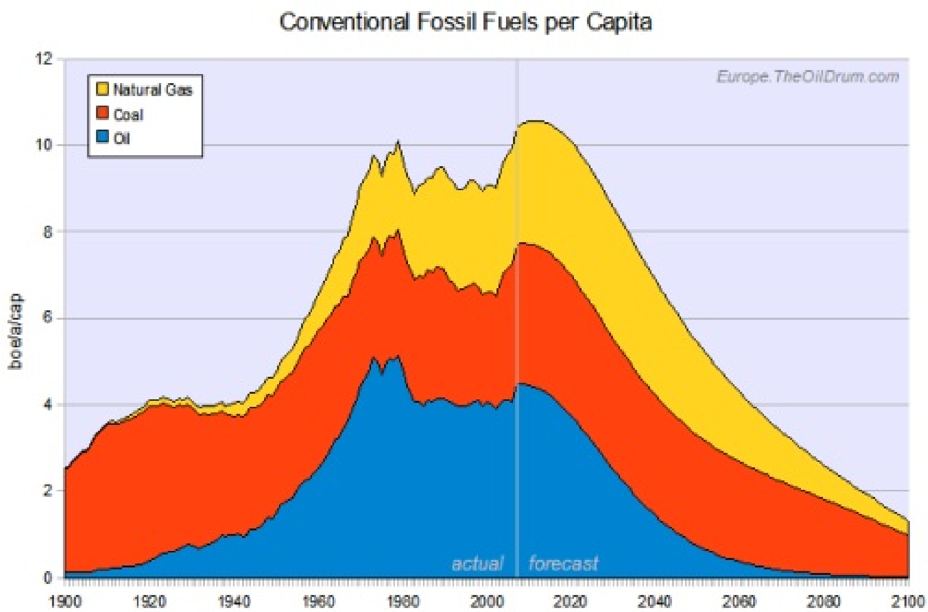
Olduvai revisited 2008

Posted by Luis de Sousa on February 28, 2008 - 11:15am in The Oil Drum: Europe
Topic: Supply/Production
Tags: alternative energy, energy per capita, olduvai, peak coal, peak natural gas, peak oil, population [list all tags]



Forecast for Conventional Fossil Fuels per Capita.
Sources: UN for Population model, Jean Laherrère [pdf!] for Natural Gas, Energy Watch Group for Coal and The Oil Drum - Khebab for Oil. Click for large version.

Foreword

My first post at TOD was published by Heading Out about 2 years ago on this same subject. Some rather naïve forecasts were made back then, without exactly addressing the main subject: can Mankind avoid the Road to the Olduvai Gorge? This is a first try in answering that question.

The work on this article started in the Spring of 2007, when Euan Mearns tried to show that Peak Oil does not necessarily imply an Energy crunch. Partly due to my critique, Euan's work would never see the light of day. Sometime later, Euan and I started working together on the work reported here, focusing on Conventional Fossil Fuels (FF). The fact that several studies on future Coal reserves and extraction rates were published in the interim, facilitated our work.

This work would end up being a collective post by TOD:E, Rembrandt kindly provided historical FF data and Chris Vernon would solve some issues with the conversion of primary energy to heat. An important leap towards the conclusion of this work was made during the weekend of the 1st of December, when the TOD:E staff gathered in Paris, kindly hosted by Jérôme.

Introduction

The Olduvai Gorge Theory was first laid out by Richard Duncan in 1989, when he observed that world energy per capita had been declining for a decade. He developed the concept of Electrical Civilization, the way of life made possible by widespread and abundant electricity and set it to the period in which world energy per capita is above 30% of its all-time peak. The Theory was postulated it in the following way:

- Industrial Civilization can be described by a single pulse waveform of duration X, as measured by average energy-use per person per year.
- The life-expectancy of Industrial Civilization is less than one-hundred (100) years: i.e., X < 100 years.

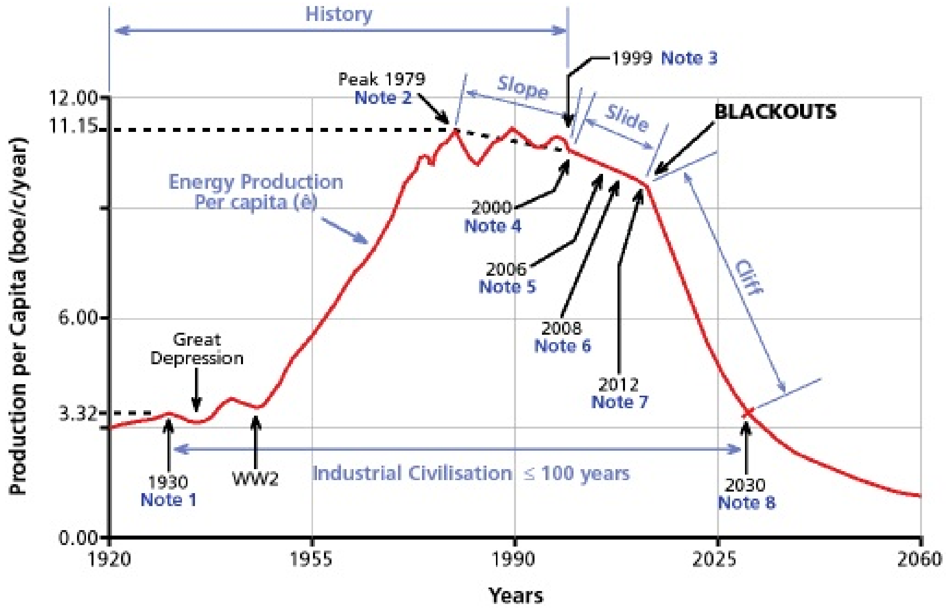


Figure 1 *- The three phases of the Olduvai Decline. Source: WolfAtTheDoor.*

The post-peak period develops in three phases:

- **The Olduvai Slope** – a period of slow decline;
- **The Olduvai Slide** – a period triggered by Peak Oil when decline would accelerate;
- **The Olduvai Cliff** – the collapse of Electrical Civilization with overwhelming decline of energy per capita.

This seminal work would result in Duncan's collaboration with geologist Walter Youngquist. Together they would forecast future Oil production for more than 40 countries, confirming Duncan's initial forecast of a decline in energy consumption in the not to distant future.

As the years went by it became clear that world energy per capita was in a plateau, not a decline, and in 2005 the 1979 peak was surpassed. Still, almost ninety percent of the total energy used world wide comes from fossil fuels. If such dependence on finite resources remains, the Olduvai Theory may eventually unfold.

