Is the 2000 Watt Society Sustainable in Switzerland?

François E. Cellier
Department of Computer Science
ETH Zurich
CH-8092 Zurich
Switzerland

Email: FCellier@Inf.ETHZ.CH
URL: http://www.inf.ethz.ch/~fcellier/

Abstract

Recently a debate has arisen here at ETH Zurich centering on the question whether the envisaged "2000 Watt Society" is inevitable. Why shouldn't we be allowed to use more energy? Wouldn't it be more important to limit greenhouse gas emissions? A report about the new energy strategy of ETH Zurich was published in the Oil Drum in May 2008.

In this presentation, we discuss whether the 2000 Watt Society is at all sustainable, and if so, what it will take to keep energy supply at that level after the end of ample and cheap fossil fuels. What are the implications of energy deprivation to our society? Can we stave off famine? How can we maximize our chances of getting through the emerging world-wide crisis relatively unscathed? What are the pitfalls in designing and implementing a strategy that helps us achieve these goals? How much time have we got left?

Predictions are notoriously difficult, especially when they concern the future. So, how sure can we be that our predictions are correct? How can we convince the public at large that there is a real and present danger looming in the not too distant future, despite the fact that at this point in time few signs of any problems are noticeable yet here in Switzerland, and particularly, as the crude oil price has recently fallen to one fourth of the value it was at in early July of last year?

This paper is based on a talk presented by the author at the Zurich Physics Colloquium a few days ago. The talk is available on the net both as a Powerpoint presentation and as a podcast.

A Sankey Diagram for Switzerland

Let us start by analyzing the current energy situation here in Switzerland. This is best represented by a so-called "Sankey" (energy flow) diagram:
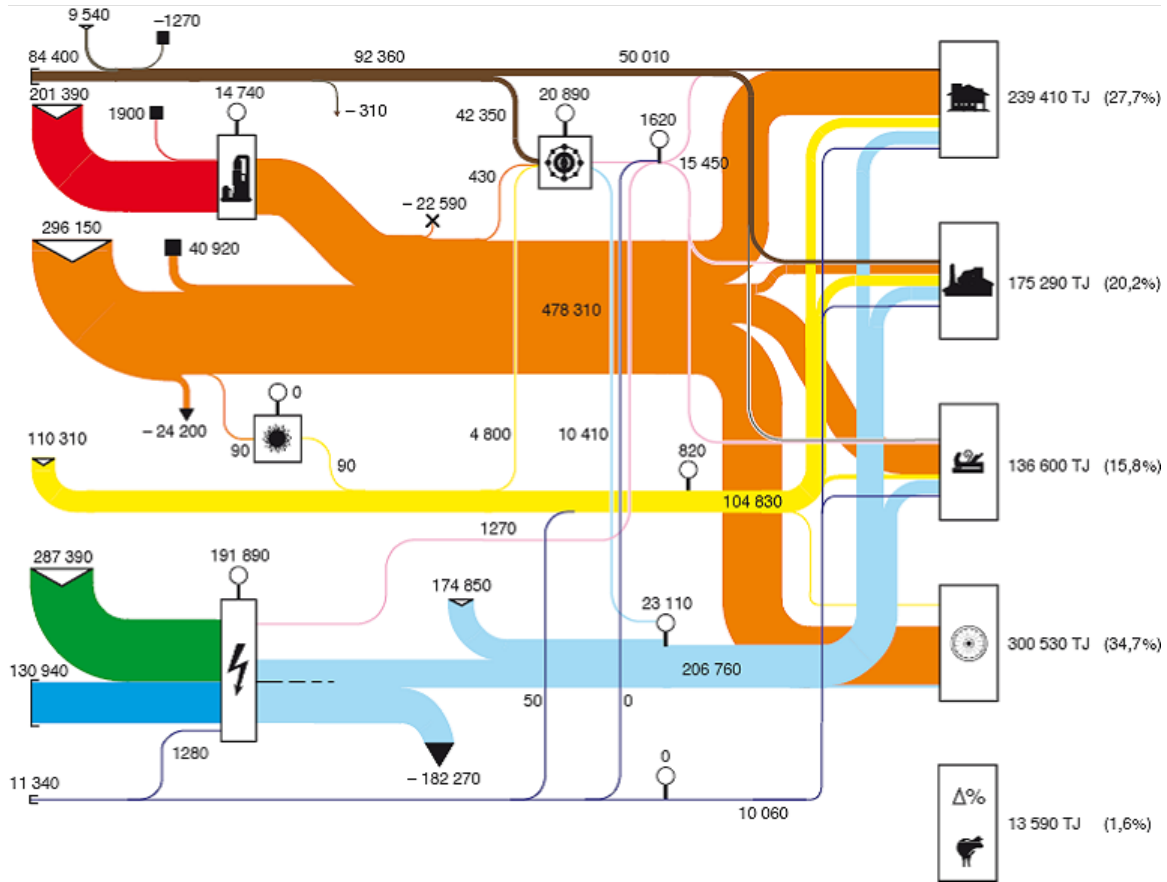
Fig.1: Sankey diagram of Switzerland - source: Dr. Michael Piot, Swiss Federal Office of Energy

The diagram shows on the left hand side the produced and procured (imported) sources of energy. Different types of energy are marked in different colors. The brown energy at the top represents wood. The wood is grown in Switzerland. The red energy below represents crude oil that is being imported and refined in Switzerland. The most prominent orange energy represents refined oil imported into the country. The yellow energy denotes gas. Gas is also imported. The green energy denotes nuclear fuel. Although we have currently five nuclear power stations in Switzerland to convert the nuclear fuel to electricity, the fuel rods themselves are being imported. The blue bar represents water power. It is available locally and is converted to hydro-electric power in turbines here in Switzerland. The thin dark blue energy source at the bottom represents everything else: solar, wind, geothermal. Together they make up only about 1% of the total energy mix currently consumed in Switzerland.

On the right hand side, the diagram shows the consumed energy. At the top, the private homes are being depicted. The dominant form of energy consumed in households is heating oil, as most private homes in Switzerland are still being heated by central oil heating systems. Hence if we decide to save electricity by exchanging our light bulbs for fluorescent lamps, we do relatively little to alleviate the peak oil problem, even if we save substantial amounts of electricity. Below are shown industrial buildings. These consume much less energy, and they have already been fairly well optimized. Not much can be done to improve their energy consumption further. Below, the diagram shows the service sector including all government buildings, schools, hospitals, etc. They are similar to the private homes in their energy consumption pattern. Yet below is the transportation sector. This is the largest consumer of fossil fuels in Switzerland. The narrow blue line represents the electricity consumed by our railway system. The unconnected bottom block

shows the energy consumption by agricultural enterprises. It is important to have this information, as we must produce food for our population. This by itself turns out to be highly problematic.

