Energy Strategy for ETH Zurich: A Critical Review

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Abstract

40 professors of ETH Zurich, one of the most highly reputed and visible technical universities on this planet, belong to the Energy Science Center, a collaborative effort created in order to study the challenges that lie ahead in terms of resource depletion and the effects exerted by our presence on the global dynamics of our planet. Currently, the potential ramifications of *peak oil* and *global warming* are the Center's main focus.

A year and a half ago, six of the professors decided to define a new Energy Strategy for ETH Zurich, to determine how ETH, through research and educational activities, could contribute to finding solutions to these rapidly emerging and ever more pressing issues.

In February 2008, they published the results of their collective efforts in a brochure that can be downloaded from the web in either German or English. Last week, they finally presented the results of their studies to the broader public in a special energy science colloquium entitled 1 t CO_2 and/or 2 kW per Capita? Strategic Goals and Transformation Paths for the Energy System of the Future. The presentation (in German) can be downloaded from their website in streaming video format.

This paper provides a critical review of the seminar talk presented by Prof. Boulouchos, who spearheaded the research effort, as well as of the recommendations made by the committee.

Fossil Fuel Depletion: How Fast Will It Happen?

Prof. Boulouchos started out by talking about the proved fossil fuel reserves. To this end, he relied on a graph from the BP Statistical Review of World Energy 2007:

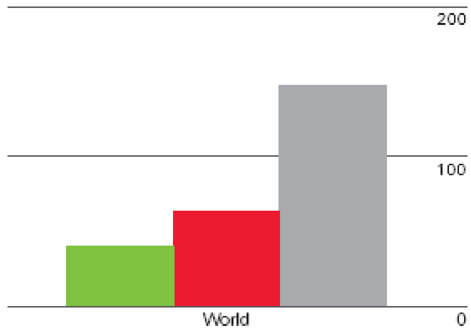

Fig.1: Proved reserves of oil, gas, and coal

The report shows that there are currently 40.6 years of proved reserves of oil (green), 63.3 years of proved reserves of natural gas (red), and 150 years of reserves of coal. We were informed that these numbers carry an uncertainty factor of two, i.e., the true reserves may be twice as large; and we also learnt that the real reserves of coal are probably considerably larger than the proved reserves of 150 years, most likely more than 200 years and possibly closer to 300 years.

Hence, we were told, there is no urgency. While we shall eventually run out of fossil fuels, it will not happen during the next 10 years. Don't worry, be happy!

Although Prof. Boulouchos did tell us that these reserves had been calculated with the assumption of *continued current consumption levels*, the broad public, only too eager to receive good news for a change, is unlikely to fully appreciate this en-passant qualification.

Has the committee at least been consistent in its message? The answer to this question is a clear and unambiguous no. Prof. Boulouchos showed us a graph according to which the world population will continue to grow until roughly the year 2100, leveling off at about 10.5 billion people (cf. Appendix A); at the same time, the population of Switzerland will grow proportionately, leveling off at 9 million people. In addition, we were informed that, 50 years from now, there will be 3 billion cars roaming the surface of this planet instead of the 800 million cars that we have now. Yet, *current consumption levels* (on which the predictions are based) equal *zero growth*: The population is no longer growing, and neither is the per capita consumption of resources.

In all likelihood, the public will take away from the presentation the impression that peak oil is not happening any time soon. There is really nothing to be worried about. We can continue to use oil for 40 more years. By that time, we shall have the technology available to switch to gas and continue for another 20 years; and after that period, we will somehow switch over to coal and continue for 80 additional years. By that time, we shall have thought of something else.

The public, including some politicians, may not even know that at this point in time, we are using 35.76% oil, 23.67% gas, and 28.41% coal to meet our needs, and when we replace oil and gas by coal, we shall need at least three times as much coal as we are currently using in order to have the same amount of energy available. Consequently, the remaining 80 years will shrink to a mere 27 years.

Prof. Boulouchos did not tell us anything about the Hubbert curve (cf. Appendix B). He did not tell us that peak oil occurs when there is still as much oil left in the ground as we consumed up to this point; i.e. from the beginning of the oil age. He did not tell us either that in order to ensure a "robust" annual growth of 3.5% we would need to produce more oil during the next 20 years than all the oil we have pumped out of the ground since the beginning of oil exploration.

