other major grain crops to have short stature that facilitated the heavy application of fertilizers, especially nitrogen. As a result, crop yields per hectare were significantly increased for the newly developed grains. Yet, in 75 countries, less grain was produced by 1990 than at the beginning of the decade.

At best, world grain yields per hectare are slowly increasing, at the most about 1% per year, while human population numbers and their food needs are increasing at a greater rate than food production can supply their needs. As the world population increases it outstrips increases in food production. Thus, it is becoming more apparent that the food supply cannot keep up with the needs of a rapidly increasing human population.

On a per capita basis, world grain production has declined since 1984. Grains make up about 80% of the world food crops. Shortages of the basic resources for a productive crop system now currently exist. These worldwide losses in fertile cropland, loss of fresh water, and diminishing fossil energy supplies used in mechanization, fertilizers, pesticides, and irrigation are having negative impacts on crop production.

Per capita use of fertilizers worldwide during the past decade declined 17%, while available cropland resources per capita decreased more than 20%. A total of 560 million ha of the 1500 million ha of cropland worldwide has been seriously degraded because of soil erosion. Irrigated land area in developing countries declined about 10% over the past decade. A total of 20% of the irrigated croplands worldwide suffer from salinization — a result of poor irrigation and drainage practices.

FOSSIL ENERGY USE IN CROP PRODUCTION

154.2 Of the total fossil energy consumed in the world of about 384 quads, approximately 270 quads are used in developed countries and 114 quads in developing countries. The population in developed countries is less than 2 billion while more than 4 billion live in developing countries. [i.e. usage is about 135 quads per billion people in developed countries and 28 quads per billion people in developing countries.]

Developed countries use approximately 40 quads of fossil energy [for food production and delivery], but only about 16 quads of this are used directly for both crop and livestock production. The remaining 24 quads are used for food processing, packaging, distribution, and preparation.

In contrast, in developing countries approximately 28 quads are consumed in agricultural production. Little fossil energy is used in cooking because biomass energy (fuel wood, crop residues, and dung) is the prime fuel. From 2 to 3 kcal of biomass energy are used to prepare 1 kcal of food in developing countries. [Thus about 35 quads of biomass energy are required for food preparation.[1] Including these 35 quads, the total energy for the food system for all countries is 40 + 28 + 35 = 103 quads, which for a population of 6 billion works out as an average of 14 kWh per person per day. This is a substantial proportion of the 48 kWh per person per day that some authorities — with whom we agree — estimate as being the minimum (as an average) to sustain a civilized way of life.[2]] …

Most of the fossil energy used in world food production is oil for farm machinery and pesticides while natural gas is vital for the production of nitrogen fertilizers. …

In developed countries people consume an average of 3400 kcal of food per person per day, whereas people in developing countries consume 2400 per day per person.

[From the data in this section, the total energy input per J of food amounts to 4 J in developed countries, and within the range of 4 J to 5 J in developing countries (depending on actual fuel usage).[3] This result is perhaps surprising, but the potentially high figure for developing countries can probably be accounted for by the inefficient methods that are widely used in developing countries to burn biomass as a fuel.]

Renewable Energy

155.2 Nitrogen can be produced using electrical discharge to convert atmospheric nitrogen to nitrate. However, about 200,928 J of energy are required to produce 1 kg of nitrogen by this method, compared to 78,078 J required using fossil energy dependent technologies. Based on current renewable energy technologies, a quantity of energy produced using renewable technologies costs from five to ten times more than an equivalent amount obtained from fossil energy sources.

Future Technologies

155.3 In the past decades, advances in science and technology have been instrumental in increasing industrial and agricultural production, improving transportation and communications, advancing human health care, and in general improving many aspects of human life. However, much of this success is based on the availability of resources in the natural ecosystems of the Earth.

Technology cannot produce an unlimited flow of the vital natural resources that are the raw material for sustained agricultural production. Genetic engineering holds promise, provided that its genetic transfer ability is wisely used. For example, the genetic modification of some crops, such as rice, to have high levels of iron and beta-carotene would improve the nutrition of millions of people in the future, particularly those in developing countries where rice is the prime grain consumed. In addition, the possibility exists for biological nitrogen fixation to be incorporated in crops, such as corn and wheat.

… Yet there are limitations to what technology can accomplish. In no area is this more evident than in agricultural production. No known or future technology could, for example, double the quantity of the world's fertile cropland available for production. Granted, synthetically produced fertilizers are effective in enhancing the fertility of eroded croplands, but their production relies on sustained supplies of finite fossil fuels. …

To date, biotechnology that started more than 20 years ago has not stemmed the decline in per capita food production during the past 17 years. Currently, more than 40% of the genetic engineering research effort is devoted to the development of herbicide resistance in crops. This herbicide-tolerance technology has not increased crop yields, but instead generally increased the use of chemical herbicides and polluting the environment. …

SUMMARY

156 Based on the information presented, if current trends in human population growth and fossil fuel consumption continue into the future, projections for the adequacy of tomorrow's world food supply are not encouraging. When the world population expands to nearly 8 billion as projected in about 15 years, food yields will have to increase 33%. The factors that govern our success in achieving this are dependent on our dedication to conservation and judicious use of our natural resources, increasing political and economic stability, and most vital, reducing the world population. The basic equation of people versus food and energy intensifies the imbalances between the human food supply and the natural resource needs of a rapidly growing world population.

Endnotes

1. Food consumed in developing countries is 2400 kcal per person per day, so with a population of 4 billion, the energy in total food consumed is 2400 x 365 x 4186 = 14.7 x 10^{18} J (14.7 EJ).
   Taking the mid-point between 2 and 3 kcal per kcal of food, indicates that food preparation requires 2.5 x 14.7 x 10^{18} = 34.7 EJ = 35 quads.
2. Vaclav Smil has given this estimate of 48 kWh/person/day (i.e. 2 kW/person), basing it on providing primary education and adequate health care. Howard Hayden gives relevant evidence in relation to less temperate climates when he records that, prior to introduction of electricity and railways, energy use in the USA amounted to an average of 89 kWh/person/day (i.e. 3.7 kW/person).
3. Total energy used in developed countries for food production and preparation is 40 quads = 42.2 EJ. The energy in total food consumed in developed countries is 3400 x 365 x 4186 x 2 x 10^9 = 10.4 EJ.
   So energy used per J of food consumed is 42.2 / 10.4 = 4.0 J.
   Total energy used in developing countries for food production and preparation is 28 + 35 = 63 quads = 66.5 EJ.
   The energy in total food consumed in developing countries is 2400 x 365 x 4186 x 4 x 10^9 = 14.7 EJ. So energy used per J of food consumed is 66.5 / 14.7 = 4.5 J. For brevity, this calculation uses the midpoint value of 2.5 kcal per kcal of food. Similar calculations for each end of the range of ratios given, namely 2 kcal of fuel used per kcal of food consumed and 3 kcal of fuel used per kcal of food, give results of 4.0 J and 5.0 J respectively (for the total energy used per J of food consumed).

ENERGY TRANSITIONS: HISTORY, REQUIREMENTS, PROSPECTS [1]

by Vaclav Smil — A Review Essay by Andrew Ferguson

Abstract The book under review is by a fine scholar of wide ranging knowledge whose special focus is energy. It is a considerable improvement over his 2003 book *Energy at the Crossroads*, because he now displays considerable, wise, misgivings about the transition to renewable energy. However, his doubts are mainly about whether the transition can be made sufficiently quickly. By failing to fully recognize the implications of uncontrollable inputs, especially when conversion mechanisms have a low capacity factor (the best example being photovoltaics), he does not get a measure of the ultimate limits of what he calls the 'unfolding transition' to renewable energy. Because of that, he does not draw attention to the most important conclusion of all, namely that the present population has only reached its present size because of the availability of fossil fuels, so that if we have to go back to using animate power (as has been done to some extent in Cuba when facing oil shortage) then only a much smaller population could be supported.

In reviewing David MacKay's *Sustainable Energy — without the hot air*, I found that there was so much of interest that 14 pages were needed to bring out the important points. I have found the same with this book by Vaclav Smil. Although there are similarities between the books there are also big differences. The *similarity* is that both books fail dismally to take full account of the problems of uncontrollables (so readers may note some repetition in the two reviews). The *difference* is mainly that MacKay leans over backwards to make his book easy for anyone to understand, mainly by presenting energy matters on a per person basis and whenever possible using 'kilowatt hours per day' as a measure of power. Smil makes no such concessions, and I will start by covering the meaning of terms with which a few readers may not be familiar.

Meaning of terms. Joules (J) constitute the modern basis of energy units. k (kilo) stands for 1000; M stand for a million; and G (giga) for a billion; thus 1 MJ is a million joules and 1 GJ is a billion joules; 1 TJ (terajoules) is a trillion joules (or 1000 billion joules i.e. 1 x 10^{12} J); 1 PJ (petajoules) is a million billion joules (1 x 10^{15} J); and 1 EJ (exajoule) is one billion billion joules (1 x 10^{18} J). These numbers may seem hard to grasp, but normally it is only a matter of comparing one figure with another in order to get the gist of what is being explained.

Having now displaced the horsepower unit, watts (W) are the almost universal measure of power (1 W = 1 joule per second). Thus common power units are either watts (W), kilowatts (kW), megawatts (MW), or gigawatts (GW).

