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THE FUTURE SUPPLY of NATURE-MADE OIL and GAS

A Summary Report On The

Conference Jointly Organized By The

United Nations Institute for Training and Research

and the

International Institute for Applied Systems Analysis

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P R E F A C E

The Conference on the Future Supply of Nature-Made Oil and Gas was sponsored by the United Nations Institute for Training and Research (UNITAR) as part of its Programme of Future Studies, directed by M. Philippe de Seynes, and by the International Institute for Applied Systems Analysis (IIASA) as part of its Energy Systems Project, headed by Dr. Wolf Häfele. Dr. Joseph Barnea for UNITAR and Professor Michel Grenon for IIASA were responsible for the organization of the conference, assisted by numerous individuals both within and outside their respective organizations. The success of the conference was a result of this fine institutional cooperation and of the participation of some ninety scientists, engineers, geologists, economists and other specialists who combined their knowledge to make an assessment of the world's future supply of nature-made oil and gas, in the light of presently evolving knowledge of reserves and recovery technologies for conventional as well as new types of resources. This report, which attempts to convey a preliminary, non-technical resume of the proceedings of the conference, also owes its existence to the support of the Centre for Economic and Social Information of the United Nations Economic and Social Affairs Department and to the efforts of Mr. Peter Collins.

INTRODUCTION

In the wake of the recent strategy of OPEC countries, as well as under the influence of the dramatic reports of the Club of Rome, widespread fears have been expressed in regard to the future availability of petroleum and natural gas, the sources of energy which have, for the last decades, fuelled global industrial development on an unprecedented scale. A point which is often missed in such speculations is that while, as a result of oil price increases, the growth of petroleum consumption may have declined somewhat under the impact of conservation measures (although much more of the recent decline was due to a cyclical recession), at the same time the petroleum and gas resource base has probably been greatly enlarged. Resources which in the past have been regarded as uneconomic and left out of the inventory of reserves, may now or in the foreseeable future, become exploitable under remunerative conditions. In fact, the probability now exists that the "age of petroleum" may extend far beyond earlier predictions, and not just the most pessimistic.

The reason why oil and gas resources came to occupy such a unique place in the supply of energy lies undoubtedly in the fact that they came to be regarded until very recently as cheap, easily accessible sources of energy. Another important reason was that they were susceptible to being used for all purposes, in which respect they are quite unique. This advantage will remain and there is no reason to believe that, with the probability of high energy prices for over a very long period, energy derived from nature-made oil and gas would not continue to occupy a considerable place in the total world energy picture. Its future will depend on whether, and for how long, newly discovered oil and gas, or newly developed unconventional types of hydrocarbon resources, will remain competitive with alternative sources. It may well be that petroleum and gas would tend to be reserved for the transport and chemical industries, where they would be hard to replace, while other sources would meet the requirements of electricity and heating. But even that is far from certain.

In the choices made there will from now on be taken into account the sensitivity of contemporary societies to the "side-effects",i.e. environmental degradation. Decisions may also be influenced by institutional constraints, as changes in institutional arrangements tend to lag behind technological progress. Because of all these uncertainties, it is difficult to speculate seriously on the morphology of the energy economy of the future, but at least the point of departure of the Laxenburg Conference was clear: the customary evaluation of petroleum reserves as petroleum in the liquid state flowing out under its own pressure includes only about a quarter of the total potential conventional oil resources, often referred to as oil-in-place; similarly, conventional gas reserves include only associated gas in oil fields and gas in conventional gas fields. With the current higher prices not only are larger amounts of low quality oil likely to become economic, but the other non-conventional types of hydrocarbon resources found in nature, such as oil shale, tar-sands, heavy crude, and various types of gas, such as gas in tight formations, geopressure zones, and hydrates, must be appraised anew. All these sources may potentially contribute to meeting the needs of a growing world economy, and to widening the range of options open to individual countries with very different resource endowments.

The problems and preoccupations which led to the Conference therefore fall well within the general framework of a New International Economic Order as defined by the General Assembly of the United Nations. If the objectives of such a new order are to be achieved, not only must the global supply of energy be assured at all times, but attention must also be given to the very specific problems of less-developed countries for which resources and technology that are suitable to the specific conditions of their development must be found. It was, therefore, natural for UNITAR, an arm of the UN, to take a look, as one of the first activities of its Programme of Future Studies, at the problems of petroleum and gas resources. It was also natural for the International Institute of Applied Systems Analysis (IIASA), an international organization devoted to the systematic analysis of resources, constraints, operations and strategies, and which is currently engaged in an intensive energy programme, to join with UNITAR in this effort. Both organizations benefitted greatly from their mutual co-operation in the preparation of the conceptual framework and detailed programme of the conference. In addition, UNITAR is deeply indebted to IIASA for the most efficient arrangements made in Laxenburg for the event.

On the first topic to be considered, conventional petroleum, its occurrence, exploration and extraction, there was extensive discussion devoted to the technologies, costs and logistic requirements for raising recovery rates of oil-in-place, and the differing national experiences in this regard elicited a lively participation. The next item, on unconventional petroleum resources - oil shales, heavy crudes and tar sands - evoked even more interest as the speakers described advanced technologies either newly introduced or still in the experimental stage.

After reviewing conventional natural gas, the conference turned to unconventional and future gas resources, in fact considering over a dozen types of natural gas - such as, gas in tight formations, organic shales, marsh gas, landfill gas, coal-field gas, gas from geopressure zones and gas hydrates. A presentation on the potential of oil in the deep-sea concluded the technical presentations, before the conferees concerned themselves with the tough problems of constraints - logistical, manpower, economic and environmental - that have to be faced.

The Conference was a scientific and technical one. Its specific concern was to examine the current estimates of present and potential supplies of petroleum and gas and the development of technologies needed for their efficient and economic exploitation. Some 70 experts, among the most highly competent to be found in the world and coming from the major centres of knowledge on the agenda items, gathered from 5 to 16 July 1976 to exchange views and experiences. They had access to 60 papers scanning the broad spectrum of the most recent experiments and information. They were mostly geologists and engineers. Some economists and experts in systems analysis also usefully took part in the discussions and presentations. Most of the participants remained for the whole period of the Conference.

This must be taken as a measure of the interest they took in the proceedings. Even before the first paper was read, the reason for this interest became quite apparent. The participants discovered that they had not met before in personal discussion, even within the confines of their own nationalities, with experts working on other petroleum-oriented disciplines. Neither had they previously attended a gathering where the totality of petroleum and gas resources had been examined with a view to assessing their potentialities for the future.

This not only confirmed the suspicion which led the sponsoring organizations to plan the conference, but it also highlighted a major problem of the current world predicament, namely, the lack of an organized and systematic information and communication process on developments of vital importance to the future of mankind. This defect of the world's institutional arrangements is in itself intriguing. It is obviously linked to the principle of confidentiality, which pervades private as well as public entities when adventurous and expensive technologies are involved. It is true that at least on the basis of the last 25 years' experience, it could hardly be said that confidentiality has hindered technological progress. It is not prudent, however, to rest on past experiences. In energy today, the international community is confronted with a new situation, with the prospect of a difficult transition from one energy regime to another. And it is possible that arrangements which have served the world well on previous occasions, will not remain appropriate for tomorrow's problems. Even if one does not share in the pessimistic scenarios which are currently influencing thinking on world problems, it is by no means certain that shortages - local, regional or even global - may not occur and endure, perhaps for protracted periods of time. It is also probable that the development of new technologies will absorb increasing expenditures, and that the maturation period both of R and D and of investment programmes will lengthen. It would therefore appear imperative to minimize the cost of duplication in research and development, and to insure that the application of new technology is not unduly delayed for institutional reasons. This would require that competition and co-operation, on a national as well as an international basis, be seen in a different perspective and combined in different ways than today. Confidentiality is by no means the only concept which may have to evolve in line with changing circumstances and a growing sense of urgency.

It is notable that R and D establishments in the field of energy are rapidly evolving in the direction of greater diversification. New governmental institutions, of which the rapid build-up of the Energy Research and Development Administration (ERDA) in the U.S. is perhaps the most striking, but by no means the only example, are more and more taking up parts of the tasks which were previously carried out in private companies, or in autonomous public entities. Nevertheless, some of the most creative research will continue to be done in private companies and their co-operation in an effort at monitoring, appraising, forecasting, and pursuing technological developments will be essential in the future.