Per Capita Power Consumption

Let us add all of the sources of produced and procured energy together and divide this number by the total population of Switzerland. The data are summarized in Fig.2.

Primary Energy	TJ	%	Source
Wood	84400	7.52	local
Crude Oil	201390	17.95	imported
Refined Oil	296150	26.4	imported
Gas	110310	9.83	imported
Nuclear Fuel	287390	25.62	imported
Hydropower	130940	11.67	local
Other Renewables	11340	1.01	local
Total:	1121920	100	
local:		20.2	
imported:		79.8	

Fig.2: Total energy production/procurement in Switzerland

Switzerland produces and procures a total of 1.12 EJ of energy per year. Of this total amount, 20.2% are produced locally, whereas 79.8% are imported. Dividing this energy by the number of seconds in a year, we obtain 35.576 GJ/sec = 35.576 GW of consumed power. Dividing this number by the total population of 7.85 million people, we obtain a total per capita consumption of 4.53 kW.

This number is considerably lower than what BP list as Swiss power consumption in their annual statistical energy review. The BP statistics are referenced frequently, because this is the most comprehensive collection of energy data publicly available today. Where does the discrepancy come from? BP is an oil company, and as such, they don't consider water power as a "primary" source of energy. To them, only stuff that is dug out of the ground is "primary" energy. Hence they are asking themselves, how much oil Switzerland would have to buy from them and burn in order to produce as much electricity as we are getting out of our water turbines. They rate the efficiency of fossil fuel burning electric power plants at 33%, and therefore assign a "handicap" to Switzerland by bumping the "primary" energy numbers for our water power up by a factor of three. The so modified statistics are shown in Fig.3.

Primary Energy	TJ	%	Source
Wood	84400	6.1	local
Crude Oil	201390	14.55	imported
Refined Oil	296150	21.4	imported
Gas	110310	7.97	imported
Nuclear Fuel	287390	25.62	imported
Hydropower (x3)	392820	20.77	local
Other Renewables	11340	0.82	local
Total:	1383800	100	
local:		27.69	
imported:		72.31	

Fig.3: "Corrected" energy production/procurement in Switzerland

So, now Switzerland is consuming 1.38 EJ/yr, corresponding to 43.88 GW in total, or 5.5887 kW per capita.

These numbers are still somewhat skewed, because neither the Swiss Federal Office of Energy (SFOE) nor BP consider material flows other than those of primary energy carriers. Switzerland imports lots of goods from foreign countries (including food) that consume energy for their production. This is called grey energy, and grey energy has not been included so far in the energy statistics. Whereas Switzerland is an export nation in monetary terms (we earn more money by selling stuff and services to other countries than we spend on buying stuff and services from them), we are an import nation in terms of grey energy, i.e., we are importing considerably more grey energy than we export.

There are no hard numbers available to quantify the amounts of surplus grey energy imported, but it is generally accepted that this corresponds to roughly 1/3 of the accounted energy. Thus adding the grey energy into the energy balance, Switzerland consumes between 7-8 kW of power per capita (using BP accounting methods).

How Much Energy Is Our "Fair Share"?

Let us try to answer that question in a round-about way. To this end, we shall first look at the so-called ecological footprint, produced for the Swiss Government by the Global Footprint Network:
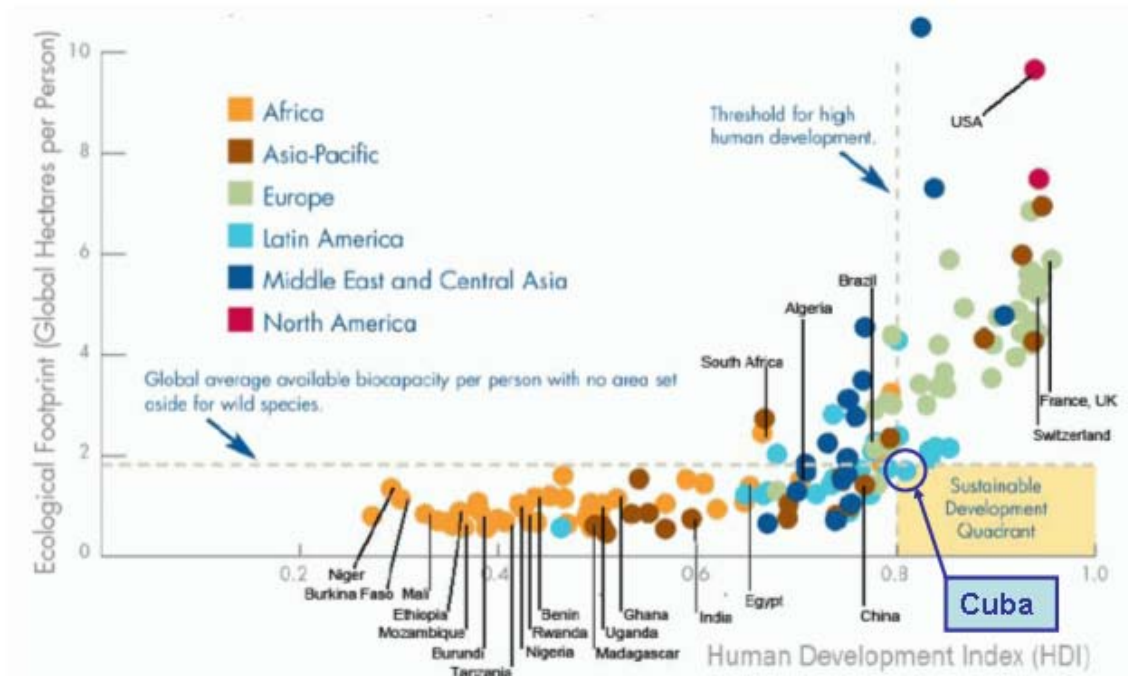
Fig.4: Ecological footprint – source: Living Planet Report 2006

The graph shows on the vertical axis the amount of land area used per capita to support the life style of the average inhabitant in different countries, and on the horizontal axis the so-called Human Development Index (HDI), an index measuring the living standard in these countries.