An alternative measure of energy, to joules, and one with which most people are familiar, is a specified power for a specified time, for example a kilowatt hour (kWh), which is a thousand watts for an hour. A kWh is the unit used to measure electricity. 1 kWh = 3,600,000 joules (or 3.6 MJ) — the result of from there being 3600 seconds in an hour.

When figures are given as energy units per year, e.g. 63 GJ/y (often it is written as just 63 GJ with the year being implicit), it can be helpful to translate that into terms of power. To do so divide by 31.5 to get kilowatts (kW), thus 63 GJ/y is an average power of 2 kW.

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1. *Energy Transitions: History, Requirements, Prospects* by Vaclav Smil. 2010. Praeger: Santa Barbara, California; Denver, Colorado; Oxford UK. Hardcover, US$35, GBP25.

That can then easily be turned into energy units per day by multiplying by the number of hours in a day, thus 2 kW = 48 kWh/d.

Some people may be unfamiliar with the term 'order of magnitude'. One order of magnitude refers to a factor of 10, two orders of magnitude to a factor of 100, and three orders of magnitude to a factor of 1000. With that preliminary look at units, let us proceed to the book itself. But first I should say that Smil does not group together all his thoughts on one subject, say photovoltaics, but returns to the matter several times. To give a better flavour of the book, in this review I to some extent follow the book in this.

Vaclav Smil is an outstanding scholar with wide-ranging knowledge of many subjects. His main interest has always been energy, and that is the focus of about half of the twenty-six books which are listed at the front of his latest, *Energy Transitions: History, Requirements, Prospects*. In the April 2005 OPT Journal, I reviewed his 2003 book *Energy at the Crossroads*. From the Abstract, this was the main thrust of my review:

> Smil asks the question, "What comes after fossil fuels?" On grounds which do not stand up to scrutiny, he asserts, "This question should not be asked with either regret or unease." In fact, his presentation of 'data' is likely to mislead the reader and, *contrary to his conclusions*, it appears unlikely that there are significantly useful substitutes for fossil fuels.

Does he remedy those failings in this book? He does to some extent, for here he displays extensive "unease" about our future prospects, but while he puts before the reader most of the facts that are relevant, he does not follow them up so as to draw appropriate conclusions about the likelihood of the human race *actually* making what he often refers to as the "unfolding transition" to renewable energy. Neither does he ask an important related question, namely, even if *with the support of fossil fuels* that transition starts to 'unfold' to a significant extent, as he hopes, to provide say 30% of all energy, will the progress that has been made regress as fossil fuels become so scarce, and therefore so expensive, as to be no longer widely available? Why that is likely to occur may not be obvious, but we will return to the subject later.

Within the book there are significant omissions — that is there are important points that are avoided. A simple example of one such omission arises with this statement (p. 149.1), "Production of fertilizer ammonia now needs more than 100 Gm^3 of natural gas per year." Having stated that need, he does not go on to ask the next obvious question, namely what would happen if the 100 billion cubic metres of methane per year were no longer available. Yet he points out in this book, as he has in previous books, that a substantial proportion of the present 7 billion people on Earth are alive only because we discovered how to make synthetic nitrogen fertilizers. So what is the answer to that question which he leaves hanging in the air? It is that it is dubious that we could produce the necessary amount of nitrogen fertilizers without having fossil fuels available as feedstock. Although it is true that by using large amounts of electricity, nitrogen fertilizers can be produced from the plentiful nitrogen in the air, it is only economically feasible to do so where, as in Iceland, there is so much hydroelectricity and geothermal energy available, in excess of local needs, that electricity costs only 2¢ per kilowatt hour (kWh). Such situations are rare.

Despite weaknesses of this type, which we will note as we go along, the book has much of interest, so let's sift through for its gems of information, while picking up the general drift of his approach to the subject, and noting its shortcomings.

A large part of the book is devoted to a thorough study of the rates of transition from biofuels (mainly woody material) to coal, then from coal to oil, and then from oil to gas and nuclear. Smil uses graphs to show how the shares of these fuels have changed over time, both globally and — with eight well-chosen case studies — for individual nations. He does the same thing for engines (prime movers) used to transform the heat energy contained in these fuels to the type of energy we want — chiefly *motion* for transport and factory machinery, and *electricity*, which is a useful form of energy for many purposes. These matters are of considerable historical interest, but the conclusion is less useful, namely that it generally takes at least half a century for the transition to reach the stage where the new energy is taking a fifty per cent share of the whole, but sometimes, particularly within smaller nations, it can take only a few decades. As we will see, he makes the valid point that his mooted "unfolding transition" to renewable energy has characteristics that should incline us to the view that the transition will be long rather than short. But the really important questions — which he sheds almost no light on — are how far this transition to renewable energy can progress, and whether the progress made can be sustained without the benefit of fossil fuels. So far, the transition has proceeded such a small way (2%) that it would hardly register on his graphs of energy transitions, but that does not lessen the importance of determining the prospects for the transition becoming significant, and trying to see whether there are ultimate limits to its progress. Indeed the matter could hardly be more important, for few people would dispute that we will be unable to support the present population on the meagre energy sources that used to be available to us before the fossil fuel age. I will argue that it is dubious how much greater they will be when the fossil fuel age ends.

A matter of fundamental importance when it comes to estimating what population could be supported by renewable energies is the amount of energy needed per person to sustain a pleasant style of life. This is something that Smil has attempted to estimate in previous books. Taking all direct and indirect uses of energy into account, he has estimated that each person needs about 2 kilowatts (48 kWh/d or 63 GJ/y). In the present book, a paragraph on page 10 throws a different light on this issue, and hints at the same result:

> The difference between average per capita energy use in modern and traditional societies is significantly greater when compared in useful terms rather than as the rates of gross energy consumption. For example, thanks to a relatively easy access to extensive and rich forests, the average U.S. wood and charcoal consumption was very high: about 100 GJ/capita in 1860, compared to about 350 GJ/capita for all fossil and biomass fuel at the beginning of the twenty-first century. But as the typical 1860 combustion efficiencies were only around 10%, the useful energy reached only about 10 GJ/capita. Weighted efficiency of modern household, industrial, and transportation conversions is about 40% and hence the useful energy serving an average American is now roughly 150 GJ/year, nearly 15-fold higher than during the height of the biomass era.

Of course the wood and charcoal consumption does not constitute all the energy being used in 1860. A substantial part of the energy would take the form of prime movers. For instance, with reference to the United States, Smil writes (p. 89.5) :

> In 1850 draft animals accounted for about 70% of the country's total prime mover capacity; their share fell below 50% during the early 1870s as steam engines (mostly on railroads but also in factories and on ships) became the dominant prime mover.

Taking into account the need for prime movers in addition to heat, and such facts as that to maintain a modern society a certain amount of electricity is essential, the aforementioned seems to provide some confirmation of Smil's earlier estimates, arriving at 2 kW/p (24 kWh/p/d), which were made on the basis of national well-being outcomes — providing adequate education and health care.

On page 39.2, Smil expands on the advantages of energy in the form of electricity:

> Its other much-appreciated advantages include precise control of delivery (ranging from less than one watt for the most efficient microchips to multigigawatt flows in large national or regional grids), focused applications on any conceivable scale (from micromachining to powering the world's largest excavators and the world's fastest trains), and of course, no need for storage and the ease of using (flipping the switch) energy that is noiseless and, at the point of conversion, absolutely clean.

The "no need for storage" presumably refers to the end user *most* of the time, for it is clearly not applicable to electric vehicles or portable devices such as laptops. Moreover the difficulty in storing it is perhaps the greatest *disadvantage* of electricity, so that those operating the grid have to ensure that they can produce exactly the amount of electricity that is being demanded during every second of every day, which they do by having extra plant available to take on and offline as necessary.

Referring to global electricity, Smil makes it clear why it is still too early to get a clue as to how renewables might show similarities to any previous transition pattern (p. 39.7):

> Despite their recent rapid expansion, all forms of new renewable electricity generation supplied only about 2% of the 2005 total, with most of it coming from wind turbines … geothermal plants were the second-largest renewable contributor.

As uranium (and thorium to some extent) supply is limited, even if there is a resurgence in building nuclear fission plants, it will only give more time to make such transition as we can (and start reducing the human populations to sustainable levels). Nevertheless there is some interest in our current nuclear position, and Smil gives interesting data for the share of electricity produced by nuclear installations in various countries (p. 47.3):

> No other major economy was able to derive as much electricity from nuclear fission as France (recently about 78%). New capacities (almost solely in Asia) brought the total power installed in nearly 450 reactors to about 370 GW in 2005 and increasing load factors (for the best stations more than 90%) raised the aggregate generation to just over 2.6 PWh. [based on the 370 GW capacity, this works out at an average load factor of 80%]. Besides France, the countries with the highest nuclear electricity share (setting aside Lithuania, which inherited a large Soviet nuclear plant at Ingalina that gave it a 70% nuclear share) are Belgium and the Slovak Republic (about 55%), Sweden (about 45%), and Switzerland (about 40%); Japan's share was 29%, the United States' 19%, Russia's 16%, India's 3%, and China's 2%.

In addition to the extensively exploited flow of rivers to produce hydroelectricity, Smil mentions the contribution made by alternative forms of water power, (p. 47.8) :

> France's La Rance (with 240 MW capacity, completed in 1966) remained the twentieth century's only small commercial tidal power plant, and designs for wave- and ocean current-driven plants did not progress beyond theoretical proposals and a few small, temporary demonstration devices. … Installed capacity of wind turbines reached 18 GW in 2000, no more than 2% of the global total, but given the low average load factor (on the order of 20–25%), wind-powered generation remained below 1% of the world total. And PV remained completely marginal, with peak capacity of just over 1 GW by 2000.