A closely related problem is that of the magnitude and orientation of research and development programme. There is some anxiety, or at least perplexity, in regard to their adequacy, and the feeling exists that their progress may be seriously hampered by lack of financial resources, by the vagaries and uncertainties of the decision-making process with regard to environmental protection, and by the ever-present desire of public authorities to enlarge their tax basis. The adequacy of financial resources available to research and development is a question which plagues public as well as private entities, even under non-competitive conditions. The question of financial equilibrium could not be left aside even in the framework of a technical conference. It elicited an expression of concern, since the great variety of new, unconventional sources of petroleum and gas which have to be considered in the light of new economic conditions would suggest the need for a significant increase in research and development expenditures and since it is not clear that this is at present taking place.

For some of the participants, at least, the urgency of rapidly developing new types of petroleum and gas resources was compounded by the present uncertainties regarding the prospects of nuclear energy, which during the last twenty-five years had in many places been regarded as the natural replacement of oil resources, on the basis of assumptions which are now increasingly questioned. Although this problem was not discussed as such, it did underly some of the statements made and strengthened the view that the search for viable energy alternatives and the encouragement of a broader-based and more balanced research and development effort should be actively pursued.

It must be underlined once again that the Conference was concerned with supplies and their future availability. Although it could not avoid touching on a number of other aspects which are part of the framework in which the petroleum industry operates, it would be wrong to draw, from its proceedings, any very specific conclusion about optimum future energy policies. The Conference did, however, contribute significantly to greater understanding and knowledge in regard to the question of supplies. It thereby accomplished the specific task which it had set for itself. And it did lead to one general finding which derives its reliability from the wide consensus that emerged among outstanding experts of the different branches in the petroleum and gas industry. This is that the vast resources which have been classified as nature-made petroleum and gas are likely to represent a promising option in the search for alternative energy sources and in the shaping of a global energy policy. It is, therefore, well worthwhile to undertake a concentrated effort to fill rapidly the gaps in knowledge which still becloud the future of a number of the resources examined at the Conference.

This general finding should now serve to encourage further studies and conferences.

At the top of the agenda would naturally appear the technical investigations of some of the more fascinating resources about which little is known at present: geopressure zones, tight formations, hydrates. According to some estimations, their potentialities are immense, provided the technological and financial problems can be solved, and it would be desirable to increase our knowledge in regard to their location, especially in developing countries, and the time needed for their development.

One important topic which the Conference did not approach in a systematic way, although it was taken into account in the discussion of each of the individual resources, is the question of the side effects, or of the environmental degradation inherent in certain processes. It would be a logical consequence of the Laxenburg Conference, if a systematic and comparative study of the environmental impact of various petroleum and other energy resources were to be organized in the near future. Environment is now an important factor affecting the development of resources, even if the importance attached to it still varies greatly from one place to another and from one resource to another.

It would also appear urgent to investigate the institutional problems mentioned briefly in this introduction and which may create obstacles to the expansion and the desirable orientation of research and development programmes, i.e. the arrangements for monitoring research and development and for the communication and dissemination of information, the role of competition and co-operation, the adequacy of financing.

Finally, it must be remembered that there is a trade-off between resource conservation and resource development. The Conference did not purport to investigate the problem of conservation, but this decision must not be construed as indicating a preference of the sponsoring organizations for one or the other method of meeting energy requirements. Rather, it is obvious that both must be combined. It would, therefore, be relevant to the broader purposes of the Laxenburg Conference, if a stock-taking exercise was planned for the near future with the objective of achieving a better view of the "state of the art" in energy conservation. As in the case of petroleum supplies, it is probable that, up to now, there has not been a systematic appraisal in this respect at the international level.

CHAPTER I

OIL

Petroleum and natural gas, the future availability of which was the principal subject of the Laxenburg meeting, have been defined as naturally occuring fluid, semisolid, or solid mixtures of hydrocarbon and non-hydrocarbon molecules. As a source of tar, pitch, butane, propane, methane, gasoline, fuel-oils, naptha, kerosene, lubricants, waxes, asphalt, coke and a number of other materials and chemicals, petroleum is one of the richest minerals known to man. It is generally accepted that petroleum in whatever form originates from organic matter, a point of considerable importance to geologists involved in exploration. Interpreting information acquired over many years of exploration both above and below ground gives them a fair idea of the chances of finding petroleum in any given area. Even so, some of the most important fields today were only discovered after years of patient field and laboratory work, inspired originally perhaps by the "hunch" of a single geologist who persisted despite long frustration and disappointment. The great finds in the Algerian Sahara and, more recently, in west Siberia are examples of this.

Estimating the Resources

Oil... petroleum in its liquid form... is currently the most important hydrocarbon source of energy and it appears likely to remain so for many years to come. This much was apparent from the general papers and discussions on the world's petroleum resources, but the same early sessions brought to light problems of definition and terminology that were to crop up again and again during the next two weeks. While there are many and complicated ways of evaluating the amounts of oil (or gas) in any given area, results are meaningful only insofar as they are comparable, and this depends on agreement as to what constitutes a "resource". In general, it was accepted at the conference that this word described the petroleum believed to be present in the earth's crust, while quantities positively identified by exploration and testing were referred to as reserves. The term recoverable reserves was taken to mean that part of reserves that could be extracted at a cost that was economic at present prices with present technology. A figure of 1.5 to 1.8 trillion barrels (BTU equivalent) was given for the total of developing countries cumulative reserves... that is, the amount already consumed plus that considered to be "economically recoverable with present technology". At the same time, it is widely felt that a possibly equal amount of recoverable petroleum remains to be discovered. The point was made in one of the papers that most of the world, particularly in the developing countries, off-shore and on the ocean floor has never been systematically explored for oil and gas. In fact, even the most authoritative estimates should be considered tentative and time-specific, not only because, as one authority put it, "many basins round the globe have been explored to such a limited extent that meaningful estimates are impossible", but also because the ceaseless technical advance of the world's petroleum industry means that every day, some part of the overall resources will be moving into the category of economically recoverable reserves. This is one of the reasons why contradictory statements are made, often with apparently equal authority, about the present and immediate future state of oil and gas resources. Yet another factor is that different countries indicate certain categories of resources as being "subeconomic" (USA) or "non-commercial" (USSR). This may refer to small fields which are not worth developing under the circumstances existing at the time the resource was so classified. But as prices for crude oil or gas increase, this part of the picture may change; it may change, too, if a major field is discovered in the neighbourhood of known small, subeconomic fields, at which time the investment in the new major field may make the exploitation of the small fields all at once economic.

These are only some of the reasons why the publication of figures for resources, in contrast to those for actual production, can never be on anything more than a very approximate basis. Allowance also has to be made for the fact that estimates of oil-in-place are based on analysis of data obtained from sampling the rock being explored and from various methods of "down-hole logging", i.e., the recording by means of various electronic and other devices of conditions hundreds or thousands of feet below the surface, and such estimates can only be as good as the information provided, and have to be accepted keeping in mind the inherent margin of error.

Getting the Oil

Although crude petroleum has occasionally been found in caverns or large fissures deep underground, in general it is contained in rock formations of various types. It normally occurs in the spaces between the grains in sandstone formations, or among the crystals of carbonate rocks. Nor are such spaces filled by oil alone: normally the oil is associated with water, which in most instances forms a layer between the oil and the solid matter. The amount of oil held in any rock, therefore, will depend largely on the size of the pore spaces between the grains, and on the amount of water present. Occasionally, however, it is the oil that is present as a coating around the grains of sand, with water filling the spaces in between.

In the early days of the industry, drilling was carried out where there were obvious surface indications of oil, seeping out of the ground or in petroleum springs, or, as gas, burning spontaneously at the surface. Oil thus discovered flowed naturally into the wells by gravity, or was "driven" by underground water. As drilling became deeper and more speculative, oil containing large amounts of associated gas was struck. The pressure of this gas caused the familiar "gushers", which resulted in the wastage not only of the gas, which had first to exhaust itself, but also of large quantities of oil. Little attention was paid to what was actually going on underground, or to the conditions governing the flow of oil into such wells, which often yielded no more than 10 percent of the "oil-in-place", with a maximum of around 30 percent. Sooner or later, when this natural "gas-drive" was exhausted the well would have to be abandoned, unless some other natural mechanism such as gas or water from surrounding strata flowed into the reservoir and maintained the pressure.