Finally, Prof. Boulouchos said nothing about the decreasing EROEI in oil production. He never mentioned that the "low hanging fruit" has already been harvested and that producing the remaining oil is becoming increasingly difficult and costly both in terms of money and energy invested. He never pointed out that we cannot produce the remaining oil fast enough to support our addiction to exponential growth much longer, nor did he make us aware of the fact that we are now on the plateau of oil production. He avoided broaching the subject that once we fall off the plateau, which invariably will happen within the next few years, the countries of the world will be in a fierce competition for ever faster dwindling resources, a competition that is ultimately unwinnable.

When Will Peak Oil Occur?

World oil production is almost flat by now. A number of scientists maintain that the peak oil event (usually defined as the maximum amount of oil produced per time unit) occurred in 2005. Others speculate that the peak hasn't been reached yet, and that a slightly higher maximum output will be reached anytime during the next year or two. However, most oil professionals agree that peak oil is essentially taking place as we speak.

Yet, the precise moment of peak oil *production* is irrelevant. Since production is now flat while the world population is still growing, the per capita oil consumption is already decreasing. Peak oil could alternatively be defined as the moment of maximum per capita oil consumption. That moment, however, occurred already in 1979. At that time, the world-wide per capita oil consumption was at an all-time high of 2.2 liters per person and day (cf. Appendix C). In the meantime, it already decreased to a value of 1.8 l/person/day, a reduction of 18%. With the world population still growing, it is very unlikely that this number will ever rise over and above its peak value again, except if a large segment of the human population were to die rapidly as a consequence of either a world war or a world-wide epidemic.

Why did the moment of per capita peak oil consumption come and go almost unnoticed? It happened because most of the oil (both in absolute terms and per capita) is being consumed in the highly developed nations, whereas population growth occurs primarily in developing countries. In this respect, the peak of oil *production* is still somewhat relevant because at the moment of peak production, the decreasing availability of oil will start to impact Europe and the U.S as well. As oil is no longer available in sufficient quantities to meet the demands of even financially strong customers, the price of the commodity will rapidly increase, leading to turmoil in world markets.

Already this week, we are getting a glimpse of things to come. We learnt that in 2007, more rice was produced worldwide than in any previous year, and yet, there is suddenly a shortage. The present shortage of rice occurred because the increase in production no longer matches the increase in population. The lack of available rice on the world markets had to be counteracted by moving rice out of the national reserves and putting it on the market, thereby rapidly depleting the (relatively modest) reserves. As a consequence, the rice producing nations put export limitations in place to make sure that sufficient quantities of the staple remained in their own countries to feed their own population, which in turn led to a further decrease in the availability of rice in importing nations.

Clearly, the same pattern will occur with respect to the oil as soon as we fall off the plateau. Oil exporting nations will withhold a larger portion of their oil in order to satisfy the needs of their own industries and people. Consequently, the decline in the international oil *trade* will be steeper than the decline of oil *production* alone.

We cannot know with certainty when the world will fall off the plateau, but it will happen within the next decade, most likely sometime around 2012 or 2013. Thereafter, we will be marching irrevocably down the rear end of the Hubbert curve. The result will be high unemployment coupled with a high inflation rate, social disruption, widespread famine, and a worldwide depression that will dwarf the ravages of the Great Depression of the 1930's.

Should we thus be worried about energy depletion in general and peak oil in particular? I certainly think so. Although Prof. Boulouchos did not explicitly lie to us, he presented correct facts in a deceptive fashion that could easily mislead an unsuspecting and uninformed public. In my view, it is highly questionable for a professor of a reputed institution such as ETH to imply that peak oil and peak food are minor problems that will occur in the distant future, and to deny the magnitude of the crisis we are about to face. ETH, as an institution, is trusted by both the government and the Swiss population as a source of reliable information, and it has a powerful influence on both political and social policy formation in Switzerland. As such, its professors ought to feel the obligation to tell the truth in a clear and unambiguous fashion, even when this truth is very difficult to deal with.

How Much Energy Can We Consume?