That is a fairly useful summary, but it would have given a more complete picture to have mentioned that the average power of La Rance is 60 MW (Mackay 2008, p. 84), so the load factor achieved is 60 / 240 = 25%. Even more important is to mention that the probable load factor of the PV would be of the order of 15% (only 10% in Germany where it is not so sunny, but a substantial amount of PV is installed). The low load factor of photovoltaics is something that Smil does not treat adequately; but it is an important matter to which we will return. Note that in nearly all contexts, 'load factor' is synonymous with the phrase 'capacity factor', the latter term most often used in the case of wind turbines.

The breadth of Smil's knowledge is always impressive, as here, where he seeks to throw light on the need to combine a large amount of animate power to substitute for activities now easily accomplished by machinery powered by fossil fuels (page 50.6):

> Domenico Fontana's erection of an Egyptian obelisk (originally brought to Rome during Caligula's reign) in the St Peter's square in 1586 is an outstanding illustration: 140 horses and 900 men were needed for the job. And before the introduction of internal combustion engines the world's first combines in California and Washington were pulled by more than 30 horses.

Smil illustrates something often overlooked by other authors, namely some of the difficulties associated with creating a world based on renewable energy (p. 61.1):

> Wind turbines are now seen as great harbingers of renewability, about to sever our dependence on fossil fuels. But their steel towers are made from the metal smelted with coal-derived coke or from recycled steel made in arc furnaces, and both processes are energized by electricity generated largely by turbogenerators powered by coal and natural gas combustion. And their giant blades are made from plastics synthesized from hydrocarbon feedstocks that are derived from crude oil whose extraction remains unthinkable without powerful diesel or diesel-electric engines.

Those thoughts lead to serious consideration of the fact that a totally renewable energy society may be forced to turn back to using animal power. Smil is informative on that matter when writing, on page 70.9, that the,

> Power of draft animals depends on their sex, age, health, experience, endurance, harness, and soil and terrain. Steady pulls amount to about 15% of body mass for equines and 10% for other draft animals at speeds ranging typically from just about 0.7 m/s for oxen and about 1 m/s [2.2 mph] for horses. These rates result in a power of 300–500 W for smaller and 500–800 W for larger animals. Even draft horses in traditional societies did not average one horsepower (745 W), and if a weighted mean (considering the preponderance of weaker bovines) was around 500 W, a common draft animal worked at a rate of 7 (six to eight) adults.

Further down the same page, Smil puts this *animate* contribution into the context of all energy available to those living prior to the fossil fuel age:

> On the global scale the inanimate prime movers (except for sails, whose overall energy contribution is hard to quantify) were thus, at best, marginal sources of power during antiquity, and the situation did not change substantially until the nineteenth century. My approximate calculations indicate that by 1850 draft animals supplied roughly half of all useful work, human labor provided as much as 40%, and inanimate prime movers delivered between 10% and 15%.

On page 89.5, with reference to the USA, Smil tells us that in 1850 draft animals accounted for about 70% of the country's prime mover capacity. It is the great failing of this book that it does not recognize that the mooted transition to new renewables may not be viable, and if so we may have to return to using animate power.

Moving on to fossil fuels, an important concept — used by several oil geologists in trying to predict their future availability and recently by David Rutledge with respect to coal — is

M. King Hubbert’s production curve, so it is worth quoting from page 80.5, where Smil, mistakenly I think, implies a weakness in Hubbert’s use of the concept:.

> Hubbert’s (1956) often-cited production curve anticipated annual production of 1.2 billion barrels in 2000, but the actual rate was 2.8 billion barrels, nearly 2.5 times higher and output in 2008 was almost 70% above the rate forecast for that year.

But there is surely a good reason for that error in forecasting. The peak of U.S. production occurred in 1970, amounting to 537 Mt. As Smil says, the actual rate in 2000 was 2.8 billion barrels, or 382 Mt, but after the oil peak in 1970, the USA started importing oil. By 2000 it was consuming about 940 Mt/y, and *importing* about 50% of its annual consumption. If all the oil imported over the three previous decades had been produced in the USA — and of course Hubbert did not try to estimate the level of imports — it seems likely that the actual US production figures in 2000 and 2008 would have been in line with Hubbert’s 1956 prediction.

Returning to the subject of wind power, which various people such as ex Vice President Al Gore, and Vice President of the Earth Policy Institute Lester Brown, believe to offer a total solution to energy problems, on page 91.9 Smil writes, “U.S. wind generation rose 9.3 times between 2000 and 2008 (from 5.6 to 52 GWh).” That is an astonishing growth rate but it is not record breaking, for as Smil goes on to note, “During a similar early stage of its development nuclear generation increased much faster, more than 16-fold during the eight-year period between 1964 and 1972 (from 3.3 to 54.1 GWh). This is not surprising given the fact that average units of nuclear stations have power two orders of magnitude larger than average wind turbines.”

The 31% per year rate of growth in the output of wind turbines would achieve remarkable things if continued, but that is unlikely. Smil notes this to be the case in a paragraph which represents a substantial step towards realism as compared to his *Energy at the Crossroads*. He writes (p. 92.2):

> Continuation of the 2000–2008 rate of growth would have the U.S. wind turbines generating around 20% of all electricity by 2020 and roughly two-thirds by 2030. As I will show in the next chapter, achieving the former share would require an extraordinary effort, while the latter share is impossibly high: No intermittent source could supply that much electricity in a nation with such a high per capita consumption, with such a relatively high base load, and with such poorly developed long-distance HV transmission. An even more sobering fact is that besides wind there is no other new generation technique that can be seen as a major near- to mid-term contributor at the multi-GW scale.

Smil takes a small step forward in recognizing limitations to development of renewables, but this paragraph is far more notable for what it omits. There are the following omissions:

a) While it is true that no intermittent source could supply two-thirds of electricity, the more important point is that with the gap between peak output and average output of wind turbines, wind could not supply more than about 30% of the total electricity supply, and even that percentage is dubious.

b) The high per capita consumption is irrelevant to the aforementioned limit of 30%, and although a high base load does limit the use of uncontrollables, the 30% limit is likely to apply to the electricity demands in every developed country.

c) The intimation that a well developed long-distance HV transmission would greatly change the picture is a hope rather than a fact. In a study by Jim Oswald, made by the Oswald Consultancy Ltd for the Renewable Energy Foundation (Oswald 2006), it was found that in the UK, even if wind turbines were spread from Land’s End to the

> Shetland Islands, there would still be occasions when the wind turbines developed close to their full capacity, and other times when they produced next to nothing. Any prediction about what HV transmission could achieve by way of smoothing output needs to be backed up by a study relevant to the particular place.

Smil later returns to the problems of renewables but still does not recognize the significance of *upper limits* to the use of uncontrollable inputs. He writes (p. 104.9) :

> Moving away from fossil fuels will be a *protracted affair* even in those countries where the requisite sources are readily available, because every society will have to deal with the twin challenge of low power density and intermittent flows of renewable energies. [my italics]

What he says is true, but the key question is to what extent it will be possible to overcome those twin challenges. As we will see, that is a matter to which Smil gives inadequate consideration. That is apparent when he enumerates the main problems of making the transition to renewable energy (p. 108.4):

> It is imperative to realize that the process will be considerably more difficult than is commonly realized. Five reasons explain the challenge: the overall scale of the coming shift, be it on the global level or in the world's largest economies; magnitudes of renewable energy resources and their surprisingly uneven distribution; the intermittent, and to a significant degree unpredictable, nature of most renewable energy flows; lower energy density of the fuels produced to replace solid and liquid fossil fuels; and perhaps most importantly, substantially lower power densities with which we can harness renewable energies.

The five reasons he gives are sound, but it is a serious omission that he does not go on to address the fact that the most important of these five is the variable nature of the somewhat higher power density sources (wind, PV, solar thermal), and the fact that this variable nature introduces a need for a large proportion of the electrical energy to be *controllable* so as to balance the variable inputs of the *uncontrollables*. Only when that problem is combined with the fact that the main potential new source of controllable energy is biomass, with its very low power density, does the seriousness of the outlook becomes apparent. It is necessary to understand this point in order to appreciate why there is an ultimate limit to the possibilities of transforming the vast amount of solar energy that is available, into forms of energy useful for humans. It is most unfortunate that Smil does not appreciate this, because otherwise he realistically sums up the problems of his mooted transition, as for instance here (p. 110.6):

> Reviewing the potentially usable maxima of renewable energy flows shows a sobering reality. First, direct solar radiation is the only form of renewable energy whose total terrestrial flux far surpasses not only today's demand for fossil fuels but also any level of global energy demand realistically imaginable during the twenty-first century (and far beyond). Second, only an extraordinarily high rate of wind energy capture (that may be environmentally undesirable and technically problematic) could provide a significant share of overall future energy demand. Third, for all other renewable energies maxima available for commercial harnessing fall far short of today's fossil fuel flux, one order of magnitude in the case of hydro energy, biomass energy, ocean waves, and geothermal energy, two orders of magnitude for tides, and four orders of magnitude for ocean currents and ocean thermal differences.