Increasing Performance

With the development of the science of reservoir engineering, which, after a study of the oil-bearing formation, made it possible to control the flow of oil, a larger proportion of the oil-in-place became recoverable. In most areas the figure of about one-third is currently given as the recovery rate. There are two different approaches to the problem of maintaining, or increasing, the original flow of oil. The most common is the injection of fluid... usually water or steam to augment the controlled natural pressure within the reservoir. This has been called assisted or enhanced primary or secondary recovery, the principal agent of which is the self-descriptive "water flooding". To quote one conference paper: "So well developed and understood is water flooding as a recovery mechanism that every field in the least bit favourable /position/ will sooner or later be water-flooded". Fully successful water-flooding under the right conditions may result in the recovery of as much additional oil as was produced under the original (primary) recovery system, or, to put it another way, in the total recovery of from 30 to 35% of the original oil-in-place.

In addition to water flooding, the injection of steam may be used, especially where the crude oil is of such high viscosity that it will not flow freely (under reservoir conditions). Steam so used is injected into the actual producing well, which may or may not then be shut off while the reservoir rock heats up, causing oil to flow again. This process may be carried out several times during the useful life of a well, and is then referred to as "cyclic steam" stimulation. A third method, also particularly useful for the recovery of heavy crude, is in-situ combustion. In this system the oil is ignited within the well, combustion being maintained by injecting large quantities of air. When a great deal of water is present, this is turned to steam, or its temperature greatly raised, so that in effect a steam or hot water drive is provided. In continuous steam drive which is, in many instances, gradually replacing other methods, steam is forced into injection wells, arranged according to any one of a variety of standard patterns, from which it drives the oil into the production well or wells, which are situated in the spot or spots calculated to draw off the greatest amount of oil. It is not normally a primary production, but it may be used in conjunction with one of the other types of enhanced recovery techniques. Whichever method is used, it is evident that the actual production of the steam requires a good deal of energy, which may in some favourable situations be provided by waste gases, but which may involve a considerable capital outlay and at the same time support an appreciable steam-plant manufacturing industry. The use of steam, hot-water (much less frequently used), and in-situ combustion are classified as thermal recovery techniques.

It is estimated that nearly half the oil produced daily in the USA comes from water flood projects, the system being especially valuable for recovering further oil from wells that have been, or would otherwise be, abandoned. In recent years, however, water or steam are often used from the start to provide more efficient recovery of oil. The Conference heard how in the USSR enormous quantities of water are so used every year, while application of this system from the very commencement of operations in new wells was given as one reason why the recovery rate there was reported by a Soviet petroleum expert to have reached as high as 45%, in contrast to an average of about 33% in the USA. All future development in the USSR, in fact, would be based on water flooding or,where more suitable, on various other systems for ensuring a freer and more controlled flow of oil.

Tertiary Recovery

Problems of terminology came up again when the various means of increasing recovery efficiency were being discussed. Thus, "tertiary recovery" was described as "a mopping-up operation after the use of water drive". But many of the techniques covered by that term can be and are already being used in primary operations. To quote again from a conference paper: "the terms primary, secondary and tertiary have no significance in current terminology". Although inevitably these terms will continue to be used, and are firmly established in the literature, it looks as if the phrase "enhanced oil recovery" will gradually come to be accepted to describe any way of getting more oil from a well than could be otherwise recovered. "Tertiary recovery", of course, will still correctly describe operations that comprise the third phase in a total recovery process. The techniques involved in tertiary recovery processes are complicated but they are based on two main concepts. The first is to increase the "sweep" (or the area) reached by the flooding agent, by which it is hoped to obtain oil not hitherto reached; the second is, by decreasing the surface tension between the oil-in-place and the flooding medium, to make it flow more easily. To do this, various chemical materials are added to the water used for flooding the reservoir. Those most commonly used, or from which the best results are expected, include surfactants, polymers, microemulsions, and various systems classed as miscible drives. Surfactants are materials chosen for their ability to improve the efficacy of injected water by lowering the surface tension between the solution injected and the oil, thus promoting freer flow. Polymers are used to increase the viscosity of injected water, bringing it closer to that of the oil, and thus increasing the volume that can be "swept". Microemulsions, also referred to as micellar solutions, are emulsions in which the droplets of the added materials are less than one micron (1/1000 mm) in size. Such an emulsion may be a mixture of a hydrocarbon (oil), alcohol, a surfactant and water, which will mix with oil-in-place so that there is no interface between the liquids in the reservoir and the mixture flows freely. The same general principle is behind the miscible drives, which are based on various methods of mixing gas with the oil in the reservoir, and for some of which recovery rates as high as 90-100% in the swept area are claimed. Also classed as a miscible drive is a process using alcohol instead of gas but like the use of foam drive, this does not appear yet to have reached the stage of commercial feasibility. Finally, and perhaps the most promising of the new techniques, is the use of carbon dioxide (CO_2). This is said to have many advantages over the other methods discussed, both in its effects on the viscosity of both water and oil and in reducing surface tension. A limiting factor could be its availability and also, especially if it has to be compressed and transported long distances, its cost.

None of these processes is perfect for the purpose for which they are intended, their efficacy in each case being affected by temperature, pressure, salinity of the water in the reservoir, nature of the reservoir rock, and viscosity of the oil-in-place. All are more or less costly, and quoted additions to the cost of crude recovered with their use range from $0.80 per barrel for polymer flood to $10 per barrel for the most expensive CO_2. Nevertheless, it is to be expected that as oil prices rise and development of these processes advances, the point will be reached where several of them become economic, used separately or together, and eventually their use for the recovery of 50 to 60% of the oil-in-place may be recognized as a reasonable objective.

Unexploited and Unconventional Sources

So far, most of this report has been concerned with oil from "conventional" resources, that is, oil of comparatively low viscosity obtained from wells drilled to reservoirs at varying depths, on land or off-shore. One of the features, and indeed one of the purposes, of the Conference was to draw attention to less conventional resources which, for one reason or another, have not hitherto been exploited to any great extent, but which are expected sooner or later to be important sources of oil.

Among the most important of these resources, in terms of the near future, are heavy crudes, tar sands, and oil-bearing shales. Heavy crudes and tar sands are essentially highly viscous petroleum which are arbitrarily distinguished according to their viscosity as measured by API gravity. In rough practical terms, a heavy crude will flow, while a tar sand will not. Heavy crudes, also known as bitumenous sands or oil sands, occur in many parts of the world; they are often considered to be oil saturated sandstone reservoirs that have lost the lighter, less complex components of the oil by evaporation or in other ways. They occur at comparatively shallow depths and are found in many countries, including some that are at present major importers of petroleum. The biggest identified resources in this category appear to be those of the well-known Orinoco oil belt in Venezuela, estimated in one conference paper to contain no less than 4.2 trillion (4.2×10^{12}) barrels of heavy crude oil - almost six times the same paper's estimate for total reserves of oil recoverable by present technology from known "conventional"sources. A further one trillion barrels are estimated to be contained in the tar sands of Alberta, Canada, and deposits of the same order of magnitude would appear to exist in USSR; among developing countries other deposits exist in Madagascar (1.75 billion barrels) and Albania...

Heavy crudes are an excellent example of a resource which has benefitted from technological advances. Thermal recovery of heavy crudes has boosted production greatly in the last few years due to the use of cyclic steam injection, which was called in one conference paper the most exciting development in the 1970's for the recovery of heavy crudes. The exchange of results of more efficient recovery techniques and of programmes of further testing led to an appeal for new forms of international technical co-operation. In Venezuela, for instance, the petroleum recovered from heavy crudes is already being marketed to some extent as heavy fuel oil and asphalt. However, to make better use of this resource, an initial upgrading process is planned, using steam for the recovery of oil that will then be upgraded by various techniques, which enable the resultant coke by-product to be used as fuel for steam raising. A later phase will include advanced upgrading to higher quality fuels. A major obstacle, however, is the short supply of local technology and trained personnel for implementing this planned three-phase development.

A never before attempt was made to calculate and classify the world's presently known reserves of heavy crudes - tar sands according to their API gravity. The resulting chart brought out the truly great extent of this resource and also served to underline those areas where more research and testing are needed. The chart, because it was incomplete, went directly to one of the purposes of the conference, as it showed the utility (and present lack) of uniform definitions in petroleum resource estimation.