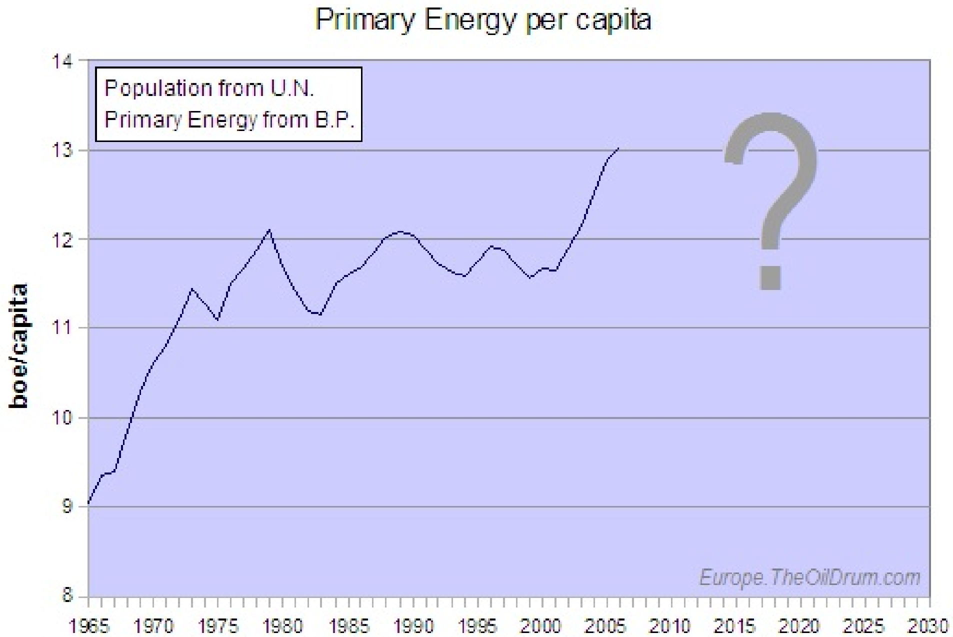


Figure 2 *- World Primary Energy Per Capita. Population from UN, Energy from BP BOE - barrels oil equivalent.*

This work tries to assess how the decline of Conventional Fossil Fuels may unfold and how can Mankind avoid the Road that may take us back to the Olduvai Gorge.

The Future of Conventional Fossil Fuels

In the context of this work, Conventional Fossil Fuels represents the kinds of these resources in production today. These may include fuels usually called Unconventional like the Tar Sands or Coal Bed Methane. It is assumed that none of the Unconventional Fuels Fossil will have a visible impact on the overall world energy production for two main reasons: the volumes produced are unlikely to be significant (e.g. Tar Sands) and the net energy balance of some is doubtfully positive (e.g. Ultra-deep Offshore). The one exception is Coal where in-situ gasification might turn important Resources into Reserves (this issue will be dealt with later).

Our approach has been to use what we regard as the best researched and most reliable estimates for future global oil natural gas and coal production. Each fuel is re-based in "oil equivalent". And we use the UN population forecasts to derive a per capita FF forecast. However, the main objective of this work is to develop scenarios for alternative energies (nuclear and renewables) that may partially fill the energy gap left by declining FF. These scenarios are not forecasts but have been produced to illustrate the scale of the energy problem that now confronts Mankind.

Oil

For Oil, the forecast made by Khebab using a Loglets Transform, was chosen. This scenario is in line with those of several other researchers: Jean Lahèrrere, Colin Campbell, Chris Skebrowski and Kenneth Deffeyes. Laid down this way, Oil Production peaks by 2012.

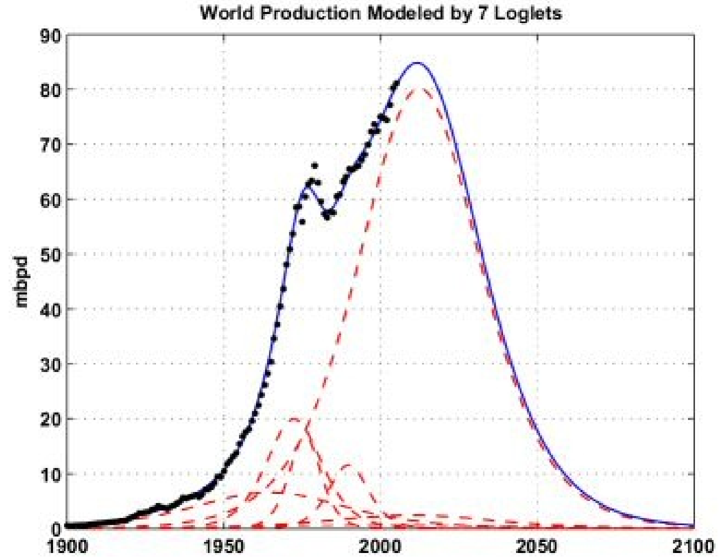


Figure 3 *- Conventional Oil Forecast (including NGL) according to the [Loglets Transform](http://europe.theoildrum.com/node/3565).*

Natural Gas

The scenario chosen for Natural Gas is that produced by Jean Laherrère portraying a peak by 2030. This scenario can be considered optimistic to some extent, but takes into account the high degree of uncertainty on Natural Gas forecasting, among other reasons, due to poor data on past discovery and production. This forecast also includes Coal Bed Methane and other Unconventional gas sources.