His order of magnitude assessments are of course very rough, for instance Smil writes (p. 108.7) that, "By 2010 the global use of fossil energies runs at the annual rate of roughly

400 EJ, ” so the “one order of magnitude” he proposes indicates that biomass could produce 40 EJ/y (1.3 TW) of presumably new energy to replace the fossil fuels. But would that be possible? MacKay and Smil both use a power density for biomass of 0.5 W/m^2. This is generally acceptable although somewhat optimistic in that it represents 9 tonnes of dry biomass per hectare per year, which could only be achieved under favourable conditions, and even then it would be challenging to continue such a harvest without impoverishing the soil. However, let us for the moment accept that 0.5 W/m^2 is possible. It works out at 158 GJ/ha/y. To produce Smil’s proposed 40 EJ would therefore require 250 Mha, which is equivalent to all the forest and woodland in the USA, and the production at the rate of 9 t/ha/y from such a vast area is improbable. Moreover Smil has reiterated the point made by others that humans are already appropriating 40% of the planet’s net primary productivity, and that it would be unwise to appropriate more; but let us pursue further the usefulness of that 40 EJ/y, and assume that we do our best to supplement it by the use of wind power, with its much higher power density. As noted there is a limit on the use of wind power because it is variable (uncontrollable): it cannot comprise more than about 30% of the whole, thus we need first to consider how much electricity we can generate in total given 40 EJ/y of biomass.

It is unlikely that biomass can be converted into electricity at a better efficiency than 30%, thus the 40 EJ can be used to produce 12 EJ of electricity. Since the input from wind turbines is limited to 30% this means that, including the wind supplement, we could produce 12 / 0.7 = 17 EJ/y, which is a mere 4.3% of the total current 400 EJ provided by fossil fuels. There is of course a significant amount of existing biomass energy being used, also hydro power and a little geothermal, but when it comes to *replacing* the fossil fuel flux, it is apparent that the prospects are dire in a way that Smil fails to recognize by not taking into account *both* the problem of variability *and* the very low power density of biomass — the latter *especially when used to produce electricity*.

It is evident that biomass is a key factor in limiting the potential for renewable energy supply, so it is good that Smil covers it in some detail (p. 114.2):

> Fast growing willows, poplars, eucalypti, leucaenas, or pines grown in intensively managed (fertilized and if need be irrigated) plantations yield as little as 0.1 W/m^2 in arid and northern climates but up to 1 W/m^2 in the best temperate stands with typical good harvests (about 10 t/ha) prorating to about 0.5 W/m^2. Crops that are best at converting solar radiation into new biomass (C_4 plants) can have, when grown under optimum natural conditions and supplied by adequate water and nutrients, very high yields. National averages are now above 9 t/ha for U.S. corn and nearly 77 t/ha for Brazilian sugarcane. But even when converted with high fermentation efficiency, ethanol production from Iowa corn yields only about 0.25 W/m^2 and from Brazilian sugarcane about 0.45 W/m^2.

In giving the figure 77 t/ha for sugarcane, Smil makes a very common error, arising from failing to take account of the moisture content. Moisture content in fresh cane is always high, though dependent on weather conditions, decreasing during the harvest period from June to November, starting about 80%. It would probably be about right to take the moisture content at about 70%, thus the 77 t/ha equals 23 t/ha dry weight, and dry weight is of course what determines the calorific value. There are other points he might well have included. First that although the ethanol produced from Iowa corn (maize) yields ethanol to the extent of 0.25 W/m^2, it is universally agreed that the inputs needed to produce the ethanol are about equal to the energy in the ethanol, so there is no net energy gain (although it is possible to argue that there is some on the basis of by-products). This is not true of sugarcane since the bagasse (additional biomass not used to produce the sugar) can be used to provide much of the energy needed for such things as distillation. However, as in the case of corn, sugarcane causes a high rate of soil erosion, so neither procedure can be regarded as *sustainable* methods of making energy available in liquid form.

Smil does bring out the very low power density of ethanol and some associated production problems (p. 115.1):

> Even if the entire U.S. corn harvest was converted to ethanol, it would produce an equivalent of less than 15% of the country's recent annual gasoline consumption. Biofuel enthusiasts envisage biorefineries using plant feedstocks that replace current crude oil refineries — but they forget that unlike the high energy-dense oil that is produced with high power density, biomass is bulky, tricky to handle, and contains a fairly high share of water.

Smil goes on to elaborate on other problems with biofuels, but those already mentioned should suffice. On the same page, Smil brings up some telling points regarding why, on a global basis, the use of biomass is severely limited:

> Three independently conducted studies agree that human actions are already appropriating perhaps as much as 40% of the Earth's NPP [Net Primary Productivity] as cultivated food, fiber, and feed, as the harvest of wood for pulp, timber, and fuel, as grass grazed by domestic animals, and as fires deliberately set to maintain grassy habitats or to convert forests to other uses. This appropriation is also very unevenly distributed, with minuscule rates in some thinly populated areas of tropical rain forests to shares in excess of 60% in East Asia and to more than 70% in Western Europe. Local rates are even higher in the world's most intensively cultivated agroecosystems of the most densely populated regions of Asia (China's Jiangsu, Sichuan, and Guandong, Indonesia's Java, Bangladesh, the Nile Delta). …
>
> Any shift toward large-scale cultivation/harvesting of phytomass would push the global share of human NPP appropriation above 50% and would make many regional appropriation totals intolerably high. There is an utter disconnect between the proponents of transition to mass-scale biomass use and the ecologists whose Millennium Ecosystem Assessment (2005) demonstrated that essential ecosystemic services that underpin the functioning of all economies have been already modified, reduced, compromised to a worrisome degree.

Smil is there indicating something that David Pimentel and I have seen again and again, namely that people who should know better make fanciful proposals without considering the many impacts that such proposals are likely to imply, for instance making ethanol from corn without considering the need for more water and the consequences of soil erosion, or proposing uses of resources which other enthusiasts are also claiming as being available and necessary to achieve the mooted 'transition' to renewable energy.

Returning to photovoltaics (PV), Smil's understanding of the essential point about PV is weak. On page 117.3, referring to an insolation of 150 W/m^2 (about right for Europe at the latitude of the UK) he writes:

> If today's best experimental designs (multijunction concentrators with efficiency of about 40% become commercial realities we could see PV generation power densities averaging more than 60 W/m^2 and surpassing 400 W/m^2 during the peak insolation hours. As impressive as that would be, fossil fuels are extracted in mines and hydrocarbon fields with power densities of 10^3–10^4 W/m^2 (i.e., 1–10 kW/m^2),

There is a minor error in the assumption that a 40% efficiency under test would produce 0.40 x 150 = 60 W/m^2 power density out in the field. The efficiency measured in the laboratory, *with the radiation perpendicular to the panel*, is not the same as the efficiency achieved when the light is coming in at a low angle. A factor of about 0.8–0.9 needs to be applied to account for that, but that is minor, and we will ignore it; The major omission is the failure to take note of the significance of the difference between the suggested average of 60 W/m^2 and the peak of 400 W/m^2. That is a capacity factor of 60 / 400 = 15%. So between the two figures there is nearly a 7-fold difference, which means the PV will certainly start to be a nuisance when it is contributing 1 / 7 = 14% of electricity to the grid, and probably before that, since the peak output may come when national demand is below average, for instance during a sunny summer weekend. The situation in practice may turn out to be even worse. as reported in OPTJ 11/1, p. 12, the German grid authorities recently indicated they think that there may be trouble when a 5% PV penetration is reached.

It may be thought that Smil must be aware of the significance of low capacity factors, but does not dwell on it, however as we will note later, there are other indications that he is unaware that a low capacity factor is the Achilles heel of PV.

There is a further point that also needs stressing, namely that by introducing PV, with its high peaks, the opportunity to use other uncontrollables, which would be better to use on account of their higher capacity factors, is decreased, as they may get close to their peaks at the same time as PV (and perhaps at a time of fairly low demand).

As Smil misses some of the most troublesome aspect of PV, it does not help much that he is sensible in his description of the cost of PV systems (p. 123.8):

> The PV industry's more realistic expectations are to reduce the price of typical modules to $1.5–2/W within 10 years, implying a halving of the cost in seven to eight years. But this does not mean that the cost of actual PV installations will be halved as well, because the costs of other components (inverters and regulators) and the cost of installation may not fall that fast. After all, despite the falling costs of PV cells, the cost of electricity generated by typical residential systems (with capacities of about 2 kW) has hardly changed since the year 2000, when it was close to 40 cents/kWh: During the second half of 2009 it was still between 35 and 36 c/kWh. And even the largest industrial installations (up to 500 kW) were generating electricity in 2009 almost as expensively as in 2000 at 19–20 c/kWh.

Another point that might have been made is that such costs are inevitably estimated on the basis of what the owner of the PV plant needs to get to make an adequate return, and does not include the extra costs incurred by the grid operator in having to accommodate uncontrollable and continuously varying inputs into the grid, which can only be done by operating controllable plant at a lower average capacity factor. However, I reiterate that costs are not as important a problem as the low capacity factor of PV.

A sound point that Smil makes is to argue that to the extent that it occurs at all, the transition to renewable energy will be slow because of the investment in fossil fuel plant (p. 126.2):

> During the first eight years of the twenty-first century China more than doubled its coal extraction and it added almost 300 GW of new coal-fired electricity-generating capacity, more than the combined thermal-generating capacity installed in the EU's five largest economies (Germany, France, United Kingdom, Italy, and Spain) by 2006. Even by using a very conservative cost average of $1,000/kW, the latter building spree represents an investment on the order of $300 billion and these plants will operate for at least 30–35 years to recover their cost and to make a profit.