In his presentation, Prof. Boulouchos stated that the energy arriving at our planet from the sun is larger by two or three orders of magnitude than our needs. We currently consume only a tiny fraction of solar energy directly. Hence, by increasing the percentage of solar energy in generating electricity, we should be able to cover our energy needs indefinitely. In his perception, the goal of a 2000 Watt society, embraced by Switzerland during the last decade, is unnecessary. We can easily afford to continue consuming 4-5 kW per person.

In order to assess the correctness of this assertion, we need to review where the demand of a 2000 Watt society came from.

If we divide the current total energy use of this globe by the total population, we end up with a per capita value of roughly 2 kW. Thus, in order to facilitate a more equitable distribution of the available energy resources, rich nations should reduce their energy consumption to allow the developing world to consume more energy.

Yet, will even 2 kW of energy per person be available 50 years from now? In order to answer that question, we need to look at the current energy mix. Worldwide, energy is utilized in practically equal parts for electricity, transport, and climate control. Roughly 2/3 of our electricity is generated from fossil fuels, while almost all of the energy used in transportation and climate control that is not electric is derived from fossil fuels. According to BP, we obtain 87.83% of our total energy needs from fossil fuels. More precisely, 35.76% of our total energy consumption is oil-based, 23.67% is based on natural gas, and 28.41% is based on coal.

50 years from now, most of the oil and gas will be gone. Hence close to 60% of the currently available energy will no longer be available. Unless we come up with new sources, the per capita available energy will be below 1 kW world-wide 50 years from now, even if we assume that the population remains constant in the meantime.

What does the situation look like in Switzerland? The percentage of energy invested in electricity, transportation, and heating is comparable to world averages. Luckily, we produce very little of our electricity (less than 2%) from fossil fuels. 65% of our electricity is hydro-electric, and 30% is produced by nuclear power stations. Yet, almost all of our non-electric transportation needs are covered using oil, and also most of our heating systems are oil-based. According to BP, 43.45% of the overall energy used in Switzerland is oil-based, 9.31% is based on natural gas, and 47.24% is based on sources other than fossil fuels. Switzerland uses very little coal (0.34%).

Yet also in Switzerland, more than 50% of the current energy will be gone 50 years from now. Furthermore, Switzerland produces 21.72% of its energy from nuclear power stations. Since the Swiss people are in favor of moving away from nuclear power, only 25% of the currently available energy will be left by 2058. As we are now consuming 6 kW of energy per person, we can reasonably expect to have only 1.5 kW per person available in 50 years time without the oil, gas, and nuclear power.

It is easy to see that the proposition of a 2000 Watt society was based less on the desire to achieve an equitable distribution of available resources than on a rational estimate of the constraints that we face as we go about the business of developing energy resources. The assumption that we shall be able to continue using 4-5 kW per person is unrealistic, unless the Swiss population decreases by at least a factor of two.

Evidently, we should endeavor to develop alternative sources of energy. Increasing investment in solar and wind energy is definitely a worthwhile goal. Yet, the probability that we can replace 75% of the currently available energy by developing alternative energy sources within the next 50 years is literally zero.

A rather realistic possibility does exist that we may have more per capita energy resources at our disposal due to an accelerating decrease of the world population.

Peak oil equals peak food. As the food resources of the planet are no longer sufficient to feed the entire population, food exporting nations will withhold more of their agricultural products to feed their own people. Consequently, international trade in food items may, 50 years from now, be a small percentage of what it is currently.

Unfortunately, there is no hope that Switzerland can continue to feed its population of 7.5 million people without massive food imports. During WW-II, Switzerland had only 4 million inhabitants, an agricultural area twice as large as it is now, and 7 times as many farmers. Switzerland was able to feed its population *barely* on a diet of 1800 calories per day.

Thus, the Swiss population may be considerably smaller 50 years from now, and under those circumstances, the per capita available energy may not be as big a problem as it seems now. Yet, the prospects regarding how such a feat is achieved and the costs in terms of human misery are downright terrifying.

Emission Of Greenhouse Gases

Prof. Boulouchos told us that the global warming problem is much more important and urgent than the energy depletion problem. In his view, it is human nature to exploit all available resources, i.e. all of the remaining coal will eventually be dug out of the ground and burned, unless we find alternative sources of energy that make burning the remaining coal unattractive. Since the resulting CO_2 remains in the atmosphere for at least a century, this is a problem that must be tackled urgently. We don't have much time.