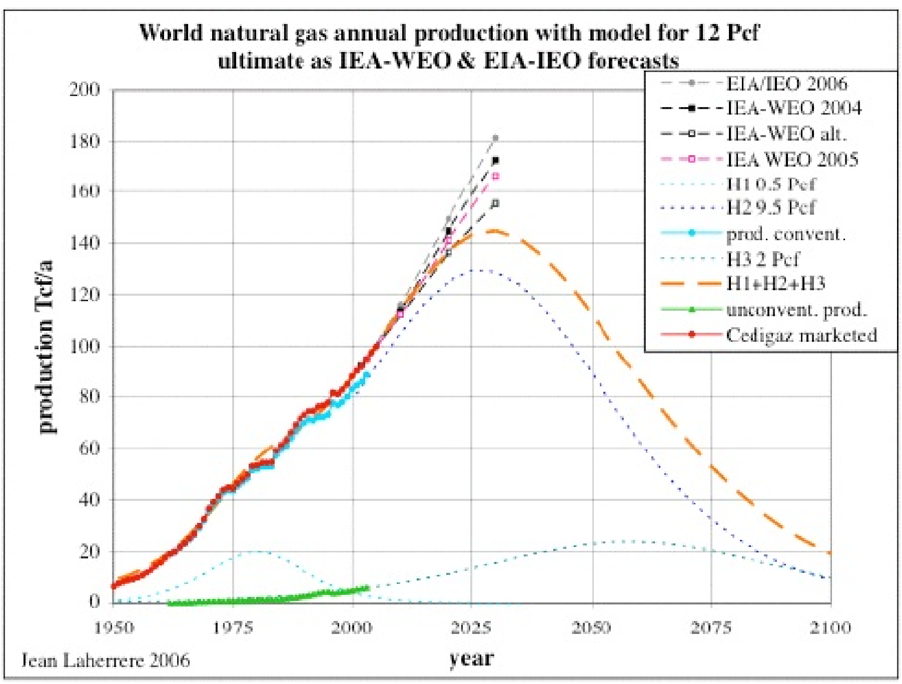


Figure 4 *- Natural Gas Forecast (including Unconventional). Source: Jean Laherrère [pdf!].*

Coal

Coal has been regarded as an infinite resource on a generation time scale, but recent assessments imply otherwise. The following graph shows three independent forecasts, by Jean Laherrère, the Energy Watch Group and David Rutledge, all peaking before mid-century. Of these the one made by the Energy Watch Group was chosen, for being at the midst of the three and for the thoroughness involved in its production. This scenario presents a plateau roughly from 2020 to 2040.

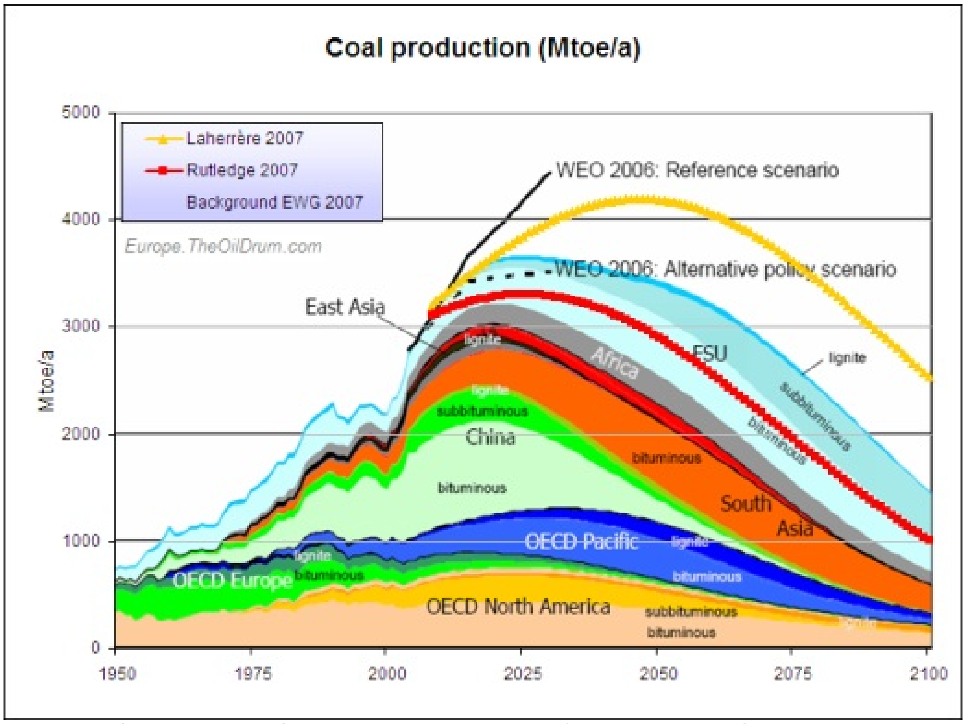


Figure 5 *- Conventional Coal Forecasts. Sources: [Jean Laherrère [pdf!]](), [Energy Watch Group]() and [David Rutledge](). Click for large version.*

Fossil Fuel Olduvai

When added together these three forecasts present an overall Conventional Fossil Fuels peak by 2018, forming a single cycle which by itself is a notable result. If for instance a higher Coal estimate is used, the peak hardly moves and the only visible effect is a slowdown of the decline.

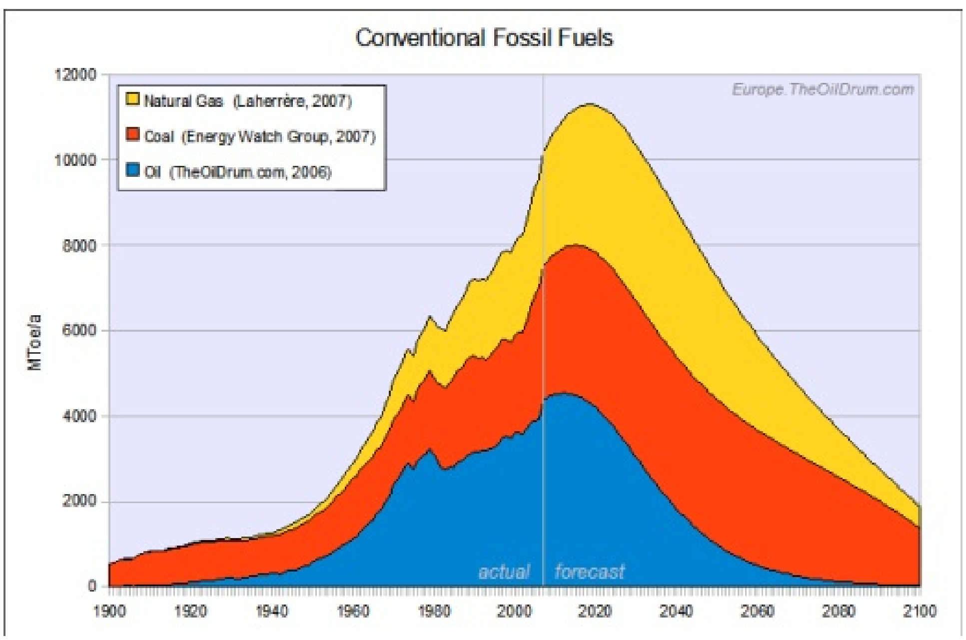


Figure 6 *- Together the Conventional Fossil Fuels are set to peak before 2020 describing a single cycle. Sources: [Jean Laherrère [pdf!]]() for Natural Gas, [Energy Watch Group]() for Coal and [The Oil Drum]() for Oil. Click for large version.*

A population model was developed using United Nations data, to which a single logistic cycle was adjusted. World Population tops 7 billion just after 2010, reaches 8 billion before 2030, 9 billion by 2050 and stabilizes after that to end up in 9.8 billion by the end of the century.