The countries of this planet follow a banana-shaped curve starting on the lower left with people, mostly from sub-Saharan African nations, consuming very few resources while living under dismal conditions, and ending on the upper right with the U.S. and the U.A.E., two countries whose inhabitants consume exorbitant amounts of resources while leading very good lives.

Switzerland uses 5.1 hectares per person and consumes 5.5 kW of power per capita. The U.S. uses 9.6 hectares per person and consumes 9.8 kW of power per capita. The two measures are almost proportional to each other, i.e., we can mark the vertical axis in kW of consumed power instead of hectares of used land, and the curve will remain almost unchanged.

Using hectares as a measure of consumption has the advantage that we can add up the entire usable surface of our planet and divide it by world population. In this way, we obtain an available land area of 1.8 hectares per person. We are currently using on average 2.2 hectares per person, i.e., we cannot continue to use as much as we currently do in a sustainable fashion.

In order to allow developing nations to improve their living standards, we must allow them to use up more of the world's resources. We cannot do so in a sustainable fashion, unless the rich nations give up some of their own usage.

Our goal should be to bring all countries into the orange area at the lower right corner of Fig.4, where they can lead a life of acceptable comfort, while not charging the resources of our planet in an unsustainable fashion. Currently, there is only one country in that area: Cuba. Thus, if President Obama is serious about his commitment to sustainability, then his slogan should no longer be "Ich bin ein Berliner," but rather "Soy un Cubano."

If Switzerland wants to bring its ecological footprint down to 1.8 hectares per person, it needs to reduce its energy consumption to roughly 2 kW per capita. This is how the idea of the 2000 Watt Society was first created.

Unfortunately, Switzerland may under those conditions not be able to maintain the same living standard that Cuba currently enjoys, because Cuba is a tropical island that can grow food year round, whereas Switzerland needs to either spend real energy to store food for the winter months or spend grey energy to import food during those months, and in all likelihood, Switzerland will need to do both.

How Much Power Can Switzerland Consume in a Sustainable Manner?

Let us now analyze how much power Switzerland can consume in a sustainable fashion. To this end, we shall now look at the consumption side of the Sankey diagram. This is summarized in Fig.5.

Secundary Energy	TJ	%
Wood	50010	5.82
Oil	487310	56.73
Gas	104830	12.2
Nuclear Electricity	68920	8.02
Hydro Electricity	137840	16.05
Other Electricity	10060	1.17
Total:	858970	100

Fig.5: Energy consumption in Switzerland

We consume considerably less energy than we produce and procure because of the losses in energy conversion. Our current nuclear power plants have an efficiency of only 30%, and also hydro-electric power was charged with an (artificial) efficiency factor of 33%.

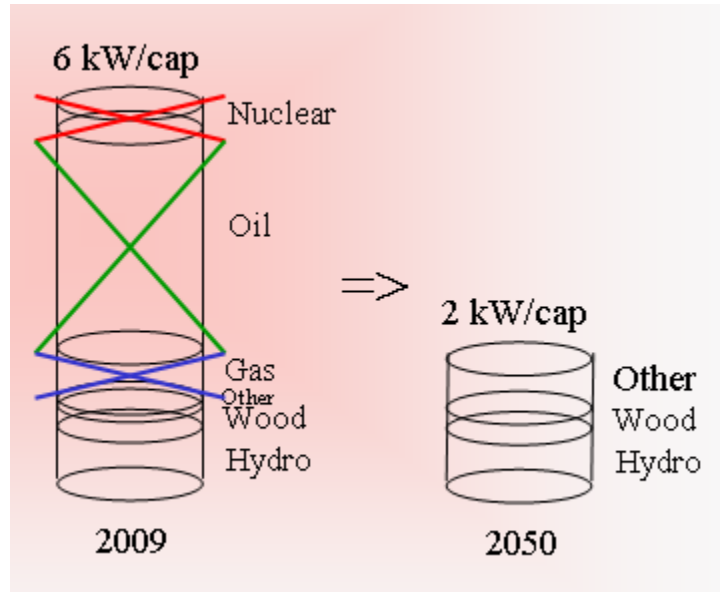In Fig.6, I displayed the numbers of Fig.5 graphically.

Fig.6: Energy consumption in Switzerland today and tomorrow

A large majority of the Swiss people are not in favor of nuclear power. The licenses of our five current nuclear power plants will expire within the next 20 years. Unless we replace them by new nuclear power stations, and at least until now, there is no will to do so, this power will simply go away.

The oil and the gas will no longer be available in significant amounts, thus we cannot rely on having those still at our disposal by 2050. Assuming that we aggressively increase all alternative types of energy (solar, wind, geothermal) by a factor of ten, which may be difficult but doable, we will have only 2 kW per capita available by 2050.

Hence the 2000 Watt Society makes sense also from an entirely different angle: not as a lower limit of how much we may consume with a good conscience, but rather as an upper limit of how much will be at our disposal after the availability of cheap and ample fossil fuels has drawn to a close.

When Will We Run Out of Oil?

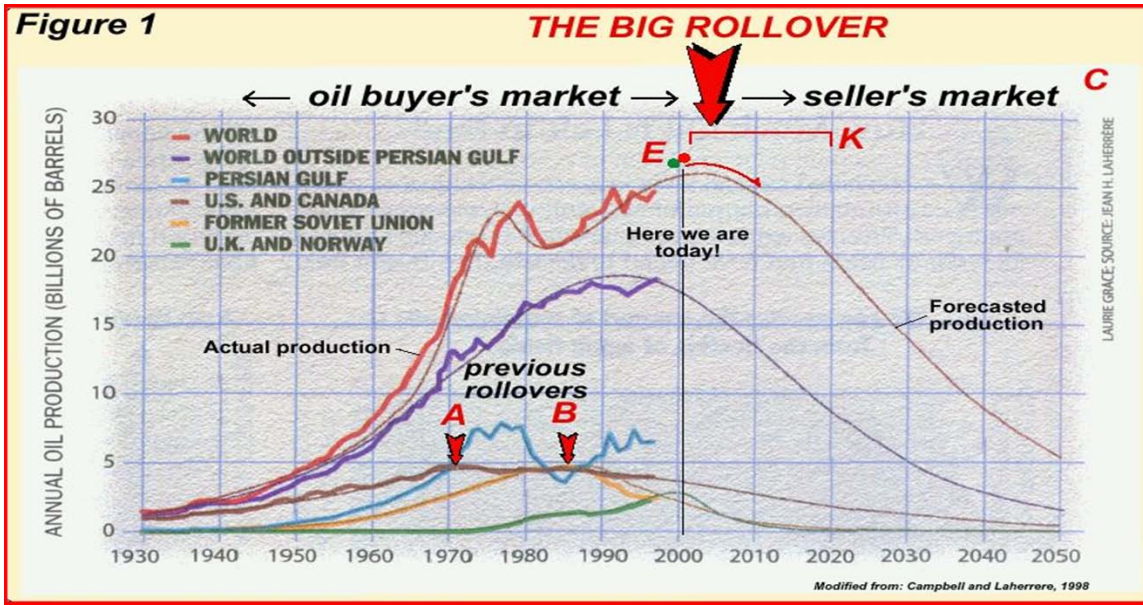The United States Geological Survey (USGS) predicted in 1998 that world oil production would peak around 2003:

