# OPTIMUM POPULATION TRUST

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> Almost all environmental activists seem to be oblivious to the contradiction built into their thinking. They are in effect saying, "Please help us save the planet by calling for a switch to the use of renewable energy sources — which can sustain consumer society and will pose no threat to our obsession with affluent lifestyles and economic growth." Even getting people to attend to such unthreatening messages is very difficult. …
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> The 'tech-fix optimists', who are to be found in plague proportions in the renewable energy field, are open to the same criticism. If the position underlying this book is valid, then despite the indisputably desirable technologies all these people are developing, they are working for the devil. If it is the case that a sustainable and just world cannot be achieved without transition from consumer society to a Simpler Way of some kind, then the transition is being thwarted by those who reinforce the faith that technical advances will eliminate any need to think about such a transition.
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> *Renewable Energy Cannot Sustain a Consumer Society*, Ted Trainer, 2007.

The Optimum Population Trust (UK): Manchester

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

**INTRODUCTION**

Martin Desvaux has now reached Chapter 14 in his synopsis of Clive Ponting's great book, *A Green History of the World*. Chapter 14 is about cities and has relevance to our present predicament because the growth of cities has been facilitated by cheap fossil fuels. Our grandchildren are likely to see the reverse. In this series Martin continues to survey the first edition of the book. At a later stage he will look at the changes that Ponting incorporates in the revised edition published in 2007, *A New Green History of the World*.

I am indebted to such an extent to others for several of the papers in this edition, that it is hardly right for them to appear under my name. For *Photovoltaics, Batteries, Tractors, Horses, and Biofuels* (pp. 7-13), it was John Howe (www.solarcarandtractor.com) from the state of Maine, USA, who was the main source of my data, emanating from his tests of the potential of vehicles driven by electricity captured via photovoltaics. We discussed many points including horses. But when it came to making comparisons with horses, it was an old book that David Pimentel still had in his possession which came to the rescue. My piece attempts to compare the merits of battery driven tractors with horses and biofuels. Entering into a conceptual world without the backup of fossil fuel energy is bound to be somewhat speculative, but I hope this piece throws some light on the subject.

In *Food Aid* (p. 14) Walter Youngquist, author *of GeoDestinies* and a great source of strength to OPT by virtue of the steady stream of information we receive from him, uses Haiti to illustrate a problem that OPT is forever trying to bring to public attention.

The next three pages (pp. 15-17) review the fine book just published, *Biofuels, Solar and Wind As Renewable Energy Systems: Benefits And Risks*, edited by David Pimentel.

The book just mentioned sensibly focuses on biofuels, this being the most difficult problem. A recent article in *Nature* looks at the easier problem of producing electricity without emitting carbon. The next two pages (18-19) review that article.

*Growth Rate Plots: An Introduction to the Concept* (pp. 20-21) was the result of much discussion between John Nunn and myself. I would never have started investigating the subject were it not for a book that Walter Youngquist kindly sent me, titled *Beyond Oil: The View from Hubbert's Peak*, by Kenneth Deffeyes. This two page piece is an explanation of one alternative way in which the data that produces Gaussian production curves can be presented; that alternative presentation shows clearly how, as the peak of production of a limited resource is approached, the amount of the resource that will ever be extracted becomes clear. We may be at that point with coal.

It was only because of the great generosity of David Rutledge in making all his data available, including the hugely impressive Excel spreadsheet that he has developed, that I could approach the subject the way I do in *Rutledge's Hypothesis* (pp. 22-28). The essence of Rutledge's idea is that it is possible to apply to the extraction of coal the same concept of Gaussian curves used so successfully by M. King Hubbert with respect to oil (actually Hubbert used logistic curves but the difference is small).

As the above makes clear, I am indebted to others for much of the contents of this issue, and as always to Yvette Willey for her help in checking and publishing it.

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## CLIVE PONTING'S *A GREEN HISTORY OF THE WORLD.* Part 6

A synopsis by Martin Desvaux PhD CPhys MInstP

> *"A twofold national problem is how to preserve the wilderness in the country and how to get rid of the jungle in the cities.*" *Bill Vaughan*

### Introduction to the Sixth and Seventh Instalments

Cities and affluence — twins born from the human drive for the mirage of a better future — have done little to diminish the aggregate poverty of our species, and in the process may yet bring about its demise. The quotation distils the essence of chapter 14 of Ponting's seminal work, which was republished in a revised form as *A New Green History of the World* in May 2007. The Seventh Instalment, Chapter 15, *Creating the Affluent Society* will appear in the next issue of the OPT Journal.

### Chapter 14: The Rise of the City

Clive Ponting sets the scene for this chapter with the opening statement:

> One of the greatest changes in the way people live has been due to the rise of the city in the last two hundred years. Cities developed at an early stage in the growth of settled societies and have generally been regarded as one of the distinguishing characteristics of a civilized society. However for thousands of years they played a very small part in the lives of most people. Until 1800 only a tiny minority — no more than two-and-a-half per cent of the world's population — lived in cities. … With the use of fossil fuel energy sources and increasing industrialisation, truly urbanised societies began to emerge in Europe and North America. In 1900 about one in ten of the world's people lived in cities …[which] continued to increase in number, size and importance in the industrialised world.

Just eighty years later, city dwellers had grown to fifty per cent (about 2.5 billion people) of world population.

Originally, Neolithic groups lived in small settlements, but over a few thousand years there emerged several early cities, such as Uruk, Ur and Lagash in Mesopotamia and others in China, the Indus valley, Egypt, Peru and Mesoamerica. Over four thousand years, they acted predominantly as ceremonial centres and were roughly the size of small modern day towns. In Egypt, they were populated by priests and craftsmen whilst peasants lived in the rural surroundings; by contrast, in Mayan cities, peasants lived in the cities, 'commuting' to their fields. Cities gradually developed into independent administrations which distributed food, housed craft and administration centres and controlled trade. Virtually all pre-industrial towns had surrounding walls for defence as well as taxation of goods entering via the gates. In contrast to their modern derivatives, cities' streets were labyrinthine, narrow alleys leading to a centre, in the vicinity of which lived the rich in expensive houses, alongside public buildings; the poorer population lived nearer the walls. Many towns had several fields and orchards within their walls, and areas demarcating crafts and religions were carefully segregated (e.g. Jewish ghettos in Europe).

As empires grew, so also did pre-industrial imperial capitals such as Rome, Peking and Pataliputra as well as coastal trading capitals such as Athens, Venice and Genoa. Cities attracted administrators, priests, craftsmen, traders, and the rich along with their slaves and servants, with populations growing up to 800,000 in the process. However, *"Lacking a firm economic base and dependent as they were on the imperial fortunes of the great empires, these imperial cities often declined as quickly as they grew. Vijayanagar, the* *capital of the main Hindu empire in India in the thirteenth and fourteenth centuries, was virtually deserted after the Mughal conquest.*"

In Asia, trade networks influenced the formation and growth of cities from the first century. From the second century BC, China's cities, such as Nanking, contained around ten per cent of the population; by 1200 AD, there were many cities containing several hundred thousand people after which urbanisation then appeared to go into reverse. Ponting summarises Europe's changing fortunes at that time:

> In Europe, the Mediterranean area was the centre for all the most developed societies and empires until at least the eleventh and twelfth centuries. Even after the fall of the Roman empire in the west in the fifth century, the Mediterranean remained economically the most advanced area of Europe and the size of its cities reflected this fact… The pattern of settlement in the north and west of Europe was very different. Under the Roman empire there had been only a few towns in the area, many linked to military settlements and most containing no more than a few hundred people. After the collapse of the empire, nearly all these Roman foundations decayed drastically. For five or six centuries there was little trade and industry in north-west Europe and the scale of its agricultural surplus was generally insufficient to support more than a very small urban population.[1]

By 1000 AD, Europe had only around 100 towns, half of which were in Italy. Three centuries on, as industry developed, Europe's town count had risen to about 3500, of which about a quarter could claim populations of over 25,000. Most however had less than 2000 people who made their living from the land and traded at the weekly market alongside a limited number of craftsmen. They thus formed a predominantly agricultural society. Between 1300 and 1800, growth of the preceding three centuries was not maintained; populations, following the Black Death and the end of the Medieval Warm Period, declined rapidly and only recovered slowly: *"Between 1350 and 1550 the number of market towns in England fell by two-thirds."*

Because cities could not feed their populations without recourse to the agricultural resources around them, they evolved their wealth from manufacturing, trading, local administration and taxes. As they developed they attracted more people from the overpopulated countryside, but in many cases such people were only able to do low-paid casual work and frequently had to resort to begging.

Existing towns in European colonies of the Americas became the foundation of modern cities, e.g. Mexico City was based on the Aztec Tenochtitlan and Incan Cuzco. Where no towns previously existed – as in North America and Australia – new settlements became the seed from which the cities developed.

Up to 1800, 'city' towns containing barely 2.5 per cent of the world's population had, in the main, less than 10,000 people; America had only five cities containing over 10,000 inhabitants. In the old world, city populations ranged up to about 1 million. Then, in the eighteenth century, the fuse of population growth – lit gradually by technological development, manufacturing and fossil fuel extraction – caused city populations to rocket during the nineteenth century:

> The results of this change were first apparent in Britain – in 1851 Britain was the most urbanised country in the world but more than sixty per cent of its population still lived in the countryside.... By 1900 three-quarters ...lived in cities and one in five of the population lived in London…. The total numbers living in British cities rose from about two million in 1800 to about 30 million in 1900.

The world's city population followed suit, quadrupling during the nineteenth century and causing other changes: *"For the first time, cities, although still reliant on the countryside for their food supplies, ceased to be parasitic on the national economy and began to make a* *major contribution, primarily through increased industrial output."* Just as food was the fuel of population growth in the world as a whole, industry fuelled its growth in the cities. The towns that grew were those based either on local natural resources such as salt, coal (Sheffield), wool, imported cotton (Manchester) or on the facilities needed to move them around (Swindon and Crewe – railways). London continued to be Britain's commercial and financial centre but also grew a variety of 'sweated' workshops for the clothing trade.

In Europe, similar developments followed. In Germany, the Ruhr towns developed on ports (Hamburg, for example), the coal and manufacturing industries, and "*Berlin became the hub of the railway system* ... " As population and poverty grew in Europe, emigration fuelled the growth of American cities; 23 towns in 1830 with over 10,000 people became fifty cities by 1910, with over 100,000 inhabitants. Ponting paints the big picture:

> Before 1800 most cities in the world were small in area – they were places which people could walk across to conduct their business. Rome in the second century AD was still largely contained within the Aurelian wall which enclosed an area of about five square miles. Roman colonial cities were much smaller – London covered 330 acres and Bath only 23 acres. The area of medieval London was about 700 acres. Cities in the nineteenth century began to sprawl. At ever greater distances from the centre suburbs grew up, mainly relying on new transportation systems to bring the ever greater urban population into their workplaces. Such developments significantly changed the nature of cities. Until the widespread growth of suburbs, the centres of towns had been the place where the wealthy lived. Industrialisation and the massive influx of mainly poor people seeking work led to … huge slums … in the centres of cities, such as the Covent Garden and Holborn areas of London, and many of the wealthy, together with the growing number of people working in offices and other service industries moved out to the more salubrious suburbs and surrounding countryside.

