# Evolution and outlook for fossil fuel production costs

Jean-Philippe Cueille, Jean Masseron

Centre Économie et Gestion

# Evolution and outlook for fossil fuel production costs

*Jean Philippe CUEILLE*
*Jean MASSERON*

July 1996

**Cahiers du CEG - n° 25**

**Texte de conférence**

Également disponible en français

ENSPM - Centre Économie et Gestion
228-232, avenue Napoléon Bonaparte, Boîte postale 311
92506 RUEIL-MALMAISON CEDEX.
télécopieur : 33 (1) 47 52 70 66 - téléphone : 33 (1) 47 52 64 08

La collection "Cahiers du CEG" est un recueil de présentations de travaux réalisés au Centre Économie et Gestion de l'ENSPM, Institut Français du Pétrole, travaux de recherche ou notes de synthèse. Elle a été mise en place pour permettre la diffusion de ces travaux, parfois sous une forme encore provisoire, afin de susciter des échanges de points de vue sur les sujets abordés.

Les opinions émises dans les textes publiés dans cette collection doivent être considérées comme propres à leurs auteurs et ne reflètent pas nécessairement le point de vue de l'ENSPM ou de l'IFP.

Pour toute information complémentaire, prière de contacter :

**Axel PIERRU** *tél. :* **33 (1) 47 52 64 08**

The "Cahiers du CEG" is a collection of articles carried out at the Center for Economics and Management of ENSPM, Institut Français du Pétrole. It is designed to promote an exchange of ideas on the topics covered.

The opinions expressed are the sole responsability of the author(s) and do not necessarily reflect the views of ENSPM or IFP.

For any additional information, please contact :

**Axel PIERRU** *tél. :* **33 (1) 47 52 64 08**

The following paper was given by Jean Masseron at the 19th Annual International Conference of the International Association for Energy Economics held in Budapest from 28 to 30 May 1996.

The authors would like to thank Frédéric Laurent, doctoral student at the Center for Economics and Management of ENSPM, for his research work on the subject.

# Evolution and outlook for fossil fuel production costs

**Jean Masseron, Jean Philippe Cueille**

**Institut Français du Pétrole**

It is an honour for me to be here this morning and to share with you some ideas on the evolution and outlook for the production costs of fossil fuels. The subject is a vast one but fortunately the theme of this round table session - sufficient energy at falling energy prices - provides a framework that enables us to restrict ourselves to a few of the aspects involved. We have reached the last day of our international conference and a lot of important things have been said. So it is rather an uncomfortable privilege to be a speaker today because - I quote a well known French humorist - "some people talk during their sleep but only lecturers talk during other people's sleep".

In the early 1970s, the club of Rome drew people's attention - in a manner which has gone down in history - to the finite nature of world energy resources and to the inevitability of a crisis, in view of the consumption trend prevailing at the time. Twenty-five years later, the energy scene has changed completely and present concerns are very different, and yet paradoxically very similar. True to the spirit of the club of Rome, we are today concerned with global conservation, with stabilising $CO_2$ emissions and more generally with sustainable development.

I don't need to tell energy specialists such as yourselves that our industry is a long term one, with periods of adaptation that last decades and fundamental characteristics that shape its structure and prevail in spite of all the evolutions that the industry has undergone. The share of fossil fuels in the world energy balance was around 95% in 1970 and today stands at 90%. Within a foreseeable future, that is within the next 25 years, scenarios predict only a slight decrease to the 80-85% level (Figure 1). We are today faced with energy prices, before tax, that are similar, in real value, to those of 1973, and questions that were pertinent at the beginning of the 1970s may perhaps still be valid today, in a different context.

I feel that this is, to a certain extent, the aim of this morning's session, and that the subject of the evolution of fossil fuel production costs, which I propose to discuss with you, is certainly a key factor with respect to the future mobilisation of energy resources. The level of requirements has already been stressed during the conference and it is vital to study the way in which energy industry costs, and those of the oil and gas industry in particular, have evolved and will continue to evolve in response to further demand.

Future increases in production seem to be more a question of economics than one of the availability of resources. Even if uncertainty prevails with regard to the amount of energy reserves and the possibility of new discoveries, there is a certain consensus on the abundance of resources. As you know, there are significant reserves of coal and they will last for several centuries at the present rate of production. Oil and gas reserves are obviously less plentiful but they should meet energy needs for a large part of the next century. In spite of alarmist forecasts at the beginning of the 1970s, reserves have grown considerably over the last 25 years while at the same time satisfying sizeable cumulative oil and gas consumption requirements. If we take non-conventional sources (extra-heavy crudes, oil shales, tar sands) into account, it is clear that the resources exist.

From the economic standpoint, satisfying consumers' fossil fuel requirements will depend on both their production costs and on the ability to make them competitive on the consumer market. The foreseeable evolution in the CIF costs of the different fuels seems to be the relevant economic indicator. Logistics are an expensive item where solid fuels and natural gas are concerned, as can be seen in Figure 2. Actually, this cost structure will allow me to explain more precisely how I intend to structure my exposé. I shall start by analysing coal from both angles, that of production costs and that of logistic costs. However I am not, as you know, an expert on this energy source so I shall be brief. I then propose to examine the question of oil and gas.

Over the last 15 years the international coal trade has developed strongly, whereas CIF costs to the port of unloading in the importing country have decreased (Figure 3). An analysis of some coal industry characteristics will help us to understand the situation.

Current coal production costs vary greatly from one country to another, and within the same country from one mine to another. Leaving aside exceptional cases, costs may range from $10/ton in open cast American mines to around $100/ton in less accessible European mines. This cost range is not so very different from that of oil and gas, except that much of world coal production (especially in Europe) is heavily subsidized. Of course international competition does not operate fully for social reasons and because solid fuel is often the country's sole domestic source of energy. This practice is nevertheless being gradually phased out insofar as subsidies are becoming an increasing burden in the present unfavourable economic context, and the principle itself is everywhere proving incompatible with the current liberal and global trend. Coal production worldwide should therefore become increasingly competitive, with reduced costs compatible with international price trends.

At this point I think I should analyse the performance of coal producers and exporters. The cost of coal is influenced by a number of factors, causing it to rise or fall. Firstly, there is no international coal market cartel, hence competition is fierce among exporting countries. This has led to significantly improved performance in all segments of the coal industry (production, domestic transportation international transportation). Secondly, another important feature of coal production is the high cost of manpower. Since 1980 the latter has increased significantly in most countries. However the trend toward open cast mining, the mechanisation of a number of mines, more intensive use of the more effective production methods (longwall mining systems, draglines, etc.) have enabled considerable gains in productivity. In the space of 15 years the latter has been multiplied by a factor of 2 in the USA, by 2.5 in Australia and by 3 in South Africa, resulting in an overall reduction in production costs.

Similarly, domestic and international transportation costs, which account for a large share of the CIF cost of coal (as can be seen in Figure 2) have decreased. Shipping costs have decreased due to the use of larger ships and also on account of the existing overcapacity. Domestic transport competition (rail or waterway) is generally less fierce than on the international scale, due to monopolies, but gains in productivity have been achieved and they have had their repercussions on freight rates. In the United States, for instance, productivity gains in rail transport have increased by 50% since 1980, through the use of aluminium cars, longer trains, automation and computerization.

It is difficult to foresee exactly what coal production costs will be in the next 10 years, but the falling trend in costs, related chiefly to improved productivity, should prevail and compensate for the factors that increase costs (manpower, more stringent regulations). Furthermore, outsiders have appeared on the market (Indonesia, Colombia, Venezuela, etc.), further increasing competition, and the move toward open cast mining will continue. It is estimated that, worldwide, open cast mining will account for 50% of coal produced in 2000. The trend is therefore likely to be toward more capital-intensive mines. Similarly, the gradual modification of ports to enable them to accommodate large ships will provide economies of scale with respect to transport. CIF coal costs, in constant money, should therefore decrease slightly. I must point out, however, that the International Energy Agency sees things a little differently (Figure 4). In all events, if coal is increasingly used for electricity generation it is the cost of clean technology rather than that of production that is likely to be predominant.