Tar sands because of the greater technological barriers to their recovery are not yet being exploited to any significant degree, and for this reason exploration for deposits has not taken place. Those large deposits we know about happen to be located close to large conventional or heavy crude areas, as in Alberta (Canada) and the Orinoco (Venezuela). The conference did hear of plans to surface mine suitable deposits, but the bulk of reserves cannot be mined and await development of advanced technology, which is the subject of active R and D efforts in Canada and the U.S. A number of different techniques have been tried for oil recovery from these sands, including the use of petroleum solvents, of steam, and of in-situ combustion; some form of recovery employing in-situ combustion is considered to be the most likely solution. However, it was admitted that the technology necessary for economically viable in-situ combustion of tar sands is not yet beyond the experimental stage in Alberta.

Like heavy crudes and tar sands, oil shales are widely distributed in the earth's crust and many efforts, on the very small as well as on a large scale, have been made to exploit them. Oil shales are considered to be those shales containing more than five percent organic matter, the usefulness of the shale from the point of view of oil production depending to some extent on the nature of the original organic material involved. Although the oil potential of shale has long been recognized, it is only recently that exploration and research have been much concerned with it. Consequently there are gaps in our resource knowledge and in our production capabilities. We do know that large deposits exist in the USA and Brazil, followed by the USSR and Zaire, and that deposits have been found in every region so far seriously explored.

Nevertheless, very little detailed exploration of these strata appears to have been carried out, other than in the Rocky Mountain area of the United States and in the deposits located in Estonia in the USSR. Some small-scale exploitation was carried out in France, Scotland and Sweden until quite recently, and at present there are projects for developing this type of resource in France, in the Federal Republic of Germany (FRG) and in other places, too. But the huge deposits known to exist in many developing countries, such as in Zaire and Burma, have only been marginally exploited, if at all, and in regions such as the Indian peninsula potential oil shales appear not even to have been identified, although their existence is considered more than likely. However Brazil, whose deposits are second only to the United States according to present knowledge, does have an oil shale extraction plant on-line. Still, so little has been the interest in this field that there is not yet even an internationally agreed system for reporting the assay value of the shale or the resource potential of deposits. The wide distribution of this resource means that once the technology is perfected, many more countries will be able to produce oil.

The sharp rise in oil prices has spurred just such research. It seems axiomatic to state that the extent to which shales can be considered worth developing is limited in the first place by their oil content. However, research and development efforts have recently given attention to the multi-purpose exploitation of the shale, that is, the extraction of other minerals from the shale in order to make oil production economic. Uranium, nahconite, coal, sulphur, and a number of other minerals have been found in shale and could add considerably to the revenue derived from mining it.

Mining of oil shale poses materials handling and environmental problems for which the conference learned of some ingenious solutions. A quite different approach has been adopted in the USSR and the FRG, where oil shale is burned directly as a fuel, as in thermal electricity plants. The most promising process is the in-situ conversion of oil shale, in which only 20% of the shale actually has to be mined. The developers of the process claim that with shale containing 15 gallons/ton (which is not particularly rich shale) oil can be produced to compete with conventional oil at today's prices, and as prices rise, more and more could be brought into production. While the in-situ process has not been put into commercial operation, it was felt that if prices continue to rise, shale will undoubtedly become a major source of oil, as present resources are known to exceed three trillion barrels.

CHAPTER II

GAS

Natural gas is generally thought of as a less important source of energy than oil, and to some extent this was borne out by the papers at the Conference. Discounting those that discussed hydrocarbon resources in general, three papers dealt with oil for every two concerned with gas... roughly the same proportion, curiously enough, as that for reserves of oil and gas given in the papers. However, whereas the likelihood of finding very large and unexpected new conventional oil fields is generally considered to be small, the prospects for new finds of conventional natural gas seem somewhat better. This has been borne out by recent experience in the USSR, which already has about one-third of the identified conventional global reserves of natural gas. Estimates quoted for the USSR at the Conference show "a 28-fold increase to 1966 from 1940, whereas by 1975 the increase in recoverable reserves as compared to that in gas production was 95.9 times greater". This of course is partly controlled by official production policy, but it indicates the general picture of natural gas in the world as a whole: a rapid and increasing rise in reserves when compared with current production. This has been summed up in another estimate indicating a rise in global reserves of 250 percent during the past ten years.

At 1975-76 production and consumption rates, currently identified reserves of gas should ensure some 50 years supply. Whether they last as long depends on a number of factors. One of these is the greater use of gas to maintain pressure in oil wells and thus to increase the rate of oil recovery. Another is a tendency to use more gas as the primary source of energy in industry, and also as the raw material in various manufacturing processes... for example, in the petrochemical industry and as feedstock for fertilizer manufacture, a demand that might increase rapidly as long as the world food situation remains a factor.

As already pointed out, a considerable proportion of the quantity included in total reserves is accounted for by "associated" gas, that is, gas in oil reservoirs, either dissolved in the oil or as "free gas" held in gas caps above the oil. This is the gas that supplies the initial pressure driving oil out of the wells; it is also the gas that is so wastefully flared or vented from wells in areas where either the demand or the technology for its use or conservation is absent. The proportion of gas reserves contained in this associated gas has been given as 40 percent of total reserves and the development of these reserves is essentially linked to that of the oil industry. Applying the same 40:60 ratio for associated to non-associated gas to the estimated global reserves, it is evident that the amount of non-associated "conventional" gas yet to be discovered is proportionately higher than that to be expected from increased oil production. As to geographical distribution, one authority expects some 70 percent of these new reserves to be discovered in-land, 30 percent off-shore... but whether the latter figure includes such new reserves as may be discovered on the continental slope and ocean bed, is not clear.

Since petroleum reservoirs contain both gas and oil, it has been usual in the past to classify them according to the proportions of these two substances present when the reservoir is first surveyed. This is expressed in terms of the quantity of gas, in cubic feet, to that of oil, in barrels. Thus a reservoir containing from zero to a few thousand cubic feet of gas per barrel of oil is considered to be an oil reservoir, and the gas is "associated gas"; from 5,000 to 100,000 cubic feet, it is termed a gas-condensate reservoir and above 100,000 cubic feet of gas per barrel of oil, a gas reservoir. As either gas or oil are withdrawn and as the pressure and temperature within the reservoir change as a result of this process, the proportions may also change. For this reason it is now considered more satisfactory to base the classification of gas reservoirs on the pressure-temperature relationship within the reservoir, rather than on the proportions of each produced at the surface. The descriptions - gas, gas-condensate, or oil reservoir - remain unchanged.

Recovery Mechanisms for Gas

As in the case with oil, recovery from gas reservoirs depends on a number of interacting factors: the nature of the rock, the composition of the gas, the gas-oil ratio and the temperature and pressure within the reservoir are only some of them. The efficiency of recovery also depends on whether it is a gas or a gas-condensate reservoir, and this also changes according to the gas-oil ratio of the fluid produced at the surface. In general, gas recovery efficiencies are much higher than those for oil, it being possible to recover virtually all the gas from certain types of reservoirs under optimal conditions, although overall oil and gas recovery figures will be somewhat lower in most instances.

Many gas reservoirs are closely associated with underground aquifers, and the water thus present may provide all or most of the energy required for gas and oil production at the surface, the producing mechanism then being referred to as water drive, the term partial water drive being used where an aquifer provides only a part of the necessary energy. Under certain conditions of temperature and pressure, gas may condense within the reservoir, thus of course changing the gas-oil ratio, and this is termed a "retrograde condensate" reservoir. Gas recovery may be as high as 95 percent for a reservoir of this type, although overall recovery will be lower.

As with oil, various more or less sophisticated techniques are used to obtain the highest possible recovery from gas reservoirs of whatever type. One process used in gas condensate wells is to strip from the gas the condensate liquid produced at the surface and re-inject the gas into the reservoir, thus maintaining reservoir pressure and enabling more condensate to be recovered. This process, which may use additional gas to that from the well itself, is called gas-cycling, and can give condensate recovery rates as high as 65 percent. However, like all enhanced recovery systems, it requires a good deal of investment in plant and materials.

