World Nuclear Association Annual Symposium
5-7 September 2001 - London

Revival of nuclear power in the 21st century

Maurice Allègre

Two or three years ago, the future of the nuclear industry looked far from bright. Even the competivity of nuclear with fossil fuels seemed questionable, due to low oil and gas prices.

Now, things are looking better for nuclear. Oil and gas prices have risen and, surprisingly, some energy shortages have started to appear. Is this a significant trend or merely a flash in the pan? Are we witnessing the swan song of nuclear or, on the contrary, is it the dawn of a real revival for the nuclear energy?

The purpose of this paper is to demonstrate that, in the longer term, the nuclear industry can have a brilliant future.

It is easy to list the conditions for a future revival of the nuclear industry:

- First of all, the industry will have to remain strong and alive, with all the necessary professional competences. No new Chernobyl must be allowed to happen. And higher safety is a fundamental requisite.
- Nuclear power will be accepted if it acquires an "ecological image", in line with sustainable development, or at least if it ceases to be considered as a sort of anti ecological devil! The growing importance of the greenhouse effect will contribute to a better acceptance of nuclear power, which does not produce any greenhouse gases. But the main challenge for an "ecological nuclear" will remain the waste problem. The general public still has to be convinced that safe solutions do exist and can be implemented for nuclear waste management.
- The last condition is that the nuclear electricity generation will have to be competitive with fossil fuels on a sound economic basis. The higher the prices of fossil fuels, the better the competitivity of nuclear.

Moreover, if the high prices of fossil fuels result from shortages of resources and if the "new renewables" are not able to fill the gap, then, in the long term, nuclear energy will be seen to be indispensable.

The waste problem can be solved, as was argued in the author’ s previous paper presented at the UI 1998 Symposium. This paper demonstrated that the **Deep Geological Repository** was the inevitable and only ethically correct solution giving passive protection to far future generations.

The conclusion of this paper was: "It is sometimes difficult to understand how such divergent opinions can be sustained on these matters. Radioactivity is indeed a very touchy issue, but there are other reasons.

The nuclear industry finds it difficult to explain the technical questions involved, and is not completely trusted after several communication mistakes made in the past. Scientists are very happy to get funding to carry out research on very interesting and long-term projects. The aim of anti-nuclear groups is to fight as strongly as possible by any means the deep repository concept, in order to be able to say in fifteen years' time that nuclear energy has not been able to find a solution for the disposal of waste, that this is a major concern, and that it is thus not reasonable to renew the existing nuclear park!

In trying to clarify the debate, the conclusion can be summarised in the following statements:

- The deep geological repository is the only ethically correct solution in the long term which gives passive protection to far future generations. It allows retrievability, if needed, for a certain time before final closure. The deep repository is in all cases an unavoidable solution. Separation and transmutation could be a partial, and very expensive, solution. It could only be a complementary solution to a deep repository.
- Surface or shallow storage is a temporary solution. It could never be considered a permanent solution. The do nothing option, i.e. to leave the waste indefinitely in scattered surface storage locations, is not ethically acceptable. Our generation must prove that a solution does exist to provide passive protection to far future generations against nuclear waste.
- Our generation must provide the financing, make all the studies, and create a consensus to demonstrate the feasibility of deep repositories. Our children will have the responsibility to take the decision to implement or not to implement such repositories. Our grandchildren will have the responsibility to keep such repositories open for a certain period of time, and eventually to close them to assure long-term passive protection.

This conclusion is still correct today. As time goes on, it becomes more and more urgent to make progress in the right direction. Some ideas made popular by politicians are very dangerous and could force waste management into a complete dead end: such ideas include "extreme retrievability" or the so called "indefinite surface or subsurface storage". This kind of trap, which the nuclear world is in danger of falling into without realising what is happening, would surely jeopardise the whole future of nuclear energy. This would be a pity for our world which is not yet conscious that the golden age of oil is passing fast.

Coal is abundant but nobody expects that it will make a complete comeback and compensate for a probable lack of oil and gas. Since the new renewables will not be in a position to take a large share of the world energy production, hydrocarbons will remain in the long term the main competitor for nuclear. The competitivity of the next generation of nuclear plants will thus be highly dependent on the future price of oil and gas.

If we assume that it will take roughly ten years to decide on the next generation of nuclear plants, ten years to construct them and that their lifetime will be forty years, the middle lifetime point of this next generation will be in 10 + 10 + (40/2) = 40 years.