In accordance with the recommendations made by the [Intergovernmental Panel on Climate Change (IPCC)](), the Committee came to the conclusion that the emission of CO_2 must be reduced to a level at or below 1 ton of CO_2 per person per year. Prof. Boulouchos went on to state that if we are able to attain this goal without decreasing our high energy consumption level, then high energy consumption per se is unproblematic. Hence, a preferable goal for Switzerland for the year 2100 ought to be to reduce the emission of CO_2 to 1 ton per person per year, rather than reducing energy consumption to 2 kW per person.

I agree with the committee that the CO_2 emission is an important facet that needs to be addressed. Moreover, reducing our greenhouse gas emissions to safe levels will not occur automatically. We need to actively pursue the goal of reducing the CO_2 emissions. Consequently, the goal of a 1 t CO_2 society is indeed a very useful goal. By contrast, the energy contraction will occur whether we want it or not. Unfortunately, reducing our CO_2 emissions does not by itself remove the real and present danger to our society caused by the impending fossil fuel depletion.

Let us look a little more closely at the relationship between the two goals. To this end, we shall study yet another measure of our impact on the planet: the Ecological Footprint. At the current time, humans on this planet use, on average, 2 hectares per person to support their lifestyle. Yet, there are only 1.8 hectares per person available. In other words, we are clearly living beyond our means.

Comparing the three metrics, we see that on average, the world population is consuming 2 kW of energy per person, is emitting approximately 4 t CO_2 per person per year, and is making use of 2 hectares of land per person. By contrast, Switzerland is consuming 6 kW of energy, is emitting 5.5 t CO_2, and is using 6 hectares; while the U.S. is consuming 10 kW of energy, is emitting 20 t CO_2, and is using 10 hectares.

As a ballpark figure, 1 kW of power corresponds to 2 tons of CO_2, which in turn correspond to 1 hectare of land. The relationship is not perfect because the CO_2 emissions depend quite a bit on the energy mix. Switzerland is emitting less CO_2 because it features a below average percentage of coal in its energy mix.

A rigid constraint is the total surface of the planet available for human activities. If we were to increase the percentage of bio-fuels within the energy mix, land use per consumed energy would increase. As we cannot increase land use any further, the total available energy would decrease. On the other hand, if we increase the percentage of coal in the energy mix, CO_2 emissions per kW of energy would increase. In order to keep CO_2 emissions down, we would have to reduce our energy consumption.

Our goal should be to keep the energy consumption high while reducing both the surface area and the CO_2 emissions per unit of power. This can only be accomplished by increasing the percentage of clean energy (solar, wind, tidal, geothermal) within the overall energy mix.

This is also what the committee recommends. ETH should thus increase its research and educational efforts in furthering and promoting clean energy.

Getting More Bang For The Buck

As we have demonstrated, an energy crunch is inevitable as fossil fuels become less available. Switzerland will not be able to maintain its current level of per capita energy consumption through the 21st century, unless the population decreases together with the available energy. In all likelihood, we shall have to live on 2 kW per person within 50 years.

Does the reduction in available energy necessarily imply a reduction in comfort? This is not the case as shall be shown.

Currently, Switzerland spends roughly 1/3 of its energy on non-electric transportation. All of it is oil-based. Let us discuss the energy efficiency of our current transportation system.

A fuel engine, be it a gas engine or a Diesel engine, has a maximum energy efficiency of about 35%, i.e., only 35% of the energy content of the fuel is being converted to locomotion. The remainder of the energy is lost. Yet, this level of efficiency is only achieved during times of maximum acceleration, which is rarely the case. Most of the time, the engine is operated just slightly above idle. Under such driving conditions, the energy efficiency of the car is reduced to somewhere around 20%.

In addition, the average car in Switzerland weighs 1350 kg, but transports only 130 kg of useful load (passengers and luggage). Hence, the "pay load" is below 10% of the total weight. Thus the overall efficiency of the car is somewhere around 2%. 98% of the energy stored in gas or Diesel fuel is wasted in the process.