Suburbs developed with extensive housing estates to provide accommodation, and London spread out, mainly via unplanned development, to subsume nearby villages, such as Highgate and Hampstead, before marching across the countryside in all directions. Towards the south, expansion into Southwark followed thanks to new bridges and ferries.

All this development led to the parallel development of mass transport systems. After horse-drawn omnibuses were introduced in France, New York developed a 700 strong horse-drawn vehicle system along Broadway by 1853. Overall, "*Horse-drawn public transport had some effect on living patterns but the development of railways brought about major changes. In London the steady building of railway lines from the 1840s led to the growth of new, largely residential suburbs such as Camberwell, Hornsey, Kilburn, Fulham and Ealing."* This means of transport flourished in many American cities until the 1890s, by which time 5700 miles of track had been laid, before "electrified trolleys" started to replace them. To handle the rising need to move people around, London introduced the first underground railway in 1863, several decades ahead of other cities which followed suit, e.g. in Boston (1897), Paris (1900), Berlin (1902) and New York (1904).

The way that cities developed varied significantly throughout the world. In North America, where population density was low and land cheap, urban sprawl was extensive; Boston's radius grew from two to ten miles between 1850 and 1900. Overall, urbanisation grew from 2.5% in 1800 to 41% by 1985, and the number of cities with a population of over 1 million grew from 9 in 1890 to 230 by 1980.

Development was generally poorly planned, if at all. In Paris, Haussmann cleared slums in the 1850s, and in London, housing jumped the 'green belt' to extend its sprawl. In the Soviet Union, despite a highly planned economy, all attempts to constrain Moscow's population, first to 5 million (1935), then 7.5 million (1971) failed; by 1990, it reached 10 million. Japan remained predominantly rural until 1955, after which it followed the trends of the USA and Europe. In 1920, 80% of the people lived in the country, but this all changed with the construction of the railways in 1923. In Tokyo (previously Edo), the result was a trebling in population from one to three million between 1920 and 1930; the green belt disappeared by 1960 and a fifty-mile urban sprawl became established by 1977.

In several countries, to quote Ponting: "*Concentrated industrialisation in the nineteenth century, based upon the exploitation of deposits of coal and other raw materials, brought about the formation of the first conurbations – large, formless, urban masses caused by the expansion and joining up of a number of settlements without a single urban focus*." Cases in point were: the Black Country and the Five Towns of the Potteries in Britain; the development of the *Randstad* (ring towns) in the Netherlands which now comprise eight major cities; the German *Ruhr* which grew from 0.9 million (1871) to 4.5 million (1939) and ended up with a population of 5.5 million spread across 11 cities covering four districts; Japan where one conurbation extends from Tokyo to Kobe; and in the USA where there exists *" ... a string of cities linking Boston and Washington DC and containing over fifty million people (about a quarter of the population) in just one-and-a-half per cent of the area of the country."*

Although the twentieth century saw the appearance of the large metropolis, urbanisation peaked in the second half in industrialised countries. In Britain, France, Canada, Germany and the Netherlands, many cities started to decline in population from around the 1960s. In the third world, the timing was different. In Lagos, a sixteen-fold increase took place during 1950-1985, and in Nouakcholl in Mauritania, a forty-fold increase during 1965-1985. In contrast to nineteenth-century city growth, such rapid expansions in the third world led inevitably to higher mortality rates, social inequality and unemployment, poorer housing, more slums and weaker social bonding.

In the developed world, although cities improved generally with accumulation of wealth, one downside was poorer mass transport and increased congestion as cars became the favoured mode of travel; the average speed of cars in New York declined from 11.5 m.p.h. in 1907 to 6 m.p.h. in 1970. Similar trends occurred in Paris and London. In Japan, Britain and the US, trends in the second half of the century were similar. Poor housing – often with inadequate sanitation – inadequate transport networks, increased ghetto populations, inadequate medical facilities and social degradation (*inter alia* drug abuse and crime) have led to social challenges that have yet to be effectively addressed. Ponting sums it up:

> The rise of cities is a phenomenon linked to the exploitation of fossil fuels and industrialisation in the nineteenth century, together with the development of greater trade and more complex financial transactions on a national and eventually a worldwide scale. Despite increasing wealth in the industrialised world, cities have become areas where environmental problems, in many cases specific to urban life, are concentrated. These range from air pollution from vehicles, to poor living conditions exemplified by estates consisting of large tower blocks of flats with people crowded together with often limited living space (a marked characteristic of Japan and the Soviet Union), long commuting journeys often on inadequate public transportation systems, excessive noise and the multitude of social problems that flow from growing unemployment, social inequality and urban decline in the city centres. Most of the people who live in cities – about three-quarters of the population of the industrialized world and half of the people of the world as a whole – are now subjected to such problems on a daily basis.

1. Following the Romans' invasion of Britain, London's population grew to 45,000 by 300 AD. It then declined to 10,000 by 350 AD before collapsing to only fifty people after the Romans departed in the early fifth century.

# PHOTOVOLTAICS, BATTERIES, TRACTORS, HORSES, AND BIOFUELS

by Andrew R.B. Ferguson

**Abstract.** As fossil fuels dwindle, there will have to be a change to different ways of farming, and of providing transport for essential commercial goods such as food. Engineer John Howe's experiments show up the limitations that apply to using photovoltaics and batteries. Using this combination, it might be possible for a farmer to farm 20 hectares. However, equally as likely, once fossil fuels become scarce, this technique may prove too expensive.

An alternative is for farmers to make use of some of their productive land to grow biofuels, by means of which they could carry out cultivation using typical internal combustion engine tractors. It is shown that 20 hectares could be farmed using soy oil in place of diesel, but there would be a need for about an additional 5 hectares to be farmed to produce the biofuel needed. In other words, 20% of the total land used would have to be utilised for producing the fuel used on the farm. Difficulties of expense in running small scale biofuel processing plants might be a barrier there too.

The task of cultivating the 20 hectares with horses is also considered. The major problem with that is the additional land needed. The extra land needed is estimated at 7 hectares, about a third of the land which is being cultivated.

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In previous issues of the OPT Journal, it has become apparent that photovoltaics are not suitable for contributing more than a small proportion of power to an electrical grid, and that their low capacity factor makes them unsuitable for producing hydrogen by electrolysis (in both cases unless storage becomes feasible). However, some families — mainly those which are unable to connect to the grid — use only batteries in conjunction with photovoltaic (PV) modules to provide themselves with power at home. This suggests the possible use of batteries, recharged by PV, for other vital requirements. At least it is worth investigating whether batteries combined with PV modules could do some useful work on the farm, because when fossil fuels become scarce, maintaining farm output is of paramount importance. One clear advantage is that the batteries, when not being used for the relatively short periods of time that plowing, harrowing, and harvesting are being carried out, could be used to carry out transport tasks and to power the farmhouse throughout the 24 hours. Those are points to return to later.

Engineer John Howe has done excellent ground work on the subject, with the aim of determining the practicability of this approach.{1} It is his work that — with his guidance — I am about to recount, with special reference to the experiments he has made with the fourth of a series of test vehicles that he has built, namely an 8N Ford Tractor. It is a tractor of substantial size. The original version, before modification, weighed 1130 kg. With batteries, the modified version weighs 1680 kg. The original liquid fuel version was rated at 22 horsepower.

In the modified tractor, the battery pack consists of ten DEKA 9C12 220 Ah batteries. Each battery is rated at 75 amperes with a capacity of 150 ampere hours (Ah). At the 12 volts provided by each battery, each battery can thusefully store 150 x 12 = 1.8 kilowatt hours (kWh). The batteries are connected together in series to produce 120 volts.

Operating at the same 75 amperes, i.e. maximum power output, they can operate for 2 hours, thus providing a total capacity of 18 kWh.

The power output is 75 amps x 120 volts = 9 kW(electrical), equal to 12 horsepower. About 5 horsepower is needed just so the tractor can move itself in soft ground; the remaining 7 horsepower being needed to do the required work. That sounds like a lot of horses to have in hand, but of course the electrical energy does not convert with perfect efficiency into propulsion power. And we may note that the original tractor was apparently able to offer a surplus pulling power of 17 horses.

The energy value of the total 18 kWh battery capacity is equivalent to 0.5 gallons of gasoline. However electric motors are more efficient than internal combustion engines, so in terms of ability to do work, the 18 kWh is about equal to 1.5 US gallons, 5.7 litres, of gasoline. Even doing fairly heavy work, like 16-inch plowing (this means plowing over a lateral distance of 16 inches, 40 cm), or double-disk harrowing in new ground, at 2 mph (3.2 km/h), the tractor will have sufficient energy stored in the batteries to plow, or harrow, 0.2 hectares (2000 square metres), which it will do in 2 hours.

So far that is moderately encouraging. Heavy ground might slow them up, but in moderate ground, a team of two horses would plow a hectare in about 8 hours; so in 2 hours they would manage 0.25 ha. Thus over a two hour period the rate of plowing with 2 horses is comparable to the battery powered tractor.

The problems arise in the recharging of the batteries. If 14 square metres of module were used, then at a typical peak output rating of 150 watts per square metre ($W/m^2$), the peak output would be 14 x 150 = 2.1 kW. At the 120 volts used, that is 2100 / 120 = 17.5 amps. That is below the maximum charging rate, but, as will become apparent later, when several sets of batteries are used sequentially, there is no point in recharging faster, so we will consider using only 14 square metres of module with one set of 10 batteries.

How long will it take to recharge the 10 batteries? Even if we assume summer in the mid west of the USA, where insolation is fairly high — about 270 $W/m^2$ — the 14 $m^2$ of panel will provide only 399 watts,{2} or 399 x 24 = 9.58 kWh per day. Thus to recharge the batteries with a full 18 kWh would take 18 / 9.58 = 1.9 days. Recognizing that some days will be less sunny than average, it is clear that 2 days should be allowed for recharging.

To plow only 0.2 hectares in 2 days (i.e. at a rate of 0.1 hectares per day) is obviously inadequate. It is hard to see anything like modern life continuing if a farmer cannot cultivate as much as 20 hectares (a square of 450 metre sides), so let us use that area as a basis for analysis. With this one set of batteries and modules, it would take 200 days to plow 20 hectares. That is excessive. So as to be able to work continuously for 8 hours a day, we need to consider solving the recharging delay problem by using a sufficient number of batteries and PV modules. If we had 8 sets of batteries and 8 x 14= 112 $m^2$ PV modules that would allow 8 x 2 hours = 16 hours of work to be done, without recharging. The important point is that the two days of work would be covered by charged batteries, and those two days would allow sufficient time for the first set of batteries to have been fully recharged, so work could continue at the same rate, day in day out, indefinitely. Working 8 hours a day, the tractor would achieve 0.8 hectares per day. Thus the 20 hectare field could be finished in 20 / 0.8 = 25 days. That seems like an acceptable proposition.

Let's just do a rough cross-check on that, so as to see that the energy captured equals or exceeds the energy used. In two days, 8 periods of plowing will be done, each of 2 hours.

Since each two hours requires 18 kWh That is a total of 8 x 18 = 144 kWh. In two days, the 112 $m^2$ of modules will capture 153 kWh.{3} That is slightly above 144 kWh, but then one cannot expect every two day period to have average or above average insolation, so some margin for lower insolation is advisable.