Fig.7: Peak oil prediction – source: L. Magoon, U.S. Geological Survey

The measurement data end in 1997, because the graph is already more than 10 years old. An updated graph of a similar nature depicting both oil and gas together is shown in Fig.8.
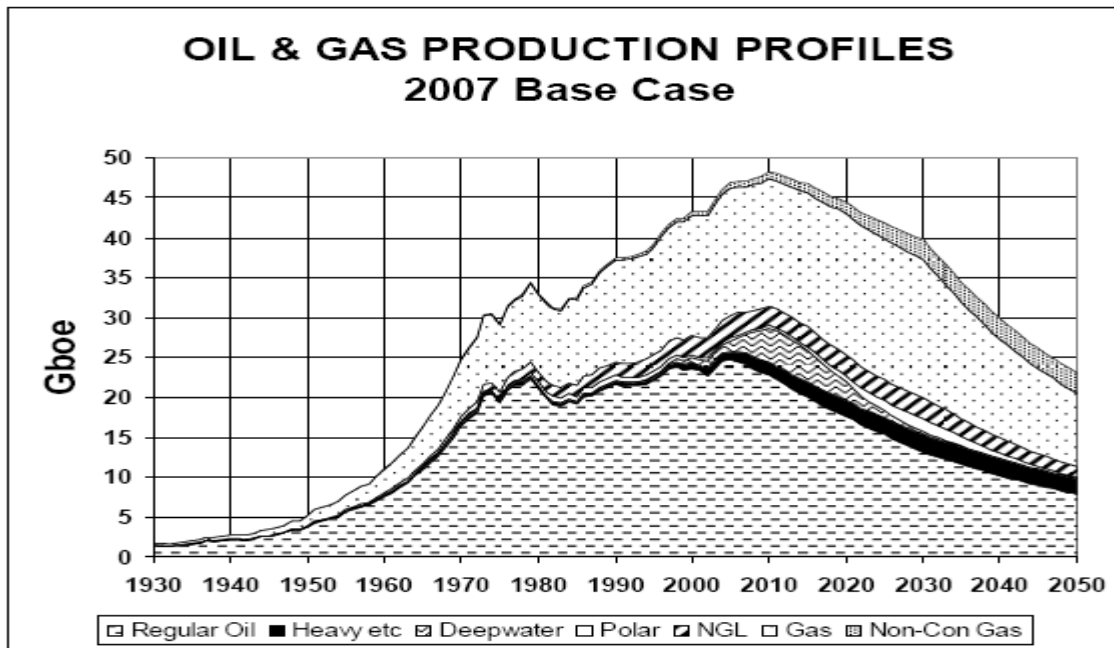

Fig.8: Peak oil and gas – source: C. Campbell, ASPO Ireland

Colin Campbell predicts oil and gas together to peak by 2010. These predictions are based on a method developed more than 50 years ago by M. King Hubbert. Hubbert predicted that world oil would peak around the turn of the century.

The technique is very simple. Each individual oil and gas deposit exhibits similar production patterns. First the production increases over time, then it peaks, and thereafter, the production decreases rapidly. All of these deposits together must, as a consequence of the law of large numbers, follow essentially a Gaussian distribution. The integral of the bell-shaped Gaussian distribution (the error function) can be approximated by a logistic curve:

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

where $P(t)$ denotes the total production up to time t.

We can use past measurement data of P, and perform a least squares fit to determine the best values of the unknown parameters a and b. This can be done either using global data directly, or for different regions of the globe separately. The final value:

$$P_{max} = a / b$$

represents the total amount of oil (and/or gas) that will ever be produced.

I applied this method to the last 22 years of global oil production. The results of the curve fitting effort are shown in Fig.9.
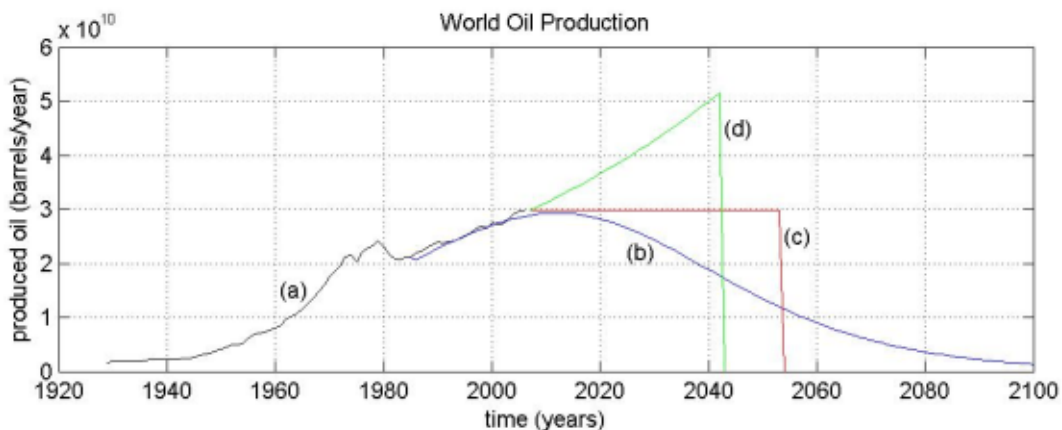

Fig.9: Curve fitting past oil production data. The measurement data are plotted in black as curve (a); the Gaussian (Hubbert) prediction is shown in blue as curve (b); a constant exploration model is depicted in red as curve (c); and a continued exponential growth model is given in green as curve (d). Explorations (c) and (d) come to an end, when the total oil according to Hubbert's method has been produced.