How can this figure be improved? First, electrical vehicles have considerably higher "fuel" efficiency. It is quite feasible to attain an efficiency of 40%. Furthermore, by reducing the average weight of the car to 900 kg, it is possible to increase the percentage of useful load by 5% from 10% to 15%. Thus, the energy efficiency of the average car can be improved by a factor of 3 from 2% to 6%. We thereby save 20% of our overall energy without any significant reduction in comfort.

The heating of houses is another area where significant energy savings can be achieved. 50% of our oil, i.e., another 22% of our entire energy, is wasted on low-temperature heating. By constructing more new houses to minergy or minergy-P or even minergy-P-Eco standards, a lot of energy can be saved. Just a week ago, Prof. Leibundgut, another member of the Energy Science Center, informed us in the previous Energy Science Colloquium that it is now possible to construct a minergy-P-Eco building that is energy neutral, i.e., that delivers as much (solar) energy back to the grid as it draws from it. The construction costs for a minergy-P-Eco standard house are only 18% higher compared to the construction costs for traditional (high energy wasting) houses.

Of course, Switzerland has many older buildings that are under monument protection and that cannot be upgraded to a minergy standard. Yet, it should become mandatory that *new* buildings are constructed to at least minergy if not minergy-P standard. Also, laws should be implemented that, during the renovation of existing buildings, make it mandatory to spend a fraction (e.g.18%) of the total renovation costs on improving the energy efficiency of these buildings. In this way, Switzerland could easily save another 15% of its energy without any reduction in comfort.

A further 10% of the overall energy could be saved by other means, e.g. by improving the energy-efficiency of appliances, such as light bulbs and refrigerators. In this fashion, 2 kW per person 50 years from now might feel more like 4 kW per person in the present.

Yet, with respect to housing construction, even more savings are possible. During the process of construction alone the same amount of CO_2 is released into the atmosphere that the house will emit during a full 50 years of its existence, respectively its use. The production of cement is the worst culprit contributing to CO_2 emissions associated with construction.

As long as we live in a growth economy, a significant fraction of the total energy is spent on the continued growth of the economy and not on its maintenance. As we undergo the transition from a world of exponential growth to one of sustainability, the energy that is currently being spent on growth is freed up.

For this reason, 2 kW in 50 years might actually feel more like 6 kW now. To put it differently, the coming energy crunch will require adaptation, but at least in the long run, does not necessarily have to bite. Unfortunately, adaptation takes time, time that we don't have. Peak oil is now, and we aren't ready to face it.

Luckily, as we adapt as a society to the decrease of our energy resources, and as we forcibly reduce the percentage of fossil fuels utilized in our energy mix, CO_2 emissions will be reduced concomitantly. Quite possibly, a level of 1 ton of CO_2 emissions per person per year may be achievable not by the end of the century, as proposed by the committee, but already within the next 50 years.

Sustainability: When And How?

We can be confident that sustainability will be attained. Our planet will see to that, whether we like it or not. We have no say in *whether* it will happen, and even relatively little say in *when* it will happen. The only thing that we can influence is *how* it will happen.

Sustainability means *zero growth*: zero growth in population as well as zero growth in per capita resource utilization. It also means zero interest for our investments.

As a species, we worship growth. We absolutely hate sustainability. It runs counter to everything we were taught and believe in. It threatens our drive for expansion and multiplication, for the gratification of our personal wants, and our greed for ever increasing profit and wealth and power. Yet, sustainability is inevitable. We can only choose whether to live in sustainable misery or in sustainable comfort.

Key to a relatively comfortable transition from exponential growth to steady-state conditions is getting rid of our addiction to oil as fast as we can and rapidly increasing our investments in clean energies, first among them solar and wind.

Yet, installation of new energy systems takes time, which we unfortunately don't have any longer. We should have listened more than 30 years ago when Hubbert told us about world peak oil hitting us around the turn of the century. We should have listened when Forrester and Meadows told us about the potential risks of a massive die-off starting around 2030. We did not. We continued with our dance around the golden calf. Life is good. Why worry. When problems arise, we'll think of something. We have always been good at that.

Exponential growth has been with us since the beginning of human history, and it has served us well. It has given us incentive and motivation to always strive for a better future. Exponential growth has always been our friend, but now, it has become our enemy.