The competitivity of the next generation of nuclear power plants will thus be governed by the price of oil and gas around year **2040.** This paper seeks to demonstrate that this price will be high, due to a real shortage of reserves.

Oil and gas reserves

Usually, two types of oil are taken into consideration:

- Conventional oil, namely oil which is similar to the types of oil already produced, including deep offshore. It represents almost 100% of the oil produced.
- Unconventional oil, whose total production is now only 1 Mb/j, namely heavy oil or bitumen from Venezuela and Canada. Its production is far more difficult and the cost is higher, but significant improvements have been made and a large increase of this type of production is expected, even though the production of such "unconventional" oil faces big environmental problems such as strong greenhouse gas emissions.

Oil and gas reserves are not precisely defined. There is no real consistency in the data. Thus, figures are not reliable and hard to compare from different sources. The following categories are usually considered:

a) already produced
b) proven
c) yet to be found

These figures are linked by the following relations:

discovered to date = (a) + (b)
yet to produce = (b) + (c)
total ultimate reserves = (a) + (b) + (c)

Hydrocarbons are generated from vegetal material only in sedimentary basins, some of them being favourable to the creation of hydrocarbons, and some of them not. They migrate upwards and accumulate only if they find some trap (for instance an anticline made of porous rocks covered by impermeable layers) where they can stay for millions of years, waiting to be discovered. Such fields can be very large or very small, numerous or scarce, and easy or not to produce, depending upon the tightness of the host formation, initial pressure and viscosity of oil. One can understand why the hydrocarbon potential of sedimentary basins is highly variable.

Reserves as defined are only "recoverable reserves". The laws of physics make it impossible to recover 100% of oil in a given place. A major part of it, 50 to more than 90%, remains trapped in the geological formation, even when gas or water is injected to maintain pressure. It is sometimes possible to get a better sweeping of the host rock (solvent injection) but at a very high cost which makes it a kind of "unconventional oil". The recovery factor of gas is around 80%, twice that of oil.

Ultimate recoverable reserves of a basin are dependent upon the price of oil, which determines the boundary between economical and uneconomical fields but, in practice, oil can be produced or not and the sensitivity of reserves to price is not so high.

The oil industry is almost 150 years old and is a mature industry. Exploration surveys have been made all over the world and good statistics are available. It is thus possible to forecast the overall potential (ultimate reserves) of a basin as soon as a sufficient number of wells has been drilled. The main point is that oil and gas are a *finite amount of non renewable resources*. Whatever the technology and the skill of petroleum engineers, you cannot find oil which does not exist!

The debate

Since reserves are not a simple and precise notion, there is a big debate between optimists and pessimists.

Optimists gather under the banners of the United States Geological Survey and of some experts (Adelman). They base their case on the way the world petroleum industry reacted after the oil shock of 1973. At that time, a tremendous technical and financial effort led to the discovery of a lot of new reserves outside the Middle East and the factor "world proven reserves/production" rose progressively to 40. There is thus apparently no shortage. The optimists argue that technical progress will continue and lead to further improvements in the recovery factor and that new areas will be opened up to production. Moreover, during a field' s lifetime, its reserves usually increase because of the better knowledge of the geometry and characteristics of the field, thus increasing the number of proven reserves; this is the so called reserve growth phenomenon.

Pessimists (Campbell, Laherrère) emphasize first how much some reserves are "political" reserves rather than technical reserves. For instance, several OPEC countries suddenly increased their claimed reserves by 300 Gb around 1988, these spurious revisions being caused by a change in the calculation of OPEC production quotas based on total reserves! They also suspect USGS and US DOE of showing some political optimism!

Their basic argument relies upon the so called "peak curve" of King Hubbert. In the fifties, this bold geologist dared to announce that the domestic production of US crude oil could not go on climbing inexorably and would have to decline after 1970….and this is exactly what happened! But, at the time of his prediction, he was heavily criticised by all the "gurus" of the oil industry. Today, US consumption of oil is still increasing, while domestic production is decreasing and represents less than 50% of consumption, as President Bush pointed out recently.

Campbell and Laherrere have produced very good arguments to predict that we are very close to the "peak point" of the world oil production:

- in any area where companies are searching for hydrocarbons, the so called "creaming effect" has a tremendous importance: since elephants (giant fields which represent a major part of the world oil production) are large, they are caught first and new discoveries become smaller and smaller as exploration in one area becomes more and more mature.
- If, on a curve plotting reserves versus years, reserves are backdated to the date of discovery in order to cancel the reserve growth factor, then a real deficit appears between discovery and production. Even if the authors underestimate the discoveries of recent years, it is true that, for the past 20 years, there has been such a deficit and that the number of giant fields discovered every year shows a

decreasing trend. The discovery of many smaller (and more costly) fields does not offset the decline of the giant production fields.