I will now come to the heart of my subject - oil and gas. I should like to make a short incursion into the past in order to throw some light on the present and the future. The first oil shock increased the price of oil and made consumers aware of their dependence on it and of the vulnerability of oil supplies. This feeling was intensified by the Iranian revolution in 1978 and was the prelude to the second oil shock.

In an attempt to replace the resources they lost during nationalisations by producing countries, the international oil companies launched into exploration and production in a manner that might be termed frantic. The higher prices of crude allowed them to return to more costly, mature areas such as the 48 lower states of the United States, and to prospect and develop fields in new, more difficult and geologically uncertain areas (North Sea, non-OPEC developing countries, etc.).

This resulted in a sharp increase in investment. Between 1973 and 1982, investment in exploration and production worldwide doubled in constant money. Operating costs also increased sharply. Consequently, there was a significant rise in total production costs. There were virtually no incentives to control costs, crude prices were high and were expected to rise even higher, and in addition, the bulk of the increase in expenses was borne by the drastic tax systems instituted by the host countries (goldplating). The idea in everybody's mind was to produce as fast as possible, at any price (or rather at any cost !). Experts predicted a constant and unavoidable increase in technical costs. What counted was access to reserves - and expensive, sophisticated enhanced recovery techniques were contemplated. The increased costs could at best be only slightly attenuated or deferred due to technical progress. The economic theory of exhaustible resources further strengthened the idea.

This picture of the pre-1980 oil industry that I have just painted for you in a few minutes is admittedly something of a caricature. I nevertheless feel that it reflects the ideas and modes of behaviour that prevailed at the time. Moreover, in that high-cost environment, the oil industry strongly intensified scientific research (Figure 5). The extended research and development budgets made it possible to explore a whole series of new techniques, to establish a base of new knowledge that would pave the way to current achievements.

Let us now return to the present situation. At first glance, compared to the end of the 1970s and the start of the 1980s, we might think we were living in another world. In the space of 15 short years, we have moved from a period of intense oil-related nationalism with high crude prices to a very liberalized environment with moderate crude prices. The international oil companies have extended their activity to virtually the entire planet (ex USSR, Venezuela, onshore China). Strong competition developed for the benefit of their knowhow and the source of funding that they represent. Only a few countries, that can be counted on the fingers of one hand (Saudi Arabia, Kuwait, Mexico, etc.) are today closed to foreign upstream activity - and for how much longer? The idea of supply security has been abandoned in favour of the tyranny of cost cutting. The oil and gas industry has become fundamentally cost conscious, and this is in itself a cultural revolution. Between 1945 and the beginning of the 1980s, the corporate power and efficiency was measured in terms of volume rather than cost. In the 1950s and 1960s, the accent was on developing the cheap supply of Middle-Eastern oil and finding outlets for it, and after the first oil shock the major concern, as I pointed out, was in finding new crude sources. It took the price collapse of 1985/1986 and the realisation that its effect was lasting to fundamentally modify the industry's pattern of behaviour.

In ten years considerable changes have taken place. With regard to costs, there has been a complete reversal in trends (Figure 6). Admittedly there was considerable scope for savings and a series of measures resulting in relatively marked reductions in costs were implemented without much difficulty. Nevertheless, the really significant savings were achieved by major changes involving the use of more efficient techniques and a complete overhaul of work methods and corporate organisation.

The most important technical advances on an industrial scale concern seismic, drilling and production methods and schemes. 3D seismic has made it possible to discover smaller accumulations or more elusive traps, to considerably decrease the number of dry exploration and delineation wells, and to improve knowledge of the reservoir during production. With respect to drilling, which is often the largest item in upstream expenditure, great progress has been made and has led to increasingly complex well architecture, making it possible to exploit thinner geological formations providing access to hydrocarbons previously considered to be unrecoverable. Figure 7 shows that in addition to horizontal wells which are now common practice, we also have 2D multidrain configurations, then 3D multibranch configurations, along with highly deviated wells with complex trajectories. Furthermore, the use of slim hole drilling, chiefly for exploration purposes, is also a cost reducing factor. With respect to offshore, technological progress has mainly resulted in lighter platforms. A platform offering comparable technical performance is 30 to 50% lighter. Multiphase flow pumping is also starting to develop in some favourable cases, and this could in the long run replace offshore production platforms.

The recent period is characterised not so much by revolutionary technologies as by the rate at which technological innovations have spread. In harsh geological and climatic conditions, the upstream oil sector tended to prefer proven technologies and innovations were brought in very gradually. However necessity prevailed. In order to remain competitive in a context of durably moderate prices, the companies had to reconsider their traditional development schemes. But the process did not stop there, because at the same time the companies completely overhauled their organisational and operational methods and refocused on their core business. They gave up those activities that did not coincide with their intrinsic skills or for which they did not have the critical size. Internally, in order to avoid the repetition of tasks and to promote an interprofessional approach, they abandoned the sequential approach and instituted the multidisciplinary approach whereby all the specialists involved (geologists, geophysicists and reservoir engineers) work together from the start of the project. New relationships were established with services and equipment companies. The latter relinquished the role of supplier to become a full partner in the project, participating in its initial definition, implicated from the start in its execution, and earning their share of the profit through improved performance, for as somebody said in a BP report: "sharing the risk and pooling expertise brings significant profits". They have also assumed the management of smaller suppliers by offering integrated services. All these changes in fact streamlined corporate structures and contributed to a certain standardization of equipment.

The upstream oil industry has therefore undergone a complete mutation in the space of about ten years. The combination of rapidly spreading technical progress, improved operational efficiency, and intensified competition affecting the margins of all the players has led to substantial reductions in costs. These reductions are the result of both of lower operating costs and the improved efficiency of the operations themselves. Figure 8 shows the rise in the drilling success rate and in the increase in reserves added per well in the United States. This evolution is of course not restricted to the United States and can be evidenced in the rest of the world. The total cost reductions achieved by the industry as a whole can only be estimated. However in less than ten years the oil companies seem to have managed to cut the technical cost of the barrel by 30 - 40%. This is a remarkable achievement for an industry that is more than 100 years old, particularly in an increasingly difficult geological and technical environment.

What is the outlook for the years to come? First, we must remember that gains in costs have basically only affected those regions where the international oil companies were active. Around half of world oil production (Saudi Arabia, Iran, Irak, Kuwait, Mexico, Venezuela, Russia, China) has so far benefited very little from the progress that has taken place over the last ten years. The gradual opening up of some of these regions to foreign oil companies will not significantly cut costs but will provide access to substantial low or moderate cost crude oil potential. If geopolitical considerations of supply diversification were not involved, this would permit an affirmative answer to the question: "sufficient energy supply at falling prices"?

There is one current feature of the oil industry that is paradoxical from the point of view of economic theory, and that is the fact of starting by producing high-cost resources. The balance between OPEC and non-OPEC production, and in the long run between the Middle East and the rest of the world, seems to constitute the constraint required to guarantee supply at acceptable prices. Contrary to the forecasts made in the early 1980s, instead of inexorably declining, non-OPEC production has never been healthier. Concern with the finite nature of oil and gas reserves seems to have been temporarily put aside. Technological progress and human creativity have pushed back the frontiers.

Nevertheless, as shown by my previous historical review, the oil industry initiated its cost cutting policy at a time when there was great scope for gain. The experience acquired by the companies during the last decade has inexorably changed corporate thinking, but the situation ahead of us is perhaps less favourable. Figure 6 indicates a slowdown in cost cutting over the last few years. Does this plateau mean that costs will rise?

There is no immediate answer to this question due to the diversity of existing situations and the disparity of available cost data. Nevertheless, there still seems to be scope for cost cutting but the opportunities are less visible due to the more difficult production conditions, involving, in addition, problems of safety, of environmental protection and of dismantling installations. Gains in costs are more difficult to achieve but the industry considers that it has not yet reached its limit and that there are still significant gains to be made.