Now to look in more detail at the comparison with horses. David Pimentel has provided me with background information about this, supporting his own experience with data from Morrison (1946).

We have noted that a team of two horses might plow at a rate of 0.125 ha/hour, so 20 hectares would take 160 hours. A team of horses can plow for 8 hours a day according to Morrison (1946), so that would take 20 days of work. That is actually better than the battery powered tractor; but there is a rule of thumb which says that a team of two horses is adequate for contributing to the management of 10 hectares. Thus we should really consider two teams to be required, with two plowmen of course, cutting the time to 10 days. Obviously a substantial improvement over the tractor. In fact since oxen plough at about two-thirds of the speed of horses, with a similar set up, they would achieve the task in 15 days, which is still faster than the tractor.

Then there is the question of the area of land needed for the horses. Using data from Morrison (1946), a team of two horses would require 0.8 ha of pasture; 450 kg of corn, needing 0.06 ha; and 1.2 ha of hay land. That works out at just about 1 hectare per horse. So for the four horses that we are considering, 4 hectares would be needed.

But another factor to account for is that horses need time to mature into working animals, so allowance needs to be made for replacements for the 4 horses; ideally there should be reserve horses too. With a small group like this, John Howe suggests that the land needed for replacement and reserves might be as much as a hundred percent, but for a larger group of horses fifty percent would suffice. Too much precision is obviously not possible, so let us pencil in an additional 3 hectares, making a total of 7 hectares for the two teams with backup.

So about a third as much land is needed to maintain the horses as is being cultivated. Some confirmation for that estimate is given by Britain's experience in the 1900s, for Britain only has about 18 million hectares of ecologically productive land, and the following information from Clive Ponting (2007) is therefore broadly in line.

> In the early twentieth century Britain had a horse population of about three and a half million…. In 1900 Britain's horses consumed 4 million tonnes of oats and hay every year (taking up the production of about 6 million hectares of land).

The land needed by horses provides one good reason for using PV and batteries rather than horses. Another is that it might take a long time to revive the skills of a sufficient number of plowmen. Yet another is that the PV system offers several advantages in addition to plowing and harrowing, as will be mentioned later. But before counting the benefits, we need to look at the costs inherent in installing 112 square metres of module and 80 batteries.

The 112 square metres of module, rated at 150 $W/m^2$, would have a peak capacity of 16,800 watts. At a slightly optimistic fully installed cost of $5 per peak watt, that would cost $84,000. The batteries cost about $200 each, so 80 would cost $16,000. Assessed on a 20 years basis, and assuming the PV modules to last 20 years, and including four lots of batteries, the total cost would be $148,000, or $370 per hectare per year (although that might be somewhat reduced by the trade-in value of the used batteries).

While that cost looks bearable (at about 5 cents per kg of corn), it is based on the present cost of energy. The cost of lead acid batteries, PV modules, their installation, and the cost of the tractor, are all related to the cost of energy. Without the benefit of fossil fuels, energy would be much more expensive, and the increased cost of energy would impinge on raw materials (which need energy to mine and refine), and energy is needed for manufacturing the product and delivering it to where it is wanted. So the whole concept, even if possible while fossil fuels are available, looks like being too expensive to bear when fossil fuels are no longer available. Thus we hardly need to pause to consider other problems, like the cost of the lead used in the batteries when such use become extensive (thieves are already stealing lead off roofs in the UK), or note that the farmer would already be impoverished by the high cost of nitrogen fertilizer, which needs a lot of energy, or pause to reiterate the positive sides, such as that 112 batteries each of 1.8 kWh capacity could store 202 kWh, which would be a wonderful thing for the farmhouse during the winter months. Moreover even when the tractor was working 8 hour shifts, there would always be one set of modules that was not in use (because the batteries are in the tractor) and the output from the PV modules could be used to supply current directly to the farmhouse.

It is a good prospect, but the big question is whether it will be possible in a world without fossil fuels. Without doubt, that world will be a materially impoverished one, and perhaps the most telling question to ask is whether this system is one that could be adopted in a poor country such as Cuba, because without the benefit of fossil fuels, that is the sort of situation that humans will be experiencing. The answer to the question must surely be that it is quite likely that it will *not* be possible, so let us now turn to biofuels, to see if they could offer a more attractive alternative than returning to the use of horses.

### The biofuels alternative

The task of fermenting maize (corn), and distilling it to remove about 95% of the water to produce ethanol suitable for use in internal combustion engines, is a task that could not be undertaken at small-scale farm size. However, it is possible to envisage the necessary processing to produce a suitable biodiesel from an oil crop being done at a small scale. Of all the oil crops, soybeans are probably the best choice for a renewable energy world, as they need little or no additional nitrogen (the most energy intensive fertilizer). Thus it would seem sensible to choose soy oil as the biodiesel to evaluate. What we need to see is whether it offers a better alternative than either horses, or batteries recharged by PV (which as mentioned may not be economically viable).

As Table 1 shows, the *gross* output per hectare is 524 litres of soy oil per hectare. However liquid inputs are required for the cultivation of soybeans. For reasons that will be amplified later, we need to budget for 23% of the soy oil output to be used as inputs, so this leaves 524 x 0.77 = 403 litres (106 US gallons) per hectare as "useful" output for cultivating other crops. If we allocate 4.5 hectares of land to growing soybeans, then the "useful" output of biodiesel would be 403 x 4.5 = 1814 litres per year.

Turning now to how that "useful" oil is to be used, it depends on the crop exactly how much liquid fuel is required for cultivating and harvesting, but to get a general idea let us take the figures that are appropriate to soybean production, namely about 90 litres per hectare.[4] Therefore aiming to cultivate the same 20 hectares that were previously considered, the biofuel requirement would be 1800 litres. So the 4.5 hectares of soybeans provide sufficient "useful" biofuel for the 20 hectare task, but more land is required for non-liquid fuels needed in the production of the soy beans.

So far we have only considered the *liquid* inputs needed to produce the soybeans. In addition to the liquid input, there is a substantial non-liquid energy input required. The liquid input amounts, as a first step, to about 17% of the gross biofuel output,{4} while the remaining inputs are about equal in energy content to 117% of the gross biofuel output. For these reasons, the whole process is an energy loser, insofar as it requires in total, as inputs, 134% of the energy contained in the gross output of biofuel (Pimentel and Pimentel, 2007).{5} We can calculate that additional energy requirement in the following manner. The gross biofuel yield was mentioned above as 524 litres per hectare, so the 4.5 hectares we are using to produce biofuel would yield a *gross* energy equivalent to 524 x 4.5 = 2358 litres of soy oil. The energy density of soy oil is about 34 MJ/litre, so at 117%, the total additional (additional to liquid) energy demand for producing the soy oil from 4.5 hectares is 2358 x 34 x 1.17 = 94 gigajoules (GJ). The gross yield of an energy crop like short-rotation woody perennials might optimistically be put in the region of 160 GJ per hectare per year. Thus we need about 0.6 hectares to supply the 94 GJ of non-liquid energy. But harvesting this area and transporting the wood to where it is needed will also use some liquid energy, probably at least 5% of the gross wood output from the 0.6 hectares, i.e. 94 x 0.05 = 4.7 GJ. That is equal to about 138 litres of biofuel. As a proportion of the total gross output of liquid, that is 138 / (524 x 4.5) = 6%. That 6% liquid output needs to be added to the 17% used in providing the straight forward liquid inputs for cultivation of the 4.5 hectares of soybean , and thus a total of 23% of the output will need to be used as liquid input (the figure drawn out of the air earlier without explanation!).

**Conclusion**

We can now sum up the position like this. Using a tractor and biofuel, 5.1 hectares of land is needed to provide the inputs to farm 20 hectares. Of this, 4.5 hectares needs to be arable land and the remaining 0.6 hectares needs only to be suitable for growing an energy crop such as short-rotation woody perennials. This is less than the 7 hectares needed to provide horse power. Moreover the biofuel powered tractor would plow at a rate of about 0.15 hectares per hour, so working an 8 hour day, it could cover the 20 hectares in about 17 days (an improvement over the 25 days taken by the battery powered tractor).

However, even the biofuel operation might run into cost problems, depending on how simple and cheap can be made the process of producing the soy oil from the soy beans.

The battery plus PV option has the advantage of not using ecologically productive land, but as already mentioned it may not be viable economically in a world that is impoverished by shortage of fossil fuels.

The above theoretical calculations probably give a fairly realistic idea, but they cannot be held with any certainty without trying them out in practice. It should be a priority to explore every alternative, as John Howe is doing with batteries and PV, so as to get a good idea of whether the theoretical calculations are in the right region, because we need to know ahead of time what situation we will be in as fossil fuels become scarce, so that we can make useful estimations of the population that could be supported without their benefit. It is likely to be a small fraction of the present world population, not only because of these limitations on food supply but because of the need to provide energy for keeping warm and for manufacturing processes.

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## Endnotes

1. John Howe's website is at, www.solarcarandtractor.com
2. There are two ways to do the calculation. As a rough estimate, PV panels capture one tenth of the insolation (radiation that falls on them) so each square metre of module would capture 270 x 0.10 = 27 watts, and the 14 square metres would capture 27 x 14 = 378 watts.

   A more accurate way is to use the rule of thumb to calculate the capacity factor of the modules at the assumed average insolation of 270 W/m$^2$: (270 / 1000) x 0.70 = 0.19, i.e. 19% (OPTJ 4/2 pp. 28-41). The 14 m$^2$ of module would have a peak capacity of about 14 x 150 = 2100 watts. Thus the mean output from the full 14 m$^2$ would be 2100 x 0.19 = 399 watts.

   It should be noted that this is an average seasonal calculation. By choosing a sunny day, the capacity factor could be at least 27% (such figures were recorded in Colorado). However only farmers plowing small areas have the luxury of waiting for sunny days.
3. From the previous paragraph, 14 m$^2$ provides a power output (average over a day) of 399 watts, so 1 m$^2$ provides a power output of 399 /14 =28.5 watts. In two days (i.e. 48 hours), 112 m$^2$ would therefore provide 48 x 112 x 28.5 = 153 kWh.
4. Pimentel and Pimentel (2007, p. 323) give the following liquid inputs per hectare:
   Diesel 442,000 kcal, gasoline 270,000 kcal, LP gas 25,000 kcal, for a total of 737,000 kcal.
   The calorific value of 1000 kg of soy oil derived from 5556 kg of soybeans is 9 million kcal.
   Thus the calorific value of the soy oil derived from 2668 kg of soybeans (harvested from 1 hectare) is:
   9,000,000 x 2668 / 5556 = 4,322,000 kcal.
   So the total liquid input amounts to 737,000 / 4,322,000 = 17% of the soy oil output.
   737,000 kcal = 3085 MJ. At 34 MJ/litre (LHV) this is about 90 litres of soy oil.
5. Pimentel and Pimentel (2007), page 325, actually shows input as being 132% of output, but David Pimentel told me that he had subsequently come to realize that there was also a need for 200 ml of methanol per litre of soy oil for esterification purposes. Thus the necessary adjustment to the table has been made, thereby increasing the input to 134% of the output. Note that the calorific value of the methanol was calculated on the basis of producing it from wood, thus much reducing the fossil fuel energy that would be needed were it to be produced from natural gas.