BP tell us that, according to their best estimates, we still have enough conventional oil for 40 years. The prediction is made under the assumption of a continued constant exploration. This corresponds to the model (c) of Fig.9. Their statement is thus in fairly good agreement with the Hubbert model, as the two areas between the red and the blue curve are of equal sizes.

Luckily, BP's assumption of continued constant exploration won't hold. The law of large numbers gets in the way. The low-hanging fruit has already been harvested. Fig.10 shows new oil discoveries over time, in accordance with USGS.
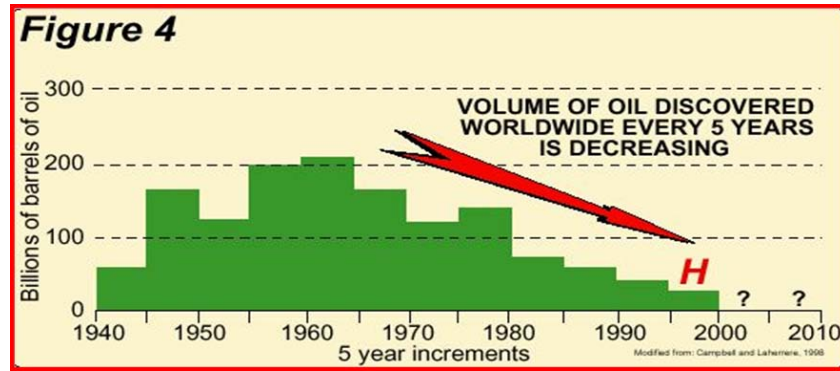
Fig.10: New oil discoveries – source: L. Magoon, U.S. Geological Survey

The new oil discoveries follow quite well an exponential decay curve. This is how BP are able to estimate the remaining not yet discovered oil.

It is very fortunate that BP won't be able to keep the production up until the end, because an abrupt termination of oil production after another forty years would mean the end of the world as we know it. Exponential decay is bad enough, but an abrupt termination is equivalent to driving a car into a brick wall at 100 miles per hour. The ride is beautiful while it lasts, but the end is not pretty.

BP calculated their reserve estimates at a sales price of $80/barrel. If the price is much lower, then many of the remaining deposits cannot be exploited economically. If it is higher, then more oil deposits will become economically exploitable. Thus, we may actually have more oil available than currently predicted by BP, but not much more, as I shall demonstrate. In either case, the year of the peak doesn't change by much. Peak oil is not going to occur in the distant future. It is happening now.

What About the Oil Price?

Before peak oil, we are living in a buyers' market. Different oil producers compete for customers, and only those who offer the best prices can sell their product. The price of oil is dictated by production cost, and oil is consequently cheap.

After peak oil, we are living in a sellers' market. Different customers vie for oil, and only those who are willing and able to offer the highest price will be able to buy. The price of oil is dictated by market forces, and oil is consequently expensive.

Last summer, we came into the vicinity of peak oil, and consequently, the price of crude was rising rapidly. In the mean time, the world economy tanked for reasons that I don't wish to explore. Some people believe that the economy tanked because of high oil prices, but the reason is actually irrelevant to the analysis.

As the economy turned sour, fewer goods were produced, and consequently, less oil was needed. The demand for oil shrank by a few percentage points, and this sufficed to drive the oil market back into pre-peak territory. Consequently, the oil price came down once more.

Yet, our fortune won't last. Because of the current low oil prices, several new oil projects have already been delayed, as these deposits cannot be exploited economically at a price of $50/barrel. This drives the oil supply down.

As soon as the economy will start to recover, the demand for oil will rise again, which will drive the oil market immediately back into post-peak territory. It may take a few more months or possibly a year for this to happen, but the low oil prices are not to stay.

As we move down the Hubbert curve, no reduction in demand due to a shrinking world economy can keep the oil price down.

We are still consuming oil at almost the maximum rate, and much more than what we are using now is simply not in the cards.

Even worse, as oil becomes a scarce commodity, the oil producing nations will satisfy their own needs first before they export. Consequently, the international oil trade will shrink even faster than oil production.

The Curse of Shrinking EROEI

Most of the cheap oil has already been produced. The remaining oil is more difficult to get at, and therefore, its production is more expensive. Yet, this is not only a question of *price*. It is also a question of *energy* consumed in the process of developing these deposits. We need to take into account the *Energy Returned On Energy Invested (EROEI)*. Unfortunately, the EROEI of oil is shrinking rapidly.

Charlie Hall has compiled a list of EROEI values for different energy sources. It is reproduced here as Fig.11.
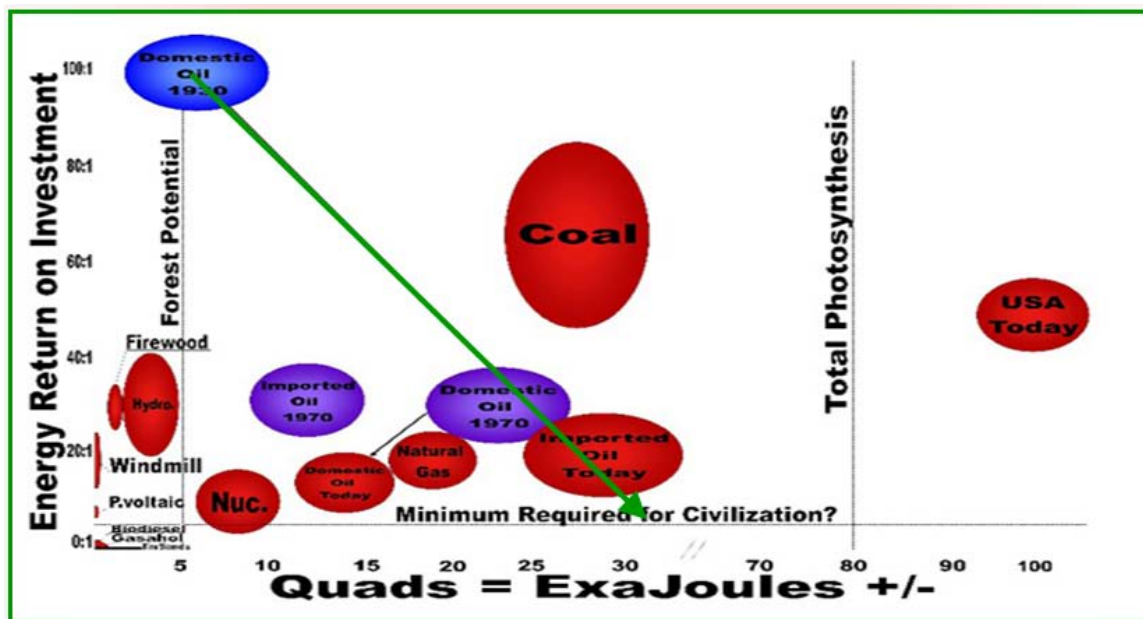

Fig.11: EROEI for different energy types – source: C.Hall, The Balloon Diagram and Your Future

U.S. domestic oil had an EROEI value of around 100 in the early years of oil exploration. You dug a hole somewhere in Pennsylvania, and the oil came gushing out. By 1970, the EROEI of

U.S. domestic oil had already shrunk to a value of about 30. Oil imported into the U.S. today has an EROEI value of below 20.