The point he makes is valid, but the far more important point, which he does not make, is that, for example, an average 300 GW of *controllable* electricity would be needed to support about an average 130 GW *uncontrollable* input from wind turbines. Were the controllable element not to be available, then the grid could not be run on the basis of the wind turbines alone. In other words, the biggest challenge with the transition to living on renewable energy is to find sufficient controllable inputs. This is the reason that while something may be possible *with* fossil fuels, it may be impossible *without* them.

Having dealt with PV and electricity production fairly thoroughly, let's return to the intractable problem of liquid fuels, as Smil does at the top of page 118:

> Low extraction power densities would be the greatest challenge in producing liquid fuels from phytomass. If all of America's gasoline demands were to be derived from corn-based ethanol, the crop would have to be grown on an area roughly 20% larger than is the country's total arable land. And land claims of corn-based ethanol would be much worse outside the United States: Global corn-yield averages only a bit more than half of the U.S. mean.

Another problem is surely worth drawing attention to, namely the one I mentioned earlier, that the energy inputs for preparing the ground, fertilizing, sowing, harvesting, and turning the corn into ethanol (most of the energy goes in distillation) amount to about the same amount of energy as is contained in the ethanol. Producing ethanol from corn is thus a way of slightly decreasing the need for *liquid* fuel but is only possible because coal and gas can provide some (about 85%) of the energy inputs needed to produce it.

A couple of points arise from a paragraph on page 133.9 which reads:

> In 2009 the net summer capacity of the U.S. fossil-fuelled stations was about 740 GW and they generated 2.8 PWh of electricity, which means that the load factor (number of hours they were generating a year) was about 44% (with averages of 73% for base-load coal-fired stations but only 25% for predominantly peak-load natural gas-fired generation). In 2007 wind and solar electricity contributed just 35 TWh (less than 0.9% of the total), and with installed capacity of 17 GW its load factor was just 23%.

The first point is about the definition of "load factor." Although I have seen a similar one given in places other than this book, it is misleading. A somewhat more accurate description, based on the same 'conceit', would be 'the number of hours during the year that the plant would need to be generating at its full capacity in order to produce the achieved output'. The completely realistic description, which I normally give, is 'the ratio between the amount of electricity generated and the amount that would be generated were the plant to operate continuously at full capacity'. That allows one to talk about winter and summer capacity factors, which may be very different. That however is just a matter of words and hopefully many people would read between them. What is more important is the *reason* that the "predominantly peak-load natural gas-fired generation" only operated at a 25% load factor. The reason is because demand is so variable that one needs controllable plant that can be taken offline and brought online when necessary. *But that is not the reason* for the 23% load factor of wind. Wind input amplifies the problem of variable demand, meaning that more *controllable* plant is needed to operate in conjunction with it. Were demand constant, the natural gas-fired generation would be operating at or above the 73% of coal-fired plant providing base-load.

Smil goes on to write, "This means (assuming a high degree of HV interconnection to distribute a concentrated wind generation) that two units of generating capacity in wind and solar would be needed to replace 1 unit of capacity currently installed in coal- and gas-fired plants." There is an element of truth in that, but it misses several important points:

a) The assumption that a high degree of HV interconnection would flatten out supply is speculative. As mentioned on page 12, Oswald has shown that over the whole British Isles the curtailing of peaks and troughs is only slight, despite the usually highly variable weather in its various parts. The outcome of such complete interconnection would still be some periods of no output and other times when the wind turbines were producing very close to full capacity (about 98%).

b) Even if the HV interconnections *could* flatten the output from the wind turbines, that would only provide a base-load, not provide controllable inputs to follow demand.

c) It is misleading to intimate that the power from wind turbines could replace controllable power simply because it provides the same amount of energy, because as noted, 30% of wind input needs to be supported by 70% of controllable input.

d) It is misleading to group solar (presumably PV) and wind together, since, unlike wind, about 15% of PV input needs to be supported by 85% of controllable input.

Smil does recognize some of the implications of the low load factors. Starting with wind turbines he writes (p. 138.3):

> Average load factor for the European Union between 2003 and 2007 was just 20.8%, with the high of 29.3% for Ireland and Greece and the low of 18.3% for Denmark. Similarly, solar PV capacity factors averaged below 25% even in such sunny places as Arizona, and studies show that (because of the limited flexibility of base-load units) increasingly large amounts of unusable PV generation would be produced when PV capacities would reach 10–20% of a system's total capability.

His asserted mid-point of 10–20% penetration for PV is approximately correct, for as pointed out on page 16, at an average 15% capacity factor (likely to be true in some places, such as the whole of the USA with PV plant widely spread), PV would only produce, at maximum, 1/7 (14%) of the total electricity. The slight advantage of PV in a nation that uses a lot of air conditioning is that high output will tend to occur when demand is fairly high. Even that is not a perfect match, as high demand tends to be in the evening rather than midday.

The section starting on page 129, *National Aspirations: Goals and Realities*, provides an excellent compilation of the many instances in which governments, NGOs, and individuals managing to make their voices widely heard, like Al Gore, set targets or make predictions about what could be achieved with renewable energy which are either impossible or incredibly unlikely; moreover all those which can be checked against reality are shown to fail dismally. Smil finishes the section with these words (p. 142.3):

> A world without fossil fuel combustion may be highly desirable, and eventually it will be inevitable, and our collective determination could accelerate its arrival — but making it a reality will demand great determination, extraordinary commitment, substantial expense, and uncommon patience as the process of a new epochal energy transition unfolds across decades.

In one sense Smil is right in saying that the transition is "inevitable", but that is not the key question. The key question is whether the transition back to living only on renewables will take us back to where we were before we started to exploit fossil fuels or whether it will be so successful that we will have a substantial part of the energy available to us now. If the former, then a massive die-off of population is inevitable, but then, as I have seen in some of Smil's previous writings, such considerations are for him taboo. He prefaced one of his books with a quotation that urged the view that it is the duty of the scholar to be optimistic. He seems to take that duty so seriously that he is ready to avoid the more awkward considerations concerning renewable energy!

The means by which he evades the more troublesome questions can be elucidated with two quotations from page 145. In the first one, he is attempting to explain the circumstances in which there can be a rapid transition to using wind power:

> Wind-powered utility generation is thus at the forefront of the unfolding energy transition and there is no doubt that countries with particularly windy climates can generate not just 20% but 30% of their electricity using large wind turbines — particularly if they are relatively small and are already well connected to grids of adequate capacity or if the construction of new links precedes a commitment to higher rates of wind-driven generation. Denmark — where wind generated almost 20% of all electricity in 2007 and where large offshore projects are to raise the share to 50% by 2025 — is a foremost example of this combination: It has a relatively small market (total generating capacity is less than 10 GW) and excellent interconnections with the hydro-rich Scandinavia to the north with large thermal systems in Germany and beyond to the south.

All those points are just about true, but there are several matters which may lead the reader into an incorrect interpretation of the figures he gives

a) Smil does not give the *really important* figure that Denmark can only use 8.5% of the wind-generated electricity directly (The rest has to be exported. He does give the reasons why Denmark is in a special position to do this).
b) One reason that Denmark can only use 8.5% directly is that it has not built a sufficiently good transmission line from the west of the country where most of the electricity is generated to the east of the country where most of the population is. This is significant for two reasons. First, it indicates that 8.5% does not indicate the point at which a country starts to have a problem with uncontrolled inputs from wind, Secondly it indicates that countries may not be willing to build transmission lines just to accommodate peaks of input from uncontrollable sources.
c) Smil does not make it clear what he means when he writes there is “no doubt that countries can generate as much as 30% of their electricity using large wind turbines.” Of course they can generate as much as that, and probably more, as is likely to be the case with Denmark and with Scotland. But that is useful only as long as there is either a much larger pool of electricity demand into which to offload peaks of wind output, or neighbouring countries relying extensively on hydroelectricity — an ideal situation as in Denmark. In those situations there is hardly a limit to the amount of electricity that can be generated in windy countries, but all countries cannot rely on other countries to absorb their peaks, so the important question is how much input from wind can be used in a self-contained system. The answer is more than Denmark’s 8.5% but maybe never as much as 30%, for although 30% is a theoretical possibility, anything more than about 10% remains to be demonstrated.

Further down the same page (145.9) Smil writes:

> There can be no long-term future for renewable electricity without a mass-scale commercial success of PV generation, but despite some remarkable progress in lowering the cost of producing and installing the PV modules and increasing their maximum unit capacities, this conversion is considerably less mature than the harnessing of wind power: in 2007 the world added about 94 GW of wind turbines but only about 4 GW of peak PV power. …
>
> And as with all technical innovations, a definite judgement regarding long-term capability and reliability of wind driven or PV generation is still many years ahead.

The last sentence is arguably not significantly true, since, as already pointed out, the low capacity factor of PV limits it to supplying about 15% of the total. Moreover it would be unwise to let it get near this, as it would ‘shoulder out’ the input from wind turbines, which, as mentioned, alone could get to supply as much as 30%. It seems strange that Smil does not realize this. He provides confirmation that he really does not see the stranglehold that low capacity factors have on the development of PV when, on the penultimate page, after stressing the need to reduce per capita energy use, he writes (p. 151.4):

> Until we get such history-changing conversions as reliable, inexpensive PV cells generating electricity with 50% efficiency or ….