Unconventional Gas Resources

In the United States, much research has been carried out in recent years with a view to developing production from gas-bearing strata that have hitherto been inaccessible and are therefore not classified as "gas resources or reserves". This may seem strange in view of the great increase in global gas reserves quoted at the beginning of this chapter. This is because these "new" conventional reserves are largely in the USSR, Iran, Algeria, and the North Sea area; in the United States itself, the ratio of reserves to production has been quoted as 11:1, a position that has been called "uncomfortable" in view of the fact that 28 percent of the energy requirements of the USA are provided by natural gas.

In these circumstances, among the strata to which particular attention has been paid in the United States are the so-called "tight" sandstones. From the practical point of view, these are identified as "low-permeability reservoirs not amenable to recovery with conventional completion techniques". They cover very large areas, especially in the Rocky Mountain region, where according to a conservative estimate they may contain more gas than the total of presently recognized reserves for the country as a whole. Some of these formations underlie oil-shales that are also beginning to be exploited with advanced methods. The techniques applied to the tight sandstones all rely on artificial fracturing of the reservoir rock, with the aim of "increasing the area of rock surface in direct communication with the well bore, thereby creating a pressure sink into which the gas in the low-permeability sands will move". The first system to be examined was the use of chemical explosions, long practised as a successful method of increasing recovery of oil and gas. This was abandoned as not being effective at the depths and in the conditions of tight sandstones; the fractures were soon closed up due to the weight and pressure of the overlying rocks.

The second of the new techniques,initially regarded as the most promising, was nuclear fracturing. This relied on underground nuclear explosions to produce conditions such that gas would flow into the rubble-filled cavity caused by the explosion and hence into the well-bore. Three separate experiments were carried out but none of them produced satisfactory results. Meanwhile, the whole concept of using nuclear explosions in this way produced such violently antagonistic public reactions that the entire programme, which had envisaged as many as 30,000 such explosions, was abandoned in the U.S.A.[1.]

The third system and that which was proved most satisfactory and worth developing so far, is massive hydraulic fracturing (MHF). The idea itself is not new, for the practice of pumping liquids into difficult formations, in order to produce artificial fractures and thus release oil or gas, has been followed for more than a quarter of a century. (This is to be distinguished from the various water-flooding and enhanced recovery techniques described in Chapter II, and which are not intended physically to affect the reservoir rock). What is new is the scale of the operations: in the later 1940's, wells might be treated with 800 gallons of liquid, a figure that rose to 10,000 gallons by the mid-1950's. Recent experiments carried out in the Rocky Mountain basins, however, involve quantities of from one-half to one million gallons of liquid, carrying with it upwards of one million pounds of sand. The liquid is now usually a water-based polymer emulsion of high viscosity; the objective is the creation of a very large fracture extending perhaps as much as 1,500 feet on either side of the well-bore and vertically for perhaps 1,000 feet. The sand is necessary as a "proppant", to keep the fracture open so that the gas in the rock is provided free access to the well bore. If this were not done, the sheer weight and pressure of rock... some

1. In two papers contributed by the U.S. Energy Research and Development Administration, assessments of the technical short-comings of nuclear fracturing made clear the decision to abandon the use of the technique.

of the experimental wells being already at depths of 20,000 feet and more ... would close the fracture, as happens with fractures caused by chemical explosions. Given optimum conditions, it has been calculated that the yield from wells treated in this way may be increased as much as seven times, but even at lower rates of increase the system can be economically viable.

Obviously, a system using such vast quantities of material is subject to a number of constraints. The logistic problems of providing millions of gallons of water and quantities of sand will vary according to local conditions. The cost, not only for these substances but also for the chemicals required for the emulsion of gelled fluid and for transporting, storing and pumping on a large scale, may impose limitations on the whole operation. Moreover, for complete success, it appears to require much more detailed knowledge of the nature of the rock formations involved in each reservoir than is normally available. To quote one of several Conference papers on this subject, "There must be permeability (of the reservoir rock) and MHF cannot create this permeability. The lower limits of this permeability have not yet been defined". Another major constraint may well be the quantity of water required. Although most of this fluid is in fact recovered, the amounts involved are large enough to impose severe restrictions in areas where water is not naturally abundant. Finally, there is one over-riding factor that affects all projects for developing new or advanced methods of gas recovery: the well-head price of gas. While it is felt that MHF can be economic under certain conditions, one of these is that the gas being sought should be in a single bed of sandstone. Where there is a question of producing from multiple layers at different depths, "the well-head price of natural gas would have to be doubled before fracturing... could be economically justified".

However, organic shales in certain regions can be exploited as sources of natural gas, as for example in the Appalachian Basin in the United States, where it is estimated that more than 600,000 wells have already been drilled, and where proximity to good markets in the East of the country means rather favourable economic conditions. Unlike many formations, these shales produce gas steadily over long periods, in some cases for over 50 years. Such production, however, has in general required from the beginning, fracturing of one sort or another, which has meant, in many cases, the use of chemical explosives. Recently, however, hydraulic fracture has been used, not on the very massive scale described above, but in accordance with the local requirements. This has proved very successful, the wells stimulated by hydraulic fracture having produced very much more gas... in some cases, twice as much, and producing a given amount in a much shorter time than those where explosives have been used. Although in terms of what can be called classical oil and gas production organic shale is an unconventional resource, it may, as do developments such as that previously described, perhaps fall into the "sub-economic" or "non-commercial" category, its status depending more on the controlled price of gas than on its availability.

The Conference heard about two other sources of natural gas, both of which have been examined in recent years in the United States, where a possible shortage of conventional natural gas has been foreseen. One of these was marsh gas... the naturally occurring methane that is emitted by rotting vegetation or other organic matter in marshy areas in many parts of the world. Superficially, this might seem a useful source of gas especially in the humid tropics, where suitable conditions abound. The problem, however, appears to be in collecting the gas in sufficient quantity to make it worthwhile transporting, or to ensure a regular supply for immediate, on-the-spot use. One proposal was to cover an area... say, one acre... of marsh with plastic sheeting, the gas being removed through a fitting at the centre of the sheet. However, this proposal, to which there were objections on environmental grounds, was still in the experimental stage, as were other proposals. In a paper on marsh gas, it was further suggested that peat bogs may well be a source of methane, but no data was available to confirm the rate of (natural) production.

The second novel resource is gas from urban and other refuse, known as "landfill gas", since the refuse from which it is derived is habitually tipped into deep pits or similar areas. In the anaerobic conditions in such landfills, organic materials are broken down by bacteria, and a mixture of gases, of which the largest consituent is methane, is produced. If this methane can be recovered it can provide a valuable source of energy, available at a competitive price and with very much less capital investment than that required by any of the more conventional processes.

Landfill gas, being produced by the decomposition of organic wastes, could in theory be available at any site where such waste is allowed to accumulate in very large quantities. In fact, it is likely to be a really valuable source of energy where the landfill site is reasonably close to, and is fed by, the waste from a large city, preferably a million or more inhabitants. This is a system in which the economies of scale are operative, and besides the fact that gas transport in small quantities is very expensive, it is also in big cities that there is the greatest demand for such gas. Even then, a number of factors have to be considered. For example, the amount of waste generated varies widely, from 1.1 pound per head of urban population in Ireland and Italy to 3.5 pounds in the big cities of the United States. The proportion of that waste actually disposed of into landfills likewise varies from country to country and city to city. Insofar as recovering the methane produced from landfills is concerned, the system is to sink wells in the normal fashion, and then pump the gas out. The rate of pumping is carefully controlled to avoid the risk of sucking in air through the surface of the fill and thus diluting the gas; in general, the deeper the fill, the higher the rate can be. The gas is collected and then cleaned, a process in which economies of scale are again evident, but which can be expensive if the wastes contain toxic materials. Gas with a comparatively low (50 percent) methane content can then be used for some industrial purposes, but for urban domestic use further cleaning may be necessary to raise the content to 75 percent or higher. So far, no very large landfill gas projects have been set up, but pilot experiments indicate that the minimum size of operation that is likely to be economic requires a yield of about one million cubic feet of gas/day. There is in operation in southern California a landfill producing a million cubic feet of methane/day and estimated capable of producing five million cubic feet/day at presently prevailing competitive prices. If that can be produced, a cheap and reliable source of energy may be available to supplement local supplies. Moreover, unless the system of waste disposal is changed, it is a source that will be constantly maintained by the inhabitants of the city consuming the product.