We always knew that we were in an exponential growth race against finite resources, but this knowledge was purely abstract and mathematical. It did not concern us directly. Now, the limits to growth have become real and ever present. We are driving our vehicle at high speed into a brick wall. We see the wall ahead of us, but rather than hitting the brakes hard, we close the eyes and press the accelerator down a little deeper to listen to the power of our engine one more time. It feels so good. The sound is hypnotizing.

Appendix A: Logistic Population Model

The population graph that Prof. Boulouchos showed us is based on a logistic fit of past population data. To this end, available population data are fit to the differential equation model:

$$dP/dt = a \cdot P + b \cdot P^2$$

with unknown coefficients *a* and *b*. The resulting population growth model is shown in Fig.2:

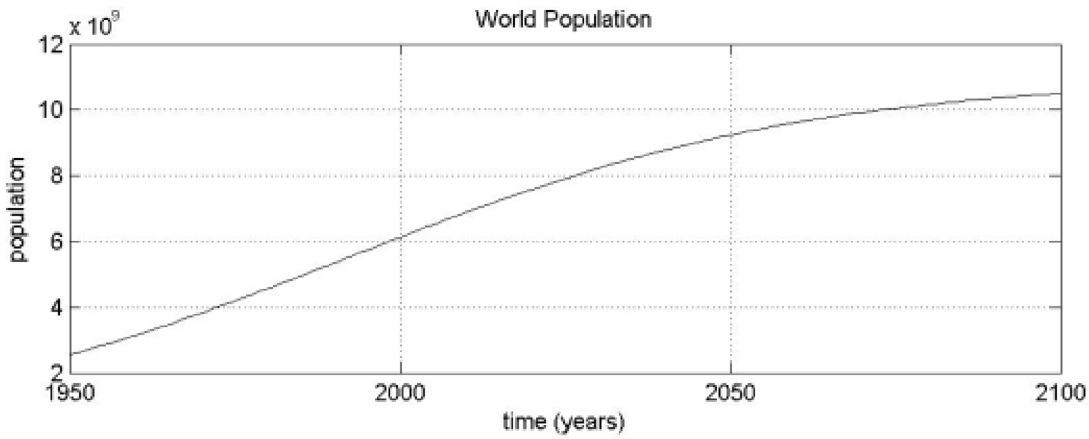

Fig.2: Logistic world population growth model

MATLAB code generating this model using a least squares fit can be downloaded from the web.

It is a shallow extrapolation model that does not take into account the effects of resource depletion on world population development. An improved (deep) model can be obtained using the System Dynamics approach advocated in Limits to Growth. However, Prof. Boulouchos' talk was based on the simple logistic population growth model presented above.

Appendix B: Hubbert Extrapolation of World Oil Production

M. King Hubbert proposed a simple logistic model to predict future oil production. He predicted in the mid 1950s that U.S. oil production would peak around the year 1970. His predictions of future U.S. oil production turned out to be highly accurate. Hubbert subsequently predicted in the 1970s that world oil production would peak around the year 2000.

A Hubbert oil production model can be formulated as a logistic model, whereby the logistic curve is being fitted to the total produced oil, i.e., to the integral of the curve that describes the annually produced oil.

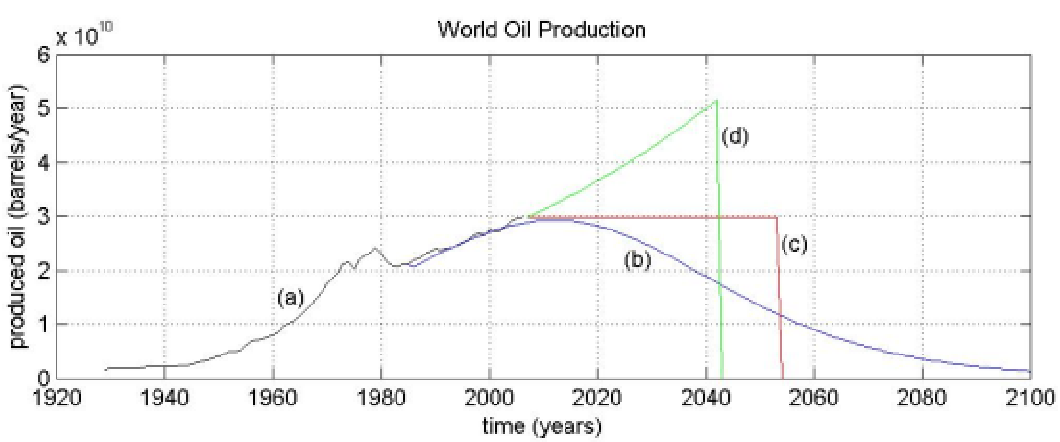

Fig.3: Predictions of future oil production

Fig.3(a) shows the historical data of world oil production from 1930 until 2006.