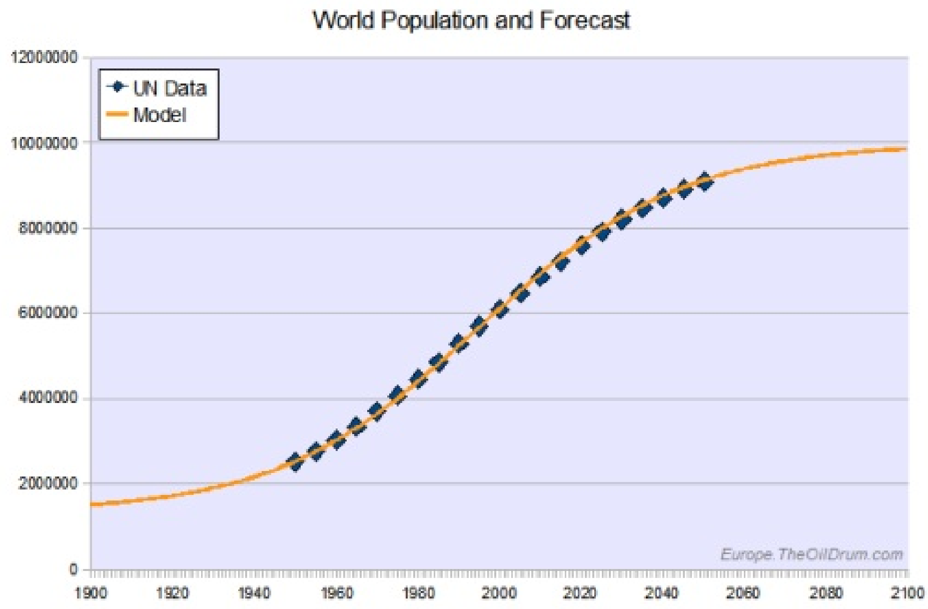


Figure 7 *- Population growth model using a single logistic cycle.*
Base data source: UN. Click for large version.

The outcome of these models is a Fossil Fuel per capita peak by 2012 in tandem with Peak Oil, although it is maintained above 10 barrels of oil equivalent from now up to 2020. By 2050 that number is below 6 barrels of oil equivalent per capita declining to just above 1 by the end of the century. Led by the Conventional Fossil Fuels, the Olduvai Pulse is interpreted to be much longer than anticipated by Duncan, extending its life for 160 years, from 1910 to 2070.

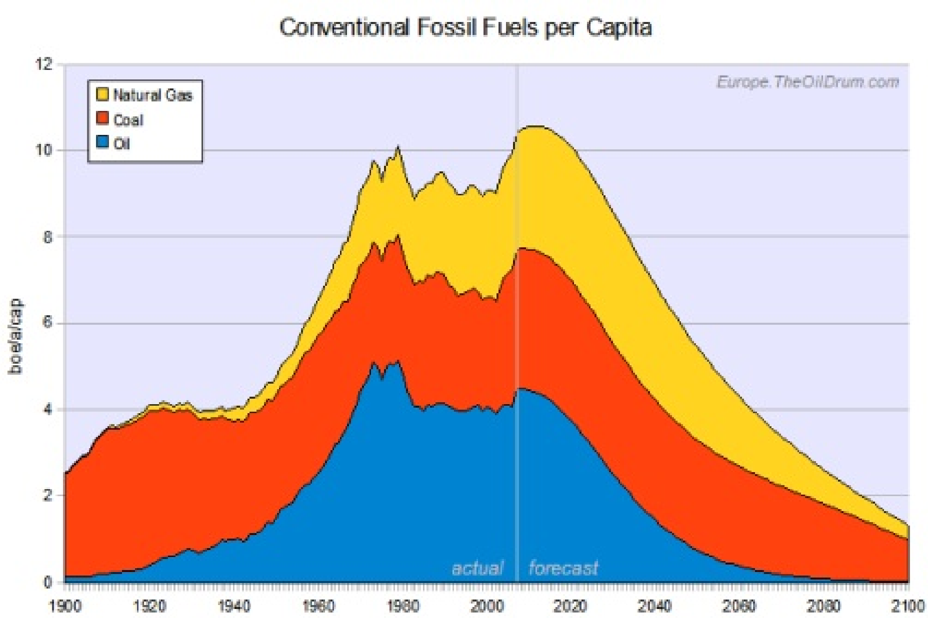


Figure 8 *- Forecast for Conventional Fossil Fuels per Capita.*
Sources: UN for Population model, Jean Laherrère [pdf!] for Natural Gas, Energy Watch Group for Coal and The Oil Drum for Oil. Click for large version.

The total useful energy drawn from Conventional Fossil Fuels equates today to more than 300 Twh every day, or the equivalent to 4250 Nuclear power plants working non-stop.

The Scenarios

Henceforth this article tries to assess what actions are required for the current standards of living to be sustained throughout the XXI century. Using again the United Nations population forecast the build up of alternative energy infrastructure is determined in order to compensate for the decline of Conventional Fossil Fuels.

Four different scenarios are presented: two in which several alternative energy sources are used to cover the gap left by the Fossil Fuels. And two others where world energy use undergoes a significant efficiency improvement enabling living standards to be maintained on a much lower per capita energy consumption. A fifth scenario, where world population declines significantly is not presented here.

The alternative energy sources considered are the following:

- **Nuclear** - assuming that no shortages of nuclear fuel may unfold or that new technologies like breeder reactors or accelerator driven systems are timely developed. Nuclear went from friend to foe during the XX century to emerge again as an alternative with the end of cheap Oil. Concerns with the fuel supply have been present since the 1970s, to which Thorium and breeder systems promise to put an end, perhaps one or two decades from now. Problems could remain with waste disposal, due to negative public opinion, and weapons production. Accelerator driven systems and fusion rectors could in their turn solve these last problems, but if successful are several decades away.

  The basic infrastructure unit used corresponds to a 1 Gw plant operating at full capacity.

- **Unconventional Coal** - assuming the development of technologies needed to access deeper seams, offshore or other constrained resources. Great uncertainty surrounds the future of Coal Resources not extractable today. Technologies like in-situ gasification can potentially access seams presently inaccessible while at the same time addressing concerns with CO2 emissions; but a proof of concept is yet to be achieved. Unconventional Coal is also a non-renewable resource that may not look like the best alternative to build a sustainable future upon, although it can eventually provide an important launch pad for it.