This is wrong because it is an illusion to think that cells with 50% efficiency will make much difference. They would enable us to gather more electricity from the space available on our roofs, and probably thus reduce some installation costs, but they would not make any difference to the fundamental problem of PV, its low capacity factor — for that is almost entirely a function of the difference between the level of insolation at midday and the average level of insolation over twenty-four hours.

On page 148.4 Smil makes a point that I have often reiterated, that it is not only the popular media and politicians who tend to mislead the general public:

> Unfortunately, common expectations of energy futures — shared not only by poorly informed enthusiasts and careless politicians, but, inexplicably, by too many uncritical professionals — have been, for decades, resembling more science fiction than unbiased engineering, economic, and environmental appraisals.

Although I would not suggest that Smil's assessment resembles science fiction, there is, as I have pointed out, a lack of attention to basic engineering problems. I hope that I have not appeared here to be too dogmatic about the problems of uncontrollables in general, and PV in particular, but I have treated these problems in considerable detail in previous issues of the OPT Journal (and the essential points have not been challenged).

On page 151.3, there is an example of how Smil studiously avoids implicating population in his analyses. Referring to energy consumption in the U.S. he writes:

> The country's average per capita use of primary energy in 2010 … was no higher than in 1970!

What Smil omits to say is that between 1970 and 2010 the U.S. population rose by 52%.

Conclusion

This interesting book is a step forward from *Energy at the Crossroads*, being more realistic about the problems of making a transition to renewable energy, but is seriously flawed by not appreciating the difficulty of incorporating uncontrollable inputs into an electricity grid. And it is positively dangerous to the extent that it encourages the almost universal, *but probably misplaced*, belief that if we only try hard enough, then we will surely make a successful transition to supporting a population of nine billion on renewable energy.

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LIQUID FUEL, POPULATION, AND LIQUID ENERGY SUPPLY PER PERSON

by Eric Rimmer and Andrew Ferguson

Abstract. Decline in liquid fuel supply must inevitably lead to decline in population. The question is how that decline is to occur.

In 1956, oil geologist M King Hubbert predicted that US oil production would peak in the early 1970s. At the time, he was derided both within and outside the oil industry. Nevertheless in 1970 the peak of US oil production did occur. In 1969, Hubbert made two estimates of the time when *world* oil production would peak. The more optimistic one was based on an estimate that ultimate oil production would be 2.1 trillion barrels. Using that figure he predicted that world oil production would peak around the year 2000. Since Hubbert's success in making a prediction for the US peak, several people have used his basic concepts to make similar predictions. Moreover it has become clear that as the peak of production is approached, it is not necessary to guesstimate the total amount of a fuel that will be produced, because the changing pattern of production itself provides an indication of that figure (on just such a basis, David Rutledge (2010) made an analysis related to coal production covering all the important coal producing countries).

As recounted in Colin Campbell's 1997 book, *The Coming Oil Crisis*, many geologists — as well as Campbell himself — have been warning that the peak of oil supply would be around 2005-10. Until now, this assessment has been vehemently opposed by the international energy agencies and by the oil companies, many of whose spokesmen argued, at least until very recently, for a peak of oil supply in 2040 *or later* — obscurely implying, and not being challenged by interviewers, that therefore there was no problem !

The time for argument about the decade in which the peak will occur is now past, and our attention needs to turn to how to deal with declining supplies of liquid fuels, and soon thereafter a decline in the availability of all fossil fuels. The situation is summed up by Figure 1, which shows the interaction between declining liquid fuel supply and a continuously increasing (until 2050) population.

Here are some relevant details about the origin of the all-important forecast of liquid fuel supply. Petroleum geologist Jean Laherrère (whose accomplishments Colin Campbell writes about in detail) combines data from the Energy Information Agency (within the US Department of Energy) with his own estimates of ultimate production of 300 billion barrels of natural gas liquids and 500 billion barrels of extra heavy oils (note that the last constitutes about a quarter of the estimate of ultimate conventional oil extraction of 2100 billion barrels). The curve in Figure 1 encompasses all these liquids, although, due to constrictions of space, the term 'oil' is sometimes used in Figure 1.

Some points to note about the graph are these. Between 1979 and 1985 there was a precipitous drop in oil supplies due to the OPEC embargo, which led to a drop in the use of oil per capita from 26 kWh/p/d (26 kilowatt hours per person per day) to 21 kWh/p/d (3.8% per year). Reasonably, this was thought to be the cause of the economic recession. After that, as more non-OPEC oil became available, oil use per capita increased slowly to reach 22 kWh/p/d in 2005, but it dropped back to 21 by 2010. This drop is not as steep (1.0% per year) as the drop between 1979 and 1985, but because we are in the region of the peak of oil supply, a steep decline appears likely to develop until 2050, when it will be 9 kWh/p/d. After that, were the population to stabilize at 9 billion as shown in Figure 1 (and almost everyone talks about a *stabilized* population rather than a decreasing one), from this low level of liquid fuel per person, the rate of decline would slow, reaching 1.4 kWh/p/d by 2200.

Between 2010 and 2055, the rate of decline in the per capita liquid fuel supply is 2.1% per year, while the decrease in liquid fuel supply is at the slower rate of 1.4% per year. The reason for this of course is that the population is still increasing during that period. After 2055 the two rates remain equal at 1.2% per year.

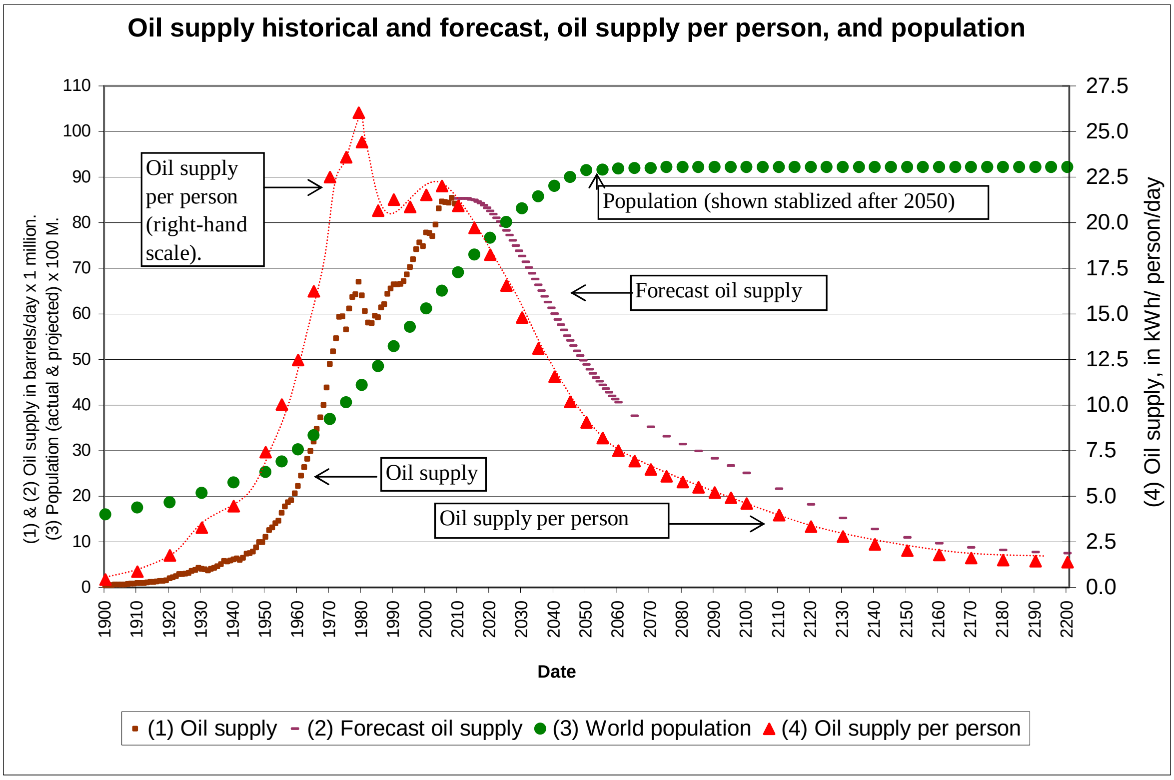
The *average* figures given conceal uncomfortable realities. For instance, in the UK, in 2010, we use about 43 kWh of *liquid* fuels per person per day (within an overall average fuel use of 125 kWh/p/d). In the US, the figure for average *liquid* fuel used per person is about 100 kWh/p/d, within an overall average fuel use of about 250 kWh/p/d. Furthermore this overall figure does not include the embodied energy in imports. For the United Kingdom, the total (not just liquid) energy embodied in imports would be at least an additional 40 kWh/p/d (MacKay 2008, p104).

In the United States, population is expanding rapidly, so any increases in efficiency in the use of fuel, e.g. more efficient cars and driving more slowly, is likely to result at best in a fairly unchanging demand for liquid fuels. Vaclav Smil (2010, p151) makes the point that between 1970 and 2010 per capita fossil fuel use in the United States remained constant. What he did not say is that during the same period population increased by 52%, *resulting in consumption increasing by 52%* !