Fig.3(b) shows a Hubbert extrapolation model that is based on the last 22 years of historical production data. The model postulates that the peak of world oil production will occur around 2012. The model predicts further that the total amount of oil ever to be produced is $2445 \cdot 10^9$ barrels. Out of those, 50% have already been produced, i.e., still to be produced are $1222.5 \cdot 10^9$ barrels. This number is consistent with the proved oil reserve figures published by BP. According to BP, the proved oil reserves are $1209.5 \cdot 10^9$ barrels.

Fig.3(c) shows a constant exploitation model. This is the oil utilization model, on which the oil reserves of 40.6 years are based. According to this model, we continue to produce and consume oil at the current level for 40.6 more years, after which time it will be all gone.

Fig.3(d) shows an exponential growth model. To obtain it, I calculated the average exponential annual growth rate over the last 10 years (1.58%), and postulated that oil exploitation shall continue to grow exponentially. Using this model, the remaining oil reserves will last for another 28 years only. After that time, the oil will be gone.

The constant and exponential growth models are not plausible. As we near the end of oil exploitation, it will become exceedingly more difficult and expensive to produce the remaining oil. Hence, the Hubbert model is the most plausible of the three models by far.

The Hubbert model is also the most benign of the three models. Any discontinuity in oil production, as stipulated by the constant and exponential models, would surely lead to a total collapse of our society at the moment when oil exploitation ends.

Yet, this knowledge does not help us very much. It goes against everything we grew up with. Like true addicts, we do everything we can to prolong exponential growth for just a little while longer.

MATLAB code generating these models can be downloaded from the web.

Appendix C: Per Capita World Oil Production

I took the world oil production of Appendix B and divided it by the population calculated in Appendix A. In this way, I obtained the per capita amount of oil available for consumption.

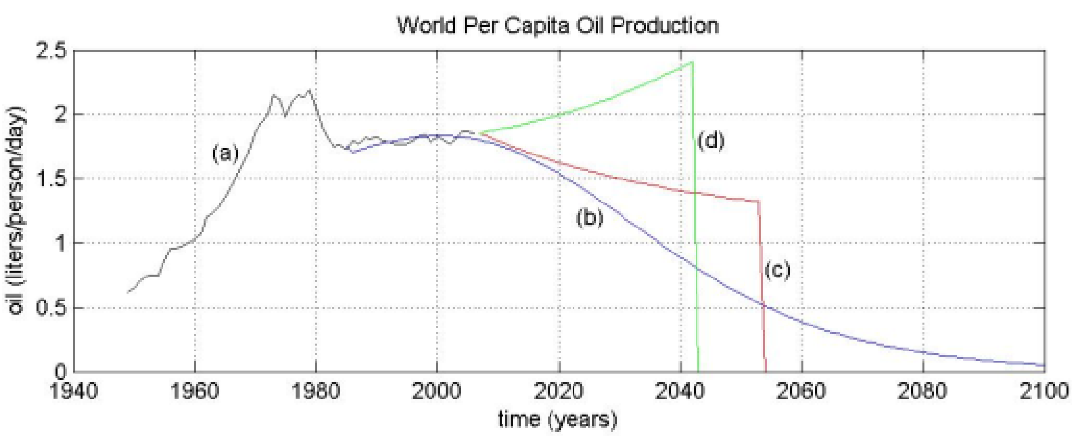

Fig.4: Per capita world oil production

The model shows that the peak in per capita oil production occurred in 1979. At that time, 2.2 liters of oil per person and day were produced. This peak value is unlikely to be attained ever again. Even using the constant model, the per capita oil production will decrease, because world population is still growing. Only the exponential growth model shows a temporary recovery of per capita oil production that leads to a short period of yet higher per capita production values just prior to the total collapse.

MATLAB code generating this graph can be downloaded from the web.