  The basic infrastructure unit used corresponds to a 600 Mw plant operating at full capacity.

- **Wind energy** - both on its onshore and offshore forms. A renewable energy source with a proven track record, is now technologically where Nuclear was in the 1960s. In Europe the offshore infrastructure is still young and could revolutionize the electricity generation sector. Presently, the main challenge to this alternative is energy storage, although in this case technology (or the lack of thereof) should not be a problem.

  The infrastructure units correspond to 3 Mw turbines operating at 30% load for Onshore Wind and to 5 Mw turbines at 40% load for Offshore.

- **Solar** - the dormant giant? At an earlier stage of market penetration compared to Wind, it will certainly undergo the same kind of growth. Due to the simplicity of passive systems and the falling costs of photovoltaics, a Solar revolution could be on the making. Especially in the warmer countries of the Temperate Regions this will likely be a major energy source in the XXI century.

  The basic infrastructure unit reflects the average insulation at 40º latitude per Km2 captured with an efficiency of 15%.

These alternative energy sources were compared to the Fossil Fuels on the grounds of the electricity they produce. To generate useful energy, Fossil Fuels generally undergo a process in which they are transformed into heat that is then captured as motion, electricity, etc. With some of the alternative energy sources a similar process takes place (e.g. a Nuclear reactor that heats water into steam that turns a turbine generating electricity).

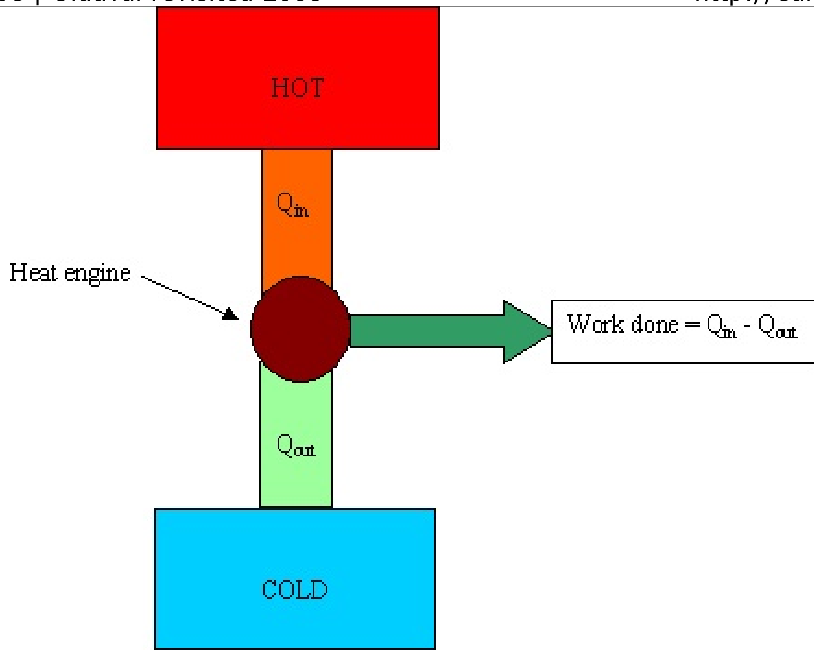


***Figure 9** - Simple schematics of a Carnot heat engine.*
Primary Energy refers to Qin, Useful Energy to work done (W). The engine's efficiency is given by W/Qin.
Click to know more.

Given that for most of the alternatives the nameplate generation capacity refers to electricity output, the numbers shown henceforth refer to this stage of energy generation. For the primary energy to heat transformation an efficiency of one third was used. This is a postulated round number that seems representative enough; a combined cycle Natural Gas power plant probably achieves a higher efficiency, while for a Daimler internal combustion engine it will likely be lower. As an example, using this efficiency number, a 1 Gw Nuclear power plant operating during an hour replaces 3 Gwh of primary energy from the Fossil Fuels (approximately 1800 boe).

Before moving on two important implicit assumptions of these scenarios should be made explicit:

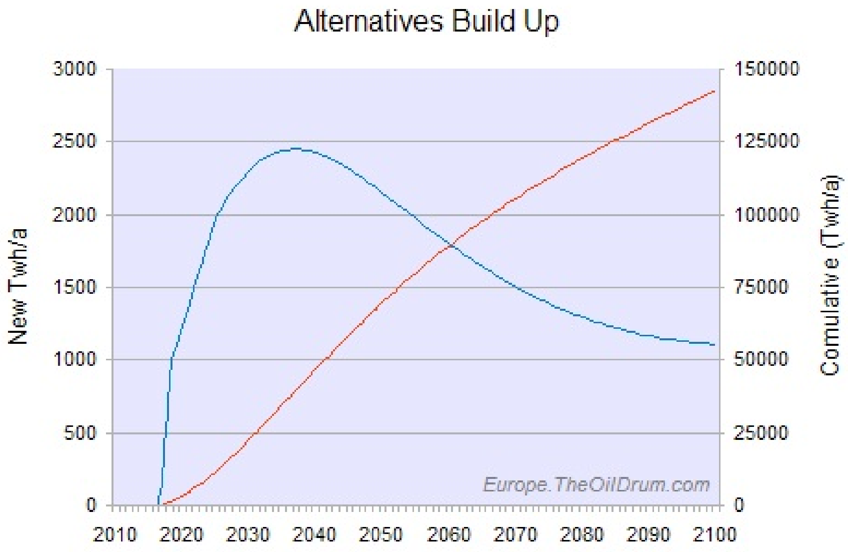
- **Net Energy** – it is assumed that the overall Energy Return on Investment of these alternatives is exactly the same of the overall Conventional Fossil Fuels. That is hardly the case, but the difficulty in assessing Net Energy accurately impedes a sound analysis on this ground. Especially in the case of Coal, that likely has a return on investment much higher that the other sources, this issue could be determinant. Future work will have to address this problem.

- **Energy Vectors** – it is assumed that all energy vectors are substituted by electricity (the only exception being passive solar use: cooking, water heating, etc). The reasons why will be explained in future work, but it implies the build up of additional infrastructure that is not present in the numbers shown below.

The following curves will show the number of new plants or equipments needed each year to cover the lag left by the fossil fuel decline.

Scenario I – A single energy source.