Furthermore China, India, and Indonesia will all be striving to move up towards European consumption levels — at least they will until the price of liquid fuels becomes prohibitive. Thus we must not expect an equitable reduction in distribution of the remaining liquid fuel supplies. The richer countries are likely to pay more for fuel, while the poorer countries will be starved of supplies, unless steps are taken to mitigate that by the oil-producing countries rationing oil production, as was suggested needs to be done in the article on *Rutledge's Hypothesis* — in the OPT Journal October 2008, pp. 22-28. Such rationing is desirable anyhow, as we need to be frugal with the remaining liquid fuels so as to eke them out, and give the world at least a possibility of making the necessary adjustments (a long time is needed because reducing the size of populations takes a long time). Such a scheme would also allow a degree of provision for the poorer countries to have a useful minimum amount of oil on preferential terms, but that is only likely to happen if the oil-producing countries can be brought to see that an *apparently* altruistic use of their remaining oil is likely to stand not only the world, but also themselves in good stead in the longer term, for it is unlikely to be beneficial to a nation to make itself unpopular with other nations by aiming only to get the highest price possible for the assets it has the good fortune to own. Moreover it behoves the oil producing nations to look at the long term as well as the short term, and to that end eke out their supplies.

Before 1890 there was an insignificant demand for oil as there was little need for fossil fuel energy to produce electricity or run the railways, yet in the USA, it is estimated that the overall use of energy prior to 1890 amounted to 89 kWh/p/d — that is an average power of 3.7 kW (Hayden 2004, p20). As will be reiterated later, although the peaks of natural gas supply and coal supply will occur after the peak of liquid fuel supply, those peaks are fairly likely to occur not many decades after that of liquid fuels, so the shortage of liquid fuels cannot be met by using other fossil fuels. It may be noted (Figure 1) that the liquid fuel supply settles down to about 7 million barrels (of oil equivalent) per day by 2200, this being one estimate for what will be available from biofuels. Does that look plausible? MacKay gives a power density for ethanol from corn of 0.22 W/m^2. That is reasonable for the US, as it is based on 2965 litres of ethanol per hectare. To derive the equivalent of 7 million barrels of oil per day would require about 280 million hectares of corn (maize) crops. That is about 10 times the total area used for growing corn in the US. Moreover it is generally agreed that the energy *inputs* to produce ethanol from corn considerably exceed

Figure 1. The prospects for a world with declining supply of liquid fuel, is shown (triangles) in terms of kilowatt hours per person per day (kWh/p/d) as numbered on the right-hand scale. Against the left hand scale the graph shows liquid fuel ('oil') production in millions of barrels per day and world population in hundreds of millions. Developed countries would be off the right-hand vertical scale. For instance, the liquid fuel consumption figure for the UK is about 43 kWh/p/d, and for the USA it is 100 kWh/p/d.



the *output* as ethanol, so further land, about 5 times the area currently used for growing corn crops, would be needed as non-liquid input to provide the energy to produce the ethanol. The power density of ethanol from sugarcane is much better, but the areas where sugarcane can be grown are limited. In summary the prospects for doing anything approaching this with a population of 9 billion to feed and provide with fibres is extremely remote.

The stable population of 9 billion shown in Figure 1 is only a scenario, and indeed an unlikely one, since with limited fossil fuels available, world population is fairly sure to be driven downwards by starvation if not by voluntary action. This is because to provide a reasonably comfortable but modest lifestyle, and to provide a good education and health care, there is probably a minimum *average* overall energy requirement of 2 kW, which is 48 kWh/p/d. Moreover we noted the pre-1890 requirement in the USA for 89 kWh/p/d. Today — now that we are no longer using horses as animate prime movers — a significant part of those totals would need to be in liquid form. These minimum requirements for overall energy are off the right-hand scale as far as Figure 1 is concerned. Moreover natural gas supply is likely to peak within a few decades of oil, and although coal supply is harder to predict, there is a good case for thinking supply may peak around 2026 (see *Rutledge's Hypothesis* in the OPT Journal October 2008, pp. 22-28).

One fundamental change that is needed is for economists to turn their attention to asking themselves the question : How can an economy be made to work for the benefit of all citizens *during a long period of enforced continuous contraction*? If they could provide an answer to this question, then at least a few politicians may put their heads above the parapet and try to persuade their citizens to accept that the idea of a growing economy needs to be abandoned. Any mention of that is rare, and I treasure the 18 October 2008 issue of *New Scientist* which had on the cover, *The Folly of Growth: How to stop the economy killing the planet.* Since then the subject has disappeared into a black hole !

To what extent would it be possible to mitigate the overpopulation problem that has been outlined? We probably have to assume that the next forty years is the minimum time needed to adjust to the reality of the problem, during which time it is fairly certain that population will increase to 9 billion. But if by then the world could have achieved a total fertility rate of 1.3, then by 2200 (the last date shown in Figure 1) the population would decrease to about 2.4 billion — a probably sustainable level. Six countries have managed to lower their total fertility rates to 1.3. But perhaps the most important thing to appreciate is that not all nations are likely to achieve this, so every nation must take responsibility for lowering its total fertility rate and adopting a balanced migration policy (as many in as out) so that it attains a level of population that it can sustain on renewable resources.

Total fertility rate represents the average number of children per woman. To put the idea of a decreasing population in another perspective, world population is currently, in 2010, expanding at about 1.2% per year. Suppose we could turn that around to achieve a mere 1% per year contraction, starting say in 2075. By 2200, that would achieve a world population of 2.6 billion, which would be fairly close to a level of population that could be sustained on renewable energy.

Probably the most we can hope for is that civilization can be preserved in some places. The tiny island of Tikopia, about 5 km^2, is the outstanding example of what can be achieved by controlling population. For over a thousand years it kept its population low enough to preserve a pleasant way of life (Montgomery, 2008, p222). It could probably have managed another thousand years were it not to have been discovered by people from other lands. There is hope for the human race, but only if our politicians become as wise as the Tikopian chiefs.

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THE LIMITATIONS OF SOLAR THERMAL DUE TO SEASONAL VARIANCE

by Andrew R.B. Ferguson

Howard Hayden, writing in 2004, stated that the SEGS (Solar Energy Generating System) plants produced 90% of the world's direct solar electricity. The figure is likely to be lower than that by now, but nevertheless the size of SEGS gives an indication that the results achieved at the nine separate units that comprise SEGS should be a good guide to solar thermal performance, at least for its latitude in the Mohave desert of California, 35 degrees. The area in North Africa where solar thermal might be placed (not near the coast as cloud occurs there) is about 30 degrees, so although the mean annual irradiance is almost identical (at 250 W/m^2) some lessening of the difference between winter and summer should be expected, but since there are no useful data from there, SEGS provides our best guide to the seasonal variance of solar thermal performance in those very hot situations which are the only places suitable for solar thermal plant. SEGS is a troughs system, the troughs being aligned north-south (to produce the best overall performance); they rotate to follow the sun as it moves from east to west.

The biggest problem with solar thermal is the difference between winter and summer performance. Trainer (2007, p168) tells us that "About 41% of SEGS VI annual output occurs in the three summer months, and over the four winter months of the year cumulative output is only about 10% of the annual total." Excluding the input from natural gas, this means that the solar input achieved a capacity factor of 35% during the three summer months, but only 7% during the four winter months.[1]

As we already know from wind turbines, a capacity factor of 35% is still very limiting, meaning that about 80% of the electricity still has to come from a controllable source.[2] If in addition to this, during four months of winter 28% of the rated capacity has to come from a controllable source in order to boost the 7% winter performance up to the summer performance of 35%, as the above figures suggest, then the sun is contributing only a small fraction of the total energy needed to produce electricity within an electrical system. To some extent that is already evident from the year round capacity factor of the *solar* thermal system (i.e. having subtracted the gas supplement), 22%, because that is lower than many wind turbine arrays, but the difference between the winter and summer performance is a special problem, because if natural gas is not available to even out summer and winter capacity factors, then a large capacity to store electricity is required. Indeed to bring the four winter months up to the annual average capacity factor of 22%, it would be necessary to store 23% of the *total solar output,*[3] and that is without allowing for heat losses. There is currently no indication that a way will be found to store electricity in large amounts over many months. Much is made of the fact that solar thermal allows for some storage of electricity because the heat stored is available to continue to produce electricity during the night, but the length of storage and amount of storage needed to deal with *seasonal* variation is well outside the capacity of heat storage.

The above makes it clear that solar thermal, without some superb, yet-to-be-invented, storage system is not going to be able to play a significant part in supplying renewable energy. To emphasize the difficulties, it is worth mentioning that the ratio of about 1 to 5 between 'winter' and 'summer' performance is an *average*. In 2002, the same SEGS 'winter' to 'summer' power ratio was 1 to 9.5 (Trainer 2007, p168).

The above is sufficient to appreciate the limitations of solar thermal troughs but renewable energy fantasists tend to spend much time emphasizing the amount of solar energy that is available for capture, so it may be worth mentioning that the overall efficiency of SEGS in turning radiant energy from the sun into electricity is 13%.[4]

It is not easy to get a feel for an efficiency of 13%, but this may help. In the Mohave desert in California, and in North Africa, the mean annual irradiance on a horizontal plane, as taken from Kreith and Kreider (1978, p17), is 250 W/m^2. 13% of that is 33 W/m^2. If we go as far north as mid-Scandinavia or Siberia, or go slightly further south than Cape Horn, mean annual irradiance is 100 W/m^2. So to find 33 W/m^2, northwards we would need to go into the artic circle. To capture the meaning of 13% efficiency, we can imagine being in the artic circle with a solar thermal device that is 100% efficient. With such a low irradiance the device would not be very useful. Although sometimes 'too hot the eye of heaven shines', having only 13% of the energy that is available as annual sunshine is not a viable proposition for modern life even in some of the hottest spots on Earth. All renewable energy systems are bedevilled by either a combination of variability and low power density (for SEGS, Hayden, 2004, p190, calculates that as 11 W/m^2), or just *very low* power density, as with biomass (0.5 W/m^2) and biomass derived fuels (e.g. 0.22 W/m^2 for ethanol, and that is a gross figure, i.e. not net of the inputs needed to produce it).