So, with an adequate amount of research, there is still considerable scope for progress. For instance, the success rate in exploration can still be improved by the untiring search for improved knowledge of basins, for a better understanding of the conditions of hydrocarbon generation, and by the use of increasingly sophisticated seismic imaging techniques. Ten years ago the success rate was one well out of seven drilled, and today it is one out of four in known areas, and the target of one out of three by the beginning of the 21st century is feasible. Similarly, significant gains in drilling are still possible, both in terms of cost cutting and increased recovery rates. Furthermore, there is another area with strong potential for cost cutting and that is offshore production. It is growing steadily and concerns an increasing number of countries. A large proportion of costs stems from the necessity to install production platforms for processing the produced effluents before shipping them to the coast. The continuing progress in subsea production and multiphase pumping, the capacity to prevent hydrate formation in pipelines, and the resolution of problems of measuring effluents should gradually make it possible to limit the use of deep water production platforms.

All these developments should not only contribute to a reduction in costs, but more specially they should provide access to new reserves. The latter will of course stem from new discoveries, but they will also to a large extent result from the mobilisation of known resources that were hitherto unexploited because they were located in small, more complex, deeper and more inaccessible fields. The 200 Mb offshore field at a water depth of 150 m will always be welcome, but the new frontier of the oil industry today consists largely in better exploiting the potential that exists in mature areas or areas nearing maturity on which there is plenty of knowledge and where considerable infrastructure already exists. It is in this context that we can ensure "sufficient supply at falling prices". In this respect, the example of the United Stares is encouraging. Although the extent to which the country has been explored is without parallel, the American companies manage somehow to renew reserves in proportions corresponding approximately to the year's production. Areas like the Gulf of Mexico have a new life ahead of them, due mainly to deep water developments. Fields located at depths of over 1000 m, such as Shell's Mensa project at a depth of 1600 m, are taking over from the more traditional types of production.

Similarly, assuming a constant oil price in constant money, production prospects for non-OPEC countries seem reasonably safe up to 2000, with these regions likely to produce an extra 4 - 5 Mb/d. Overall, these projections should remain valid, even if oil prices fall only slightly. A more marked fall in prices, which can never be excluded due to OPEC's difficulty in keeping to its production ceiling, would not really affect supplies until after 2000 in view of the long lead times involved in oil and gas production and of the large proportion of initial fixed costs in productions costs.

I have already mentioned the organisational changes that have taken place within the oil and gas industry. I feel that there is scope for still more change. Integrated service suppliers will be able to offer the companies even more complete services. Moreover, strategic alliances between companies and the major equipment and service companies are likely to develop further. The companies have come to realise over the last few years that individual attempts by the different players (companies and suppliers) to reduce costs can lead to a less than optimum situation, due to the loss of efficiency at the company-supplier interface. By fully involving the main supplier(s) from the design stage of the development of a field, new possibilities for cost cutting are apparent and this allows overall optimisation of operations. This approach seems to have potential for substantial savings with respect to the various petroleum-related operations.

These are my feelings with regard to the current situation. However my long experience of the oil industry has taught me that most economic projections in the field of energy turn out in practice to be wrong. We have seen a few examples this morning. We would be better advised to follow the realistic approach of the well known French writer Saint-Exupéry who said "the future is not something one predicts, one has to make it happen".

In my view the oil industry is clearly heading in this direction. The progress achieved through the technological impetus and the revolution in operational methods will help it to prepare to meet the challenges of the future, that is to ensure "sufficient supply at falling prices" in the short and medium term, and in the longer term to enable the mobilisation of non-conventional hydrocarbons as efficiently and economically as possible.

I would now like to briefly mention the prospects for natural gas. Generally speaking, production costs of natural gas throughout the world are not as well known and are less studied than those of coal or oil. The estimate provided by Figure 9 will nevertheless give us an order of magnitude. Costs vary greatly according to the size of the field, its location, the water depth if it is offshore, and the climatic conditions. Natural gas production uses the same techniques as oil production and is generally carried out by the same companies. Although there are some constraints that are specific to natural gas production, most of the gains in production costs that we have just observed for oil apply equally to natural gas.

Consequently I think it is more relevant to look at the cost of logistics. International transports costs, whether by pipeline or methane carrier, constitute a major component of the cost of gas delivered to the consumer country, as we have already noted (Figure 2). The figure of around 45% that you can see here includes pipeline transportation costs and transit fees payable to the countries concerned when it is shipped in gaseous state, or the cost of domestic transportation from the field to the coast, liquefaction and transportation by methane carrier when the gas is shipped in liquid state. This is an estimation of the situation in France in 1995. France uses four natural gas suppliers: two of them are relatively close to France (the Netherlands and Norway) and their costs of gas delivered to the French frontier are fairly low. This is why 45% is in reality very low in relation to the situation that will prevail in Europe in the years to come. When the time comes for gas to be supplied by producers that are further afield, transportation could amount to 60 - 80% of the CIF cost. Figure 10 clearly shows the level of transportation costs for natural gas, whether on land or at sea. The overland transportation of natural gas is 3 to 5 times greater than that of oil for the same amount of energy, and the cost of maritime transportation by methane carrier is approximately 10 times higher. This puts into perspective the implications of reductions in logistical costs for a sufficient supply of natural gas in a moderate energy price context. On the basis of current prices and costs, many more distant sources of natural gas are not competitive. If there is a reduction in energy prices, natural gas would be the fossil fuel whose development is most likely to be affected, in spite of its undeniable advantages in terms of supply source diversification, lower $CO_2$ emissions and its efficiency in electricity generation. It is therefore urgent to reduce transportation costs.

Like oil production, cost cutting will be the result of better standardization of equipment, increased competition and very cost-conscious project teams. Nevertheless, since natural gas transportation is intrinsically capital-intensive, potential gains will be related to technological progress and economies of scale. This is particularly true for natural gas transportation by methane carrier. In view of the technological advances currently achieved, we can today contemplate the possibility of doubling the unit size of liquefaction trains and using larger capacity methane carriers. These developments would allow an immediate overall gain of around 10%, which could be increased to 20 - 25% with greater technological changes (Figure 11). With respect to natural gas transportation by overland or subsea pipeline, in addition to the economies of scale already mentioned, there is potential for cost cutting through improved steel quality which would make it possible to reduce pipe thickness and welding time and consequently the time required for laying the pipeline. This factor has a significant impact on costs where subsea pipelines are concerned.

These cost reductions are fundamental for two reasons. Firstly they will make new gas projects cost effective and secondly they will allow acceptable prices to be charged for gas delivered to the consumer countries. However, the development of sufficient natural gas supplies will no doubt involve some thinking on the principle of fixing gas prices. The very high value of natural gas in some of its applications, such as electricity generation, should earn it a premium and possibly lead in the long term to disassociation of its price from that of oil. Pricing formulas that protect the seller against a fall in oil prices and the purchaser against the risk of a rise in prices should be designed. There is scope here for energy economists.

I should like to conclude by returning to the question of oil. The last 25 years seem to have illustrated the fact that oil costs and prices follow similar trends. When prices rise, costs also increase, causing the industry to turn to new regions with costly barriers to cross in terms of technology and infrastructure. On the other hand, once prices have decreased, the companies have further exploited their assets, made full use of the existing infrastructure, developed greater synergy with their main suppliers (both in terms of the reduced cost of services and through the strategic alliances formed) and have thus achieved significant cost reductions. We have seen that, unless there is a price collapse, there are good prospects in the medium term for balanced production between OPEC and non-OPEC regions, that is until the beginning of the next century. After that, modifications in the geopolitical environment and in the supply-demand balance could completely change the picture. I will therefore conclude on a low-key note by simply expressing my confidence in the creativity and capacity to adapt of our industry in meeting the challenges that are bound to arise. There is a saying in France that "uniformity leads to boredom". Well, we shall never be bored in the oil and gas industry.