In this first scenario it is shown how each of these energy sources can tackle the energy gap left by declining FF on its own. In this case, new infrastructure must be deployed starting in 2018 rising fast to a peak deployment rate before 2040 and then slowly easing down. At peak, more than 4 500 Thw must be generated from new infrastructure. By the end of the century this sums up to a 140 000 Twh of energy generated per year from alternative energy sources.



Nuclear | Coal | Offshore Wind | Onshore Wind | Solar | Energy

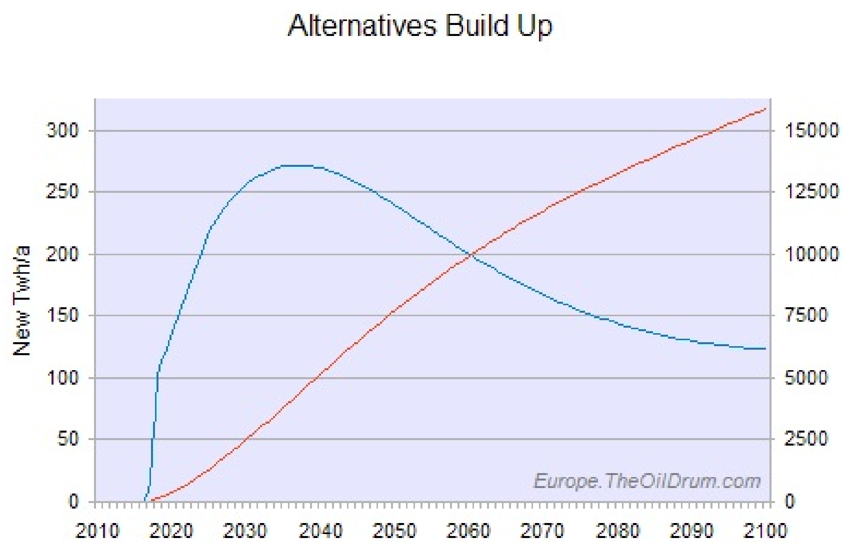
Figure 10 *- Infrastructure build up for Scenario I.*
Blue curve - infrastructure units per year. Red curve – cumulative infrastructure.
Click links for other energy sources.

Table 1 *- Scenario I in numbers.*

Scenario I	New infrastructure per year at peak	Total infrastructure in 2100
Nuclear	90	5 400
Coal	155	9 000
Offshore Wind	46 000	2 700 000
Onshore Wind	100 000	6 000 000
Solar (Km2)	3 000	190 000

Scenario II – Three simultaneous energy sources.

The second scenario considers the case where three of these alternative energy sources are deployed simultaneously to fill the energy gap. This results in the previous numbers being divided by three, with the following curves assuming that two other alternative energy sources are being stepped up simultaneously. Peak is now at 1 500 Twh generated per year from each additional source, reaching more than 45 000 Twh generated per source per year by the end of the century.



Nuclear | Coal | Offshore Wind | Onshore Wind | Solar | Energy

Figure 11 *- Infrastructure build up curves for Scenario II.*
Blue curve - infrastructure units per year. Red curve – cumulative infrastructure.
Click links for other energy sources.

Table 2 *- Scenario II in numbers.*

Scenario II	New infrastructure per year at peak	Total infrastructure in 2100
Nuclear	30	1 800
Coal	50	3 000
Offshore Wind	15 000	900 000
Onshore Wind	35 000	2 000 000
Solar (Km2)	1 000	60 000

The Efficiency Wedge

For the remaining scenarios a world wide improvement in energy efficiency is factored in. Presently the world's consumption of fossil fuels is close to 70 Gboe (just over 10 boe/cap/a), while the global GDP is just under 70 T$. This results in less than 1 000 dollars generated for each barrel of oil equivalent consumed. The following graph shows the relation between fossil fuel use and GDP per capita in several countries, both developed and developing nations, excluding the Middle East oil producers.

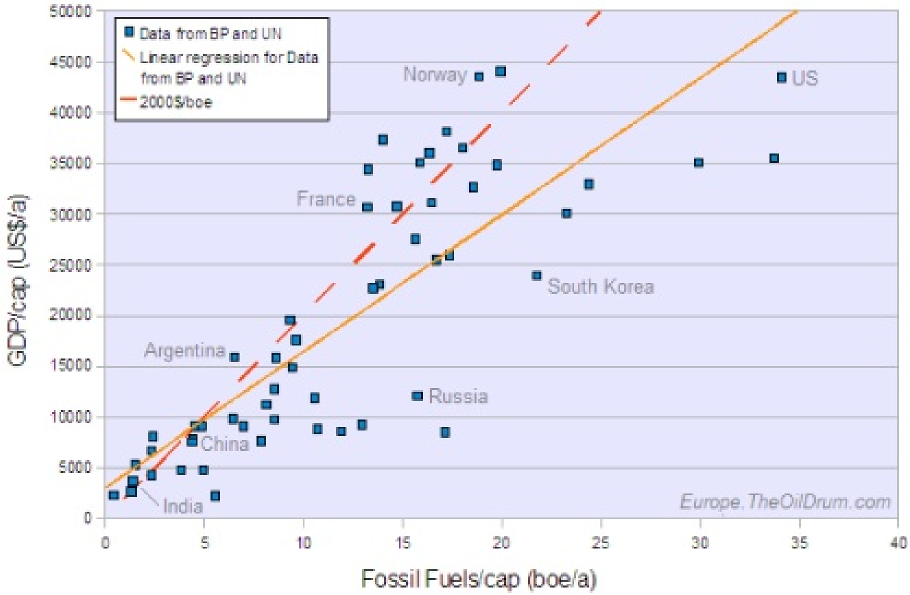


Figure 12 *- GDP generated per barrel of oil equivalent consumed of Fossil Fuels. GDP from Wikipedia, Energy from BP.*

World average GDP per capita was calculated with data from more than 180 countries resulting in 10 000 dollars per year. Using the trend in Figure 12 it becomes apparent that such average wealth standards should be sustained with just 5 barrels of oil equivalent per capita per year. This results in an efficiency of 2 000 dollars produced per barrel of oil equivalent, a number that is used as the target for global energy use efficiency.

The trend also shows that higher income countries are those that tend to have lower energy efficiency. So being, a global increase in energy efficiency use would be achieved mostly at the expense of developed nations. Some highly populated developing nations with lower energy use efficiency would likely also need some improvements.