**Table 1.** Inputs to produce and transform 2668 kg of soybeans (the average yield of 1 hectare) into 480 kg, 524 litres, of soy oil, as a suitable substitute for diesel fuel[a]

| | Quantity/ha/yr | MJ/ha/yr | |
|---|---|---|---|
| **Inputs** | | | |
| Soybeans | 2,668 kg | 15,679 | |
| Electricity[b] | 130 kWh | 1,401 | |
| Steam | 2,714 MJ | 2,714 | |
| Cleanup water | 322 MJ | 322 | |
| Space heat | 306 MJ | 306 | |
| Direct heat | 884 MJ | 884 | |
| Losses | 603 MJ | 603 | |
| Stainless steel | 5 kg | 318 | |
| Steel | 10 kg | 494 | |
| Cement | 27 kg | 213 | |
| Methanol (needed for transesterification)[c] | 105 L | 927 | |
| **Total** | | 23,861 | |
| Gross output of soy oil = 524 litres = | | 17,816 | |
| Liquid inputs = 17,816 x 0.23 = | | <u>4,098</u> | |
| So output of ‘useful’ liquid | | 13,718 | = 403 litres soy oil/ha/yr. |

So power density[d] = at 34 MJ/litre = 403 x 34 MJ = 13.702 GJ/ha/yr = **0.43 kW/ha**[e]

**Notes to Tables**

a. This table is derived from two tables (pp. 323-325) in *Food, Energy, and Society*, 3rd edition, by David and Marcia Pimentel (2007). The first of those two tables shows the energy analysis for the cultivation and harvesting of the soybeans, but only the result is shown here (first row of the table).

b. The original tables explain and reference the derivation of the energy inputs, but that information is not repeated here. The original second table dealt with 1000 kg of soybeans. The figures here have been adjusted to deal with the 2668 yield from one hectare in one year, and also for one missing item (later advised to me by David Pimentel), namely the 200 ml of methanol needed per litre of soy oil for transesterification of the soy oil (see next Note).

c. The energy for the 200 ml of ethanol needed per litre of soy oil was calculated on the basis of the inputs needed to provide the methanol from wood, using the data in Giampietro et al (1997). 1.73 kg of wood is needed per litre of methanol, so here the amount of land for growing wood is negligible.

d. This **0.43** kW/ha is only a “partially net” power density, because only the liquid inputs have been subtracted. To allow for the non-liquid inputs, an additional (134 - 23) = 111% of the input would be needed, i.e. 1.11 x 17.816 GJ = <u>20</u> GJ/ha. Using the rather optimistically high figure of 160 GJ/ha/yr to provide that non-liquid energy from woody crops, would require an additional 0.13 ha. The effect of needing 0.13 hectares more land would be to decrease the power density to = 13.702 [GJ/ha/yr] / 1.13 = 12.1 GJ/ha/yr = **0.38** kW/ha. Even that is not the end of the story, because some liquid inputs will be needed to harvest and transport the wood. Even if we put that as low as 5% of the 20 GJ yield, providing that required liquid fuel will reduce the “useful” output by 29 litres (= 0.03 GJ/ha), and thereby reduce the 0.43 kW/ha figure to 0.40 and the 0.38 figure to **0.35** kW/ha. The last figure is the fully net power density, and amply indicates the basic problem with biofuels: low power density.

e. The equivalent power density for ethanol from Brazilian sugarcane is 4.12 kW/ha (see p. 15), but there are many reasons why farmers cannot grow sugarcane (high rainfall and temperature are needed) and produce ethanol from it. One important reason for choosing soybeans is that they need little or no nitrogen, and nitrogen is the most energy intensive fertilizer.

## FOOD AID

by Walter Youngquist[*]

The caption, to an appealing picture of small children, reads: “Hunger deepens as Haiti awaits food aid.” I have been to Haiti. It now has 9 million people living in an area smaller than Malheur County, Oregon. Overpopulation has also destroyed almost all the original forest, resulting in the worst erosion I have ever seen in the 70+ countries I have been in. As a result, Haiti has for many years been on the international food welfare program. From population pressures on the environment, more countries are continually being added to this food welfare program.

The United States has been one of the chief sources of this food, as it currently is expected to be now in the food crisis in Haiti. The Population Reference Bureau (2007 chart) projects the Haitian population will rise from 9 million to 11.5 million in 2025 and 14.3 million by 2050. Obviously, under current procedures the result of providing more food for Haiti is more Haitians. It is clear that the problems of Haiti only become worse with international food aid. This fact now applies to many regions, so the current food aid programs in both the near and long term only exacerbates the problem. It is counter-productive.

Adjacent to the United States, Mexico now has 107 million people, projected to grow to 125 million in 2025, and 132 million by 2050. In a failed economy, Mexico simply dumps its surplus population across its northern border, providing maps and information pamphlets on how to make the crossing. With 302 million people in the United States now, the PRB predicts 345 million will be here in 2025, and 420 million by 2050 — an increase in just 43 years of more than 118 million. The United States does not now have the resources to take care of the people already here. The U. S. now imports 65% of its oil, and 16% of its natural gas, and, since 2002, has been a net importer of agricultural products, the deficit in which in 2007 was more than $10 billion dollars — imports versus exports.

In Mexico the population problem is simply shipped north, accounting for about 80% of U. S. population growth and nearly 100% of California's growth. In the United States, crowds everywhere and imports from the rest of the world, totaling more than $2 billion a day, indicate the population is beyond domestic sustainable size.

Nearly all problems are related to population growth. Dr. Albert Bartlett has made this observation:

> *Can you think of any problem in any area of human endeavor on any scale from the microscopic to the global whose long-term solution is in any demonstrable way aided, assisted, or advanced further by increases in population, locally, nationally or globally?*

Increasingly, across the globe, nightly television brings to our living rooms photos of malnourished people, particularly touching are the starving children. *But the population problem is homegrown, and must be solved at home*. Advanced countries can provide the means and the knowledge for a given country to adjust its population to its sustainable food resource base, but implementation of that action becomes an individual responsibility, and collectively a national responsibility. Thus far this most fundamental of all humanity’s problems is consistently ignored by nearly all — if not all — public officials everywhere. It has never, to my knowledge, become part of any political platform or a politician’s agenda seeking office or one seeking to remain in office. All of the above also relates to the United States.

IT CANNOT CONTINUE TO BE IGNORED!!

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**BIOFUELS, SOLAR AND WIND AS RENEWABLE ENERGY SYSTEMS: BENEFITS AND RISKS.** David Pimentel (Ed.) * — a review essay by Andrew Ferguson

This book is very well timed, as it is becoming apparent to everyone that renewable energy has severe limitations — still to be fully explored. The most difficult hurdle to jump is that of finding a substitute for oil. Moreover if scientists fall at this hurdle there is little realistic chance of jumping over any of the others, because the manufacture and maintenance of systems such as wind turbines, wave devices, photovoltaics and transmission systems — from the mining of the ores to the installation and maintenance of energy capture devices — is unlikely to be possible without a suitable liquid fuel. So it is entirely appropriate that about fifteen of the twenty chapters have the production of biofuels as their main focus.

Wind power is covered in one chapter. The main points made comprise the now almost well-established facts, that due to its uncontrollability wind power is unlikely to contribute more than about 20% of the total electricity supply, unless a way is found to store electricity in appropriate quantities. Moreover the output being electricity, and there being currently no clear route from electricity to a type of 'liquid' fuel that is practical to use, wind turbines do not resolve the need for liquid fuels.

Photovoltaics do not get covered in any detail, but since the all-important ratio between the peak output of the energy-capture system and its mean output is even greater with photovoltaics (about 5 even in Arizona) than with wind (about 3), electricity from photovoltaics is evidently even more difficult to integrate into an electricity grid than wind.

One outstandingly useful chapter, **Bio-Ethanol Production in Brazil**, by Robert Boddey et al., contains a meticulous analysis that takes full account of the normal production system for sugarcane, namely to plant one year and then harvest the next year and then, for the following four years, to harvest from the same planted stock, or ratoon as it is called, during which time very few inputs are needed other than the effluent from the ethanol production process. Indeed the inputs in the subsequent years are shown to be less than one tenth of the inputs in the year of planting.

The mean gross ethanol yield is 6281 litres per hectare per year (L/ha/yr). Of course some liquid fuels are embodied in the production of most of the consumables, e.g. in the steel, stainless steel and cement that are used, but it is hard to assess that accurately, and we need only note the *overt* use of liquid fuels during the production and transport processes, which is assessed as 160 litres of ethanol /ha/yr [1] (a mere 2.5% of the gross output; this does not include the more substantial figure for distribution[2]). Thus the ethanol yield net of liquid inputs is 6121 L/ha/yr, which amounts to 4.12 kW/ha.[3] That power is simply conceived of as 41 light bulbs, each of 100 watts, being on continuously. The vision of them sitting in an area of one hectare (each bulb set within a space of 244 $m^2$) immediately shows the paucity of energy capture, as does the consideration that the power density amounts (depending on local insolation) to about 4.12 / 2000 = 0.20% of solar insolation, or 20 parts per ten thousand.

Ethanol from sugarcane is in a superior class from all other methods of winning liquid fuels from biomass. This is because of the high biomass produced by sugarcane — in Brazil this is about 77 tonnes per ha (fresh) per year which, because Brazilian sugarcane is harvested somewhat drier than in most places, is probably about 15 t of dry matter ha/yr. What is left over after extracting the sugar for fermentation is known as the bagasse. This bagasse can be used to provide the heat for distillation and to generate the electricity needed for the conversion process (there is even a bit left over). It is this which makes the output

* *Biofuels, Solar and Wind as Renewable Energy Systems: Benefits And Risks*. D. Pimentel (Ed.). 2008. Springer (springer.com). ISBN 978-1-4020-8653-3, e-ISBN 978-1-4020-8654-0, US$90, £44.

to input ratio of ethanol production from sugarcane so outstandingly favourable — although for how many decades it will be possible to remove 15 tonnes of dry matter biomass without impoverishing the soil remains an open question. According to some agronomists, sugarcane causes more soil erosion than any other crop grown in Brazil. Leaving that aside, the essential point is that Boddey et al. assess the *entire* fossil fuel inputs as a mere 11% of the gross ethanol output. As an approximation, we can therefore afford to ignore the detail of all the inputs except the liquid ones, and concentrate on the previous calculation of the output (*net* of liquid inputs) as being 6121 L/ha/yr.

To the vision of 41 light bulbs per hectare, let us add the thought that the United States currently uses about 20 million barrels of petroleum each day. To substitute for this using ethanol from Brazilian sugarcane would require 380 million hectares of sugarcane.[4] This is about equal to all the cropland, cropland idle, cropland in pasture, and grassland in pasture in the United States.[5]

Of course sugarcane can only be grown in rather special areas, ones which combine exceptionally good rainfall with high temperatures. But it is not worth considering the problem of location, when it has already become apparent that diverting about 20% of U.S. cropland to growing corn for ethanol production has had deleterious consequences, being a considerable factor in increasing all food prices. Thus it can be concluded that there will not be available even a significant fraction of the required 380 Mha.