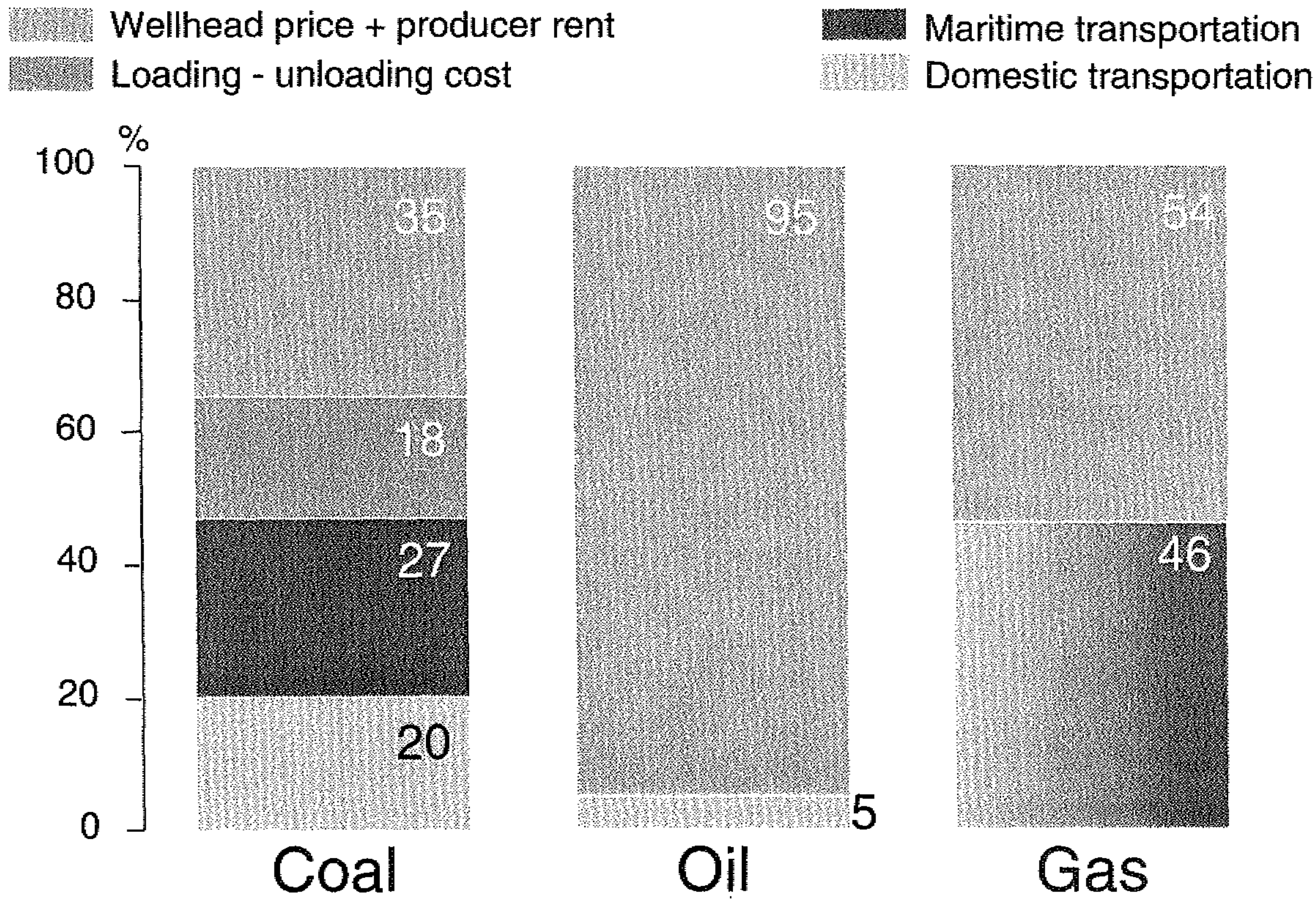
# Projected world demand for energy ($10^9$ toe)

| | 1980 | 1990 | 2000 | 2010 | 2020 |
|---|---|---|---|---|---|
| Oil | 3.0 | 3.1 | 3.7 | 4.2 | 4.8 |
| Gas | 1.3 | 1.7 | 2.3 | 2.9 | 3.6 |
| Coal | 1.8 | 2.2 | 2.6 | 3.2 | 3.7 |
| Nuclear | 0.15 | 0.45 | 0.6 | 0.8 | 1.1 |
| Hydropower and others | 0.45 | 0.55 | 0.8 | 0.9 | 1.1 |
| Total | 6.7 | 8.0 | 10 | 12 | 14.3 |