As the EROEI shrinks to a value of 1, it no longer makes any sense to produce it irrespective of its price. Why would anyone want to burn one barrel of oil to produce one barrel of oil in return?

Charlie Hall estimates further that energy produced at an EROEI value of below 5 cannot support our society sustainably. The reasons for this claim will become clear in due course.

Notice that bio-fuels of the first generation (such as the bio-fuels produced from corn in the U.S. and those produced from sugar cane in Brazil), shown in the lower-left corner of the graph, have EROEI values in the vicinity of 1. The EROEI of U.S. bio-fuels is reduced by irrigation needs and by highly automated production involving large plantation machines that consume lots of diesel fuel. The EROEI of Brazilian bio-fuels is reduced by the need to destroy (burn) large areas of rain forest first followed by a rapid degradation of the land.

Second generation bio-fuels, especially those produced from algae, may have higher EROEI values, but it is too early to know already, where their EROEI will be. Also, just like in the case of the first generation bio-fuels, they cannot be produced in sufficiently large quantities to solve our energy problem. They may help, but they are no cure.

The Dynamics of Our Energy Economy

Charlie Hall plotted a series of Sankey diagrams depicting the dynamics of our energy economy. Fig.12a shows the situation in 1949.
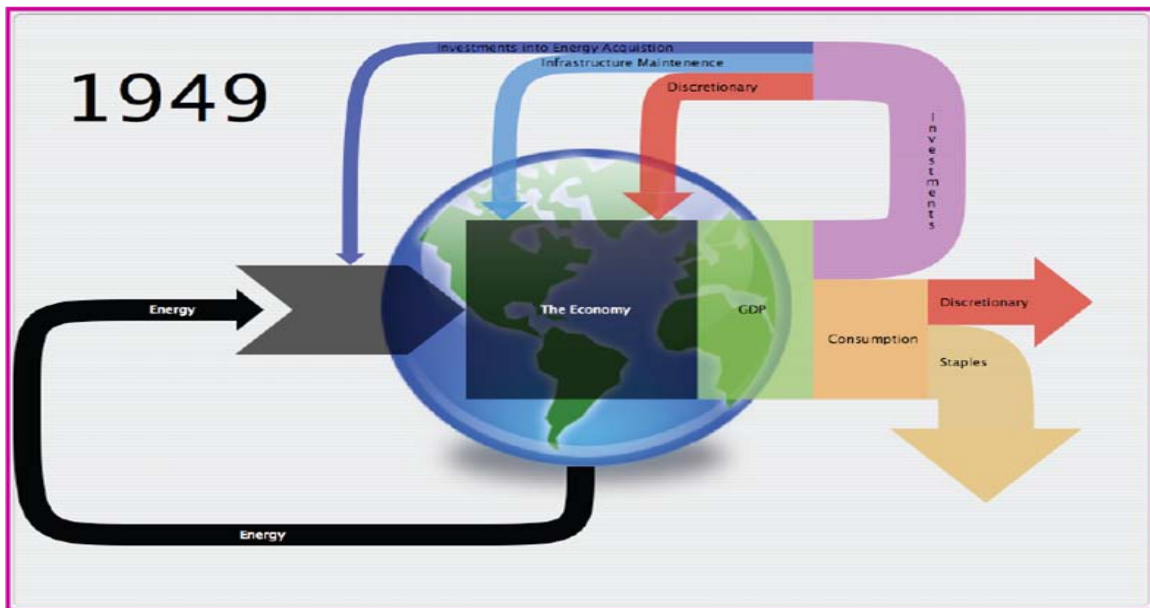

Fig.12a: Energy and economy diagram for 1949 – Source: C. Hall, Economic Implications of Changing EROI Ratios

The economy is driven by several feedback loops. The black feedback loop at the bottom denotes the EROEI. Energy needs to be invested to produce more energy. By 1949, the EROEI is high, and therefore, the feedback is drawn as a relatively narrow vector.

The production of energy also costs money. This is shown by the dark blue feedback loop at the top. Money is also spent for maintaining the infrastructure, as shown in clear blue. Some money is furthermore invested in improving the infrastructure. This is shown in red as discretionary investment.

Some of the money generated by our economy is not re-invested but spent. Some money is spent on food. This is shown in clear brown. The remaining money is used for discretionary spending, such as flying to the Maldive islands on a vacation.
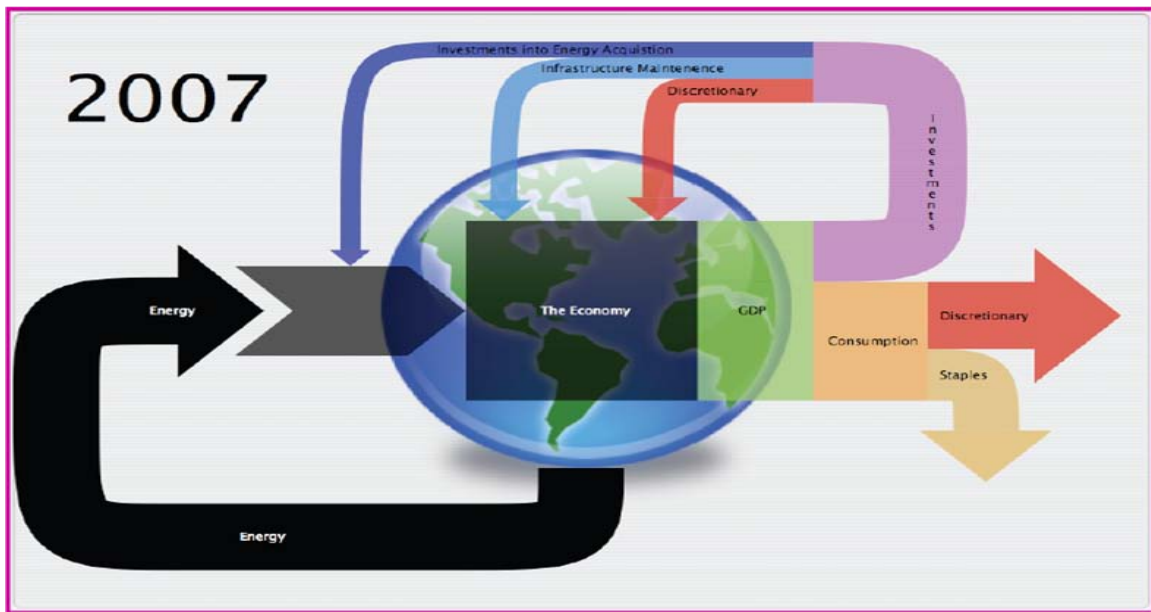
Fig.12b shows the same Sankey diagram for 2007.