The extent of the problem also becomes apparent when the alarming extent of U.S. population growth is considered. Because of the number of illegal immigrants, this is consistently underestimated by the Census Bureau authorities; Virginia Abernethy put the figure at between 1.4% and 1.7% per year.[6] Even the lower figure would mean that every year an additional 380 x 0.014 = 5 million hectares of sugarcane would have to be planted to provide for increasing population.

Or again consider the hypothetical situation in which the U.S. population is halved and each person uses a mere *eighth* of their present consumption of oil. The area of sugarcane then needed would be 380 /2 /8 = 24 Mha — the area of the whole United Kingdom.

Europe is far less extravagant in its per capita energy use, consuming about half the amount used in the U.S. However Europe does not have the option of growing sugarcane.

Edwin Kessler, in Chapter 11, **Our Food and Fuel Future**, encapsulates the lessons of the whole book, and compressed a great deal of it into these paragraphs (p. 259):

> Developed countries are critically dependent on the liquid fuels required by present day transportation of goods and services and by agriculture and are dependent upon various fuels for generation of electricity. Authorities and the media present physical growth as an economic and social need, but consumption and its growth ultimately cause declining availability and increasing price of fuels and energy. Increased burning of carbon fuels with increase of carbon dioxide in Earth's atmosphere is the principal cause of increasing global warming, which is well-measured and the probable source of future disruption of world ecosystems.
>
> Regrettably for humanity, the power of new technologies has not yet been accompanied by vitally needed political and cultural developments in the U.S. and in many other countries. The political system in the U.S. seems unable to mitigate processes that contribute to global warming nor adequately address declining supplies of liquid fuels, nor does it discourage social pressures for continued physical growth. …
>
> Various current U.S. programs are examined and none appear effective toward prevention of a future disaster in human terms. The social organism is not ready now to sacrifice for future gain or even for sustainability.

Kessler puts a precise finger on the reason that there is a delusory public appearance of progress in the development of renewable energy (p. 267):

> Further, the programs so far implemented in the United States appear to be means for accumulation of wealth by a relatively small number of beneficiaries who have both the power to control legislation and ability to create a public perception that realistic steps are being taken when the fact is opposite. The incorrect public perception allows business to proceed as usual even though collapse may be just around the corner.

Tad Patzek, in Chapter 2 — **Can the Earth Deliver the Biomass-for-Fuel we Demand?** — provides a similar Olympian overview of the current human condition. The Abstract to his chapter sums up the overall situation thus:

> In this work I outline the rational, science-based arguments that question current wisdom of *replacing* fossil plant fuels (coal, oil and natural gas) with fresh plant agrofuels. This 1:1 replacement is *absolutely* impossible for more than a few years, because of the ways the planet Earth works and maintains life. After these few years, the denuded Earth will be a different planet, hostile to human life. I argue that with the current set of objective restraints a *continuous stable solution* to human life cannot exist in the near-future, unless we *all* rapidly implement much more limited ways of using the Earth's resources, while reducing the global populations of cars, trucks, livestock and, eventually, also humans.

It has to be said that not all chapters in the book are as lucid or relevant to the long overdue need for urgent action as the ones referred to here. But taking these chapters alone, it would be hard to imagine a more thorough presentation of the realities of the problem which economists, politicians and the commercial world refuse to recognize. Not that academics can be entirely absolved from blame. There remains, even today, a substantial minority whose work appears to be little better than that of accredited lobbyists. Whether their thinking is distorted by hope of pecuniary gain, a need to follow the herd, or a personal desire for an outcome that feels comfortable, is often hard to say. What seems certain to me is that when matters are complex, as they invariably are in the field of energy and social organization, many academics are more influenced by what they would like to believe than by dispassionate analysis. That is why I always try to lay matters out so that an educated layman can check the calculations for themselves. Absolved from these strictures are the thirty contributors to this valuable book, and the greatest credit must go to David Pimentel, who after so many years of trying to call the attention of the public to the existential crisis, took upon himself the task of bringing this book to publication.

## Endnotes

1. Liquid inputs (Table 13.4, p. 333) are 1064.4 + 2334.8 = 3399.2 MJ/ha/yr. At a calorific value for ethanol of 21.25 MJ/L that is 3399.2 / 21.25 = 160 L/ha/yr.
2. Boddey et al. do not make an estimate of the energy needed for distribution, but the figure given by Pimentel and Patzek, page 363, citing DOE, 2002, indicates 6.5% of the gross output.
3. 6121 L/ha/yr x 21.25 MJ/L = 130 GJ/ha/yr = 130 / 31.54 x $10^9$= 4.12 kW/ha.
4. 20 million barrels a day = 7.3 billion barrels a year. The energy content of 7.3 billion barrels of oil, based on a calorific value for oil of 43 MJ/L, is 7.3 x $10^9$ x 159 x 43 x $10^6$ = 49.9 x $10^{18}$ joules. At an ethanol calorific value of 21.25 MJ/L, that is 2.35 x $10^{12}$ litres of ethanol. At a *net* (of liquid inputs) ethanol yield of 6121 L/ha/yr this would require 384 Mha of sugarcane.
5. The areas referenced are cropland, 135 Mha; cropland idle, 21 Mha; cropland in pasture, 36 Mha, grassland in pasture, 183 Mha; for a total of 375 Mha. The figures are taken from page 18 of Pimentel, D, Pimentel, M. 2008. *Food, Energy, and Society*. Third edition. Boca Raton, Fl; London; New York: CRC Press. ISBN 978-1-4200-4667-0. CRC Press website http://www.crcpress.com.
6. Page 26 of *The Extent of the Immigration Problem in the USA*, Virginia Abernethy. *Optimum Population Trust Journal*, Vol. 7, No 1, April 2007. Manchester (U.K.): Optimum Population Trust. 32 pp. Archived on the web at www.members.aol.com/optjournal2/optj71.doc

## CRITICAL COMMENTS ON *NATURE'S* "ELECTRICITY WITHOUT CARBON"

by Andrew R.B. Ferguson

*Electricity without Carbon* was the title of an article kindly sent to me by Val Stevens, recent chair of OPT. It was taken from *Nature* Vol. 454/14, Aug 2008. The authors were a team of *Nature* journalists. It contains some useful figures, but there are omissions and weaknesses. It is on the latter that I intend to comment briefly.

1. **Hydroelectricity**. There is no mention of the fact that sometimes hydropower is barely available for protracted periods in summer, because in low rainfall conditions the operators want to conserve water in the dams.
2. **Nuclear power.** The authors give insufficient weight to the fact that building *fast* nuclear reactors remains more of an aspiration than a done deed. Because they don't consider inputs (see below) they ignore the conclusions of several energy analysts that within a few decades the energy cost of extracting the uranium, refining it, building the power plant, disposing of the wastes, and decommissioning the power plant will require more energy that the electricity produced.
3. **Biomass**. The authors suggest a 40% efficiency could be achieved in conversion to electricity. In fact conversion of biomass is not as efficient as when using pulverized coal, and a more appropriate figure would be about 30%.[1]

   The authors suggest the amount of biomass that could be made available for conversion, from half a billion hectares of unused land (supposedly still available) plus forest waste, etcetera, would amount to 68,000 terawatt hours (68,000 x $10^{12}$ watt hours). This seems unduly optimistic in view of the following rough check calculation. A sustainable yield from forest land worldwide, i.e. without using fertilizer, is about 3 dry tonnes per hectare per year. To gather 68,000 terawatt hours of biomass at this rate would require 4080 million hectares,[2] an area about five and a half time the total area of cropland, pasture, grazing land and forest in the United States.
4. **Geothermal.** The summary Verdict given is: "Capacity might be increased by more than an order of magnitude. Without spectacular improvements, it is unlikely to outstrip hydro and wind and reach a terawatt." In the main text, this is qualified with the observation, "Large-scale exploitation requires technologies that, although plausible, have not been demonstrated in the form of working systems." Thus perhaps a more judicious Verdict would be this, "The present capacity of 10 gigawatts might possibly be increased to around 100 gigawatts. With the aforementioned capacity factor of 75% that would be about 4% of present electricity consumption. If ideas which are plausible but not yet demonstrated prove viable — with the environmental damage being containable — the output might even reach 1000 gigawatts."

   A more serious distortion is that no mention is made of the decline of output as time passes, yet this is what Howard Hayden tells us in *Solar Fraud*[3] (p. 29):

   > Geothermal energy generates 0.31% — one part out of every 320 — of our electricity. … Most geothermal electricity is produced in California. Those sites are not producing as well now as they did a few years ago. For example, the Geysers Geothermal Power Plant in California was designed to produce 1984 MWe, but never quite achieved the goal. According to Pacific Gas & Electric, "the geothermal fields have been in gradual decline for several years." PG&E expects the capacity to drop to 700 MWe, and is no longer able to use it to supply 'baseload', constant, around-the-clock electrical power.

5. **Photovoltaics**. We must give the authors credit for mentioning what the industry tries to keep hidden, namely the low capacity factor of photovoltaics. They say, "Of all renewables solar currently has the lowest capacity factor at about 14%." But they fail to point out the most important implication of this. Since the peak output from photovoltaics is likely to be about 100%, the ratio between the peak output from the system and its mean output is 100 / 14 = 7.1. It is this which makes the output from photovoltaics hard to integrate into an electricity grid. Wind is hard enough, and its ratio is about 3. Neither do they mention that the problems of variability, which 'uncontrollables' introduce into the electrical grid, compound one another: the wind may be dying at the same time that the photovoltaic arrays are being clouded over.

6. **Uncontrollables**. When the authors quote costs for the electricity generated by various means, e.g. wind, they do not include either the costs of additional transmission, or the costs incurred by the rest of the system which has to be able to adjust to the uncontrollable inputs from the uncontrollable sources.

7. **Upward pressure on prices**. The authors make various references to prices going *down* with increasing scale of production, but make no reference to the equal probability of prices going *up* as fossil fuel becomes more expensive.

8. **The input problem.** The authors always hazard an estimate of the outputs from each of the various possible sources, but they do not mention the inputs, yet that is a major problem with renewables. Not only do the inputs often represent a significant proportion of the energy output, but also the type of input required is often substantially liquid, and at present there is no good solution to producing liquids from renewable sources.

9. **Using the same source many times over!** The authors do not sufficiently dwell on the fallacy in considering one problem alone, e.g. electricity by itself. For instance, the above mentioned 68,000 terawatt-hours of biomass — supposedly available for electricity generation — in another analysis would most likely be made available for providing heat for industry and domestic use, and in yet another for providing cellulose for a still-to-be-proven conversion of cellulose to liquid fuel.

In summary, this article is useful to a degree, but it glosses over several problems, particularly the fact that the whole scenario of relying on renewable sources of energy when fossil fuels are scarce depends on finding a way to produce sufficient liquid fuels to undertake the task of production, installation, and maintenance of a huge energy infrastructure. In the case of uncontrollables, that infrastructure includes not only the renewable plant but also controllable plant which can produce the same mean output as the renewable plant, so as to deal with the situation when the uncontrollables are not contributing.