The potential of coal-field gas as a source of methane was also mentioned at the Conference but there was no time to discuss it in detail. Coal-field gas, that is methane associated with coal-seams, has long posed a serious danger of explosions in the coal-mining industry. Thus, the drainage of the methane before a coal mine is opened would not only increase mining safety, but also make a new source of gas available. In a geochemical paper on geochemistry submitted to the conference, it was speculated that the methane in coal-fields may well be derived from the microbiological decomposition of the cellulose of plant debris.

The sources of natural gas discussed in this chapter range from conventional gas in oil fields to the less conventional potential resources held in tight formations, in organic shales and in landfills. But the Conference also heard about less well known resources which, if their potential could be realized, could completely change the global picture of hydrocarbons as a source of energy. These are discussed in the next chapter.

CHAPTER III

RESOURCES FOR THE FUTURE

Reserves of oil and gas from conventional sources will, globally speaking, be sufficient to last well beyond the end of the present century, even if there are temporary shortages of certain products in some areas. This was apparent by the end of the first week of the Conference. But while there was general agreement that oil and gas from such sources would last at least until about the time period 2020-30, it was also expected that some resources not now being exploited would by then be contributing increasingly to global supplies.

Petroleum from the Ocean Bed

No one knows what oil and gas resources the ocean may hold, but enough is known of the location and extent of sedimentary areas on the sea floor for the presence of oil-bearing strata to be foreseen as a very high probability. In considering the potential of the sea floor as a whole, it must be realized that what is under discussion is not the continental shelf - the belt of comparatively shallow water that is already being exploited in many parts of the world. Some of this so-called "off-shore" petroleum comes from extensions of known, and already exploited, inland fields, as is the case off the coast of California, the Gulf of Mexico, Venezuela, Nigeria and certain Far Eastern countries. Among exceptions to this are the North Sea deposits, and those off Australia in the Bass Strait between the Australian mainland and Tasmania. While it was pointed out at the Conference that in fact only a very small part of the total continental shelf has in fact been explored from the point of view of potential oil-or gas-bearing deposits, it is not this possible resource that appears to hold out the greatest promise for the future. What the Conference heard about was the prospect of finding oil or gas in the continental slopes and the floor of the ocean deeps.

The first of these potential resource areas to be discussed was the so-called "small marginal basins" which are found, for the most part, to the landward side of groups of islands and deep ocean trenches. Two reasons were given as to why these could be especially promising from the point of view of hydrocarbon accumulation. In the first place, they are the recipient areas for much of the material swept out to sea off edges of the continental shelf, from shore erosion and from the deltas of large rivers, material which contains usually large amounts of organic matter. Secondly, these same conditions, combined with upwellings from deeper water, provide ample nutrients for the phytoplankton which is the largest biological source material for deposits that eventually will yield oil or gas. These areas of sediments have already been examined in a number of places, including the Mediterranean Sea, the Black Sea, and the Gulf of Mexico.

The second category of possible deposits are those of the continental rises, areas of much older sediments, geologically speaking, that lie between the lower reaches of the continental slopes and the deep ocean floor. It is believed that the geological conditions under which the continental rises have been formed, are such that source beds containing organic matter, and reservoir rocks such as sandstones in which oil and gas accumulate, may be widespread, although they may not be so productive as the equivalent strata in the marginal basins. However, the total area covered by these formations is extremely large, for they occur all down the Atlantic coast of South America; off both west and east coasts of Africa, around the Indian Ocean and Bay of Bengal, off much of Australia, and in the Arctic and Antarctic.

On the basis of analogy with known similar formations inland, the deep ocean "diapirs", which are domes of salt or mud that protrude through other strata, are also considered to be potential sources of oil and gas. Many of these are found off the deltas of major rivers, such as the Niger, Amazon or Mississippi; and appear likely to provide the right sort of situations for hydrocarbons to have accumulated in the same way as in similar formations on land. Finally, there is the possibility of vast quantities of hydrocarbons in the lower reaches of the continental slopes and on the deep ocean floor itself. Obviously, the exploitation of such deposits in the deep ocean as described above is unlikely to take place in the very near future. In fact, it was pointed out at the Conference that the greatest care has been taken, when drilling in the sea bed from the research ship Glomar Challenger - whose expeditions are the main source of information in this field - not to drill into formations which are considered likely to yield oil or gas, in order not to risk a blow-out. What, in fact, is needed now, is the purchase of the equipment that could be used on such a research vessel, to enable it immediately to contain any such accident which, however welcome from the point of view of oil discovery, could be environmentally damaging. The cost of continuing exploration with such a vessel, fully equipped to deal with such an emergency, is reckoned at about $30 million a year for several years... a comparatively small price to pay for an initial evaluation of the hydrocarbon resources of the ocean bed, which if fully explored and developed could make a vital contribution to the problem of world energy supplies.

An important institutional obstacle to exploitation of the deep sea is the still unresolved legal questions concerning ownership and control of ocean resources. This uncertainty, besides acting as a disincentive for any enterprise to invest large sums in exploring for oil and gas, causes governments to discourage their companies and nationals from engaging in such activity.

Gas from Geopressure Zones

No sessions of the Conference aroused more interest than those that dealt with two potential new sources of natural gas - the gas from geopressure zones, and the mysterious gas hydrates, the very existence of which was largely conjecture until the present decade. Geopressure was defined at the Conference as "any interstitial fluid pressure in the sub-surface that reflects a part of the overburden (rock) load". Zones where they occur are characterized by fine-grained sediments that have been rapidly deposited. The phenomenon of geopressure occurs sometimes over very large areas... in the Gulf of Mexico, for example, some 150,000 square miles (375,000 km^2)... and at great depths... up to 50,000 feet; the top of the zone may however be less than 8,000 feet below the surface. One other essential feature is that the zone should underlie rock that makes a pressure seal. Under these conditions, at the high temperatures which are normal deep in the earth's crust and with the very high pressures involved, petroleum hydrocarbons undergo natural "cracking" processes analogous to those in a refinery. One result is the accumulation of methane, which continues until all the water present is saturated. Excess methane collects in reservoir rocks above the zone; some 8,000 such reservoirs are already being tapped for commercial production inland from the Gulf of Mexico.

Much of the methane already being recovered from wells in many parts of the world is considered to have come from geopressured areas, coming out of solution as temperatures and pressures decline. What is now envisaged, as described to the Conference, is the recovery of this gas "at source", as it were, either by deliberately creating the above condition in carefully engineered fields, or by drilling large capacity, deep wells and separating the methane from the resultant water-flow. One problem (or perhaps blessing in water-short areas) to be resolved if the latter alternative is adopted would be the control and disposal of very large quantities of hot water... for conditions in geopressure zones can mean water at $300^{\circ}F$ - $500^{\circ}F$ and a pressure of 10,000 psi.

The contribution that methane from geopressure zones may be able to make to energy resources in the future is by all accounts enormous. The only area where the situation has been investigated in detail, the Gulf of Mexico, may contain as much as 49×10^{15} cubic feet of methane or about the equivalent of the energy content (in BTU's) of total coal resources of the U.S. Although only limited exploration has been so far carried out in other parts of the world in attempts to assess the global dimensions of these resources, they exist in every continent, often beneath the deltas of large rivers such as the Nile, Niger, and Ganges, and, as a result of a different type of geological development, along the edges of the great mountain chains. Particularly interesting could be the presence of such zones in many European countries, or, as in the case of Britain, Ireland and Norway, offshore; the importance of this lies in the fact that, as was pointed out in another session of the Conference, Northwest Europe is likely to be short of natural gas within the next 15 years and will be forced to begin importing it, if new sources are not found and developed. Many of the developing countries, too, appear to have vast geopressured areas. On the quantitative side,therefore, the promise of geopressure zones is immense; so, however, are the technical and other problems likely to be involved in the recovery of this resource. The cost of drilling water wells to the necessary depth, say 15,000 feet, has been given as about $2 million/well; this would only be worthwhile if such a well continues producing for many years at a stretch. The problem of disposing of the enormous quantity of water involved could, it is believed, be solved by making use of its high temperature and pressure for electricity generation or in industrial processing. On the environmental side, the danger of subsidence if such large quantities of water are withdrawn from underground has to be faced. But in general, it is believed that if the water can be used in industry or for electricity generation, the development of geopressure zones will indeed be a viable proposition. It is not likely to happen tomorrow, although pilot production could start within the next three to five years, and if this is successful, large scale production could be possible anytime before the end of the century.