Fig.12b: Energy and economy diagram for 2007 – Source: C. Hall, Economic Implications of Changing EROI Ratios

What has changed is that the EROEI of energy production has shrunk dramatically. Consequently, the black feedback loop is now much thicker. However, the overall economy has grown, and therefore, there is still a lot of money available for discretionary spending. We are in fact more wealthy than in 1949.

Fig.12c shows the same Sankey diagram as estimated by Hall for the year 2030.
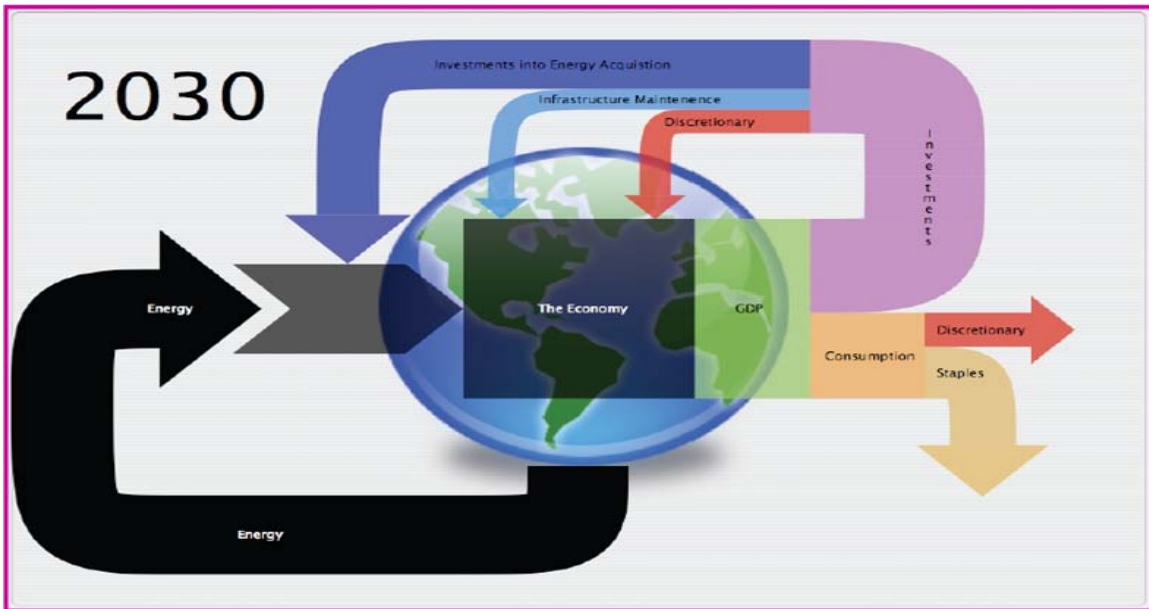
Fig.12c: Energy and economy diagram for 2030 – Source: C. Hall, Economic Implications of Changing EROI Ratios

What has changed is that peak oil is now behind us. Consequently, the oil has become very expensive, and a much larger percentage of our wealth is required to acquire energy. Consequently, the dark blue feedback loop is now much thicker as well. Therefore, less money is now available for discretionary spending, and we have all become poorer again.

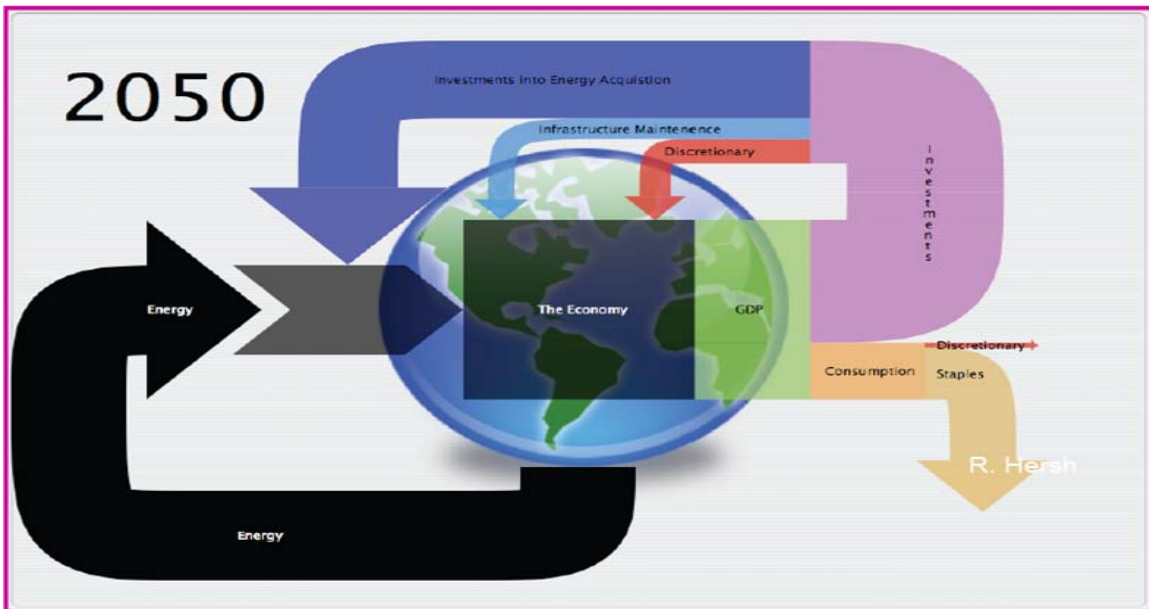Fig.12d shows the same Sankey diagram, now projected to the year 2050.