## Endnotes

1. To avoid long distance transport fairly small plants have to be used for biomass. Plants of less than 1 megawatt capacity have an efficiency in the 5–10% range, and plants in the 5 to 25 megawatt range have efficencies in the 15%–30% range. With small plants there is probably a better opportunity of using combined heat and power, which depresses the efficiency of producing electricity but raises the overall efficiency.
2. 68,000 TWh = $68 \times 10^{15} \times 3600 = 244.8 \times 10^{18}$ joules.
   So area required, at 3 dry tonnes/ha, = $244.8 \times 10^{18} / (3 \times 20 \times 10^{9}) = 4080 \times 10^{6}$ hectares.
3. Hayden, H. C. 2004. *The Solar Fraud: Why Solar Energy Won't Run the World* (2nd edition). Vales Lake Publishing LLC. P.O. Box 7595, Pueblo West, CO 81007-0595. 280 pp.

## GROWTH RATE PLOTS: AN INTRODUCTION TO THE CONCEPT

by Andrew R.B. Ferguson

It was the inspiration of Shell geologist M. King Hubbert that the consumption of any finite resource is likely to follow a curve that is somewhat similar to the Gaussian curve shown in Figure 1. The area under the curve shows the total amount of the resource likely to be extracted. The trouble would seem to be that one needs to know the total amount of the extractable resource before a suitably sized Gaussian curve can be drawn — one which will encompass all of the resource that will ever be recovered. With oil in the United States, there was a reasonably good idea of the ultimate amount of oil that would most likely be extracted, so Hubbert could draw a curve and thereby predict, back in 1956, that the peak of oil production in the USA was likely to occur at about 1970. This was denied by virtually all other geologists and economists but turned out to be right.

It seems that it was only in 1982 that Hubbert came to appreciate (or perhaps that he then decided to let the rest of the world know), that the production figures could be plotted another way, namely the way shown in Figure 2, which is known as a "cumulative growth rate plot." The vertical axis shows the ratio of the amount produced in a given time — normally a year although five year periods are shown in this purely hypothetical example — divided by all the production up to that time, i.e. the cumulative production. The horizontal axis shows simply the cumulative production at that time. What the line of this graph is essentially showing is how fast the cumulative production is growing. It grows very fast at the start, but the growth rate gradually slows up.

At the beginning, say during the first five years as shown on Figure 2, the amount produced and the cumulative amount produced will be the same, so the ratio will be 100%. Thereafter the ratio will fall rapidly; but then a surprising thing happens: some considerable time before the peak is reached (in 2000), the ratio starts to fall at a *steady* rate, and thus produces a straight line. This makes it very easy to predict the ultimate production. It is only necessary to extend the straight line until it crosses the horizontal axis, and since at that point the ratio would be zero, there could be no more production, and the ultimate would have been reached. Hey Presto!

Even with a perfect Gaussian curve there is some error in estimates made by extrapolating the straight line, but the main source of problems is that actual production fails to produce a reliably straight line — in other words actual production does not follow a Gaussian curve. There is then some room for debate about whether an excursion from the straight line is going to be perpetuated or whether it is a temporary blip.

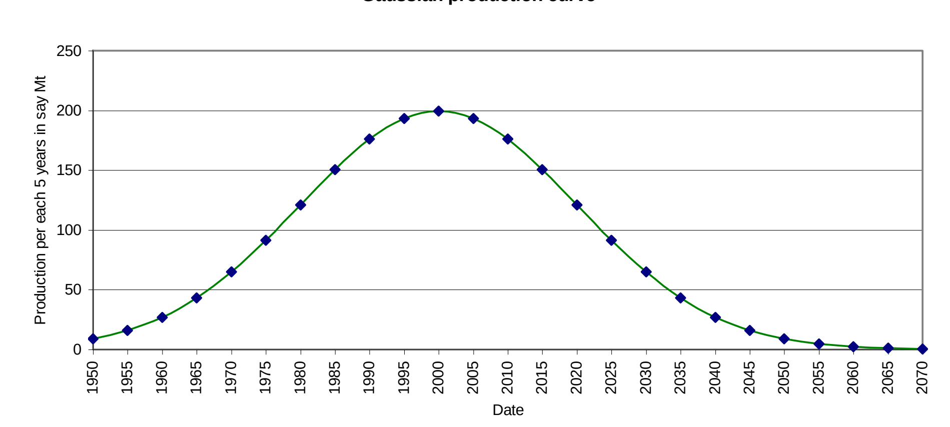
Incidentally there is another bell shaped curve, a logistic curve, which is very similar and it does produce a straight line to the end, but it fits reality less well than the Gaussian curve. The important point is that although no mathematical curve will *precisely* describe the future production curve, such a bell shaped curve does give a very good approximation to the ultimate production, and hence to other important milestones, such as when half the extractable resource will have been used, and when 90% of it will have been used.

The importance of getting a good approximation can hardly be exaggerated in the context of the fact that petroleum geologists have not been able to agree, *on the basis of studying reserves and resources*, whether the ultimate for oil is 2 trillion, 3 trillion, or 4 trillion barrels. However those petroleum geologists who have been paying attention to Hubbert (supported it must be said by a very shrewd understanding of reserves), settled on 2 trillion barrels some decades ago, and thereby put the peak of production in the period 2005-2007. The present price of oil, and recent figures for production suggest that they were right.

As mentioned, the real world does not produce very neat Gaussian curves, but the idea remains powerfully useful. It has been the inspiration, and also the perspiration, since it must have been a daunting task, of David Rutledge to apply the growth rate plot idea to coal, with some very surprising results. This short exposition is an introduction to the next piece, *Rutledge's Hypothesis*. I should also say that it was Kenneth Deffeyes, in his book *Beyond Oil: The View from Hubbert's Peak* (2005), who succeeded in making Hubbert's 1982 method clear to laymen like myself; and I have to thank Walter Youngquist, one of the petroleum geologists who did get the oil peak spot on, for sending me Deffeyes' book. Also a warm thank you to John Nunn, who put me in contact with Ronald Cormack, who knew the esoteric formula for producing Gaussian curves, and hence made it possible for me to produce the two figures below.

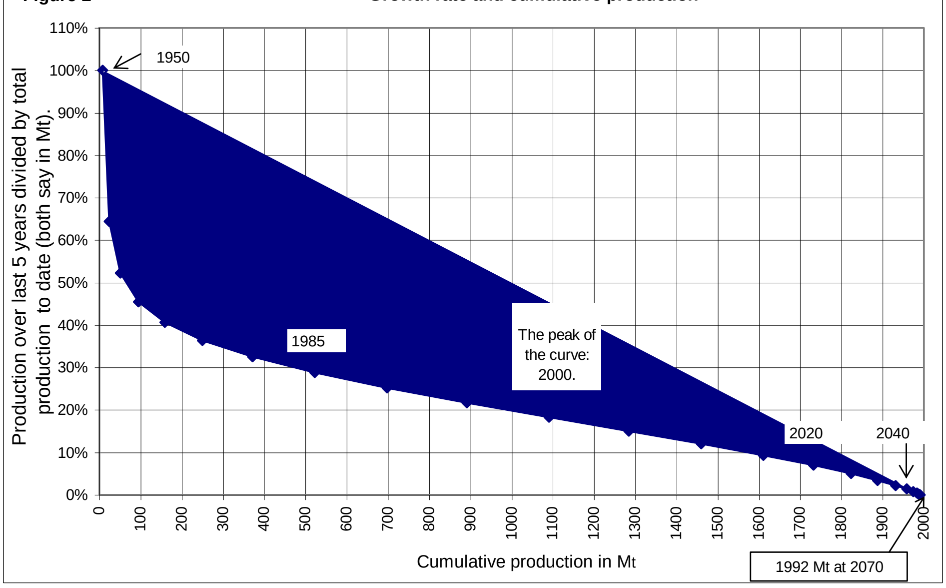
**Comment [arbf1]:** Both these curves come fr Gaussian per Cormack (4).xls, the Trials sheets.

**Figure 1**




Note that both of these Figures suggest that mega tonnes be used as the quantity, but for many purposes it is more suitable to use energy units, e.g. barrels of oil equivalent (boe).

**Figure 2**



## RUTLEDGE'S HYPOTHESIS

by Andrew R.B. Ferguson

**Abstract.** Rutledge's Hypothesis, as I term it, is that it is possible to estimate the amount of coal that humans will be able to extract, by using the methods that were employed so successfully by M. King Hubbert, and others since him, with respect to oil production. Professor David Rutledge's results are startling. He projects that the remaining coal that will be extracted amounts to about half of currently estimated reserves, implying also that the resources, often quoted as being many times reserves, will prove useless. His analysis suggests that by 2021 half of all fossil fuels will have been used, and that by 2076, 90% will have been used. It is suggested here that while this hypothesis may not be right, it behoves us to take precautionary action on the basis of it being correct, in part because the action which it is appropriate to take is the same as that which needs to be taken anyway to reduce the risk of catastrophic climate change. The most significant suggestion for appropriate action is to reduce *supply* at the same time as attempting to reduce *demand*.

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Professor David B. Rutledge is chair of Engineering and Applied Science at the California Institute of Technology in Pasadena. His main field of work is not geology. But seeing the paramount importance of the subject of energy, he diverted some of his time to finding out whether the technique developed by Shell geologist M. King Hubbert to predict the course of oil extraction could be applied to natural gas and coal. He presented this work as an Earnest C. Watson Lecture (available on DVD and via the internet).

He reasoned that if Hubbert's technique could be applied to coal, it would be a breakthrough, because coal 'resources' are often held to be many times greater than 'reserves', yet no one has a clear idea whether there is a good chance of those 'resources' being turned into 'reserves'; that is to say, no one knows whether it is likely that the coal will ever be extracted. Worse than that, a March 2007 study by the Energy Watch Group[1] showed that in the great majority of cases these coal 'reserves' were being revised downwards at a rate that far exceeded the rate at which coal was being extracted, hence even the so-called 'reserves' were suspect. For instance, Germany downgraded its hard coal reserves by 99% (!) in 2004, and Poland downgraded its hard coal reserves by 50 percent compared to 1997, and its lignite and subbituminous reserves in two steps, since 1997, to zero.

What I term Rutledge's Hypothesis is simply the hypothesis that Hubbert's technique — as developed by him in 1982, and set out more recently with greater clarity by Kenneth Deffeyes[2] — could usefully be applied to coal. I do not set out to argue that this *hypothesis* already deserves to be a *theory*, but rather that the evidence for it being true is sufficient that the human race would be well advised to take precautionary action on the basis that it may be right. What then is the evidence?