No assumptions are made concerning wealth distribution, it is just set that, on average, each barrel of oil equivalent generates 2 000 dollars of GDP worldwide. Such is already the case in several countries, both developed and developing nations, as seen in the following table:

Table 3 *- GDP generated per boe of Fossil Fuel consumed in several countries.*

Country	GDP(US$)/boe(FF)
Colombia	3 348
Peru	2 897
India	2 698
Switzerland	2 673
Sweden	2 599
Argentina	2 451
France	2 326
Norway	2 312
Republic of Ireland	2 210
United Kingdom	2 207
Austria	2 204
Hungary	2 097
Italy	2 089
Pakistan	2 051
Denmark	2 028
Brasil	2 018
Germany	1 887
China	1 730
USA	1 274
Canada	1 052
Saudi Arabia	462

Reflecting this relation a model was thus developed in which the fraction of today's annual energy (derived from the fossil fuels) use per capita slowly declines throughout the XXI century to 5 barrels of oil equivalent (approximately 2.8 Mwh of useful energy).

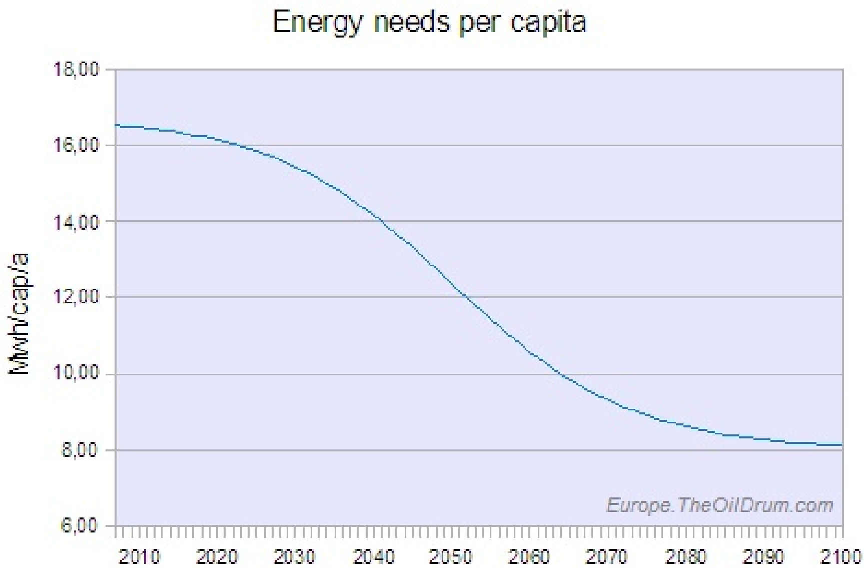


Figure 13 *- The Efficiency Wedge model: primary energy needs per capita fall to 5 boe/a (8.5 Mwh/a) through the XXI century.*

In light of this model the previous scenarios are revisited. The build up curves are markedly different, showing two distinct phases of growth. At first the alternative energy sources must grow rapidly to fill the gap, but as the efficiency wedge factors in, the build up almost stalls by mid century. Then, as the conventional fossil fuels reach their final days the build up has to slowly increase again.

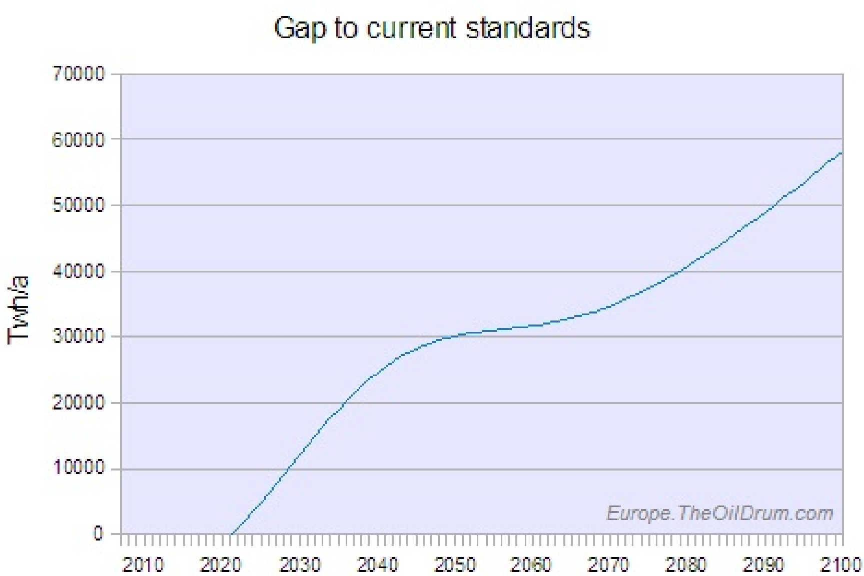
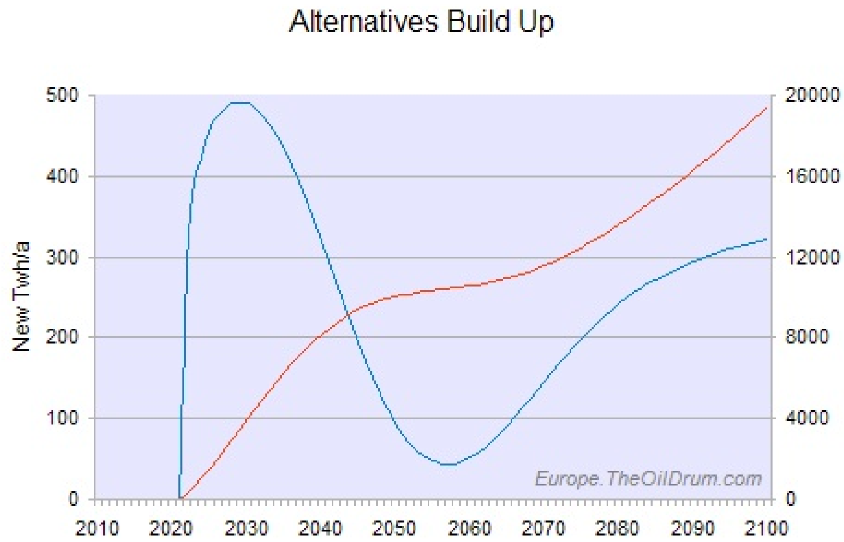


Figure 14 *- With the Efficiency Wedge the build up curves start latter and exhibit two distinct phases of growth.*

Scenario III – A single energy source with efficiency wedge.

Scenario III illustrates the amount of new infrastructure required for each of the alternatives assuming that the energy efficiency wedge reduces our consumption by half towards the end of the XXI century . Infrastructure build up now peaks just under 1 500 Twh additionally generated per year, summing 60 000 Twh of energy generated per year by 2100.