Fig.12d: Energy and economy diagram for 2050 – Source: C. Hall, Economic Implications of Changing EROI Ratios

The EROEI of energy has shrunk further, and the cost of energy has increased some more. The black and the dark blue feedback loops now consume all of our resources that aren't needed to simply stay alive. The amount available for discretionary spending has shrunk to zero.

As the amount available for discretionary spending turns negative, the infrastructure falls apart, as we can no longer maintain it. Consequently, we can no longer feed the entire population, and the die-off begins.

Hall's model may actually be a bit conservative, as it doesn't take into account the uneven distribution of wealth in different regions of the planet. Comparing Asian Americans in California with African Americans in Mississippi, we notice a difference in life expectancy of 15 years. African Americans in the Southeast of the U.S. die 15 years younger on average simply because of economic conditions.

For this reason, it must be feared that the die-off will begin much earlier than 2050 in some regions of the world.

What Does This Mean For Switzerland?

Switzerland is in a relatively comfortable position as far as electricity is concerned. We produce almost none of our electricity from fossil fuels. Hence I do not expect our grid to disintegrate permanently any time soon. Brownouts and blackouts may become more frequent than they are now, but they will not lead to a complete breakdown of the grid.

Yet, we nevertheless import 70-80% of our overall energy (depending on the accounting method), and most of our imported energy is based in fossil fuels: oil and gas. Therefore, we will have to learn to live on considerably less energy than we have available today.

What Can Switzerland Do?

The most cost-effective way of countering energy shortage is through *energy savings*.

Switzerland should aggressively push for minergy housing. Neighboring regions, such as Vorarlberg, for example, have done so in recent years much more effectively than Switzerland. In Vorarlberg, almost all new houses are now built to minergy standard. The government pushes this technology aggressively and offers subsidies to new home builders to make it more attractive economically to built to minergy standard. In contrast, only about 20% of new houses in Switzerland are built to minergy standard. The Swiss government needs to do more, much more in fact, to push energy-efficient homes.

Switzerland needs to push for more fuel-efficient lighter vehicles. The weight of the average passenger car in Switzerland has risen in the last 15 years from 1200 kg to 1500 kg. Quite clearly, the Swiss government has failed to educate the population about the bad consequences of wasting energy on equipment that is unnecessary and doesn't even improve the quality of life in a significant way.

Most governments spend currently millions and millions of Dollars trying to reactivate their stalling economies. Investing in energy infrastructure, e.g. through government incentives directed at measures that promote energy savings, may do so much more effectively than throwing money into the fangs of money-hungry investment bankers.

[Energy saving measures alone can reduce the Swiss energy consumption by 40%](#) without sacrificing the life style of its inhabitants to a significant extent.

Switzerland should furthermore invest in infrastructure for a *more robust grid*, thereby reducing the risk of repeated brownouts and blackouts.

More incentives should be offered to let people use electricity during off-peak hours.

A refrigerator or freezer doesn't need to consume electricity on a 24/7 basis. It would make sense to install a smart sensor between a refrigerator and the wall outlet that senses instability in the grid and temporarily switches off the device whenever the grid becomes more unstable.

The same holds for electric heat pumps. They can also be temporarily switched off. [Smart controllers can optimize electricity consumption by heat pumps](#) to occur primarily during off-peak hours.

Switzerland should invest aggressively in *solar and wind power*. These alternative sources of energy won't be able to replace the energy currently imported in the form of fossil fuels in their entirety, but every bit helps. We'll need all that we can get.

Switzerland needs *one more generation of nuclear power stations*. Switzerland should pursue the construction of one new nuclear power station at every one of the five current locations to pick up the load when the licenses expire for the old power stations. Otherwise the pressure will be large to keep the old power stations running beyond the time they can be used safely.

Nuclear power in its current form is not sustainable either. [We'll also run out of uranium.](#) Yet, new nuclear power stations will take some pressure off the energy situation by buying us more time to transition to sustainability.

Hopefully by the time the new nuclear power stations need to be shut down, we shall have come up with other sources of energy to pick up the remaining load. If we are lucky, we'll have these new sources of energy on-line even earlier, and in that case, we may be able to retire our nuclear power stations even before their licenses expire.

As we still have not solved the final nuclear waste storage problem, as we still don't know what to do with the used nuclear fuel rods, I recognize that I advocate adding a few more IOUs to an already large stack, but the alternative looks even worse.

Switzerland can't go it alone.

[Switzerland currently imports 40% of its *food*.](#) Switzerland cannot feed a population of close to 8 million people from food produced locally. Switzerland is in fact the worst of all European nations in this respect. We rely heavily on food imports beside from energy imports.

As the economic situation deteriorates, Switzerland's dependence will become more critical, as we won't have as many surplus financial resources available to ensure imports.

Durable agreements with the EU nations are therefore very important.

Switzerland is in a relatively comfortable position with respect to *greenhouse gas emissions*. The reason is that Switzerland uses hardly any coal at all. For this reason, our [per capita CO_2 emissions](#) are about half of those produced by other Western European countries.

Yet, greenhouse gas emissions are a veritable problem, and Switzerland needs to contribute to its solution, primarily by helping developing nations to invest in cleaner technologies.

Conclusions

When I walk through the streets of Zurich and look into the windows of the shops, I don't notice any change yet. There is no shortage of anything. Energy is cheap and amply available. The inflation rate has come down. Unemployment hasn't picked up yet. It is still below 3%.

For this reason, I cannot blame the average Swiss for walking through life with blinders on. Life is good, they think. There isn't a worry in the world. Those who predict doom are just that: doomers. There is no reason to listen to them, let alone take them seriously.

With this article, I hope to wake some of my compatriots up from their sleeping-beauty slumber. Problems that lie ahead don't need to be obvious and visible in order to make them predictable.

Peak oil is taking place as I write. An immediate and inevitable effect of peak oil will be rapidly rising energy prices, and those are accompanied by a further downturn of the economy. This is going to happen irrespective of what we do.

Yet, this does not mean that we cannot prepare ourselves and thereby soften the impact of these events on the Swiss population. In fact, we should have started preparing much earlier, as [we have known about these problems for more than 30 years already](#). The longer we wait, the more difficult and costly it will be to avert the worst. If we do nothing, we'll experience the full brunt of peak oil and its consequences, unmitigated and merciless.