Parallel to the legal questions of ownership and control of ocean resources, legal problems concerning the development of the resources in geopressure zones will have to be solved. The extraction of the water from subterranean basins covering, as they do, hundreds and thousands of square miles with no respect for national borders, poses a novel and perhaps, like the Law of the Sea, a not unmixed legal situation, which can probably only be solved by the adoption of international conventions.

Gas Hydrates

The author of one paper dealing with geopressure zones summed up by writing: "we can now cultivate the resource, instead of just searching for and developing accidental gas occurrences". The same can certainly be said of the last and certainly the most unconventional of the new hydrocarbon resources discussed at the Conference: gas hydrates. This substance consists of molecules of natural gas, usually methane, linked with molecules of water to form ice-like crystals. The conditions under which they are formed have one thing in common with geopressured methane, namely very high pressure. On the other hand their formation also requires low temperatures... in contrast to the high temperatures of geopressure zones... so that they are above all characteristic of the permafrost regions of the far North, for example in Siberia, where they were first observed, in Canada and, presumably, the Arctic and Antarctic regions. Even though estimates of this little known resource can only be very vague approximations, it is considered that the quantities of methane involved are enormous; for example, a figure of some tens of billions (10^9) of cubic metres is given for one large West Siberian gas-field alone. But at present, these figures are of purely academic interest, for the fact is that in the permafrost regions gas hydrates are more of a nuisance than anything else. This is because the hydrate layers cause anomalies in drilling logs... a fact which in Canada led to their identification... and also make drilling more difficult in various ways. Another point, relevant to any future efforts to recover methane from hydrates, is that the high pressures involved in these substances, and which become effective when they decompose to give off the gas, preclude the use of conventional coring equipment for their exploration. This is only one of many technical problems associated with drilling in hydrate zones, even where it is normal natural gas that is being sought, usually below the hydrate level where temperatures preclude their formation.

Besides their presence in the permafrost, hydrates are thought by some experts to exist in many, if not most, of the sediments in off-short areas and continuing down to the sea floor, where temperatures and pressures seem to be suitable for their formation. However, while one Conference paper considered that they might be found in sediments covering as much as 90% of the ocean bed, another authority maintains that "the zone of hydrate formation is better considered a zone of potential hydrate formation". Whatever the answer to this unsolved question, two points are evident: hydrates do exist in quantities sufficient to make them a potential resource for the distant future; and at present, the commercial recovery of methane from hydrates is more in the realm of experiment and testing than practical petroleum technology.

CHAPTER IV

CONSTRAINTS - AND THE TRANSFER OF TECHNOLOGY

The extent and availability of oil and natural gas; the fuller use of conventional resources opened up by enhanced recovery; the possibilities of using some hitherto untapped unconventional resources; all combined to confirm the feeling of conference participants that the future of petroleum and natural gas as sources of energy was by no means as bleak as many people had come to believe. Nonetheless, beneath this fairly optimistic view of the future was an undertone of deep concern at the constraints on the actual production of oil and natural gas. These constraints, reference to which was a feature of almost every discussion, came under four main headings:

1. technical
2. financial and economic
3. political and environmental
4. manpower

However, although they fall into these convenient categories, there are few if any situations where any one can be considered in isolation from one or more of the others. Anyone familiar with the problems of economic development will be aware of this. Such people will be aware, too, of the particular nature of this complex of constraints when it comes to the installation and application of new ideas and techniques in developing countries... the process now summed up as "transfer of technology". For this reason, these two aspects of the future of energy from petroleum and natural gas were considered in the same series of discussions during the final sessions of the Conference.

Research and Development

Technical constraints fall into two categories: those imposed by lack of knowledge and those due to failure to apply that knowledge. Examples of both categories were provided again and again during the Conference discussion. Thus, with reference to the immediate future of oil from conventional resources, it was pointed out that insufficient knowledge of reservoir characteristics can be a major constraint to the efficient application of tertiary recovery methods even in fields the characteristics of which may previously have been considered as well known. At the other end of the time spectrum is the vast area of ignorance as to the size, and recovery potential of gas hydrates, or the lack of precise knowledge of the petroleum resources of the ocean floor, due in part to the shortage of an advanced exploration vessel equipped with the necessary controls for ensuring that drilling into oil-bearing strata does not lead to a major environmental accident. This, too, is an example of the way in which a technical constraint is tied to a financial one, since there is no doubt that the former could be overcome if the latter did not exist.

The essential point to which conferees addressed themselves was whether research and exploration would be done at a rate high enough to ensure an adequate supply of oil and gas, without unnecessary shortages or erratic and destabilizing price changes.

Problems of Finance and Economics

The link between technical and financial constraints is particularly close. It was pointed out at the Conference that recently published figures for the amount spent by the petroleum industry on R and D, which indicate a sharp decline, might be misleading. But the fact is that unless profitable results can be expected from technical advances, the funds for research are unlikely to be forthcoming at a time of financial stringency. Firms whether public, private or mixed must foresee future revenues to justify present expenditures. This is especially unfortunate for two reasons; in the first place, as was also pointed out by several speakers, research... and especially fundamental research of the type needed for the better understanding of the newer, less conventional resources... is done not for tomorrow, but with an eye on the day-after-tomorrow. Secondly, all research and development is, in the last analysis, concerned with the transfer of technology. Although it is true that some branches of the oil industry not unnaturally keep parts of the results of their latest technological developments to themselves, especially at times of intense competition, there is a tendency for this attitude to change. But unless the financial resources are forthcoming for those advances in the countries where the industry is most highly developed, developing countries will have fewer opportunities to share in the benefits of technological innovations that may make known resources economic to develop or other resources suddenly of immediate value.

But quite apart from the indirect restraints due to the effect of minimal financing for development, the actual sums required for the application of existing technologies are beyond the capacity of some sectors of the industry and even of some governments. How good are the chances of finding the much larger sums that will be required for the exploration and development of as yet unidentified resources in most of the countries of the Third World, or for the exploitation of known resources under conditions of political instability in many such countries? As one expert of international repute put it, no private company can be blamed for asking the question: "How can we make an investment programme when the best we can expect is to get our money back?" One suspects that same logic often in the government owned company.

Into this gap of uncertainty, governmental and regional (and even international) entities are playing a larger and larger role, in both developing and industrialized nations. The Conference appreciated that, as the providers of seed capital, the initiators of research, and the co-ordinators of energy development programmes, these public enterprises seem to be just the catalysts called for.

Political and Environmental Constraints

From the financial and economic to the political and environmental constraints is an obvious step, and indeed these are so inextricably interwoven that none can be considered separately. The policy of maintaining an artificially low price for natural gas in the United States was referred to by many speakers as a typical political/economic constraint, and the same applies in Great Britain and elsewhere. Reference was also made to the rapid and multiple increase in the price of crude oil in 1973/74. One very important result of this was that the higher selling price of finished oil products made it worthwhile for the industry to invest in and develop advanced technologies... for example, certain types of tertiary recovery... previously considered uneconomic. But if prices are maintained at artificially low levels, research and development, essentially directed at the distant future, tends to come to a halt. The Conference was presented with several examples of recent cuts in research budgets from those working for oil and gas companies, even though those responsible for the cuts realized they may be counter-productive in the long-run. Active encouragement from the public sector was regarded as a necessary remedy. Where more purely political difficulties are likely to be encountered is in the exploration and development of petroleum and gas from the continental slopes and the sea-bed. This is a subject that comes within the scope of the United Nations Law of the Sea Conference, but to what extent it may be possible to reach any agreement is not clear. Moreover, the problems of who owns what could arise not only in connexion with actual petroleum from the continental slopes, but also, as noted above, in the case of geopressure zones, which in certain areas could well overlap national boundaries. Even petroleum exploration in sensitive areas can be affected by political constraints, as for example in the eastern Mediterranean, and these political constraints are hardly likely to lessen if new resources are actually discovered.