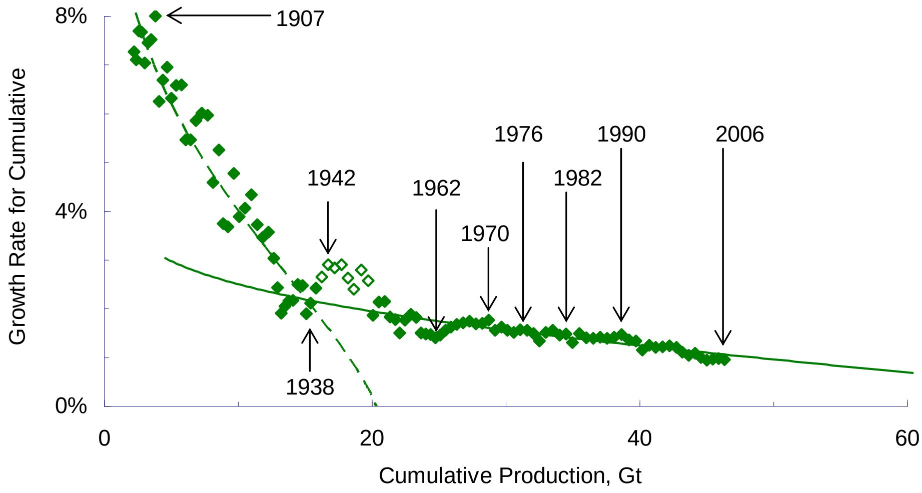
In his fifty minute lecture (available at http://rutledge.caltech.edu), Rutledge looks at the coal production of one nation after another, pointing particularly at the long history of coal mining in Britain. He shows that in almost every case it has been possible to predict what the 'ultimate' amount of coal extracted is going to be decades before the peak of production has been reached. And he shows that, at the same time, those who were trying — often very laboriously — to estimate 'reserves' were still coming up with totally erroneous estimates. I will not follow through all his illustrations here, but look at coal production in the USA as an example of the strengths and weaknesses of the technique.

Figure 1 shows the particulars for US coal production east of the Mississipi. The vertical axis shows the ratio, "current production divided by all production that has occurred to date" (expressed as a percentage). The horizontal axis is simply all the production that has occurred to date. The very first year that anything is extracted, the ratio will of course be 100%, and for some time after that the ratio, which can be called the growth rate, or cumulative growth rate, will drop fairly rapidly, and somewhat erratically, but as consumption nears the half way mark of all that can be extracted, the decline in the growth rate settles down into a close approximation to a straight line. This makes it possible to predict the 'ultimate', since when the growth rate hits the horizontal axis and thus becomes zero, the 'ultimate' has been reached.

On this basis, Rutledge projects remaining coal for eastern US and western US (without Montana) of 70 gigatonnes (Gt), which can be compared with 'reserves' of 175 Gt. Montana is an unknown quantity; it is supposed to have 'reserves' of 68 Gt, but very little is being extracted. Obviously there are reasons why the coal is not being extracted, but predicting whether those reasons (such as poor quality coal, environmental damage, and cost) are going to become invalid in the future is anybody's guess. What can be said — on the basis of Rutledge's Hypothesis — is that the coal that will be extracted in eastern US and western US (without Montana) is likely to be about 40% of the so-called 'reserves'.

However, the idea that the straight line on the graph in Figure 1 is going to remain the appropriate straight line can be challenged. Note that between 1962 and 1970 the growth rate was on a quite different path (increasing rather than decreasing). It could be that the restrictions on emissions that occurred when it became evident that acid rain was doing a great deal of damage, which in turn led to the use of natural gas instead of coal, has been the main factor leading to the subsequent decline in the cumulative growth rate. We may have to wait a few more years, that is until gas becomes really expensive, before being sure that the line shown in Figure 1 is in fact the relevant line.

Figure 1. David Rutledge's graph of declining growth rate of USA Coal production east of the Mississipi (with some dates added for easier comprehension).




**Comment [arbf2]:** This is taken from US coal tab in DR_080129_Rutledge XLS.xls (remember set Figure number).

That analysis might somewhat shake our confidence in the technique, but when Rutledge shows one country after another in which wild early estimates of 'reserves' gradually close in on the prediction emanating from the Rutledge Hypothesis, it is evident that there are good grounds for concluding that although it may be imperfect, it is a lot better than relying on 'reserve' estimates.

## World Fossil Fuels

Let us now turn from the USA to the world, and from coal alone to all fossil fuels. Although Rutledge does not go into details about applying his technique to oil and gas, it is evident that for these two hydrocarbons he arrives at similar conclusions to the geologists' reserve estimates. It is now widely agreed that the final production of oil will be about 2.0 trillion barrels of oil equivalent (Tboe). Thence, we can infer that, for natural gas, Rutledge is arriving at a figure of 2.9 Tboe (as per the legend to Figure 3), which accords well with the predictions of geologists that gas (which of course we started exploiting later than oil) will peak a couple of decades after oil. What makes Rutledge's predictions notably different is his 'ultimate' figure for coal, of about 2.3 Tboe (and thus remaining coal of about 1.4 Tboe), which we may note is less than gas, and not at all the sort of "almost inexhaustible supply" that economists would prefer us to believe in!!

Looking at Figure 2, however, it is clear that we cannot have a lot of confidence that the straight line is going to remain valid. It is evident that between 2002 and 2006 the trend has been divergent from the straight line. This change, since 2002, is shown even more strikingly in Figure 3, with the line labelled "Ongoing fit for ultimate." By 1998, the line had been straight for about 15 years, and until 2002 it seemed that estimates for the ultimate would remain fairly steady. However, in 2002, as the Chinese started to build power stations at one per week and change from bicycles to motor cars, estimates for the ultimate start to rocket upwards. As the line shows, the ultimate shot up from 5.5 Tboe in 2002 to 7.5 Tboe in 2006. Slight variations are possible,[3] but without doubt the ultimate has been rocketing upwards, so it is necessary to wait to see whether this change is temporary, or whether it persists long enough to establish a new estimate for the ultimate. We have not yet reached the state that Rutledge noted with US oil and British coal production, with ongoing fits for the ultimate seemingly hunting around to a steady mean value. So with the world fossil fuel situation, even more than with the USA coal, we do need to allow some more time to find out if the greater difficulty in extracting oil, natural gas and coal will have the effect of bringing down the decline in growth rate so as to give us renewed confidence in the straight line that is apparent between 1983 and 2002.

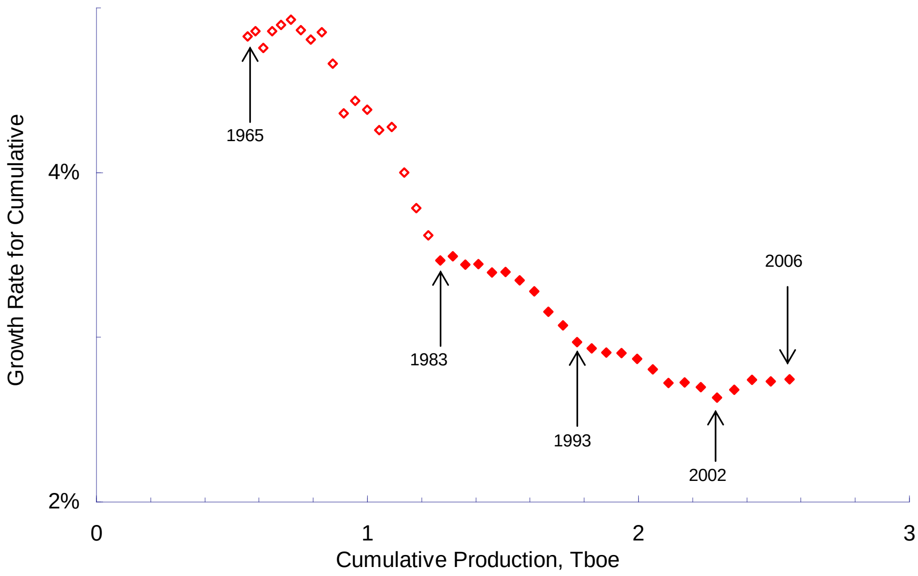
**Comment [arbf3]:** This was the previous note "The difference between Rutledge's estimate and mine is that he uses Excel's Solver to calculate the ultimate whereas, using the san data, I use a straight line extrapolation. This type of extrapolation essentially is the same a assuming that the straight line between the f and last points of the "straight" line is the res of a logistic curve (which does produce a straight line in a cumulative rate growth plot) There is really no perfect method, especially real curves are neither Gaussian or Logistic."

Background for the new note is contained in Excel file "Gaussian per Cormack (4.2)".

Thus we now need to look at Figure 3 with considerable skepticism. Nevertheless it is worth noting that if Rutledge is right, we will reach the halfway point in 2021. A halfway point is of great importance in the context of consuming a resource, since from then on production is likely to be in permanent decline. Perhaps more striking is the fact that it is predicted that by 2076 we will have consumed 90% of our resources of oil, gas, and coal.

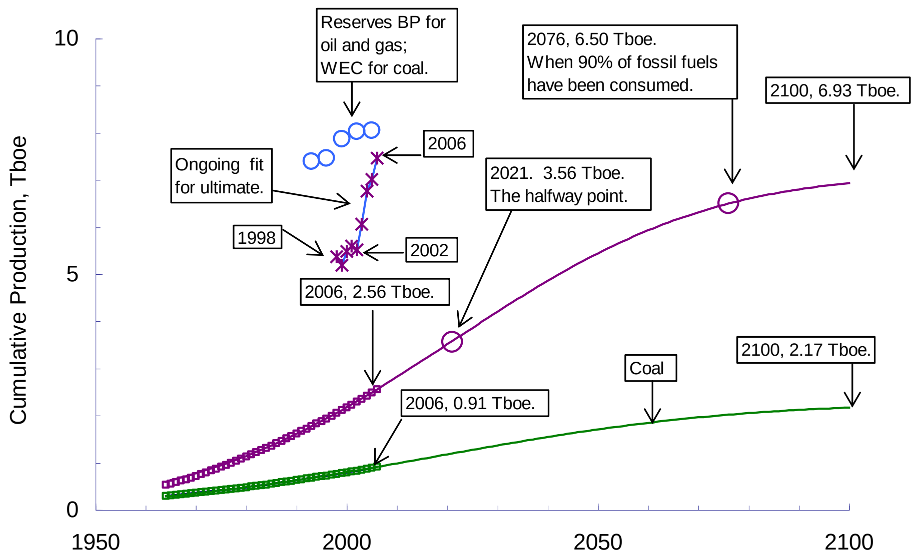
But what, it may be asked, is the significance of these predictions if they are still as uncertain as has just been argued? The answer is that although they are indeed uncertain, (1) it would be disastrous if the predictions were right and we took no action; and (2) the action that we need to take also needs to be taken to avoid the probability of catastrophic climate change, so it can be concluded that it would be wise to take appropriate action on the basis of the possibility that the predictions are fairly accurate. So what are the actions that the human race should be taking? Figure 4 shows three scenarios for fossil fuel emissions starting in 2010. In 2005 (latest firm figure at the time of writing), the world was emitting about 7.7 Gt of carbon, as carbon dioxide, per year, from the burning and flaring of fossil fuels. Were the world to continue increasing such carbon emissions at the rate that obtained in the previous five years, then by 2010 annual emissions would amount to 8.5 gigatonnes. That is where the angular line commences.

**Figure 2.** David Rutledge's graph of the declining growth rate of world fossil fuel production (with some dates added). N.B. The vertical axis of the graph starts at 2%. If it were to start at zero, a straight line extension through the 1983 to 2006 data points would meet the horizontal axis at 7.5 Tboe (i.e. the 2006 estimate of the ultimate is 7.5 Tboe).