Source: CEG-IFP

fig.1

# CIF cost structure (France, 1995)

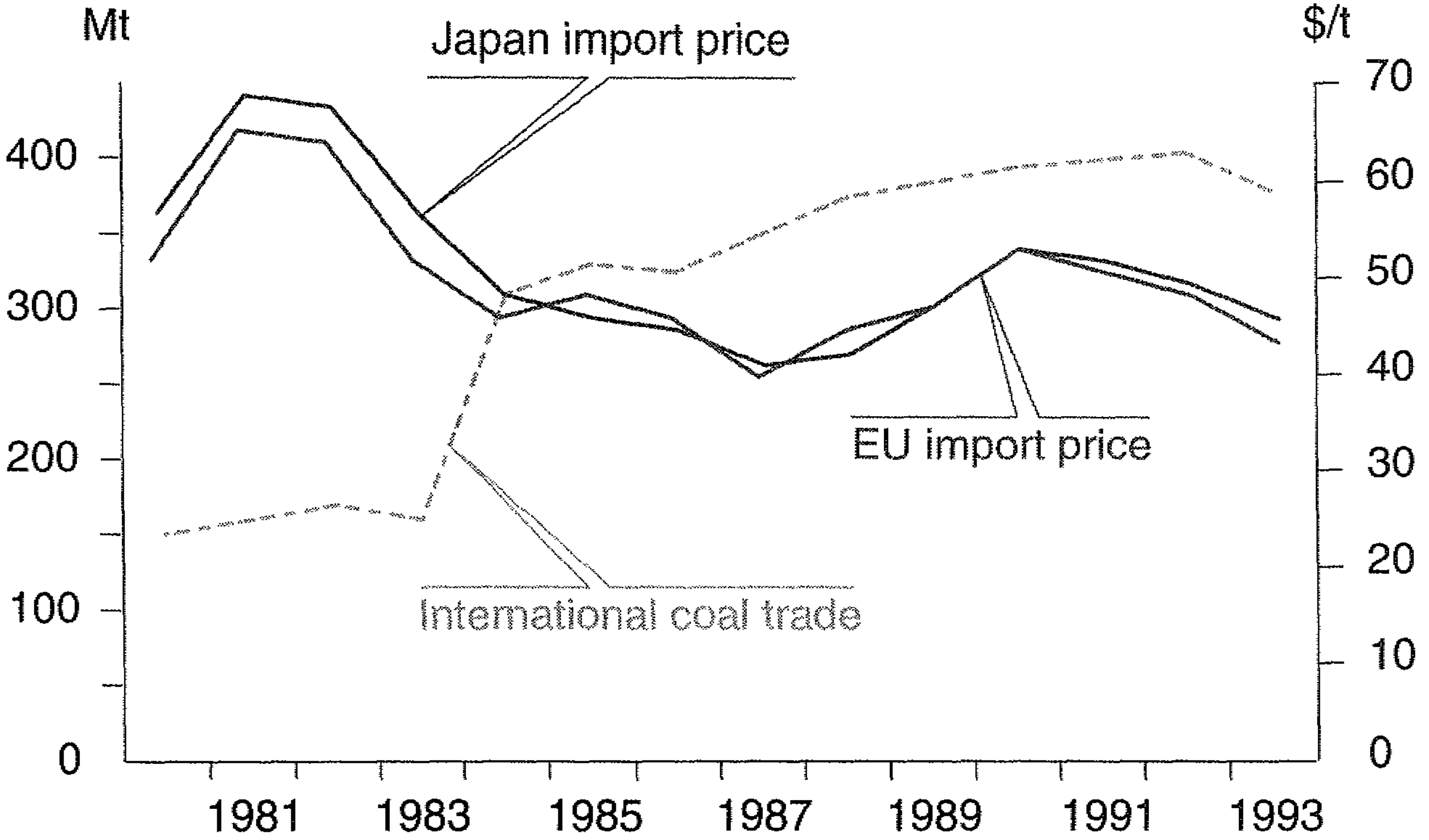



Source: Cedigaz, CDF, IFP



fig.2

# International coal trade and import prices

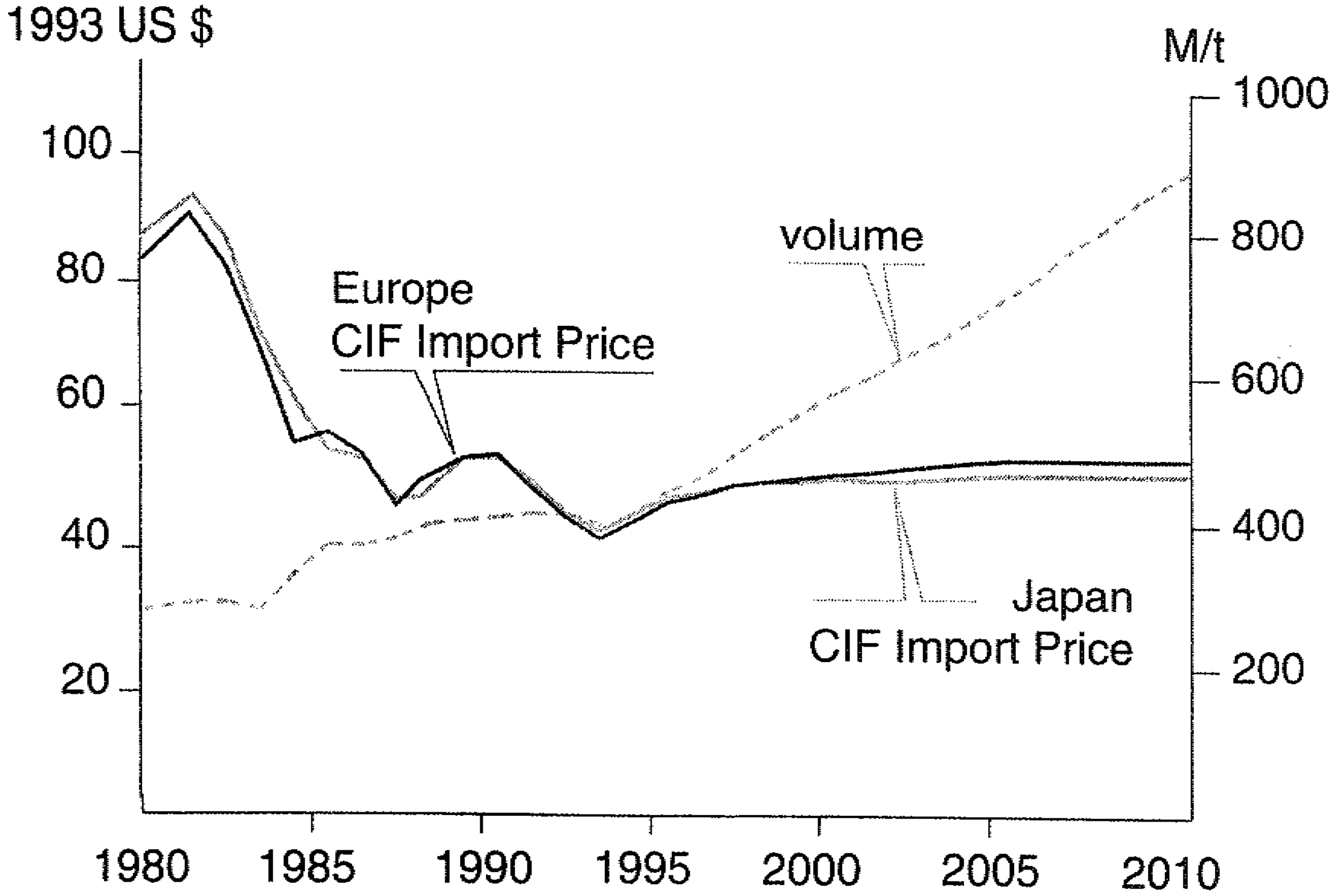



Source: Coal information

19th IAEE International Conference

fig.3

# International coal trade - volume and prices: forecasts



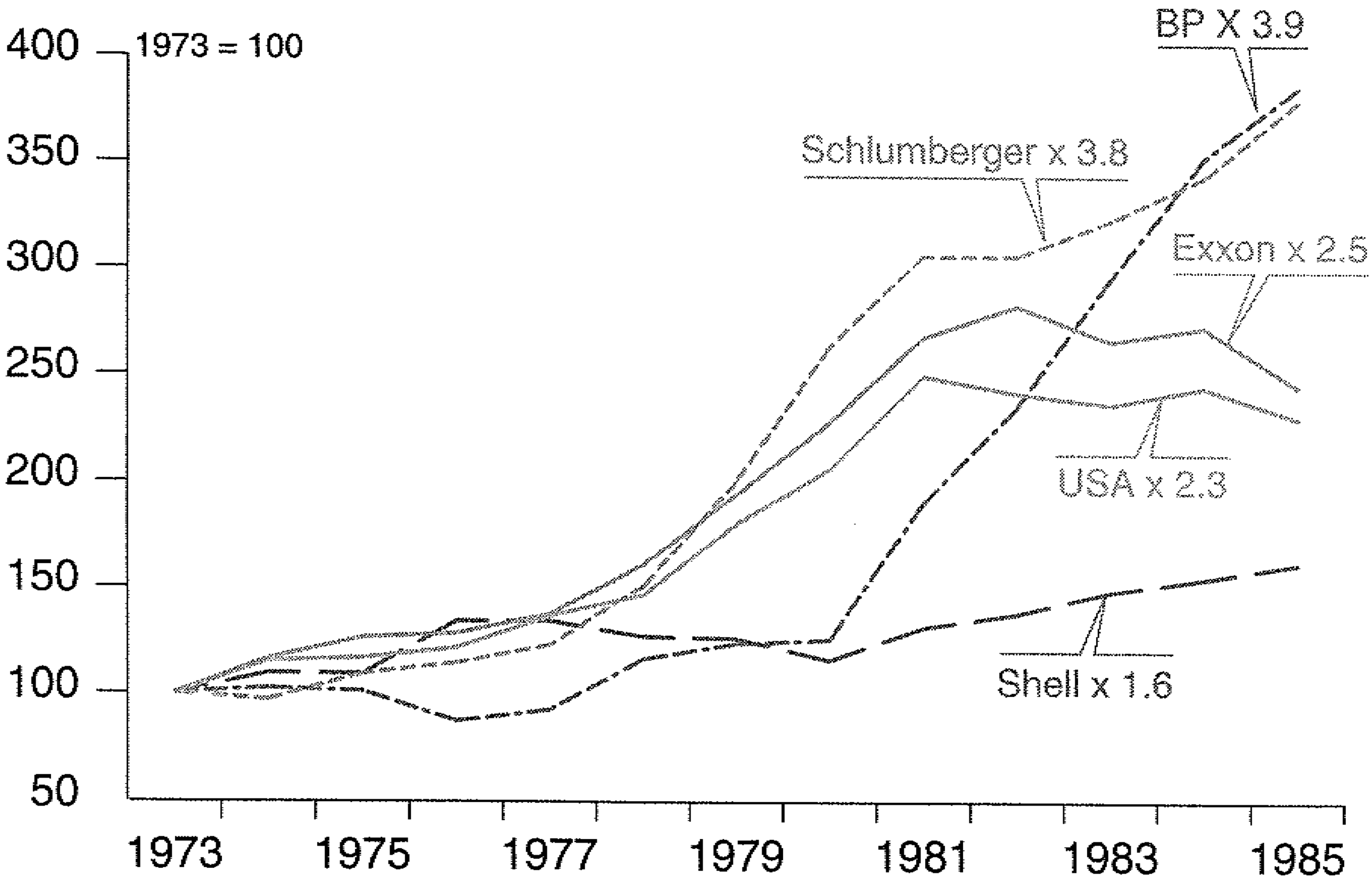

Note: Volume refers to total hard coal trade. Prices relate specifically to seaborne trade.