Finally within this group of constraints to development come problems related to the environment, which were not systematically discussed at the Conference. However, the subject has found such a prominent place in the public's mind that it was referred to in paper after paper, in the presentations, the discussions and in the corridors during breaks. In considering the prospects for large-scale production of oil from shale, the topic came up again and again. Surface mining of shale was attacked on the grounds that it could involve the handling of enormous quantities of rock causing the disfigurement of the land; on the other hand, in a presentation by a representative from the French Geological Survey (BRGM) an experiment was described that actually improved the land once the shale was mined. Because environmental constraints vary according to the area, whether agricultural, desert, or off the coast of a populated region, under exploration or development, and according to the process employed,it was not possible to predict the consequences for the development of any resource without knowing local conditions. It was agreed that gone were the days, when development could go ahead without any constraints due to environmental concern. Even where, as in the case of the Alaska pipeline, the result is largely confined to a delay in bringing new fields into production, the effect is bound to be felt.

Manpower: an Over-riding Constraint?

The final constraint, and the one that could prove the most serious in the next ten to fifteen years is a shortage of trained manpower. The Conference heard frequent references to this as an area of concern in almost every branch of the petroleum industry. In part this was due to the economic situation, and may be seen as a delayed effect of financial and political constraints, while at the same time there is inevitably a feedback from the manpower shortage to the ability of the industry to respond rapidly to calls for more exploration, and for more and quicker advances in engineering and technological development. Moreover, this situation affects government and commercial interests alike. If there are minimal incentives for developing new technologies, it is increasingly impossible to justify spending money on research. And if there is no future in research, the best and in particular, the most enterprising, young scientists and technologists tend to leave the industry or train for a career in some other field. The effect of this may be particularly serious for developing countries that otherwise may be in a position to set up their own national oil industry. If there is a shortage of manpower in the established oil and gas industry of the developed countries, the chances of personnel being available to advise and train cadres of petroleum scientists and technicians elsewhere is increasingly remote. Here the effect of the economic downturn is apparent in universities already, whose capacity to train geologists and engineers has been reduced, a situation which must be considered serious, at a time when universities should expand their technical training programmes to meet the manpower requirements. Globally, the manpower constraint is likely to be felt with increasing severity in the immediate future when a considerable deficiency, brought about by qualified personnel leaving the industry over the past few years, has to be made up; the manpower situation, in fact, is already critical, and it cannot be solved easily or rapidly.

Special Problems of the Developing Countries

One surprising fact which became evident during the Conference is the small extent to which exploration for hydrocarbons has been carried out in the developing countries. From whatever viewpoint this situation is examined... number of wells drilled, total footage of these wells, number and density of exploratory wells in areas prospected, the picture is the same: discounting the Middle East, less than five percent of the exploratory effort has been in the developing countries. But even allowing for the fact that, according to most experts, the likelihood of finding many new "giant" fields in those areas already explored is small, although this opinion was not universally shared, there would still be undiscovered potential for many of the countries of Africa, Asia and Latin America, particularly when one learns that the United States, where by far the greatest share of all drilling has been carried out, is not geologically speaking a specially favoured region... as is, for example, the Middle East. There are, it is true also, flourishing oil industries in North Africa, in Nigeria and Venezuela, and promising but smaller ones in other parts of Latin America, Africa and the Caribbean. But in general, almost nothing has been done to explore the rest of the African continent, most of Latin America, and vast areas of Asia including India, off whose coasts, as was indicated in Chapter III, there is a likelihood of large oil and gas deposits.

The reasons for this lack of exploration are many and complex. In the first instance, the tendency has always been to go for the "easy" oil, exploiting it more and more intensively as the demand increased, rather than risk capital and time in looking for resources about whose prospects little or nothing is known. The scale of capital investment that is required has up to now made it wiser to base resource development on an existing national industry, as long as this is possible and profitable, rather than to set up an entirely new complex of facilities.

Another more important reason is the principle of permanent sovereignty over natural resources and its possible conflicts with traditional arrangements involving foreign capital for the development of oil and gas resources in developing countries. Developing countries urgently need cooperation not only in scientific and technical fields but also in setting up the infrastructure of a petroleum industry. The pattern of such co-operation may be somewhat different from that originally developed under the aegis of the large international companies. Recent experience has shown that arrangements for obtaining expertise and technology are already changing, and indeed with the assistance of the companies themselves. It is a safe bet that they will be further diversified.

In the last analysis transfer of technology is essentially a person to person affair and training becomes of paramount importance. It has often been said that training, like research, is not for today or tomorrow, but for the day after. This may have been valid for countries with a well established petroleum industry and in periods of energy abundance. However, for developing countries and with the prospect of possible shortages, training must be carried out in the shortest possible period, in some of the disciplines at least. Only when a minimum human infrastructure is ensured, can developing countries acquire the confidence to look ahead and to begin training for the more distant future, when they will be using their own scientists and technologists, or when they will be at least in a position to make the best possible use of those from abroad.

EPILOGUE

A SUMMING UP

The Laxenburg Conference opened with a question: for how long could the world continue to rely on petroleum as its main source of energy? Due to price and technical uncertainties, the reply, like the question, was open-ended. Additional petroleum and gas resources would most probably be available albeit at a substantially higher cost not only for the next two or three decades but very likely during the period of transition to the use of renewable energy sources even if this transition period should last a hundred years or more. The contribution which oil and gas, whether from conventional or from new sources, could make to meeting the world needs during that time will obviously depend on the parallel development of other sources of energy, which in turn would to some extent determine whether oil and gas resources would be reserved for some specific uses, namely transportation and the petrochemical industry. A new perspective in regard to the future availability of nature-made petroleum and gas such as seems to emerge from the Conference would undoubtedly influence the outcome. It must be repeated that the Conference was not specifically concerned with the problems of integrating the use of petroleum with other energy resources.

The conference was acutely aware of the uncertainties pertaining to technology development as well as to political, institutional and, more and more, environmental constraints in the development of resources. In such a general context, investment decisions involving heavy expenditures will face acute difficulties, particularly when the development stage is reached for gas from geopressure zones, tight formations or hydrates. It was clear time and again that long-term price, cost, and demand uncertainties make dependence on market signals unreliable. A more sophisticated approach, which would not exclude judgement and intuition, would be needed to allow for the long lead-times necessary and to justify the expenditures in R and D and exploration. Moreover, it was generally felt that some form of international action including the monitoring of developments, the dissemination of information and the comparative analysis of options would become inevitable, and interest was shown in the potential of the United Nations for such a role. Since most constraints and uncertainties discussed would affect other energy resources as well as petroleum and gas, a global outlook at the energy situation, as a continuing discipline within the universal system, could not be much delayed. This is required for the global purpose of the world economy, but it is also in the specific interest of many developing countries from which a considerable part of the future petroleum and gas would most probably come.

It is interesting to note that among experts from different countries meeting for the first time within the Conference, ideas began to be discussed for collaborative projects in some of the unconventional resources. Thus there was a French call for a joint European approach to the development of oil shales; there was the interest shown by participants from the USSR in a possible large joint study for developing geopressure zones. And although it was not the subject of a formal session, there was an awareness of the potential for increased automation both in managing existing resources, (as was seen during a visit to the Austrian oilfield) or, as with the automated submarine research craft developed both in the United States and France, for new methods in exploring and drilling the sea-bed. And at every stage, the use of computer models for management, for forecasting, and for economic and financial control was seen as an increasingly important aspect of the petroleum industry.

The conference could not in itself produce recommendations, nor even very definitive findings, which would allow governments to compare various energy sources and decide on their options, nor did it deal with specific ways and means of overcoming the present constraints to resource development. It nevertheless provided very valuable insights and information which will prove useful to the petroleum industry and generally to the professional energy community. The results of the conference may be of particular interest to three types of countries: 1) those which are in the process of developing a comprehensive and consistent energy policy and which may have underestimated the potential of petroleum and gas resources; 2) those which are increasingly questioning already established policies or plans under a new perception of the risks pertaining to nuclear power; and 3) those which have reason to believe that they possess one or more of the types of resources discussed at the conference.

Although the experts came in the majority from high technology countries, one of the Conferences's main benefits may redound to developing countries, if steps are rapidly taken to disseminate its results, and if these add a stimulus to international cooperation.

For those who attended the Conference it is hard to escape the conclusion that a new era of international energy cooperation must now be initiated. Within such an international framework individual countries would be free to develop the pattern of energy production or acquisition best suited to their preferred development style and policies, to the vision of their future and to their judgement as to how they can maximize the use of their resource endowment over the various phases of their development.