Nuclear | Coal | Offshore Wind | Onshore Wind | Solar | Energy

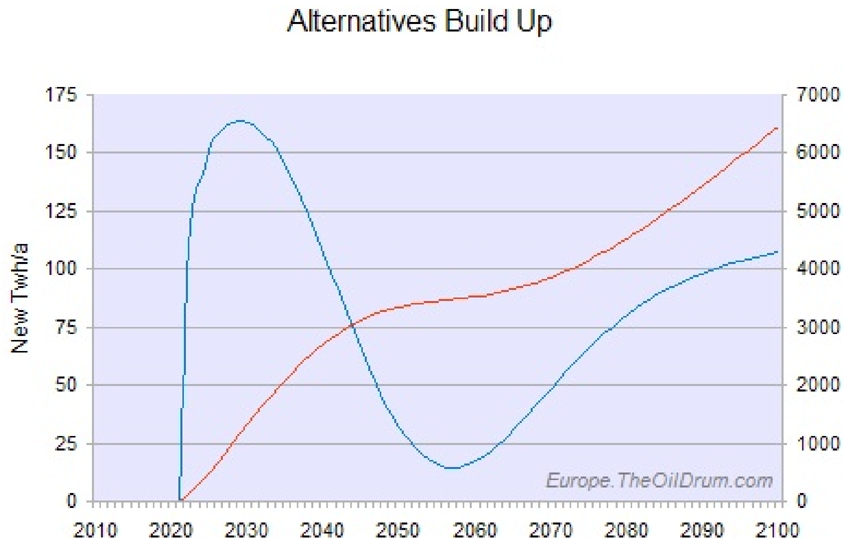
Figure 15 *- Infrastructure build up curves for Scenario III.*
Blue curve - infrastructure units per year. Red curve – cumulative infrastructure.
Click links for other energy sources.

Table 4 *- Scenario III in numbers.*

Scenario III	New infrastructure per year at peak	Total infrastructure in 2100
Nuclear	55	2 200
Coal	90	3 700
Offshore Wind	28 000	1 100 000
Onshore Wind	62 000	2 500 000
Solar (Km2)	2 000	75 000

Scenario IV – Three simultaneous energy sources with efficiency wedge.

The last scenario looks at three alternatives simultaneously tackling the energy gap with the efficiency wedge reducing consumption. Infrastructure build up now peaks with 500 Twh additionally generated per year, summing 20 000 Twh generated per year by century's end.



Nuclear | Coal | Offshore Wind | Onshore Wind | Solar | Energy

Figure 16 *- Infrastructure build up curves for Scenario IV.*
Blue curve - infrastructure units per year. Red curve – cumulative infrastructure.
Click links for other energy sources.

Table 5 *- Scenario IV in numbers.*

Scenario IV	New infrastructure per year at peak	Total infrastructure in 2100
Nuclear	19	740
Coal	30	1 200
Offshore Wind	9 300	370 000
Onshore Wind	21 000	820 000
Solar (Km2)	640	25 000

Conclusion

According to our analysis, conventional fossil fuels are set to peak in a decade or so and following that, decline will open an ever widening gap from today's per capita energy use. Based on finite FF resources, energy per capita is indeed headed towards a cliff, and this may lead Mankind back to the Olduvai Gorge if action is not taken to address this problem. Many of those who have studied this problem in the past have concluded that the journey back to Olduvai is unavoidable.

The analysis presented here suggests that it is within the capacity of human endeavor to build new energy gathering infrastructure to substitute for the decline in conventional fossil fuels. By combining energy efficiency measures with the simultaneous expansion of solar, wind and nuclear energy Mankind may secure a civilised existence for the XXI century. A tremendous opportunity exists to build a more sustainable energy future and building this future will provide vast opportunity for economic growth and prosperity.

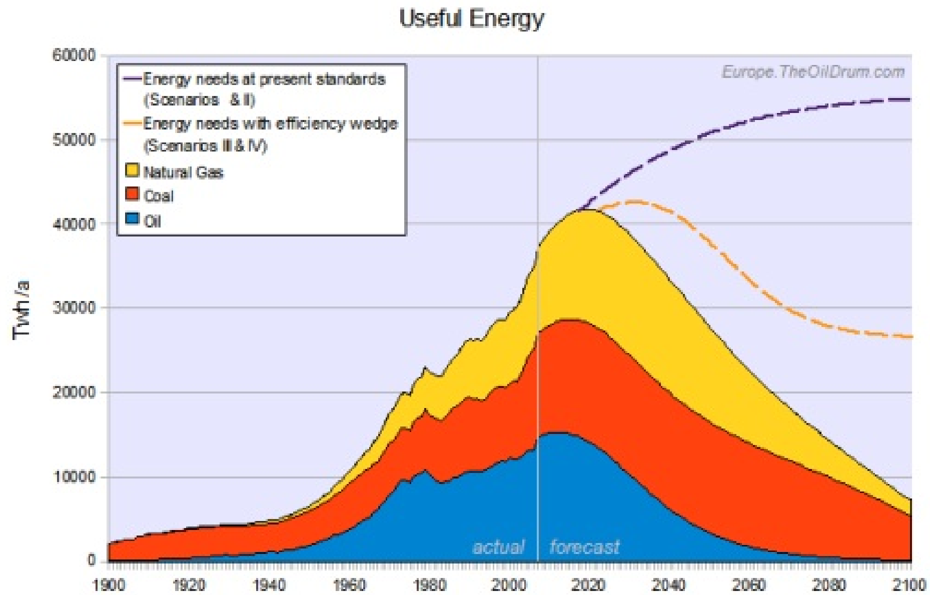


Figure 17 *- Useful Energy from the Fossil Fuels.*
The solid areas reflect the useful energy got from the Fossil Fuels according to the data and models used. The dashed lines reflect the total energy needed to maintain current standards of energy use per capita, with the orange line also factoring in the efficiency wedge model.
Click for large version.

The next two to three decades are crucial, where the fastest build of alternative infrastructure is needed, and when the efficiency wedge will have the slowest effect. But the numbers contemplated here are not insurmountable, and should be tackled with the right commitment and timely action.

To all the humans facing the Road to the Olduvai Gorge, Good Luck!

Luís de Sousa
Euan Mearns
TheOilDrum:Europe

Annex

Following is a spreadsheet with the data and calculations involved in the making of this article:

Open Document version:
http://www.theoildrum.com/files/Olduvai2008.ods [240Kb]

Microsoft version:
http://www.theoildrum.com/files/Olduvai2008.xls [660Kb]