Source: IEA



fig.4

# R&D Petroleum Industry Expenditures (1973-1985)

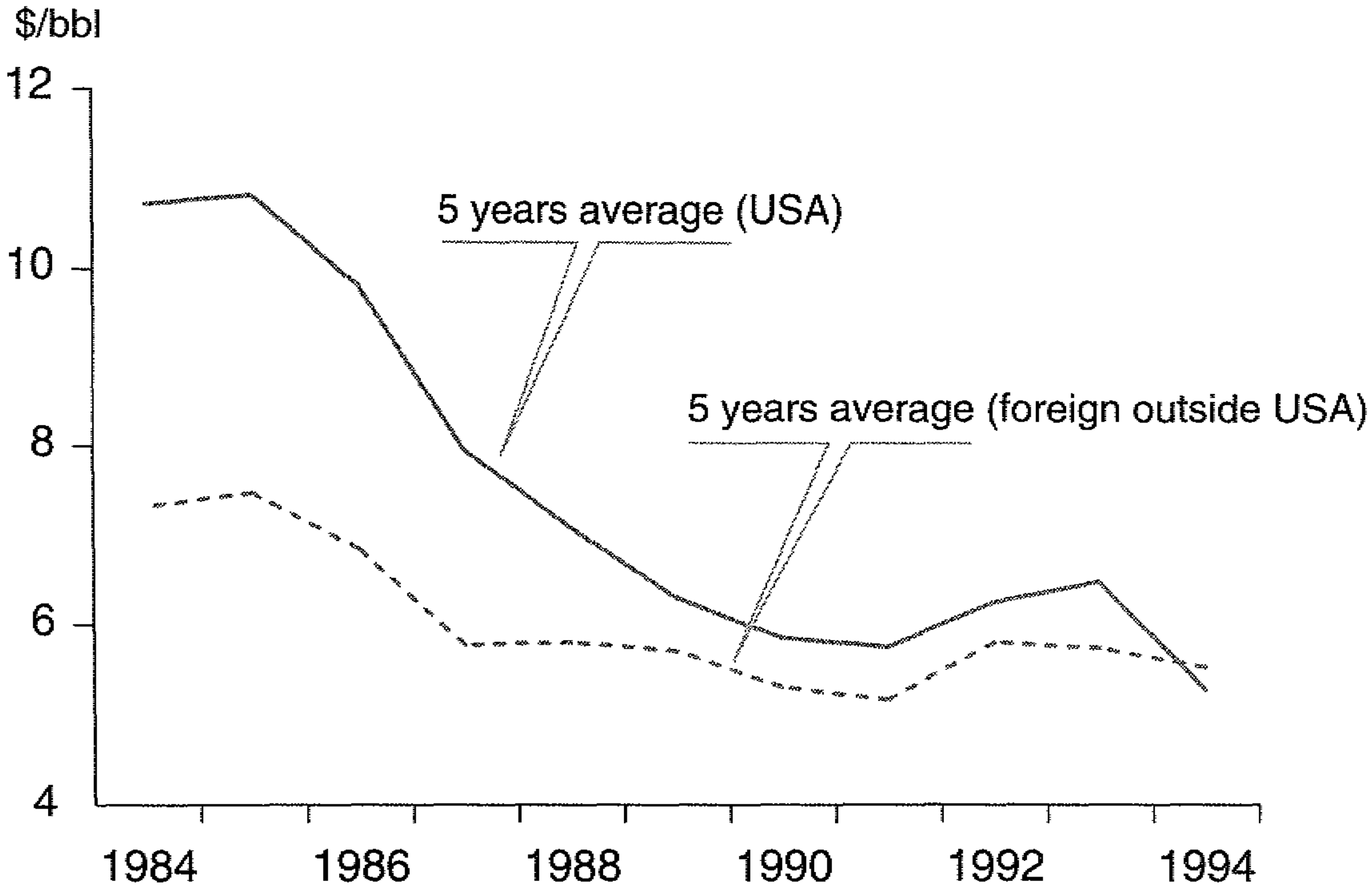



Source: Annual reports, IFP/DSEP.