**Comment [arbf4]:** See next Comment.

**Figure 3.** David Rutledge's graph of the cumulative production of world fossil fuel (top line) and coal production, with a few additions. Note that putting the total final production at 7.2 Tboe, and coal at 2.3 Tboe, leaves 4.9 Tboe for oil and gas; and putting the oil final production at 2.0 Tboe, gas must be 2.9 Tboe. The "Ongoing fit for ultimate" is my addition; it shows estimates for the ultimate based on straight line extrapolations between 1983 and the 'current' date.




**Comment [arbf5]:** This Figure and the previo one are taken from the "World Fossil Fuels" tab o DR_080129_Rutledge XLS.xls.

The straight line on the graph represents a hypothetical instantaneous cut back to the 1990 emission rate of 6.0 Gt/yr. The purpose of envisaging that is because the straight line in Figure 5 (the one with square blocks as data points), thereby acts as a benchmark. It is evident that even the 1990 rate of emissions would be dangerous, as it would lead the world gradually, by 2100, to a concentration of 520 parts per million (ppm). 430 ppm is now thought of as a possible danger point (and on recent evidence it may be lower). These data come from the Hadley Centre.

Returning now to Figure 4, and the smoothly curved line which represents the geological limits of production as estimated by Rutledge, first we need to note that the line based on his data starts at about 7.2 Gt for 2010. This is remarkably optimistic, since 2005 emissions were 7.7 Gt according to the data that I am using.[4] I have challenged Rutledge on this point, but it seems that it is merely that he is basing his emission projection for 2010 on what seem to me rather forlorn hopes of a reduction by then, rather than an increase. Accordingly, although the following paragraphs speak to the line shown on Figure 4, we should bear in mind that the curved line is optimistic.

Anyhow the 2010 emissions inevitably start above the 1990 level. By 2050 they start dropping below the 1990 level, i.e. an improvement over the 1990 'benchmark', and as Figure 5 shows, the carbon dioxide concentration would then peak at 453 ppm, by about 2070, with a slow drop thereafter. Thus if Rutledge is right, geological limits will ensure that the world is *almost* all right on emissions; but not quite, we need to do more. In fact whether he is right or not, we need to do more, because we should be aiming to restrain that peak to 430 rather than 450 (some believe that we have already passed a safe limit). So whether he is right or wrong, we need to effect the same containment of emissions, but there is a further consequence if he is right: by 2110 carbon emissions will be about 0.8 Gt/yr, which represents about 10% of current fossil fuel energy. It would most likely be impossible to sustain even our present population with so little energy, let alone the likely larger one that the present growth rate in the human population suggests will be on Earth by then.

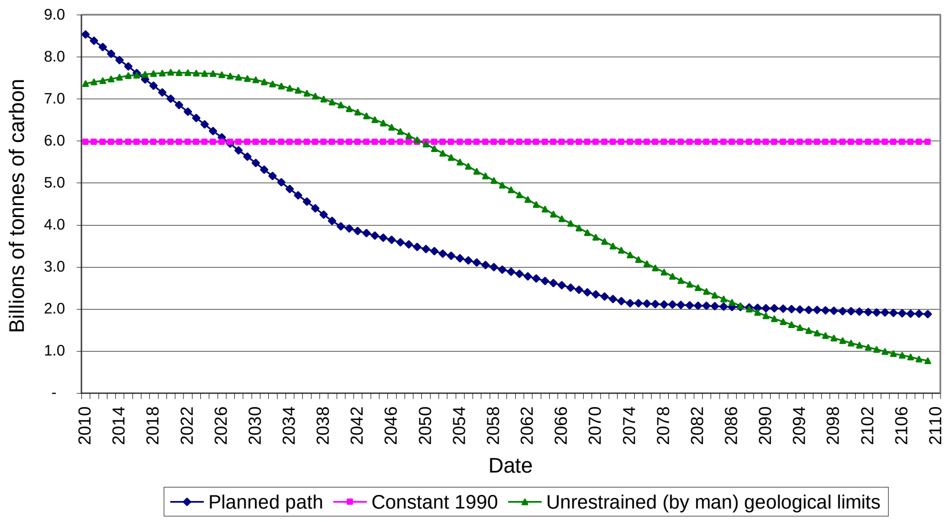
Therefore the sensible action is to restrict the supply of fossil fuels, approximately as shown by the angular line on Figure 4. Whether or not Rutledge is right, this should confine the carbon dioxide concentration to about 430 ppm, and if he is right, it will importantly mean that in 2110 we will still be able to maintain about 20% of our present fossil fuel consumption. As Rutledge also points out, we need to preserve some hydrocarbons because of the important chemicals they contain. Moreover the remnants of fossil fuel would allow those nations which started without delay on a policy of reducing population, the possibility of reaching a situation where they could survive in moderate comfort even when there was no longer any fossil fuel energy available.

Before dwelling on details of a schedule for restricting supply, it is necessary to give brief consideration to whether there is the remotest chance of achieving that objective. Elsewhere I have looked at the matter in a two-page paper (still to be published). There is not room for that coverage here, so the ideas will indeed be expressed only briefly.

A simple aim of getting nations to agree to make reductions is bound to fail for the same reasons that the attempt to reduce carbon emissions has failed (in 1990 emissions were 6.0 billion tonnes of carbon, increasing to 8.2 billion tonnes by 2007). The essential reason for failure is the disparity in per capita emission between developed nations and developing nations. It is that which makes it impossible to move significantly towards a 'safe' level of emissions. The same problem would obviously arise in trying to get any detailed agreement about how much each nation should reduce its energy use.

Figure 4

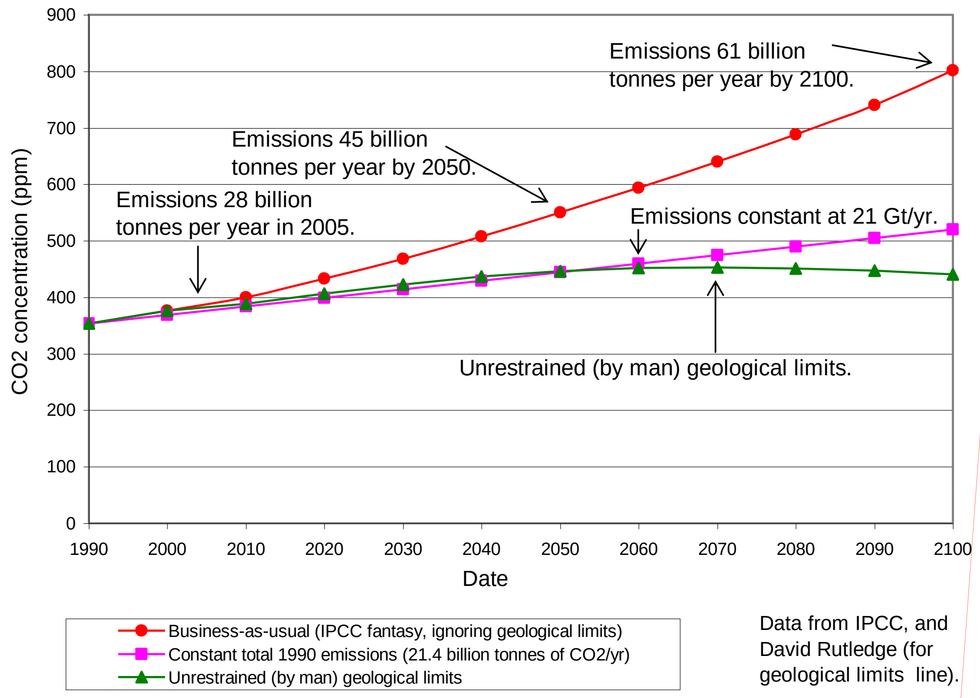
**Annual carbon emissions from burning fossil fuels**




**Comment [arbf6]:** The graph for Figure 4 is i
file "Rutledge's Hypothesis XLS (4) .xls." The gra
for the curved line derives from
DR_080129_Rutledge XLS.xls tab MagicCC, but
the data is column B of the Gas files tab. Why so
low, especially the stretched version, is a puzzle.

Figure 5

**Three scenarios for carbon dioxide emissions**




**Comment [arbf7]:** This derives from **CO2 bubble graph XLS (9).xls**, tab **ppm**.

The second reduction protocol would require the fossil-fuel-rich nations to restrict their production at a rate which slightly exceeds the reduction in supply that is likely to occur anyhow due to geological limitations. The aim for oil might be, say, 3% per year. The advantage of this approach is that the action might well be in the self-interest of the nations doing the restricting, both because it would increase the price of their product, and because it would ensure a longer life for it. The disadvantages are that all the additional wealth of owning the product in short supply would accrue to the fossil-fuel-rich nations, leading to a distinct possibility of the fossil-fuel-poor nations finding some pretext for taking over by force the fossil fuel resources that they think they 'need'.

The third reduction protocol might be termed the Depletion-taxation protocol. There is a very simple rule of economics which says that if supply cannot be increased, and it does not match demand, then the price will increase until demand drops sufficiently to match supply. The question remains as to who is going to get the benefit of the increase in price. If governments around the world levy a high tax on fossil fuels, they will thereby lower demand, and could lower it sufficiently to match supply. In this case, the benefits of the high price would accrue in large part to *all* nations, not just to those holding the resources. It seems to me that of the three options the Depletion-taxation protocol is the most likely to be possible to implement. Although I doubt that any of them will be achieved, it behoves us to continue to strive to achieve such reduction, because the alternative is the age-old practice of fighting over resources. We will consider the matter no further, but look at a scheme for arranging the reduction, on the assumption that action may be possible.

**The supply reduction schedule**

Although the constraints on supply suggested by Figure 4 are obviously not set in stone, it may be helpful to mention the assumptions on which they are based. It is assumed that the supply of oil will be reduced at a rate of 3% of current consumption per year,starting at 28 billion barrels a year (28 Gboe/yr) and reducing to a constant 3 Gboe/yr. For gas the assumption is a reduction of 0.5% of current consumption per year, starting at 2.0 billion tonnes and continuing until reaching 1 billion tonnes per year. For coal the reduction rate assumed is 1.25% of current consumption per year, with coal production starting at 4.9 billion tonnes of coal equivalent per year and reducing until levelling out at 1 billion tonnes of coal equivalent per year.

The overall effect is to 'save' the energy between the curved line and the angular line for later use, allowing the fossil fuel age to be continued, albeit in attenuated form, well into the twenty-second century. Time is of the essence, even for nations well placed to make the transition to the much smaller populations that can be supported without fossil fuels, and wise enough to do so, because with the best will in the world, reduction in population is a slow process, unless undertaken by Mother Nature.

1. The latest update of the March 2007 report is available at: http://www.energywatchgroup.org/fileadmin/global/pdf/EWG-Coalreport_10_07_2007.pdf
2. Deffeyes, K.S. 2005. *Beyond Oil: The View from Hubbert's Peak.* New York: Hill and Wang.
3. These estimates are made using straight line extrapolation from 1983 (the point at which a straight line in the cumulative rate plot becomes evident). Slight variant methods are plausible. Rutledge uses a 'normal' line as the basis for prediction, but thereby produces an even more rapid climb in estimates for the ultimate, reaching 8.5 Tboe by 2006. A straight line estimate incidentally implies that the production curve is logistic (rather than Gaussian or any other more random shape). In fact, no one knows precisely what shape the production curve will be so precise estimates are impossible.
4. http://www.eia.doe.gov/pub/international/iealf/tableh1co2.xls