For a summary of these data and further data related to SEGS see Table 1a.

Notes

1. The calculation of these capacity factors goes like this.
The SEGS units produce 900 GWh/y (Hayden, 2004, p190).
Natural gas is responsible for 25% of this, meaning the sun accounts for 0.75 x 900 = 675 GWh/y.
41% of this is produced during the 3 summer months = 0.41 x 675 = 276.7 GWh.
June, July, August have 92 days.
So 'summer' *power* is 276.7 x 10^9 / (92 x 24) 125 MW.
Rated power of SEGS is 355 MW (Hayden, 2004, p190).
So capacity factor during the 'summer' is 125 / 355 = 35%.
10% is produced during the 4 winter months = 0.10 x 675 = 67.5 GWh.
November, December, January, February have 120 days.
So 'winter' *power* is 67.5 / (120 x 24) = 23.4 MW.
So capacity factor during the 'winter' is 23.4 / 355 = 7%.

2. Assuming a 35% capacity factor and a grid covering the whole of the UK, Oswald showed that a likely limit to wind penetration was 20%. Solar thermal would have a slight advantage as it would not produce a high output in the middle of the night when demand is low, but 30% of total electricity seems a likely limit.

3. The calculation for the amount of storage is not shown here or in Table 1a below, but is done separately in the Excel file of Table 1a.

4. The aperture of the SEGS troughs is 2.3 million m^2. Insolation (on a horizontal plane) over the course of a year is about 250 W/m^2 at the SEGS site in the Mohave desert (Kreith and Kreider 1978). Thus the insolation falling on the troughs is:
$2.3 \times 10^6 \times 250$ = 575 MW = 575 x 24 x 365 = 5037 GWh/y.
The electrical output from SEGS is 900 GWh/y but 25% of that is due to natural gas supplementation, so the solar contribution is 0.75 x 900 = 675 GWh/y.
So the efficiency of SEGS in turning radiant energy into electricity is 675 / 5037 = 13%.
All data for this note, except the insolation of 250 W/m^2, is taken from Hayden, 2004, pp.188-191.

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Table 1a. Available information, theoretical and empirical, about solar thermal systems
In the table, empirical values measured (or calculated using) are shown emboldened (all are in this table).
DNI stands for Direct Normal Irradiation. When available, supplementary information about the Horizontal Irradiation -- the radiation falling on a horizontal plate -- is given in the Notes column.
Cells are left blank where there is an absence of data.

SEGS VI (trough design)

	Units	Values	Notes
General			*1 (unless otherwise noted data from Hayden, 2004)
Aperture	m^2	**2.30E+06**	Hayden, 2004
Rated power	We	**3.55E+08**	Hayden, 2004.
Fraction of gas supplement		**25%**	i.e. 25% of the power output comes from natural gas
Location			California (Hayden, 2004).
Latitude in degrees N or S	degr.	**35**	
DNI peak value	W/m^2	**950**	Hayden, 2004.
DNI over year	W/m^2		*2 (Horizontal Irradiation in SW USA is 239 W/m2)
DNI over summer	W/m^2		*2 (Horizontal Irradiation in SW USA is 324 W/m2)
DNI over winter	W/m^2		*2 (Horizontal Irradiation in SW USA is 197 W/m2)
Electrical output (solar) over yr	Wh	**6.75E+11**	Gross output over year is 900 GWh (Hayden, 2007)
So solar power output over year	We	**7.7E+07**	*3 (i.e. power output due to sun not natural gas)
Solar power output over summer	We	**1.25E+08**	41% over 3 summer months, see Trainer 2007. p168.
Solar power output over winter	We	**2.34E+07**	10% over 4 winter months, see Trainer 2007. p168.
So capacity factor over year		**22%**	*3
So capacity factor over summer		**35%**	Related to solar output (i.e. minus gas).
So capacity factor over winter		**7%**	Related to solar output (i.e. minus gas).
So winter/summer electric power ratio		**19%**	*4 This is a power ratio so time diff. is not a factor.
Horizontal insolation in this area	W/m^2	**250**	In general area, not precisely specific to site
So electricity/insolation efficiency		**13%**	This is a conversion ratio of sunlight to electricity.
Storage capacity	kWh	Nil	*5
Area to produce 1000 MWe	km^2	**92**	*6 (based on a site power density of 10.8 W/m2).

Notes to Table 1a

*1 SEGS (Solar Electric Generating System), built by LUZ International consists of nine units with an array of parabolic mirrors laid out on a north-south axis which rotate east to west. The therminol fluid delivers the heat to a Rankine steam engine. The SEGS installation includes a natural gas boiler and a gas reheater. The purpose of the gas is to assure that the steam turbine receives steam at 371 deg C regardless of the actual temperature of the therminol received from the solar field. The amount of natural gas used is such that 25% of the electricity generated is the result of the natural gas input. All these data from Hayden, 2004, pp188-191.

*2. Horizontal Irradiation abbreviates for the solar irradiation that falls on a horizontal plane. These data are from Reifsnyder W. E., and Lull H. W. , 1965, and the figures given refer to the South West area of the U.S., not the specific SEGS site.

*3. SEGS produces 900 GWh per year, but 25% of this is from the gas input, so the output attributable to the sun is $(900 \times 10^9 \times 0.75) / (24 \times 365) = 77$ MWe. The capacity factors are calculated on that basis.

*4. Trainer 2007, p168, gives data from the National Renewable Energy Laboratory. The winter/summer ratio decreases with latitude and he states it is estimated at less than 10% for Portugal (latitude about 50 deg).

*5 Hayden, 2004, in his description of SEGS does not mention any storage capacity. In the USA, where there tends to be a high demand during the day for electricity for air conditioning, electricity produced only during the day is useful (although peak demand tends to come late in the day so solar is not ideal for peak filling).

*6. For this, Hayden (2004, p190) uses National Renewable Energy Laboratory data stating a power density of 50 watts of peak power per square metre. His calculation of a site power density of 10.8 W/m2 uses a capacity factor of 22% after excluding the gas contribution, as calculated above.

THE POPULATION BUBBLE

by Andrew R.B. Ferguson

We are familiar with the financial bubble created by the delusion that we could all, without risk, enjoy living on credit, while watching the value of our houses rise steadily! Only a few people saw the fallacy before the crash brought it home to everyone. That also appears to be true of the 'population bubble' despite the evidence being plain enough.

Water shortage is one symptom of the bubble. For example, Saudi Arabia made itself self-sufficient in wheat by using water from a fossil aquifer. It has harvested close to 3 million tonnes of wheat a year, but in 2008 the Saudi authorities announce that the aquifer was largely depleted. Next year could be the last harvest. As long as Saudi Arabia has oil to sell, the Saudis will have no difficulty in purchasing wheat, but that may not be true for those living in India and China who are similarly threatened.

The World Bank says that 15% of the people in India (175 million) are fed by grain produced through overpumping, that is when water is drawn from aquifers faster than it can be replenished. In China, the figure could be 130 million. Huge aquifers are being drawn down in the United States too.

Another reason for the population bubble is that many people are moving up the food chain, consuming more grain-intensive livestock products. But the biggest reason that we are experiencing a population bubble is that the support of our present population is largely dependent on having fossil fuels to fertilize the fields, assist sowing and harvesting at optimum times, preserve the harvest, and then deliver it to where it is needed, all of which depends on cheap fossil fuels. Moreover if we try to combat shortage of oil by the conversion of grain to ethanol, that will only compound the problem of food scarcity. Indeed it is already being thus compounded. In the United States, in 2010, out of a harvest of just over 400 million tonnes, 100 million tonnes of grain went to distilleries. It is a delusion that this is doing any good since — as numerous people have demonstrated time and time again — it takes at least as much energy to produce the ethanol as is contained in the ethanol produced. The main result of producing ethanol from corn (maize) is to use up land which could be used for producing food.

Yet another reason we are living in a population bubble is that the greenhouse gases we are releasing into the atmosphere are already creating climate instability. Due to an excessively hot summer, the Russians lost 40% of their 100 million tonne grain crop in 2010. Were that to happen in the United States, with its normal 400 million tonne crop, the food shortages created around the world would be far greater.

A further indication of climate instability comes from two 'once in 100-year' droughts in Brazil which occurred in 2005 and 2010, causing substantial killing of fish and die off of large tracts of the rain forest. Loss of forest in general is a problem, because forests are being cut down faster than they are being regrown. And anyhow replanting forests is not the same as keeping old forests in place, which would preserve biodiversity.

Further indications of the population bubble are desertification and loss of topsoil. Loss of fertile land also occurs with development in China and India, as houses, roads, railways and cities are built. Similarly rapid population growth in the USA is a problem. Also rising sea levels are likely to displace large numbers of people from fertile land.

In summary, we are living in a population bubble. The only question is when people will wake up to that fact and start the process of reducing the population to a level which the Earth can continue to support over millennia.

Acknowledgement: Some of the facts mentioned above were taken from an interview with Lester Brown, President of the Earth Policy Institute, which was published in the 5 Feb 2011 issue of *New Scientist*.