fig.5

# Finding costs

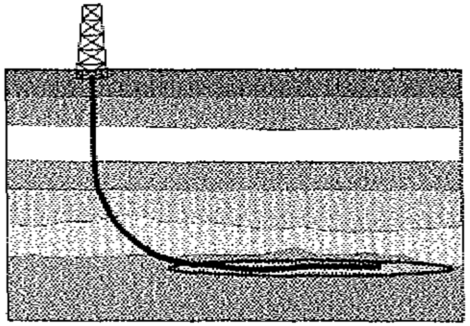



Source: from Arthur Andersen



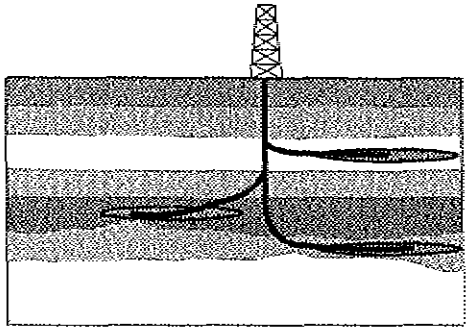
fig.6

# Complex 3D well architectures



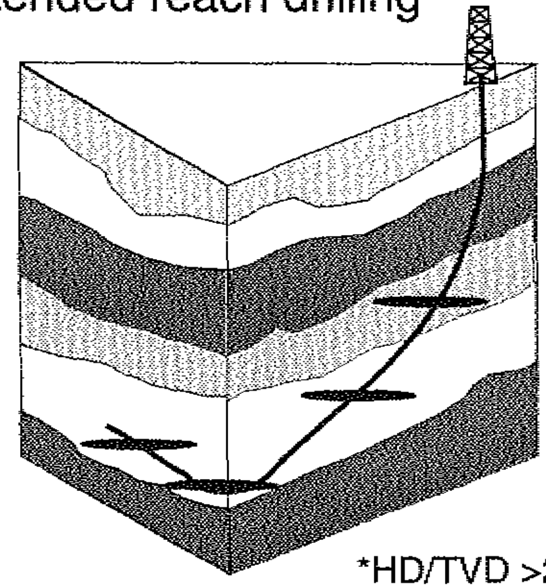
Horizontal well

**2D**



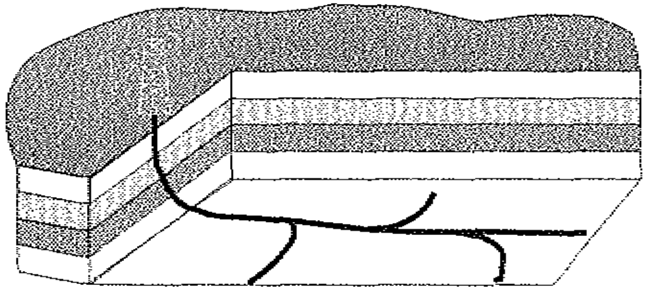
Multilateral well

3D complex well and extended reach drilling*



*HD/TVD >2

**3D**



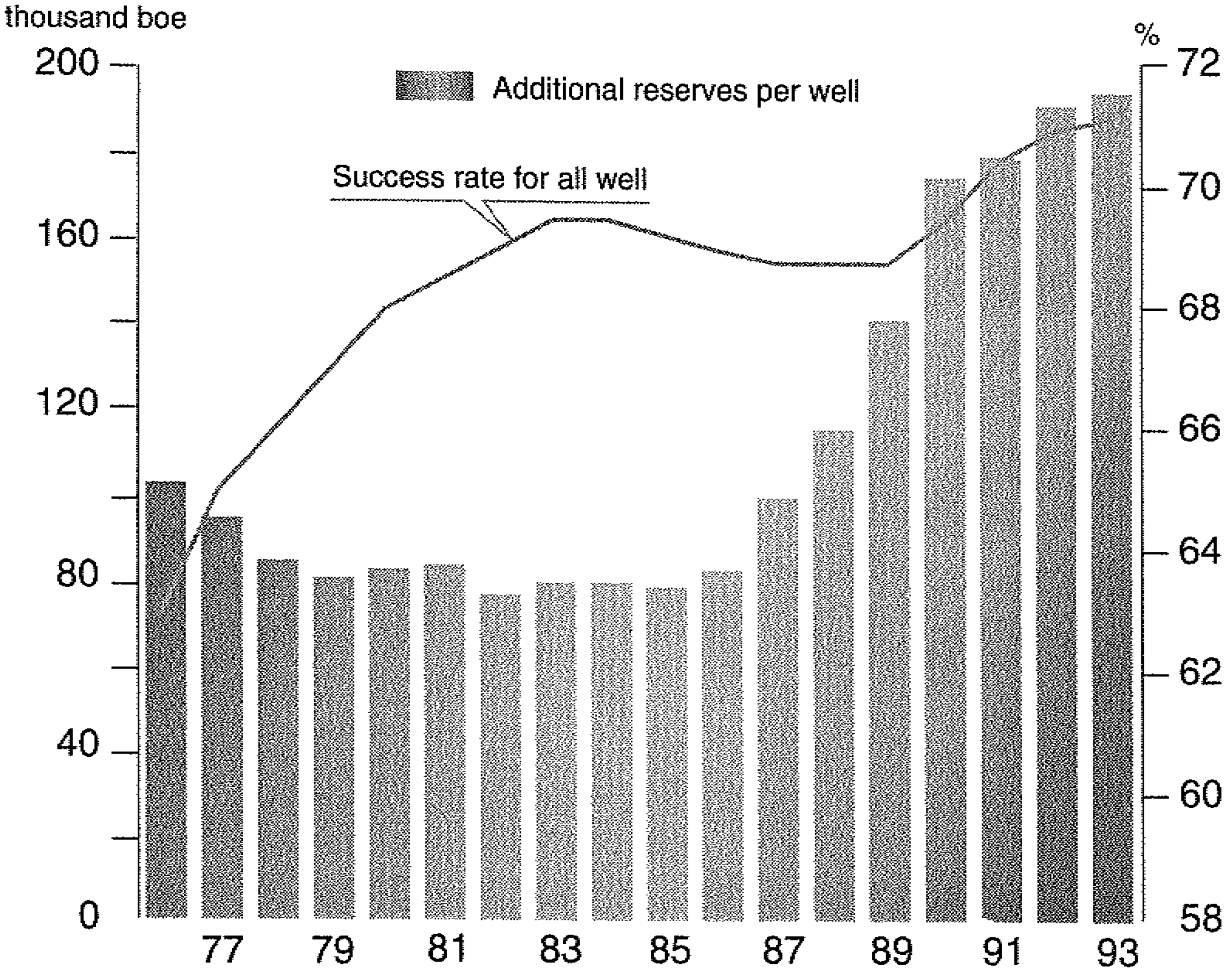
Multilateral well

Source: IFP, DSEP, EIP



fig.7

# Success rate in the USA




Source: CGES & Performance profiles of major Energy Producer 1993, January 1995



fig.8

# Natural gas production costs

| | $/MBtu * |
|---|---|
| **United States:** | |
| onshore: | 0.5 - 2 |
| offshore: | 0.5 - 2.5 |
| **Western Europe:** | |
| onshore: | 0.3 - 1 |
| North sea: | |
| south: | 0.5 - 1.5 |
| north: | 1.5 - 2.2 |
| marginal fields: | 2.5 - 4.5 (?) |
| **Middle East:** | |
| onshore: | 0.2 - 0.5 |
| offshore: | 0.5 - 1 |