- So many wells have been drilled all over the world that there is practically no virgin area left, except in protected Arctic regions. The most promising areas are deep in the Gulf of Mexico or deep in the Gulf of Guinea and the Caspian, but there is no scope for a new Middle East anywhere on earth.
- Technical progress has been very spectacular over the past 20 years, creating new tools (horizontal drilling, 3D seismic, etc) making discovery and production easier, opening up deep offshore fields, but not creating new oil. A real improvement of the recovery factor is not likely: fields are now produced correctly but at a fast rate for economical reasons.

Overall reserves

After a close comparison of arguments, the following figures are proposed for the overall world reserves forecast:

World oil reserves (in Gb)

Conventional oil

• **Already produced**	**850**
• **Proven**	**850**
• **Still to be found**	**300/500**
• **Ultimate reserves**	**2000/2200 Gb**
• **Optimistics say**	**3000**
• **Pessimistics say**	**1900**

Unconventional oil

• **Venezuela (extra heavy oil)**	**300**
• **Canada (tar sands)**	**300**
• **Others (oil shales, etc)**	**?**

World gas reserves (in Tm3)

• **Already produced**	**60**
• **Proven**	**140**
• **Still to be found**	**60/120**
• **Ultimate reserves**	**260/320 Tm3**
Optimistics say	**420**
Pessimistics say	**250**

Supply/demand balance

The present rates of production of hydrocarbons are the following:

- ❑ Oil : 77 Mb/day = 28 Gb/year
- ❑ Gas : 6.9 Gm3/day = 2.5 Tm3/year

All global energy estimates agree on a continuous increase in the demand for hydrocarbons if world growth is to be sustained. In the next 20 years, nuclear will still be limited and coal and new renewables will not be sufficient to fill the gap, pushing hydrocarbons demand up very strongly.

The following forecasts of the International Energy Agency (IEA) are generally admitted for the *world demand of hydrocarbons :*

	2000	2010	2020
Oil (Mb/day)	77	95	115
Gas (Tm3/year)	2.5	3.2	4.4

Ultimate reserves of 2000/2200 Gb of oil would mean *the peak production year taking place around 2010 or even before*. In this case the production of conventional oil will have a ceiling around 95 Gb/d and the need for unconventional oil to cover the gap would be as high as 20 Mb/d in 2020. Before 2020, the *Middle East will represent close to 50% of world conventional oil supply*

If the optimists were right, and ultimate reserves were 3000Gb, then the peak year would still be only around 2020. If production is boosted or maintained at a high level for some more years, the decrease will be steeper and come sooner.

In both cases, conventional oil will be on a downward slope after 2020 and unconventional oil will have trouble to match the world needs for oil. **The price of oil will therefore be high when the new generation of nuclear power plants starts to enter production.**

The world supply of natural gas is apparently less difficult than the oil supply because gas production and consumption are less mature than oil. Gas is still abundant on earth but requires huge infrastructure investments and is currently still a regionalised and rigid market.

The time delay between gas and oil is roughly 20/25 years but gas demand is growing faster. One can expect world gas production to peak before 2040 in all cases. The world gas decline will thus take place well within the lifetime of the next generation of nuclear power plants. Moreover, gas prices are always closely connected to oil prices. For all these reasons, it is clear **that the price of gas will be high when the new generation of nuclear will have to compete with gas powered plants.**

In conclusion, if we summarise all the challenges facing the oil and gas industry, in the case of a sustained world growth and before the middle of the century, i.e.

- the doubling of Middle East oil production in less than 20 years
- huge development of unconventional oil
- solving gas shortages in some regions
- a decrease in conventional oil in 10 or maybe 20 years, and of gas 20 years after,

We may conclude that the era of cheap oil and gas is over and that in the medium and long term, hydrocarbons prices will be high. The new generation of nuclear power plants will not need the help of the greenhouse effect to be competitive with fossil fuels, even with increases in the price of uranium. The world's hunger for energy combined with the decline of fossil fuels will create a very strong demand for nuclear.

A real nuclear revival is very likely provided that safety is kept at a very high level and that the waste problem is solved.