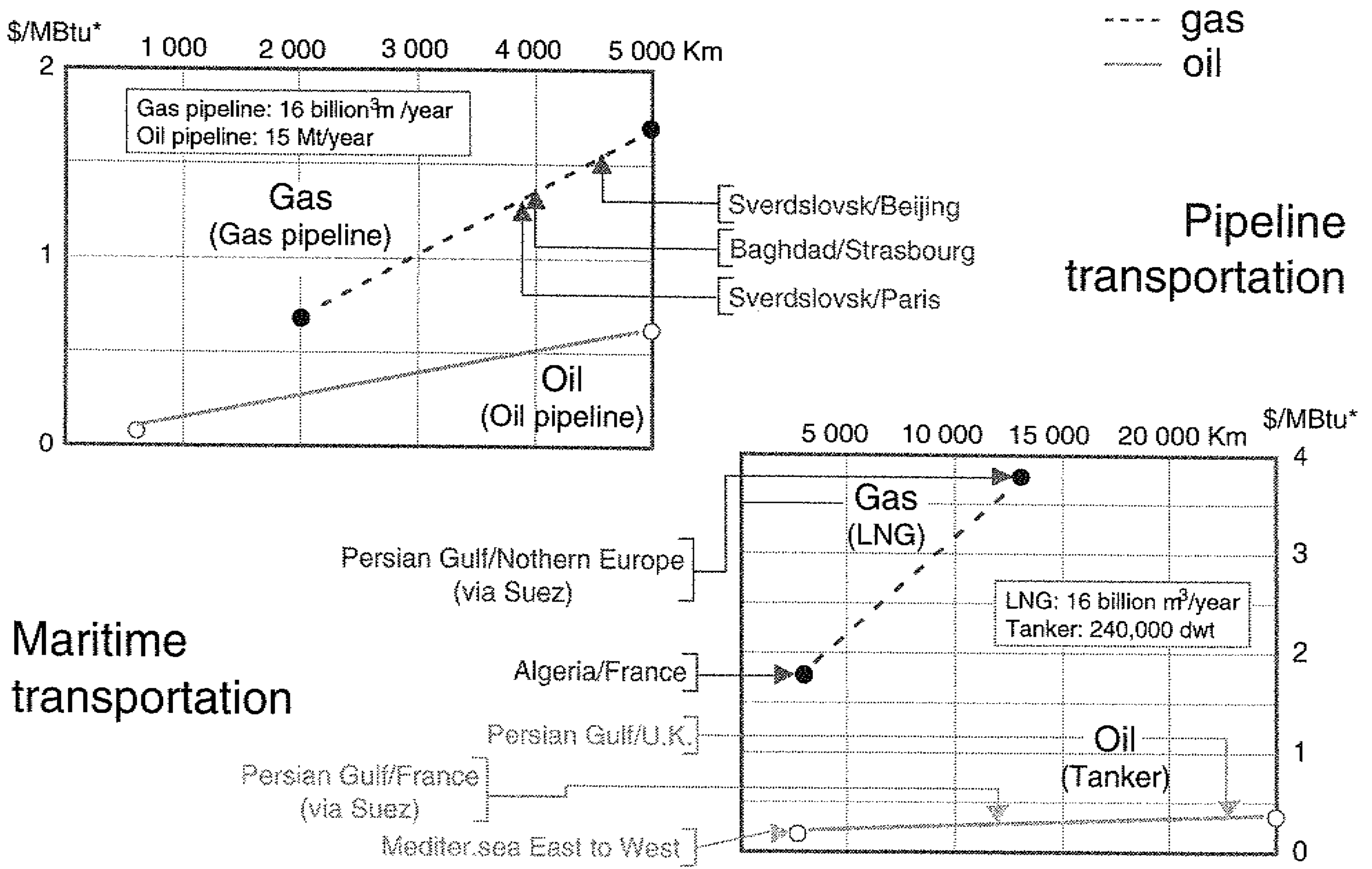
Source: Cedigaz, IFP

* 1 boe (barrel oil equivalent) = 5.8 Mbtu



fig.9

# Transportation costs

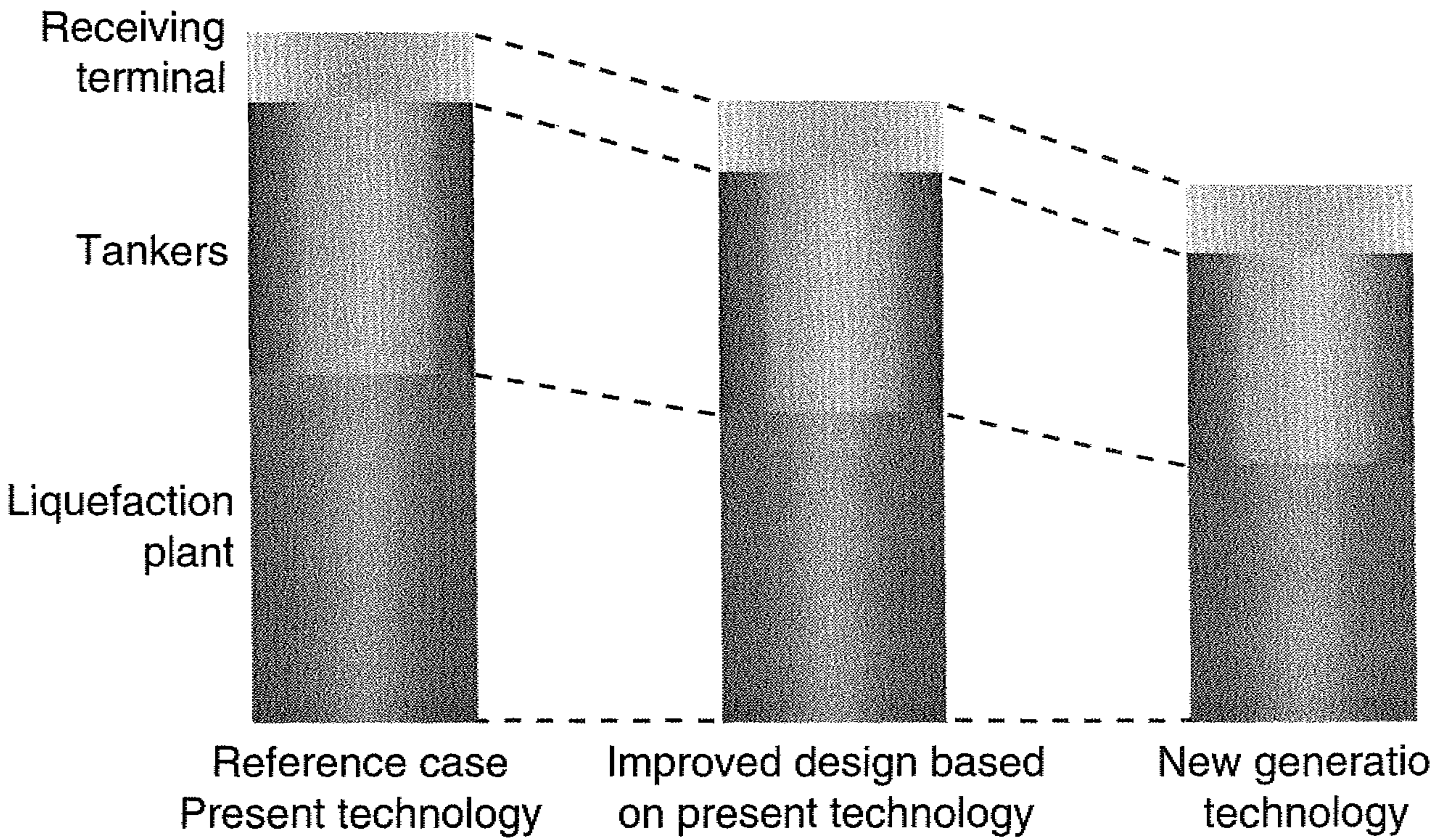



Source: AIE, IFP/DSEP/EIP, Cedigaz



fig.10

# LNG Chain - Expected investment cost reduction




Source : CEDIGAZ-IFP



fig.11

**References**

Conférence Mondiale de l'Énergie, Tokyo 1995

Panorama IFP, January 1996

Development prospects for International LNG Trade, LNG 11, Birmingham, July 1995

Oil, Gas & Coal: Supply Outlook, IEA, 1995

Coal Information 1994

Performances Profiles of Major Energy producers 1993, Energy Information Administration, US Department of Energy, January 1995

Oil and Gas Reserves Disclosures, Arthur Andersen & Co.

Petroleum Economics, Jean Masseron, 1990

Déjà parus

**CEG-1. D. PERRUCHET, J.-P. CUEILLE,**
Compagnies pétrolières internationales : intégration verticale et niveau de risque.
Novembre 1990.

**CEG-2. C. BARRET, P. CHOLLET,**
Canadian gas exports: modeling a market in disequilibrium.
Juin 1990.

**CEG-3. J.-P. FAVENNEC, V. PREVOT,**
Raffinage et environnement.
Janvier 1991.

**CEG-4. D. BABUSIAUX,**
Note sur le choix des investissements en présence de rationnement du capital.
Janvier 1990.

**CEG-5. J.-L. KARNIK,**
Les résultats financiers des sociétés de raffinage distribution en France 1978-89.
Mars 1991.

**CEG-6. I. CADORET, P. RENOU,**
Élasticités et substitutions énergétiques : difficultés méthodologiques.
Avril 1991.

**CEG-7. I. CADORET, J.-L. KARNIK,**
Modélisation de la demande de gaz naturel dans le secteur domestique : France, Italie, Royaume-Uni 1978-1989.
Juillet 1991.

**CEG-8. J.-M. BREUIL,**
Émissions de SO2 dans l'industrie française : une approche technico-économique.
Septembre 1991.

**CEG-9. A. FAUVEAU, P. CHOLLET, F. LANTZ,**
Changements structurels dans un modèle économétrique de demande de carburant.
Octobre 1991.

**CEG-10. P. RENOU,**
Modélisation des substitutions énergétiques dans les pays de l'OCDE. Décembre 1991.

**CEG-11. E. DELAFOSSE,**
Marchés gaziers du Sud-Est asiatique : évolutions et enseignements.
Juin 1992.

**CEG-12. F. LANTZ, C. IOANNIDIS,**
Analysis of the French gasoline market since the deregulation of prices.
Juillet 1992.

**CEG-13. K. FAID,**
Analysis of the American oil futures market.
Décembre 1992.

**CEG-14. S. NACHET,**
La réglementation internationale pour la prévention et l'indemnisation des pollutions maritimes par les hydrocarbures.
Mars 1993.

**CEG-15. J.-L. KARNIK, R. BAKER, D. PERRUCHET,**
Les compagnies pétrolières : 1973-1993, vingt ans après.
Juillet 1993.

**CEG-16. N. ALBA-SAUNAL,**
Environnement et élasticités de substitution dans l'industrie ; méthodes et interrogations pour l'avenir.
Septembre 1993.

**CEG-17. E. DELAFOSSE,**
Pays en développement et enjeux gaziers : prendre en compte les contraintes d'accès aux ressources locales.
Octobre 1993.

**CEG-18. J.P. FAVENNEC, D. BABUSIAUX,***
L'industrie du raffinage dans le Golfe arabe, en Asie et en Europe : comparaison et interdépendance.
Octobre 1993.

**CEG-19. S. FURLAN,**
L'apport de la théorie économique à la définition d'externalité.
Juin 1994.

**CEG-20. M. CADREN,**
Analyse économétrique de l'intégration européenne des produits pétroliers : le marché du diesel en Allemagne et en France.
Novembre 1994.

**CEG-21. J.L. KARNIK, J. MASSERON,***
L'impact du progrès technique sur l'industrie du pétrole.
Janvier 1995.

**CEG-22. J.P. FAVENNEC, D. BABUSIAUX,**
L'avenir de l'industrie du raffinage
Janvier 1995.

**CEG- 23. D. BABUSIAUX, S. YAFIL,***
Relations entre taux de rentabilité interne et taux de rendement comptable
Mai 1995

**CEG-24. D. BABUSIAUX, J. JAYLET,**
Calculs de rentabilité et mode de financement des investissements, vers une nouvelle méthode ?
Juin 1996

* une version anglaise de cet article est disponible sur demande